Model-based Environmental Decision Support

- Extended Abstract -

Peter Struss

Comp. Sci. Dept., Tech. Univ. of Munich
Garching, Germany

struss@in.tum.de

1 The Problem

Today, politics, economy, and science are challenged by severe environmental problems, many of which have global origins and/or global impact. If we want to intervene in order to achieve certain goals – avoidance of environmental damage, sustainable development of resources, preservation of species – we rely on knowledge about the respective systems and the various relevant phenomena they comprise, both scientific knowledge and traditional knowledge and experience.

Good decisions require a deep understanding of the situation and the potential impact of human interventions. And they require solid reasoning about the available knowledge and information.

If we aim at supporting this task with computer programs, we need to apply techniques of knowledge representation and reasoning. We need models, models in a general sense (not simply mathematical simulation models): a formal representation of concepts and interdependencies that allow explaining what we observe and predicting future developments and the impact of interventions. And we need powerful inference mechanisms that process these models. We need Artificial Intelligence solutions.

2 The Solution Basis

Indeed, AI has delivered theories and systems facing this challenge, especially in research on qualitative modeling and model-based systems. The former work has developed formalisms for the kind of reductionist modeling we need, both for artifacts that are established by interconnected components and natural systems comprising different interacting processes (see [Forbus 84], [Heller-Struss 02], [Struss 08]). In this approach, process models describe configurations of objects or substances and elementary dynamic changes imposed on properties of the participating objects. Examples are a chemical reaction involving certain substances, heat transfer between objects, a prey-predator relation, or the impact of an increase in agricultural productivity on the income of small farms.

Turning the informal semantics of a process, namely that the effects will be established whenever the preconditions are satisfied, into logic, a process becomes an **implication**, i.e if the conditions are satisfied, the effects are also true:

$$\begin{aligned} &\text{StructuralConditions} \wedge \text{QuantityConditions} \\ \Rightarrow \quad &\text{StructuralEffects} \wedge \text{QuantityEffects}, \end{aligned}$$

where StructuralConditions and StructuralEffects are ExistenceAssignments, and QuantityConditions and QuantityEffects contain ValueAssignments. In addition, QuantityEffects contain influences. Influences capture the impact of a process on the dynamics of the systems, i.e. how quantities change, but, nevertheless, are beyond the expressiveness of differential equations.

Since the conceptual entities (objects and their relations, processes) are explicitly represented and subject to automated reasoning, process models are conceptual models. They are also compositional. Each process model explicitly states the preconditions for a certain effect to occur. Different process models can be combined and interact via their impact on quantities of the objects in the system. The effect of one process can trigger another process by establishing its preconditions, and it can destroy process preconditions, even of itself (evaporation may finally reduce the amount of liquid to zero).

The models developed in this field of AI satisfy the requirement for context independence also in a more specific sense, namely in refraining from implementing a particular computational direction and order, which may vary with the task, available data etc.

3 A Conceptualization and General Architecture of Intelligent Decision Support Systems

A survey of definitions or characterizations of decision support systems (DSS) and of proposals for general architectures or (sub-)functions of DSS delivers rather disappointing results. Many of the offered definitions boil down to “A DSS is a computer system (or set of tools) that supports making decisions”, which turns any data base, MATLAB, excel, even Google into a DSS. When architectures are proposed, they are often presented as a huge set of tools and computational steps embedded in a confusing web of interconnections, often heavily emphasizing data-driven techniques. The components are mainly characterized as various alternative or complementary techniques, rather than by the function they implement.

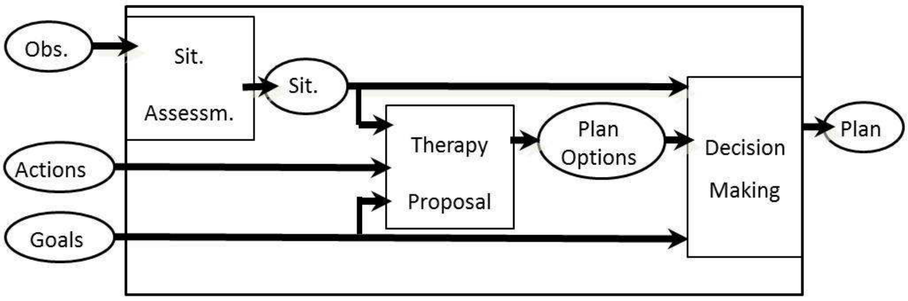
A systematic analysis and a conceptualization of DSS seem to be missing. This is not an academic question aiming at delivering a set of definitions. It is a practical necessity, if we are interested in the systematic re-use and integration of different tools and methods. And it is a prerequisite for establishing requirements on DSS and its components, especially when we want to build “intelligent DSS”.

We propose a conceptualization decision support and various generic subtasks and, based on this, develop a general architecture of intelligent decision support systems. This proposal (see [Struss 11]) is based on a small number of concepts: besides “decision”, the essential ones are “observation”, “situation”, and “goal”.

This is not an academic exercise aiming at providing definitions. The conceptualization is used as the basis for a decomposition of the task of decision support into subtasks whose input, output, and function is characterized. This is, in turn, a prerequisite for a generic architecture of decision support systems with interfaces for certain generic functions, the comparison of basic modules implementing these functions, and the configuration of systems from a set of such modules.

The high-level architecture and the relevant objects are displayed in **Fig. 1**.

Fig. 1. General Architecture of a DSS



Here, the primary subtasks, which are the knowledge-intensive ones, are

- **situation assessment**, which generates a situation description as a causal explanation of the initial observations entered to the system,
- **therapy proposal**, which seeks to select actions that promise to take the system from the assessed situation to a state that is consistent with the goals.

These primary subtasks are considered as instances of (automated) model building: situation assessment is solved by aggregating models from the model library that are consistent with the given observations, while therapy proposal means adding models of actions to the situation assessment such that the resulting moel is consistent with the goals.

Secondary subtasks require using these models for checking the consistency with goals, performing prediction, and model-based test generation. We also demonstrate that especially solutions to the primary tasks are far from being straightforward, but rather go beyond what can be formalized in classical logic and raise fundamental problems of reasoning about actions and time.

[Struss et al. 03] illustrates this approach using an example from the water treatment domain.

4 The Vision

What we are proposing is more than yet another application of the modeling technology developed in AI. Rather, it provides the starting point for a development that aims at a major qualitative step in the research on environmental problems and decision support. The grand vision is that research in relevant areas does no longer produce results only in terms of reports, scientific papers, and collections of empirical data. Instead, it produces models, more specifically model fragments as contributions to a large general library of phenomena that are relevant to a subset of environmental issues. This way, one cannot only read and understand the results obtained by other researchers (or from experience and traditional knowledge); these results are also incorporated in a set of new model fragments that are ready for being integrated in existing models, replacing refuted old models or establishing alternative hypotheses. The minute they are published this way, the results would immediately be available to other researchers, to enhancing existing models and also to checking their validity in a different context. Comparison of rivaling hypotheses would become much easier, because alternative models could easily be generated by replacing well-identified model fragments. Wouldn't this not only ease model building itself, but speed up scientific progress in the relevant disciplines?

5 References

[Forbus 84] K. Forbus: Qualitative Process Theory. *Artificial Intelligence* 24 (1-3), 1984

[Heller-Struss 02] U. Heller, P. Struss: Consistency-Based Problem Solving for Environmental Decision Support. In: Computer-Aided Civil and Infrastructure Engineering 17 (2002) 79-92. ISSN 1093-9687

[Struss 08] P. Struss: Model-based Problem Solving. In: van Harmelen, F., Lifschitz, V., and Porter, B. (eds.). Handbook of Knowledge Representation, Elsevier, 2008, ISBN-13: 978-0-444-52211-5, pp. 395-465

[Struss 11] P. Struss: A Conceptualization and General Architecture of Intelligent Decision Support Systems. In: Chan, F., Marinova, D. and Anderssen, R.S. (eds) MODSIM2011, 19th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2011, pp. 2282-2288. ISBN: 978-0-9872143-1-7.

[Struss et al. 03] P. Struss, M. Bendati, E. Lersch, W. Roque, P. Salles: Design of a Model-based Decision Support System for Water Treatment. In: Proceedings of the 18th International Joint Conference on Artificial Intelligence (IJCAI 03): Environmental Decision Support Systems, pages50-59, Acapulco, Mexico. August 10, 2003. ISBN 0127056602