Qualitative Models in Ecology and their Use in Intelligent Tutoring Systems

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Abstract

We are exploring different approaches to model qualitatively the vegetation dynamics of Brazilian cerrado, in order to assess their suitability to provide the domain-specific knowledge in tutoring systems. Two formalisms, the System of Interpretation of Measurements, Analysis and Observations (SIMAO) and the Qualitative Process Theory (QPT), are compared here in two aspects: capacity for making predictions about the behaviour of a plant population, and the generation of explanations from encoded knowledge. Both SIMAO and QPT-based models can produce similar predictions to those obtained with a numerical model of the same problem. SIMAO provides a useful qualitative algebra to make calculations with heterogeneous variables. However it is not possible to incorporate descriptions of the ecological components nor do dynamic simulations with the SIMAO-based model. On the other hand, QPT allows the encoding of qualitative knowledge and building more detailed models, but does not provide a qualitative algebra for combining empirical values of variables. Both SIMAO and QPT permit the generation of system-based explanations, whereas QPT might be more recommended to generate domain-based explanations. We also discuss the role of different organisational levels and scales of space and time in explaining the behaviour of ecological systems. A combined approach could be advantageous in building tutoring systems.

1. Motivation

Ecological modelling has been mostly based on mathematical models. Although useful when quantitative data are available and precision is required, this kind of approach is not adequate for representing qualitative and incomplete knowledge about ecosystems. It is also poorly-suited for teaching basic ecological principles: they are difficult to understand, and they lack explicit causal relations among variables.

Several approaches have been proposed for modelling and simulation with qualitative knowledge in Qualitative Reasoning (QR) (see Weld & de Kleer 1990). Some have been applied in building tools to predict the behaviour of ecological systems. They have been used, for example, in management of hydroecological systems (Guerrin 1991; Heller et al. 1995), modelling an irrigated crop system (Plant & Loomis 1991), modelling the photosynthesis process (Hunt & Cooke 1994), and applying ecological concepts to social sciences (Kamps & Péli 1995).

Our goal is to model the effects of fire on vegetation dynamics for educational purposes. Initially we are investigating the suitability of QR techniques in producing models that can represent domain specific knowledge in tutoring systems. The work reported here presents a case study in which two different QR approaches were used in modelling the same ecological problem: the System of Interpretation of Measurements, Analyses and Observations (SIMAO) (Guerrin 1991; 1992), and the Qualitative Process Theory (QPT) (Forbus 1984). The objective was to explore their potential to represent entities and relationships, make predictions and then generate explanations about the behaviour of a plant population. These approaches were chosen because SIMAO was developed in an ecological context, whereas QPT, among other traditional ontologies such as the component centred approach (de Kleer & Brown 1984) and the constraint centred approach (Kuipers 1986), is more adequate for representing declarative qualitative knowledge (Salles et al. 1996).

We will present our results in the following way: in Section 2 some characteristics of the ecosystem to be modelled, the Brazilian cerrado, are discussed. A problem is defined and represented as a System Dynamics numerical model, which will be compared to the qualitative models. The following two Sections contain details of qualitative models for the same problem, built according to SIMAO (Section 3) and QPT (Section 4). Results obtained with them are compared to those obtained in the numerical

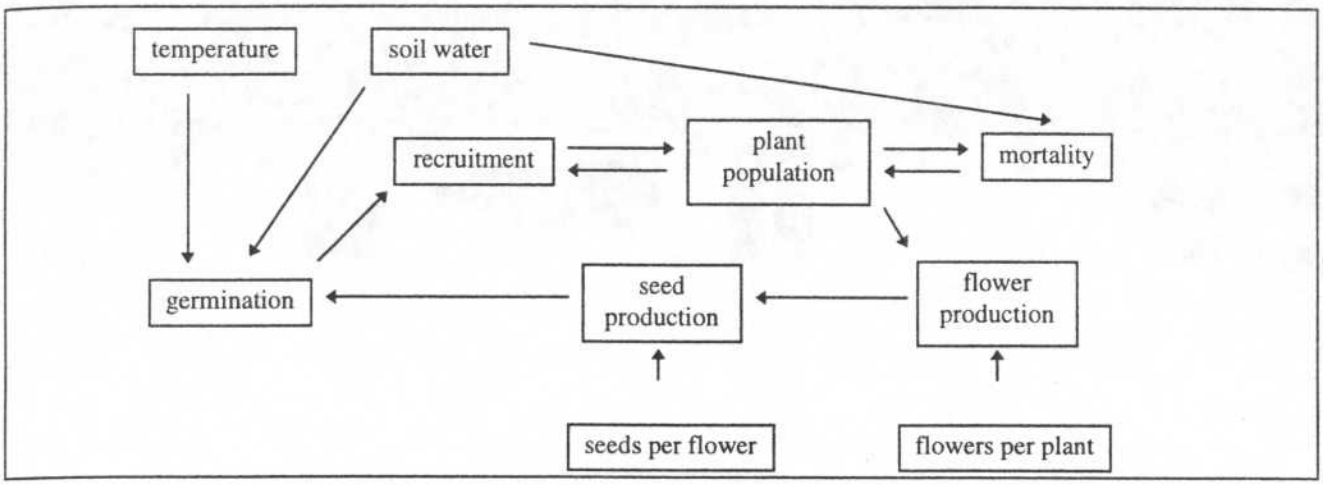

Figure 1. Influence diagram representing some factors that can affect the number of individuals in a plant population.

simulation in Section 5. The possibility of generating explanations from these qualitative models will be discussed in Section 6 and finally, in Section 7 we present our conclusions and possibilities of future work.

2. Describing a problem as a numerical model

Cerrado is a kind of savanna that covers about 2 million square kilometres in the central region of Brazil, where the climate is tropical, with a well marked dry season between May and September, and a wet season between October and April. This vegetation holds great biological diversity and can occur in many naturally well defined groups of plants, with a characteristic floristic composition (physiognomy), located at specific habitats (Eiten 1982). These physiognomies span from open fields to more or less closed forests. Fire frequency and intensity and some edaphic factors, such as the soil fertility and the amount of available soil water in the dry season, determine the type of vegetation in a given place. For example, if an area is protected against fire for a long time, and its soil is rich and deep, an open vegetation can change toward a forest.

Fire affects both the environment and the biological community in cerrado ecosystems in many different ways (Coutinho 1990; Frost & Robertson 1987). It reduces plant biomass and litter, alters energy, nutrient and water fluxes between soil, plants and atmosphere, changes availability and use of resources, and alters competition and other relationships between organisms. On the other hand, fire stimulates flowering and seed germination in some species, and can be used as a management tool.

Cerrado is nowadays under great pressure due to farming and human occupation. As we believe that any strategy for conservation involves education, our purpose is to build an Intelligent Tutoring System (ITS) to help teachers in communicating ecological knowledge about the cerrado. We found several elements that justify the development of an ITS for use in undergraduate courses in Brazilian universities. There are many students coupled with few instructors. Also, equipment for field work is expensive and most of the time it is not available. We believe that an ITS can supplement field work and even replace it in some situations, because experimentation with real systems is rarely possible.

The problem we choose to model for the present study can be illustrated by the following description: consider a scenario in which there is a large number of plants, the area has been burned recently, temperature is hot and soil is very dry. With these conditions, many biological processes can be inhibited, as for example, flowering, seed production and germination. Consequently, few flowers will be produced, there will be few seeds and many of them will fail to germinate. At the same time, some plants are going to die. Since changes in population size depend on the survival of young plants (recruitment) and mortality, intuitively we can say that in the described situation the population growth will be negative and the number of plants in the next time unit might be smaller. The set of relationships that we are trying to represent is described in the influence diagram showed in Fig.1.

System Dynamics (Forrester 1961) is probably the most used approach in ecological modelling. In this framework, a model consists of compartments and flows described through a set of differential equations. A model for the diagram in Fig.1 consists of one state variable (number of plants), three intermediate variables (number of flowers, number of seeds, number of germinated seeds), four parameters (average number of flower per plant, average number of seed per flower, soil condition and temperature), and two flows (recruitment of plants and mortality). To

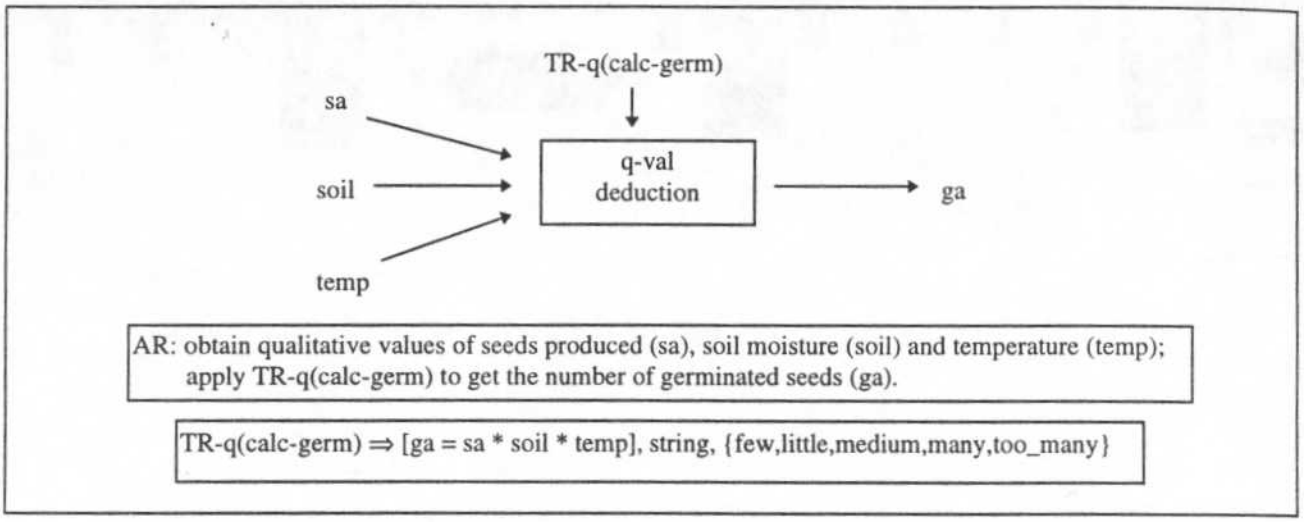

Figure 2. Knowledge Unit used to summarise inputs and procedures needed to calculate the number of germinated seeds.

implement this model we used FloMo, software developed by Robert Muetzelfeldt at the University of Edinburgh for educational purposes, in which the student can create his/her model and run numerical simulations without entering any differential equation. The results obtained with this model covering a wide range of situations will be compared with the outputs from qualitative models in Section 5. These qualitative models were implemented in Prolog and are described in (Salles 1994; 1995).

3. Modelling within the SIMAO framework

3. 1 The SIMAO formalism

The SIMAO formalism was developed by F. Guerrin (1991;1992) as a tool for the interpretation of measurements, analysis and observations commonly used in management of aquatic ecosystems. Here 'interpretation' means the ability to deduce, from a subset of input values, qualitative values of as many unknown variables as possible, and then to explain the reasoning process to give the user an overall comprehension of the phenomena (Guerrin 1992).

To encode expert knowledge, two main kinds of rules are used: *Transfer Rules* and *Action Rules*. Transfer Rules correspond to the representation of causal influences in the system, and three types are recognised: translation rules of measurements, translation rules of observations and calculation rules. Action Rules are used to control the application of the Transfer Rules. A qualitative algebra was empirically developed, based on three unary operators (increase, decrease, inverse) and three internal laws (addition, subtraction and multiplication), for combining influences between variables. These laws have some minimal properties (commutative, associative, distributive) required for calculus, as explained in (Guerrin 1992). All the statements needed to determine the value for a given variable constitute a *Knowledge Unit*. Knowledge units can be represented diagrammatically to show how input values (measurements, observations or other qualitative variables) are combined, how specific Transfer Rules and Action Rules are to be applied, and the expected output.

The SIMAO formalism was used originally in the domain of hydroecology, to make predictions about the parameters used in the management of fishponds. A subsequent application of SIMAO in controlling variables in a fermentation process is described in (Guerrin et al. 1994). However, it has never been used for educational purposes.

3.2 Developing a model and running simulations

To represent the number of plants, flowers, seeds, germinated seeds and dead plants, we used a Quantity Space (QS) with five symbols {*pp, p, m, f, ff*}, corresponding respectively to values {*very_few, few, medium, many, too_many*}. The same symbols were used to represent the qualitative values of soil moisture ({*very_dry, dry, medium, wet, very_wet*}) and temperature ({*very_cold, cold, mild, hot, very_hot*}). Two parameters were used to characterise the average number of flowers produced per plant and the average number of seeds produced per flower. For them, the QS was {*few, medium, high*}. Finally, a QS was defined to represent tendencies in population growth: {*decrease, stabilise, increase*}.

The model contains 10 Knowledge Units: one of them is presented in Fig. 2. Here, in order to calculate the number of germinated seeds, values for number of produced seeds, soil condition and temperature are required. An Action Rule (AR) explains the procedure and the specific Transfer Rule (TR) used is detailed. Inside the round brackets of TR

there is information about how to combine the inputs to get the output, the nature of input values (number, string) and the QS for that variable.

The system first creates a list of the variables for which qualitative values can be calculated, and the user can either choose to calculate values for all or one of them. Depending on the selection, some particular inputs are needed, and the user is asked to introduce them. These values are asserted to the database and used to calculate the output variable(s). The system presents the results in an easily-understood language. The following dialogue (Fig. 3) shows a simulation in which it calculates the number of germinated seeds, using as input information about the number of plants, their ability to produce flowers and seeds, and conditions of soil and temperature.

```
Which variable from the menu do you want to calculate?
>> Germinated seeds

Please, enter the values of...
[number of plants, flowers per plant, seeds per flower,
soil condition, temperature]:

>> [few, medium, high, dry, cold]

The value of germinated seeds is medium,
which is calculated from:
   number of plants = few
   average number of flowers per plant = medium
   number of flowers = medium
   average number of seeds per flower = high
   number of seeds = too_many
   soil_condition = dry
   temperature = cold
yes
```

Figure 3. Simulation with the SIMAO-based model. Parts of the dialogue in which the user introduces information are presented here in bold preceded by the mark " >> ".

3.3 Some comments about the SIMAO-based model

Guerrin points out that SIMAO enables the processing of heterogeneous values: it is possible to combine variables that are not related in physical laws, but that are *de facto* associated in expert reasoning, such as colour of the water and production of oxygen (Guerrin 1991). This is an important issue in ecological modelling, because experts often combine several different variables that could not be fitted into mathematical equations. In our model, for instance, the general appearance of the soil condition (dry, wet) was related to germination and mortality in an easy and efficient way.

However, SIMAO does not provide tools for representing the system's temporal evolution, and therefore only allows static simulations. Although it is possible to explore many different and important aspects of the ecological knowledge using static simulations, this is a limitation in modelling changes observed on the vegetation dynamics, as in the present case. Nevertheless we should note that in actual ecosystems there are many different phenomena occurring at different time scales. Therefore, it is a hard task to deal with time dependent variation in both qualitative and quantitative ecological models.

Causality is expressed in SIMAO by causal graphs. It is therefore easy to follow the steps needed to calculate the value of a variable, and explanation can be given by tracing the calculations. A limitation of SIMAO in building educational tools is the impossibility of representing declarative qualitative information, for example describing the conditions for a seed to be considered mature, with its primitives. Considering the importance of this kind of knowledge in ecology, it is difficult to build more detailed models and to generate explanation for a student with this formalism, a point which will be discussed below.

4. Modelling within the QPT framework

4.1 Development of a model according to QPT

According to QPT, the world can be modelled as a set of *objects*, and things that cause changes in objects over time are intuitively characterised as *processes*. Processes affect objects in different ways, and many of these effects can be modelled by changing some properties of the objects (Forbus 1984). An object named *Plant*, that corresponds to the actual population of plants, is the main object in our model. *Plant* is classified as a composite object, because it can be decomposed into smaller parts, such as *Flower* and *Seed*. These also are considered as the collection of flowers and seeds produced by the population. The processes identified in the influence diagram presented in Fig. 1 are *Flowering*, *Seed_production*, *Germination*, *Recruitment*, *Mortality* and *Population-growth*. Each of these processes can be described according to the template used by (Forbus 1984).

As an example we will describe the process *Germination*. It occurs when the environmental conditions are favourable, and results in young plants (seedlings) being produced. The rate of production of seedlings is influenced by the number of seeds, temperature and soil condition. The number of plants is expected to increase while the number of seeds decreases, and these are the changes caused by process *Germination*. In QPT, this information is specified in five slots, as follows: a) *Individuals* contains lists of objects or entities upon which the process is applicable, such as *Plant* and *Seed*. b) *Preconditions* contains statements referring to external conditions unaffected by the process. For example,

Germination requires the presence of a trigger, that is, something that starts germination, such as light, fire or a chemical factor. c) *Quantity Conditions* are statements about inequalities involving quantities of the objects that affect and are affected by the process. For instance, the number of mature seeds must be greater than zero for process *Germination* to occur. d) *Relations* include statements about relationships between variables that hold when the process is active, such as descriptions of new entities created by the process, and indirect influences between quantities induced by the process. In *Germination* a new quantity is created, *germination_rate*, and it cannot be negative. These influences are represented by *qualitative proportionalities* (α_Q). It is possible to distinguish positive and negative indirect influences (α_{Q+} and α_{Q-}). e) *Influences* contains statements that specify what can cause a quantity to change, through direct influence imposed by the process. For example, *germination_rate* is a direct and negative influence (I −) on the number of seeds, and a direct and positive influence (I +) on the number of plants. The set of slots used to describe process *Germination* is presented in Fig. 4.

Individuals:	*Plant* a composite object
	Seed part of a composite object (*Plant*)
Preconditions:	favourable (environmental conditions)
	presence of some trigger and water
Quantity Conditions:	[number_of (*Seed*)] > zero
Relations :	Let germination-rate be a quantity,
	¬ [germination_rate] < zero,
	[germination_rate] α_{Q+} [number_of (*Seed*)]
	[germination_rate] α_{Q+} [temperature]
	[germination_rate] α_{Q+} [soil_condition]
Influences:	I+([number_of (*Plant*)] , [germination_rate])
	I– ([number_of (*Seed*)] , [germination_rate])

Figure 4. Description of process *Germination* using the QPT primitives.

Qualitative proportionalities are used to describe how a certain quantity will change in its dependency on another quantity. Even without knowing the actual function relating them, it is possible to use these primitives to establish *correspondences* between values on the QS of both quantities. We used the qualitative calculus applied in the SIMAO-based model (cf. Section 3.2) to build these correspondences.

The collection of qualitative proportionalities is loop-free, that is, if A α_Q B, then it cannot be the case that B α_Q A. However, it is possible to model systems in which two variables are interdependent, such as feedback systems, by means of combining direct and indirect influences. This interaction, which is a general mechanism for controlling biological and ecological systems, can be represented as A α_Q B and I (B,A). For example, the rate of germination influences and is influenced by the number of seeds:

[germination_rate] α_{Q+} [number_of (*Seed*)]
I– ([number_of (*Seed*)] , [germination_rate])

Qualitative proportionalities and Influences are powerful primitives to be used in ecological modelling in building chains of causality. For example, what can cause an increase in the number of plants? There is a direct influence from germination rate. However, germination rate is influenced by the number of seeds, which is in turn influenced by *seed_production_rate*, a quantity created in process *Seed_production*. This last rate is influenced by the number of flowers and therefore depends on process *Flowering*. As we can see, this chain can be recursively expanded to include other environmental factors until the most important causal relationships acting on the number of plants are established:

I+ ([number_of (*Plant*)] , [germination_rate]
[germination-rate] α_{Q+} [number_of (*Seed*)]
I+ ([number_of (*Seed*)] , [seed_production_rate])
[seed_production_rate] α_{Q+} [number_of (*Flower*)]
I+ ([number_of (*Flower*)] , [flowering_rate])
(...)

In QPT, *Histories* are used to represent how things change through time. Although in our model there is a sequence of processes, each depending on the predecessor, which actually is a history, we did not fully explore this concept. We restricted ourselves to considering the simulation of population growth over just one time unit.

4.3 Some comments about the QPT-based model

We agree with Forbus (1993a) in that the notion of process seems natural in organising ecological knowledge, because processes play a central role in the way experts think about ecological systems. Also the possibility of expressing causality even in feedback loops with the basic elements of QPT makes it easy to generate explanations about the system's behaviour: any change must be explainable by the direct or indirect effect of a process. For example, we could combine factors as different as flowering, seed production and germination in a chain of causality, without knowing the actual functions that would relate them. This is particularly important in a tutoring system for ecological domains, in which having only partial knowledge about ecosystems is a quite common situation.

Applications of QPT so far rely on the understanding of physical laws and their mathematical expression involved on physical and engineering systems (e.g. Forbus 1984; 1993b). These laws are used to specify criteria to select values in composing each variable's Quantity Space, expressed as the *relevance principle* by Forbus (1984), and in combining values of different variables. However ecological models often include several variables, some

with a wide range of possible and relevant values. Considering that there is no equivalent knowledge about ecological laws and mathematical formalisations to combine these heterogeneous variables, we adopted the qualitative algebra developed in SIMAO and later expanded as a Dualistic Algebra (Guerrin, 1995) to implement our QPT-based system. Predictably, this decision increased the similarity of the output from both qualitative models during simulation, as shown in the following Section.

5. Comparison between qualitative and quantitative models

In order to evaluate predictions made from the qualitative models, they were compared to the numerical output from the System Dynamics model. We assumed that there is a correspondence between the ranges of numerical values and the qualitative values included on the Quantity Spaces (cf. Section 3.2). For instance, if a state variable or an intermediate variable can assume values on the range 1 - 100, then we can divide it in five intervals, and relate them to qualitative values. Therefore the interval between 1 - 19 corresponds to *very_few*, 20 - 39 corresponds to *few*, and so on. We made some simulations using the intervals 1 - 1,000 and 1 - 10,000 and we obtained similar results.

We have also used in our models two different classes of parameters, one to represent the influences of temperature (*temp)* and soil condition (*soil)*, and the other to represent intrinsic biological factors related to the production of flower and seed (*typef* and *types)*. For *soil* and *temp*, an arbitrary numerical interval between 0.1 - 0.9 was associated with the qualitative values. For *typef* and *types*, each qualitative value was associated with a multiplication factor ranging from 1 - 3. As we did with the qualitative models, the System Dynamics model was used to run simulations over just one time unit. Therefore, given the initial number of plants and some other input values, the system calculated the number of plants on the next time unit.

Outputs from the three models were quite similar. Taking a sample of 45 simulations covering the whole range of qualitative values and relevant combinations of variables, in 33 cases the numerical value matched the qualitative value obtained from the qualitative models. In 8 simulations calculated numerical values were very close to qualitative ones (less than 10% above or below the limits for the corresponding qualitative interval). Finally, only 4 simulations produced different results in quantitative and qualitative models, that is, with differences greater than 10%. In all of them, the multiplication factor used to represent the average number of flowers per plant or seeds per flower was the main reason for the discrepancy. These results confirm our view that, in this context, and over a projection period of just one time unit, predictions derived from qualitative models are good approximations to those produced in quantitative simulations.

6. Generating explanations from qualitative models

According to Valley (1992), there are two types of explanation: system-based and domain-based explanations. The former describe what has happened during a consultation, for example, which rules have been fired and which facts have been deduced. To generate this kind of explanation, a trace of the consultation must be kept: this can be retrieved, translated and then presented to the user. Domain-based explanations contain information about the domain knowledge, and justify system-based explanations. Therefore, the system can explain not only the steps it takes during the reasoning process, but also the reasons for following these steps. This kind of explanation requires an explicit representation of the domain knowledge.

The explanatory capability of a SIMAO-based system is the ability to produce a transcript, at any time, of the execution trace of predictive reasoning inferences (Guerrin 1991). Accordingly, we could generate explanations where the calculated value of a variable is linked to the set of input values used during the calculation process. The dialogue showed in Fig. 3 illustrates this kind of system-based explanation. As the SIMAO formalism does not provide other primitives to encode related qualitative knowledge, it was not possible to generate domain-based explanations.

Similar system-based explanations can be produced from the QPT-based model. However, QPT allows a more complete representation of objects and processes, using frame-like slots to model individuals, conditions, relations and influences. Thus it was not difficult to generate a wider range of explanations within this framework. Some basic questions can be answered directly from the knowledge encoded with QPT primitives, such as: a) when does a process occur? b) what are the conditions for a process to happen? c) what are the changes caused by a process? d) what are direct and indirect influences causing on these changes? More explanations can be generated by using templates. The user is presented with a menu of questions the system can respond to, and then fills in the blanks specifying the explanation required. These explanations might draw on explicit, default and derived knowledge. Figure 5 shows some examples.

To understand and explain the behaviour of ecological systems we have to consider the different organisational levels at which biological systems can be studied. There is a hierarchy spanning from the sub-cellular level up to the biosphere, as follows: {subcell, cell, tissue, organ, individual, population, community, ecosystem, biosphere}.

```
>> what_change_cause(germination)
germination causes changes in
number_of(plant)

>> (why) germination_rate  indirectly_influenced_by
          number_of(flower)
(The user enters a question using a template)

germination_rate  indirectly_influenced_by
number_of(flower)
 because
   the property is derived for germination_rate
yes
```

Figure 5. Explanations in the QPT-based model.

```
:- ask_explanation(germination_rate_is_high)
germination_rate_is_high because
activity_of_enzimes_is_maxima and
 number_of_seed_is_high.
   activity_of_enzimes_is_maxima because
    temperature_is_hot  and  soil_is_wet  and
    seed_can_germinate
      seed_can_germinate because
       there_is_trigger and there_is_water
       and seed_is_mature
          seed_is_mature because
          embryo_is_developed and
          enzimes_are_ready  and  nutrients_are_stored
yes
```

Fig. 6 Explanation in the QPT-based model.

Ecological knowledge covers mainly the levels ranging from the individual to biosphere. These organisational levels also reflect spatial and temporal scales. For an example compare the dimensions of individuals and ecosystems, which may cover hundreds of square kilometres over centuries.

This hierarchy associated with organisational levels substitutes the "first principles" in the reasoning of ecological modellers (Plant & Loomis 1991). From a pragmatic point of view, given the behaviour of an entity at any level, we should look for explanations in levels below, and the consequences might be found on the levels above that one. We expect that this general principle will be useful to solve ambiguities. This problem was not addressed in the present work because all possible ambiguities in the behaviour of the described ecological system were solved by hand using domain specific knowledge.

There is no scale that can account for all aspects involved in an ecological system. It is therefore necessary to select which are the most relevant information, and leave the noise outside the model when scaling up and down (Levin, 1992). The time scale can be used in selecting relevant variables to answer a particular question, but time alone is not enough in more complex situations (Rickel & Potter 1995). We believe that, for educational purposes, explanations would require not only time and space scaling but also explicit references to different organisational levels. An example of explanation from the QPT-based model, in which a variable at the population level (germination_rate) is linked to processes at the individual (embryo development) and sub individual levels (storage of nutrients and enzymatic activity), is presented in Fig. 6. A forward-reasoning approach could transform this explanation into a prediction about the consequences of the particular values for the state and the number of seeds.

7. Conclusions and ongoing work

In this paper we described a case study where we explored the possibility of representing knowledge, making predictions and generating explanations about the behaviour of an ecological system using two QR formalisms, SIMAO and QPT. Three models representing a set of relationships among the most important variables in a plant population's life cycle were implemented. One of them was a numerical model built within the System Dynamics framework, and the two other were qualitative models based on SIMAO and QPT.

SIMAO allows combining the heterogeneous variables involved in ecological modelling through an efficient qualitative algebra. This formalism does not deal explicitly with time, and therefore it is not adequate to be used in teaching vegetation dynamics. On the other hand, QPT is more general as a formalism and allows descriptions containing qualitative knowledge about entities, relationships and conditions. Thus it is possible to build more detailed ecological models using this approach. However, QPT does not provide a qualitative algebra for combining empirical values of variables. In implementing our QPT-based model we used the qualitative algebra developed in SIMAO. Similar predictions can be made by running simulations with both quantitative and qualitative models. Within the limits of the present work, we could capture the most distinctive aspects in the behaviour of a plant population under different environmental conditions with either the quantitative or the qualitative approach.

We can generate system-based explanations in which results from the simulations are justified by input values and intermediate calculations using both QR formalisms. However this kind of explanation is not enough to support the explanatory capabilities needed in a tutoring system. Domain-based explanations can be produced with the QPT-based model, given the possibility of encoding qualitative

ecological knowledge and representing with different primitives direct and indirect influences acting on variables.

We discussed also some problems we found in organising large amount of knowledge without having clearly stated ecological laws. Explanations and predictions about ecological systems behaviour often refer to either higher or lower organisational levels and to different scales of space and time. It is necessary to adopt a great variety of perspectives and to select only relevant information when answering questions in tutoring systems. We believe that time, space, and the organisational levels will also be required in evaluating the importance of variables in particular contexts and in solving ambiguities.

As a conclusion we can say that, depending on the purposes of the model, both formalisms can be useful in modelling vegetation dynamics. QPT might be more recommended for formalising knowledge and support automatic generation of explanations in an educational context. On the other hand, SIMAO can provide a qualitative algebra combining heterogeneous variables during simulations. A combined approach can be profitable in developing a tutoring system.

We are currently improving the explanatory capabilities of the prototype QPT-based system, and implementing models with more detailed knowledge about the effects of fire on the cerrado vegetation. Our future work has to address some problems that are challenges for the whole QR community: how to build systems that do not use numerical simulations but instead rely almost entirely on qualitative knowledge? How to handle large models efficiently? How to overcome the scaling problem in capturing the same ecological phenomena at different levels of granularity? And last, but not least, how these models will behave in real classrooms?

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