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Helping Young Students Reach Valid Decisions Through Model Checking

Ioannis Partsakoulakis, George Vouros

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Ioannis Partsakoulakis and George Vouros
Dept. of Information and Communication Systems Engineering
University of the Aegean
83200 Hellas
{jpar,georgev}@aegean.gr

SUMMARY

This paper presents the ModelsCreator decision-making module. The module aims to help young students to build qualitative models for decision-making and communicate with their teachers in the most effective way. The paper specifies the decision-making models that may be built and thoroughly describes the model checking, diagnosis and advice providing mechanisms. The model-checking mechanism compares the student models with a reference model provided by a teacher and provides active feedback to the student in order to help him/her construct a valid model. Therefore the model-checking mechanism of the decision-making module aims to facilitate students to form valid decisions in the appropriate situations, given teachers' reference models.

KEYWORDS: *Decision-making, qualitative models, model-checking, ModelsCreator, diagnosis, advice*

INTRODUCTION

Models of physical or artificial systems provide a significant means for humans to study and understand all the aspects, parameters, characteristics, entities, relations and processes that underpin the behavior of every such system. Thus, modeling can be a very strong tool in young students' hands for understanding the world and for discovering new forms of expression (Becker & Boohan, 1995), (Teodoro, 1994). Unfortunately, there is not a standard methodology for building models. Building artifacts that model real-world situations is a procedure that requires young students to think analytically. To support students in the modeling process, they must get feedback and advice concerning erroneous aspects of the models they construct so as to gradually unfold reality.

The objective of this paper is to present the ModelsCreator (Dimitrakopoulou et. al., 1997), (Dimitrakopoulou et. al, 1999) decision making module. The module aims to help young students to build qualitative models for decision making in specific situations and communicate with their teachers in the most effective way. Decision making models comprise entities that participate in a decision making situation, properties/attributes of these entities, values of entities' attributes and logical connectives that "bind" these aspects together, showing their role in the formalized situations. Essentially, decision-making models describe the situations where specific decisions can be formed and specify these decisions. It is important to be pointed that many real-world decision making situations are characterized with lack of certain knowledge and therefore humans form decisions or reach conclusions under uncertainty.

ModelsCreator decision-making module provides support for young students to build models with or without uncertainties. Uncertainties in these models are expressed by probabilities. The module provides generic (domain independent) mechanisms for model checking in order to effectively help young students find erroneous aspects in their models and reach an agreement with the teacher.

Erroneous aspects in young students models concern the role that properties/attributes of entities play in a decision-making situation. For instance, young students may under-specify the real-world situations where a decision must be formed, by missing important aspects that should be taken into account when reaching a decision. On the contrary, young students may over-specify the situations where a decision is valid by taking into account aspects that are redundant. Over and under specification may also be due to the fact that students relate aspects of the situations in concern in a wrong way. In situations that involve probabilities, they may also make wrong estimations. This paper concentrates on models with no probabilities. When probabilities are involved, then the mechanism described in this paper is employed, but the system must check probabilities as well.

Reaching an agreement with teachers in a specific problem situation is a process that involves individual reasoning and communication among young students and teachers. The decision-making module of ModelsCreator aims to facilitate communication by checking young students' models against prototype models (called reference models). It does not try to replace teacher but to act as a middleman between the teacher and the student by giving to the student certain feedback messages to drive him/her think harder about the problem. Reference models are provided by teachers, specify the situations in which a decision is valid and are associated to a certain problem situations. Then, young students' models are checked for validity in these situations.

Often, there is more than one solution (i.e. right decision) to a certain problem and more than one ways to express a solution. The decision-making module allows teachers to associate more than one reference models to a specific problem in order to specify more than one solution. Furthermore, the module can deduce when two models are logically although not structurally equivalent, allowing different expressions of the same solution.

Although a lot of work has been done in model-checking, the aim of this paper is not to provide the formal background of the procedure, but to show the functions of the decision making module for helping young students to form valid decisions in the appropriate situations.

The second section of this paper provides an overview of ModelsCreator Decision Making Module and presents the types of models that young students may construct using the software. Then, a formal description of the models created is given. Section three describes the generic mechanism for models' checking. Emphasis is given to the feedback messages provided to students concerning possible errors in their models. Section four presents a modeling scenario, where the functions of the system are exhibited. Finally, the paper concludes with some remarks and issues for future work.

MODELSCREATOR

ModelsCreator (Dimitrakopoulou et. al., 1997), (Dimitrakopoulou et. al, 1999) intends to provide a graphical environment for young students to develop models of real world configurations. Students specify how objects interact and/or related in these configurations.
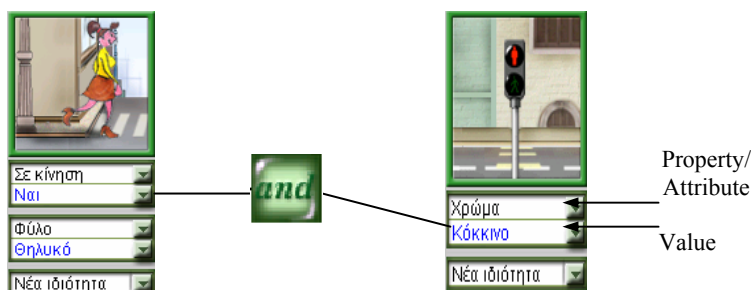
Figure 1: Entities related using the logical connective "and".

The components of models that are constructed using ModelCreator's graphical interface are entities and relations. Examples of entities are "car", "pedestrian" and "pedestrian light". Each entity has a finite set of predefined properties/attributes and for each property/attribute there is a finite set of possible values. For example the entity "car" has the attribute "type" with values "sport" and "family", the attribute "colour" with several different colour values and the property "in move" with values "yes" and "no". Relations hold between properties/attributes of entities. To relate two entities with a relation, the user has to select a property/attribute from each entity, specify a value for each property/attribute, drag and drop the relation to the modelling space and relate the selected attributes of the two entities. The result of this task is shown in Figure 1. Figure 2 shows the modelling space of ModelsCreator.

Using Model's Creator graphical environment, young students may create qualitative, semi-qualitative, and quantitative models. Although qualitative and semi-qualitative models involve numeric attributes and characteristics of entities, qualitative models involve properties of entities (e.g. "in move") or attributes with qualitative values (e.g. "pedestrian light colour").
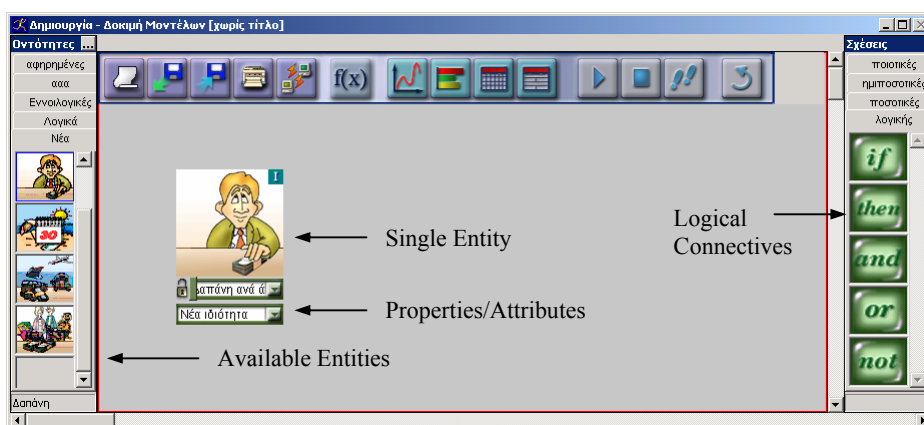

Figure 2: The modelling space of ModelsCreator.

Models for decision-making are mostly qualitative models. The relations that can be used in these models are the logical connectives "and", "or", "not", "if-then" and "else". Each decision making model has exactly one hypothesis part, exactly one decision part and at most one counter decision part. The student selects certain properties/attributes, sets the desired values and relates them with the appropriate connectives. Logical connectives relate properties of entities, or complex logical expressions involving entities' properties. For instance, in the model depicted in Figure 3, the "if" connective applies to an "and" expression, while the "and" connective, applies to an "or" expression and to a property of the entity "car".

Using such an environment, one may construct fully parenthesised expressions of arbitrary complexity that are according to the following formal grammar:

```
Expression = if Construct then Construct
           | if Construct then Construct else Construct
Construct = (Construct and Construct)
          | (Construct or Construct)
          | not(Construct)
          | Entity_Property_or_Attribute
```
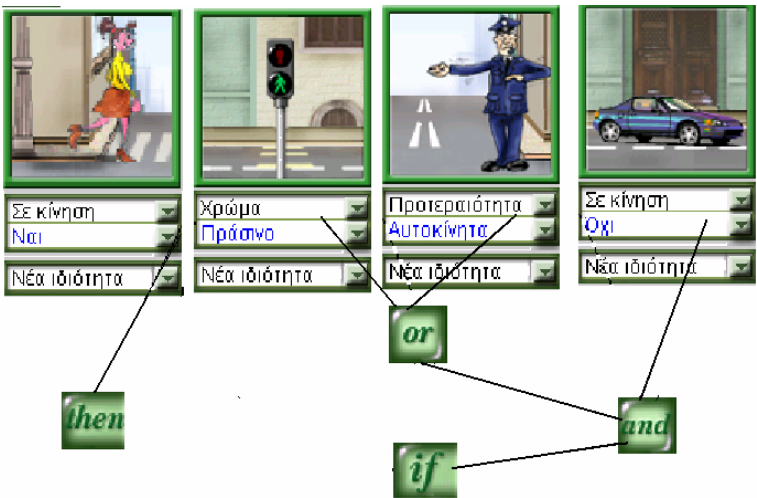

Figure 3: A decision making model[1]

For instance, the model in figure 3 is described by the following linear expression:

if "car is not in move" **and**
("pedestrian light is green" **or** "policeman gives priority to pedestrians")
then "pedestrian may safely cross the road"

Here, it is important to notice that when constructing a decision making model, it is assumed that the properties/attributes of the entities in the hypothesis part of the model have a causal effect in the properties/attributes of the entities in the decision part.

For instance, the model

if ("car is not in move" **and** "pedestrian light is green")
then
"pedestrian may safely cross the road"

is mathematically equivalent to the model:

if "pedestrian light is green" **then**
("car is in move" **or** "pedestrian may safely cross the road")

However, the second decision-making model does not express the causality effect of the car's property to the decision of the pedestrian to cross the road. Furthermore, the model reflects the wrong thought that the colour of the pedestrian light affects the "in move" property of the car.

THE MODEL-CHECKING MECHANISM

As already pointed, the model-checking mechanism of the decision-making module aims to facilitate the cooperative process between students and teachers to reach an agreement about the situations in which a decision is valid.

This is achieved by checking students' models against reference models provided by teachers. Reference models restrict the possible situations in which a decision is valid. Then, students' models are checked for validity in these situations. The objective then of the model-checking mechanism is to help young students "discover" exactly these situations that a decision must be formed, according to the teacher. This is different from the "classical" model-checking process, since the mechanism must not only check for the validity of the student model, but also must diagnose erroneous aspects in this model and provide feedback to the student.

The model-checking mechanism consists of four major steps as shown in figure 4. First, the two models (student and reference model) are converted using model-preserving formulas in equivalent Conjunctive Normal Forms (CNF). Second, the two models are compared and the mechanism draws intermediate results, which can be visualized in the form of a comparison table. Erroneous aspects of student's model may be diagnosed by inspecting the comparison table. Finally, the mechanism decides on the appropriate feedback message that should be given to the student.

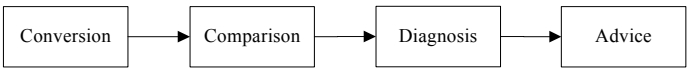In the subsections that follow, the stages of the mechanism are thoroughly described.

Figure 4: The four major steps of the model-checking mechanism.

Conversion

To preserve the causal relation between the hypothesis and the decision part of the model, the hypothesis, decision and counter decision parts of the models (student and reference) are recorded separately as such. Each part is then converted using tautologies in CNF. A sentence in CNF is a conjunction of a set of disjunctive formulas (see figure 5). Each disjunctive formula consists only of atomic formulas.

$$\overbrace{(a_1 \lor a_2 \lor \ldots \lor a_{n_a})}^{(A)} \land \ldots \land \overbrace{(z_1 \lor z_2 \lor \ldots \lor z_{n_z})}^{(Z)}$$

Figure 5: The Conjunctive Normal Form

Before comparing the two models the mechanism simplifies the sentences by removing redundant elements. These are (a) atomic formulas that are present more than once in the same disjunctive sentence (e.g. one of the a s in the formula $a \lor b \lor a$ is redundant) and (b) disjunctive formulas that form part of the whole formula and that imply the whole formula. (e.g. the disjunctive formula $a \lor b \lor c$ is redundant in the formula $(a \lor b \lor c) \land (a \lor b)$.

From here on, a CNF is considered to be simplified (i.e. does not contain redundant elements).

Comparison

The hypothesis and decision parts of each model are formed as a set of disjunctive formulas in CNF. If each disjunctive formula of one of the models is implied by the other one, then the two models are equivalent. In other words, the decisions formed by both models are valid in the same situations.

In order to compare the two models in CNF, each disjunctive formula is converted to a set of atomic formulas. For example the formula $a \lor b \lor c \lor d$ is converted to the set $\{a, b, c, d\}$. Doing so, each model is converted to a set of sets, where each inner set corresponds to a disjunctive formula and contains atomic formulas.

The model-checking mechanism compares disjunctive formulas in both models and records the atomic formulas that are missing or that are surplus in each disjunctive formula. The result of the comparison process is visualized using the *comparison table*. Entries of this table correspond to pairs of disjunctive formulas. Each entry (i,j) contains a sub-table with the missing and surplus elements of the i-th disjunctive formula compared with the j-th disjunctive formula of the reference model. For example, comparing student's formula $a \lor b \lor c$ with reference model's formula $a \lor b \lor d$ the corresponding comparison table entry is as follows:

−	{d}
+	{c}

This indicates that that atomic formula c is surplus; while the atomic formula d is missing form the student's formula.

Diagnosis

According to the above, in order the two models to be equivalent, for each disjunctive formula of student's model there must exist a matching formula in the reference model. This happens iff in each row and column of the comparison table there is a sub-table with no missing or surplus atomic formulas.

In case that the two models are not equivalent, then the model-checking mechanism can diagnose the following situations by inspecting the comparison table:

- The student has over-specified the situations where a decision can be formed: In this occasion the student has missed at least one atomic formula. This formula may correspond to an entity participating to the model, to a property, to an attribute or to a value assigned to a property/attribute of a participating entity. For instance the student may have missed the "pedestrian light" entity by not considering it at all, or it may have not specified a property of this entity that does affect the specified decision for the specific situations on hand. Another aspect of concern here is when the student has specified the right properties/attributes for the right entities, but has not assigned the proper values for (at least) one of these properties/attributes.
- The student has under-specified the situations where a decision can be formed: In this occasion, at least one atomic formula in student model is surplus. In correspondence to the above, this formula may correspond to an entity participating to the model, to a property, to an attribute or to a value assigned to a property/attribute of a participating entity.
- There is a logical connective misuse in student's model. This corresponds to situations where the student has related two entities with a wrong logical connective (e.g. instead of using the connective "and", he/she has used the connective "or"). Again, the diagnosis in this case is based on atomic formulas that are missing and surplus. An example of such a case is given in section 4.

The above cases are not considered to be of the same importance. This is useful for providing feedback/advice to the student. Doing so, the student model is assigned a score value that is a number between 0 and 100 according to table 1.

Score	Situation
0	Non recognizable error
10	There is a surplus entity
20	There is an entity missing
30	There is a surplus property
40	There is a property missing
50	Wrong value in property
60	Wrong probability value
70	Connective misuse
100	Equivalent to teacher's

Table 1: The score values that can be assigned to a student model when compared to a reference model.

Advice

The feedback message of the checking mechanism depends on the score of the current score as well as the previous scores. To each score level one or more messages are assigned with a preference. Messages with lower preference are more or equally detailed.

The aim of the system is to help the student to construct a model that is equivalent to the reference model. I.e. the student to specify the exact situations in which decisions specified are valid, according to the reference model. The feedback messages should give the appropriate advice in order students to gradually "unfold the reality", i.e. check their models and express those situations that are appropriate for making a valid decision.

To achieve this goal, the system produces messages of increasing detail by showing first the messages with higher preference. This is not the case when the student improves his/her model (i.e. achieves a better score).

For example, if the system has diagnosed that the student over-specified the situations for making a decision, e.g. by specifying the surplus entity "tree", it is proposing to the student to check the entities in the model. Later on, in case the student does not improve his/her score, it provides advice by prompting the student to check if there are any surplus entities in the constructed model. Finally, in case the student has stuck in the same erroneous situation, the system provides a more detailed advice by saying that the entity "tree" is not related to the situation being modelled.

A MODELLING SCENARIO

Returning to our example, let us assume that the situation given involves a pedestrian, a car, a policeman and a pedestrian light. Young students must form a model for reaching a decision about the pedestrian crossing the road. All involved entities are characterized by some properties and attributes that are assigned values. Young students, as already explained, must select the entities that play a role in the real world situation, the properties and attributes of these entities, assign proper values to attributes and combine all these aspects using logical connectors, towards reaching a valid decision.

Assume that the teacher has already constructed a (at least one) reference model, specifying the situations in which the pedestrian should cross the road. The reference model may have been expressed as follows:

If "the car is not moving" and ("the pedestrian light is green" or "the policeman gives priority to pedestrians") then "the pedestrian may safely cross the road"

In order to follow the modelling scenario, let C be the fact that the car is not moving (i.e. the entity "car" with the property "not in move"), L be the fact that the pedestrian light is green (i.e. the entity "pedestrian" with the attribute "colour" assigned the value "green", P the fact that the policeman gives priority to the pedestrians (i.e. the entity "policeman" with the attribute "priority to" assigned the value "pedestrians") and M the fact that the pedestrian is moving in order to cross the road (i.e. the entity "pedestrian" with the property "in move").

Then the reference model provided is as follows:

If C and (L or P) then M

It is clear that this reference model indicates all these situations, where forming the decision to cross the road is valid. The hypotheses of the reference model include all the entities that must be present in any situation where the decision is valid, and the important attributes/properties of these entities.

Now assume that a young student constructs the following model:

<p style="text-align:center">If C and L and P then M</p>

expressing his/her beliefs about the situations in which crossing the road is safe. In few words, the young student model states that to cross the road, the car must not be in move, the pedestrian light must be green and the policeman must give priority to pedestrians. Although the young student would be safe crossing the road under the circumstances specified by the model, it misses at least the situation where the car is not in move and the policeman gives priority to the pedestrians. Given this particular situation, the student's model and the reference model, it is clear that the student would not cross the road since the hypotheses of his/her model are not satisfied (are too restrictive).

According to the model-checking mechanism presented, the hypothesis and conclusion parts are in CNF, so there is no need for conversion. During the comparison phase we have the comparison table, shown in table 2, concerning hypothesis:

		C		L Ï P
C	−	{ }	−	{L, P}
	+	{ }	+	{C}
L	−	{C}	−	{P}
	+	{L}	+	{ }
P	−	{C}	−	{L}
	+	{P}	+	{ }

Table 2: The comparison table visualises the result of the compare process.

At the row labels there are the disjunctive formulas of the young student's model hypothesis and at the column labels there are the disjunctive formulas of the reference model hypothesis. Each table entry records the atomic formulas that are missing from the corresponding student's disjunctive formula and the atomic formulas that are surplus.

From the two table entries in circle, the model-checking mechanism reaches the conclusion that entities "light" and "policeman" within the model are specified in an erroneous way. This means that the way they are related among themselves as well as with the other entities in the model may be wrong. In this particular situation the model-checking mechanism detects that atomic formulas L and P should be in disjunction rather than in conjunction. This is evidenced by the fact that the checking mechanism reports that P is missing from the disjunctive formula L and also, that L is missing from the disjunctive formula P.

The system reports to the student that the model that he/she has constructed is not correct and lets him/her try again. Then, if the same fault is detected again, the system provides a more detailed feedback indicating that there is a problem with a logical connective in the model. The student has to think all the details of the model and then come back with a new model. During this process the system gradually unfolds the situations where the teacher believes that the decision formed is valid. Doing so, the system plays the "middleman" between the teacher and the student,

taking into concern the restrictions provided by the teacher and communicating with the student towards constructing a model where the decisions formed are valid.

CONCLUSIONS AND FUTURE WORK

This paper presented the ModelsCreator decision-making module. The module aims to help young students to build qualitative models for decision-making and communicate with their teachers in the most effective way. Decision making models comprise entities that participate in a decision making situation, properties/attributes of these entities, values of entities' attributes and logical connectives that "bind" these aspects together. Essentially, decision-making models describe the situations where a specific decision must be formed.

The paper specifies the decision-making models that may be built and thoroughly describes the model-checking, diagnosis and advice-providing mechanisms. The model-checking mechanism compares the student models with a reference model provided by a teacher and provides active feedback to the student in order to help him/her construct a valid model. Therefore, as already pointed, the model-checking mechanism of the decision-making module aims to facilitate the communication between students and teachers to reach an agreement about the situations in which a decision is valid.

Although the development of the decision-making module has been completed students have not used the overall application of ModelsCreator yet. Therefore, the module has been evaluated in real domains. Future work concerns the evaluation of the above-mentioned module in both diagnosis and advice-giving level based on experiments comprising young students and teachers. Proving that the model-checking mechanism described is formally sound, and extend it to diagnose more occasions where student's models differ from any reference model is left for future consideration, too.

NOTES

[1] This is an abstraction of the model that a student may create using ModelsCreator.

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