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A library of model fragments on sustainability

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This paper describes the implementation of a Library of model fragments that integrates different models and captures essential concepts for understanding sustainable development related issues, presented in meaningful ways as simulations (Salles and Bredeweg, 2007). Input models to the Library come from the NaturNet – Redime[1] Project case studies and from models about the Millennium Development Goals (Salles, 2005). As the Library includes a broad range of knowledge from different disciplines and a large number os scenarios and model fragments, it is necessary to create handles to explore the Library and to select clusters of concepts that may be used in curricula for learning about sustainability.

Literature on Qualitative Reasoning reports the use of *perspectives*, implemented by means of *modelling assumptions*, as a possible solution for this type of problem (Falkenhainer and Forbus, 1991). A perspective defines a subset of simulation models that can be created to achieve specific goals, that is, to answer questions of a particular type. From this point of view, perspectives serve an organizational function as they guide the modeller in selecting appropriate assumptions, structural relations and scenarios. Perspectives are therefore useful for defining and constraining a simulation, taking into consideration certain aspects of the encoded knowledge while ignoring the rest. When the model user selects a certain perspective, (s)he provides the context for exploring different parts of the library. Depending on which perspective is adopted, different entities, quantities, values, and causal relationships are included in the simulation.

Conceptually, modelling assumptions fall into two categories: simplifying and operating assumptions. *Simplifying assumptions* are used to make explicit how knowledge details such as the underlying perspective, approximations and level of granularity are represented in the model fragments. They provide the vocabulary to be used in the model, explicating what kinds of things exist and what sort of relationships can be held between them, and provides alternative representations for the same thing. *Operating assumptions* are used to manage complexity. In a way, they provide focus to the simulation, by constraining the model to describe relevant behaviour for answering specific questions. Typical operation assumptions include restrictions on quantity values implemented by means of inequalities between quantities and constants (e.g. *number_of* >0) and steady-state assumptions, that determines all derivatives for some class of parameters to have value zero.

Both the NaturNet – Redime case models and the Library were implemented in Garp3 (Bredeweg *et al*., 2006), using facilities for collaborative modelling, such as the sketch environment, and elements from the process-centred ontology (Forbus, 1984). Technically speaking, perspectives were implemented by explicitly representing assumptions and by using other modeling primitives, such as hierarchies of entities and model fragments, attributes, alternative quantity spaces for key quantities and alternative representations of key concepts.

[1] NaturNet-Redime, EU STREP, project number 004074. Available at www.naturnet.org.

The Library of model fragments comprises, in its current implementation, 112 entities, 1 attribute, 60 configurations, 201 quantities, 22 quantity spaces, 24 agents, 45 modelling assumptions, 202 simulation scenarios and 414 model fragments. So far, it is the biggest Qualitative Reasoning model of this kind. The Library can be explored in many ways. Two of them are discussed here: (a) by creating perspectives based in the input models, as they were presented, and (b) by creating thematic perspectives. Table 1 summarizes the perspectives created in this modelling effort.

Types of perspective	Perspectives
Case study-based	Natural ; Rural ; Semi-urban ; Urban ; Natural resources exploitation ; Natural environment rehabilitation ; Social
Thematic based	(I) Natural systems; (II) Natural disasters; (III) Human explores natural resources; (IV) Environmental effects of human activities (in interaction with natural factors); (V) Energy; (VI) Economy; (VII) Education and trainning; (VIII) Science and Technology; (IX) Legislation; (X) Stakeholder participation; (XI) Governmental plans and activities; (XII) Management actions for sustainability; (XIII) Human health; (XIV) Human well being

Table 1. Perspectives created for the Library of model fragments on sustainability.

Case-study based perspectives: Taking the case study models, seven high level perspectives to approach sustainability issues were developed, described as follows (between square brackets, the input model): (a) *Natural*: Basic case models exploring nutrient cycling, food webs, agriculture and industrial pollution, dissolved oxygen in water bodies [*Danube Delta (Dd), River Mesta (Rm)*]; (b) *Rural*: Model exploring deforestation and erosion, soil fertility, water resources, biodiversity and agricultural (crops and cattle) activities [*Rural Riacho Fundo (Rfru)*]; (c) *Semi-urban*: Model exploring urbanization, including soil erosion and the degradation of springs and streams, infiltration and underground water, and water resources in industrial activities (textile and food industries) [*Semi-urban Riacho Fundo (Rfsu*)]; (d) *Urban*: Model compares the urban situation in absence and in presence of an engineered drainage system with respect to the main consequences: floods, economic damage, transported garbage, water related diseases and the human well being [*Urban Riacho Fundo (Rfur*)]; (e) *Natural resources exploitation*: Water abstraction model explores the effects of water abstraction to produce energy on the amount of water, on fish populations; Deforestation model presents the effects of deforestation on the use of biodiversity, erosion and water resources; Global warming model presents the effects of pollution caused by petroleum and solid fuels burning on human health and global warming [*Water abstraction (Aw), Deforestation (D), Global warming (Gw*)]; (f) *Natural environment rehabilitation*: This model explores the dynamics of fish populations and the benefits from improving natural habitats and stocking [*Salmon and Bream (Uk)];* (g) *Social*: This model explores a number aspects related to stakeholder participation in the decision-making process, including legislation, governmental actions, sustainability plans, education and technological solutions [*Stakeholder participation (Sp*)].

Thematic-based perspectives: A thematic-based approach to the Library exploitation was created in order to expand the options available to the users. It is very likely that the users have problems to solve, and the case studies may address only part of these problems. Following this intuition, 14 perspectives were created to address a number of classes of problems. When more than one simulation has to do with the theme, the user would be advised to search, in different input models, the simulations that are associated to the theme by the modellers (Table1). Apparently this is a good option, because this approach favours the integration of knowledge about sustainability. For example, the perspective (I) *Natural systems*, addresses topics such as rivers; vegetation; macrophytes; blue green algae; diatoms; phyto and zooplankton; animals; population growth; biodiversity; food webs; soil integrity; fertility; and nutrients. Simulations, in this case, come from the models [*Dd, Rm, Rfru, Sp, Uk*]. Another interesting example is the perspective (VI) *Economy*: Mechanisms involving resources offer and consumption, production rate, products, residues and jobs in the three sectors (agriculture, industry and services) of economic activities; different types of resources used in

economic activities; different types of residues and pollutants produced by economic activity; (un)balanced proportions of products and residues; influences on GDP of technological innovation exploring biodiversity, uses of water resources and agriculture. The simulations concerning this perspective come from the models [*E, Dd, D, Rfru, Rfsu, Rfur*]. The interested reader can find details of these 21 perspectives and the simulations included in each group in the Deliverable D6.7.1 (Salles and Bredeweg, 2007), available in the NaturNet – Redime portal (www.naturnet.org).

The use of assumptions for reasoning with multiple models has a long tradition in Qualitative Reasoning. Most of the work on this topic focus on algorithms for automatically selecting or changing models according to certain assumptions. Differently from these previous approaches, the work described here uses no numerical information or mathematical functions to define perspectives or to implement assumptions. Using only qualitative representations of concepts, Garp3's representational apparatus creates alternative models according to the perspective taken. The first element used to create a simulation model are the entities. Increasing levels of complexity can be further obtained by means of the inclusion of new entities in the system structure. In fact, control over entities and quantities is a quite effective use of simplifying assumptions to implement perpectives. Considering that each entity is associated to a number of quantities, quantity spaces, qualitative values and qualitative states of the entity, the choice of entities and the associated elements define specific vocabulary for a certain perspective. For example, entities 'Crop', 'Cattle', 'Garage', 'Food industry' and 'Textile industry' introduce vocabulary to describe the type of residues that make economic activities unustainable (pesticides, manure, oil, organic matter and chemical pollutants, respectively). In many situations, alternative representations of the same phenomenum provide different levels of details to simulations (for example, erosion is more detailed in *Semi-urban* than in *Rural* perspective). Operating assumptions reduce complexity and give focus to the simulations. For example, correspondences between quantity magnitudes and derivatives were largely used in all the perspectives. Also, steady state conditions are useful to isolate certain parts of the causal model and, as such, to reduce the size of the simulations. Focus was provided by different means. For example, soil fertility can be determined in three ways: (a) by assuming that the quantity *Fertility* values correspond to *Nutrient* values; (b) by considering that vegetation cover determines the amount of organic matter, and calculating *Fertility* = *Organic matter* + *Nutrient*; and (c) by considering the combination of nutrients and manure, a by-product of livestock. This way, different causal chains can be constructed within the *Rural* perspective, focussing on different aspects of agriculture.

The Library provides a broad coverage to sustainability aspects. From the technical point of view, a perspective-taken approach seems to be effective to organize knowledge and simulations about sustainability. The use of assumptions was essential to integrate independent models. All in all, the Library is a good outcome of NaturNet-Redime. However, this work can be improved in many ways. Ongoing work focus on the optimization of model fragments and entities hierarchies, and in the integration of perspectives, so that new simulations may become possible. A point to be addressed in the future is shifting from one perspective to another. Identifying the requirements for such transitions will lead to better understand the nature of perspective-taking in qualitative reasoning. Concluding, the Library now can be used in the development of curricula about sustainability and, therefore, to meet one of the most relevant goals of NaturNet-Redime, to support stakeholders in finding means to make their activities more sustainable.

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