Magyar Kutatók 7. Nemzetközi Szimpóziuma
7th International Symposium of Hungarian Researchers on Computational Intelligence

Application-oriented Integration of Decisions in Product Engineering

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Abstract: More and more sophisticated engineering software constitutes highly integrated systems in recent product management environments. This quick development has not been followed by appropriate development of engineering processes, especially in support of product related decisions. The main cause of this situation is that a higher level of contribution would be necessary from the engineers involved in research and development of application of engineering software systems than presently available. As a contribution to application oriented research, this paper discusses modeling and processing capabilities of virtual intelligent environments for support of complex world of engineering decisions. An approach to virtual intelligent space by the authors as an analogue of physical intelligent space is utilized. The authors consider virtual intelligent space as an enhanced and highly integrated application of recent advanced CAD/CAM, human-computer, collaborative, product data management, Internet portal, and intelligent information processing techniques. At a high level of simulation, sensor signals of physical intelligent space are replaced by received change information about modeled objects and their environment. Processing of changes is done by intelligent behavior analysis. Adaptive action generators replace actuators. The paper starts with an outline of related issues in description of engineering objects in product models. Following this, an engineering decision oriented analysis of product modeling in engineering space introduces approach and methodological considerations by the authors. Finally, descriptions, actions and procedures for the management of product changes are detailed as main issues in the methodology proposed by the authors.

Keywords: Product lifecycle management, product modeling, integrated models, decision assistance in engineering

1 Introduction

Advanced information technology brought two main enhancements in engineering. First, sophisticated computer descriptions for engineering objects including products, humans, knowledge, production environment, etc. enhanced quality of products, their application and work of engineers. Second, engineering systems have been integrated in global computer systems where high number of advanced software tools and services are available for engineers. As a consequence of the above tendency, most of physical prototyping have being moved into virtual in the recent industrial practice. Virtual prototyping or in other words virtual manufacturing allows for prototyping without any physical manufacturing or measurements. Essential technique for representation of associative product information is integrated product modeling where large amount of well-organized data is handled. Products can be defined, developed, assessed, improved, and optimized in computer systems.

When products work in physical environments, intelligent computer control system can integrate them into highly automated complex systems such as building management systems or flexible manufacturing systems. One of the recent trends in integrated automation is intelligent space. Comprehensive systems use sensing actual inside and outside parameters as information source for intelligent computing. A purposeful computer system decides actions and provides information for actuators, control devices, and human decisions. All functions in the space are under coordinated integrated intelligent control.

Authors propose techniques for integration of model definition, communication, analysis, and decision-making processes, and introduce essential issues from integrated application of these techniques. The approach to virtual intelligent space by the authors is an analogue of physical virtual space. In the context of the proposed application, virtual intelligent space is an enhanced and highly integrated application of recent advanced CAD/CAM, human-computer, collaborative, product data management, Internet portal, and intelligent information processing techniques. At a high level of simulation, sensor signals of physical intelligent space are replaced by received change information about modeled objects and their environment. Processing of changes is done by behavior analysis. Adaptive action generators replace actuators. Two potential applications of virtual intelligent space are modeling and analysis of intelligent robot systems and simulation of a cooperating intelligent space in the world outside of it.

Integration and development of product modeling environment into intelligent engineering space can be achieved by using of integration and programming tools available in industrial modeling (CAD/CAM) and product data management (PDM) systems. Most of the software for definition and management of virtual engineering spaces are available in the form of configurable program products. The authors consider engineering environment for a virtual space as integrated application of engineering and intelligent software tools that are in possession of capabilities for integrated application. The authors did several researches in support of decisions where humans and intelligent computing cooperate. They conducted systematic analysis of recent techniques for engineering modeling and published results in book [1]. They analyzed extended application of the modification feature principle where engineering objects are described as sequences of modifications of initial objects by predefined features [2], [3]. Other preliminary research by the authors was in modeling of human intent at engineering decision [4], and integration of model description of human intent in product models [5]. Recently, the authors proposed a technique for handling of changes in models of engineering objects [6].

The paper starts with an outline of related issues in description of engineering objects in product models. Following this, an engineering decision oriented analysis of product modeling in engineering space introduces approach and methodological considerations by the authors. Finally, descriptions, actions and procedures for the management of product changes are detailed as main issues in the methodology proposed by the authors.

2 Description of Engineering Objects in Product Model

Engineering systems typically organize product description around description of shapes of mechanical parts. Form features are defined by application aspects and represented in boundary of solid part descriptions. Unified geometry in the form of B-spline curves and surfaces, and unified topology allow an unlimited extension of sets of form features. Shapes are placed in three-dimensional spaces. They can accept any other information as attributes, linked non-geometric objects, and knowledge descriptions. Possibility of including arbitrary intelligence and conventional knowledge content in description of a space has been established in professional modeling systems for industrial applications. A main track of future research is filling modeling systems with intelligent content in the industrial practice. Objective of the reported research by the authors is a contribution to these efforts.

Reference models, modeling resources, and application protocols are essential techniques for implementation of application oriented product modeling [7]. Application oriented form features [8] in computer definition of shape models demand conversion of design features into manufacturing features [9]. The authors extended the application of feature principle to behavior and adaptivity definitions [3]. Utilizing modeling related techniques of reverse engineering, an existing part can be a source of geometric definition for surface measurement; surface reconstruction; tool trajectory planning, and adaptive motion control [10]. Most of industrial applications can work with arbitrary shape, size, and location as defined in part models. In this case, robot is moving in a priori known environment. One of the methods available for motion planning considering known geometry is proposed in [11]. Smooth curve without self-loops connects the starting and destination points with the shortest possible path. Geometry information in part models and assembly constraint driven complex geometry information for subassemblies and products are often used at robot applications requiring a shape to be followed. In [12], distance between any rivets on a path, the number of turns and the overall distance are considered by a geometry driven optimizing process.

Research in intelligent computing focuses on several issues urged by applications. Excellent behavior [13] and agent [14] based techniques represent an initial stage of intelligent engineering modeling. In [15] Petri net representation is proposed for design and implementation of an execution control, which, through suitable graph-search algorithms, generates sequences of task activation/deactivation operations, which execute the desired commands maintaining the system in admissible configurations. Machine learning is essential in case of unforeseen environmental conditions. Environment composed by known and unknown elements are typical at certain applications. Robot controller can learn on-line about its own capabilities and limitations when interacting with its environment. A method is proposed in [16] where off-line supervised neurofuzzy learning and on-line unsupervised reinforcement learning, and unsupervised/supervised hybrid learning are applied at control of gripper. Application of Fuzzy methods is of essential importance [17], among others at reduction of rule sets at representation of corporate knowledge. Authors of [18] demonstrate that knowledge level based explanations of cognitive processes provided by traditional artificial intelligence and approach of embodied systems interacting with the real world in new AI can be unified. Author of [19] examined how UML, as the most widespread modeling tool of object-oriented software development, supports practical user interface development. He proposed application of the usage interaction model and the usage control model, each of which can be described by supplementing well-known UML diagrams. Product modeling is strongly connected with high precision co-ordinate measuring [20]. Modeling often serves special applications such as geometric modeling in reconstructing surgery [21].

Engineers specify sets of entities, their attributes, and associative relationships of attributes to describe and relate a set of physical and logical engineering objects. Intelligence in model of an engineering space lets engineers to know what combinations of entities, attributes and relations result the specified behaviors of given modeled objects. On the other side, intelligence helps to answer the question how will modeled objects behave.

3 Product Modeling in Engineering Space

Modeling of products for the description of all information required by engineering processes for product lifecycle needs comprehensive capability for representation of engineering objects. The authors propose engineering space as a special virtual space. Main purposes of engineering space are organized engineering processes, consistent description of engineering objects, and traceable changes of engineering processes and described objects. Computer description of a mechanical structure consists of parts, assembly constraints, and joint definitions. Key techniques are analyses of mechanism motions including checking interferences and computing minimal distances. As a basic feature of an intelligent virtual space, digital definitions of engineering objects are based on assessment of behaviors according to intent of engineers in virtual.

A question emerged in engineers is what means intelligence in an engineering or production system. The next question is how intelligence is included in the system. Presence or interfacing of a human is often impossible or simply the minimum time necessary for human decision is not available. Humans describe their own intelligence in computer for assistance of quick decisions. The original problem at modeling of intelligence is that humans are not aware of processes that actually produce their intelligence. This is why experience is the primary basis of definition of machine intelligence.

The following problem is that continuously changing situations need system that model itself. The system should be configured to analyze its own behavior during operation. This is why physical objects are engineered or controlled by behavior driven computer procedures in the proposed method. Actually, a behavior driven engineering system is not inherently intelligent but only can act intelligently at accomplishing certain tasks. This intelligence is some rational behavior of physical objects on tasks. Situations for behaviors can be learnt then adapted to tasks.

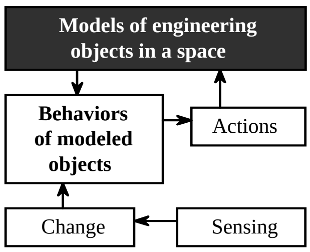

Figure 1

Virtual engineering space

Fig. 1 is a sketch of essential activities in a virtual engineering space. Modeling in the space is done in the form of interconnected descriptions of engineering objects as components and structures. Sensing function watches inside and outside changes and sends change information for processing by behavior analysis to check relevance of changed parameters to the predefined or new advantageous behaviors. When an engineer modifies a design objective in the form of new or modified behavior, its effect on related behaviors is also to be checked. Actions function communicates changes proposed by the intelligent system in inside and outside of the space. Situation is composed by parameters of impact on assessed behavior.

Engineering modeling based intelligent space handles typical engineering process related sets of information. Model of the space involves descriptions and actions (Fig. 2). Descriptions are for modeled objects and corporate knowledge. Their features, associativities, and behaviors describe modeled objects. Associativities connect entities inside and outside of the space. Descriptions of knowledge include engineer friendly representations as rules, checks, reactions, situations, and connective entities. Rules are applied for definition of entity parameters while checks help at maintaining earlier decisions and threshold knowledge. Other representations allow response to changes, composition of situations for behavior analysis, and record of networked information. Actions serve behavior analyses, lifecycle management of product data, inside and outside adaptive actions, collaboration of humans and procedures, and special browsing for group work on the Internet. Collaborative actions serve access and connection purposes. Adaptive actions are generated as attempts for modification of entities or their relationships. Situations modified by these changes are evaluated by behavior analysis.

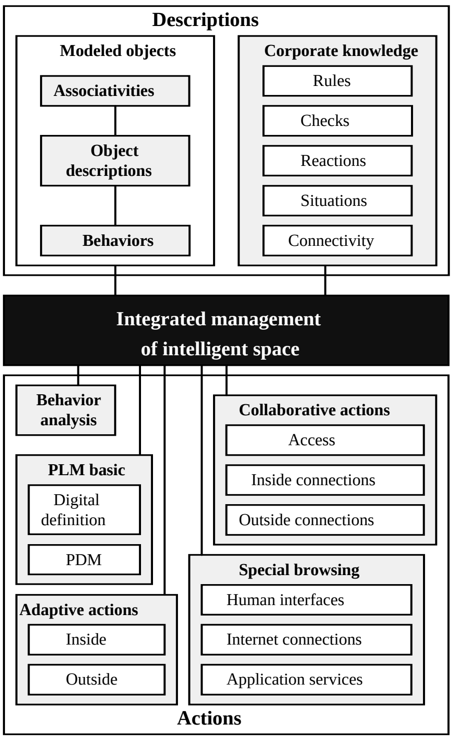

Figure 2
Integrated actions and descriptions

Processes in a virtual space integrate typical groups of engineering related information processing procedures. A logical structure of interconnected procedures is given in Fig. 3. Engineers and systems within the space and world outside of it are connected by portal procedures. Information exchange management is based on building and management of associativities. Actions are defined by behavior analysis and human related procedures. Knowledge management supports behavior analysis including learning and links to knowledge sources outside of the space. Human-computer interaction procedures communicate collaboration procedures. Product definition is under control of behavior analysis through action management.

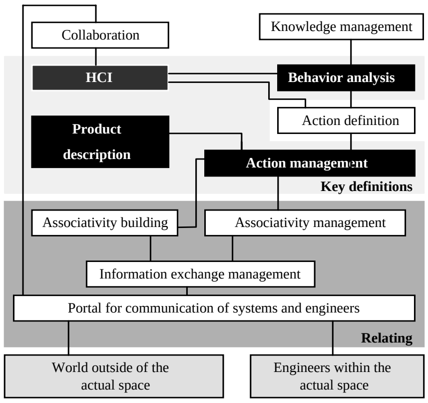

Figure 3

Connected functions in an engineering space

4 Descriptions, Actions and Procedures for the Management of Product Changes

Well-organized, transparent and safe management of changes of modeled objects and their models is still a critical problem of recent modeling systems. The main problem is handling of proposed but not accepted maybe rejected changes. Behavior-based method is used to evaluate models under development. This method assures a reflection of how the real objects behave. For the purpose of engineering activities for development, manufacturing, and application of products, behaviors represent engineering objectives. A modeled object is characterized by several behaviors according to its technical content.

Engineers control the intelligent space through specified and accepted behaviors for well-defined situations. This is the main essence of the method proposed by the authors. Any change of an object during its development affect one or more behavior. Consequently, any changes of an object and other objects in its affect zone require repeated evaluation for behaviors when a change modifies situation specified for the actual behaviors. Because behaviors represent design objectives, engineers may also change their specifications. Behavior specifications are originated from customer demands, requirements by engineering activities, experiences, and personal intents. Behavior features are applied to describe behaviors of modeled object at defined circumstances. Active behaviors define parameters of the modeled objects, while passive behaviors serve comparison of specified and actual behaviors.

Fig. 4 shows a simple example for implementation of the proposed behavior based assistance of decisions. A self-locking conical connection is created by design of two parts, *Part A* and *Part B*. Size of cone depends on version of *Part A*. On the other hand, version of *Part A* depends on version of *Part B*. Four situations are defined for four behaviors. All behaviors must be effective to serve parallel design objectives. Structure behavior depends on connecting parts while connection behavior depends on situation of placing of mated surfaces. Collision avoidance behavior is analyzed by moving volumes of parts. Finally, self-locking behavior requires appropriate cones.

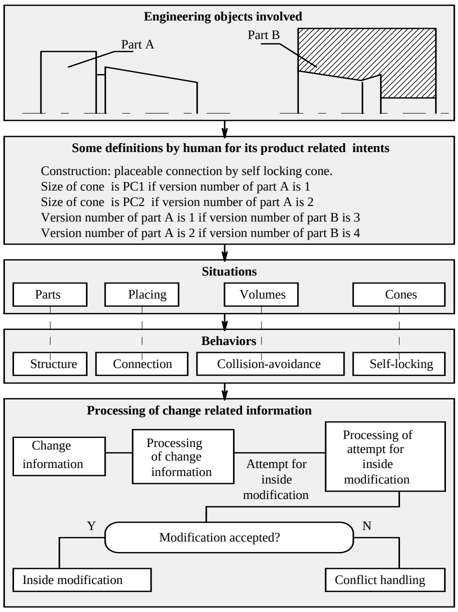

Figure 4
Situations for behaviors

Change management actions are under control of both humans and intelligent procedures for development of a product. Essential management of changes can be followed in Fig. 5. Management considers any changes of descriptions of engineering objects, physical or logical, in the virtual space as one that may modify one or more behaviors. It receives information about accepted and proposed changes from space procedures, humans, and outside world procedures. Changes are mapped as conditional adaptive actions. Their effects are analyzed.

The consequence of changes may be directly calculated modifications of elementary or composition object descriptions. Sometimes change of behaviors is necessary. In other cases, change of descriptions could be defined simply by associativities but it is abandoned due to improper changes of behaviors as revealed by effect analysis. Effect analysis may generate additional changes to be effect analyzed. Accepted decisions are considered as constraint adaptive actions. Inside changes are executed, while outside changes are proposed. In the outside world, change attempts are accepted or rejected, and new changes are generated. An intelligent system acts as an advanced navigator and not as a design automata. In an environment like this, engineers have much more chance to find a conflict free solution than in conventional modeling. Only authorized engineers and computer procedures are allowed to make space related decisions.

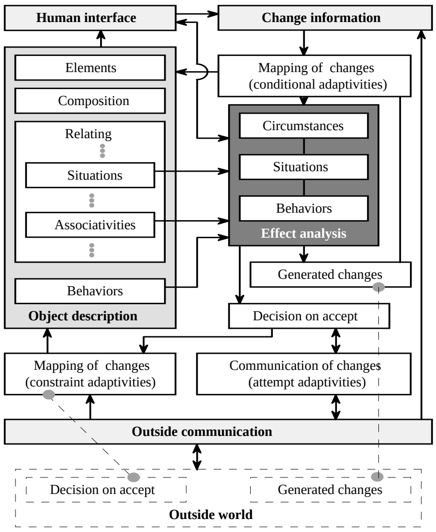

Figure 5

Essential handling of product changes

One of the main problems emerged at decisions assisted by computer model is that consequence of a change of a model describing several interrelated modeled objects extends to outside of a modeling environment. This enforces connection of modeling systems into global engineering systems in extended enterprises encouraging the authors in their studies for outside connections of the conceptualized intelligent spaces. The objects on which a modeled object has any effect are considered to be in the affect zone of that modeled object. Some objects in an affect zone may be accessed only from the world outside of the space. Despite efforts to standardized models, as reference models and application protocols, incompatible models even unmodeled objects are to be interfaced in the industrial practice.

Instances of descriptive entities, situations, associativities, adaptive actions, and behaviors are defined by knowledge driven specialization of generic object descriptions. Groups of change related activities are showed as a process in Fig. 6. As a first step, affected objects, circumstances, and situations are identified. To establish the communications, inside, outside and unavailable associativities are selected for the affected entities. The process can reveal unknown associativities but engineers must define them. Following this, values of inside and outside associativities are calculated. Then adaptive actions are generated according to specified behaviors using values of associativities. Value of an associativity may be a simple number, an allowed range, an equation even a procedure.

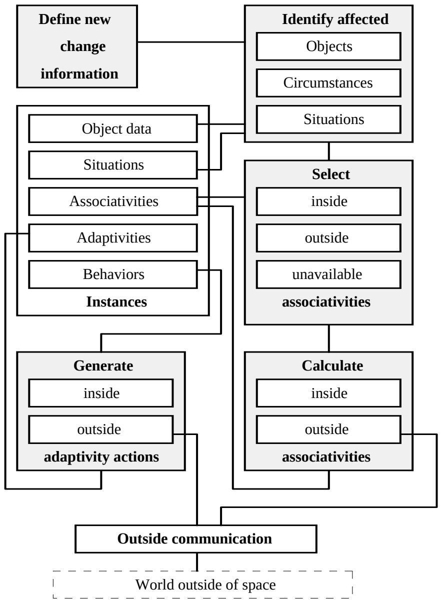

Figure 6
Activities for the management of product changes

Conventional knowledge based systems apply domain knowledge for inference or other type of decision assistance. Recent modeling systems apply corporate knowledge. The authors emphasize the personal intent nature of knowledge at engineering in [2]. This is why multiple decisions are controlled by combined intent. Simple decisions may have complex human background. For example, decision on a single dimension by an engineer who is responsible for it may apply knowledge also from scientists, standards, legislation, local instructions, and decisions of engineers on a higher level of hierarchy or customer demand. Engineers and other humans participating in these decision chains apply knowledge from other sources through a filtering by personal, corporate or even official intent.

Combined intent at decision processes in intelligent modeling is explained in Fig. 7. Decisions are supported by three basic methods. They are behavior analysis, creation of certain views of product data, and combination of intents. Human knowledge sources and outside links to knowledge are applied to complete knowledge information inside of the model. Knowledge items in conventional knowledge base are extended in the proposed solution by situations for behavior analysis, typical combined intents to assist combining of intents, effectivity to make views, and effects as rules, checks, etc. In addition, human and outside knowledge link information is included.

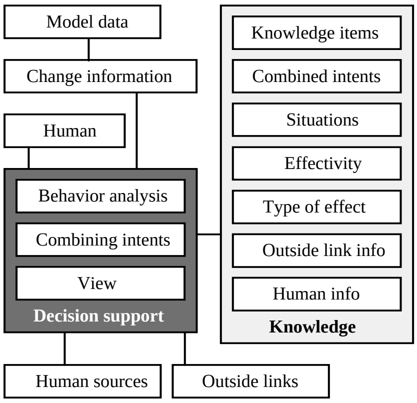

Figure 7

Decision support and possible content of knowledge

An actual engineering space is autonomous and it is developed under control of development management (Fig. 8). Development management generates development effects for the space. On the other hand, actual space generates demands for its development as a consequence of inside or outside attempts for its change. Separate coordination of development serves protection of an intelligent space against undesired modifications even development.

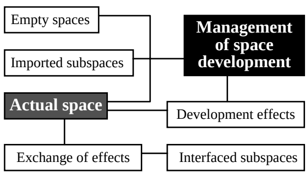

Figure 8

Development of engineering space

An experimental virtual intelligent space including essential engineering technologies of product lifecycle management is under construction at Laboratory of Intelligent Engineering Systems, John von Neumann Faculty of Informatics Budapest Tech. This pilot system will be applied to analyze potential descriptions of behaviors and behavior related procedures to fit them into the intelligent space concept by the authors.

Conclusions

A new scene of engineering in advanced and well-organized computer systems requires new approaches and methods in product related engineering. The authors joined to work in order to develop smarter engineering decisions. High number of important details must be coordinated. A higher level of organization for the handling of these details is to be established. For that reason, the authors conceptualized the virtual engineering space as an analogue to virtual intelligent space. Following this, they developed essential methodologies for description of decision related engineering objects in virtual intelligent spaces. An enhanced and highly integrated application of recent advanced CAD/CAM, human-computer, collaborative, product data management, Internet portal, and intelligent information processing techniques has been established. Some related issues including intelligent engineering modeling as background of the reported research, information content and flow, processing procedures, and intelligent engineering by virtual space are discussed. Human decisions are supported by behavior analysis, creation of certain views of product data, and combination of human intents. In the method proposed by the authors in this paper, management of changes considers any changes of descriptions of engineering objects, physical or logical, as one that may modify one or more of behaviors of the affected engineering objects.

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