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Towards a structured approach to building qualitative reasoning models and simulations

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ABSTRACT

Successful transfer and uptake of qualitative reasoning technology for modelling and simulation in a variety of domains has been hampered by the lack of a structured methodology to support formalisation of ideas. We present a framework that structures and supports the capture of conceptual knowledge about system behaviour using a qualitative reasoning approach. This framework defines a protocol for representing content that supports the development of a conceptual understanding of systems and how they behave. The framework supports modellers in two ways. First, it structures and explicates the work involved in building models. Second, it facilitates easier comparison and evaluation of intermediate and final results of modelling efforts. We show how this framework has been used in developing qualitative reasoning models about three case studies of sustainable development in different river systems.

1. Introduction

Increasingly, international policies and programs, such as the European Union's Strategy for Sustainable Development (http://ec.europa.eu/sustainable/) and the United Nations' Millennium Development Goals (http://www.un.org/millenniumgoals/), are emphasizing the importance of developing consciousness about the factors affecting sustainable development. To support this call, we are developing qualitative reasoning models of issues relevant to sustainability; the models are aimed at supporting learning about sustainable development in online interactive environments (http://www.naturnet.org/).

Model building involves transforming initially vague and general ideas into clearer and more formally specified representations. This paper describes a structured methodology to support the development of qualitative reasoning models and simulations. This framework assumes that the target software (e.g., Garp3, http://www.garp3.org) supports a compositional approach to qualitative reasoning and that knowledge, such as structure, causality, etc., is explicitly represented (cf., Bredeweg et al., 2006a,c).

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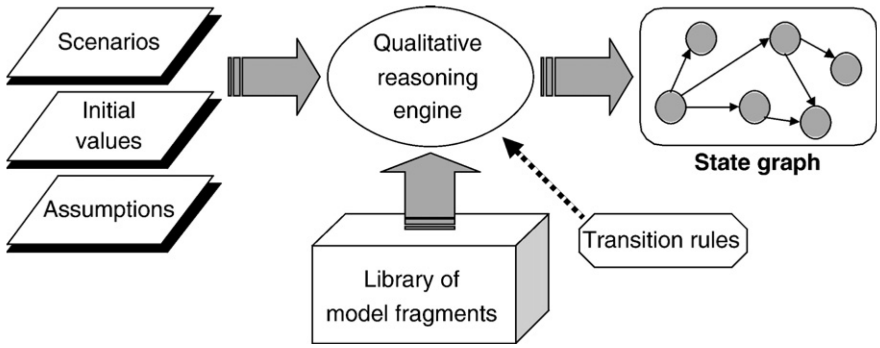

Fig. 1 – Basic architecture of a qualitative reasoning engine.

1.1. *Qualitative reasoning — a brief introduction*

Qualitative reasoning originates from artificial intelligence and concerns the construction of knowledge models that capture insights domain experts have of the structure of systems and their behaviour (functioning). An important goal is to automate this kind of knowledge (using a reasoning engine) and by doing so to support humans in analysing how the behaviour of a system evolves as time passes. To perform such a task, a qualitative reasoning engine takes a *scenario* as input and produces a *state graph* (or behaviour graph) capturing the qualitatively distinct states a system may manifest (Fig. 1).

A scenario usually includes a structural description of the physical appearance of a system, accompanied by statements about initial values and assumptions. A state graph consists of a set of states and state transitions. A state refers to a qualitatively unique behaviour that the system may exhibit (a possible state of behaviour). A state transition specifies how one state may change into another state. A sequence of states, connected by state transitions, is called a behaviour path (a behaviour trajectory of the system). A state graph usually captures a *set* of possible behaviour paths, because multiple state transitions are possible from certain states.

To generate a state graph the engine searches for applicable model fragments from a library. Model fragments can be seen as reusable (conditional) statements that capture knowledge about the phenomena existing in a certain domain. Model fragments applicable to a scenario are assembled by the engine and used to infer the overall behaviour of the system. They are also used to infer the facts that are true in each of the successor states.[1] In general, a model fragment requires certain structural details to be true. If the required structure exists the model fragment is activated for that (partial) structure and introduces the behaviour details that apply to the structure. A specific model fragment can be activated multiple times, namely for each occurrence of the (partial) structure to which it applies. For further details see e.g. Bredeweg et al. (2006d). A fundamental aspect of building a qualitative model is thus the construction of a library of model fragments, for a certain domain (Physics, Ecology, etc.), that can be used to reason about the behaviour of a set of systems belonging to that domain.

1.2. *A structured approach to modelling*

Building a qualitative reasoning model is a complex task. It requires the creation of a library of model fragments and accompanying scenarios such that simulation of those scenarios produces output that satisfies the modelling goals. A structured approach that supports step-wise clarification, implementation, and documentation of the model creates momentum that makes success more likely (Salles and Bredeweg, 2003). Such an approach can be realised by decomposing the overall task into subtasks and have subtasks focus on the different kinds of knowledge that need to be represented in the model. It is also helpful to explicitly represent intermediate results addressing different levels of detail, and while doing so progress from general characteristics towards specific details. The latter is even more helpful when the intermediate results can be represented in software, enabling computer-based reasoning and thereby providing the basis for automated feedback and support. Following these general principles, we have developed a structured approach consisting of six main steps (see Fig. 2):

1. Orientation and initial specification: establishing what should be modelled, why and how.
2. System selection and structural model: identification of the target system structure and its constituents.
3. Global behaviour: general specification of the behaviour that the model should capture.
4. Detailed system structure and behaviour: detailed specification of the behaviour to be captured.
5. Implementation: creation of the model ingredients in the model building software, simulation, and debugging to improve and optimize the model and obtain the required results.
6. Model documentation: documentation of the model and underlying argumentation.

Fig. 2 may suggest that our framework proposes a waterfall approach to building models. This is however, misleading. In fact, the framework reflects a kind of spiral approach (Boehm, 1988) in which a set of ingredients (initially specified in the concept map) is gradually established and refined into

[1] This implies, among other things, that the set of facts may change and can be different for alternative states.