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Observing Collectivities: The Combinatory Systems Approach in Social Sciences

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Abstract: Since Thomas Schelling's attempt, in Micromotives and Macrobehavior, to offer a logical explanation of why collective macro behaviour derives from the micro behaviours of intelligent agents and Conway's discovery of the fantastic world of Life, the study of the behaviour of collectivities has been a very complex subject of study, and for this reason a fascinating and interesting one as well. If observed from a certain distance collectivities appear distinct with respect to the individuals that compose them and, due to the interactions of the micro behaviours, seem capable of producing interesting macro behaviours to which many relevant collective phenomena of self-organization may be associated; four of these processes are: the accumulation of objects, the spread of features or information, the pursuit or exceeding of a limit, and the attainment and maintenance of an order among the micro behaviours. To understand, explain and, to a certain extent, control these collective phenomena I have formalized the simple Theory of Combinatory Systems. In plain words, by Combinatory System I mean any unorganized collectivity made up of a plurality of similar agents producing analogous micro behaviours; the macro behaviour of the system, as a whole, derives from the combination of the analogous micro behaviours (hence the name Combinatory System); but, on the other hand, the macro behaviour directs the subsequent micro behaviours according to a feedback relation. The action of a set of recombining and necessitating factors guarantees the maintenance over time of the dynamics of the system, so that when the system starts up "by chance" it then maintains its behaviour "by necessity", as if an invisible hand regulated its time path and produced the observable effects and patterns. This paper presents the fundamental ideas and mechanisms that underlie these systems, along with some models that illustrate the self-organization activity in collectivities.

Keywords: Behaviour of Collectivities, Combinatory Systems, Combinatory Automata, Social Dynamics, Populations and Collectivities, Systems of Accumulation, Systems of Diffusion, Systems in Pursuit, Systems of Order

Collectivities as Units

COLLECTIVE PHENOMENA ARE the essence of life at any level, both for human beings – who operate in populations, tribes, associations, teams, social units, and so on – and for animals, which operate in crowds, hordes, flocks, flights, herds, schools, and so on.

From an endogenous perspective (Bertalanffy, 1968), collectivities can be observed as units composed of a plurality of similarly unorganized elements – or agents — which appear distinct with respect to the individuals they are composed of and show an autonomous observable macro behaviour (change in the state of a collectivity over time) – which can lead to observable macro effects – which derive from the interactions of the micro behaviours (change of the agents' states over time), or derived micro effects, of the agents.

The behaviour of the collectivity can be *defined* as *local* – or based on limited information – if the micro behaviours derive from *local information* possessed by the agents (a person acquires a good because he observes that at least N friends have bought it; an elephant in a herd runs to the left because the elephants on its right push it in this direction) or *global* – or based on synthetic information – if the micro behaviours depend on *global information* (over time and/or space) possessed by all the agents (all the students rise because the teacher orders them to; all the animals flee because they see the fire advancing).

Originally, the study of collectivities followed the traditional *macro* approach, which produces a macro description of the *global* behaviour of collectivities by only following general *macro* rules and ignoring the micro behaviour of the agents.

Within the Sciences of Complexity the *macro* approach is typical of Population Dynamics Models, which try to represent population behaviour (increase, evolution, co-evolution and competition) in terms of the number of their elements, using, for example, Malthusian models and Volterra-Lokte equations in various forms (Lokta 1925; Volterra 1931).

Von Bertalanffy's General System Theory (1968), Wiener's Cybernetics (1948), Haken's Synergetics (1977), Forrester's Systems (Industrial) Dynamics approach (1961), Senge's System Thinking approach (1990), and Maturana's and Francisco Varela's Autopoiesis approach (Maturana and Varela 1980) offer powerful conceptual frameworks and practical tools for building models of the behaviour of collectivities.

The Complex Adaptive Systems approach, in particular (Gell-Mann, 1995), studies how collectivities interact and exchange information with their environment in order to maintain their internal processes over time through adaptation, self preservation, evolution and cognition.

A *micro* (or internal or synthetic) explanation of how a collectivity's macro behaviour derives from the agents' local information (Gilbert 1995) was offered by Thomas Schelling in his very famous Micromotives and Macrobehavior (1978), and by Conway in his fantastic world of Life (Gardner 1970). The analysis of the *local* behaviour of collectivities implies a Recursive Approach, and the Cellular Automata Theory – introduced in the late 1940s by John von Neumann (Burks 1966) – allows the researcher to explore complex systems as lattices whose behaviour depends only on local rules defined for cells (Dewdney 1990).

As Holland attempts to demonstrate, the genetic algorithms approach (Holland 1975) and the related genetic programming approach of Koza (Koza 1992) are the most powerful approaches to understanding and showing the *hidden order* in collective behaviour.

Collectivities as Combinatory Systems. The Central Idea

The macro behaviours of a collectivity can produce many important phenomena or effects: the accumulation of objects, the spread of features or information, the pursuit or exceeding of a limit, the attainment and maintenance of an order among the micro behaviours, and the interdependent dynamics of individual *improvement* and collective *progress* in the overall state of the collectivity.

The simple Theory of *Combinatory Systems* is useful in understanding, explaining and, to a certain extent, controlling these collective phenomena.

In plain words, by *Combinatory System* I mean a *collectivity* (as defined above) whose macro behaviour – as a unit – derives from the "combination" of the *analogous micro behaviours* of its similar agents (hence the name Combinatory System), but, reciprocally, whose *macro* behaviour (or the macro effect) is *self-produced global information* that *determines*, *conditions* or *directs* the subsequent *micro behaviours* of the agents, since agents, consciously or unconsciously, act (exclusively or prevalently) on the basis of global information which they directly produce and update over time (Mella 2005; 2007).

On the one hand, the global information is – or derives from – a synthetic variable whose values are produced by the combination of the micro states of the agents, but, on the other, these values affect the subsequent states of the agents as a result of a *micro-macro feedback*, acting over a period of time, that produces self-organization in the agents' micro behaviours (Fig. 1), as if an Invisible Hand or an Internal Organizer produced the observable effects and patterns.

There is nothing strange here: the *invisible hand* is nothing other than the *micro-macro feedback* action (or *circular causality*) that generates and updates the global information which organizes the agents' micro behaviours in order to produce self organization or *synchronization*.

The combinatory systems approach is *neither* a *macro* approach, since it also refers to local rules by considering micro behaviours, *nor* a *micro* approach, since it also includes the macro behaviour in the model of the *system.*

It is rather a *micro-macro* approach, precisely in that the *operating rules,* describing the behaviour of the system, must in some way include not only *local rules* but also the *micro macro feedback*.

Combinatory Systems theory considers the existence of the micro-macro feedback as the condition for a complex system to be conceived of as a combinatory system.

Nevertheless, under this condition we can observe that – in general – the *micro-macro feedback* occurs only if the number of agents that develop the micro behaviour exceeds a *minimum number* (*critical activation density*) and remains below a *maximum number* (*critical saturation density*), which is defined for each specific system.

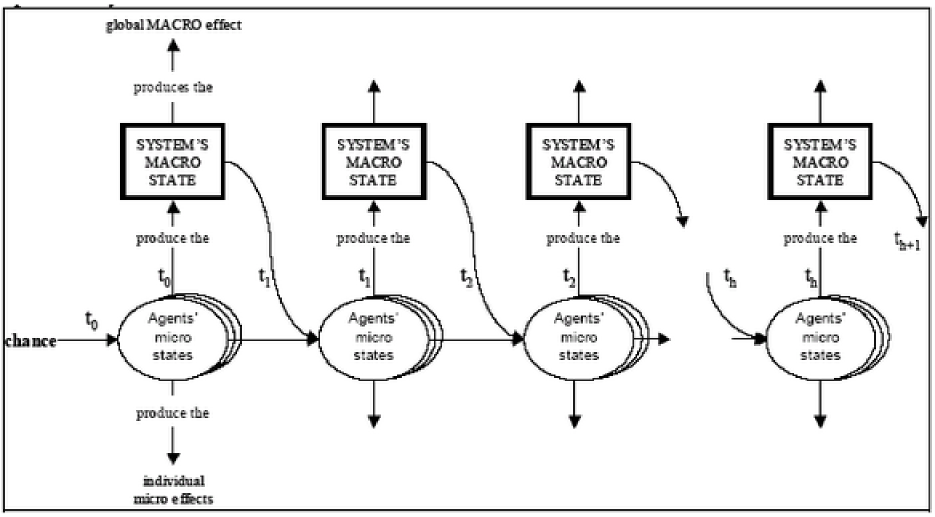


Figure 1: The Operative Logic of a Combinatory System

Combinatory systems generally are set off *by chance*, but if they reach the *critical activation density* they maintain their dynamics *by necessity*, due to the presence of necessitating and recombining factors.

Necessitating factors are all those factors that force the agents to adapt their micro behaviour to the system's macro behaviour; they may result from obligation, conviction, imitation, convenience, utility, desire, or the operative programme of the individual elements.

The existence of one or more necessitating factors is indispensable but not yet sufficient; the system must also be able to recombine the micro behaviours (or the micro effects) in order to produce the macro behaviour (or the macro effect); some *recombining factors* (rule, convention, constraints, algorithm, etc.) deriving from the environment must operate in the system so that, through the micro-macro feedback, the necessitating factor can also operate.

Therefore, *to interpret the activity of combinatory systems we must always understand the nature of both the recombining factors and the necessitating ones* since, without the joint action of these factors, there would be no micro-macro feedback and the collective phenomena the theory tries to explain would not be produced.

Models of Combinatory Systems

Combinatory systems can be represented by different models of increasing complexity.

The simplest models are the *descriptive* ones that indicate in words – or by patterns analogous to Fig. 2 (energy inputs are not included) – the fundamental elements necessary for understanding the operative logic of systems that produce observable collective phenomena.

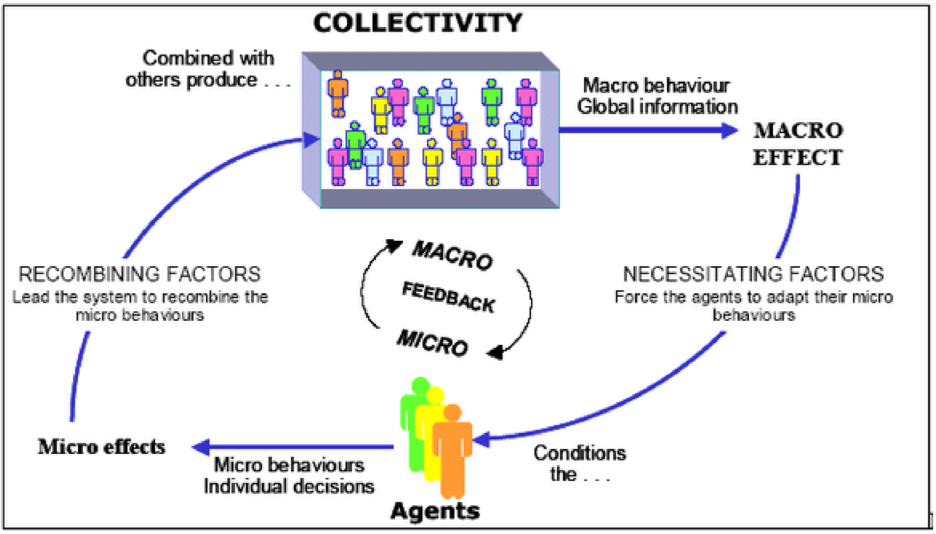


Figure 2: The Descriptive Model of a General Combinatory System

The more powerful models are the *heuristic models* that try to simulate the system's dynamics by stating - or constructing ad hoc – a set of rules specifying: (1) the micro, or necessitating rules producing the micro behaviours of agents as the consequence of the necessitating factors; (2) the macro, or recombining rules that produce the system's macro behaviour, due to the presence of recombining factors; (3) the *micro-macro feedback* that allows the system to produce the observed phenomena; (4) the strengthening, weakening and control actions, when possible or admitted.

Finally, we can build a combinatory automaton (Mella, 2007) that specifies the mathematical and statistical simulation model that produces the micro and macro behaviours of the Combinatory Systems (Fig. 3).

Let us suppose that in a village in Libya with N=100 white houses an inhabitant – after a journey in Syria – *by chance* decides to paint (micro behaviour) his house blue (micro effect). As the colour is pleasing, *by chance* another inhabitant imitates the first one, then another and another.

Referring to figure 3, we can represent this phenomenon with the aid of a Combinatory Automaton of N=100 cells, whose analytical state – in terms of colour of the houses at a given moment – is represented by the arrow $a_i(t_h)$ = ["white" or "blue"], $1 \leq i \leq 100$, h= 1, 2, …

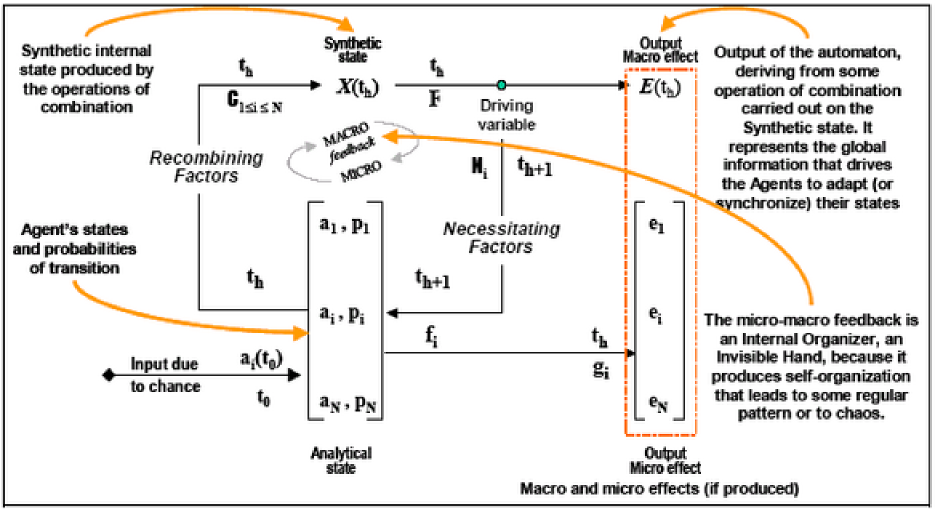


Figure 3: Model of Combinatory Automaton

If we denote the white house as 0 and the blue house as 1, we can also represent the synthetic state of the automaton as simply $X(t_h)=n\square N$ in terms of blue houses, $0 \leq n \leq 100$, considering that $[100-X(t_h)]$ represents the synthetic state in terms of white houses.

At time t_0, the synthetic state is $X(t_0)=0$ (blue houses); at t_1 the analytical state becomes $X(t_1)=1$.

If the activation density is reached, then the *internal feedback* begins: the higher the number of blue houses (global information), the stronger the incentive for people to paint their white houses blue, and the faster the change in colour of the houses in the village.

The *analytical state* of the village is modified due to micro behaviour (individual inhabitants that paint their houses blue) that causes micro effects (individual houses that change from white to blue); but, *combined together,* these micro behaviours give the idea of a macro behaviour, that of the village, understood as a collectivity, that changes the colour of its houses. The macro behaviour thus produces a macro effect (gradual change of colour) which is the global information that, in turn, influences the micro behaviours as part of an internal feedback which operates according to the *probability of transition of state* "$p_i(t_h)$" for each inhabitant; a probability that depends, in turn, on the *synthetic state* of the system. Thus we can write: $p_i(t_h)=F[X(t_h)]$, or simply: = $p_i(t_h)=F[n]$ (the probabilities can also indicate potentiality, frequency, likelihood, etc.). It is important to note that the change in state of each house occurs during a finite period of transition of state – that needed to do the painting – but this period is not considered in this Combinatory Automaton.

To describe the behaviour of the combinatory automaton in changing its states, the model must specify in the most accurate way possible the form of the probability function, $p_i(t_h)=F[n]$, for each agent and for the $0 \leq n \leq 100$ admissible states of the village (automaton).

These probabilities should offer a numerical indication of all the observable, or even imaginable characteristics in each $a_i(t_h)$, such as to make a change of state possible, plausible, probable, likely. This therefore expresses the influx of *necessitating factors* that regulates the individual choices of whether or not to paint.

According to the general model in figure 3, and considering the previous assumption, we can build the following *Combinatory Automaton* to simulate the Libyan village:

$$\begin{cases} a_i(t_h) = \{\text{“1”} or \text{“0”}\}, \ 1 \le \mathrm{i} \le \mathrm{N}, \ \ \mathrm{h} = 0, 1, 2, \dots \\ a_i(t_0) = \{\text{“1”}\}, \ 1 \le \mathrm{i} \le \mathrm{N} \\ X(t_h) = \sum_{1 \le i \le N} a_i(t_h) = n(t_h), \quad \mathrm{h} = 0, 1, 2, \dots \\ a_i(t_{h+1}) = \{\text{“1”} \times p_i[n(t_h)] \ \ or \ \ \text{“0”} \times q_i[n(t_h)]\}, \ 1 \le \mathrm{i} \le \mathrm{N} \\ OPERATIVE\ PROGRAMME \Rightarrow define: \ \mathrm{N}, \ \ p_i[n(t_h)], \ 1 \le \mathrm{i} \le \mathrm{N} \end{cases}$$

As N=100, the most important step is defining the probabilities of transition of state. If we simply suppose that these probabilities are non agent-dependent and assume the form:

$$\mathrm{p_i}[\mathrm{n(t_h)}] = \frac{\mathrm{n(t_h)}}{\mathrm{N}} = \frac{\mathrm{n(t_h)}}{100}, \ \ 1 \le \mathrm{i} \le 100,$$

then the system's macro behaviour is *irreversible* and the diffusion accelerates, since the village becomes entirely blue.

If we abandon the hypothesis of irreversibility and consider the possibility that each inhabitant may change his decision and re-paint his blue house white – so that we admit that a cell could change its state from “0” to “1” as well as from “1” to “0” – we might assume, for example, that the probabilities take on the following values corresponding to a tent map centered on n=50.

$$\mathrm{p_i}[\mathrm{n(t_h)}] = \begin{cases} \dfrac{\mathrm{n(t_h)}}{100} & \text{if } \ 0 < \mathrm{n(t_h)} \le 50 \\ 1 - \dfrac{2\mathrm{n(t_h)} - 100}{100} & \text{if } \ 50 < \mathrm{n(t_h)} \le 100 \end{cases}$$

If we produce the micro behaviours of the cells – expressed as a series of “0” or “1” – and the macro behaviour of the automaton – expressed by the series of number of white houses – by a lattice of (10□10) cells, over 50 discrete instants, using random numbers to simulate the individual decisions, according to the dynamics of the probabilities of transition of state, we find a *chaotic macro behaviour,* in the sense that the automaton shows dependence on initial conditions and does not produce cyclical structures in its dynamics.

Figure 4 shows the control panel of the automaton. Figure 5 shows the results of some tests.

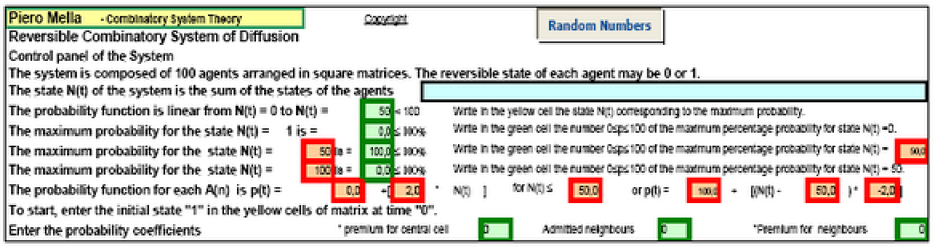
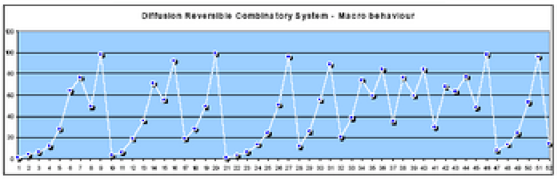
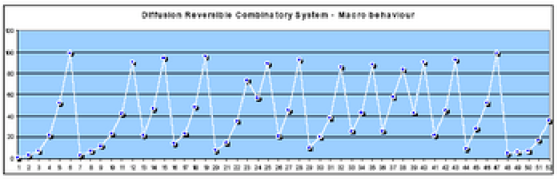


Figure 4: Control Panel of the Combinatory Reversible Automaton Simulating the Libyan Village

Test 1: Initial Casual Painting and Macro Behaviour Simulated with Different Random Numbers

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0





Test 2: Initial Casual Painting and Macro Behaviour Simulated with Different Random Numbers

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
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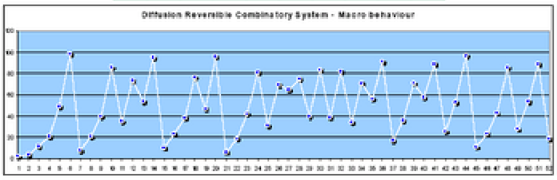

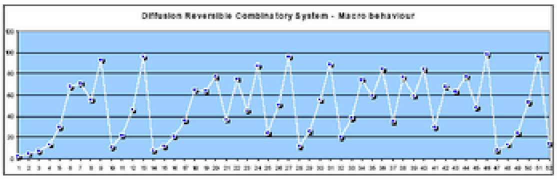

Figure 5: Tests for Reversible Automaton Simulating the Libyan Village

Typology of Combinatory Systems

On the basis of the previous definitions it is possible to identify four main classes of phenomena derived from Combinatory Systems.

1. Systems of accumulation, whose macro behaviour leads to a macro effect which is perceived as the accumulation or the clustering of “objects”, behaviours or effects of some kind; this logic applies to quite a diverse range of phenomena, among which the formation of urban or industrial settlements of the same kind and of industrial districts, the grouping of stores of the same type in the same street, the accumulation of garbage, graffiti, writings on walls; but it can also be applied to phenomena such as the breaking out of applause, the formation and maintenance of colonies, forests, herds and schools.
2. Systems of diffusion, whose macro effect is the diffusion of a trait or particularity, or of a “behaviour” or “state”, from a limited number to a higher number of agents of the system; systems of diffusion explain quite a diverse range of phenomena: from the spread of a fashion to that of epidemics and drugs; from the appearance of monuments of the same type in the same place to the spread and maintenance of a mother tongue, or of customs.

3. Systems of pursuit produce a behaviour that consists in a gradual shifting of the system toward an "objective", as if the system, as a single entity, were pursuing a goal or trying to move toward increasingly more advanced states; this model can represent a lot of different combinatory systems: from the pursuit of records of all kinds to the formation of a buzzing in crowded locales; from the start of feuds and tribal wars in all ages to the overcoming of various types of limits.
4. Systems of order produce a macro behaviour, or a macro effect, perceived as the attainment and maintenance of an ordered arrangement among the agents that form the system; systems of order can be used to interpret a large number of phenomena: from the spontaneous formation of ordered dynamics (for an observer) in crowded places (dance halls, pools, city streets, etc.) to that of groups that proceed in a united manner (herds in flight, flocks of birds, crowds, etc.); from the creation of paths in fields, of wheel-ruts on paved roads, of successions of holes in unpaved roads, to the ordered, and often artificial, arrangement of individuals (stadium wave, Can-Can dancers, Macedonian phalanx).

Selected Collection of Combinatory Systems

Having defined the concept of Combinatory System, I consider it useful to offer a representative collection of typical systems which might be considered as an archetypal structure whose significance can be applied to a wide typology of collective phenomena.

"Pile-of-Garbage" System

How often have we observed squares, streets, courtyards, fields, woods and other frequented places (environment) with garbage spread over them; and, unfortunately, how many times have we found piles of garbage in the most improbable sites!

We can consider piles of garbage as the macro effect of a combinatory system that acts according to the following heuristic model: Micro behaviour and necessitating factors – If you need to throw away refuse without being reprimanded by others, look for a garbage dump (global information); if you cannot find one, throw it where you see a garbage pile that is already formed, if you do not want to be criticized by others and wish to reduce pollution.

Macro behaviour and recombining factor – If the environment is favourable to the formation of a pile of garbage, there are enough passers-by who throw away garbage, and, above all, there are no other ways to throw away refuse, then there will be an increase in the number of people who throw away their garbage on already-formed piles, thereby conserving and increasing them.

Micro-macro feedback. chance and necessity – The pile is the macro effect of the discarded refuse, but it conditions the amount of subsequent littering. The system activates when, "by chance", an initial pile of garbage is formed; the micro-macro feedback inevitably makes it larger.

Stengthening, weakening and control actions – A sign reading "garbage dump" or "garbage disposal prohibited" represents the best strengthening action. The prompt removal of the initial refuse and a careful vigilance represent weakening factors.

"Urban-Settlement" System

A city appears as the result (macro effect) of individual decisions to build a house in a favourable place; but the presence of a city provides *global information* that favourable living conditions have been found, and this influences the individual micro behaviours; the city itself indicates the favourable conditions (recombining effect).

Heuristic model: Micro behaviour and necessitating factors – If you need to build a house, look for favourable conditions (opportunities, services, protection, etc.); if there is a city there already, assume that favourable conditions exist; leave your house to your descendants.

Macro behaviour and recombining factor – The construction of new houses strengthens the urban settlement; the strengthening and growth of the city represent global information that favourable conditions exist, and this influences the micro behaviours. The older and larger the city is, the greater the incentive for new arrivals to the area to locate there.

Micro-macro feedback. chance and necessity – The city is the result of individual decisions to build a house in a favourable place; but the presence of a city influences the individual micro behaviours (the city itself indicates the favourable conditions). A city arises "by chance" but, once begun, the phenomenon is "by necessity" maintained over time as long as the necessitating factor operates.

Strengthening, weakening and control actions – Overcrowding, the increase in the time needed to cross a town, the desire for solitude, and the need to preserve the surrounding areas: these all represent weakening factors. Examples of strengthening factors are the danger of mass inflows of people, tourist attractions, tax incentives for construction, and the supply of attractive urban services.

Industrial Districts and Colonies

The logic of the previous combinatory system also applies to the industrial settlements of companies in the same line of production. Why is Valenza, Italy, the capital of jewellery, Vicenza of goldsmithing, Cantù of chairs, Como of silk, the Silicon valley of chips? The answer is similar to the one we have seen in the case of urban settlements.

We also encounter the same logic in other contexts of natural systems: why are there many single-valve shells on some cliffs while on others they are scarce? Why do sponges concentrate in certain marine areas and not in others which, nevertheless, have similar conditions? Why, where by chance a seed takes root and a plant grows, does a woods made up of similar plants arise? All of these questions have the same answer: when *by chance* an initial biological settlement is formed the necessitating factor of reproduction combines with the recombining factor of the presence of colonies to activate the micro-macro feedback: the colony is formed by the individual elements, but this facilitates reproduction and the consequent expansion (Mella, 2006).

"A-Fashion-is-Born" System

A fashion – whether clothing, clocks, cars, toys, a particular linguistic form, and so on – arises in a given environment from a novelty that is introduced (micro behaviour), "by chance", by a given creator for the purpose of getting away from the usual routine.

Heuristic model: Micro behaviour and necessitating factors – If you need to stand out, abandon the traditional way and follow an innovation, undertaking an imitative micro behaviour.

Macro behaviour and recombining factor – The diffusion of the innovation in the environment, which represents the effect of the imitative micro behaviour, increases the desire to adhere to a fashion; the greater the amoung of imitative behaviour, the more powerful is the fashion and the more pressing the desire to follow it, until the saturation point is reached.

Micro-macro feedback. chance and necessity – The diffusion of an innovation is the result of the imitative micro behaviour of the single individuals, but this also conditions future behaviour. Once, "by chance", the imitative phenomenon has begun, it is maintained "by necessity", until the saturation density is reached.

Strengthening, weakening and control actions – Publicity and social gratification represent strengthening factors for the system; social disapproval (the fashion of driving at break-neck speed in cars, for example) and repression represent weakening ones.

"Tower of Babel" System

Among the most powerful, widespread and easy to verify combinatory systems are the linguistic ones. The Catholic religion has found in the presumption of the Tower of Babel and the failure of its construction an explanation to justify the presence of many different languages, while the theory of combinatory systems provides the justification for their maintenance and change across generations.

Heuristic model: Micro behaviour and necessitating factors – While raising and educating your children, teach them the language of your forebears; consider as an error any syntactical or semantic deviation and try to eliminate these; your children must be able to communicate within the collectivity (necessitating factor).

Macro behaviour and recombining factor – The community preserves and diffuses the ancestral language, which is spoken using the same structure generation after generation; the language is codified and passed on without changes (recombining factors).

Micro-macro feedback. chance and necessity – The language is preserved by being taught to newborns; it is thus the macro effect of past micro behaviour, but it also conditions future behaviour. A new language, or a variant of the old one, can be introduced in a given territory "by chance"; when the system is activated the linguistic foundation is maintained "by necessity" through its transmission to newborns.

Strengthening, weakening and control actions – The creation of schools and the cataloguing of linguistic rules in a written form (syntax) considerably strengthen the system; periodic immigrations can instead weaken it.

Among the many combinatory systems with a functioning logic similar to the one we have just seen are those that lead to the preservation of the *national religion*, and of local and *territorial uses* and *customs*.

"Beat-the-Record" System

A record, in any sports category, determines the "absolute best". Those who compete are not content to equal the record but do all they can to beat it. Thus, records are gradually improved.

The phenomenon of chasing a record and the attempt to beat it can be interpreted with the aid of combinatory systems: the improvement of a record and the raising of the average performance in competitions (macro effect) is caused by the results (micro effect) obtained by the competing athletes (micro behaviour), who spread general competitive activity (macro behaviour). The results, in turn, are conditioned by the records to beat.

Heuristic model: Micro behaviour and necessitating factors – If there is a record and you want to stand out and show you are "the" best, then you must compete to win and to beat the record.

Macro behaviour and recombining factor – The record is held in esteem by the collectivity; the general attempt to beat the record increases the "desire for the record" and improves the average performances; thus, in order to compete successfully a more intense training is needed, which leads, sooner or later, to the record being improved.

Micro-macro feedback. chance and necessity – The improvement in the record and the increase in the average performances in the competitions are caused by the results of the athletes who, in turn, are conditioned by the record to beat; the first record occurs "by chance" but is maintained "by necessity" as long as it is favourably judged by the collectivity.

Strengthening, weakening and control actions – If honour is heaped on the record-holder and victory carries with it considerable prize money, then the system is strengthened due to the increase in gratification. If the setting of the record causes injuries or the cost of the competitions becomes too high, then there is a weakening.

Variant: the above system can be broadly generalized, since falling within the logic of this system are all cases where there is a limit – for example, a speed limit – or a rule, and this limit and rule is disregarded, giving rise to micro behaviour that involves exceeding the limit, which ends up causing the abandonment of the limit itself.

"Eternal-Feud" System

If Abel had had a vindictive son, then the latter would probably have taken revenge on Cain or his son, and the most ancient feud on the face of the earth would have begun.

Even feuds can be interpreted as a combinatory system that is easy to describe, since it is similar to the record system.

Someone "by chance" is wronged; if he forgives the wrongdoer or seeks justice through the proper authorities, the feud does not begin. This barbarous custom (macro behaviour) begins instead when the person who has suffered the wrong (micro effect) takes revenge (micro behaviour), thereby creating the occasion for a counter-vendetta, which, in turn, requires a violent reaction.

If "by chance" the feud begins, then it is maintained "by necessity" (macro behaviour), since the reasons for the start of the feud become unimportant; the person who suffers the vendetta of another feels he has been wronged and that he is in the right. This combinatory system explains feuds between individual families or factions (Guelphs and Ghibelines) as well as those between town districts, tribes, even peoples and nations, such as the centuries-old wars among peoples in the Middle-East, North Africa and the Balkans still testify to today.

"Trace-a-Path" System

How do paths form? Once again the Theory of Combinatory Systems immediately makes clear the origin of this phenomenon. Heuristic model:

Micro behaviour and necessitating factors – If you need to cross an area try to cross it (field, slope, rockface, etc.) using the maximum rationality; if there is a path in the right direction, or a direction not too different from the desired one, take it; otherwise look for a route that optimizes your individual rationality parameters.

Macro behaviour and recombining factor – The path forms from the successive superimposition of individual tracks that guides a flow of persons in the indicated direction, thereby producing the macro behaviour of the combinatory system.

Micro-macro feedback. chance and necessity – We cannot know from where chance will bring us the individuals and where these will be headed, but when the path is formed in a given direction after the macro effect has occurred, then all the succeeding individuals are forced (rationality assumption) by the system to take the path and thus cross in the predetermined direction, even if it appears as if the micro behaviour is marking the path.

Strengthening, weakening and control actions – If the path arises in an open environment and is viewed as an efficient route, then strengthening actions can be carried out: the placing of kerbstones, paving and asphalting (the first Roman paths became roads that still today provide the most efficient routes), indications on maps, etc.; if the path crosses private territory, then weakening actions can be carried out, the most drastic of which are the "No Trespassing" sign and surveillance.

Conclusions and Challenges

Combinatory System Theory studies the collectivities of similar agents whose analogous micro behaviour produces a macro behaviour that refers to the collectivity as a whole; the macro behaviour of the collectivity produces a macro effect that represents global information that guides the subsequent micro behaviour, thereby producing forms of self-organization and synchronization, as well as forms of chaotic behaviour.

With the aid of unsophisticated Combinatory Automata I have tried to demonstrate that even Combinatory Systems, in which the reversibility in micro behaviours and effects is admitted, may show cyclical, irregular and even chaotic behaviour.

A question arises: why is this theory able to explain so many and so varied a number of phenomena, even though it is based on simple features?

The theory of Combinatory Systems represents an efficient tool for the *procedural explanation* of dynamic phenomena that derive from the action of collectivities that can be considered as observational units and not only as aggregates of individuals.

Three aspects of this theory make it particularly effective:

1. it is not limited to describing the macro behaviour of the unit based on general rules or the individual behaviours based only on local rules, but tries to uncover and explain above all the *feedback* between the macro and micro behaviours or their effects; the Combinatory Systems approach is *neither* a *macro* approach *nor* a *micro* approach, but a *micro-macro* approach, or a *meso approach* (House/Rousseau/Hunt 1995), precisely in that the *operating rules,* describing the behaviour of the system, must in some way include not only *local rules* but also the *feedback* between the *micro* and *macro* behaviour that acts out over many cycles;
2. to understand the phenomena attributable to the action of combinatory systems the theory tries to uncover and make clear the *necessitating factors* (that cause the micro behaviour of each agent in the system) and the *recombining factors* (that produce and maintain the unit's macro behaviour). The theory then concludes that, in the presence of suitable necessitating and recombining factors, "chance" will trigger the dynamic process of the system that "by necessity" is then maintained and influences the individual behaviours;
3. the *procedural explanation* offered by the theory not only allows us to understand the operating mechanism that produces the phenomena under examination, but also permits us to determine the most effective forms of control.

The challenge of Combinatory System Theory is threefold: (i) to develop more general and further sophisticated Combinatory Automata for any specific class of combinatory system; (ii) apply the theory to understand collectivities operating in the real world; (iii) specify, for any real observed collective phenomenon, the sets of necessitating and recombining factors which allow us to interpret and control the collectivity that produces it.

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About the Author

Prof. Piero Mella
Born in Pavia, graduated in March 1969 with a first class degree in Industrial administration, in 1985 I won a chair as a full professor and lectured in Business Economics and Administration at the Faculty of Economics of Pavia. In 1986 I was elected Head of the Department of Business Research at the University of Pavia. From 1987-88 to 1992-93 I was Dean of the Economics Faculty at the University of Pavia. Since it was founded in 1990 I have been the scientific Director of the Masters in Accounting, Budget and Financial Control in profit organizations, set up by the University of Pavia. In 1997 I became Co-ordinator of the Doctorate in Business Research at the University of Pavia. In 2000 I created the scientific web site www.ea2000.it. My interests also deal in the fields of Complex and Holonic Systems and of Networks. In 1997 I have proposed the Combinatory System Theory, described at the web site: www.ea2000.it/cst.

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