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「人間と自然との新しい対話」

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Profile of Lecturer

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1959~ Director of the "Institute Internationaux de Physique et de Chimie", fondés par E. Solvay, Brussels

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"Thermodynamic Theory of Structure, Stability and Fluctuations"
en collaboration avec P. Glansdorff.
Wiley & Sons, London, New York, (1971).
"Self-Organization in Non-Equilibrium Systems, From Dissipative Structures to Order through Fluctuations:"
en collaboration avec G. Nicolis J. Wiley and Sons., (1977).
"La Nouvelle Alliance, Les Métamorphoses de la Science,"
en collaboration avec. I. Stengers, Galimard, 1981, Paris, France.
"From Being to Becoming, Time and Complexity in the Physical Sciences,"
W.H. Freeman & Co., San Francisco, U.S.A., 1980.

All these monographs have been translated in various languages.

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●会　員

15におよぶ国立アカデミー及び数多くの学会に所属する。

●近年発表の論文

『構造・安定性・揺動の熱力学理論』
P. グランスドーフと共著
1971年、ニューヨーク、ロンドン、
ワイリーアンドサンズ出版

『非平衡システムに於ける自己組織化、散逸構造から揺動による秩序まで』
G. ニコリスと共著
1977年、J. ワイリーアンドサンズ出版

『新約、科学の変容』
I. スタンガーと共著
1981年フランス、パリ、ガリマール出版

『存在から生成へ。物理科学に於ける時間と複雑性』
1980年米国、サンフランシスコ
W. H. フリーマンアンドカンパニー出版

尚上記の論文は各国語に翻訳されている。

このレポートは昭和58年11月17日、ホテル・オークラにおいて行なわれた1984年度本田賞授与式の記念講演の要旨をまとめたものです。

MAN'S NEW DIALOGUE WITH NATURE

Lecture at the Conferring Ceremony on the 17th of November 1983, in Tokyo

Professor Ilya Prigogine
The Winner of The Honda Prize 1983

I

The recent growth of technology gives a new urgency to the everlasting problem of the relation between science and nature. What kind of dialogue is man entertaining with nature through science and culture?

This is quite an ambitious question, and it would be presumptuous to hope give it some general answer. However, what I would like to emphasize here is that the perspectives in which we see this question today is quite different from what it was only a few decades ago; this change is the main subject of my lecture.

It is hardly an exaggeration to state that one of the greatest dates in the history of mankind was April 28, 1686, when Newton presented his Principia to the Royal Society of London. We may take this date as the birthday of modern science. Viewed in this fashion, modern science has now reached to age of three centuries. Newton brought together in a synthesis of unprecedented scope the traditions of technological practice and of theoretical speculation.

The Greeks, especially the Hellenistic period, had astute engineers; everybody also knows the outstanding contribution of greek philosophy to our understanding of nature; and ancient astronomy represents monuments of mathematical ingenuity. Since Newton, these trends have been united. Every body is aware of the fact that this has led to a drastic change in the life of humanity.

Let us emphasize the extraordinary ambition inherent to the newtonian scheme. The infinite variety of nature would in principle be reduced to the exact laws of motion, as formulated by Newton. Once initial conditions are known, the outcome of every situation could, in principle at least, be predicted with absolute certainty.

These are two characteristics of this scheme I would like to stress: it corresponds to a deterministic description of nature: no place is left to any uncertainty; it corresponds also to a reversible description, as Newton's laws don't imply any distinction between past and future. This grandiose intellectual structure was however not without problems. How to understand the position of life, of man, in a universe described by classical science as a giant automation?

We find this contrast expressed in the works of Einstein, probably the greatest scientist of the 20th century. On one side, Einstein emphasized the importance of deterministic laws. Everybody knows that he was for this reason opposed to the usual interpretation of quantum mechanics. On the other hand, he stressed, with equal conviction, the role of creativity in the research programs.

How to reconcile the two attitudes? Is man outside the universe he describes? the famous french biologist Jacques Monod had a way of making this contrast explicit by stating that the laws of biology were compatible with the laws of physics, but not included in them.

In the classical vision we herited from the 17th century, nature appeared as passive, as submitted to the creative impulse of man. It is not astonishing that as stated by professor Aida "In much modern scientific and technological development, nature (the "natural order of things") has been regarded as an opponent to be conquered rather than as an asset to be utilised".

The history of science over the three centuries which followed the newtonian synthesis is a dramatic story indeed. There were moments where the program of classical science seemed near completion: a fundamental level, which would be the carrier of deterministic and reversible laws, seemed in sight. However, every time also, something went wrong. The scheme had to be enlarged, and the fundamental level in the sense of the classical program remained elusive.

Today, wherever we look, we find evolution, diversification and instabilities. A fundamental reconceptualization of science is going on. We knew since long that we are living in a pluralistic world in which we find deterministic as well as stochastic phenomena, reversible as well as irreversible. We observe deterministic phenomena such as the frictionless pendulum or the trajectory of the moon around the earth; moreover, we know that the frictionless pendulum is also reversible. But other processes are irreversible, as diffusion, or chemical reactions; and we are obliged to acknowledge the existence of stochastic processes if we want to avoid the paradox of referring the variety of natural phenomena to a program printed at the moment of the Big Bang. What has changed since the beginnings of this century is our evaluation of the relative importance of these four types of phenomena.

The artificial may be deterministic and reversible. The natural contains essential elements of randomness and irreversibility. This leads to a new vision of matter: no longer passive, as described in the mechanical world view, but associated with spontaneous activity. This change is so deep that I believe we can really speak about a new dialogue of man with nature.

Even at the start of this century, continuing the tradition of the classical research program, physicists were almost unanimous to admit that the fundamental laws of the universe were deterministic and reversible. Processes which did not fit this scheme were supposed to be exceptions, nearly artefacts due to some apparent complexity, which had itself to be accounted for by invocing our ignorance, or lack of control on the variables involved. Now that we are at the end of this century, we are more and more numerous to think that the fundamental laws of nature are irreversible and stochastic; that deterministic and reversible laws are applicable only in limiting situations.

It is interesting to inquire how such a change could occur over a relatively short time span. It is the outcome of unexpected results, obtained in quite different fields of physics and chemistry such as elementary particles, cosmology or the study of self-organization in far-from-equilibrium systems.

Who would have believed, fifty years ago, that most, and perhaps all elementary particles are unstable? That we would speak about the evolution of the universe as a whole? That far from equilibrium, molecules may communicate, to use anthropomorphic terms, as witnessed in the chemical clocks to which we shall turn later in more detail?

All these unexpected discoveries have also a drastic effect on our outlook on the relation between "hard" and "soft" sciences. According to the classical view, there was a sharp distinction between simple systems, such as studies by physics or chemistry, and complex systems, such as studied in biology and human science. Indeed, one could not imagine greater contrast than the one which exists between the simple models of classical dynamics, or the simple behaviour of a gas or a liquid, and the complex processes we discover in the evolution of life or in the history of the human societies.

Still, this gap is now being filled. Over the last decade, we have learned that in non-equilibrium conditions, simple materials such as a gas or a liquid, or simple chemical reactions, can acquire complex behaviour. This unexpected complexity leads to the appearance of broken temporal or spatial symmetry, to chaos, and to patterns of increasing diversity.

II

In the evolution towards the complex, with its connotations of irreversibility and stochasticity, thermodynamics has played an important role. It may be useful to contrast the description of a system in terms of classical dynamics with the thermodynamical one. (Figure 1.)

In the former, we consider typically a given number of points interacting through some type of potential. A typical example could be the system formed by the sun and the earth. Of course, they are also the other planets and other starts, but they are treated as a kind of perturbation.

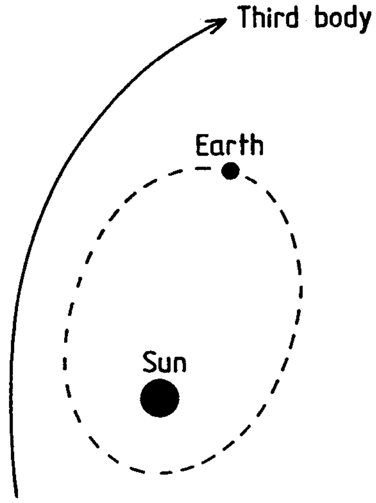

Fig. 1 Dynamical description of a three-body system. The approach of a third body can only lead to a permanent deformation of the earth's orbit.

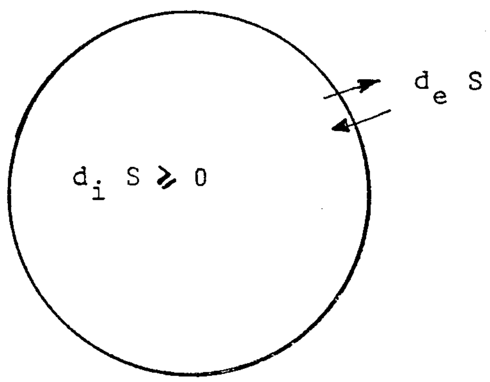

Fig. 2 Time change of entropy, split into entropy flow (d_eS) and entropy production (d_iS) according to relation $dS=d_eS+d_iS$.

In contrast, thermodynamics is based on the concept of entropy, as illustrated on figure 2. Entropy has a quite unique behaviour. Its time changes can be split into a term d_eS, corresponding to the flow of entropy which the system exchanges with the outside world, and a term d_iS, corresponding to entropy production inside the system. As d_iS is always positive or zero, irreversibility can only create entropy, but not destroy it. For an isolated system, there is no entropy flow, and S changes only due to entropy production: entropy increases monotonously as the system approaches equilibrium, corresponding to a maximum of entropy.

For a long time, the interest of thermodynamics concentrated on isolated systems at equilibrium. Today, our interest is shifting to non-equilibrium systems, interacting with the surrounding through the entropy flow. Let us emphasize an essential difference with the dynamical description. In thermodynamics, we are dealing with embedded systems. The interaction with the outside world through entropy flow plays an essential role. This immediately brings us closer to situations like towns or living systems, which can only survive because of their embedding in their environment.

From the start, the thermodynamical point of view is one of interaction, we could say a 'holistic' one. But there is more: suppose that in the example expressed by figure 1, we have some foreign body approaching the earth: this would lead to a deformation of the earth's trajectory, which would remain for ever. Dynamical systems have no way to forget perturbations.

This is no more so when we include dissipation. A damped pendulum will reach a position of equilibrium, whatever the initial perturbation. Again, let us emphasize how much closer to life is the thermodynamic description. If I impose large oscillations to an undamped pendulum, its period slows down and remain so for ever. However, when I run, my heart's beats increase; but when I rest, it turns back to the normal state.

In thermodynamics, perturbations may be forgotten. In the thermodynamic description including dissipation, we have attractors.

Without attractors, our world would be chaotic. No general rules could ever have been formulated. Every system would pose a problem apart. We can now also understand in quite general terms what happens when we drive a system far from equilibrium. The attractor which dominated the behaviour of the system near equilibrium may become unstable, as a result of the flow of matter and energy which we direct at the system. Non-equilibrium become a source of order; new types of attractors, more complicated ones, may appear, and give to the system remarkable and new space-time properties.

Let us illustrate these general statements with two examples which are widely studied today; we first consider the so-called Bénard instability. It is a striking example of instability in a stationary state giving rise to a phenomenon of spontaneous self-organisation; the instability is due to a vertical temperature gradient set up in a horizontal liquid layer. The lower face is maintained to a given temperature, higher than that of the upper. As a result of these boundary conditions, a permanent heat flux is set up, moving from bottom to top.

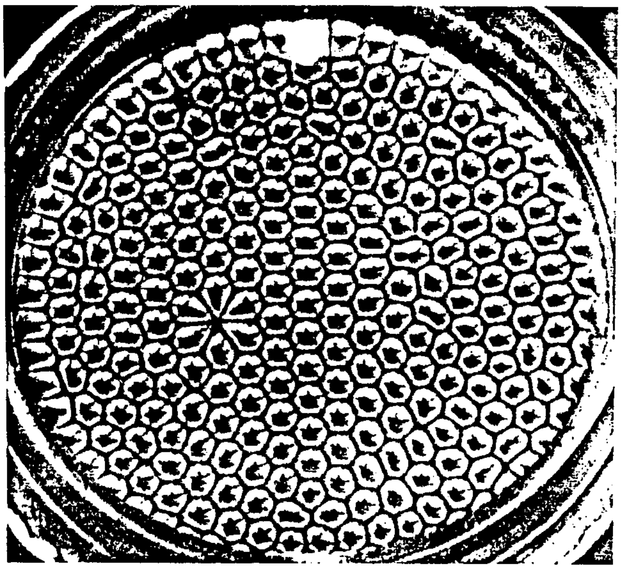

Fig. 3 The Bénard instability in a thin layer of liquid.

For small difference of temperature, heat can be conveyed by conduction, without any convection; but when the imposed temperature gradient reaches a threshold value, the stationary state (the fluid's state of 'rest') become unstable: convection arises, corresponding to the coherent motion of a huge number of molecules, increasing the rate of heat transfer. In appropriate conditions, the convection produces actually a complex spatial organization in the system.

There is another way of looking at the Bénard phenomenon. There are two elements involved: heat flow and gravitation. At equilbrium conditions, the force of gravitation has hardly any effects on a thin layer of the order of 10mm. In contrast, the the Bénard instability, gravitation gives rise to macroscopic structures. Non-equilbrium matter becomes much more sensitive to the outer world conditions than matter at equilibrium. I like to say that at equilibrium, matter is blind; far from equilibrium it may begin to see.

This can also be illustrated by the example of chemical oscillations. The Belousov-Zhabotinski reaction is a well-known chemical clock. The striking results obtained by Zhabotinski became available in the late 1960. I cannot discuss here the detailed mechanism. But I would like to point some general features. Ideally speaking, we have a chemical reaction whose state we control through appropriate injection of chemical products and elimination of waste products. (Figure 4.)

Suppose that two of the intermediate components are respectively formed by red and blue molecules in comparable quantities. We would expect to observe some kind of blurred color with perhaps, occasionally, some flash of red or blue spots. This is, however, not what actually happens. In appropriate conditions, we see in sequence the whole vessel become red, then blue, then red again: we have a chemical clock. In a sense, this violate all our intuition about chemical reactions. (Figure 5)

We were used to speak of chemical reactions as being produced by molecules moving in a disordered fashion and colliding at random. In contrast, the existence of chemical clocks shows that far from being chaotic, the behaviour of the intermediate species is highly coherent. In a sense, the molecules have to be able to "communicate" in order to synchronize their periodic change of color. In other words, we deal here with new supermolecular scales, both in time and space, produced by chemical activity. In a stirred chemical reactor, we can only observe temporal behaviour (which may be periodic or 'chaotic'). In other cases, we may also see the appearance of space structures. Figure 6 shows the spectacular Krinsky sprials, which remind us strikingly of spiral galaxies at the cosmological scale.

Another important concept is bifurcation. A system presenting a multiplicity of solutions may be characterized by a bifurcation diagram. We see that at critical points new types of solutions emerge (see Figure 7). There is also another element I would like to emphasize. Near a bifurcation point such as P, the system has a choice between the two branches; we may therefore expect a stochastic element.

Quantum mechanics appears to us so revolutionary because it introduces a stochastic description in the microscopic world. The new developments we have summarized here suggest that this stochastic type of behaviour may also appear in the macroscopic world.

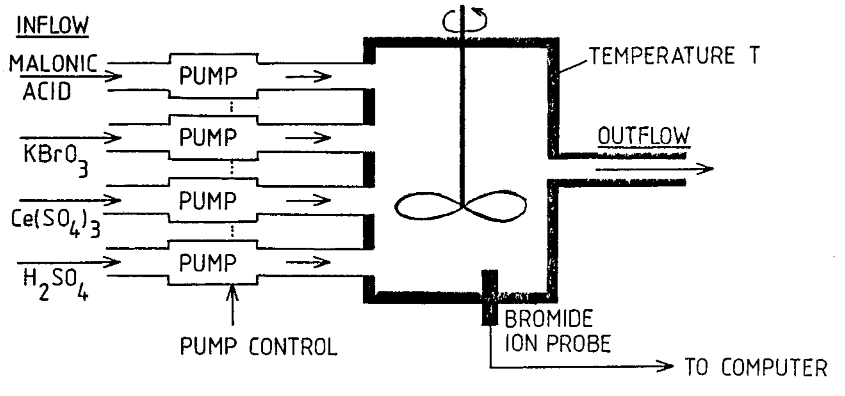

Fig. 4 Schematic representation of a chemical reactor used to study the oscillations of Belousov-Zhabotinsky reaction.

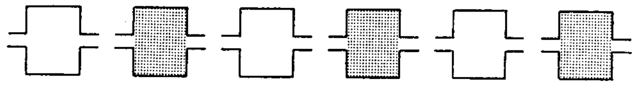

Fig. 5 Successive states of the reactor show the periodicity of the reaction.

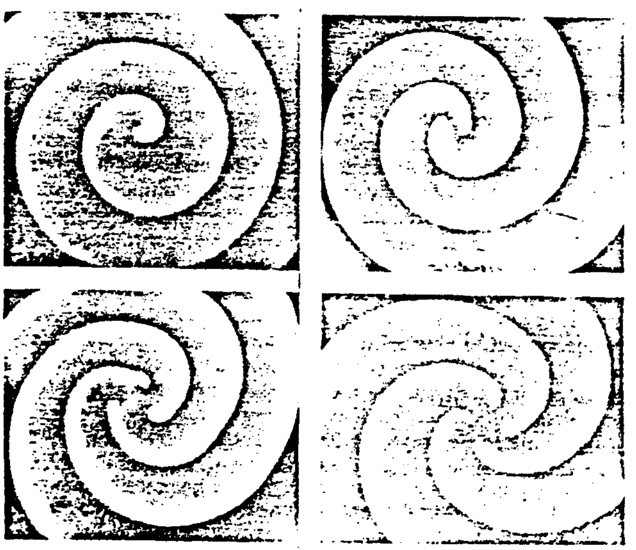

Fig. 6 One-, two, three-, and four-armed vortices in an active excitable (by courtesy of V.I. Krinsky).

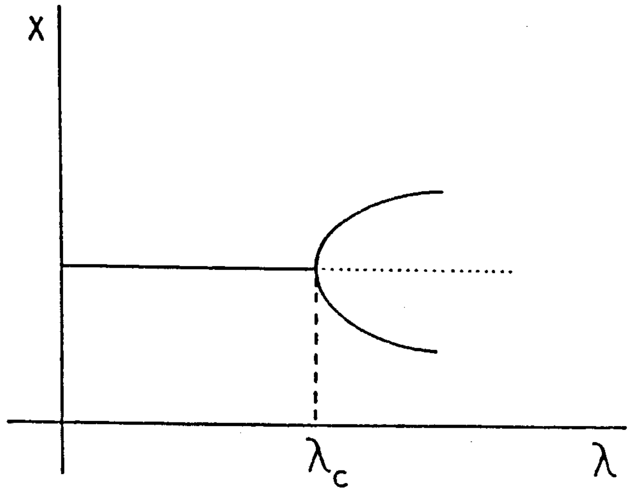

Fig. 7 Symmetrical bifurcation diagram. X is plotted as a function of λ. For $\lambda < \lambda_c$ there is only one stationary state, which is stable. Two new stable stationary states appear for $\lambda > \lambda_c$ while formerly stable state become unstable.

III

The concepts which we outlined in the previous section diffuse today in a large domain, including biology, social sciences and climatology. One of the main problems in front of us is to understand large scale regularities which shape our environment.

Let me give two examples of what I have in mind, and consider first the problem of climate. We know now that climate has fluctuated violently over the past. Climatic conditions that prevailed during the last two or three hundred millions years were extremely different from what there are at present. During these periods, with the exception of the quaternary era (which began about two millions years ago) there was practically no ice on the continents, and the sea level was higher than its present value by about 80 meters. A striking feature of the quaternary era is the appearance of a series of glaciations, with an average periodicity of one hundred thousand years, to which is superposed an important amount of noise. What is the source of these violent fluctuations which have obviously played an important role in our history? There is no indication that the intensity of the solar energy may be responsible for these fluctuations.

Let us now consider a problem on which, on the contrary, we are stunned by the remarkable uniformity and the lack of fluctuations: in chemistry, we deal often with chiral molecules. For example, in most amino-acids the central carbon is asymmetric: there are two configurations, let us say R and L isomers. The relation between the two is somewhat similar to left- and right-handed spirals. The curious fact is that amino-acids in proteins are always in the L configuration.

A somewhat similar example is the case of particles and anti-particles. From the point of view of quantum theory, they play nearly indentical roles. Still, the world is made out of particles, while anti-particles are to be produced in accelerators.

We begin to have the tools to understand these two extreme situations: climate is described by highly non-linear equations, involving both the absorption and the emission of solar light. In short, this leads to two types of climate: a cold one and a moderate one. There are of course fluctuations around these two climates. However, these fluctuations taken alone would not be sufficient to tilt the climate from one type to another.

But in additiona, the eccentricity of the earth's orbit leads to a very slight periodicity in the solar influx. This has a major consequence, which was derived by two independent research groups: such very small outside perturbation leads to amplification of the transition probability from one climate to the other.

We begin in this way to understand the glaciation periodicity of one hundred thousand years. The point which I want to emphasize is that the internal noise may amplify minute external perturbations, leading to major changes in climate.

Let us turn to the second question: we have seen that matter in non-equilibrium conditions may become very sensitive to outside perturbations. This is specially true in the neighbourhood of bifurcation points.

A very minute difference, which may exist in the stability of right-handed or left-handed molecules (leading for example to differences of energy of activation of somewhat 10^{-15}) may suppress the stochasticity inscribed in a 'symmetrical' bifurcation, and lead to a preferential selection of one of the states.

This may lead to applications in a wide range of fields. We may construct new types of highly sensitive switches. However, a price has to be paid: these switches are very slow. We have to maintain the bifurcation parameter near to the bifurcation point for long periods (the exact value of which may vary from hours to minutes, according to the kinetic equations).

As these two examples show, we begin to have the tools to understand some basic features of our environment. Moreover, in addition to quantitative applications, there are qualitative ones, in which the concepts which I have outlines may lead to a new way of considering long standing problems, such as the behaviour of animal or human societies.

Let us take the example of ants societies. I have been very impressed by the fact that the total number of ants living on earth is estimated to be on the order of 10^{15}, which means millions of ants/human being. The total biomass of ants is therefore comparable to the exploding biomass of mankind, and ants may claim to have had a greater ecological succes than man. How is this possible? Classically, ants were considered as automata, repeating again and again the same behaviour. This seems to be wrong: ants are very "attentive" to their environment, and their behaviour is a striking mixture of determinism and stochasticity:

Communication errors feed the society's imagination.

The environment in which an ant colony lives is more or less predictable in time and space. We can compare two extreme food situations. Tree aphid colonies are sources with a long lifetime (up to 4 or 5 months). On the contrary, a dead bird is a very unpredictable source.

Taking the case while exploiting the aphids, stable roads are developed from the nest to the aphids' group and very few ants are scattered outside the highways. These structures result from the interplay between the long lifetime of the aphids group and the amplification mechanisms inside the colony.

When an ant discovers the dead bird, it communicates its discovery to its nesmate, but in this case no stable structures are developped, and the communication between ants seems very unefficient: numerous ants loose their way from the nest to the food source, and walk randomly on the foraging area.

In fact, this randomness in behaviour and communication has an adaptative value, and reflects the optimal tuning between systematic exploitation and research of new food sources. The level of optimal noise depends on the characteristics of food sources.

On the other hand, a possible reaction of the any colony is to damp the external fluctuations with homeostatic mechanisms. Division of labour furnishes a good example of this. Let me briefly mention recent experiments which show that the degree to which an ant is prone to work is a function of a lot of variables, including the proportion of "active" and "lazy" ants.

The experiment consists to measure the number of brood's transports by each worker during a nest moving. The experimental colony is a "synthetical colony" in which the workers are close of each other (they are sisters, members of the same cast, and have ± the same age). Despite the great homogeneity between them, there is a stable division of labour, and we can distinguish between "active" and "lazy" ants. If you isolate a lot of "lazy" ants and reproduce the same experiment, a significant proportion of them will become actives as a consequence. (Figures 8 to 11)

This suggests that activity as such is not merely genetically determined, but contains a large 'social' component. The application to anthropology is tempting. We have seen that simple molecules in the Belousov-Zhabotinski reaction may present an astonishing variety of non-equilbrium structures and behaviours; when the units become much more complex, as is the case in animal or human societies, we may expect an immense variety of behaviour, without any appeal to genetic determinism. Let us now turn to a specially interesting, but also outstandingly difficult problem: the application of those ideas to human societies.

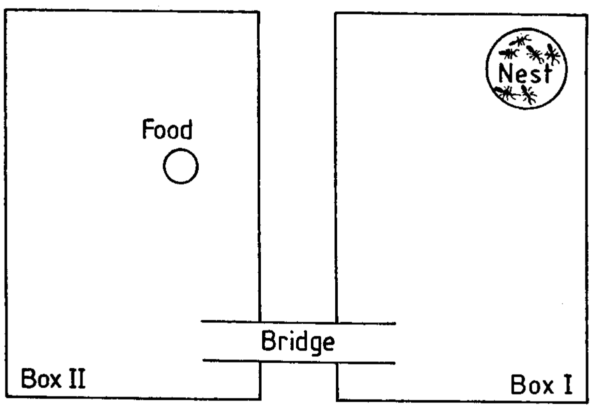

Fig. 8 Initial conditions for nest moving experiment. Before the experiment, the whole ant population lives in the nest. The test begins when the nest population (brood and workers) is dropped in box II.

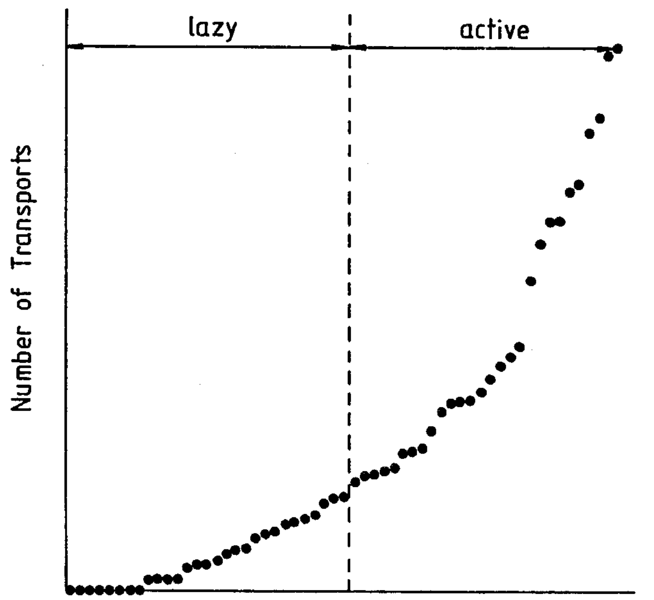

Fig. 10 Series of individual workers ranked according to their transportation activity. This graph shows that a small amount of worker performs the most significant amount work: the population is heterogeneous: the right half of workers ("active") performs some 80% of total transport, the other half some 20%.

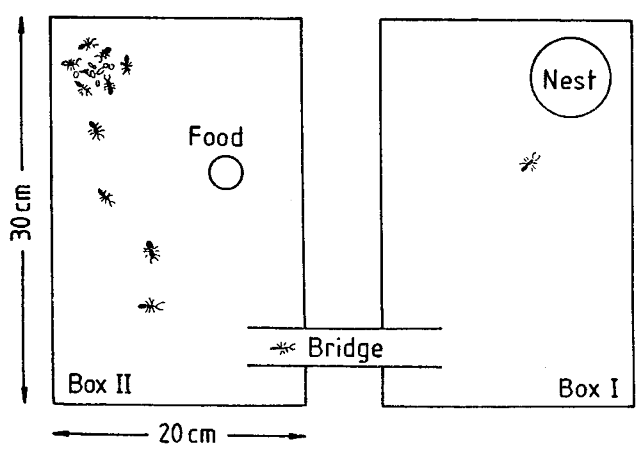

Fig. 9 After an exploration phase, transportation of brood by workers begin. Each ant which cross the bridge is identified and checked if it transports any brood or not. At the end of experiment, all brood is back to nest, and we sum the number of brood transported by each worker.

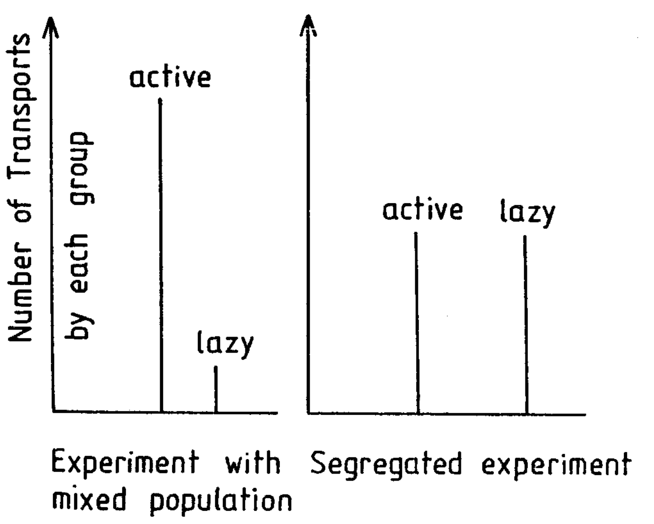

Fig. 11 Distribution of performance in heterogenous (experiment presented at figure 10) and inhomogeneous ant populations: when active and lazy ants are segregated, their performance becomes more or less equivalent.

IV

There is now a widespread interest in, and recognition of, the vital importance of the creative self-evolution of complex socio-technical systems. Self-evolution refers to the process of structural change, of diversification, and the emergence of hierarchies that can be generated in such systems.

It is importnat to notice that some roots of the complexity found in human systems may already be identified in chemistry and physics, as I have shown in the previous parts of this lecture. However, it is clear that socio-technical systems have specific features.

A central issue in this context is the question of evolution of a system composed of different groups of actors who interact with each other through various cooperative and competitive mechanisms, reflecting the perception they have of their particular situation and of the rules pertaining to their roles.

They operate through limited, local knowledge and the consequence of their actions generally lead the whole system to successive instabilities, where structure evolves; revisions of some of the rules and roles become necessary to permit the continued functioning of the system.

The global features of such systems do not therefore reflect the fulfillment of a 'master plan' but rather an evolution of process and structure in directions not necessarily planned, intended or desired by any single actor or group of actors.

The concepts emerging from the study of dissipative structures -and specially the complex interplay between instabilities and deterministic behavior- permit us to build computer models of complex systems such as cities and regions containing several cities, models which are capable of generating the type of structural evolution as we have described.

Economic and behavioural uncertainties explore constantly the stability of a given spatial structure, as individual decisions and initiatives are made. The economic reality of supply and demand operates a selection on these initiatives, amplifying some and eliminating others.

Sometimes growth or decline is purely quantitative, the qualitative features remaining unchanged. But at other moments, near to bifurcation points, entirely new trends can appear which will reorganize completely urban structure and introduce both new, advantageous aspects and new problems.

From this we see that contrary to the usual descriptive models employed in planning and policy analysis, the computer simulations of urban evolution by P. Allen and his collaborators, which generate spatial organization, can also predict moments when spatial instability may occur and structural change may result. In this way the long term, global effects of particular actions or policies can be explored where today only the immediate most direct effects are considered (if indeed they are) before a decision is made. Since the Allen model contains both the land use and the transportation flows of goods, services, commuters and energy consistant with that land use pattern, we may see that the apparently different phases of urbanization emerging successively in reality, can be generated by the evolution of a single simulation.

In this section, some simulations will be described, most of which are performed on a city with characteristics and a history somewhat inspired on these of Brussels, Belgium, and displayed on an hexagonal grid of points. The distances between the points are given in the matrixes dij, resulting from calculations on a transportation system also based on that of Brussels. (Figure 12)

The initial conditions of these simulations, shown on figure 16, supposes simply that most

Overall characteristics of the simulated city

	End of phase 1	End of phase 2	End of phase 3
Total employment	729 600	669 500	674 300
Active residents	462 670	411 560	414 200
Coeff. of employment	1.58	1.63	1.63
Structure of industry	25%	22%	22%
Structure of tertiary	75%	78%	78%

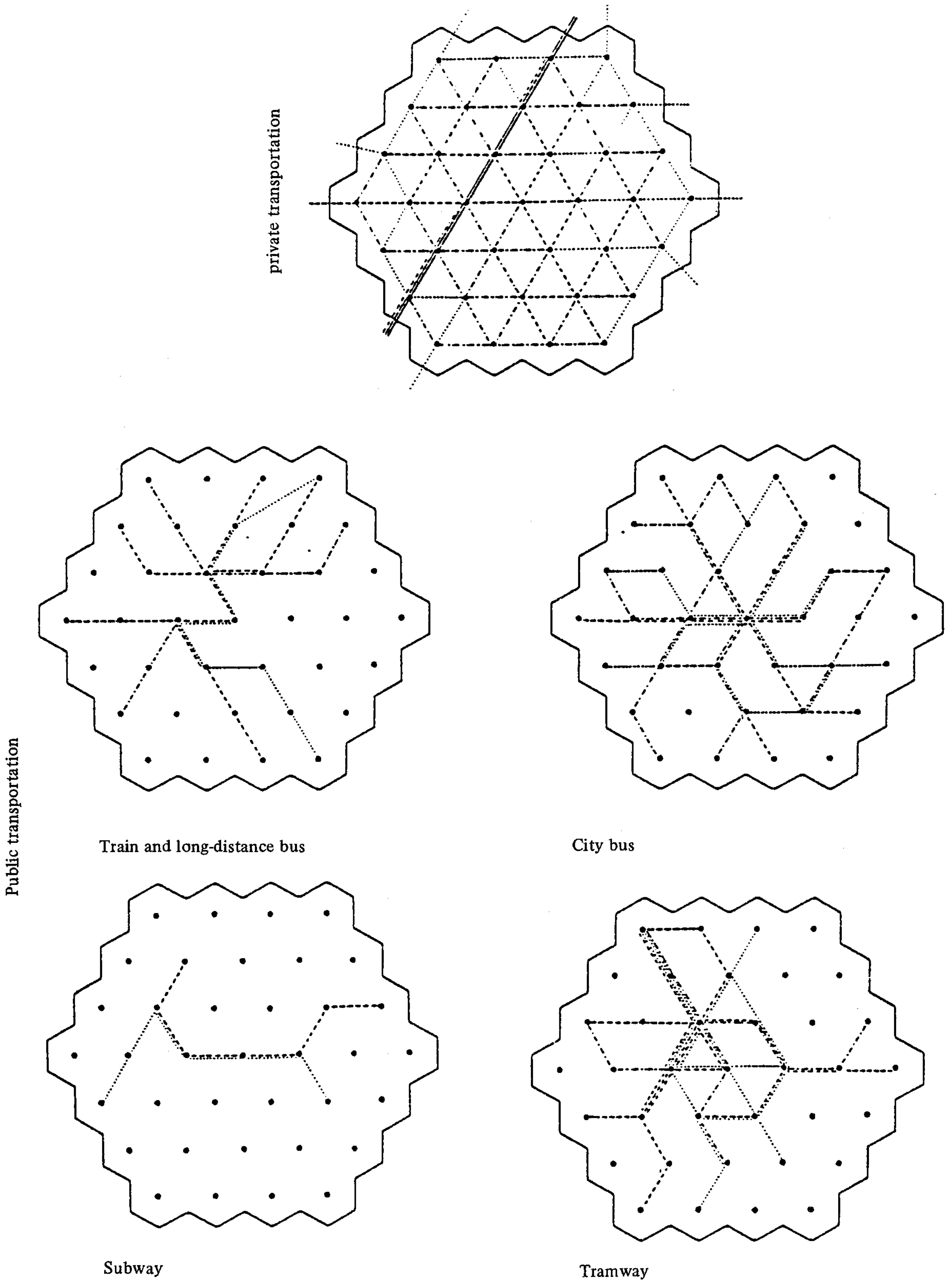

Fig. 12 Transportation distance networks

jobs and residences were concentratedon the central point of our lattice. Some industrial activity however, by definition highly dependent on good access for bulky raw materials and first products, was located on cheaper land along the canal just outside the city. This condition corresponds roughly to that of Brussels around 1880; the simulations show how urban structure emerges spontaneously during the subsequent growth.

The simulations describe a city that at first (t=0 till t=10) went through a phase of growth, mainly due to a demand for industrial goods from outside the city itself (Figures 13 and 14). This process started the well-known urban multiplier, which gave rise to an increasing tertiary sector, partly with long-range characteristics, and an increasing urban employment for the city residents and commuters. After this prosperous phase (t=10 till t=20), the demand for exporting industrial goods fell, but the market for exporting tertiary services and goods remained and even grew. This is to some extent the history of many West-European cities (Figures 14-15). The growth starts at first in the north where acess is found to be best, and continues south of the centre once the crowding in the north is too strong. When demand for heavy industrial goods decreases, industry leaves the south first. At first, light industry is located near the heavy industry, but, as its character is evolving towards high technology type industry, it relocates more and more to the east to concentrate finally in single pole at a highly accessible highway intersection. During the period of industrial decline the employment in light industry grows very slightly and remains concentrated on the one point east of town. The exporting tertiary grows rapidly in the very centre of the city, which is the overall most accessible and most prestigeous point.

At t=5 this points reaches a saturation level and the Central Business District (CBD) functions begin to spill over into a first ring of surrounding points. Quickly however, the growth is concentrated on the point just east of the existing pole. Both points specialize to a large extent in their functions also during the second phase.

The rare tertiairy establishments first grow in the centre as well, but, as soon as there is a market large enough, new shopping zones come into being near the periphery of the city. This evolution stablises when 5 such centres have emerged. During the second phase the 5 survive but no new can grow. This is partly due to the declining number of residents within the city and the well established markets per shopping areà. The spreading of the elementary services throughout the city is influenced by the distribution of both the population and the rare tertiairy shopping centers. The blue collar residents concentrate mainly along the canal in three poles: the north, center and south, which also are the zones of high blue collar employment. At the end of the first period the relatively cheaper transportation costs of the blue collar actives allows them to live further away from their jobs.

This leads to a spreading of blue collar residents throughout the entire city and even beyond the city limits in the commuting area. In the same way white collar actives tend to locate in suburbs outside the 37 points of our urban area during phase 2 and become commuters. Within the urban area of the system they already lived in the other fringe and distributed over the city, but avoiding blue-collar concentrations.

Starting from the point in time (t =20) in the evolution of our city we may test some scenarios concerning the possible future of the city under some different conditions. Figure 16 and the table above show the situation of the city after ten more units of simulation time (t = 30) without any parametric change. From these, one concludes that the differences with the situation at t=20 are minor.

The first scenario concerns the construction of a new subway line in the public transportation system, which goes north south through the city. The model is run for t=20 to t=30, with the subway present, and the setting of structure is compared with that obtained at t=30 without the subway. This improvement in the transportation network has a positive effect on the economy of the city as there is a 2.4% increase of the total employment and 4.5% more actives reside in the city. Mainly blue collar resident (+5.4%) return to the city (figure 17), more specifically to the areas around the termini of the subway system. More city residents also means increased demand for services and consequently there is an increase and a small redistribution of tertiairy services to be observed; which is strongest for the elementary, retail services.

Another interesting scenario, summarized in figure 18, is about a possible investment in a rare tertiairy shopping service; our simulation shows that the size of the investment, its spatial location, and the precise moment when it occurs are very important. As one can see in figure 18 an investment of 40 units on a point in the south-east of the city at time t=10 gives rise to a sucessfull shopping center. However, exactly the same investment, made at the later time t=20, fails, because of an insufficient market, the population being already absorbed by existing shopping zones. The same size of investment later (t=20) doesn't succeed because of the lack of a sufficient market already served and absorbed by the existing shopping zones. With an investment of 50 units, the launching at t=20 is sucessfull. Otherwise an investment of 40 units at t=20 will lead to a seventh peripherical center if one chooses a less well served point, such as the one to the north and east of the previous one.

The next scenario tests the effect telematics could have on the location of the CBD, as it will lessen, to a large extent, the need for aggregation of the CBD functions. Figure 19 makes this clear for different values of the parameter of cooperation of the CBD services $P^{2.2}$, and shows in an extreme case ($P^{2.2}$ = .0011) the CBD collapsing completely.

The last scenario is probably the most significant in demonstrating the strength of a model like this with its emphasis on general mechanisms which produce spatial structures, instead of on spatial structures as such. The Allen model permits to simulate quantitatively the same city (all parameters are the same, initial condition and the networks are the same) but instead of having a canal north south through the city there is now at the same location a line of hills, which is unattractive (less accessible) to industry. The simulation ran from t=10 till t=10 and clearly the structure of the city (figure 20), as compared to t=10 of the reference structure is completely different, with industry absent on the mountain ridge but spread out in the periphery of the city where the land is cheap and crowding least. White collar residents now live in the hilly part of the city, highly attractive to those since they can avoid living in industrial and crowded areas. In the residential pattern there is a preference for the northern part of the city and therefore also tertiary services locate near their market to the north as well.

In summary, such computer models permit to study in a quite detailed way the evolution of complex structures such as towns. The practical importance of such computer models has still to be assessed. It is obvious that the predictions based on these models have to incorporate numerical values of parameters, which can only be observed through the study of past evolution. Only when we understand the past can we predict the future; there is a strong naturalistic element in this approach. Examples of concrete studies involving this element begin now to appear. We may quote in this context a simulation of the inter-region evolution of the USA.

Let us come back to some more general features of man's dialogue with nature.

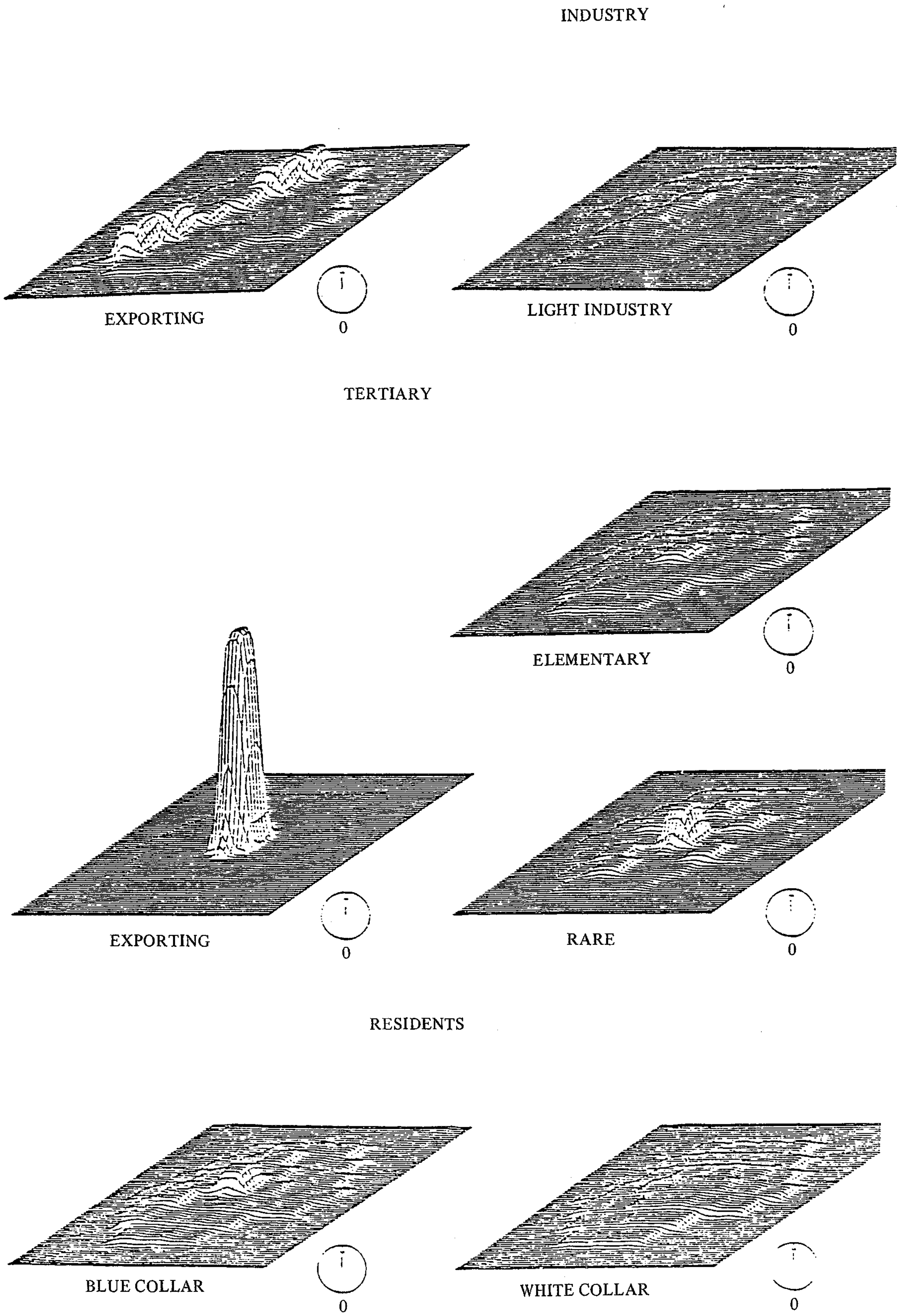

Fig. 13 Initial distribution of the seven variables: reference structure at the beginning of simulation

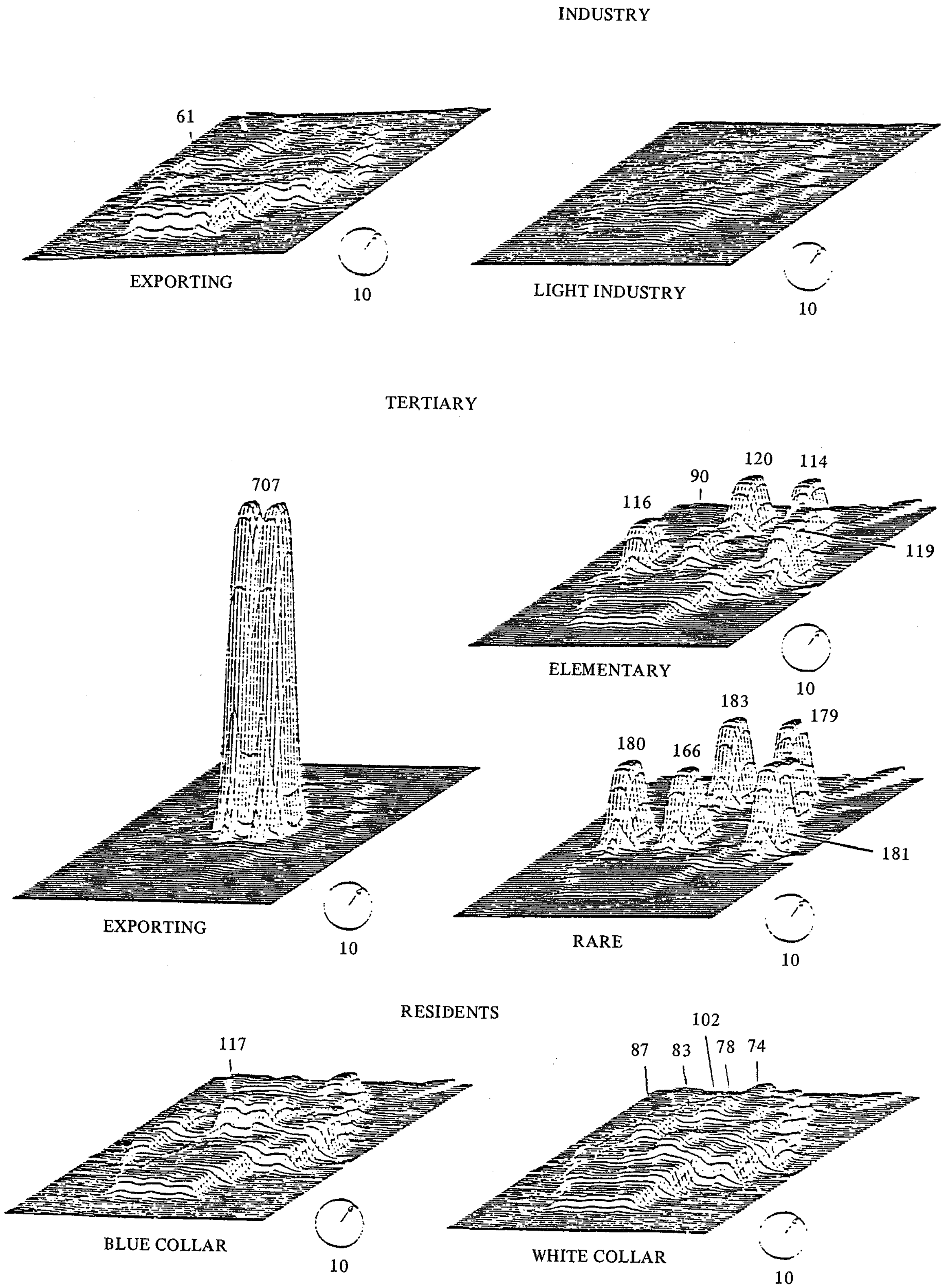

Fig. 14 Reference structure at T = 10 (end of phase 1)

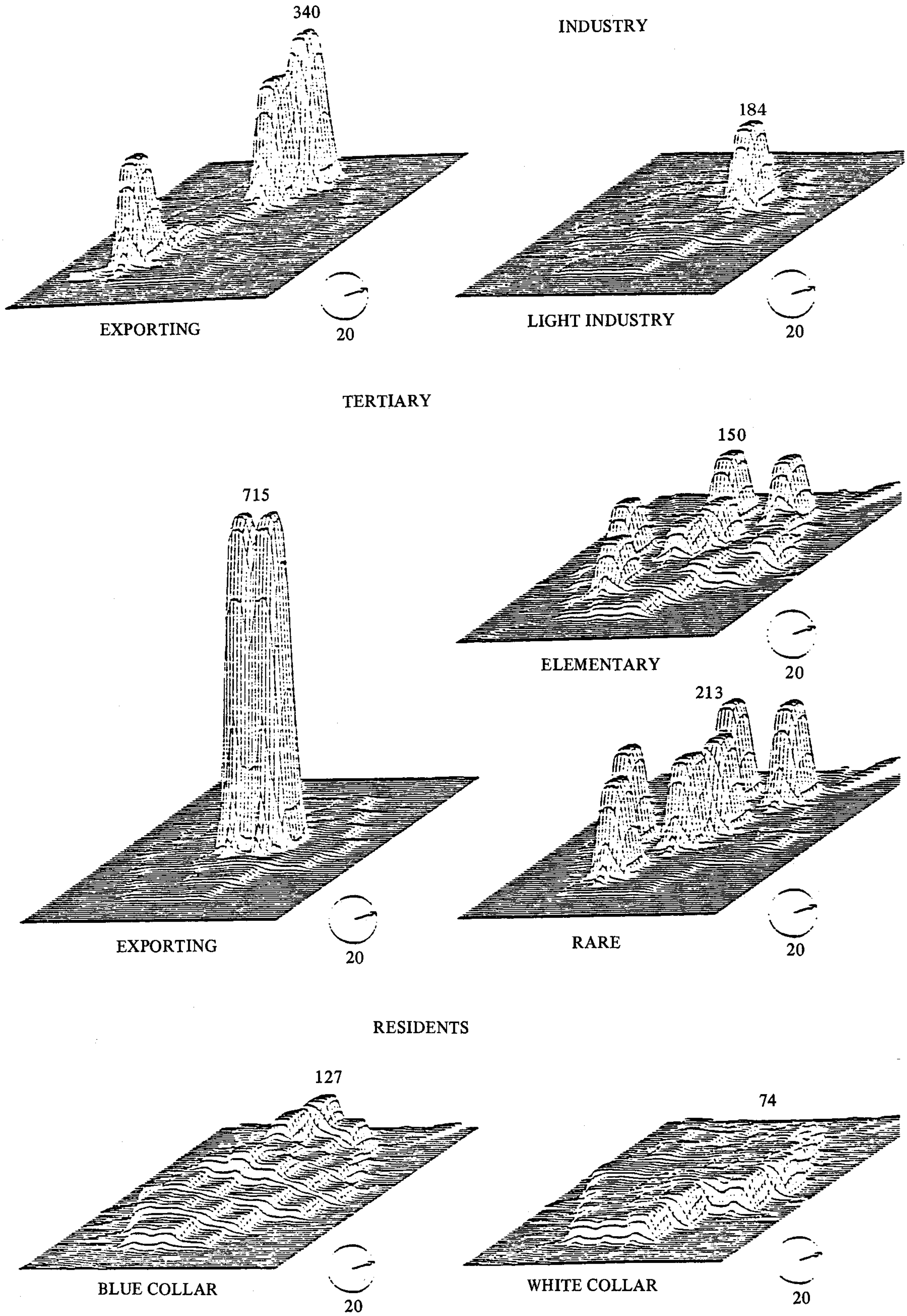

Fig. 15 Reference structure at T = 20 (end of phase 2)

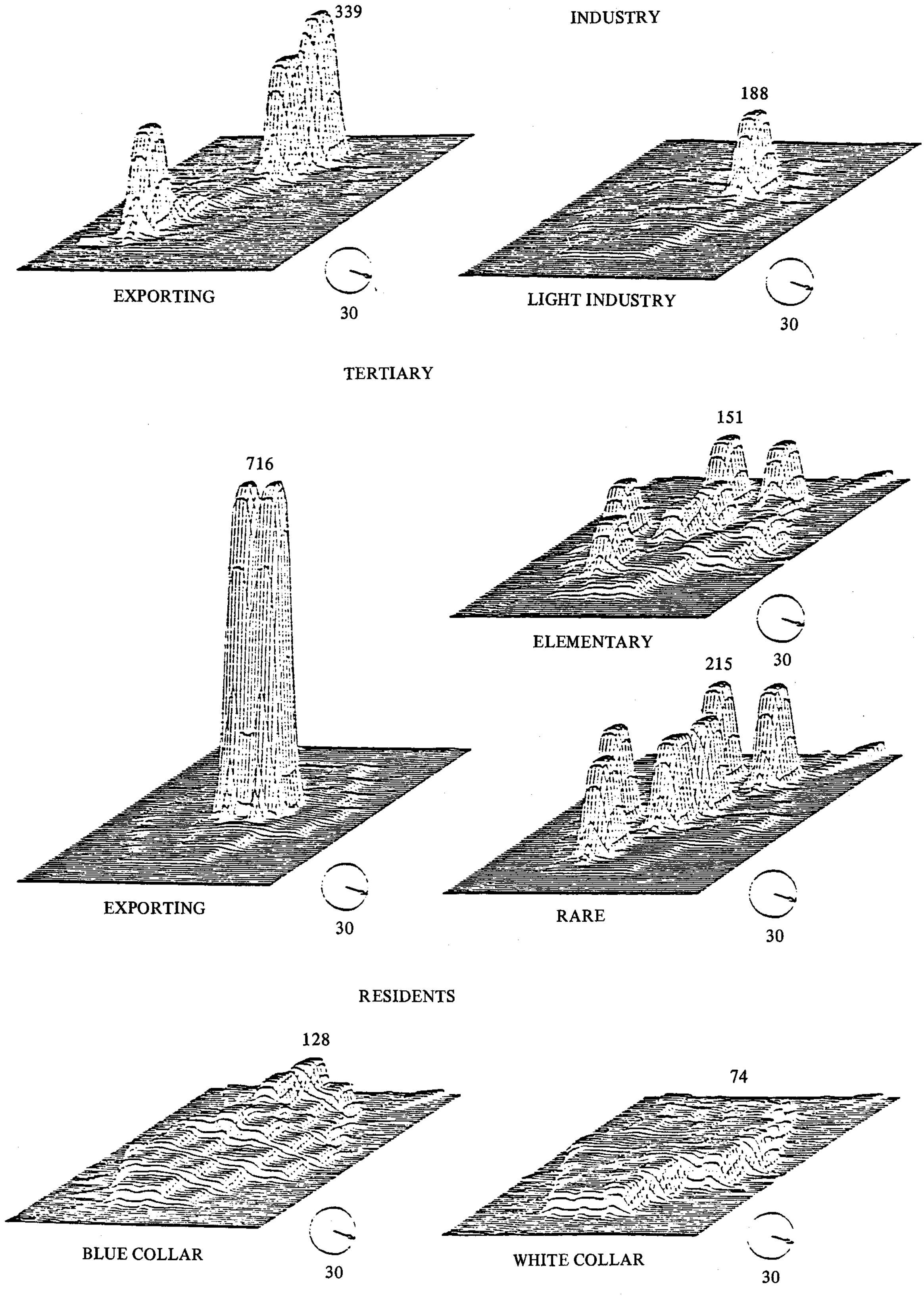

Fig. 16 Reference structure at T = 30 (end of phase 3)

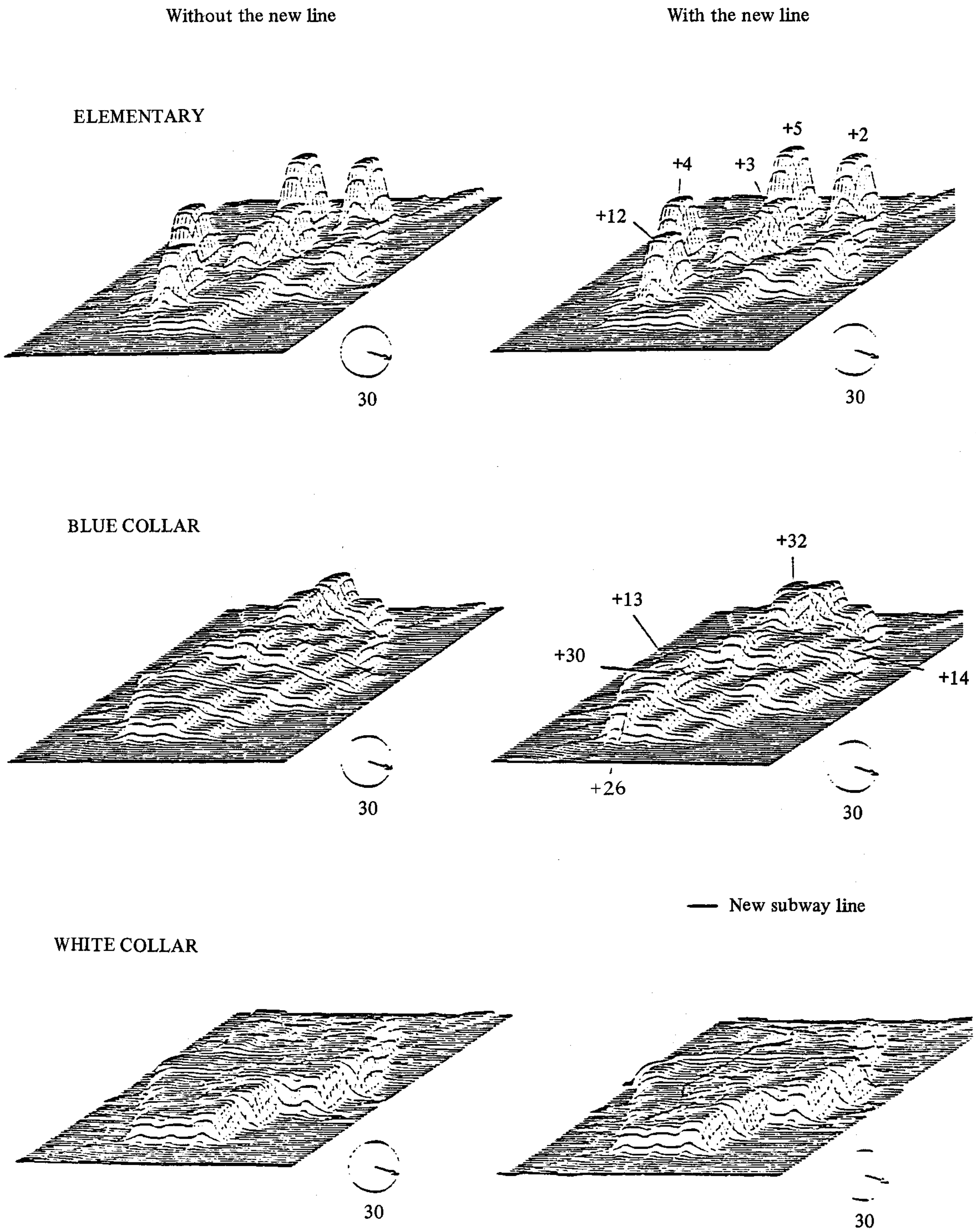

Fig. 17 Possible effects of the construction of a subway line north-south of the city.

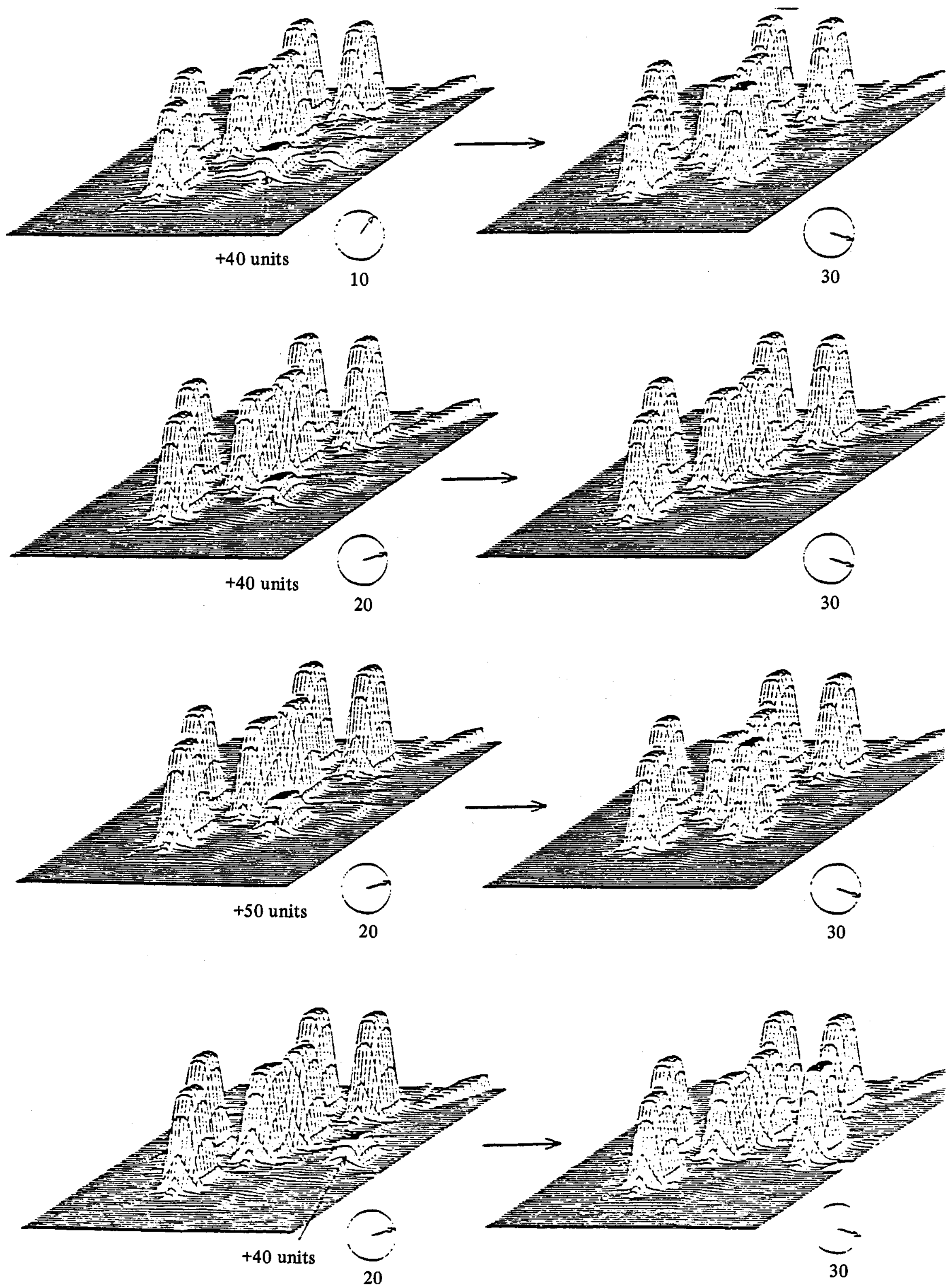

Fig. 18 Possible launching of a shopping center, showing the critical choices of size, moment and place of the investment.

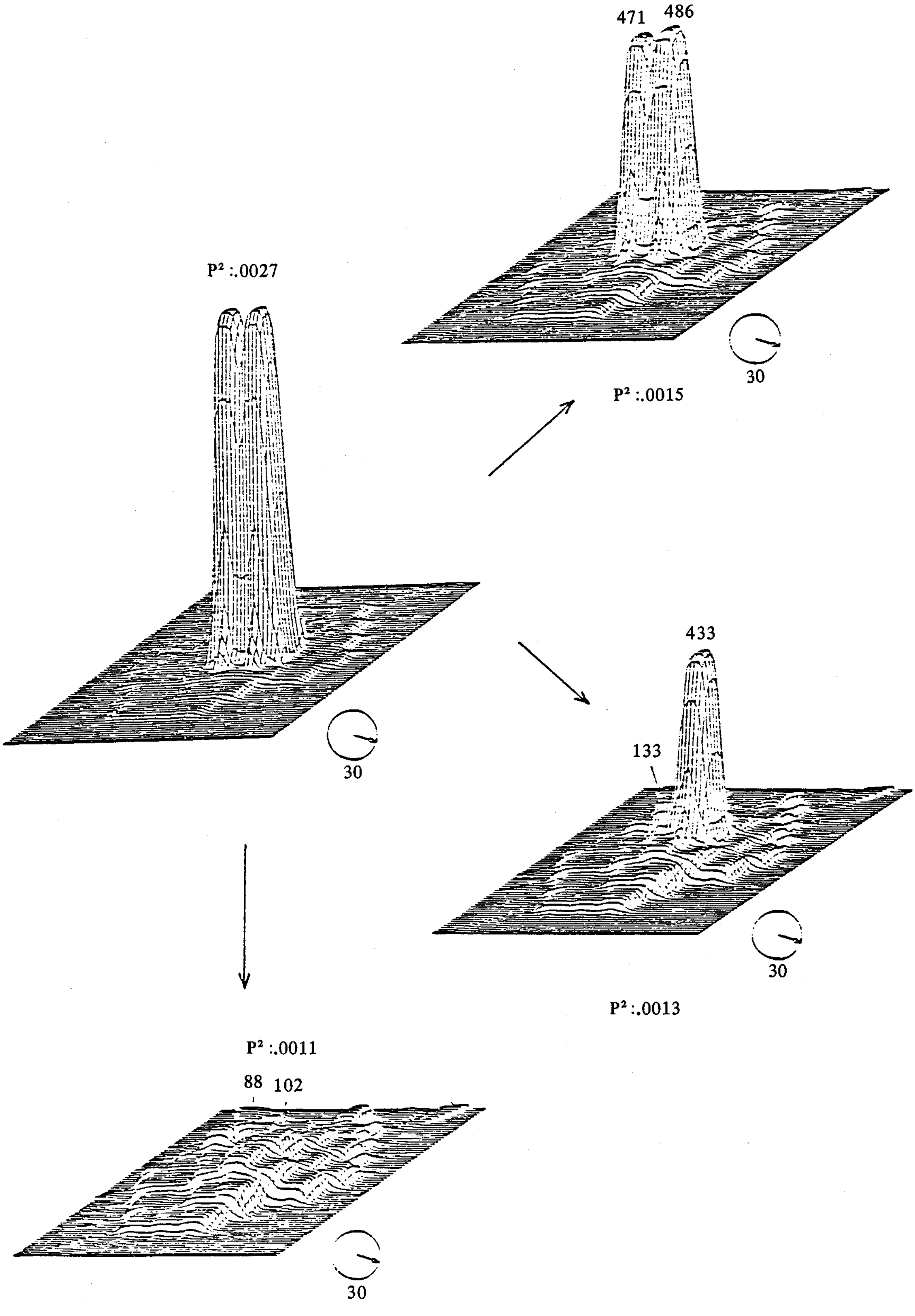

Fig. 19 Possible futures of the CBD according to increasing usage of telematics (reduces the need to aggregate).

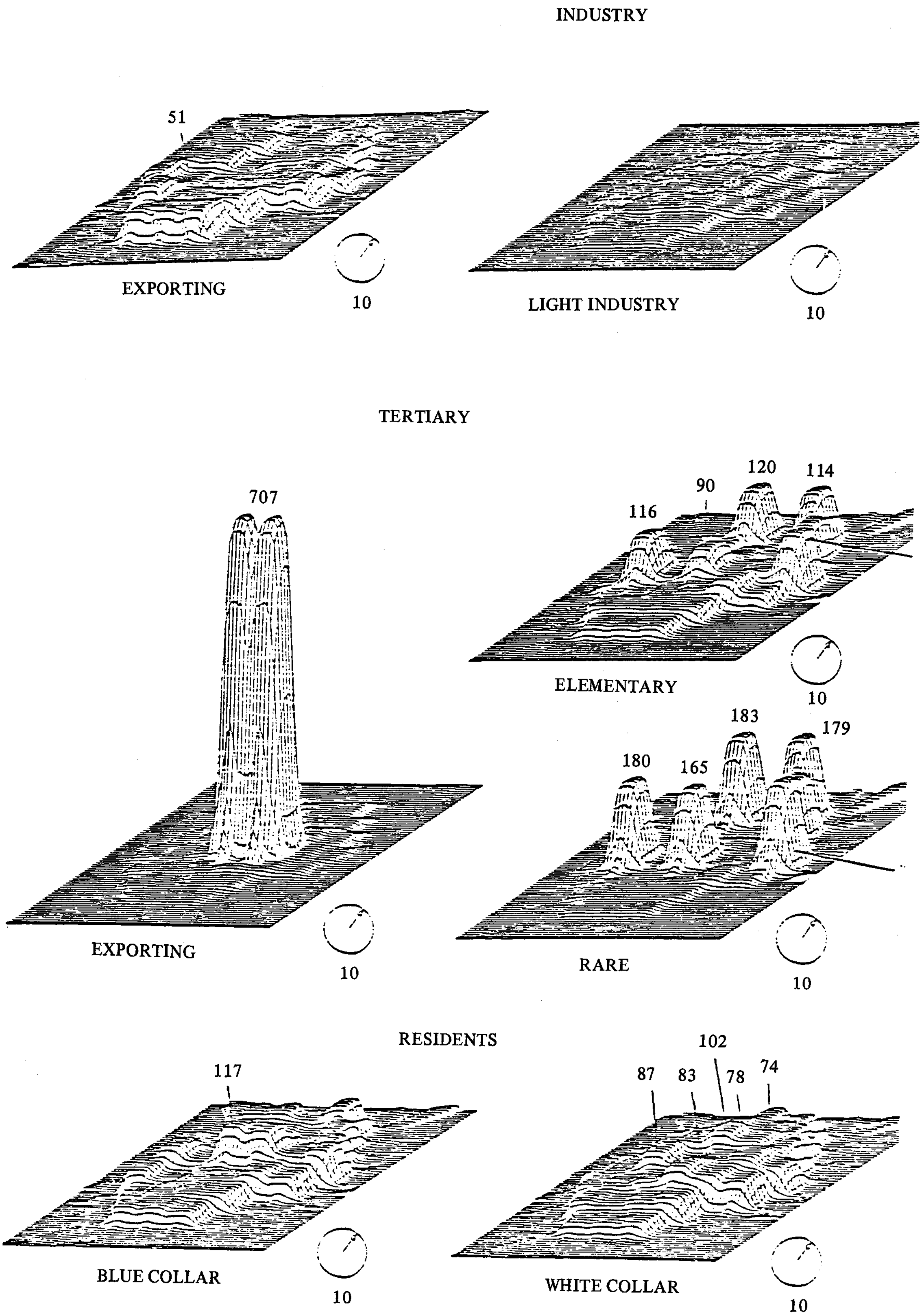

Fig. 20 Distribution of jobs and residences in a city with a mountain ridge instead of a canal (at T = 10)

V

We may now conclude. Classical science had a dualistic basis: on one side, we had the world viewed as a huge automation; and on the other, man, outside of the nature he was describing. Obviously, this position can only be quite fragile. How to maintain this privilege? Is man similar to some God, or is he nothing but a machine, which only is not informed about the fact that it is itself a machine? This frailty could only generate some form of anxiety. We come now near to the year 1984. This is also the title of the world-famous utopia drawed by Orwell. Here we see a blue-print for a society into which time is indeed an illusion, as was often stated by Einstein. The official slogan is: "Who controls the past controls the future: who controls the present controls the past". Control is only possible through oppression. Books, newspapers are rewritten, history is reduced to meaningless fluctuations.

In Orwell's novel, the Great Inquisitor O'Brien, torturing his victims, repeats that there is no reality outside of his mind. Curiously enough, we can see that this materialistic society, focalized around Power for its own sake, meets thouroughly the requirements of a philosophical idealism of the most pure vein.

The same anxiety appears in Huxley's Brave new World. It is 20 years since Huxley died. This novel remains as powerful as ever. Will future societies be patterned along the scheme of insect societies? It should be noted, we have insisted on this point, that insect societies are much less deterministic than generally assumed. Recent development in animal behavior suggest us a way out of the nightmare which obsessed us: the so-called 'loss of personal identity'.

Our new outlook on the nature around us begins to be more compatible with what we see inside us.Our relation with nature, and specially the problem of learning and measuring, become only meaningfull in this perspective, which incorporates instability and irreversibility. What could be the meaning of a learning process of tomorrow would always be given today?

The message modern science carries appears to us today as having a more universal character than it used before. It is more acceptable to other cultural traditions. We recover at present some glimpses of the harmony between man and nature which is so much in the chinese and japanese vision of nature.

The Honda Foundation has consistently emphasized the concept of ecotechnology as corresponding to the embedding of technology in life. The trends in modern science I have described lead to an embedding of scientific and philosophy, and overcomes the traditional separations between the "two cultures".

The highest form temporal existence can take is "caring" (Sorge in Heidegger's terms). A striking example of this caring is the activity of the Honda Foundation. Therefore, let me take this opportunity to wish Soichiro Honda and the Honda Foundation a long and successful activity.

I would like to express my deep thanks to Serge Pahaut and Pierre Kinet which helped me to the preparation of this text.