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Automatic generation of explanations: AGE

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Abstract

Explaining how engineering devices work is important to students, engineers, and operators. In general, machine generated explanations have been produced from a particular perspective. This paper introduces a system called automatic generation of explanations (AGE) capable of generating causal, behavioral, and functional explanations of physical devices in natural language. AGE explanations can involve different user selected state variables at different abstraction levels. AGE uses a library of engineering components as building blocks. Each component is associated with a qualitative model, information about the meaning of state variables and their possible values, information about substances, and information about the different functions each component can perform. AGE uses: (i) a compositional modeling approach to construct large qualitative models, (ii) causal analysis to build a causal dependency graph, (iii) a novel qualitative simulation approach to efficiently obtain the system's behavior on large systems, and (iv) decomposition analysis to automatically divide large devices into smaller subsystems. AGE effectiveness is demonstrated with different devices that range from a simple water tank to an industrial chemical plant.

Keywords: Generation of explanations; Qualitative reasoning

1. Introduction

Communicating knowledge, in verbal or written form, is an important human learning activity. In engineering, explaining how a particular device works is relevant to engineering students, designers and operators of industrial plants. These explanations, however, are normally given from a particular point of view and without considering the user's particular needs. Machine generated explanations of physical devices normally considered a particular perspective (e.g., functional identification (Kitamura et al., 2002)). Explanations related to a particular device can be given from different perspectives depending on different needs. An engineer may be interested in knowing the causal dependencies between different state variables. She may be interested in observing how the state variables evolve over time, or what is the main function of a particular device. Her interests may focused on particular state variables and/or particular subsystems. All these explanations are important and provide complementary information to a user. This paper describes a system called automatic generation of explanations (AGE), which can produce explanations of engineering devices in natural language considering different perspectives. In particular, AGE produces causal, behavioral and functional explanations, considering user selected state variables and subsystems.

The goal of AGE is to create understandability through the generation of natural language descriptions produced by several inferences processes like causal order, qualitative simulation and subsystem reduction.

This paper is organized as follows. Section 2 describes the general architecture of AGE and how it produces its different explanations. An evaluation of AGE in terms of applicability and usability is given in Section 3. Section 4 reviews related work and Section 5 provides conclusions and future research directions.

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2. AGE

Physical devices are specified in AGE by joining individual engineering components, such as pumps, valves, tanks, tubes, stoppers, reactor, etc., taken from a library of components through a graphical interface or alternatively by selecting a previously constructed device. Joining components was introduced by Gruber and Oisen (1994). In AGE, each component of this library is associated with a qualitative model as in QSIM (Kuipers, 1994). We adopted qualitative models because they provide an adequate abstraction level from which useful explanations in natural language can be easily produced, and they allow predictions about the behavior of the system in the absence of exact quantitative information.

A qualitative differential equation (QDE) model is an abstraction of an ordinary differential equation, consisting of a set of real-valued variables and functional, algebraic and differential constraints among them, where the values of variables are described in terms of their ordinal relations with a finite set of symbolic landmark values, rather than in terms of real numbers. A quantity space is a finite, totally ordered set of symbolic *landmark values* representing qualitatively important values in the real number line (Kuipers, 1994).

The complete specification of a physical component in AGE, requires, besides a qualitative model, the semantic meaning of each state variable and all of its landmark values, as well as its input/output variables in order to connect it with another component. For instance, Fig. 1 shows semantic information (in Spanish) associated with a tank filled with water. Each component is also associated with a meaningful name to the user and the name of the substance that it is carrying. In case of chemical reactions within the component, it is the user's responsibility to specify the products.

AGE follows a compositional modeling process (e.g., see Falkenhainer and Forbus, 1991) to construct a global qualitative model that takes into account conservation of mass and energy (e.g., the pressure is assumed to be constant between components and all the input and output flow variables of a particular component must sum zero). AGE also identifies the exogenous variables.

AGE's architecture (more details can be found in González-Brambila, 2003), once a global qualitative model has been constructed, is shown in Fig. 2. Given a qualitative model of a particular device, AGE: (i) generates a global flow sheet that is used for functional explanations, (ii) obtains causal dependencies from the qualitative model to produce causal explanations, (iii) simulates the qualitative model to produce behavioral explanations, and (iv) uses this simulation with functional analysis to produce functional explanations. The following subsections explain each of these steps in more detail.

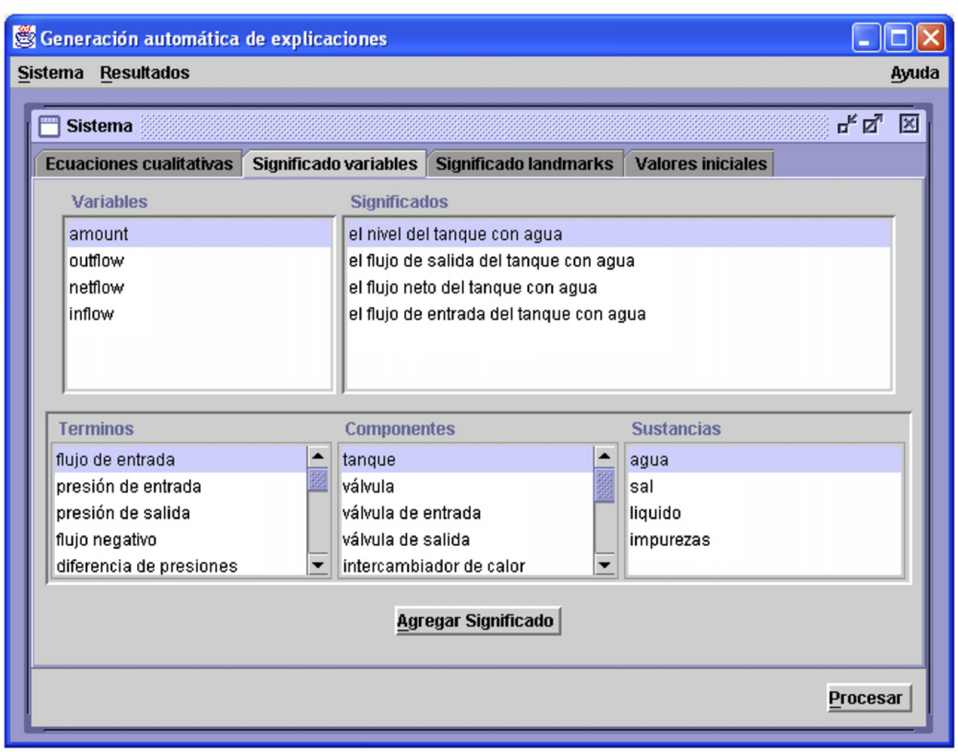

Fig. 1. Semantic information associated with each state variable. Each variable (e.g., amount highlighted in the upper half) has information about its meaning (*the amount of water in the tank*), and information about the substance and related component (e.g., *input flow* highlighted in the lower half, is associated with a particular *tank* and with *water*).