Geophysical Research Abstracts
Vol. 18, EGU2016-13684-1, 2016
EGU General Assembly 2016

A Categorical Framework for Model Classification in the Geosciences

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Models have a mixed record of success in the geosciences. In meteorology, model development and implementation has been among the first and most successful examples of triggering computer technology in science. On the other hand, notorious problems such as the ‘equifinality issue’ in hydrology lead to a rather mixed reputation of models in other areas. The most successful models in geosciences are applications of dynamic systems theory to non-living systems or phenomena. Thus, we start from the hypothesis that the success of model applications relates to the influence of life on the phenomenon under study. We thus focus on the (formal) representation of life in models. The aim is to investigate whether disappointment in model performance is due to system properties such as heterogeneity and historicity of ecosystems, or rather reflects an abstraction and formalisation problem at a fundamental level.

As a formal framework for this investigation, we use category theory as applied in computer science to specify behaviour at an interface. Its methods have been developed for translating and comparing formal structures among different application areas and seems highly suited for a classification of the current “model zoo” in the geosciences. The approach is rather abstract, with a high degree of generality but a low level of expressibility. Here, category theory will be employed to check the consistency of assumptions about life in different models. It will be shown that it is sufficient to distinguish just four logical cases to check for consistency of model content. All four cases can be formalised as variants of coalgebra-algebra homomorphisms. It can be demonstrated that transitions between the four variants affect the relevant observations (time series or spatial maps), the formalisms used (equations, decision trees) and the test criteria of success (prediction, classification) of the resulting model types.

We will present examples from hydrology and ecology in which a transport problem is combined with the strategic behaviour of living agents. The living and the non-living aspects of the model belong to two different model types. If a model is built to combine strategic behaviour with the constraint of mass conservation, some critical assumptions appear as inevitable, or models may become logically inconsistent.

The categorical assessment and the examples demonstrate that many models at ecosystem level, where both living and non-living aspects inevitably meet, pose so far unsolved, fundamental problems. Today, these are often pragmatically resolved at the level of software engineering. Some suggestions will be given how model documentation and benchmarking may help clarifying and resolving some of these issues.