

# Design: Structure, Process, and Function

## A Systems Methodology Perspective

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### 1 Introduction

Systems methodology comprises approaches to systems analysis on the one hand, and systems engineering on the other. Systems analysis develops an understanding of a system, its elements, and its environment that describes their functional, structural, and behavioral aspects. Systems engineering transforms operational user needs into system architectures, performance and functional requirements for system elements, and internal and external interface definitions. The common element of both systems analysis and systems engineering is design.

Design in systems methodology is the combination of two interactive loops, one addressing the relationship of the design object to its environment, the other addressing the relationship of the design object to its parts. For systems analysis, e.g., the medical science of physiology, these loops consider structure, function, and process in the context of environment to develop information (what), knowledge (how), and understanding (why) of the system and elements being studied.

This chapter presents the interactive loops of the design process in systems engineering, and explains the use of analogous interactive loops in systems analysis, considering Harvey's analysis of the function of the human heart and Cold War analysis of Soviet national missile defenses. The core systems analysis insights of Singer, Churchman, Ackoff, and Gharajedaghi are adapted into an exposition that accurately describes both the pioneering scientific work of Harvey and the modern pragmatic work of Cold War military intelligence analysts.

### 2 Definitions of System, Function, Purpose

#### 2.1 Definitions of "System"

The analysis of design in systems methodology leans heavily on the modern notion of a system, especially the definitions of Bertalanffy and Ackoff.

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Bertalanffy (1969, 55–56): “A system can be defined as a set of elements standing in interrelations. Interrelation means that elements,  $p$ , stand in relations,  $R$ , so that the behavior of an element  $p$  in  $R$  is different from its behavior in another relation,  $R'$ . If the behaviors in  $R$  and  $R'$  are not different, there is no interaction, and the elements behave independently with respect to the relations  $R$  and  $R'$ ”

Ackoff (1981, 15–16; see also 1972; 1974): “A system is a set of two or more elements that satisfies the following three conditions. [1] The behavior of each element has an effect on the behavior of the whole. ... [2] The behavior of the elements and their effects on the whole are interdependent. ... the way each element behaves and the way it affects the whole depends on how at least one other element behaves. ... [3] However subgroups of the elements are formed, each has an effect on the behavior of the whole and none has an independent effect on it.”

Ackoff concludes from his definition that every element of a system has essential properties that belong to it only by virtue of its being an element in the system, and also that every system has essential properties that belong to none of its elements individually or in aggregation. Systems analysis exploits these two conclusions to locate function among the essential properties of an element that it has only in virtue of its being in a system, and to locate the purpose being served by a function among the essential properties of the system that belong to none of its elements. These are critical razors for winnowing candidate functions and candidate purposes.

Ackoff’s and Bertalanffy’s definitions are compatible, but Ackoff’s definition avoids explicitly introducing the relations  $R$  as explaining differences in behavior of  $p$ , leaving the behaviors unexplained. This leads explicitly to that abandonment of reductionism that is characteristic of systems thinking. Bertalanffy’s definition is important for illuminating why it is that systems have the kinds of irreducibility that are made implicit in Ackoff’s definition: it is the relations of the elements to the system and to one another that give the elements their system-dependent properties on the one hand, and the system its emergent properties on the other. In a nested system-of-systems, Bertalanffy’s definition helps to explain what Ackoff’s definition describes, particularly the distinction between functions and purposes.

## 2.2 *Distinguishing Function from Purpose*

Functions are not arbitrary properties of system elements; they must be among those properties that are essential to the element, in light of the definition of a system (interdependence of behaviors of system and elements). This distinguishes the pumping of a heart in a cardiovascular system from its audible thumping.

Similarly, the ends served by the functions of the elements, i.e., the purposes of the system, are among those properties of the whole system that are essential to the system. For instance, if a function of the heart in the cardiovascular system is to pump blood, and circulation of blood is the purpose served by that function, then this entails that circulation of blood is an emergent property of the cardiovascular