Behavior Based Modeling as an Advanced Tool for the Engineering Practice

László Horváth*, Imre J. Rudas**

John von Neumann Faculty of Informatics, Budapest Tech Polytechnical Institution,
Népszínház u. 8., Budapest H-1081 Hungary
*horvath.laszlo@nik.bmf.hu
**rudas@bmf.hu

Abstract: This paper introduces a modeling method as a contribution to advanced modeling of products where the main objectives are changing from simple description and relating of engineering objects to description of engineering process related entities and modeled object behaviors. In the proposed method, techniques have been introduced by the authors to include intelligent model features in industrial CAD/CAM systems. The reported research was started from earlier achievements by the authors in development of integrated feature based product modeling. As a solution for intelligent modeling, an active model is proposed that integrates knowledge from modeling procedures, generic part models and engineers. Paper starts with a discussion of knowledge content in engineering models, and actual issues in intelligent modeling based engineering. Then the proposed knowledge based modeling by associative entities is explained. Application of computational intelligence in engineering systems is detailed and behavior based model with intelligent content, involving specifications and knowledge for the design processes are emphasized. Following this, an active approach to feature driven modeling of engineering objects is outlined and basic considerations are concluded.

Keywords: Engineering modeling, behavior modeling, virtual environment, computational intelligence

1 Introduction

Increasing amount of principles, methods and practices are available for efficient and productive work of engineers in computer systems. Advanced digital product definition techniques emphasize engineering process and product behavior aspects.

Shapes, assembly relationships, joints, tolerances, finite element related parameters, cutting tool paths for computer control of machining and product structures are engineering objects to be described in models of product that is positioned for e-business. Engineering modeling is being extended to the entire life cycle of products. Integrated application of virtual technology is the essence of concept of digital enterprise and other forms of extended companies, where all engineering activities and equipment controls are done within a highly integrated modeling system. However, key participants of engineering processes are still skilled engineers who are sitting at computers with advanced user communication features. Engineers expect more and more computer assistance at their decisions in a changed industrial environment, where quick and efficient engineering decisions are needed to survive competition in the market. One of the important objectives of next future research in this area is human decision assistance during interactive part modeling sessions. The demanded modeling needs model representation that describes behavior of modeled objects for various circumstances. Then this model can be used at analysis of object behavior in virtual. Lack of modeling methods appropriate for this purpose motivated the authors to investigate possibilities and means of new enhancements in knowledge based active modeling procedures.

Recent advancements in shape centered engineering modeling is motivated both by expectations for high performance of part and well-engineered shape. Performance of modeled objects is assessed by using of various implementations of finite element analysis. Advanced shapes are carried by parts and best produced by advanced surface model driven and computer controlled manufacturing of tools for making parts, or the parts themselves [6]. Stand alone part model objects are integrated into product models by using of structure descriptions and associativity definitions. Results of the part design are protected against modification by the definition of shape, dimensions, and associativities as constraints.

The above outlined scenario is a good starting point for development of virtual environment based engineering modeling, where advanced knowledge technology is integrated with advanced product modeling technology. The purpose of this paper is to give an outline of an advanced concept and a modeling method for intelligent model features in engineering modeling that are ready for implementation in industrial CAD/CAM systems. A preliminary of the reported research is development of a methodology to integrate manufacturing process modeling with form feature based part modeling by the using of relationship and constraint definitions [1].

Paper starts with a discussion of knowledge content in engineering models, actual issues in intelligent modeling based engineering. Then the proposed knowledge based modeling by associative entities is explained. Application of computational intelligence in engineering systems is detailed and behavior based model with intelligent content, involving specifications and knowledge for the design processes are emphasized. Following this, an active approach to feature driven modeling of engineering is outlined and basic considerations are concluded.

2 Knowledge content in engineering models

Product model related, application oriented, feature driven and associativity related are the main advanced characteristics of engineering modeling. Models utilize unified geometry and topology for the purpose of shape definition. An important assumption is that the model, in which new or modified features are defined, may be created in an other modeling system and by an other engineer. At the same time, multiple designer operation mode of concurrent group work of engineers is assumed where several engineers handle the same model. Both modeling procedures and engineers utilize model-related knowledge in order to achieve an effective product modeling process. Knowledge communication associated with model data communication serves assistance of problem solving in a multiple designer and multiple modeling system. Purpose of the reported research is getting more information about nature and characteristics of feature based product models then development of a unique active modeling approach and method. The research involves analysis of structure and behavior some typical features.

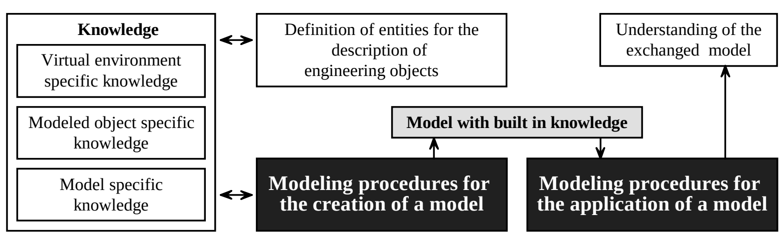

Fig. 1. Approach to knowledge based modeling

An important characteristic of models is the knowledge content. Knowledge content of model entities is utilized during design process at definition of product objects and simulations. An initial concept to integrate knowledge in modeling was to include knowledge in modeling procedures of CAD/CAM systems. This approach supports representation of generally applicable and domain related knowledge. However, most of the knowledge is company, product, even human related one. Moreover, knowledge changes from company to company and product to product. The only effective way is integration of this knowledge in models of abstract or instance product objects. This new approach is anticipated to be one of the most researched and developed area in model based engineering design during the next few years. Significant part of knowledge for later processing of a model is model, modeled object or modeling system specific (Fig. 1). Knowledge is often not available at the application of the model and must be exchanged together with the model between modeling systems. Built-in knowledge helps engineers at development, modification and application of the model and prevents model quality from deterioration at later application and modification. By now, knowledge content and other advanced features resulted a modeling, where models can answer most of important questions about the modeled object before, during and after their manufacturing. Recently, advanced modeling systems that include models of this kind are called as virtual environments**.**

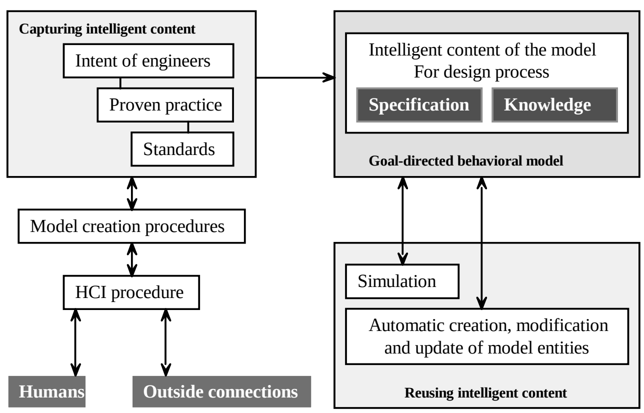

Fig. 2. Emulation of intelligence in modeling

Model with the capability of reaction to changes in its environment using behavior related knowledge can act as an intelligent design of the modeled objects. This model communicates built in knowledge even decisions with modeling procedures or humans to save earlier decisions and human intent, while new decisions and intents are captured in the model. Knowledge content of model is developed simultaneously with development of model. Behavior based models with intelligent content involve specifications and knowledge for the design processes (Fig. 2). Specifications are results of design with appropriate explanations. Modeling of design intent is described as specification in the approach of the authors [2]. Knowledge normally is related to given specification but it is also can be independent of any specification. Definition of specifications and knowledge needs authorization according to role of engineer in the product development team, and stage of the design process.

Forthcoming development and application of the model utilize its intelligent content at creation, modification and update of model entities.

Representation of knowledge should be as simple as it can be in order to ease of definition in the every day industrial practice of engineers. Consequently, the most appropriate forms of knowledge are formulas, rules, and checks. Compliance of the model with proven practices and standards also must be ensured. Behavior based modeling offers a conversion of implicit engineering practice into explicit knowledge. Creating a new model is enhanced by application of models of abstract objects. An abstract object carries characteristics of a set of similar objects. At creating of a new modeled object instance from the model of an abstract object, actual characteristics of the instance object are set. This process also can be automated by including knowledge in model objects. Model of an abstract object may involve domain, company and designer related knowledge. Model of an instance object generally contains domain, company, product and designer related knowledge. Information about origin knowledge and its validation also should be included. Otherwise, responsibility for the product cannot be evaluated.

Humans and computer procedures can create model objects in a virtual environment as autonomous intelligent agents (Fig. 3). Intelligent agents are autonomously working procedures in the software system with goal-directed behavior interacting with given environments [5]. Human control is realized directly by interaction with model creation procedures, or indirectly by specification or knowledge placed in agents. Behaviors can be modeled in a multi-agent system. This modeling environment constitutes a reactive system. Reactive behavior of agents are controlled by appropriate creation of the model. Series of circumstances are identified as situations and responded by models in the virtual environment. Models are utilized in automatic or human controlled interactive, real-time simulations. Simulations are applied for analysis of critical situations and events during manufacturing and application of the modeled product. Simulation is a key technique for virtual prototyping where advanced modeling is applied to move physical prototyping activities into virtual environments. Real time assessment and analysis are assisted by appropriate intelligent procedures. Goal-directed behavioral representation in agent-based modeling of engineering objects offers advanced simulation by emulation of intelligence. This is allowed by knowledge-driven modeling that captures and reuses intelligent content (Fig. 2). At the same time intuition, creativity and innovation of humans are also utilized in the course of their direct application, offered by interactivity, or by enriching the knowledge of agents. Competition-orientation of design engineering urges and stimulates application of behavioral techniques.

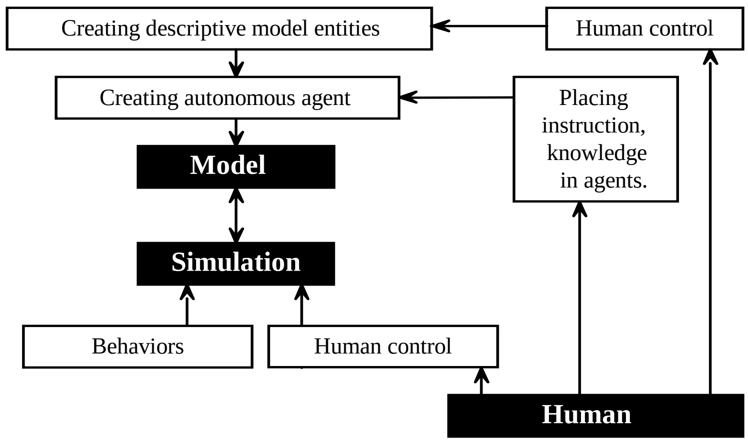

Fig. 3. Autonomous agents in models

In problem area specific virtual environments, situations are analyzed at application of virtual environment for problem solving. Virtual environment is used to determine influence of prevailing circumstances on some parameters in the model. Circumstances are created by humans or generated automatically in the virtual environment. In the engineering practice, there are two typical simulations. Best appropriate variants are selected or consequences of a decision are revealed for given set of circumstances. The first simulation allows for revealing all parameters that influence a selected parameter. The second simulation allows for determining impacts, it is best applied to design modifications. Finally, variants can be adapted or combined by engineers and the new variant can be analyzed in the virtual environment.

Advanced shape centered engineering design uses form feature driven shape-modeling [8]. Form features are elementary building blocks for shape modeling and act as modifiers for a previous shape. A sequence of shape modifications produces the final shape of the part. Other non-geometric part and part manufacturing information, including suitable and available manufacturing resources, can be mapped to form features. Typical shape representation of form features includes unified topology and geometry. Virtual prototyping sometimes is completed by rapid prototyping. Rapid prototyping equipment can be driven by voxel model that is a spatial subdivision model of the shape. A method for conversion of topology-geometry based shape model to voxel model and manipulating voxel model for rapid prototyping are discussed in [4].

3 Associative entities in knowledge based models

The most widely accepted modeling method defines form features and attaches attributes and geometric model representations to them. In the author's approach, the feature principle is extended and generic or instance part related knowledge is included in the model on a way that allows for its active application. Some previous background researches by the author for modeling of part manufacturing processes, human-computer procedures and design intent are utilized. The method is appropriate for modeling on the basis of application oriented reference models. A simple but effective method for integration product model related partial models is definition of associativities between model entities [3] (Fig. 4.). Creation and modification of model entities rely on definition then maintaining of associativities. Associativities to be maintained are defined as constraints. Maintaining associativities at modification of models involves propagation of the effect of changes in models. Propagation of any change of model at any stage of modeling makes product design consistent with intents, goals and decisions. Knowledge is often related to associativities so that it is beneficial to include it in associativity definitions. Modeling procedures generate associativity alternatives appropriate for the actual situation and offer them for humans in the course of interactive definition of models. This feature of modeling systems prevents erroneous associativity definitions by humans. Perhaps one of the best examples for application of associativities is assembly modeling in mechanical systems. As a typical method for automation of this activity, computer procedures propose the most appropriate constraints for a part placement while human drags the part into position by a pointing device. Mechanical constraints are created then used to adjust part position and establish contacts automatically.

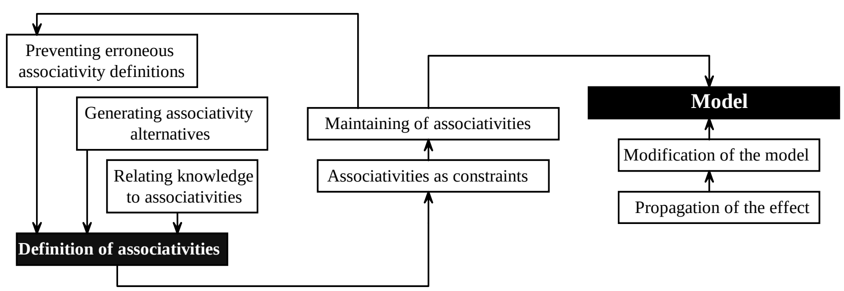

Fig. 4. Associativities in knowledge based models

Creating and global modification of a multi-surface shape complex as a single surface while preserving design characteristics, demands shape definition related knowledge both in modeling procedures and models (Fig. 5.). Taking styling, mechanical design and manufacturing knowledge and specification into consideration often results conflict to be resolved by the engineer who is responsible for the related decisions. Knowledge acts according to the purpose and specification of modification. A typical purpose can be fitting a surface complex in a given solid model environment [7]. The related knowledge is represented in the form of rules, checks, control curves, etc. Input parameters as guiding surfaces, other outside world entities, and digitized physical geometry are used by knowledge assisted surface modification procedures. Previously established design constraints valid for the surface to be modified such as point, tangent and curvature continuity must be unbroken during modifications. Existing topology and topology related knowledge are applied to propagate effects of surface modifications. An other important area for application of intelligent computing is recognition of sketched shape and creating surface model for it. Other surface related intelligent modeling could be utilized by reverse engineering to transform shape related knowledge from the physical world to virtual.

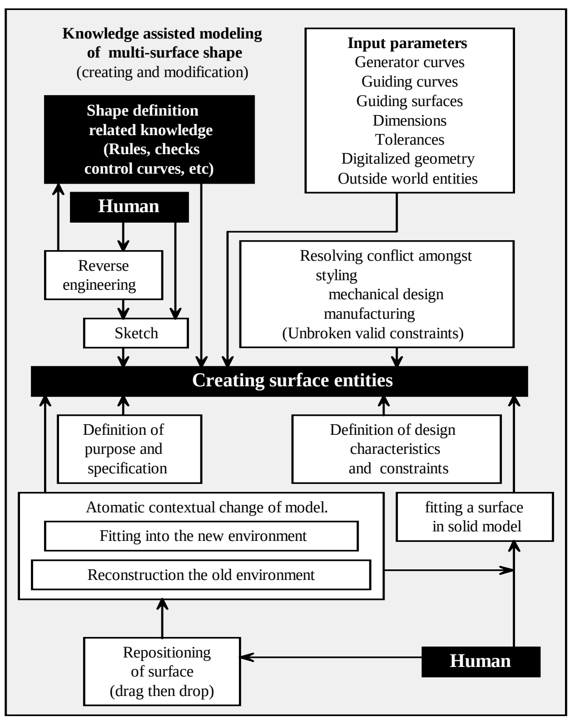

Fig. 5. Knowledge based handling of complex surface features

Repositioning by dragging then dropping of a form feature by graphic human interaction of human during development of part model is followed by its mathematically correct automatic fitting into the new environment and reconstruction the old environment without any other human interaction. This feature of intelligent modeling is called as automatic contextual change of model. It is enabled by behavior based, reactive geometric model. Other important area of knowledge based modeling is nonlinear mathematical optimization problem of mechanical parts by using of numerical algorithms. Mathematical programming optimizes design for design goal while satisfies specific design limits. Design limits, such as material strength or allowable displacement are functional requirements of the design process. Design goal represents the optimization intent such as cost, volume, time, mass, stress and displacement. Sensitivity analysis provides information the degree to which a change in each design parameter influences the structural performance. At adaptive analysis a converged analysis solution is achieved automatically.

4 An active approach to feature driven modeling

The authors proposed an active and knowledge based version of feature, associativity and constraint driven modeling of parts. The resulted model is able to inform engineers about consequences of creating a new, a modified, or a new instance model entity. It comprises knowledge from three sources, namely modeling procedure, generic part model and engineer. Because feature based part model is supposed to be applied, representation of feature related knowledge was analyzed. Modeling of a part is considered as a single process from conceptualization to manufacturing even to life end procedure, according to the scope of product modeling. In the feature approach extended by active knowledge, comprehensive groups of features as volume adding and subtracting form features, form conditioning features, finite element features, load features, machining features, measurement features, associativity features, rule features and check features serve full feature orientation throughout the part related engineering process. Design alternatives, offered by humans or part modeling procedures, can be recorded in the part model together with the related knowledge. Intelligent modeling methods are useful in every day engineering practice. Engineer can specify that should not be created so that entities will have the required characteristics.

New features can be launched for the modeling system both by human and remote created model. There is an actual set of known features in the modeling system at each moment (Fig. 6.). Most of the features are generic ones and part models include their instances. Others are defined only for the model under development and cannot or must not be applied in other models. A generic model can be applied generally or only by given individuals. Privacy policy is an important aspect at implementation of this approach. As an example, some features can be applied only within given projects. Features are in possession of information and knowledge necessary to simulate behavior of the modeled objects. At including a new or modified feature, some environment related information as previously defined related features, restriction definitions for prospective features and production resources are defined in order to integrate the new feature in the existing part model. Receiving this information, the related existing features react to the feature related model development activity. Consequently, features are aimed to create information about the effect of model changes and to communicate this with the related features. The above outlined approach also offers a real solution for reconstruction of exchanged models in remote receiving CAD/CAM systems. Definitions and behavior information for features also can be placed by engineers and experts in their hosts and can be accessed through Internet. Also, advice taking can be made available by remotely residence engineers in this way.

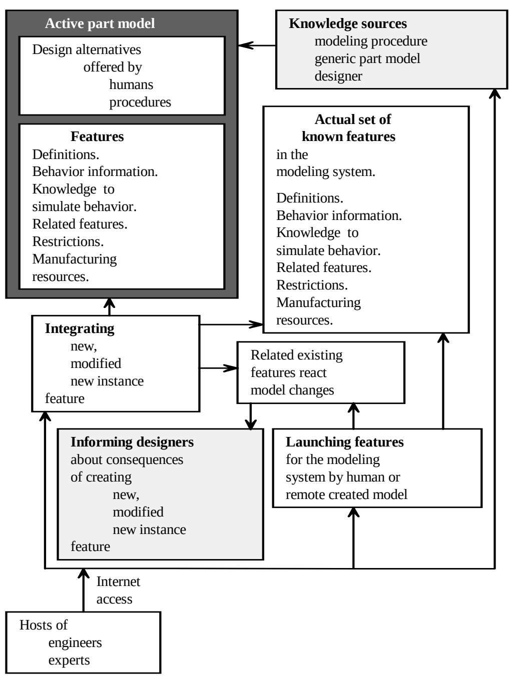

Fig. 6. Modeling with active models

Feature definition in case of agent based active model is outlined in Fig. 7. Feature definitions are stored in feature library in the modeling system *A*. During creation of the active model human defines a new feature *FF1*. Other possibilities are definition of modifications or instances of new features. Besides feature instance specifications, knowledge to launch the feature *FF1* by active model in the modeling system *B* is also included in the model.

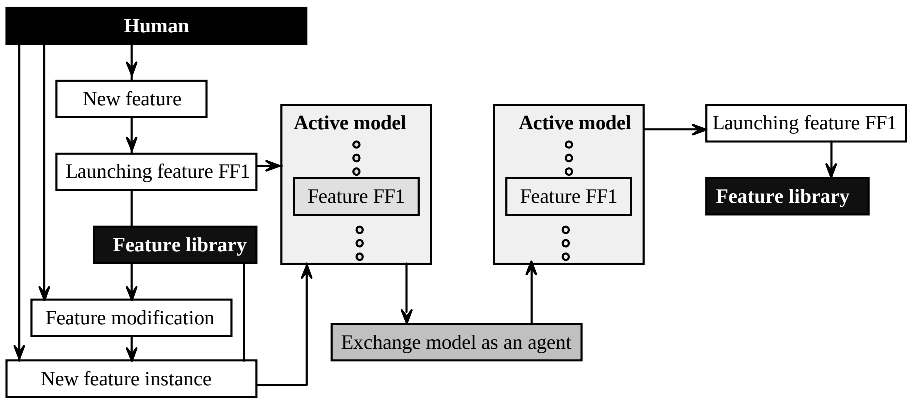

Fig. 7. Feature in active model

Conclusions

The authors introduced a research for enhanced, knowledge based version of feature, associativity and constraint driven modeling of parts. Paper gives an outline of the proposed process-centric model based development of products using digital definition techniques in the form of active model. The proposed model includes model representations that describe behavior of modeled objects in different circumstances. Some possibilities and means of new enhancements in active modeling procedures, that work on the basis of knowledge based methods, are investigated. Automatic, reactive feature based propagation of any change of model at any stage of the modeling process makes design consistent with intents, goals and decisions. Feature models involve specification and knowledge representations necessary to simulate behavior of the modeled objects. Active models act as agents after exchange them with other modeling systems at applications of model. Intelligent modeling methods are useful in every day engineering practice.

Acknowledgments

The authors gratefully acknowledge the grant provided by the OTKA Fund for Research of the Hungarian Government. Project number is T 037304.

References

[1] Laszlo Horvath, Imre J. Rudas: "Constraint Based Modeling of Automatic Shape Generation", in proceedings of the *1999 IEEE International Conference on Systems, Man, and Cybernetic, Human Communication and Cybernetics, IEEE*, Tokyo, Japan, 1999, Volume 4, pp. 457-462

[2] László Horváth, Imre J. Rudas and Carlos Couto: "Human Intent Models in Integrated Product Modeling", in proceedings of the *2000 26th Annual Conference of the IEEE Industrial Electronics Society*, Nagoya, Aichi, Japan, pp. 1274-1279.

[3] L. Horvath, I. J. Rudas: "Integrated Associative Modeling of Parts and their Machining Process by Features", in *proceedings of the ICMT 2001 conference*, Singapore, pp. 316-321.

[4] Gy. Herman: "Voxel Based Geometric Modeling in CAD, a New Approach", in proceedings of *INES'2000, 2000 IEEE International Conference on Intelligent Engineering Systems*, Ljubljana, Slovenia, pp: 53-56.

[5] M. Tambe, W. L. Johnson, R. Jones, F. Koss, J. Laird, P. Rosenbloom, and K. Schwamb, Intelligent agents for interactive simulation environments, *AI Magazine,* v. 16, n. 1, 1995.

[6] Les Piegl - Wayne Tiller: *The Nurbs Book,* Springer-Verlag, 1997

[7] Freitag, S., Opitz, K.,: Enhancements in blending algorithms, *Hewlett-Packard Journal*, October 1995, pp. 24-34

[8] Mannistö, T., Peltonen, H., Martio, A. Sulonen, R.: Modeling generic product structures in STEP, *Computer-Aided Design*, Vol. 30, No. 14, 1998, pp. 1111-1118