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The concept of problem complexity

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Abstract

Recognizing the impact of system complexity on the success of a system's development has created significant research efforts towards measuring system complexity. In particular, the research community has proposed techniques to measure three types of system complexity: (1) structural complexity, which measures the complexity resulting from physical interconnection of components; (2) functional complexity, which measures the complexity resulting from interconnection of system functions; and (3) organizational complexity, which measures the contractual interconnection of the different organizations developing the system. The majority of these metrics focus on measuring aspects of the complexity of an existing system or design. However, a metric to anticipate the complexity induced by the problem itself on a system's development is lacking. We therefore present the concept of Problem Complexity as the complexity level that a set of requirements can impose to any system fulfilling them. In addition, we mathematically demonstrate using the concept of joint entropy how problem complexity defines the minimum level of complexity a system can achieve for a given set of requirements. The paper suggests an analytic formulation to measure the complexity induced by a set of requirements in a system's development that is based on a set of heuristics that facilitate identification of conflicts between requirements. The use of such analytical formulation is showcased on a notional case-study.

Keywords: system complexity; problem definition; entropy.

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1. Introduction

Levels of system success or failure, or in other words system affordability, are often measured in three dimensions: performance, cost, and schedule. Several researchers have related system and development complexities to difficulties in meeting expectations in those three dimensions.[1,2,3,4,5] Since reducing complexity is therefore necessary to facilitate success, it is of paramount importance to identify the origins of complexity in a system's development.[5]

Two major research trends address this topic, which will be discussed in the next section. The first one investigates how the complexity of a system can be measured. The second one tries to identify factors that correlate to variability of system affordability and aim at estimating expected affordability impact, yet they are unable to measure actual complexity. Although their value is out of question, they have two significant limitations. Measuring complexity of a system requires a system's architecture or a design to exist and, consequently, efforts to reduce complexity can only occur after some effort has already been invested in the system development. Estimating affordability impacts enables more adequate definition of cost, schedule, or risk budgets, yet it cannot help in mitigating or reducing complexity itself.

This paper addresses the following question: would it be possible to anticipate the dynamic range of complexity of a system or its development may have before the actual development begins? In other words, given a set of requirements, would it be possible to determine the minimum complexity level we could expect of a candidate system or its development? To answer them, we propose the concept of Problem Complexity as a measure of the size of the solution space and mathematically prove that it limits the minimum level of complexity that a system of its development can achieve.

This paper is organized as follows. Section 2 discusses various understandings of complexity in systems engineering and provides a review of existing literature on the topics of system complexity measures and cost growth factors. The concept of problem complexity is presented in section 3, together with a mathematical definition and a discussion on how different complexity types can be treated in comparable manner. Its use is showcased in section 4. The paper concludes with a short summary of the conclusions and a proposal for future work in section 5.

Nomenclature

C	complexity index
C_f	functional complexity index
C_o	organizational complexity index
C_p	problem complexity index
C_s	structural complexity index
r_f	functional requirement
H	scaling factor related to a conflicting requirement heuristic

2. Literature review

2.1. Understanding system complexity

In complexity science, complexity is often defined as "that property of a model which makes it difficult to formulate its overall behavior in a given language, even when given reasonably complete information about its atomic components and their inter-relations".[6] In fact, this notion of emergence is what sets apart complex systems from complicated ones.[7,8,9,10] Because emergence exists in systems with large numbers of independent variables of highly unknown interactions[11], the study of complexity in system or product development has primarily addressed three dimensions[12,13], which seem to be correlated[12,13,14,15](ref. Table 1).