Unified feature based integration of design and process planning

G. Chen [1], Y.-S. Ma [1*], G. Thimm [2] and S.-H. Tang [2]

[1]CAD/CAM Lab, School of MPE, Nanyang Technological University, Singapore 639798
[2]Design Research Center, Nanyang Technological University, Singapore 639798
[*]Email: mysma@ntu.edu.sg (Ma Y.-S.)

Abstract: To realize concurrent engineering, different product development stages must be linked to each other on the basis of an integrated and consistent product information model. Features are used as information units for associating specific sets of geometric entities. In this paper, semantics of design and machining features are discussed. Furthermore, feature association and unification for information sharing are proposed.

1. Introduction

To achieve concurrent engineering for a mechanical product, many applications are involved. In the product model, the sub-models for each application can be treated as a view. Each view has uniquely defined information entities, such as functions and behaviors in conceptual design, topological entities and form features in detailed design as well as setups and machining operations in process planning. This is why in the reality different product models are used for different applications. However, the information entities used are essentially associated. Views are linked to each other via associated entities referenced. Any modification in a specific view must assure the consistency of the whole information model. This aspect has not been fully investigated till now. Identifying information entities, relations, constraints in each view and further generalizing common entities are the first step for developing a consistent product information model. Features are used to associate relevant primitive geometric entities to represent a significant meaning in a specific application. Traditionally, only form features are used. There lacks explicitly defined relations between feature attributes and constraints, which together represent feature semantics. These gaps make tracking and managing design or process plan changes difficult. In this paper, semantics of design and machining features are discussed; feature association and unification are proposed.

2. Related Work

Wood *et al.* generalized commonly used 11 features as well as their related 53 functions in the design of plastic parts [1]. Ranta *et al.* highlighted the information gap between conceptual and detailed design [2], and used an intermediate layer of structural entities/relations to map functional model to feature model. Roy *et al.* pointed out that for a given part function and geometry, the behaviors as well as functional relations between involved geometric entities are uniquely determined [3]. Britton *et al.* proposed a function-environment-behavior-structure model for designing injection mould assembly [4]. A pre-developed mould structure library and an action phenomenon library were used to generate mould structures. Choi *et al.* proposed a hierarchical logic for freeform cavity surface machining [5]. A set of concepts, including freeform features, machining features, unit machining operations and mapping rules between them were proposed. Ye *et al.* proposed an assembly object definition [6]. Assembly objects and primitive/combined constraints were used to determine the position/orientation of parts in mould assemblies. Thimm *et al.* proposed a graph-based method for automatic process plan generation and tolerance analysis for rotational parts [7]. Ma *et al.* proposed the associative feature concept to describe geometric association between feature entities [8]. It highlights that an ideal data structure of a feature definition must be flexible and self-contained.

3. Conceptual Design Features

In the conceptual design stage, the combinations of geometric patterns as well as interactions among them realize product functions. Each geometric structure (an assembly or a part) interacts with others to generate a particular behavior for realizing one or more functions. A primitive conceptual design feature is defined as a set of interacting geometric entities, which are critical to realize the required primitive product functions. To support functional reasoning, conceptual design features must include function-related attributes and constraints. Conceptual design feature geometry only includes those geometric entities, which are indispensable for realizing the function. A conceptual design feature definition is given below:

Attributes:	semantics; functions; behaviors (input and output); dimensions; tolerances; and material specifications
Constraints:	spatial constraints; functional constraints
Geometries:	critical geometrical-entities
Methods:	create; edit; check validity; query information

Primitive conceptual design features can be pre-defined and combined to form new ones. A conceptual design feature model represents an assembly that is only partially and vaguely specified in this stage. It consists of a set of primitive or combined conceptual design feature instances. Inter-feature spatial and functional relations are defined among different interacting conceptual design features to realize overall product functions. In this stage, product functions govern the choices of geometric structures and interactions among them. The semantics of a conceptual design feature are represented by the associated attributes of those critical entities.

4. Detailed Design Features

In the detailed design stage, the conceptual design, i.e. critical geometric entities and interactions among them, are further refined into complete product geometries and specifications. A primitive detailed design feature is defined as a set of related geometric entities and has the following definition:

Attributes:	Semantics; patterns; parameters (e.g. diameter); dimensions; tolerances; positions; orientations; material; roughness
Constraints:	geometric constraints; algebraic constraints
Geometries:	parts; assembly; components; features; geometric and topological entities; references; derived entities
Methods:	create; edit; check validity; query information

Primitive detailed design features can be pre-defined; and several related ones can also be defined as a combined feature. A detailed design model is an assembly, which consists of a set of sub-assemblies or components. All sub-assemblies and components are contained (not necessarily in one-to-one manner) in parts. A part consists of a set of primitive or combined detailed design feature instances. Referenced and derived geometrical entities are included in such parts as well. Referencing mechanism enables relations among entities across different parts. Dimensions or tolerances are defined as constraints and attributes in their corresponding levels of parts. Inter-feature geometric or algebraic relations are defined as constraints too. Critical geometric entities of a conceptual design are referred by and associated to the final product model. The required interactions are embedded into appropriate entities' methods, which can manipulate geometric entities, constraints as well as attributes. The associative correspondences between the conceptual and the detailed design models must be managed via a feature manager even though a conceptual design could be realized by multiple detailed designs. The semantics of a detailed design feature are embedded as attributes in different levels. They can be retrieved and modified via supporting methods.

5. Machining Features

Feature-based process planning covers two processes, operation planning and machining passes. Hence, the features involved can be roughly divided into macro machining features (operations) and micro machining features (machining passes). These features have the corresponding methods of generation, aggregation, and sequencing. Machining operations can be defined according to setup or cutter changes. Within each operation, there are one or more machining passes. Machining parameters are determined in the scope of each pass. A primitive machining feature is defined as a set of related geometric entities that represents the volumes removed or faces generated during a machining cut. The primitive machining feature definition is given below:

Attributes:	semantics; machine information; tools; machining parameters; operational and locating datum; dimensions; tolerances and roughness of the machined faces
Constraints:	Machining constraints (power, workspace, etc.); tool constraints (cutter radius, flute length, etc.); geometric constraints
Geometries:	features; geometric and topological entities describing the workpiece before and after the operation or cutting pass
Methods:	create; edit; check validity; query information

The overall process plan of a single part consists of a set of machining features which are sequenced and scheduled according to the nature of precedence of operations and the availability of resources. It can be hierarchically divided into two levels. A part has a set of operation machining features at the first level, each operation feature can be achieved in the same machine with a single setup; it can be machined with one-time location and clamping for the workpiece. Furthermore, each operational machining feature is characterized by unchanged cutting tool. At the second level, each operation feature can be further derived as a set of primitive machining features, i.e. machining pass features. Some of them can be further decomposed into the nested cutting passes, where the machining faces are evolved with incremental changes in both geometry and status attributes. Constraints are defined in the corresponding levels. *Machining allowance allocation constraint*, i.e. depth of each cut, is defined for the micro machining features here to cater for such nested machining passes. *Machining sequence constraints* are defined in part, and operation feature levels, which are further classified as datum constraints, machining constraints (accessibility, rough prior to finish, etc.) and preference constraints (e.g. minimizing tool change). Similarly, the semantics of a machining feature are represented by embedded attributes. The validity of machining features must be checked whenever the design is amended.

6. Feature Association and Unification

From the above analysis, it can be appreciated that different application features have different entities, constraints and semantics. Theoretically, they are linked to each other via some associative relations among the entities used in different applications. The associative entities used by the conceptual design model, and related to the detailed design model, are the critical geometric entities. The required interactions among them represent the behavior of the conceptual features. As long as these critical entities/interactions are not modified, the corresponding product conceptual design (or in turn, the functions) can be regarded as still valid. This characteristic can be used to adjust final product geometry and parameters to lower manufacturing cost or shorten manufacturing time. The associative entities used by the detailed design feature model and related to the machining features are the final product geometry and attributes. These links must be established and maintained for concurrent engineering. However, in reality, communication among different application feature models is difficult due to the different data formats and the lack of association. Feature association can be achieved by a set of relations, including internal references and external references. Internal references relate entities in the same feature, while external references relate entities of different features. Furthermore, different applications link to each other based on associative relations. Hence, feature associations describe feature interactions and are crucial for managing feature validations and invoking necessary feature modifications.

On the other hand, based on the identified generic feature semantics, elements, and relations, a unified feature-modeling scheme has been proposed (to be reported in a separate publication) to integrate applications for information sharing and consistency control. Feature unification means using unified feature concept to represent generic characteristics and methods of different application features.

Application features are derived from unified features. It provides a generic format and common granularities for different applications. Feature association and unification are the two basic elements of the proposed unified feature-modeling scheme. With these two enrichments, features can be used as an interface information type to link different applications to, and hence control consistencies of, the centralized and unified product model. Then the synchronization of detailed geometric modeling and conceptual reasoning processes can be supported.

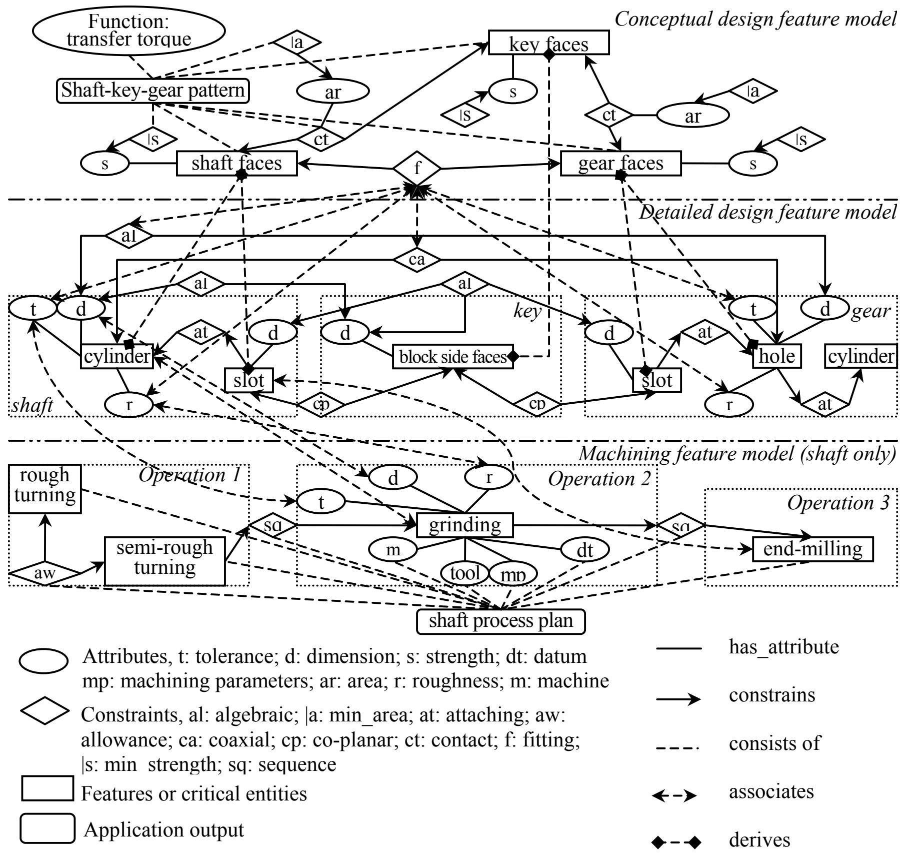

Figure 1 Feature semantic map

7. Example

The development process of a shaft-key-gear mechanism is used to illustrate the unified feature-modeling concept. As shown in Figure 1, in the conceptual design feature, shaft, key and gear faces, are the critical geometric entities. Spatial and functional constraints include fit type, minimum contact area and minimum material strength; they are established under the control of functional reasoning rules. In the detailed design stage, the only assembly includes three parts, shaft, key and gear; they contain six form features. Detailed design features, such as the slot on the shaft, are derives from the critical geometric entities at the conceptual level. Spatial and functional constraints, such as fitting, are transformed and associated with the geometric constraints and attributes in detailed design. In the process planning stage, four machining features (rough turning, semi-finish turning, grinding and end-milling) are created for shaft. Machining sequence and machining parameters are generated under the control of process planning application. For clarity, in Figure 1, some entities and relations are left out. This simple example roughly shows the complicated relations between different applications. Different application views are associated with the final product geometry. Such feature association makes the unified feature modeling approach feasible.

8. Conclusion

In this paper, feature-based integration for conceptual design, detailed design and process planning are discussed. Two basic concepts, feature association and unification, are discussed in the context of a unified feature modeling scheme for information sharing and consistency control. It is expected to provide a theoretical basis for the application research in feature-based concurrent engineering.

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