A Formal Description of the Basic Concepts of System Theory for Transportation

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Abstract. In this paper some of the basic concepts of system theory are presented in a formal way. This is done with the help of the formal modeling language petri-nets. An example out of the transportation is used to illustrate the discussed concepts.

1 Introduction

There are models, principles and laws that apply to generalized systems or their subclasses, irrespective of their particular kind, the nature of their component elements, and the relations or "forces" between them. So it seems legitimate to ask for a theory not for systems of a more or less special kind, but of universal principles applying to systems in general. The aim of this paper is to give a general formalization of some of the basic concepts, such as "boundary of a system", or "emergent property" used in systems of different kinds (see [5]). The formalization of some fundamental concepts of system theory shall provide a common basis for all branches of science. In each of these branches the common (abstract but formal) definitions made here can be instanciated with domain-specific terms.

In chapter 2 we introduce some of these concepts in an informal way. Afterwards, in chapter 3 we use petri-nets as a formal modeling language to formalize the concepts presented in the second chapter. Chapter 4 focusses on an example from the transportation to clarify the introduced concepts.

2 Basic Concepts of System Theory

In this chapter we'll outline the basic concepts of system theory in an informal way (see [1]). An idea of these concepts is the basis for the following chapters.

2.1 What Is a System?

To start with the beginning: One can imagine, that in the beginning there existed only a totally homogenious and unformed *primary-matter*. In order to create something, one has to establish a *distinction*. Where these distinctions come from (whether from some kind of mystic creator or likewise an observer), does

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not matter here. But how can these distinctions be made? The primary-matter elements are ordered in some way. Due to this ordering they can be distinguished from other elements. So, these ordered elements fulfil special relations and conditions (in contrast to the non-ordered elements) – as a consequence, the *ordered elements can be separated from the non-ordered ones*. The established relation between the ordered elements is also called *organisation* or *structure*. This organisation itself determines, how the system operates and which processes can be performed. One must not misunderstand "organisation" as a static concept; here an organisation consists of *operations* and *processes* – the organisation of a system determines, how the system operates, depending on a concrete order of system elements. The set of all conditions that are fulfilled by an element is called the element's *state*. The state of the system is defined as the state of all the system's elements. As a consequence, the organisation and the state of the system determine, how the system operates.

So, a system consists of (a set of) elements (selected from all possible elements), that are related in a special manner and therefore enable certain processes.

2.2 A System and Its Environment

That, whereof a system can be distinguished (that, what is beyond the system), is called *environment* – the system embeds its own elements, thus the environment is excluded. The effect is: Environment is environment only in relation to a special system; there is no environment without a system. As a consequence, the unformed primary-matter in the beginning is not an environment in our sense.

All the parts of a system's organisation that depend directly on its environment or that affect directly its environment form the *boundary of a system*.

2.3 Subsystems and Emergence

If one examines a system without taking its environment into account, it is apparent that the system is divided into functional parts: For every operation there are components or *subsystems*. These subsystems are achieved due to differentiations: "The establishment of new system/environment-differences as part of the initial system."([2])[1] The above mentioned elements can be regarded as subsystems, if they form a functional part.

Interdependencies between subsystems may lead to a new organisation on the system level. If this transformation of organisation is not deducible from only the subsystems but with taking into account the interdependencies between them, we call these transformations *emergence*.

3 Formal Modeling with Petri-Nets

In this chapter the basic notations of petri nets [3] are outlined. We use petri nets here, as an instrument to formalize the concepts introduced in chapter 2.

[1] "Etablierung neuer System/Umwelt-Differenzen innerhalb des Ursprungssystems." ([2], translation J. R. M.).