Contemporary Systems Thinking

Piero Mella

The Combinatory Systems Theory

Understanding, Modeling and Simulating Collective Phenomena

Springer

Piero Mella

The Combinatory Systems Theory

Understanding, Modeling and Simulating Collective Phenomena

Springer

piero.mella@unipv.it

Piero Mella
Department of Economics and Management
University of Pavia
Pavia, PV, Italy

ISSN 1568-2846
Contemporary Systems Thinking
ISBN 978-3-319-54803-6 ISBN 978-3-319-54805-0 (eBook)
DOI 10.1007/978-3-319-54805-0

Library of Congress Control Number: 2017941621

© Springer International Publishing AG 2017
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

piero.mella@unipv.it

Preface

> If in the midst of a crowd you stare intently at the moon, all around you will suddenly do the same. It is inevitable (Anonymous)

THE TEXT—This study adopts the logic of Systems Thinking (Mella 2012) and Control Systems (Mella 2014a), presenting a simple and hopefully complete theory that I have called the *Theory of Combinatory Systems*, which is able to describe, interpret, explain, simulate, and control collective phenomena and their observable effects. Why do paths form in fields? Why does a fashion quickly arise, only to disappear just as quickly? Why are some park benches or walls covered in graffiti while others nearby are spotless? How does a feud develop? Why, in Pavia, in the span of a few decades, have over 150 towers been built, all alike, without any apparent function, if not a symbolic one? How can we explain the birth, branching out, or extinction of a species? Why do dangerous wheel tracks form in certain sections of highway while in others the asphalt, which is of the same quality, appears to resist the stress of traffic? How do we explain urban and industrial settlements in circumscribed areas? What mechanism can we use to explain the maintenance of languages and dialects in limited areas? Why do mounds of garbage spontaneously form in certain areas? Why do industrial innovations quickly spread? What is the force behind the continual improvement in the quality of products? Why do individuals chase records? Why does a background buzz arise in crowded rooms, which causes everyone present to talk in a louder voice? Why are speed limits and no standing rules invariably ignored despite rigid controls? How does spontaneous order arise in a ballroom when a waltz is played? How does order in the flight of a flock of birds arise and maintain itself, so that the flock is so compact as to appear a single organism with its own movement? And what about the movement of a herd of elephants in flight, which is an incredibly destructive mass? Or what about the mechanism followed by the Can-Can dancers at the Moulin Rouge to allows them to remain aligned? How did the Hoplites create a Macedonian phalanx and maintain its order?

Despite specific differences among these phenomena—many of which are "one way", non-repeatable or reproducible—they can all be *described* or *explained*, and thus *understood*, using the model, as simple as it is general, of "combinatory

piero.mella@unipv.it

systems"; that is, systems formed by collectivities, or populations of non-connected and unorganized individuals of some species, which appear to be directed by an invisible hand that guides the analogous actions of similar individuals in order to produce an *emerging collective phenomenon*.

THE FUNDAMENTAL IDEA—Collectivities can be viewed as units formed by a plurality of *similar* elements or agents, each of which produces similar *micro behaviors*—and in many circumstances also observable *micro effects*—which, "in combining", produce a *macro behavior* that gives rise to collective macro phenomena—and noticeable *macro effects*—which do not refer back to the individual micro behaviors, even if they necessarily derive from the agent's micro behaviors. If, on the one hand, the macro phenomena are produced from a "combination"—hence the term "combinatory systems"—of the agents' micro behaviors, on the other hand, at the same time those phenomena condition the agents' behaviors, as part of a *micro-macro feedback* relationship that represents the "invisible hand" that seems to guide the individual behaviors and produce the collective phenomena.

The combinatory systems generally are set off "by chance", but when activated they maintain their dynamics "by necessity", due to the presence of *necessitating* and *recombining factors*. The action of the *micro-macro feedback*, which is guaranteed by the contemporaneous presence of *necessitating* and *recombining factors*, turns these collectivities into true systems, which can be observed as a unit as well as a multiplicity of elements, and which I have termed combinatory systems.

The feedback arises from *necessitating* factors, which force the agents to adapt their micro behavior to the system's macro behavior, and is maintained by the action of *recombining* factors, which lead the collectivity to recombine the micro behaviors, or the micro effects, in order to produce and maintain the macro behavior, or the macro effect. Combinatory Systems Theory emphasizes and tries to identify those necessitating and recombining factors, since *recognizing the existence of a* micro-macro feedback *and understanding the nature of both the* necessitating *factors and the* recombining *ones is indispensable for interpreting collective phenomena as deriving from a combinatory system*. In this sense the path dependence may be considered as proof of the action of the *micro-macro feedback*, even if Path Dependence Theory does not explicitly include this mechanism in the explanation of the path dependence.

THE FIELD OF ENQUIRY—Combinatory systems are not easily recognizable; nevertheless, they are widely diffused and produce most of the social and economic collective phenomena involving the accumulation of objects, the spread of features or information, the overcoming of a limit, and the achievement of general progress as the consequence of the individual pursuit of particular interests. Combinatory systems, together with their effects, are observable in the biological, social, political, economic, business, and organizational fields. The theory appears to be of interest to the fields of biology, ecology, economics, and social research, since the category of combinatory systems includes the defined phenomena of self-organization, population dynamics, whose evolution is influenced by the history of the population itself, and, in general, the collective phenomena where individual behavior is, to a greater or lesser extent and in various forms, influenced by the collectivity's "general macro

piero.mella@unipv.it

behavior", which is produced by the micro behaviors of the members of the collectivity.

Combinatory systems do not lend themselves to being *represented* and *interpreted* by means of traditional systems logic—that is, the logic of *organized* systems—but can be studied according to the proposed new Combinatory System Theory. Many of these collective systems are usually studied in the context of the *theory of complex systems* and *synergetics*; however, these disciplines offer an *external* description of these systems and do not bring out the conditions, factors, and rules that produce the feedback between micro and macro behaviors. The simple theory of combinatory systems presented in this study offers an *internal* interpretation by emphasizing the operative mechanisms that justify the behavior of such systems. In particular, Combinatory System Theory interprets, includes, and generalizes the "allelomimesis" and "stigmergie" approaches to the ordered behaviors of collectivities of agents.

THE THEORY OF COMBINATORY SYSTEMS—In plain words, the typical operative logic of any "social" combinatory system can be summarized by the following simple decisional rules that direct the micro and macro behaviors:

1. A collectivity of $N \geq 2$ agents constitutes the "base" of the system.
2. Each agent is characterized by an individual variable of some kind (qualitative or quantitative) whose values—at any time t_h—represent the individual micro states.
3. The collectivity is characterized by a global variable (qualitative or quantitative) whose values—at any time t_h—represent the system's macro state, which in turn represents global information for the agents.
4. Due to the presence of an opportune set of *recombining* factors, the system state—at any time t_h—derives from the "combination" (to be specified for each situation) of the individual states, following macro or recombining rules.
5. Each agent can perceive a gap (positive or negative) between his individual state and the state of the collectivity.
6. Due to the presence of an opportune set of *necessitating* factors each agent—at time t_{h+1}—decides, or is forced, to attempt to expand or reduce the perceived gap following the micro or necessitating rules.
7. As long as the necessitating and recombining factors are maintained, the *micro-macro feedback* can operate.
8. The agents are characterized by an initial state at time t_0; in most cases this initial state may be assumed to be "due to chance".
9. The *micro-macro feedback* operates between the limits of the minimum activation number and the maximum saturation number of the agents presenting the state that maintains the *micro-macro feedback*.
10. The sequences of state values over a period represent the macro and micro dynamics, or behaviors, of the system and the agents.

According to this logic, when the actions of the agents are simultaneous, the agents of the system appear to synchronize their micro behavior. However, each micro behavior updates the global information, and this recreates a divergence that exerts even more influence on the individuals to conform to this information. For this reason, combinatory systems can also be called "self-produced global information

piero.mella@unipv.it

systems", in order to distinguish them from local information systems, whose typical model is represented by complex systems simulated by cellular automata.

The behavior of the system can be conditioned by environmental actions that can *strengthen* or *weaken* its behavior. For this reason the control of the system's behavior can be carried out by means of appropriate *strengthening* or *weakening* actions; it can directly operate on the macro behavior—we will define this as *macro* or *external* control (or *exogenous* control)—or it can influence the micro behaviors: in this case the control will be termed *micro* or *internal control* (or *endogenous* control).

Typology of combinatory systems—This outlined logic can be observed in five relevant classes of combinatory systems, which differ with regard to their macro behavior and/or their macro effect:

1. Systems of *accumulation*, whose macro behavior leads to a macro effect which is perceived as the accumulation of objects, of behaviors, or of effects of some kind.
2. Systems of *diffusion*, whose macro effect is the diffusion of a trait or particularity, or of a "state", from a limited number to a higher number of elements of the system.
3. Systems of *pursuit*, which produce a behavior 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.
4. Systems of *order*, which produce a macro behavior, or a macro effect, perceived as the attainment and maintenance of an ordered arrangement among the elements that form the system.
5. Systems of *improvement* and *progress*, whose effect is to produce *progress* in the overall state of a collectivity as a consequence of the agents' need for individual *improvement*. We can go so far as to state the existence of a true law (metaphysical) of "progress" that originates from the action of biological and, above all, social combinatory systems.

Control Systems in Combinatory Systems—From the above definition, it is easy to understand that "social" combinatory systems function due to the presence of *micro control systems* which, operating at the individual level, lead to uniform micro behavior by individuals in order to eliminate the (gap) with respect to the objective that is represented—or revealed—by the global information (macro behavior or effect) (Mella 2014). This can be better understood by referring to two simple examples.

What causes this buzz to form? It arises from the voice level (micro effect) of those present when they speak to each other (micro behavior); in turn, the voice level is recombined by the shape of the room in order to produce the buzzing noise. But why do those present speak in a loud voice (macro behavior)? Because there is the buzzing noise (global information) which prevents them from being heard, this becomes the minimum constraint (objective) to exceed in order to be heard; if the individual voice level is not adequate (gap), it is not possible for each agent to communicate. Thus, if the buzz increases, those present, in order to be heard, must raise their voices. It seems they do this all together, as if the global information forces them to synchronize their micro behavior, but this causes the buzz to increase further, which obliges those present to raise their voices even more, which increases the buzz, which forces those present … etc., as part of a reinforcing loop that takes

piero.mella@unipv.it

the buzz to the maximum level of tolerance (constraint). Once this is reached, the individual Control Systems induce the speakers to be quiet for a brief moment, as we have all witnessed firsthand.

Let us now consider the system that produces the process for "passing on a *language* within a population". All parents pass on their mother tongue to their children (micro behavior), who thus learn this language (micro effect). The population communicates (macro behavior) using the mother tongue (macro effect), which represents the global information that obliges families to teach that language to their children (constraint/objective) in order not to disadvantage them in their communication. The feedback is evident but—remembering the bad marks inflicted on us by our teachers because of syntax errors—we can imagine there are also external Control Systems that both reinforce the main combinatory system, by detecting deviations between the language of the group members and the codified mother tongue, and try to eliminate these deviations by using the traditional levers of academic teaching to correct the syntax. The existence of so many languages and equally numerous dialects shows how powerful this combinatory system is and how efficient the individual and external Control Systems are. Thus, combinatory systems for the spoken language are some of the most powerful systems operating in human society.

Combinatory automata—The simplest models to represent combinatory systems are the *descriptive* ones that indicate in words, or with the aid of diagrams and figures, the fundamental elements necessary for understanding the operative logic of systems that produce observable collective phenomena and, above all, how the *micro-macro feedback* works (Chap. 1). More powerful still are the *heuristic* models that try to simulate the system's dynamics by stating—or constructing ad hoc—a set of rules specifying the fundamental elements of the combinatory systems behavior (Chap. 2). "Combinatory Automaton" is a more sophisticated tool to simulate combinatory systems (Chap. 3). This is composed of a lattice, each of whose cells contains a variable representing the state of an agent. The value of each cell at a particular time depends on a synthetic global variable whose values derive from some operation carried out on the values of the cells and represent the synthetic state of the automaton. The micro-macro feedback connects the analytical values of the cells and the synthetic state of the automaton.

The automaton may be stochastic, if a probability is associated with the transition of state of each agent; in the opposite case it is deterministic. In stochastic combinatory automata, when both probabilities and periods of transition of state are agent/time/state sensitive, the probabilistic micro behaviors are conditioned by the macro behavior of the entire system, which makes the micro-macro feedback more evident.

The "social" combinatory systems that are most interesting and easiest to represent are the irreversible ones (build a tower or not, teach French or English to babies). In these systems both the micro and macro behaviors produce permanent effects that may be viewed as increasing or decreasing cumulative processes in which the probabilities of micro behaviors depend on the macro behavior of the collectivity as a whole. "Chaos" arises in combinatory systems when the hypothesis of reversibility is introduced (e.g., to speak or to keep quiet in the next minute, wear a

piero.mella@unipv.it

skirt or miniskirt on different days, choose road A or B on different days). When reversibility in micro behaviors or in micro effects is possible, the combinatory system's macro behavior, or macro effect, can show a cyclical dynamic and, under certain conditions concerning the probability function regarding the transition of state of the elements, a chaotic one as well, when no cycles are recognizable in the time series of the system starting from random initial values.

THE LAYOUT OF THE TEXT—The text is composed of four chapters, in which I have tried to treat the subject matter at a level accessible to all. Chapter 1 presents the basic ideas behind the theory, which are analyzed in some detail. Chapter 2 describes the heuristic models of several relevant combinatory systems in the context of the five typical classes. Chapter 3, while not making particular use of sophisticated mathematical and statistical tools, presents the Theory of Combinatory Automata and builds models for simulating the operative logic of combinatory systems. Chapter 4 tries to answer three questions: are combinatory systems "systems" in the true sense of the term? Why is this theory able to explain so many and so varied a number of phenomena, even though it is based on a very simple *modus operandi*? Are combinatory systems different than complex systems?

The book is "for everyone". There is no prerequisite required to read and understand it, in particular math, statistics, and computer knowledge. The statistical tools used for the construction of Combinatory Automata are among the most basic. The simulations, where possible, are performed in Excel to facilitate the use of random numbers and to perform tests with different data. I have endeavored to make the text simple and enjoyable to read, thanks to the many examples taken from the most diverse fields, while also supplying food for thought for further in-depth analyses.

Pavia, PV, Italy Piero Mella

piero.mella@unipv.it

Contents

piero.mella@unipv.it

piero.mella@unipv.it

piero.mella@unipv.it

piero.mella@unipv.it