Behavior and Design Intent Based Product Modeling

László Horváth, Imre J. Rudas

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

Abstract: A knowledge based modeling of mechanical products is presented for industrial CAD/CAM systems. An active model is proposed that comprise knowledge from modeling procedures, generic part models and engineers. Present day models of mechanical systems do not contain data about the background of human decisions. This situation motivated the authors at their investigations on exchange design intent information between engineers. Their concept was extending of product models to be capable of description of design intent information. Several human-computer and human-human communication issues were considered. The complex communication problem has been divided into four sub-problems, namely communication of human intent source with the computer system, representation of human intent, exchange of intent data between modeling procedures and communication of the represented intent with humans. Paper discusses the scenario of intelligent modeling based engineering. Then key concepts for the application of computational intelligence in computer model based engineering systems are detailed including knowledge driven models as well as areas of their application. Next, behavior based models with intelligent content involving specifications and knowledge for the design processes are emphasized and an active part modeling is proposed and possibilities for its application are outlined. Finally, design intent supported intelligent modeling is discussed.

1 Introduction

Model based development of products uses advanced process-centric digital product and manufacturing process definition techniques. Shapes, parts, assembly relationships, joints, tolerances, finite element related parameters, cutting tool paths for computer control of machining and product structures are main objects to be described in feature and associativity driven product models. Products are positioned for e-business among others by the help of using model-based approach. Scope of engineering modeling is being extended to the entire life cycle of products. Comprehensive application of virtual technology is the essence of the concept of digital enterprise where all engineering activities and equipment controls are done within a highly integrated modeling system.

Key participants of engineering processes are still skilled engineers who are sitting at their computers with advanced user communication features. Engineers expect more and more computer assistance at their decisions in changed industrial environments where quick and efficient engineering decisions are needed to survive competition in the market. However, modeling methods that really enhance human decision assistance capability of engineering modeling procedures during interactive part modeling sessions are not available. Powerful decision assistance use analyses that need behavior based modeling of engineering objects in various circumstances. In other words, analysis of object behavior is done in virtual. The authors investigate possibilities and means of new enhancements in knowledge based active modeling procedures.

Advancements in part related engineering modeling is motivated both by expectations for high performance parts with well-engineered shape. Performance of modeled objects can be assessed by using of various implementations of finite element analysis. Advanced shapes are best produced by advanced surface model driven and computer controlled manufacturing of parts or tools for making parts [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.

Despite these fantastic advancements some important aspects of modeling could not follow this evolution. One of them is application of active models. 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 models. This modeling is suitable for implementation in industrial CAD/CAM systems. Preliminaries of the reported research are developments in methodology to integrate manufacturing process modeling with form feature based part modeling by using of relationship and constraint definitions [1].

Design intent covers results of a complex human thinking process. Modeling tools in present day CAD/CAM systems are not suitable for description of this process. Advanced, customer oriented product design requires frequent modification of earlier decisions. Moreover, modification of result of a decision often causes a need to modification of results of other decisions. This is impossible in the lack of proper background information for the original decision. Consequently, modifications of original decisions require contribution of the original decision-maker or other authorized engineer. Because live communication between engineers typically is not available, the only effective way is to describe their intent in the product model to be modified. Inevitably, computer modeling should be extended to this area. The authors propose a computer method to assist the modification of decisions by modeling of design intent.

Paper discusses some issues of intelligent modeling based engineering. As an introduction, it outlines the scenario of the related activities and systems. Then key concepts for the application of computational intelligence in computer model based engineering systems are detailed including knowledge driven models as well as areas of their application. Next, behavior based models with intelligent content involving specifications and knowledge for the design processes are emphasized, an active part modeling is proposed, and possibilities for its application are outlined. Finally, design intent supported intelligent modeling is discussed.

2 Intelligent Content in Virtual Environments

An important assumption in advanced models of mechanical systems is that the model, in which new or modified features are defined, is created earlier using other modeling system and by other engineer. At the same time multiple designer operation mode in concurrent group work of engineers is assumed where several engineers handle a model. Both modeling procedures and designers utilize model-related knowledge in order to achieve effective product modeling process. Role of knowledge communication associated with model data communication is assistance of multiple designer and multiple modeling system related problem solving.

Knowledge content of model entities can be utilized in the design process at definition of product objects and simulations. An initial concept to integrate knowledge in modeling was to include knowledge to 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 and it changes from company to company and product to product. The only effective way is integration this knowledge in models of abstract or instance objects in the product model. This approach is anticipated to be one of the most researched and developed areas in model based engineering design during the next few years by the authors.

Significant part of knowledge necessary at later processing of a model is modeled object, model and modeling system specific (Fig. 1). This knowledge is not available at the application of the model so that it is to be exchanged with models between modeling systems. Built-in knowledge then helps engineers at development, modification and application of the model. It also prevents model quality from deterioration at its later application and modification. Knowledge content and other advanced features resulted modeling where models can answer most of important questions about the modeled real world object before, during and after their manufacturing. Recently, advanced modeling systems that include models of this kind are called as virtual environments.

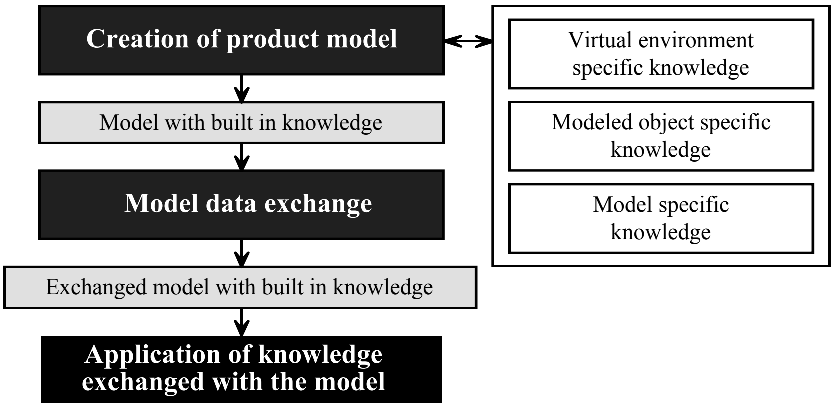

Figure 1
Knowledge in engineering modeling

Model with the capability of reaction using behavior related knowledge acts an intelligent design of the modeled object that can communicate built in knowledge with modeling procedure or human to save earlier decisions and human intent while new decisions and intents are captured in the model. Knowledge content of model is developed with its development. Behavior based models with intelligent content involve specifications and knowledge for the design processes (Fig. 2). Specifications are results of design with appropriate explanations. Model of design intent is considered to be described as specification in [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 engineers in the product development team and stage of the design process.

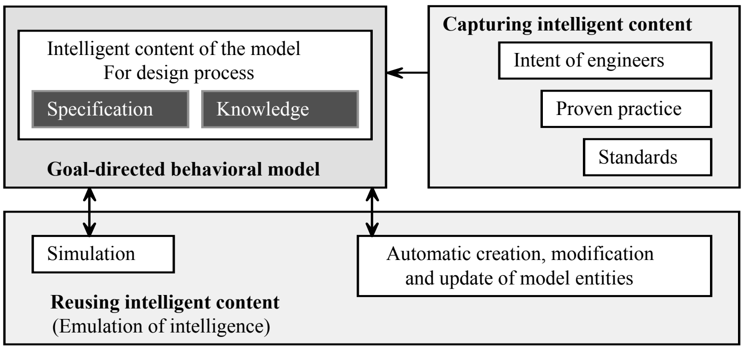

Figure 2
Knowledge assisted modeling

Forthcoming development and application of the model utilize its intelligent content at automatic creation, modification and update of model entities. Representation of knowledge should be as simple as can be so that it is easy to define by engineers in their every day practice. Most appropriate forms of knowledge are formulas, rules and checks because these are natural in engineering design. Compliance of the model with proven practices and standards can be ensured. Behavior based modeling offer 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 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 on origin and validation of the utilized knowledge should be included otherwise responsibility for the product can not be evaluated.

An advanced form of model objects in virtual environments is autonomous intelligent agent that is created by human or computer procedures (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 creating procedures or indirectly by instruction or knowledge placed in agents. Behavior of agents is modeled in a multi-agent system. This modeling environment constitutes a reactive system. Reactive behavior of agents is controlled by appropriate creation of the model. Series of circumstances are identified and responded. 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.

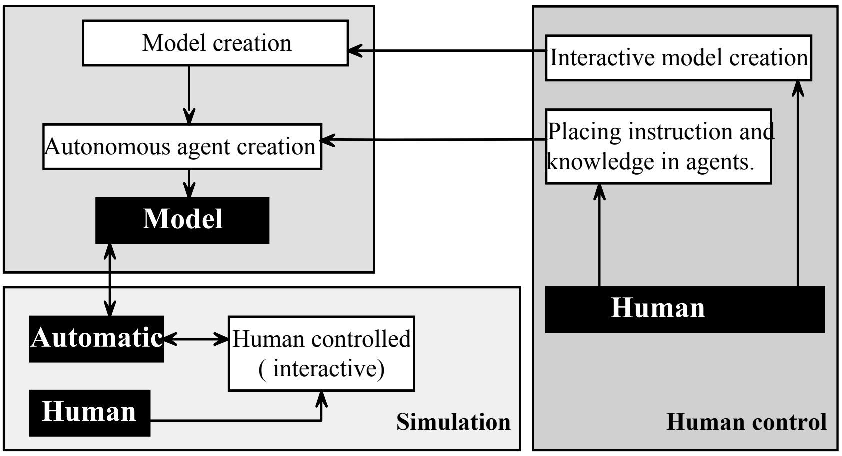

Figure 3
Model objects as agents

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. Enhanced competition-orientation of design engineering urges and stimulates application of behavioral techniques.

A virtual environment is developed specially for a problem area. Situations based on series of circumstances are analyzed at application of virtual environment for problem solving purpose. 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 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 revealing all parameters that influence a selected parameter. The second simulation allows 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 build blocks for shape models and act as modifiers for a previous shape. A sequence of shape modifications leads to the final shape of the part. Other non-geometric part and part manufacturing information including suitable and available manufacturing resources is mapped to form features. Typical shape representation of form features is unified topology-geometry. The authors have proposed application of marked Petri net with some extensions as representation of part manufacturing process model features [4]. In the Petri net model a transition represents a setup or an operation process object. Manufacturing process model features are in associative relation with form features defined on the part to be manufactured.

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 represented in models of mechanical systems.

3 Methodology for Modeling in Virtual Systems

Recent practice in modeling by CAD/CAM systems is definition of form features then attaching attributes and geometric model representations to them. In the author's approach the feature approach 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 research activities 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.

One of the most effective methods 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 means propagation of the effect of changes in models. Propagation of any change of model at any stage of modeling makes whole 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 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.

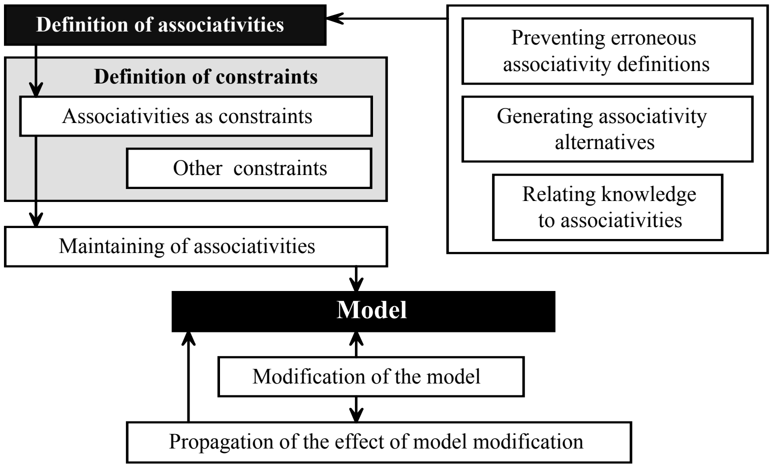

Figure 4
Associativities in knowledge based models

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 designer 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.

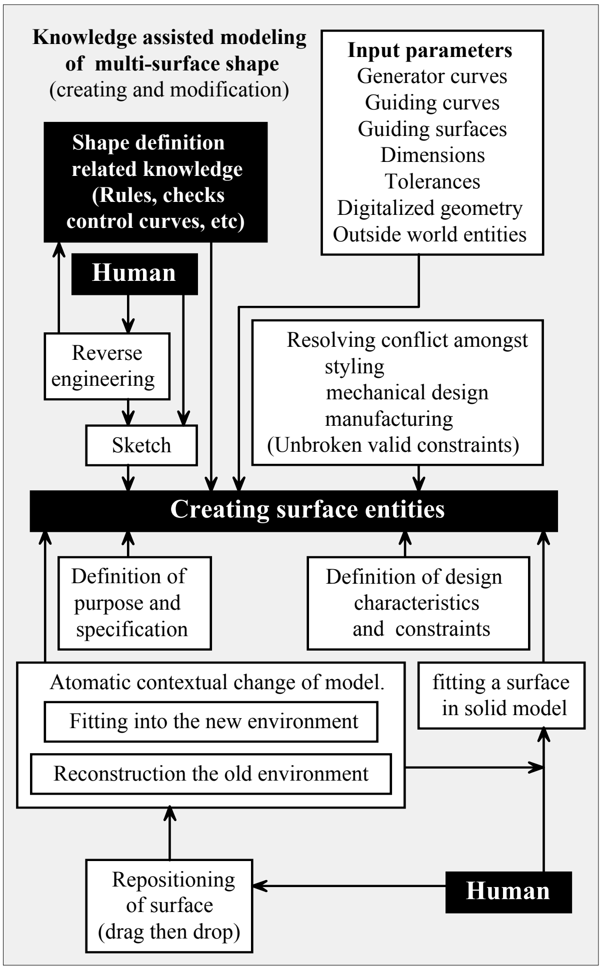

Figure 5

Knowledge based handling of complex surface features

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 is applied to propagate effects of surface modifications. Other important area for application of intelligent computing is recognition of sketched shape and creating surface model for it. Other surface related intelligent modeling can be utilized by reverse engineering to transform shape related knowledge from the physical world to virtual.

Repositioning by dragging then dropping of a form feature by human interaction of human during development of a 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 displacements 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 Part Model with Active Characteristics

The authors proposed an active part model that is able to inform designers 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 designer. 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 product 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.

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 can 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.

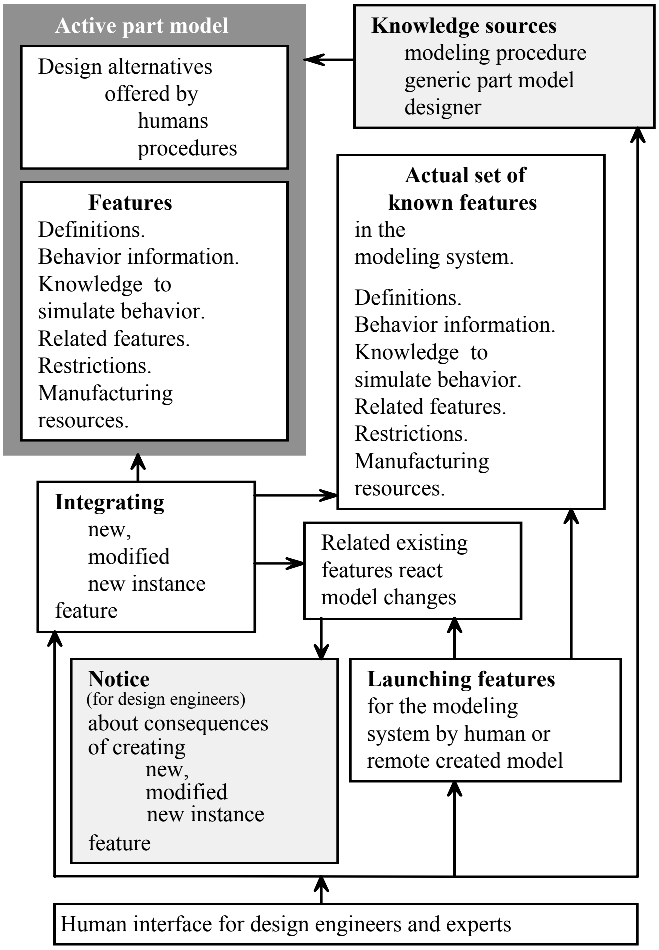

Figure 6
Active model

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 then they can be accessed through Internet. Also, advice taking can be made available by remotely residence engineers in this way.

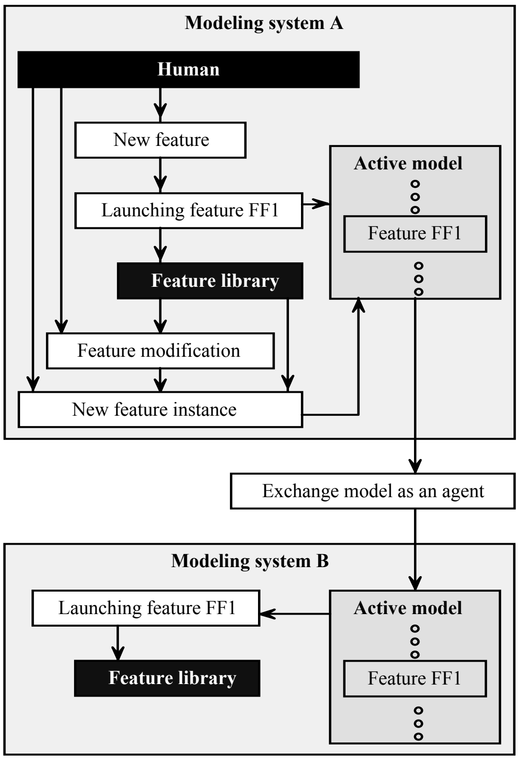

Figure 7
Feature in active model

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 the active model in the modeling system *B* is also included in the model.

5 Design Intent Supported Intelligent Modeling

Procedures for human-computer interaction (HCI) are adapted and enhanced for effective communication based design intent modeling. Modeling of design intent is in close connection with knowledge acquisition, data access and authority control, functions for human interactions, behavior of humans, human-human communications and human errors (Fig. 8). The authors restricted their research to development of design intent handling methodology and processes including effects of human related issues on modeling of human intent.

Design intent often appears in some form of knowledge, but its source is not a single knowledge base. The related knowledge is domain but also product, designer and customer related. Consequently, it can not be involved in the modeling system in one of the conventional ways. Members of a group of engineers who are working on a product design can describe or point to different knowledge sources. Sometimes a knowledge is of personal nature in other cases access to a knowledge source is allowed for several engineers in a work group.

Quality of a decision depends on the performance of the human decision-maker. This performance can be increased effectively by the using of computer based decision assistance. At the beginning of her or his career an engineer is not well trained. Description of intents of skilled engineers can support beginners at their decision making. For that reason computer can learn decisions of skilled and experienced engineers in order to support decisions of less skilled engineers. Threshold knowledge can be defined and described and then used for the purpose of excluding untrained or careless engineers from decision making and avoiding fatal errors. This approach is called as mutual adaptive human-computer interfacing [9].

Design intent often is based on observations. Design or planning tasks are solved during cognitive processes where results of decisions are found out by designers. In this case it is very difficult to describe the human thinking process. Sometimes variants for types, parameter value ranges and discrete parameter values can be defined in intent descriptions. The authors considered modeling intent for model variants among the single decided variant. This makes it possible to change the decision to a more appropriate one during the application of the original product model. Understanding a given situation can be enhanced by appropriate intent descriptions from other engineers. This is the case of human-human communication using intent description.

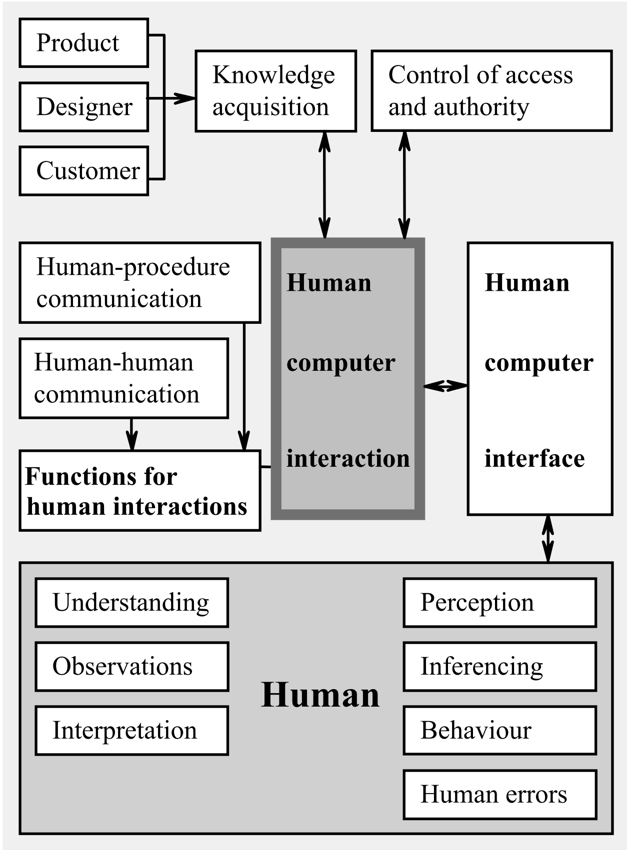

Figure 8
Human related issues

Intent description sometimes is a history description of the background of a decision by using of a chain of intent entities. Fig. 9 shows a typical chain of design intent entities and several referred entities from the outside world. Intent is mapped to a result of a decision in the product model as an entity, a parameter or a relationship of parameters. List of referred entities acts in the intent description as information source needed at processing of the intent description. Referred entities can be accessed using links included in the intent description. It should be emphasized that Fig. 4 shows only one of the possible styles of history. A history can be a simple identification of the decision-maker such as the management of a company or an authority without any explanation. History is considered as a chain of explanations for stages of a decision. Generic product models can involve generic intent models.

In the case of our example (Fig. 9) firstly a goal is defined for the decision then the related taxonomy is revealed. This is followed by a consideration of the applied procedure as a thinking process of the engineer. In other words she or he did not apply any idea from handbooks, etc. Next the applied method is selected taking into consideration of the choice that is offered by the selected procedure. Alternative procedures and methods can be involved or referred if necessary. The procedure needs input data that were defined using production rules, functions and experimental results. The origin of the experimental results is an important element of the intent description.

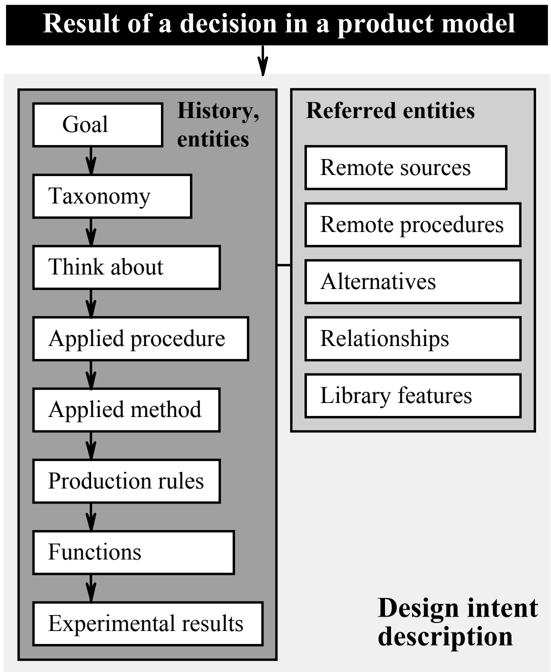

Figure 9
Structure of a design intent

Several typical considerations at modeling of design intent in the practice of modeling of mechanical parts are illustrated and discussed below by an example. Complex surfaces are often created using complex curves that govern their shape. Fig. 10 shows a section of a complex surface that consists of six component surfaces (*A-F*). Structural requirements were considered then surface types and dimensions were decided. Relationships of dimensions were defined. Then values of some dimensions were calculated. Fixed values of dimensions were defined as constraints. Other dimensions are allowed to be modified within well-defined ranges. These ranges were not described in the part model. Instead, one of the possible values was defined as a constraint. To assist later modification of this decision and to prevent later changes of the dimensions to move into illegal range, the allowed ranges of these dimensions were recorded as design intent entities. Component surfaces *A* and *F* should be flat and component surface *E* should be cylindrical. All component surfaces are described using rational B-spline functions that offer free modification of their shape. Consequently, type of *A*, *E* and *F* surfaces should be constrained to avoid modification of their shapes as free form surfaces. There is a relationship between dimensions *A4* and *R1*. Elements of the intent description for decisions at the above discussed example are:

- *Decision on relationship* A_4-R_1. This decision is based on a method by an expert. Several alternative solutions were defined. These are involved in the intent model.
- *Shape of component surfaces B and D.* Modification of these free form surfaces is allowed. Although dimensions $A_{1\ min}$ and *A6* limit the modification of these surface components.
- *Shape of flat component surface C.* This surface can be modified as a free form surface if mating surfaces of other parts are modified accordingly. Cost consequences can be estimated by a procedure that is related to the intent description and can be accessed through Internet.
- *Fillet surfaces* connecting component surfaces can be modified with keeping the continuity between the connected surfaces and them.

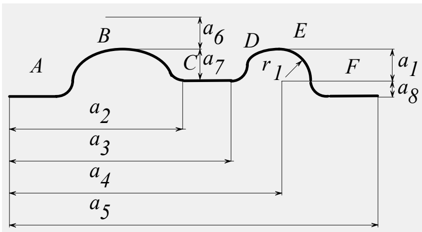

Figure 10
Design intent at the creation of a section for creating a complex surface

Is an intent count for much? Similar questions affect application of intent information. The answer is often subjective. Consequently, decisions can be assisted by the description of origin, limits, strength and consequence of omitting of intent. On the other side, sometimes engineer is not able to produce a good explain for a decision. This is because intuition and anticipation are still important factors at decisions of skilled and experienced engineers. Finally, an intent description acts on behalf of the engineer who created it.

Conclusions

The reported research is aimed to develop an 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 of the related engineers. 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 models.

Active models are proposed to describe human originated knowledge on the basis of design intent modeling. Advanced product modeling handles model entities for description of results of human decisions, but not for description of background of those decisions. Frequent modification of models is done by engineers other than the original decision-makers. Intent of the original designer is required to do this without any loss of quality of the model. The authors proposed a method for modeling the background of decisions as design intents. They proposed a method for mapping design intent model descriptions to product model entities. Intent modeling describes human thinking process and considerations behind human decisions. Intent description can be used by both model application processes and humans who handle them. Implementation of the method assumes object oriented open surface modeling systems. Referred intent entities from the outside world are applied to link intent information to the intent model that are not economical or not allowed to involve in the intent model. The proposed method can be considered as an extension of collaborative engineering. Outstanding importance of its application is where the original decision-maker is not accessible and the only assistance at modification or evaluation of an earlier decision is application of design intent description. Intent modeling is not modeling of what should be done by an engineer but what did an engineer and what are consequences of future work of other engineers. It can be considered as a well-prepared substitution of the engineer by computer procedures.

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] L. Horváth and I. J. Rudas: "Virtual technology based associative integration of modeling of mechanical parts", *Journal of Advanced Computational Intelligence*, vol. 5, No. 5, pp. 269-278, 2001.

[2] L. Horváth, I. J. Rudas and C. Couto, "Integrationration of Human Intent Model Descriptions in Product Models", in book *Digital Enterprise - New Challenges Life-Cycle Approach in Management and Production*,: Kluwer Academic Publishers, 2001, pp: 1-12.

[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] Laszlo Horvath, Imre J. Rudas, "Evaluation of Petri Net Process Model Representation as a Tool of Virtual Manufacturing", *in Proceedings of the 1998 IEEE International Conference on Systems, Man, and Cybernetics, Information, Intelligence and Systems*, IEEE, San Diego,California, USA, 1998, Volume 1, pp. 178-183.

[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

[9] Yoshikawa, H. - Takahashi, M.: Conceptual Design of Mutual Adaptive Interface. Preprint of Integrated Systems Engineering Conference, Baden-Baden, 1994, pp. 221-226.