Intelligent Authoring of 'Graph of Microworlds' for Adaptive Learning with Microworlds

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Abstract

In science education, it is important to sequence a set of *microworlds* (which means *a system and its model* limited from educational viewpoint) of various complexity adaptively to the context of learning. We previously proposed *Graph of Microworlds* (GMW), a framework for indexing a set of microworlds based on their models. By using GMW, it is possible to adaptively select the microworld a student should learn next, and to assist him in transferring between microworlds. However, it isn't easy to describe GMW because an author must have the expertise in the process of modeling. In this research, we propose a method for semi-automating the description of GMW by introducing the *compositional modeling* mechanism. Our method assists an author in generating a set of indexed microworlds and also in considering educational meanings of the relations between them. We present how to design such a function and also illustrate how it works. A preliminary test with a prototype system showed the effectiveness of our method.

Introduction

In physics education, it is important for a student to acquire the ability to make appropriate models of various phenomena in the domain. For this purpose, a set of problems are provided in which he/she must think about some physical systems and their behaviors. In each problem, the range of systems and their behaviors are usually limited from some educational viewpoint in order for him/her to be able to understand the laws/principles behind the phenomena. This is called a *microworld* [1]. For the systematic understanding of the domain theory, therefore, it is necessary to sequence a set of microworlds of various complexity (from relatively simple systems/phenomena to more complicated ones) adaptively to the context of learning.

In designing ITSs (Intelligent Tutoring Systems) with such a function, it is essential to appropriately index a set of microworlds. Especially, it is important to explain why, in the situation given by a microworld, the laws/principles are applicable and why the model is valid. It is also important to explain why/how the model changes if the situation is changed. In order to make such explanations, it is necessary to index a set of microworlds based on their models and the process of modeling.

Therefore, we proposed a *Graph of Microworlds* (GMW), which is a framework for indexing the microworlds and the relations between them based on their models and the process of modeling (Horiguchi and Hirashima, 2005). We also showed, by using GMW, it becomes possible to design a function for adaptively selecting the microworld which a student should learn next, and a function for assisting a student in transferring between microworlds. However, it isn't easy to describe a GMW because an author must make a lot of indices in a model-based way. He/She must have the expertise in the process of modeling. In this research, therefore, we propose a method for semi-automating the description of GMW by introducing an automatic modeling mechanism (i.e., *compositional modeling* (Falkenhainer and Forbus, 1991; Rickel and Porter, 1994; Levy et al., 1997)).

Adaptive Learning Support with GMW

An example of GMW for elementary mechanics is shown in Fig. 1. Each microworld is indexed with the situation it deals with, the model of the situation and the process of modeling. A student can learn the physical law(s)/principle(s) necessary for the modeling and the skill(s) for the model-based problem solving in each microworld (they are called a *learning item*). Two microworlds which deal with similar situations but different models (i.e., different law(s)/principle(s) is(are) necessary) are linked to each other with an edge. *Parameter-change rules* (Addanki et al., 1991) are attached to such an edge which relate the difference between the situations of two microworlds to the difference between the behaviors of their models. This means one model is the necessary evolution of the other (with the perturbation of situation). Such a relation between two microworlds is called an *educationally meaningful* relation. In order to make a student learn the domain theory progressively, a GMW should include as many such relations as possible.

In Fig. 1, when a student learned linear uniform motion in MW-1, MW-2 and MW-4 are identified as the candidates he should learn next because they are adjacent to MW-1. Additionally, for assisting a student in transferring from MW-1

[1]Though this term usually indicates simulation-based interactive learning environments, we, in this paper, use it for indicating a system and its model made by limiting its structure and behavior from some (educational) viewpoint.

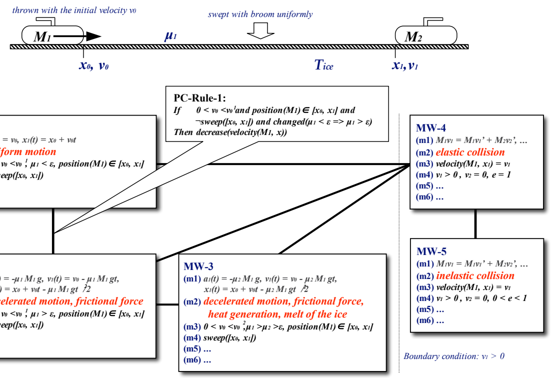

Figure 1: An example of Graph of Microworlds

to MW-2, a task is generated by using the parameter change rule, such as: *derive the velocity of M_1 when the value of μ_1 becomes greater and the friction becomes not negligible*. In this task, the necessity of the model of MW-2 is strongly suggested because the difference between the velocities of M_1 before/after the change of μ_1 can't be explained only by the model of MW-1.

In GMW, the situations and the differences between them are represented with a set of *modeling assumptions* (Falkenhainer and Forbus, 1991; Rickel and Porter, 1994; Levy et al., 1997) which constrain the viewpoint in modeling the system, the behavioral range of the system to be considered. Modeling assumptions represent the conditions about the system's structure and its state under which the model is valid. They are, however, not merely the applicable conditions of laws/principles, but the conceptualization of decision making in modeling the system. Therefore, an instance of a modeling assumption usually has its alternative(s). They are exclusive, and the model based on the latter is qualitatively different from the one based on the former. Modeling assumptions, therefore, can be a useful conceptual tool for describing the qualitative differences between various models.

Method for Assisting Authors in Describing GMW

It is not easy for (non-programmer) authors to describe a GMW. First, (1) it needs the expertise in the process of modeling to index the models with their modeling assumptions, especially because modeling assumptions are usually implicit information in models. Second, (2) it is difficult to find the various situations which embodies the law(s)/principle(s) covering the given set of learning items of the domain because its search space becomes vast. Lastly, (3) the set of microworlds must have as many educationally meaningful relations between them as possible.

We, therefore, propose a method for assisting an author in describing GMW by a *generation-test method*, in which he/she semi-automatically generates the models of various situations one after another, and judges whether each of them is appropriate to the GMW from an educational viewpoint. By using *compositional modeling* mechanism (Falkenhainer and Forbus, 1991; Rickel and Porter, 1994; Levy et al., 1997), this method is implemented as follows: First, (1) an author finds *a* situation which embodies *a* learning item (i.e., law(s)/principle(s)). The compositional modeler automatically generates the model and indexes it by its modeling assumptions. Second, (2) he/she perturbs this situation. The compositional modeler automatically generates the model of this new situation and indexes it by its modeling assumptions. Third, (3) if the new model embodies *another* learning item which is appropriate as a neighbor of the former learning item, he/she decides whether it is added to the GMW or not. If he/she judges that the difference between these two models is educationally meaningful, he/she adds the new one and the new edge between them. (4) By repeating (2) and (3) to grow the GMW, the author would finally get the whole GMW which embodies the set of learning items to be covered.

In this procedure, the work an author should do is to identify the relation between two models based on the perturbation of situation (i.e., the difference of modeling assumptions) and to judge whether it is educationally meaningful or not. In order to assist him/her, therefore, the function is desirable which makes advice on what physical meaning a difference of modeling assumptions has. In the next section, therefore, we describe a method for designing such a function by classifying the modeling assumptions based on their physical meanings and by grouping the exclusive ones which can't be made simultaneously (Horiguchi and Hirashima, 2008).

Relations between Models based on the Difference of Modeling Assumptions

We classify the modeling assumptions made in modeling physical systems into *constraints of physical structure* (CPS) and *constraints of operating range* (COR). Constraint of physical structure (CPS) is the assumption which specifies what kind of objects, relations and their attributes in a physical system are considered. CPS represents the decisions about perspectives and granularity. On the other hand, physical phenomena occur assuming a physical system is

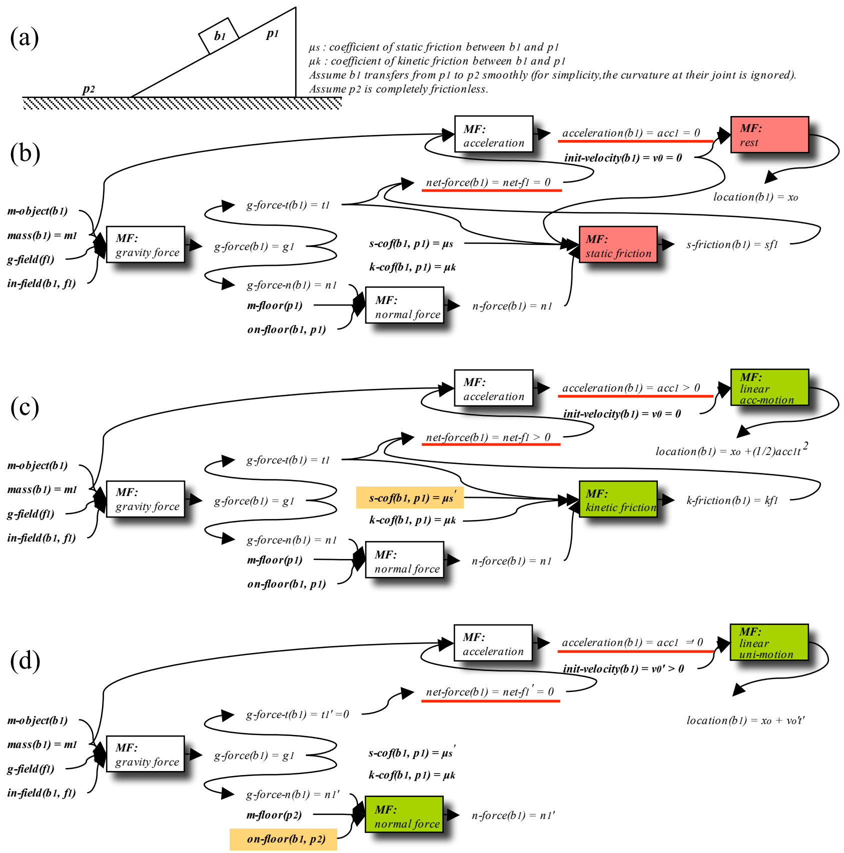

Figure 2: An example of difference between models

in a specific state. When the state changes, the model may become invalid. Therefore, a model must have the specification about the range (in its state space) within which it is valid. It is called constraint of operating range (COR).

In each type of these modeling assumptions, there are usually the sets of exclusive ones which can't be made simultaneously. For example, in a physical system, it isn't allowed to make assumptions *consider friction between two blocks* and *not consider friction between them* simultaneously as CPS. Therefore, by grouping the model fragments each of which has exclusive modeling assumption(s), it is possible to design the function for suggesting the relation between the models in two microworlds before and after the perturbation of situation. That is, first, the two sets of model fragments are compared, each of which composes each model. Then, if a pair of model fragments each of which belongs to each model and matches the same/similar partial situation has exclusive modeling assumption(s), the relation between the models is inferred from the type (i.e., physical meaning) of the assumption. Referring the relations between two models thus enumerated by the system, an author identifies the most appropriate relation and judges its educational meaning.

[Example-1] Fig. 2a shows the physical system in which an object b_1 is put on an inclined plane p_1 (to which a horizontal plane p_2 is connected). Fig. 2b is a model (i.e., a set of instantiated model fragments) of a situation of this system in which b_1 remains at rest on p_1 because the tangential component of b_1's gravity on p_1 is smaller than the maximum static friction between b_1 and p_1. It (called model-1) consists of 5 model fragments, including *static friction* and *rest*. If the coefficient of static friction is decreased in this situation, another situation may occur in which b_1 moves downward accelerated by its gravity (and the kinetic friction). The model of this situation (called model-2) is Fig. 2c and it consists of 5 model fragments, including *kinetic friction* and *linear acc-motion*.

The model fragments *static friction* in model-1 and *kinetic friction* in model-2 correspond to each other because they are instantiated by matching with the same physical structure in these models. Their CORs are exclusively different only in the modeling assumption which constrains the range of the value of the coefficient of static friction. It is, therefore, inferred that there is a difference between these models in 'the change from static friction to kinetic friction because of the change in the value of the coefficient of static friction.' The model fragments rest in model-1 and linear acc-motion in model-2 also correspond to each other because of the same reason. Their CORs are exclusively different only

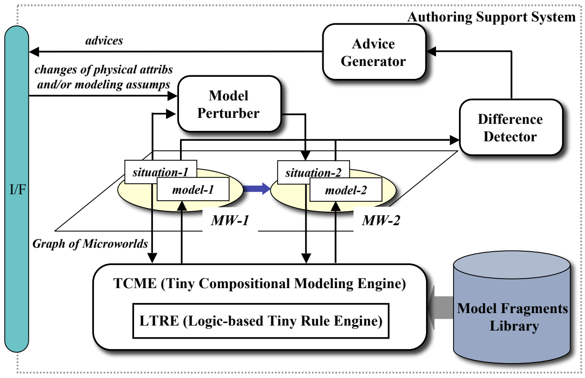

Figure 3: Architechture of the system

```
(defModelFragment (static-friction ?blk ?flr ?s-cof)
    :Individuals
    ((?blk :conditions (m-block ?blk))
     (?flr :conditions (m-floor ?flr))
     (?s-cof :conditions (static-cof ?blk ?flr ?s-cof)))
    :Assumptions
    ((on-floor ?blk ?flr)
     (applied-force ?blk (normal-force ?blk ?flr)))
    :Conditions
    ((= (v-mag (velocity ?blk)) 0.0)
     (< (mag (net-force ?blk))
        (* (static-cof ?blk ?flr)
           (mag (normal-force ?blk ?flr)))))
    :Relations
    ((Quantity ?self)
     (= (v-mag ?self) (mag (net-force ?blk)))
     (= (v-dir ?self) (+ (dir (net-force ?blk)) 180))
     (applied-force ?blk ?self)))
```

Figure 4: An example of model fragment

in the modeling assumption which constrains the range of the value of b_1's acceleration. It is, therefore, inferred that there is a difference between these models in 'the change from rest to linear accelerated motion because of the change in the value of b_1's acceleration.'

Design of a Prototype System

We developed a prototype system for GMW-authoring with our method. Note that it currently implements only basic functions: *situation interpreter/perturber*, *compositional modeler* and *difference detector*, except for (GUI-based) *user interface*. The architecture of the system is shown in Fig. 3.

Compositional modeler (we call this implementation TCME: Tiny Compositional Modeling Engine) generates the model of a given situation (i.e., a set of modeling assumptions) by applying the domain knowledge (i.e., the library of model fragments) to it. In the library of model fragments, model fragments written in the form shown in Fig. 4 are stored. They are translated into a set of *clauses* and used for the inference in LTRE. LTRE, which is a Logic-based Truth maintenance system (LTMS) coupled to a forward-chaining Rule Engine (Forbus and deKleer, 1993), maintains the dependency network of constraints of the generated model and guarantee the consistency of it.

Situation interpreter/perturber translates a given set of physical attributes and their values into modeling assumptions which are used for the inference in TCME (e.g., quantitative representation of relative position of mechanical objects are translated into its qualitative ones). If the value(s) of physical attribute(s) of a situation is(are) changed, a set of modeling assumptions of the new situation is output. An author perturbs the situation of a model by changing the value(s) of its physical attribute(s) or by changing its modeling assumptions directly to make a new model.

Difference detector detects and enumerates the differences between two given models (which are generated by TCME) with the method explained in the previous section. The differences are shown to an author with the explanations of why they appeared by the advice generator.

We developed a set of model fragments for TCME and the rules for situation interpreter/perturber which cover the basic examples of elementary mechanics. In a preliminary test, the prototype system could output the differences of models in several examples correctly. For example, in Fig. 2, when the coefficient of static friction in model-1 was decreased, model-2 was generated and the differences explained in Example-1 were output. When the friction between b_1 and p_1 was neglected in model-2 (its modeling assumption *Consider(friction(*b_1, p_1*))* was directly changed), the model of the new situation was generated (called model-3) in which b_1 moves downward accelerated by only its gravity without kinetic friction. As for the differences between model-2 and model-3, 'the disappearance of kinetic friction because of the neglection of friction (specialization of the model)' was output. Additionaly, when the time variable was increased in model-2, the model of the new situation was generated (called model-4) in which b_1 moves on p_2 at a constant velocity. As for the differences between model-2 and model-4, 'the change of relative position among b_1, p_1 and p_2 because of the evolution of time,' 'the disappearance of kinetic friction and normal force between b_1 and p_1, and the appearance of normal force between b_1 and p_2 because of the change of relative position among b_1, p_1 and p_2' and 'the change from linear accelerated motion to linear uniform motion because of the change of the value of b_1's acceleration' were correctly output.

Conclusion

In this paper, we presented a method for assisting an author in indexing a set of microworlds based on their models. Currently, it has been tested with only very small prototype. It is necessary to scale up our method by elaborating the classification of modeling assumptions for developing the larger library of model fragments.

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