Behavior and Petri Net Based Techniques for Intelligent Engineering Modeling

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Abstract

Principles, approaches and methods by the authors are discussed in this paper for intelligent application of advanced engineering modeling in industrial CAD/CAM systems. The reported research started from earlier results in development of integrated feature based product modeling. Modeling methods are introduced and an active model is proposed that integrates knowledge from modeling procedures, generic part models and engineers. Paper discusses engineering modeling for application of intelligent computing and knowledge management. Next, behavior based model with intelligent content involving specifications and knowledge for the design processes is emphasized. Then methods for some applications of computational intelligence in computer model based engineering systems are detailed including knowledge driven models as well as areas of their application. Following this, Petri net model representation of engineering objects by the authors is explained by the example of manufacturing process planning. Finally, an active modeling is proposed and some possibilities for its application are outlined.

Keywords: Engineering modeling, behavior modeling, active modeling, modeling by Petri net, virtual environment, computational intelligence.

1. Introduction

Shapes, 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. To do this, advanced process-centric, model based digital definition techniques are available for development of products. Products are positioned for e-business among others by the help of 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 concept of digital enterprise where all engineering activities and equipment controls are done within a highly integrated modeling system.

Engineering processes still require skilled engineers. They are sitting at computers with advanced user communication and model creating features. However, 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. 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 part related engineering modeling is motivated both by expectations for high performance of part and well-engineered shape. The performance of modeled objects is 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 tools for making parts or the parts themselves [7]. 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. Application of intelligent computing presently means mainly separated application of the related advanced computing methods. This completes present day advanced engineering modeling. The authors are thinking in engineering modeling that has inherent intelligence. The reported research is intended to be a contribution to this approach.

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. The reported research relies on previous research projects by the authors. They proposed methodology to integrate manufacturing process modeling with form feature based part modeling by the using of relationship and constraint definitions [1]. They also modeled the background of human activities in engineering modeling [2]. An integration of human intent model descriptions in product models was proposed in [3]. Early efforts of the authors for application of Petri net representation for modeling of manufacturing processes were summarized in [5].They also proposed an extended application of the feature principle in [4].

This paper discusses engineering modeling for application of intelligent computing and knowledge management. Next, behavior based model with intelligent content involving specifications and knowledge for the design processes is emphasized. Then methods for some applications of computational intelligence in computer model based engineering systems are detailed including knowledge driven models as well as areas of their application. Following this, Petri net model representation of engineering objects by the authors is explained by the example of manufacturing process planning. Finally, an active modeling is proposed and some possibilities for its application are outlined.

2. Knowledge Based Approach in Virtual

Advanced models in the virtual world of computers include several elements of knowledge engineering. Really this is a good starting point for wide application of intelligent computing. Models are product model related, application oriented feature and associativity driven ones and 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 in concurrent group work of engineers is assumed where the same model is handled by several engineers. Both modeling procedures and designers can utilize model-related knowledge in order to achieve an 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.

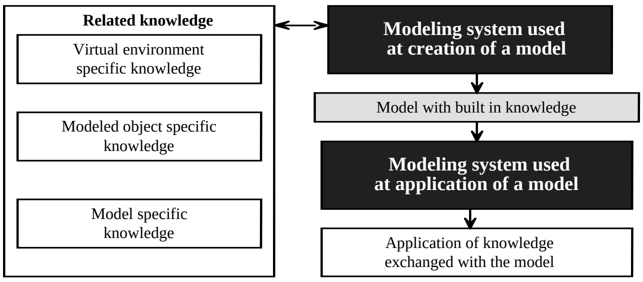

Fig. 1. Approach to knowledge based modeling

An additional important characteristic of models is their knowledge content. 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 new approach is anticipated to be one of the most researched and developed areas in model based engineering design during the next few years. Significant part of knowledge necessary at later processing of a model is model, modeled object or modeling system specific or simply is not available at the application of the model (Fig. 1). This knowledge is exchanged with models between modeling systems. Built-in knowledge helps engineers at development, modification and application of the model. It can prevent model quality from deterioration at its 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 real world object before, during and after their manufacturing. Recently, advanced modeling systems that include models of this kind are called as virtual environments**.**

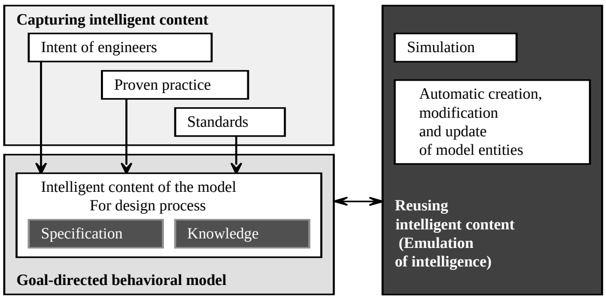

Fig. 2. Knowledge driven modeling

Model that has the capability of reaction using behavior related knowledge can act as an intelligent design of the modeled object that 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 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 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.

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 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 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.

Humans and computer procedures (Fig. 3) create model objects in virtual environments as autonomous intelligent agents. Intelligent agents are autonomously working procedures in the software system with goal-directed behavior interacting with given environments [6]. 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 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. Enhanced, competition-orientation of design engineering urges and stimulates application of behavioral techniques.

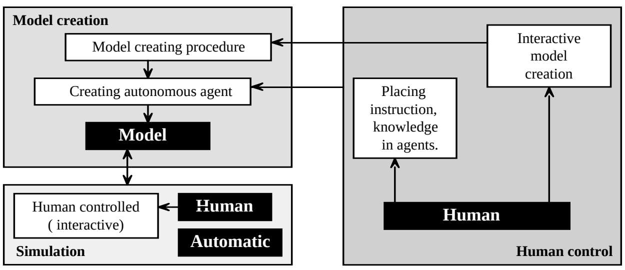

Fig. 3. Model objects as agents

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 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 reveals all parameters that influence a selected parameter. The second simulation determines 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 [9]. Form features are elementary build blocks for shape modeling 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 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.

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.

3. Basic Method of Modeling

One of the most advanced modeling methods is object definition by features. The well-proved form features carry application, shape and geometric model representation information about parts of mechanical systems. 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 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 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.

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 [8]. 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 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. 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.

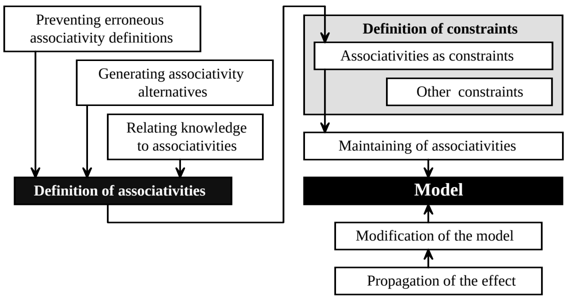

Fig. 4. Associativities in knowledge based models

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.

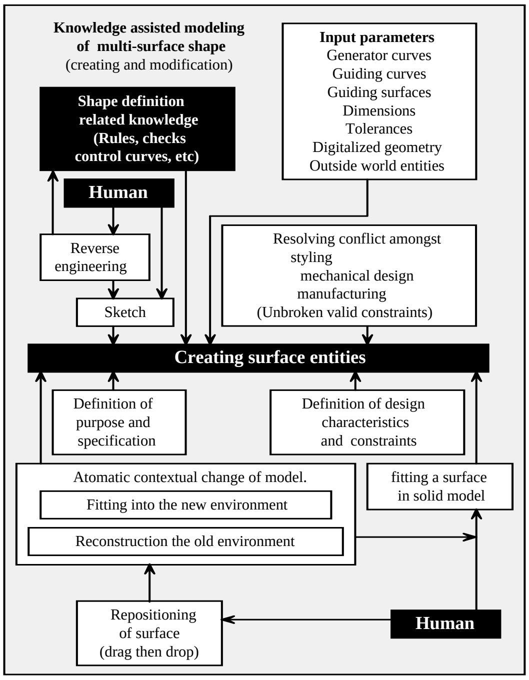

Fig. 5. Knowledge based handling of complex surface features

4. Petri Net Model Representation of Engineering Objects

In the Petri net model representation by the authors process model entities are represented by marked Petri net formalism with several extra features. In a Petri net model entity a transition represents a setup or an operation machining process object (Fig. 6.). Description of the represented process object is mapped to the transition in the form of a set of attributes. Pairs of special purpose transitions are used for creating branches representing *AND* and *OR* splits and joins. A place carries marking and links to rules for selection and evaluation of the process object represented by the subsequent transition. Constraining can be defined by using of these rules. A transition can have one of two states. If the represented process object is in the actual process, the status of a transition is *in process* otherwise *out process*.

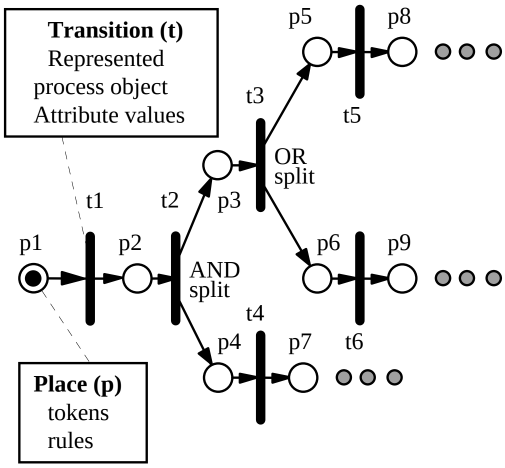

Fig. 6. Petri net and manufacturing process objects

The authors proposed generic manufacturing process model with four-leveled structure (Fig. 7). On *level 1* process variants are mapped for manufacturing of the part. *Level 2* involves process features that describe all possible sets of setups for a process variant. A setup is a segment of a part manufacturing process that uses a machine tool with the same clamping position of the part under machining. Possible sets of operations for a setup are placed on *Level 3*. Operation is a segment of a manufacturing process that uses a single cutting tool. *Level 4* is for possible tool cycle sequences. Process model can be generated for a cluster of parts or a single part.

The above outlined generic manufacturing process is described as a set of process features and their relations. A manufacturing process model entity is an instance of a generic process feature and involves all process variants suitable for a well-defined manufacturing task. Process, setup, operation and machine tool path cycle are defined as manufacturing process objects. Manufacturing process features are process, net of setups, net of operations and sequence of machine tool path cycles. They describe manufacturing process objects and their relations on the levels of process (*L1*), setup (*L2*), operation (*L3*) and numerical control cycle (*L4*). Definitions of manufacturing process features and objects are similar to as applied in every day practice of manufacturing engineering. Process, net of setups and net of operations process features have net structure and represented by Petri net.

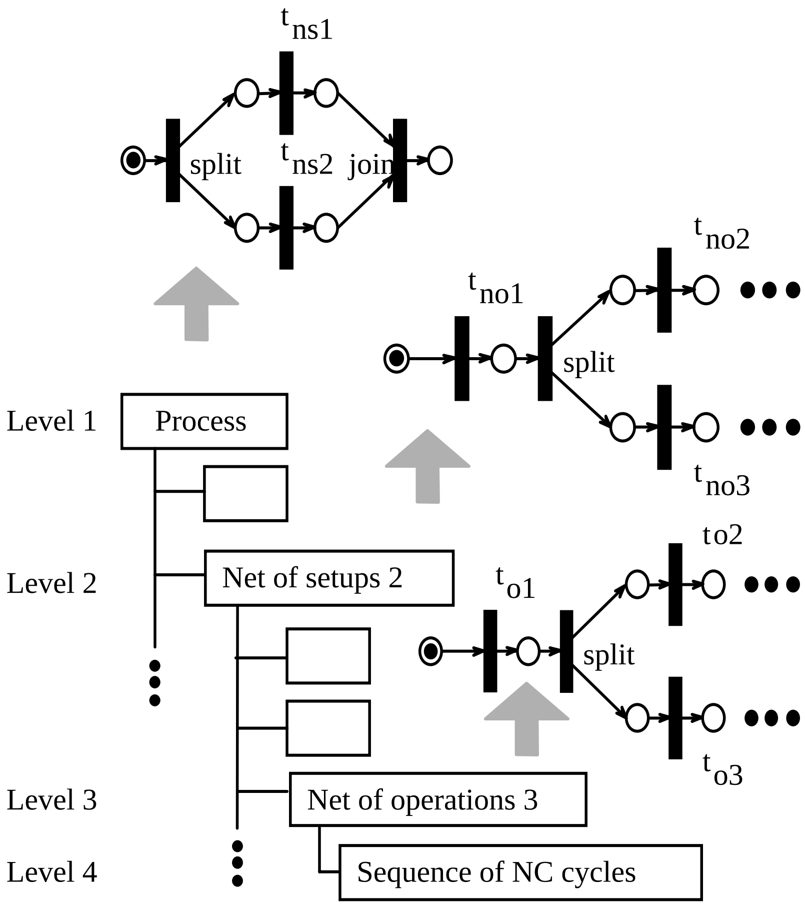

Fig. 7. Four leveled model of the manufacturing process

Part and part manufacturing process models are integrated by associativity definitions between their entities as it can be seen on Fig. 8. Associativity is a relationship definition between the related models. The sequence of shape modifications by form features in a part model can be defined as a sequence of machining operations. However, part design oriented sequences of shape modifications are often must be reordered to fulfil the demands posed by operation sequences within individual setups. Form feature is related to operation or machine tool path cycle manufacturing process object through attributes. Geometric representations are mapped to form features in the form of curve and surface sets and can be accessed through description of topology in boundary representations of shapes. Geometry is related to manufacturing process through topology.

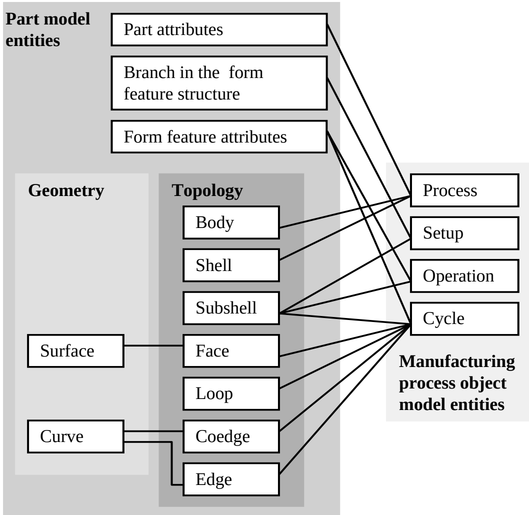

Fig. 8. Definition of part manufacturing process model associative with part model

Generic process model features are created in a generative way using information and knowledge about manufacturing task, related experience of manufacturing engineers and job floor environment. Procedure for creation of a net of operations feature can be followed on Fig. 9. The first step is definition of the manufacturing task on the basis of part, manufacturing environment and manufacturing process capability information. Capability of a machining process depends on the available machine tools, cutting tools, human expertise and skill on the job shop level. Manufacturing process feature class definitions are accessed in classification trees. Class of process feature for the manufacturing task is selected by using of rules and stored feature class related knowledge. Classification tree gives class for values of parameters in the manufacturing task. Where the tree does not give solution rules or human interaction must be applied.

Detailed creation of generic feature uses generic feature structure description stored for feature classes. Structure description also includes process object attributes. Fig 9 illustrates the process of feature creation by an example of process structure description with nine operation manufacturing process objects (*Op1*-*Op9*) for net of operations features. In this example process objects are center drilling (*Op1*), drilling with two stepped twist drill (*Op2*), drilling (*Op3*), boring (*Op4*), drilling with two stepped precise drilling tool (*Op5*), reaming (*Op6* and *Op7*), counterboring (*Op8*) and deburring (*Op9*). Structure may be described in different ways. A simple and readable version is applied:

START;

Op1; *net starts with Op1 process object*

Op2 or Op4 or Op3; *net splits, Op2 or Op4 or Op3 can be selected*

IF Op2 THEN Op7; *on the Op2 branch Op2 is followed by Op7*

IF Op3 THEN Op5 subs Op6; *on the Op3 branch Op3 is followed by Op5 and Op6*

IF Op7 OR Op4 or Op6 THEN Op8; *Op7, Op4 and Op6 is joined to Op8*

Op8 subs Op9; *Op9 follows Op8*

END>

The generic feature structure is adapted according to the manufacturing task. In our example *Op7*, *Op4*, *Op6* and *Op8* were proved to be unneeded by the analysis of the actual manufacturing task. These process objects were deleted from the structure. The simplified structure is more or less generic depending on the manufacturing task and the operations available at the considered shop floor facilities. The modified structure carries all information for creating Petri net and its objects. Transitions are defined as representations for process objects and splits and joins. Following this, place objects are created and placed and initial marking is given to the starting place.

Rules and formulas at places and transitions serve evaluation of feature representation, calculation of process object attribute values and constraining process object parameters. Net, place, transition, arc and token Petri net objects are interrelated by using of special purpose rules.

5. Active Models for Distance Applications

The authors proposed an active part model that among others generates information for 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 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.

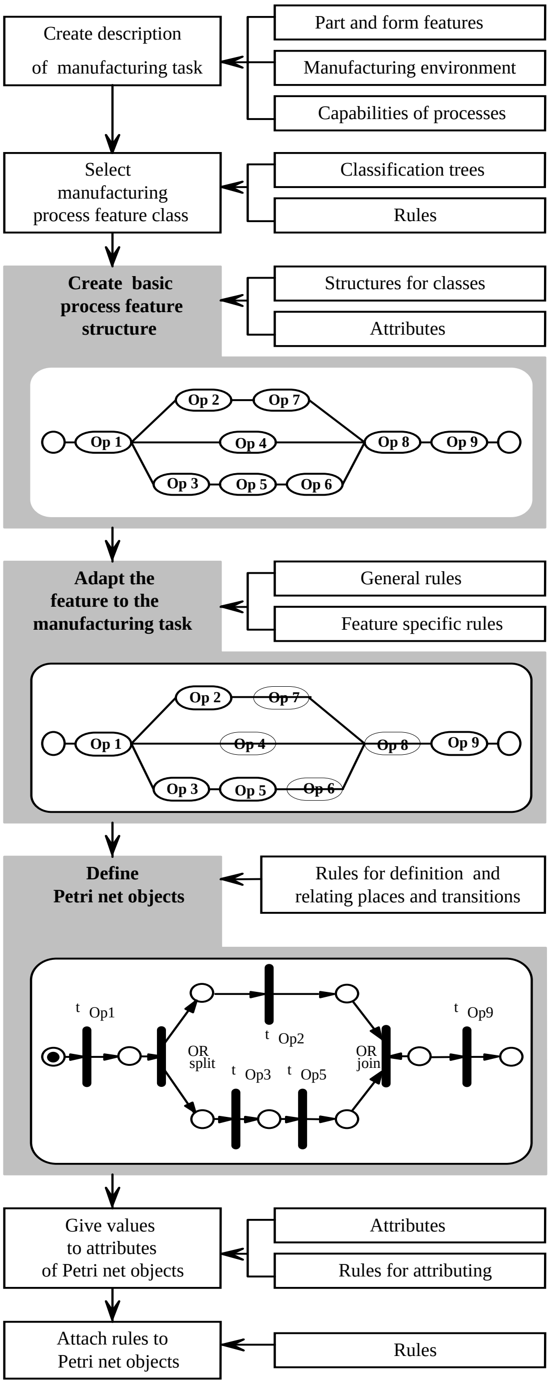

Fig. 9. Procedure for creation of a process model feature

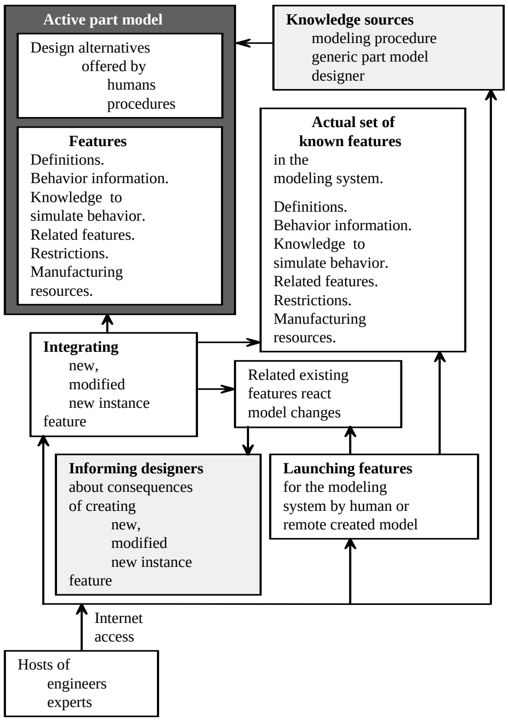

Fig. 10. Modeling with active models

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. 10.). 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. 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.

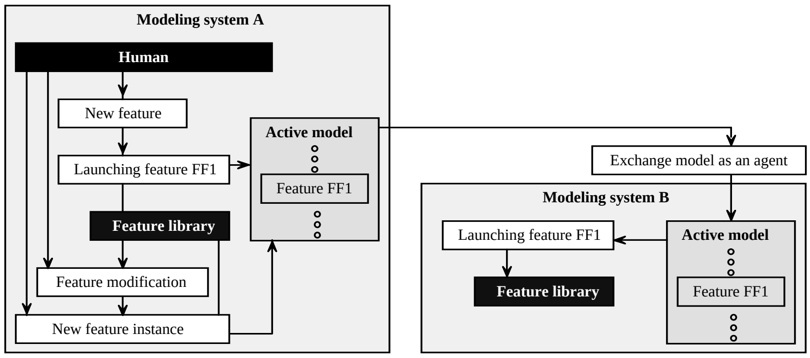

Fig. 11. Feature in active model

Feature definition in case of agent based active model is outlined in Fig. 11. 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.

6. Conclusions

Several modeling techniques have been discussed as a contribution to integrate intelligent features of models of product and production process objects The reported research is aimed to result in 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. Also a chance for integrated modeling of product and its manufacturing process is given by the application of Petri net model representation as it proposed by the authors. 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

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