Incorporating Cognitive Principles into Modeling Tools for Scientists

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Scientific Discovery

Understanding the mechanisms of scientific discovery holds enduring interest in cognitive science (Dunbar, 1999; Langley et al., 1987). Our work draws on that understanding to provide intelligent tools to aid scientists' discovery efforts. Furthermore, providing new tools to knowledge workers both transforms the supported activities and informs the process of iterative design. A key component of science is formulating quantitative models in terms of the underlying processes in a domain. Our test domain is ecosystem dynamics, in which processes such as predation, nutrient uptake, and death influence variables such as the abundance of different species. These variables influence later states of the system, as do other variables such as light or nutrient availability. Scientists in this domain develop models by specifying the components involved, the relationships among them, and the parameters that control their behavior.

PROMETHEUS and Modeling

PROMETHEUS (Bridewell et al., 2004) is distinctive because, like a scientist, it generates models with novel structures, letting the scientist concentrate on specifying the model search space while the program generates and tests candidates from this space. The system also simulates the models and assists in their evaluation.

We claim that a discovery tool should use representations tightly linked to those employed by scientists and that the methods of scientists should influence its discovery processes. To this end, PROMETHEUS represents models as variables, processes, and the influences among them, and it casts discovery as search through a space of differential equation models.

We asked three marine ecosystem researchers to revise and improve models of the Ross Sea ecosystem using PROMETHEUS. They were impressed with the system's ability to search the space of structurally different models.

Lessons Learned from PROMETHEUS

Both traditional differential equation modeling and PROMETHEUS's more structured formalism rely on variables and processes, but the two representations organize variables and processes differently. Having the system manipulate these two compatible representations provides a benefit, because each emphasizes different relationships. Differential equations relate variables in terms of material or energy flow, which highlights the variables and combines multiple processes affecting one variable. PROMETHEUS's formalism identifies individual processes and variables, which emphasizes the flow of information or influence.

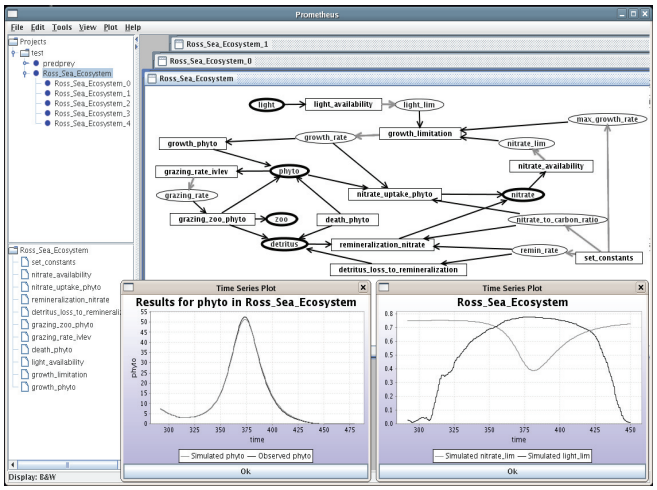

Figure 1: Model organization and value plots.

Moreover, scientists revise models by reasoning about data and parameters. Ecologists move in tightly coupled cycles among activities that vary in scope of task and information used. We learned that we must provide finer-grained control of model revision (e.g., letting individual parameters be fit as opposed to requiring a process level specification). We must support fluent switching among activities, such as adding new knowledge to the modeling library and editing data files. In addition, we identified other task needs, and we are revising Prometheus to close the product development lifecycle. Making these alterations should be simplified due to the apt representation choice.

Acknowledgments

NSF GrantNumber IIS-0326059 supported this research.

References

Bridewell, W., Sanchez, J.N., & Langley, P. (2004). An interactive environment for the modeling and discovery of scientific knowledge. Technical Report. ISLE, Palo Alto, CA.

Dunbar, K. (1999). How scientists build models: In vivo science as a window on the scientific mind. In L. Magnani et al. (Eds.), *Model-based reasoning in scientific discovery.* Plenum Press.

Langley, P., Simon, H.A., Bradshaw, G.L. & Żytkow, J.M. (1987). Scientific discovery: Computational explorations of the creative processes. MIT Press, Cambridge, MA.