Contemporary Systems Thinking

Piero Mella

The Magic Ring

Systems Thinking Approach to Control Systems

Second Edition

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Preface to the First Edition

Thinking is easy, acting is difficult, and to put one's thoughts into action is the most difficult thing in the world. – Johann Wolfgang Von Goethe

The origins – This book represents the completion and evolution of my book *Systems Thinking. Intelligence in Action* (Springer 2012), which presented the general view of the "world" considered as a "system of systems" of interconnected variables. That book presented the theory, language and basic rules of *Systems Thinking* while this book develops the theory, language and rules behind the functioning of *Control Systems*, which were presented in a single short chapter. Though this book is the logical development of the previous book, it is a self-contained work compared to *Systems Thinking* since it does not suppose any prior knowledge of Systems Thinking – whose basic concepts are presented at the beginning – but gradually introduces a true Discipline of Control Systems that is accessible to a large group of non-specialists. The choice of topics and examples – in this endless field of knowledge – derives from the need to make the Discipline of Control accessible to "everyone".

The assumptions – The idea of developing a Discipline of Control that stands on its own with regard to Systems Thinking is based on the hypothesis – whose validity I have tried to demonstrate throughout the book – that among all types of systems Control Systems occupies an absolutely preeminent position. Even if we are not accustomed to "seeing them", "recognizing them" or "designing them", they are everywhere inside and around us. Only their ubiquitous presence makes possible our world, life, society and existence, constructing an ordered and liveable world, erecting barriers against disorder, and directing the irregular dynamics of the world toward states of homeostatic equilibrium in all its vital and social environments. It is for this reason I have tried to make clear the need to gradually accustom ourselves to thinking not only in terms of systems but above all in terms of Control Systems: "*from Systems Thinking to Control Thinking*"; this is my epistemological proposal.

The objectives – This book presents a gradual path toward "educating" the reader in understanding how Control Systems truly operate and in recognizing, simulating and improving them in all fields of activity. Starting from the hypothesis that knowledge of Control Systems is not only a technical fact but also represents a

discipline – that is, "A discipline is a developmental path for acquiring certain skills or competencies. (…) To practice a discipline is to be a lifelong learner. You "never arrive"; you spend your life mastering disciplines." (Senge, 1992, p. 12) – I have set the objective of making Control Systems a topic that is, in a certain sense, simple and attractive by turning to the effective symbolism typical of Systems Thinking models and avoiding too technical and formal a treatment of the subject. Thus, the reader should know that this is not an engineering, physics, biology or economics text, nor a mathematics one either. Technical or mathematical tools are not used to construct Control Systems; instead, I use the highly simple and universal logic behind the notion itself of *control process* and the simple and universal action of the Control Systems that produce this process.

The title – Why "Ring"? – Control Systems (in their most simple form) are particular apparatuses (logical or technical) that cause a variable *Y*t to attain an objective *Y** by gradually reducing the error (gap, distance) *E*t = *Y** − *Y*t through a series of "adjustments" of *Y*t produced by acting on a *control variable*, or *lever*, *X*t, so that the values of *Y*t approach *Y**; the iterations of this process continue and, if the system is well designed, *E*t becomes zero, even in the presence of external disturbances, *D*t, which cannot be controlled by the system. Using the logical language of Systems Thinking we can easily see that a control system is a typical balancing loop that connects the three variables [*X*t, *Y*t and *E*t]; this loop is represented by a typical circular graphic model that in fact resembles a *Ring*. We can also imagine that each iteration to reduce *E*t is like a *rotation* of the *Ring*.

The title – Why "Magic"? – It is probably difficult to realize that you can read these sentences *only* because at least five fundamental automatic Control Systems, which exist in our bodies to produce vision, are acting simultaneously; that is, five *Rings* that rotate at an incredible speed. I will briefly mention these, and without any particular order (for simplicity's sake I shall omit the time reference in the variables).

The first *Ring* is the focus Control System, which works through the crystalline lens which, by varying its shape using the tensor muscles (*X*), varies the focal distance in order to eliminate the gap between the actual focus (*Y*) and that needed to read the letter (*Y**), even when the distance between the text and the reader's eye (*D*) varies. The second *Ring* is the control system which, by changing the diameter of the pupil (*X*), varies the quantity of light (*Y*) that strikes the retina (cones and rods) to maintain (*Y**) constant even with variations in the ambient light (*D*). The third *Ring* is the control system that, by using the motor eye muscles (*X*), produces the macro and micro movements in the eyeball (*Y*) in order to read the words in the line (*Y**), if necessary aided by the rotation of the head (controlled by an additional *Ring*). The fourth *Ring* is the control system that produces tears (*X*) to keep the cornea wet (*Y*) in an optimal manner (*Y**), even when there is a change in evaporation due to heat at various times from various sources (*D*). The fifth *Ring* (the final one I shall mention) is perhaps the most important: the Control System that allows us to *recognize* signs written on a page as *letters*, and the latter as *words* given rhythm by punctuation marks, which leads to the *recognition* of sentences.

Assuming that these five *Rings alone* "rotate" *only* 20 times per second, then in order to read this paragraph in, let's say 60 seconds, we need 6000 total iterations

(5 × 20 × 60), that is, 6000 control actions of which we are normally unaware: the number, in fact, required to read second by second (obviously ignoring whether or not the reader understands what he has read). Does this number of iterations seem too small? Consider that obviously these five *Rings* function continuously all day long our entire lives: let us assume on average 14 hours for 80 years. During this period the five Control Systems produce more than (145 × 109) iterations. Our five *Rings* rotate at an incredible speed only to guarantee vision, one of the five senses. Just think about the others!

Does it seem like a small number now?

The most complex "machine" on earth is probably the human brain, formed on average by (100 × 109 = 1011) neurons (in addition to an even larger number of auxiliary cells). The complexity of this machine derives from the fact that the neurons are connected by means of various types of synapses, whose overall number is estimated to be 1014. By using the simple model of the neural networks we can imagine that the synapses have a particular "weight" which determines the strength of the signal received by each transmitter neuron which is then sent to the receptor neurons, and that each neuron in turn has a specific threshold value below which the neuron does not "fire" the signals received, causing the connection with the receptor neurons down the line not to take place. It is immediately clear that for each neuron there must correspond "at least one" Control System for identifying the threshold value and that for each synapsis "at least one" Control System for sending the signals with their specific weights. At this moment our brain is working thanks to the action of (1011 + 1014) *Rings* rotating thousands of times per second, and for the entire human population [(1011 + 1014) × 6 × 109] neural *Rings* are operating (in the brain). We may not realize it, but this is "magic".

Does this seem too small a number?

The average number of cells in the body of a man weighing 70 kilograms is estimated to be 1014. Each cell, as an autopoietic and thus homeostatic system, can exist thanks to the action of a large number of Control Systems that govern the cell cycle, instant by instant, and to the other Control Systems that regulate cellular interactions. Estimating that there are *only* 100 Control Systems for each cell, at this moment your body can remain alive thanks to the action of 1016 invisible *Rings* that rotate uninterruptedly for your entire life. At this moment the human population exists thanks to the action of [6 × 109 × 1016] cellular Control Systems in addition to [(1011 + 1014) × 6 × 109] neural Control Systems, trillions of trillions of invisible *Rings* that rotate incessantly, untiringly, second after second, year after year. I am sure few people have considered this.

Do you still think this is not significant?

Without exaggerating and becoming tiresome, I would point out that the cellular control characterizes all cells of all living beings. Ants alone are estimated to number from 1015 to 1016. How many insects are there? How many birds? How many mammals? How many fish and molluscs? It is estimated that there are more than (400 ×106) units of phytoplankton in a cubic meter of water. The oceans and seas are made up of about (1.34 × 109) km3 of water, the equivalent of (1.34 × 1018) cubic meters. Overall there are (400 × 1.34 × 1024) individual plankton, single- or

multi-celled, which at this moment are kept alive by ($k \times 400\times 1.34 \times 1024$) invisible *Rings* that rotate in whirling fashion second after second. It is too difficult, useless even, to estimate the number of vegetal units – plants, shrubs, blades of grass, mushrooms, lichen, mould, etc. – and the number of cells of each individual. However, there is no need for such an estimate to grasp the impressive number of *Rings* necessary to keep the planet's flora alive.

And what about the billions of man-made Control Systems? And the trillions of Control Systems that regulate relationships between individuals, populations and species? And the endless number of Control Systems that operate in our atmosphere, seas, and in all physical phenomena?

There is a lot still to discover about how Control Systems function as motors for learning and knowledge; I will deal with this in Chapters 9 on.

If there is something magical in life, society and organization, in orders and evolution, this something is represented by the "magic" action of the "rings" which, through their ubiquitous presence and variety of forms, account for individuality, maintain the order of things, restore equilibrium and regulate interactions.

Why "magic *Ring*"? Independently of its nature, function and physical structure, each Control System always has the same structure of a *Ring*. A "magic *Ring*", in fact.

The content – The book is divided into 10 Chapters.

Chapter 1 seeks to review the basic language of Systems Thinking and the models it allows us to create. This language and these models will be the instruments for presenting the logic of Control Systems in a manner that is understandable to everyone. It is suggested that the study of Control Systems be considered as a true discipline, according to Peter Senge's conception, a true Sixth Discipline.

Chapter 2 introduces the control process, presenting the *theoretical structure* of three simple Control Systems we all can observe: those that permit us to regulate the sound volume (radio, TV, iPod, stereo, computer, etc.), the water temperature (shower, radiator, boiler, etc.) and the room temperature (air conditioner, refrigerator, etc.). Despite the simplicity of the three kinds of systems, we can gain some fundamental knowledge from them about the basic structure of a Control System by learning the basic concepts: *manager, governor, action rate, reaction rate, reaction time, delays* and *disturbances*. After presenting the general theoretical model of this system, we examine several new concepts: (1) the *chain of control*, which represents the technical structure of the process; (2) the various types of *delays* in control, extending the considerations already begun in Chapter 2; and (3) *interferences* among the Control Systems which can give rise to disturbance dynamics.

Chapter 3 proposes a *general typology* of Control Systems with examples taken from observations of reality, distinguishing among: (a) systems of *attainment* and *recognition*; (b) *continuous-* or *discrete-lever systems*; (c) *fixed* or *variable objective* systems; (d) *steering* and *halt* Control Systems; (e) systems of *collision, anti-collision* and *queuing* systems; and (f) *tendential* and *combinatory* systems; to name but a few.

Chapter 4 broadens the view of Control Systems by introducing two important generalizations: (1) *multilever* Control Systems, with levers that are independent or

dependent of each other; (2) *multi-objective* systems, with independent or interdependent objectives. In multilever systems, it is fundamental to understand the importance of the control *strategy*, that is, of the specification of the priorities for the activation of the different levers used to eliminate the deviation from the objective. In multi-objective systems, on the other hand, it is fundamental to understand the importance of the control *policy*, which decides on the order of priorities for intervening on the various objectives. To further generalize, we shall examine the notion of *impulse systems*, which play a fundamental role in life.

Chapter 5 outlines the guidelines for recognizing, observing or designing Control Systems and presents the problems that arise regarding their logical realization. It introduces the fundamental distinction between symptomatic and structural control.

Chapters 6, 7, 8, and 9 undertake a "mental journey" through various "environments", increasingly broader in scope, suggesting to the reader how to recognize therein Control Systems that, by their ubiquitous presence, make the world possible in all its manifestations.

Chapter 6 considers daily individual actions – the domestic and civic environment (the most familiar ones) – in order to arrive at Control Systems that maintain the psychic-physical system.

Chapter 7 guides the reader through the physical, biological and social environments. Particular attention is given to Control Systems that operate in Societies and in *combinatory systems*, a special class of systems which has not yet been adequately examined.

Chapter 8 considers the environment of organizations, trying to demonstrate how organizations are themselves Control Systems by presenting two basic models: Stafford Beer's Viable System Model and my own Model of the Organization as an Efficient System of Transformation (MOEST). The chapter also illustrates the logic behind the many Control Systems that operate in the network of processes in organizations and which are necessary to maintain autopoiesis and increase the efficiency of the entire organization.

Chapter 9 deals with three specific topics: (1) the *cognition process*, understood as the result of the action of Control Systems that recognize differences and order them based on Gregory Bateson's notion of "mind"; (2) the *signification process*, which allows man to translate cognitive content into signs and to form languages; and (3) the *scientific process* and the explanatory power of models.

Chapter 10, the final chapter, deals with two topics: (1) some ideas about a Discipline of Control Systems are proposed; (2) the human aspects of control. A reflection on the content and limits of this book are presented as FAQs in the final pages of the chapter.

The style and method – In order to facilitate the understanding, acquisition and practice of the discipline, Control Systems have been presented in a logical way by using the symbols of Systems Thinking to produce easy-to-construct models. Thus, I have intentionally avoided expressing Control Systems in a typically mathematical form, which would have used differential equations or differences, preferring instead to use simulation examples with "everyday resources", in particular Excel files accompanied (in a few cases) by Powersim, to demonstrate to the reader how

relatively easy it is to do the calculations to achieve the control. Moreover, I have chosen particularly simple and clear examples by presenting very common Control Systems we all can observe and experiment with in order to draw lessons in general theory from them.

The readership – The book is "for everyone". There is no prerequisite required to read and understand it, in particular math and computer knowledge. The use of the simplest tools of Excel helps in creating models for basic simulations of simple systems in order to improve understanding. However, I have felt it useful to also present several simple models in Powersim. A number of examples are aimed at systems found in organizations and companies; thus, the text can aid in the professional growth of managers, consultants and corporate employees in general. Teachers, professionals, and educated people in general can also find sources for reflection and occupational tools from the text. A word of caution for the reader: *in order to master the Control Discipline it is necessary to read this book* "slowly" *and refer the standard models presented to one's own world and experiences.*

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Preface to the Second Edition

Six years have passed since the publication of *The Magic Ring*. During this period, I have received many comments: some of appreciation, others of constructive criticism, and others, the most numerous and useful, with observations, suggestions, ideas, and starting points for reflection. In light of these comments, I started editing, integrating, and expanding my private files from the first edition for my own update. When I realized that the changes and additions had become significant, I sent the publisher a proposal, immediately accepted, to prepare a second edition.

To guide the reader, it is useful to summarize the main differences between the two editions, following the structure of the new edition.

Part I: Discovering the "Ring"

The five chapters of Part I have undergone limited changes. The comments I had received confirmed the appreciation for the chosen approach: to present the logical structure of Control Systems, adopting the language of Systems Thinking without employing the mathematical formalism of differential equations, and translating the logic of Control Systems into balancing loops that could be easily understood even by readers without a specific mathematical or engineering background.

Chapter 1. Two sections were added that developed two very simple simulation models of the explosive dynamics of a virus both before and after measures taken to counteract its spread. I have also added a section containing a list of systemic archetypes proposed by Peter Senge (1990), supplemented by a number of other "new" archetypes that expand on Senge's original list.

Chapters 2, 3, 4, and 5. Apart from a few minor changes, these chapters, which represent the core of Control Theory, have remained unchanged in both structure and content. Only Chapter 5 has been enriched with two additions: the first, new Sect. 5.6, highlights the "Risks of Failure of the Control Process Due to the Variables to be Controlled"; the second presents "The Principles of Systems Thinking Applied to Problem Solving."

Part II: The Magic of the Ring

The chapters of Part II present the ubiquitous, irreplaceable action of Control Systems in all the observable "environments" and "contexts": personal, family,

social, biological, organizational, productive, and cognitive. The most significant changes have been made to Part II, the most relevant of which are the following:

Chapter 6. There are two main additions. In Sect. 6.6, "Control System for Global Warming," four reinforcement loops caused by global warming that lead to its increase are mentioned; Sect. 6.7, "Rings Acting on Earthquakes and Tsunamis," has been added. Moreover, Maslow's model of the hierarchy of needs has been updated.

Chapter 7 (New). The "old" Chapter 7 "The Magic Ring in Action: Life Environments" has been split into two distinct chapters. The "new" Chapter 7 highlights the Magic Rings that act for the balance between the actors in the social environment and for sustainability. Many additions have been made to the chapter: a more careful examination of the control of "population longevity" and of the "dynamics of the world population"; integration of the theory of Combinatory Systems and the Tragedy of the Common Resources; Sect. 7.9, "Change Management in a Complex World", has been greatly expanded; and Sect. 7.10.2 has been added, highlighting the "Modus Operandi of Some Relevant Social Phenomena Following the Combinatory Systems Model," along with Sect. 7.10.5, "The PSC Model Applied to Stereotypes and Gender Discrimination."

Chapter 8 (New). The part of "old" Chapter 7 regarding the biological environment has been entirely rewritten and considerably expanded and supplemented, becoming the "new" Chapter 8, which deals with the vast topic of population dynamics and control from both a quantitative view, the change in the number of individuals in a population, and a qualitative one, the variation or change in the phenotypes in evolutionary processes. Several simple simulation models of population dynamics are examined in this chapter, which also considers the evolution of populations of non-biological entities, particularly robots and organizations that form the nodes of production networks.

Chapter 9 (New). This chapter considers the action of the Magic Rings, without which organizations could not exist. Modest variations have been made to several sections; nevertheless, the most important variation concerns the six new sections added to "Complementary Material,", which deal with control through Budgeting and Reporting, Cost Measurement and Control through Standard Costs, and the "External Control of the Company's Economic and Financial Efficiency" by means of Position Analysis.

Chapter 10 (New). This is a completely new chapter whose subject is the Rings that control the two fundamental variables – quality and productivity – which are vital both for organizations and for the global economic system. The chapter presents the numerous techniques for evaluating the "quality levels" together with the levers to be used to control these variables. Moreover, after presenting a coherent frame of reference, the chapter examines the drivers of productivity before discussing the consequences of continual growth in productivity and quality. The Control of Plant Efficiency through Total Productive Maintenance and Terborgh's MAPI formula conclude the additions.

Chapter 11 (New). This, too, is a new chapter dealing with warehouse control and production processes, which are typical forms of management control. A