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Qualitative Reasoning and Articulate Software

Y.C. Alicia Tang
College of Information Technology, Universiti Tenaga Nasional,
KM 7, Jalan Kajang-Puchong, 43009 Kajang Selangor, Malaysia

Abstract: Qualitative Reasoning (QR) about physical system is one of the most active research areas in Artificial Intelligence (AI) in recent years. We believe that the part taking of qualitative reasoning will help to expand artificial intelligence application in new domains such as those that are highly qualitative in nature and the development of articulate software. Educational software using qualitative model can offer high interactivity rather than merely a static content-driven tool. With this, educational software can be made more engaging and interesting. As a result, the practical value of qualitative reasoning is significantly increased in the development of Intelligent Tutoring Systems. This study reviews three prominent ontologies for QR. The suitability of applying qualitative reasoning for building intelligent educational software was also discussed.

Key words: Educational software, intelligent tutoring system, artificial intelligence

INTRODUCTION

Qualitative reasoning helps to develop a new kind of software which has potential for science and engineering education called articulate software as coined by Forbus[1]. The main aim of QR is to develop representation and reasoning techniques that will enable a program to reason without having precise quantitative information needed by traditional techniques such as numerical simulators[2]. The term qualitative reasoning pertains to the distinction between reasoning with actual numerical values and reasoning with less precise representations. Qualitative description of physical processes also provides grounds for generating causal explanation, reasoning from structure, cognitive diagnosis, etc. With these dynamic mechanisms, educational software can incorporate instructional goals and intentions, rather than merely authenticity as in traditional media that use textbook and handouts would. It helps to improve our understanding of human cognition and the development of new generation of software for various applications. It is seen that education is one of the most important areas of practical application of qualitative reasoning. One such system is CyclePad developed by Forbus[3] of Northwestern University that teaches analysis and design of thermal cycles. Qualitative physics offers two useful means of representations. First, it represents the right kinds of knowledge. Right kinds refer to the implicit causal theories of physical phenomena that the model has which include the analyzing of what happens, when it will happen, what will effects it to happen, etc. This is very similar to what students learn about science subjects in schools. Second, it represents the right level of knowledge, i.e. it captures the common sense behind the understanding of the basic principles rather than a bunch of formulas.

Benefits and promises: Qualitative models offer uses in many situations. Sometimes, precise relations among variables in a system may be hard to determine or difficult to measure, but usually it is still possible to state some qualitative relations among the variables. Even a numerical model is there, to run such a simulator will require the values of the parameters to be specified by the user before the simulation can start. This is where the user will make some guesses at these parameters. With a qualitative model, much of such guesswork can be avoided. Also, early in a design process, a designer often puts forward a rough outline of a design, including the main components, their relations and so forth. Since there is not enough quantitative data at this point, traditional quantitative techniques cannot be used. Thus, qualitative information is essential for evaluating a design at this stage. For many generic tasks, numerical precision is not required and qualitative reasoning is more appropriate. These include structural synthesis, functional reasoning and diagnosis.

RESEARCH OBJECTIVES

Most of the quantitative simulations are based on complex mathematical procedures. These procedures provide no conceptual access to the objects and their behavior in the simulation. This makes it hard for explanation use and it is impossible to derive casual explanation of the behavior of the particular system from the mathematical model. As a result, they are not suitable for inclusion in Intelligent Tutoring Environment for many subjects. It is construed that students should deeply understand the qualitative principles that govern a subject, including the physical processes and the causal relationships before they are immersed in qualitative problem solving. In this respect, qualitative physics is able to tackle from its right level of knowledge representation. On the other hand, computer artefacts for learning should be both interactive and articulate, for example by having learners to interact with a simulator of the subject matter. This would result in the so-called articulate software. It is believed that software that embodies a conceptual understanding of its domain can help learners understand and pick up better. This is exactly what qualitative reasoning can offer. Historically, simulation that done for various problem domains in sciences (such as chemistry) relied heavily on pre-coded facts and rules in their knowledge bases. Within this context, the key objectives of the study are: (1) To outline the fundamental and benefits of qualitative reasoning. (2) To introduce three ontology with examples. It is hope that this exposition will stimulate further works in the subject.

QUALITATIVE REASONING ONTOLOGY

In AI, ontology is defined as an explicit representation of a conceptualization. It has the knowledge and deduction in one framework. Several ontology for qualitative reasoning have been introduced. Among the well-known are component-centered[4], constraint-based[5] and process-centered (the Qualitative Process Theory)[6].

Component-based ontology: In this approach, three kinds of constituents are important: conduits, components and materials. The conduits are used to transport material from one component to another. System behavior is accomplished by operating on and transporting materials. Components, on the other hand, can change the form and the characteristics of materials. Confluence is the central modeling primitive in this ontology. It is a qualitative differential equation (QDE). For example, qualitative behavior of a flow rate can be expressed by the confluence dFlow_rate = Source_temp-Destination_temp, where dFlow_rate, means the variation in flow rate from source to destination. A confluence of the above generates two relationships, firstly temperature at source influences positively the flow rate and secondly temperature at destination influences the flow rate negatively. In this approach, qualitative variables can only take one value, determined by its quantity space (a collection of numbers which form a partial order). A qualitative algebra is required to combine qualitative values. As the system evolves, qualitative values of the variables change, causing transition between states. State transitions are governed by rules and each qualitative behavior of the device being modeled is a path (the conduit) through the state transition diagram. Diagrams containing all the possible states from resolving the confluences and a casual account of behavior form the total system envisionment.

Constraint-based ontology: The basis of this approach is the QDE, which is an abstraction of the ordinary differential equation. This ontology is formalized to support prediction of behavior from qualitative constraint equations. Constraint-based model can be developed either by re-writing ordinary differential equations, or by creating QDE from system causal structure. The qualitative state of a variable can be a landmark value or the interval between landmark values and is specified by a pair denoted as <qval, qdir>, respectively the qualitative value of the variable and the direction of change. There are several types of constraints, such as arithmetic, derivative, monotonic (increasing, decreasing), etc. Example of arithmetic is add(x, y, z) which means x+y = z. Variation in flow rate can be modeled as derive(N_Flow_rate, n). This means derivative of N_Flow_rate is n. This follows by n = Source_temp-Destination_temp. By rewriting the relation as Source_temp = n+Destination_temp, it can then be represented as add(n, Destination_temp, Source_temp).

Process-based ontology (the QP theory): Main primitives of this process-based ontology are views and processes. An individual view is to describe both the contingent existence of objects and object properties that change drastically with time. While a process is described by five parts: individuals, preconditions, quantity conditions, relations and influences. The slot individual contains lists of objects or entities upon which the process is applicable. Preconditions contain statements referring to external conditions. Quantity conditions are statements about inequalities involving quantities of the objects, which can be used to determine whether or not a process is active. Relations are statements about relationships between variables. Two primitives that are very important in describing the relationships between quantities are the correspondences and qualitative proportionalities. Correspondences can be used in mapping values from the quantity space of one variable to values in the quantity space of another variable. In the process-based formalism dynamic aspects are expressed by the notion of direct influence. Direct influences can only appear in processes and are presented in the slot Influences. As an example, the flow_rate is related to source_temp and to destination_temp in the process called heat-flow, which can be expressed as: flow_rate=source_temp-destination_temp. In qualitative terms, it could be written as two proportionalities:

flow_rate α_Q+source_temp
flow_rate α_Q-destination_temp

To understand commonsense reasoning one must understand how to reason qualitatively about processes, namely, the kinds of changes that occur and their effects. QP theory, in this context serves as a language to write dynamical theories and it can explain its reasoning by examining the functional dependencies that established.

ARTICULATE SOFTWARE

Articulate software understands the domain being learned in human-like ways. CyclePad, for instance, which helps students learn by engaging them in conceptual design task and it has been used experimentally in a variety of institutions for both introductory and advanced courses. Qualitative representations in the system can provide useful reality checks even in highly quantitative tasks. Besides detecting physically inconsistent designs, qualitative descriptions of physical processes give ground for explanations. According to Forbus, smarter educational software must have a better conceptual match with people's mental models. Such software should satisfy the following properties:

- Fluent-it should have understanding of the subject being taught.
- Supportive-it should include a mentoring component consisting of coaches that scaffold students appropriately.
- Generative-learners and instructors should be able to pose new questions.
- Customizable-instructor should be able to update the software's libraries.

QALSIC is the other articulate software for learning inorganic chemistry at high school level[7,8]. The domain knowledge such as chemical facts (e.g. valence electrons for each atom, atomic number for elements in periodic table) and chemical theories are constructed using QP theory. An example of chemical theory is when there is an increase in concentration of S ion, there will be a decrease in dissociation rate of the compound containing S, expressed in QP theory as dissociation-rate α_Q-concentration-of (S). Reasoning is done by constructing the views structure and invoking the candidate processes. Along the reasoning route limit analysis is conducted. Limit analysis is the determination of changes in quantities that can result in the process and view structures themselves changing. As for the explanation it is generated based on chemical theories that represented using the primitives such as the direct and indirect influences.

Educational software using qualitative reasoning: Kuipers[5,9] developed the first qualitative simulation program called QSIM. Since then, many prototypes and systems were developed using qualitative reasoning for deducing conclusion (answering question, if you like). A summary of educational software include, but not limited to the following:

- High school level mathematics by Walther and Franz[10]
  A model-based reasoning framework for handling knowledge based. Generation of explanation is only possible in modeling phase.
- CPRODS by Julie-Ann[11]
  It consists of six qualitative and quantitative models.
- A cognitive tool called MMforTED by Elio[12]
  Implemented as a hypermedia, constituted by a collection of cases of simple electrical and fluid mechanical devices. Consists of graph of models
- HOMER by Vania and Bert[13]
  Graphical representation of concepts and their relationships. Causal model viewer included.
- Ecology simulation by Paulo *et al.*[14]
  Be able to predict and explain the behavior of physical systems in qualitative terms.
- CyclePad by Kenneth *et al.*[15]. AI technologies used are:
  Constraint propagation, Logic-based truth maintenance, Qualitative representations and Compositional modeling.
- GARP by Bert[16]
  Qualitative reasoning engine implemented in SWI-Prolog.
- VisiGarp by Bouwers and Bredeweg[17]
  VisiGarp implement a graphical interface to GARP. It allows users to inspect qualitative simulation models by interacting with automatically generated visualizations.
- Intelligent Tutoring Systems for Training by Vadillo and Diaz de Ilarraza[18]

Qualitative simulation based on components ontology and QP theory. Structured behavioral explanations can be generated based on a causal domain representation. A causal model is a representation of the causal effect relationships of a model of the domain.

- QALSIC by Pang *et al.*[7]

  An Intelligent Tutoring System for teaching inorganic chemistry for high school using QP theory approach.

FUTURE WORK

Numerous systems have been developed using qualitative reasoning technique. The future work of the group is to design a conceptual framework for Organic Reaction Mechanisms, a significant part of the synthesis process for organic compounds. The nature of the subject is highly qualitative and we believe that it can be expressed using process-based ontology for its reasoning and explanation.

CONCLUSIONS

Advances in AI, particularly in qualitative reasoning, provide the scientific foundation for the birth of articulate software. A study on qualitative reasoning and the prominent ontology has been presented. The qualitative description of physical processes underlying QR ontology provides grounds for generating causal explanation and cognitive diagnosis. We believe that educational software that employs proof-by-principle technique such as one that is inherent in qualitative reasoning model will develop into the next generation of Intelligent Tutoring System.

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