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On the abstraction of conventional dynamic systems: from numerical analysis to linguistic analysis

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Abstract

Linguistic dynamic systems (LDS) are dynamic processes involving mainly computing with words instead of numbers for modeling and analysis of complex systems and human–machine interfaces. The goal of studying LDS is to establish a methodology of design, modeling, and analysis of complex decision-making processes bridging the machine world in numbers and the human world in words. Specifically in this paper, conventional dynamic systems are converted to different types of LDS for the purpose of verification and comparison. The evolving laws of a type-I LDS are constructed by applying the fuzzy extension principle to those of its conventional counterpart with linguistic states. The evolution of type-I LDS represents the dynamics of state uncertainty derived from the corresponding conventional dynamic process. In addition to linguistic states, the evolving laws of type-II LDS are modeled by a finite number of linguistic decision rules. Analysis of fixed points is conducted based on point-to-fuzzy-set mappings and linguistic controllers are designed for goals specified in words for type-II LDS. An efficient numerical procedure called α-cuts mapping is developed and applied to obtain extensive simulation results.

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1. Introduction

In its traditional sense, modeling and analysis of dynamic systems are based on computing that involves manipulation of numbers and symbols. By contrast, human employs mostly words in computing and reasoning to arrive at conclusions expressed as words from linguistic premises. Therefore, incorporating computing with words into modeling and analysis will be an interesting and important direction for future research. This is true especially when one is dealing with social, political or economical, rather than engineering or physical systems. In this paper, we outline an approach along this direction based on the theory of linguistic dynamic systems (LDS) developed by Wang [22–26].

Clearly, many efforts have already been taken toward this objective in the past [1,4,12,18]. For example, methods from knowledge based systems, expert systems, linguistic structures, multi-valued logic, fuzzy logic, and many others have been proposed and developed in the past three decades. Although these methodologies have been successfully used to solve many problems in large complex systems, none of them has led to a theoretical framework upon which concepts and methods for system analysis and synthesis parallel to those well known for conventional dynamic systems, such as stability analysis and control design, can be developed. In [22–26], Wang have used Kosko's interpretation [10] of fuzzy sets to consider LDS as mappings on fuzzy hypercubes; and by introducing cellular structures on hypercubes using equi-distribution lattices developed in number theory [8], these mappings can be approximated as cell-to-cell mappings in a cellular space [6,7], in which each cell represents a linguistic term (a word) defined by a family of membership functions of fuzzy sets; in this way, LDS can be studied in the cellular space, and thus, methods and concepts of analysis and synthesis developed for conventional nonlinear systems, such as stability analysis and design synthesis, can be modified and applied for LDS; while cell-to-cell mappings provide us with a very general numeric tool for studying LDS, it is not the most effective method to handle the special cases of type-I and type-II LDS to be studied here.

In this paper, a LDS is called a type-I LDS if its states are linguistic and its evolving laws are constructed based on conventional functions by using the fuzzy extension principle [10,28], while a LDS is called a type-II LDS if its states are linguistic and its evolving laws are modeled by a finite number of linguistic rules. The difference between type-I and type-II LDS is two-folds: First, the evolving laws of type-I LDS are of crisp forms and the fuzzy extension principle is used to assign linguistic meanings of new states based on