Book Reviews

Qualitative Process Theory Using Linguistic Variables

by Bruce D'Ambrosio
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Introduction

Probably, most of the readers of this Bulletin are quite familiar with Forbus's [2] *Qualitative process theory* which I'll refer to from now on as QPT. QPT is a popular, satisfactorily sound, and rather complete (do not read the last two words in the logical sense) theory for reasoning about the physical aspects of the daily world, viz. the enterprise of *qualitative reasoning*. (See [5] for an excellent recent review of qualitative reasoning.) The book under review is an attempt to fill in some gaps in QPT and render it more complete. And in this, it succeeds admirably.

Qualitative process theory

The book requires more than a superficial knowledge of QPT which I can't hope to present here. For that plus a wider framework to evaluate D'Ambrosio's work, the reader is referred to references [2]. Here, I give a very short introduction to QPT. Needless to say, D'Ambrosio regards QPT (and I concur with this view) as a powerful tool for reasoning about the control of complex engineered physical systems, especially when they are not properly understood or the feasibility of making observations of the systems is bleak. I would suggest at this point that the reader take a look at a non-technical article of Forbus treating precisely this issue [6].

QPT is essentially a *process-based* theory. Unlike *device-based* theories (of Johan de Kleer and John Seely Brown [7] process-based theories are more efficient in dynamical systems. The reason is that in a device-based theory every individual device component should be identified with all of its associated processes and all effects. This becomes troublesome as the number of processes increases. Equally important is the necessity of exact definitions for all interactions. Finally, a device-centered theory is not capable of representing causality, and the vanishing and creation of objects.

QPT is based on the idea that all state changes occur as a result of active processes. Therefore, the above limitations can be overridden by proper descriptions of the active processes. Of course, the notorious *frame problem* cannot be solved completely by simply identifying all possible processes. There may be all the necessary conditions for a process to take place but some other influence may cause some other process to start. This places a burden to state preconditions *ad infinitum*. A way out may be histories, invented by Patrick J. Hayes [2]. A *history* is a basic ontological primitive which is a piece of spacetime with natural boundaries, both temporal and spatial. In the older *situational calculus* - again due to Hayes and John McCarthy, cf. [2] - situations are used to model the world at different instants of time. Temporally each situation is an instant (but is spatially unbounded). By contrast, histories are descriptions of objects that are extended through time (but are always spatially bounded). Unfortunately, the generation and intersection of histories may be as difficult as the original frame problem. (After all, histories are 4-dimensional animals with funny surfaces!) Still QPT makes the assumption that for an interaction to occur there must be an intersection of histories.

In QPT, a process is described in five parts:

- Individuals: Objects participating in the process.
- Preconditions: Necessary conditions for the process to be possible.
- Quantity conditions: Desired quantities for the process.
- Relations: How the process variables are related with each other.
- Influences: What differs if a quantity is changed.

Reasoning in QPT involves four stages:

- Elaboration: Determination of all participants to meet the preconditions.
- Process and view structure: Determination of all possible process instances which are mutually consistent.
- Influence resolution: Determination of the direct and indirect effects of the process on the participants.
- Limit analysis: Predictions based on the determined influences.

Note, on the other hand, that the following ambiguities in QPT are problematic:

- QPT cannot resolve conflicting influences.
- QPT cannot order predicted results.
- QPT has no quantitative model of relations and time.

D'Ambrosio's contributions

In order to overcome these difficulties, D'Ambrosio develops a set of extensions to QPT. These extensions are built upon the notion of *linguistic variables* which represent uncertain or imprecise system-specific information [8]. It is useful to identify three components of the extension D'Ambrosio has developed:

- A *linguistic quantity space* represents partial information about quantity conditions and relate quantity orderings using linguistic descriptions of parameter magnitudes.
- *Linguistic functional strength* annotations are used by an extended inference resolution algorithm in order to resolve ambiguities.
- *Linguistic perturbation analysis* helps estimate the effects of hypothetical control actions.

When control applications are considered, *measurement interpretation* [4] becomes an important part of the theory. D'Ambrosio proposes that fuzzy control may be a good approach in problems for which the measurements have reasonable uncertainties. Here two things come into picture: *fuzzification* and *defuzzification* are defined as changing a measured value to a fuzzy value including uncertainty, and changing a fuzzy decision to a control action, respectively.

D'Ambrosio's approach to coupling symbolic and numeric computation for truth maintenance is through two technical devices: ATMS and SLP. Let's take a quick look at these.

ATMS (Assumption-based truth maintenance system) due to de Kleer is well-known. The idea is to make a proposition true using some assumptions and keep the assumptions with the proposition. Then propositions are propagated together with their assumptions. If, at any time, one of the assumption sets is realized as true, then the propositions having that assumption set are set to true. Then this also propagates. The fuzzy logic implementation of ATMS by D'Ambrosio is similar.

SLP (Support logic programming) is basically a method designed for fuzzy computations. In this system the truth value of a proposition is defined by two variables: S_l, the lower bound, and S_u, the upper bound of the fuzzy truth value. Propagations are made analogous to ATMS. In the same system, ATMS and SLP can be used in conjunction with each other and the truth value bounds are given by the conditional probabilities of the assumptions.

QPA (Qualitative perturbation analysis) is really an improvement to QPT in a theoretical sense. It starts from the classical method of small-signal analysis, develops a qualitative notion of it, and then extends the basic influence resolution algorithm of Forbus [2] to perform this analysis. QPT considers only the first derivative of a variable. In other words, it can decide that if something is zero and its derivative is zero, then it will be zero in the near future. However, QPA searches for the first non-zero derivative to make a decision about the near future. Consider a spring and a mass and assume $x = 0, v = 0, a = +$, i.e., x and its first derivative is zero at $t = t_0$. Then QPT needs more complex justifications to reach the conclusion that x will be $+$ for any $t > t_0$ whereas QPA can directly reach the conclusion.

A main premise of the work reported in this book is that problem solving in the domain of the control of complex engineered devices proceeds by an iterative process of constructing, applying, and "patching" models of the system under consideration. The following is a more detailed statement of this premise:

> *D'Ambrosio's Patching Paradigm:* Problem solving does not proceed by relying on a unique representation and manipulating it until a solution is found, but rather by selecting an initial representation, solving some problems with it, "patching" the representation in response to problems faced during this endeavor, and again continuing with problem solving. "Patches" are found on the basis of the problems encountered and the questions to be answered, and are obtained from sources of information external to the theory.

Some not-so-serious blemishes

It is difficult to grasp the underlying ideas in Chapter 2, the chapter on fuzzy logic control. This may be due to my lack of background in fuzzy logic or reflect my obtuseness. But, I insist that D'Ambrosio should at least provide a list of variables to clarify the formulas in pp. 9-13. I had much less trouble with the "program-like" declarative segments appearing in several places in the book. These, however, are not exactly the clearest programs that can be given. It wouldn't hurt to beautify them with more comments, and above all, to offer better motivation.

A few words on the style, readability, and appearance. I hate typos and I couldn't find many in this book. I think D'Ambrosio did a fine job in writing this book which was produced from camera-ready text prepared by the author using TEX. It includes many figures (for a book of its size) which are clear, informative, and nicely drawn. I observed that in various places the original figures were too big and caused some overflow. Although the references are informative enough, they are somewhat hastily prepared and omit pointers to the final versions of some papers. (For example, Forbus's seminal paper [2] is not cited. Instead, D'Ambrosio uses Forbus's 1984 MIT Ph.D. thesis. Similarly, Hayes's "Liquids" paper is cited as a memo; the reader is referred to the Weld and De Kleer collection [cf. References below] for an accessible version of that important paper.) As for the Index, I think it is fair to say that it is barely passable.

Verdict

This is a good, readable book which originated from the author's 1986 Berkeley Ph.D. thesis with the same title. I recommend it to specialists in the areas of qualitative reasoning, naive physics, and common sense reasoning. Engineers who are interested in fuzzy logic control techniques will also find a down-to-earth treatment here. Finally, process control researchers with no AI background may find in this book enough motivation and good examples to let them judge the contact points for cross-fertilization between two areas.

The following mini *Table of Contents* is provided to give an idea about where D'Ambrosio mostly spends his time:

References

[1] Brian Falkenheiner and Kenneth D. Forbus, "Setting up large-scale qualitative models," *Readings in Qualitative Reasoning About Physical Systems*, Daniel S. Weld and Johan de Kleer (eds.), Morgan Kaufmann, San Mateo, Calif., pp. 553-558 (1990). [Originally appeared in *Proc. of AAAI-88*, pp. 301-306.]

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[3] Kenneth D. Forbus, "The qualitative process engine," *Readings in Qualitative Reasoning About Physical Systems*, pp. 220-235.

[4] Kenneth D. Forbus, "Interpreting observations of physical systems," *Readings in Qualitative Reasoning About Physical Systems*, pp. 441-450. [Originally appeared in *IEEE Trans. on Systems, Man, and Cybernetics* **13**, pp. 350-359 (1987).]

[5] Kenneth D. Forbus, "Qualitative physics: Past, present, and future," *Readings in Qualitative Reasoning About Physical Systems*, pp. 11-39. [Originally appeared in *Exploring Artificial Intelligence*, Howard Shrobe (ed.), Morgan Kaufmann, pp. 239-296 (1988).]

[6] Kenneth D. Forbus, "Intelligent computer-aided engineering," *AI Mag.* **9**, pp. 23-36 (1988).

[7] Johan de Kleer and John Seely Brown, "A qualitative physics based on confluences," *Readings in Qualitative Reasoning About Physical Systems*, pp. 88–126. [Originally appeared in *Artif. Intel.* **24**, pp. 7–83 (1984).]

[8] Lotfi A. Zadeh, "The concept of a linguistic variable and its applications to approximate reasoning," Parts I and II: *Inf. Sci.* **8**, pp. 199–249 and pp. 301–357 (1975); Part III: *Inf. Sci.* **9**, pp. 43–80 (1975).

Semantic Foundations of Logic Volume 1: Propositional Logics

by Richard L. Epstein
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This is not your typical book on logic. The novel tone of this book is established by the author's desire for unity among the various logics which have been introduced to date. The basic questions addressed by this book are: "If logic is objective how come there are so many logics? Is there one right logic, or many right ones? Is there some underlying unity that connects them?" [Preface] In answering these questions it becomes apparent that a major preoccupation of the author lies with understanding and explaining the relationship between the truths of the logics, i.e. their theorems, and everyday reality and reasoning. In a nutshell the author develops and shares with the reader a process of abstraction from the natural language of everyday reasoning to a more formalized language of logic. This abstraction process is driven by the type of reasoning to be done. This basic process is responsible for the expanding collection of logics under study today. The author invites us to join him in exploring the underlying unity he is proposing as a basis for this abstraction process.

Chapter 1: The Basic Assumptions of Propositional Logic is used to establish and explain the author's basic vocabulary. In addition to providing definitions for terms like logic, sentence, and proposition the author briefly discusses two ideas which are central to his thinking and have greatly helped shape the material in this book.

The first has to do with the concepts of "abstraction" and "abstracting". The author is not a Platonist. He does not believe that the power of logic derives from the consideration of timeless and eternal truths which "abstractions" are. Rather he believes "... it is our common reasoning which comes first and that... proofs, to be convincing, must be shown to conform to that in their essentials. Confining logic to only the study of the 'timeless and eternal truths'... seems to me not only too restrictive, but a reversal of the proper development of logic." [p. 6] The author, however, does firmly believe in the process of abstracting from everyday experiences and objects to develop the ideal objects which will be the focus of a formal logic. Unlike the Platonists Epstein's starting point in the development and study of logics is the everyday reality and reasoning which the reasoner experiences and participates in.

The second of the two major ideas expressed by the author in this first chapter is the relative importance between form, i.e. syntax, and content, i.e. semantics. As might be expected from the title of this book the author emphasizes semantical considerations. This helps to differentiate this work from others which emphasize form "... as when logic is presented solely as a collection of forms of sentences which are acceptable and ways to syntactically manipulate them."

Both notions of "abstracting" and "semantics" play an indispensable part in the author's analysis and presentation of the selected logics in the rest of the book.

Chapter II: Classical Propositional Logic (PC) contains the author's presentation of this simplest of all logics (author's position). The material covered is typical of most treatments of propositional logic and is complete. The chapter includes a discussion of the role of mathematics in the study of logic and a mathematical formulation of PC is provided. The author's analyses in this chapter motivates the general framework for studying the semantic aspects of logic which he introduces in a later chapter (Chapter IV). In his concluding comments in this chapter the author briefly discusses some of the issues associated with considerations of the reasonableness and paradoxes of PC. In discussing the reasonableness aspect the author identifies a significant criterion that PC must be measured against. This criterion is: "Is it a reasonably accurate model of our pre-formal notions? Does it require us to give up a great deal of our intuitions about what's true, or what follows from what?" [p. 58] In the ensuing discussion of paradoxes he evaluates PC as failing to meet this significant criterion of reasonableness.

Chapter III: Relatedness Logic: The Subject Matter of a Proposition "S and R" in conjunction with the following Chapter IV forms the nucleus of this book. The material in this and the next chapter are original contributions by the author and his associates to the field of logic. This chapter introduces the concept of relatedness – the concept which ties the propositions of a logic with the real world as we experience it. The notion of relatedness as presented by the author is intuitively quite appealing. The author understands "... two propositions as being related if they share, either explicitly or implicitly, some common predication or both refer to some common object." [p. 64] The concept of relatedness is formalized as a relation and the properties of that relation are developed by the author in detail. To give you an example of the role that the relatedness concept plays in