Asish Ghosh

Dynamic Systems for Everyone

Understanding How Our World Works

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To: Ahan, Ashapurna, Annapurna,
Narasimha, and Owen

Foreword

Having spent over a half century in controlling industrial processes, as has the author, I too believe, that the understanding we have gained could enrich the totality of human understanding and evolution.

The approach of a process control person is to first gain a full understanding of the nature of a process before attempting to control it. We must clearly understand if it is a batch or a continuous process, we must know its inertia, time constants, safety aspects and the like. Once we understand its full "personality" and determine the goal we want to reach by controlling it, we can figure out what we can manipulate to "herd" that process in the right direction and what we need to measure, in order to make sure that our process will reach its target safely and on time.

For example, once we clearly understand that the goal of controlling a nuclear power plant is to generate electricity, while making it impossible for it to blow up; we also know that we need a totally reliable energy source to prevent its meltdown, a source that nothing on this planet can turn off. Understanding that, it is easy to conclude that such an energy source is gravity and therefore we should place the reactor under water.

Similarly, life on this planet is a process fuelled by the energy of the Sun and life is maintained so long as the activity of plant and animal life is in balance. Plants consume carbon dioxide while generating oxygen which is then used by the animals or man who exhale carbon dioxide. We know that the balance is upset when the carbon dioxide concentration in the air rises. During my lifetime, the human population on the planet has increased from 2.1 to over 7 billion and the carbon dioxide concentration of the air has also tripled. Now, if the goal of this process control system is to maintain human life on Earth, it is pretty obvious that we must satisfy our increased energy needs from a carbon-free and inexhaustible source, namely the Sun.

When I preach about technical stuff, such as the potentials of process control in such areas to my wife or kids, their eyes get blurred and these windows of their brains close. It is for this reason that books are needed which convince the non-technical reader that the scientific principles of process control are applicable to all systems, including biological and social ones, and do it in such a way that their eyes do not get blurred.

Asish Ghosh has written such a book. Read it!

Béla Lipták
Stamford, Connecticut, USA

Preface

After spending many years as a systems engineer for controlling various production processes, I began to view the world more and more as a collection of systems. In my engineering work, systems existed as manufacturing entities, such as chemical plants, oil refineries, food and drug manufacturing, and materials handling systems. As my systems view developed beyond my work, I came to recognize other types of systems, such as living beings (humans, dogs, or elephants) and mechanical entities (motorcars, bicycles, or rockets).

A system may be variously defined as "A complex whole; a set of connected things or parts; an organized body of material or immaterial things." Various organizations and institutions created by human beings, such as banks, schools, and businesses are also systems or may be considered as subsystems of larger systems. The definition of a system is not confined to any particular discipline but is very widely applicable to many different fields.

This book is a study of interactions between these systems and their environment and also about the interactions of the subsystems within a system. It explains how basic systems principles are applied in engineered (mechanical, electromechanical, etc.) systems and then guides the reader to understand how the same principles can be applied to social, political, and economic systems, as well as in everyday life.

I hope that this book will provide a wide range of readers with an understanding of how system thinking can help them to better understand how everything in this world interact. You will understand how systems behave, and will be able to apply that knowledge in your professional and your daily life. You will also understand why not taking systems perspective may limit your analysis of a situation, which may lead you to unintended or undesirable consequences.

Control system engineers will also benefit from reading this book by getting a better understanding of how feedback control, with which they are so familiar, may also be applied in natural and social contexts. Similarly, social scientists and others who are familiar with system dynamics will understand and appreciate its applications in wider areas. Given that this book is intended for a broad range of audience including non-technical readers; I have avoided using mathematical formulas.

Chapter one provides an overview of system thinking with simple examples of diverse types of systems and their underlying similarities. It discusses why feedback is fundamental to the understanding of the behavior of a system. It classifies systems into various types, such as natural, social, political, economic, and engineered and discusses why information exchange is fundamental to a system's behavior.

The second chapter gives the early history of engineered systems including descriptions of the working of the Watt Governor which was developed to control steam engines. It describes control loops and their various parts, such as sensors, actuators, and controllers. It discusses the importance of getting feedback at the right time and how delays can adversely affect the behavior of a system.

The third chapter covers non-engineered systems, such as political, social and biological entities. It shows how causal loop diagrams can be used to depict such systems, and discusses feedback and biofeedback, along with dead time and lag, as they apply in these systems. It documents a case study on the dynamics of youth violence.

The fourth chapter describes the various behavior patterns of systems, such as growth, decay, oscillation, and goal seeking. It discusses linear and non-linear behaviors and compares detail complexity with dynamic complexity. It explains why system behaviors are sometimes so unpredictable.

The fifth chapter discusses the importance of modeling and simulation for the understanding of a system's behavior. It describes software packages that are available for modeling and simulation. It builds a model of the youth violence mentioned earlier, and discusses the many different uses of models.

The sixth chapter outlines the problems one faces in optimizing a system which has multiple goals and constraints. It discusses methods of optimization, such as using a model, using hill climbing techniques, and using kaizen (optimization in small steps) techniques. It details a procedure for optimizing a decision making process.

The seventh chapter discusses why a distributed structure leads to a more robust system. It describes the need for a decentralized structure as systems get increasingly complex. Finally, it discusses agent based modeling and simulation techniques.

Discrete events and procedures are parts of any system, but they have not been discussed in any length in many system studies. The eighth chapter makes readers aware of their effects on system behavior. It depicts loop diagrams involving discrete events and procedures and show ways to model them.

Any action to manipulate a system may produce desired results but also may lead to unintended consequences. The ninth chapter illustrates a number of unintended consequences and shows how they may be reduced by increasing system awareness.

The final chapter highlights the seven main traits of a person that takes the system approach. It starts with a discussion on the creation of the right mental and conceptual frameworks and then on building realistic and interactive models. That is followed by discussions on optimization, improving efficiency and robustness, and making improvements in small steps. The chapter ends with a discussion on a holistic world view.

You may follow these chapters sequentially or for a quick overview read Chaps. 1 and 10 first and then delve into the others. If you are mainly interested in biological and social sciences you may read Chaps. 1, 3, 5, 6, 9, and 10. The appendices elaborate some of the points made in these chapters.

The book includes many examples, some of them are rather simplistic and obvious; however, they are useful because they illustrate many of the basic system principles. Then there are those that seem to be too complicated, they may be skipped during the first reading, keeping them for considerations later.

You are strongly urged to "get your hands dirty" by modeling one or more of the simple systems outlined in this book or by modifying one of those available at the websites of modeling software suppliers. You may then observe their behavior under different operating conditions and gain a better appreciation of the concepts outlined before embarking on more ambitious projects.

Asish Ghosh
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Peter Martin a former colleague and friend provided information on dynamic performance measures. Sam Kim, Jin Min Lee, and Erik Nordbye provided a valuable set of information on the youth violence project conducted by Emmanuel Gospel Center in Boston. George Karam with his philosophical insights provided me with a valuable set of suggestions.

My cousin Ashit Sarkar and my two daughters Anna and Asha helped me with the structure and the contents while Narasimha and Owen gave me valuable sets of suggestions. Last but not least, my dear friend Margaret painstakingly went through the first and the final chapters to make them more readable.

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About the Author

Asish Ghosh is a retired Control Systems Engineer. In his professional life he held various research, engineering, and consulting positions while working for ICI in England and for The Foxboro Company, and ARC Advisory Group in Massachusetts, USA. He studied Physics at Delhi University in India and Control Engineering at Cambridge University in England. He has authored and presented many papers on process control and safety systems. With Howard Rosenof he co-authored the first book on batch process control. He is a Chartered Engineer registered in UK. He now resides in the historic town of Plymouth Massachusetts with his dog Oskar.

Chapter 1
Thinking in Systems

Abstract Systems are all around us, they are sets of interrelated objects or entities that interact with each other. They can be living beings, such as humans, animals, and plants. They can be mechanical entities, such as automobiles, ships, and airplanes; or industrial plants, such as oil refineries, chemical plants, and electric power generators. There are also other entities, such as social, political, and business systems. The behaviors of these systems are shaped by their environments, by the actions and interactions of their own subentities, and also by human beings. However, it is interesting to note that all these disparate systems exhibit some common behavior patterns.

This chapter provides an introduction to the basic systems concept by describing a number of different systems in various disciplines. The chapter discusses the importance of information exchange and feedback in shaping their behavior. Why systems knowledge can help us better understand and cope with them and also enables us to build or modify them to better address our needs and desires. Finally, the chapter introduces the concept of the systems view and how that differs from a compartmentalized way of thinking.

1.1 Global Warming

We are now well aware of global warming and its negative consequences. Most scientists seem to agree that an increase in carbon dioxide (CO_2) in the earth's atmosphere is the primary reason for the climate change. CO_2 comes from carbon, which is abundant in nature. Coal, graphite, and diamond are solid carbons, while petroleum is a liquid or viscous compound of carbon. A very large part of all living beings are made of carbon compounds. Carbon combines with oxygen, which is abundant in the earth's atmosphere, in various natural and man-made processes to form CO_2, which constitutes a percentage of earth's atmosphere.

Plants use CO_2 and sunlight to make their own food and grow in the process known as photosynthesis (Fig. 1.1). Herbivores get carbon by eating vegetable matters, while omnivores and carnivores get it from plants or other animals. When

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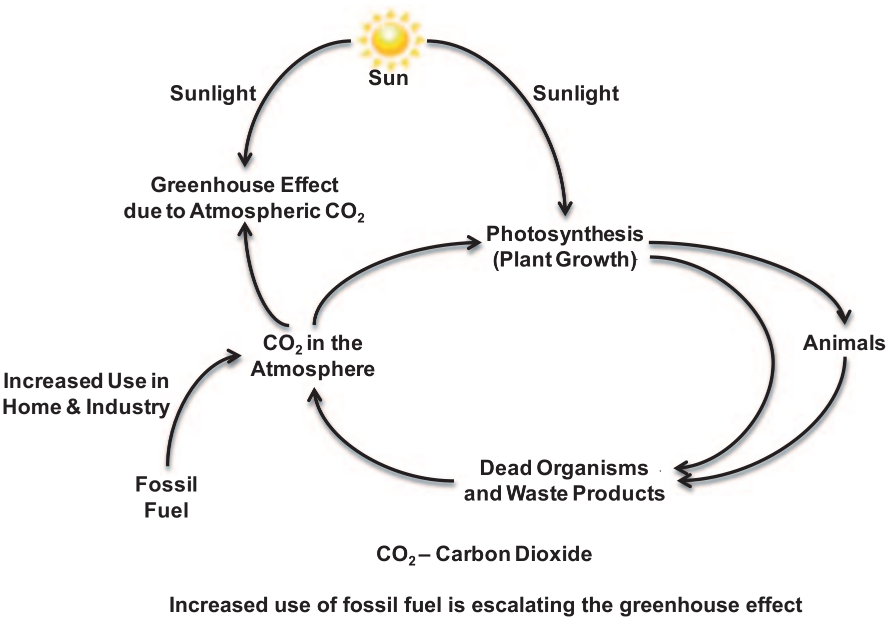

Fig. 1.1 The carbon cycle

plants and animals die and decay the carbon generally goes back to the atmosphere as CO_2. However, they may be converted into fossil fuels, including coal and oil, if get buried in earth under right circumstances but that can take millions of years. These interactions are collectively termed as the carbon cycle, which has been occurring in the nature for a very long time.

The atmospheric CO_2 level remained fairly steady when the world population was small and human beings used renewable resources such as wood and cow dung for cooking and heating. The balance was altered when we began using fossil fuels, such as coal or gasoline in large quantities for heating or as a source of energy for automobiles and electric power plants. Most of the burnt carbon now enters the atmosphere as CO_2.

Since the Industrial Revolution in the 1700s, the burning of oil, coal, and gas, combined with deforestation, has increased CO_2 concentrations in the atmosphere. In 2005, the global atmospheric concentration of CO_2 was found to be 35 % higher than it was before the Industrial Revolution. CO_2 is a greenhouse gas that traps heat from solar radiation in the atmosphere. This process is leading to global warming and the melting of ice caps in the Polar Regions.

Various ideas have been put forward to counter the increase of CO_2 in the atmosphere including carbon sequestering by injecting CO_2 gas to abandoned mines or deep in the ocean but they have not yet been tried in any large scale. The immediate and effective solution would be to reduce the use of fossil fuel and switch to green energy, such as solar, wind, and tidal powers. However, that involves economic and political systems, both national and international, which themselves are quite complex.