Introduction to Deep Systems Analysis for Scientists and Engineers

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Introduction

This introduction explains what it means to have a *deep understanding* of systems and why this is important when dealing with issues of complexity. The thesis is that such understanding can only come from a formal and systemic methodology for doing systems analysis. After parsing various systems categories, it discusses the systems understanding framework that this book will unfold.

Part 1. Foundations of Systems Understanding

In the first four chapters I provide a brief summary of the principles as developed in the *Principles of Systems Science* book (Mobus & Kalton, 2015), a system ontology, a mathematically-based definition of system, and a language of systems. These will provide foundational knowledge to be used throughout the rest of the book. It then outlines the full system knowledge life cycle, how systems analysis works to build an understanding of the workings of a complex system, to the capture of that understanding in an easily accessible knowledgebase, the construction of simulation models from that knowledgebase, to finally designing the human-sought products of understanding. These can be science experiments for the natural sciences studying systems, policy proposals and mechanisms for dealing with socio-economic issues, or complex cyber-physical systems like infrastructure.

1. Principles of Systems Science

This chapter provides a review/summary of the principles from Mobus & Kalton, along with some newer explanation. It will introduce the reader to the concept of an ontology of systems and the need for a language of systems for analysis and design. The three main methodologies of systems, analysis, modelling, and design (for policy instruments or engineering) are described and their importance explored. Particular emphasis will be put on the analysis work as key to success in other phases. Examples of failures in areas such as policy (such as environmental policies), complex machine, and software developments, where up-front analysis efforts were not sufficient, will reinforce the motivation as to why so much of the book will emphasize the analysis phase.

2. System Ontology

The chapter starts by categorizing types of complex systems along multiple dimensions. For example, it explains the differences between cyber-physical, living organisms, and supra organic systems (species, ecosystems, economies, etc.). I will provide explanation for the various levels and kinds of complexity, degrees of autonomy, and evolvability. I develop and use an ontology framework that uses these dimensions and a set of terms that are applicable across the range of complex adaptive and evolvable systems (CAES). The terms are the lexical elements for the system language presented in the next chapter.

3. System Language

Starting with the mathematical definition of system and using the ontology terms from chapter 2 I develop a system language that can be used to describe all systems. I explain how the language is used to guide analysis of systems and how this differs from other current modelling languages. The latter are constrained by assumptions about the kinds of questions that modelers in different domains of interest came up with. For example, system dynamics (SD) was developed for the particular purpose of predicting the dynamic behavior of certain kinds of systems if they could be modelled as a set of stocks, flows, influences, and feedback. The system language developed in this chapter starts with a general definition of systems that is universally applicable (even to simple systems). It is, therefore, a language that can be used to capture descriptions of details of any kind of system as it is being analyzed. This is true for both existing real systems (e.g. a specific ecosystem) or proposed systems to be designed.

The chapter will also briefly explain how, because the language is constructed from a formal model of system (given in the chapter), the discovered knowledge from analysis is captured in a knowledgebase so as to preserve the characteristics of components but also their relations with one another. This is the approach to whole systems analysis.

4. Fundamentals of Systems Analysis & Design

This chapter will run through the whole process of system understanding. It identifies the seven components or modules of the complete understanding process. These will be addressed in later chapters as described below.

The process of understanding systems involves a principle-based analysis of the system (existing or imagined) along with its interacting environment. The process of analysis should produce detailed knowledge of the components and their dynamic relations with one another at all levels of complexity. By following the procedures of systems analysis the analysts create a structured knowledgebase that will capture all of the relevant knowledge about the system. The knowledgebase design is based on the formal definition of system (from chapter 3) so that powerful mathematical manipulations can be used to, for example, check for consistencies within a level of organization and between levels. A more thorough explanation of the knowledgebase is the subject of chapter 7.

The process continues with the construction of models of subsystems (a bottom-up synthesis) to be run in a simulation environment. Subsystems behaviors are tested and the functionality of the subsystem, as a module, is verified. Higher level models of systems of subsystems (building back up the levels of organization) can be built using the abstractions of the subsystems for computational efficiency.

The final purpose of understanding systems is to propose the design of a human-desired condition or artefact. This involves extracting knowledge of the system, starting at the lowest level of organization in the knowledgebase, in the form of specifications. For existing, and particularly natural, systems this has the form of policy recommendations. For example, in an existing work process in an organization, the design of a more efficient sub-process can be tested in simulation and then specified in design.

Part 2. Core Methods: Analysis and Knowledge of Systems

Part 2 is devoted to the analysis process (as briefly described in Chapter 5) and to how information is obtained and captured in the knowledgebase (Chapter 7). The application of analysis methods is shown for several kinds of systems in Chapter 6. And Chapter 8 provides a more in-depth look at its use in analyzing an extremely complex, fuzzy and wicked system – the economy.

5. The Process of Deep Systems Analysis

This chapter details the use of the system language in conducting both top-down decomposition and bottom-up synthesis approaches to discovering and capturing system knowledge. The process resembles the General System Problem Solver methodology described in an abstract fashion by George Klir. However, concrete methods are provided and explained. I show how the language and the principles guide the process and how the information gained is organized in the knowledgebase (to be further described in Chapter 7).

The chapter provides a more comprehensive example of systems analysis and explains the mechanics of top-down functional/structural deconstruction analysis while preserving subsystem relations. It will follow the deconstruction of a relatively complex system through three or four levels of organization. This will be a fairly long chapter covering: Analysis of the environment (sources, sinks, and milieu), Analysis of the boundary, Analysis of the inputs and outputs, deconstruction of the sub-processes and internal flows, analysis of the governance structures and decision agents, analysis of the process time scales and time lag phenomena, specification of the flow volumes, etc.

The chapter will demonstrate how to construct the system map and the system components tree with appropriate indexing for entry into the knowledgebase. The reader should finish this chapter having a very deep understanding of the process as it can be used to analyze any kind of system. A brief discussion of the work load issues associated with more time spent in analysis should provide motivation to not 'cheat' on this phase of work.

6. Demonstrating the Analysis of Various Kinds of Systems: How the Ontology is Universal

Here I provide four examples of how the process can be used to analyze increasingly complex, complex adaptive, and complex adaptive and evolvable systems. The intent is to show how the ontology developed in Chapter 2 is capable of resolving all of these kinds of systems. Thus, I show that there need not be a distinction between so-called hard and soft systems.

I explain that the reason that this is possible today and the reason it seemed appropriate in the mid-20th century to distinguish these two, is that we have developed much better sensor technology and more sophisticated probing methods (aided by computer and communications technologies). These, coupled with this formal method of analysis, show us how to treat all kinds of systems in similar ways.

The chapter will provide example approaches for several systems demonstrating how to use the language to guide what the analyst should be looking for. It will focus on things like boundary analysis, showing the analyst how principled knowledge of interfaces can guide the asking of analysis questions. It will show how to deal with issues such as unaccounted for flow volumes or miss-sized stocks (e.g. overflows). It will especially examine the questions of agent decision making and data collection/information processing involved in process regulation and coordination.

7. Examining the Knowledgebase

This chapter will take a close look at the knowledgebase that is built up from the analysis process and how it maintains the important relations between multiple components in very complex systems. It starts with an explanation of the knowledgebase structure derived from the formal definition of system in Chapter 2. The architecture of the knowledgebase includes data storage of root elements (given in the formal definition in Chapter 3) in a relational database with tables reflecting the relations given in Equation 3.1. The architecture also includes elements that augment the basic relations stored in Wikipedia-like pages. A sample of knowledgebase tables and forms will be used to show how to capture the information about the system from analysis. My intention is to build a basic knowledgebase model using an existing database management tool to show how the indexing scheme works to maintain relations of components.

8. Example of the Analysis of a Complex Adaptive and Evolvable System

The chapter will do a summary analysis of a complex system important to humans – e.g. examining parts of the economic system from a biophysical perspective. It will analyze the role of money as a form of information about the availability of energy to do useful work. It will also analyze the energy costs of producing energy that is available for that useful work. I will look specifically at the energetics and economics of solar photovoltaics as a major source of electrical energy. The emphasis in this chapter is on how energy flows are absolutely important factors in all real systems and to show how to take them into account when analyzing various other kinds of systems. This chapter will draw on my own work and that of Charles Hall, et. al, and Howard T. Odum.

Part 3. Modelling of Complex Systems

This section will focus on the use of the captured knowledge to construct models for simulation. It will expand on the concepts of modeling introduced in chapter 4 and provide some examples of system models and simulations.

9. Meta-Models for Analysis and Modeling of Complex Systems

Meta-Models – Templates for Analysis and Design

This chapter will introduce the nature of meta-models or templates that are generic and found in all complex systems. It will point the reader to the appendices C, D, and E in which the meta-models will be further developed in sufficient detail that both scientists and engineers will be able to use the models for guidance in analysis and design.

Complex Adaptive (and Evolvable) Systems

This section will review the basic ideas behind CAS and CAES and provide a single meta-model of both.

It will provide numerous examples of real systems that are in these categories and relate the meta-structures and meta-functions found in them that contribute to the idea of a meta-model of CA(E)Ss.

Agents and Agency

To understand the working of CA(E)Ss we first explore the generic concept of a decision agent, from simple error correcting cybernetic loops to complex human-machine decision processing. All are based on a generic model involving some form of computation engine, a decision model (even if stochastic elements are involved) a (possibly NULL) memory store, sensory inputs and motor outputs. Agency is the capacity to act on decisions. These agents are found at every complex work process and in the overall governance structure.

Governance Systems

This section will provide a major expansion of the Hierarchical Cybernetics Control (governance) model from the Cybernetics chapter in the Principles book. I develop the complete model of the hierarchical cybernetic governance system (HCGS) and show why it is so important in complex adaptive and evolvable systems, especially for sustaining the systems over their normal life spans. The HCGS is the key to understanding extremely complex socio-political-economic systems as well as cyber-physical systems like nuclear reactors!

Economies

Building on concepts presented in Chapter 8, this section will expand the notion of an economy as the internal processes of a CA(E)S

Examples from management of organizations, government functions, and a robot "brain" will be used to demonstrate how systems analysis of CAESs has to use the HCGS model to do a complete job. I also cover the governance of the systems understanding process itself.

10. Generating Models from the Knowledgebase

The chapter provides an explanation of the purpose and methods for modeling systems based on the knowledge extracted during analysis. It explains how models are typically reduced and abstracted versions of the real systems. The most important part of this chapter, however, is showing how to construct low-level models of subsystems deep in the hierarchy of levels of organization and deriving abstractions of these for higher-level models. The subject of computational complexity and the need for abstraction for purposes of running models in simulation is covered. I will show how models of a biological neuron and "brain" system can be derived from more complex knowledge of those systems.

11. Testing and Verifying Models and the Knowledgebase

This chapter will take up the important task of assuring the quality of a model and the knowledgebase of the system. Using methods within the knowledgebase I will show how to test dynamical and structural outputs and verify that the model captures the reality of the system with respect to answering the questions by the investigator. I will also demonstrate and explain how holes in the systems knowledgebase, arising from an incomplete analysis, can be detected in simulations, giving lead to re-doing the analysis for completeness. The discussion will reinforce the emphasis on not cutting corners in analysis (to save money!)

Part 4. Artifice

The final section will address the important uses of system models for policy making and generating design specifications for engineered artefacts. My vision is to show how policies involving natural systems (the ecological system from parts 2 & 3) can be generated and tested using the system model. Another chapter will show how the design specification for my robot's brain was developed from the system model of same.

12. Designing Systems

This chapter provides a sample of design specifications derived from the knowledgebase accumulated during analysis for a complex machine. I will use my own experience with the MAVRIC robot. Here I only show how the results of a competent systems analysis is essentially a "design for free." That is, the design specification for a very complex cyber-physical system comes directly out of the knowledgebase with very little additional work. I will then turn attention to designing a workable economic system derived from the analysis done in Chapter 8. The analysis done in chapter 8 concerned only the biophysical aspects of an economy and so this chapter will consider these aspects as well.

13. Engineering Systems

This chapter will strive to show how all of the previous chapters apply to the engineering of a CAES. Carrying forward the concepts and designs in the previous chapter, I will develop a set of specifications for a workable economic system.

14. Hybrid Systems and Policies

Socio-political and economic systems as well as natural ecosystems that interface with human activities are governed by policies and policy mechanisms that should result from knowledge of how these systems work. Currently the methods of analysis are based pretty much on economic methods. My argument will be that real knowledge comes from systems analysis. This chapter walks through examples of policy and mechanism designs related to problems in ecosystem uses (e.g. forest management) and incentives for reducing carbon emissions (carbon tax). I will not be claiming to have solutions to these issues, since the analysis has not been properly done. The emphasis of the chapter, rather, will be on the need to do more rigorous systems analysis as a prelude to these important activities. The intent will be to show how doing such analysis will increase the likelihood that policies will be better than if relying strictly on typical economic analysis.

Appendices

A. Representations of Systems in the Brain

This appendix will provide a summary of what is known today about how the human brain (in particular the neocortex) represents percepts and concepts as well as their relations. A special emphasis is placed on the representation of causal relations and how they are coded into neuronal networks. The appendix will also cover the basics of knowledge construction (learning), mental models, and reasoning insomuch as what is currently understood from brain research.

This appendix will provide justification for the claim (from chapter 3) that human beings already have a mental language that is essentially like the formal language of system, but at an intuitive level. Systemness is an a priori pattern template situated in the way the brain operates.

B. System Language Specification

A formal listing of the language specification developed from the theoretical work in Chapter 3.

C. Agents and Agency

The basic model template of a decision agent is provided. Several examples from living and supra-living systems such as societies are provided

D. Governance

The basic model template for a hierarchical cybernetic governance architecture is presented and its nature and components are justified in terms of sustainability of the whole system in which it is instantiated.

E. Economies

Agents work within the governance framework to manage a whole system's economy. This appendix presents a generic model template for an economy showing how the principles of organization and function are valid at many scales of CA(E)S such as cellular metabolism, organismal physiology, population ecology, and human society (political economy).