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Functional Reasoning and Functional Modelling

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Guest Editors' Introduction

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A CAR THAT WILL NOT START on a cold winter day and one that will not start on a hot summer day usually indicate two very different situations. When pressed to explain the difference, we would give a winter account — "Oil is more viscous in cold conditions, and that causes ..." — and a summer story — "Vapor lock is a possibility in hot weather and is usually caused by ..." How do we build such explanations? One possibility is that understanding how the car works as a device gives us a basis for generating the explanations. But that raises another question, one that points to the key issue addressed in this *IEEE Expert* special track: How do people understand devices?

Model-based reasoning is a subfield of artificial intelligence focusing on device understanding issues. In any model-based-reasoning approach, the goal is to "model" a device in the world as a computer program. Unfortunately, "model" is a loaded term — different listeners understand the word to mean very different concepts. By extrapolation, "model-based reasoning" can suggest several different approaches, depending on the embedded meaning of "model."

One sense of the word "model" is illustrated by the law of gravitation, a mathematical relation representing abstractly the force of any two nonzero masses on each other. Another sense is illustrated by a model airplane, which has parts that directly correspond to parts of the "real thing" and that perform some of the same roles. Most researchers in model-based reasoning use the second sense of "model"; that is, they try to decompose a real-world device into its components, and to capture in some form within a computer program the device, its components, and the manner in which the components' actions give rise to the device's actions as a whole.

Model-based reasoning is one of the fastest growing subareas of AI, largely because it seeks to augment the more brittle, experienced-based reasoning typically found in expert systems. There are two variations of model-based reasoning that are involved in the larger goal of representing and reasoning about devices in the world. One well-studied branch has focused on ways in which behavior models are *derived*. The naive-physics work of deKleer, Forbus, Kuipers, and others exemplifies this research. The second branch has studied how behavior models are *used*, as exemplified by both circuit diagnosis work (by deKleer and Davis, for example) and function-based research (by Chandrasekaran, Franke, Sticklen, Abu-Hanna, and others).

Reasoning based on a device's functions and constituent components is an emerging line of research that shows promise in dealing successfully with some recalcitrant model-based-reasoning problems, the most severe being the computational complexity of using models once they are constructed. The functional approach considers how people deal with complex devices. If we have no familiarity with a device, we must expend considerable computational resources to "figure out" what the device does and what we might use it for. But if we have prior experience with a device — if we have already figured out what it does — then we will have an easier time both understanding the device and reasoning about how it will behave in a given circumstance.

The central tenant of the functional approach is that once we know the purpose (function) of a device and the functions of its constituent parts, we can then use that knowledge to organize our overall knowledge of the device. Moreover, for reasoning about the model — for doing, say, simulation, diagnosis, or design modification — the fact that knowledge about the device is organized decreases the computational load considerably.

This issue and several succeeding issues of *IEEE Expert* present several reports describing work in functional reasoning and

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functional modeling. Although the articles are based on diverse perspectives and problem domains, they show that there is an emerging cohesive viewpoint — the functional viewpoint — within which we can represent and reason about complex real-world devices. The functional viewpoint is relatively new, and these articles raise a number of research questions that, in the coming years, could yield robust tools for capturing knowledge and reasoning about complex devices in real-world situations.

Jon Sticklen is an assistant professor in the Department of Computer Science at Michigan State University, where he also serves as research director of the new Knowledge-Based Systems Laboratory. His research interests center on applying and extending the model-based reasoning methodology called functional reasoning, and his research domains include capturing design knowledge in aerospace, modeling landscape-level ecological systems, and modeling processes in composite-material fabrication.

Sticklen has written several articles on knowledge-based systems, including the theoretical and philosophical background, task-specific architectures, diagnostic reasoning systems, and model-based reasoning approaches. He has a BS degree with honors in physics from Ohio State University, an MS degree in astrophysics from Columbia University, and a PhD in computer science and artificial intelligence from Ohio State University.

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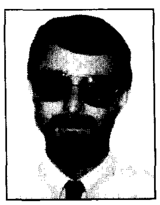


William E. Bond is a senior scientist with the Applied Mathematics and Computer Science Program at McDonnell Douglas Research Laboratories. His research focuses on developing and applying artificial-intelligence techniques of machine learning and model-based reasoning to problems in device simulation and diagnosis. Bond recevied his PhD from Rensselaer Polytechnic Institute.

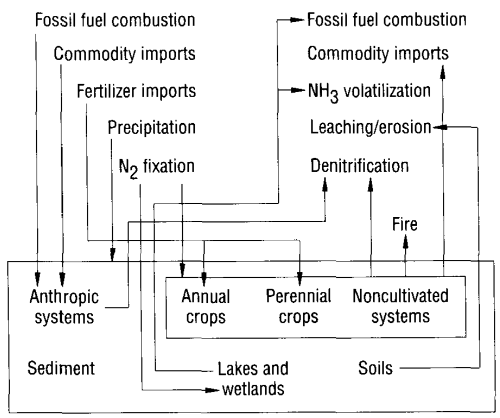
About the cover

The cover of this issue is a composite satellite view of the African continent and several more detailed views of West Africa. Functional reasoning has been applied to develop a qualitative model for West Africa's nitrogen cycle (detailed in Jon Sticklen and Rula Tufankji's "Utilizing a Functional Approach for Modeling Biological Systems," to appear in *Advances in Mathematics and Computers in Medicine*). Portions of the system appear below.

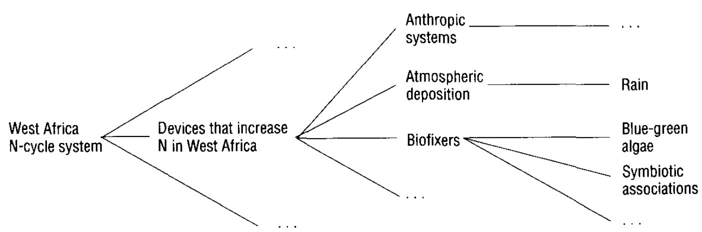
Very large grain ecological perspective is the focus of a relatively new field of biology known as landscape-level ecology. At the landscape level, all important organism interactions are studied simultaneously to ultimately arrive at a comprehensive understanding of the entire ecosystem.

Traditional ecological modeling techniques have two major limitations for use at the landscape level. First, even if the underlying science for the biological cycles is well understood, traditional techniques do not handle complexity well. Second, the underlying science is not always well understood, and current mathematical modeling techniques cannot easily incorporate concepts that are not well understood at all levels of detail.

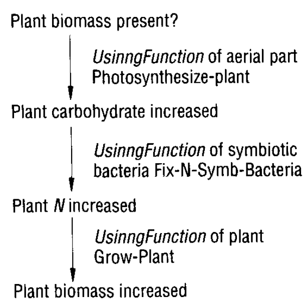
The working computer system built from the West Africa model was developed by the AI/KBS Laboratory at Michigan State University (eaded by Jon Sticklen) and biologists at the Kellogg Biological Station at Hickory Corners, Mich (led by G. Philip Robertson). Their collaboration now centers on developing function-based models to capture the ecological understanding needed to support sustainable agriculture.



Traditional flux model.



Device decomposition from a functional viewpoint (N is nitrogen).



Causal fragment for understanding how symbiotic associations of plants and bacteria operate.