Title:
A Framework to Support 3D Explicit Modeling Education and Practice

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Introduction:
Recently a new approach to modeling in computer-aided design for mechanical engineering (MCAD) has emerged. It is referred to as *3D explicit modeling*, and also sometimes known as *direct modeling*. This modeling approach is based on the definition of 2D regions, which can be pushed, pulled, and twisted interactively, to manipulate the shape of a CAD model. Geometric constraints, along with so-called driving dimensions, can then be placed directly on the 3D model allowing for geometric rearrangements according to desired functionality.

One major objective in the development of this modeling technique was to overcome difficulties related to the editing and reuse of feature-based CAD models. Feature-based systems were introduced with the aim of providing modeling systems capable of facilitating both the initial design/modeling phase and the editing and reuse of geometric models afterwards. However, what was intended to be a triumph of feature-based systems, supported by parametric functionalities, the single modeling operations (feature) and the design feature history tree, has unfortunately turned out to have some significant disadvantages. Without knowledge relating to the original design intent and initial use of features, feature history trees tend to become complex and ambiguous to the point of being incomprehensible. In today's practice this unfortunate situation is aggravated by CAD models being frequently exchanged between different systems, because in many cases information on feature trees is partially or entirely lost during data conversion. This renders those CAD models unfit for editing and reuse.

Background, Scope and Objectives:
Not only is explicit modeling a different approach to CAD model editing, but, as a modeling technology, it is redefining the modeling paradigm itself. Feature-based modeling is founded on the concept of local elementary functional shapes (features), composed by following a particular modeling sequence (feature tree). In contrast, the explicit modeling approach considers the model shape as a whole at each stage of the modeling process, without reference to the sequence of previously executed operations. Hence, explicit modeling is history independent in the sense that the order of modeling operations used to create a model does not directly impact the way the model can be altered.

Design intent preservation is a well-known issue in the MCAD domain [1]. Creation of 3D models that are capable of capturing and preserving the design intent is important from several viewpoints [2]. It is necessary to communicate the functional meaning of a component and to be able to make model adjustments without modifying or even destroying geometric entities related to functional requirements. It is in this context that motivations arose for work on a methodological approach, where design intent in the form of semantics related to component shape could be specified and preserved using explicit modeling technology. This endeavor requires first the development of a framework where traditional engineering concepts will find the appropriate conceptual and practical correspondence with framework entities and modeling system functionalities. Such a framework can also provide a foundation facilitating explicit modeling education within MCAD curricula and can impart sufficient strategic knowledge and understanding to enable students to use CAD systems as knowledge intensive design and communication tools which can properly develop and convey design intent.

The objective of the work presented in this paper is to develop a framework based on the concept of functional dimensioning features. This is aimed at supporting a methodological approach to explicit modeling with a focus on issues related to its use in CAD education and practice. In this context, particular preference is given to the definition of methodologies aimed both at preserving design intent and supporting best practice, and also at stimulating the teaching of strategic knowledge.

Outline and Approach:

The framework described in this paper aims at relating principles and concepts defined by the Geometric Product Specification (GPS) Standards to functionalities provided by explicit modeling systems. The intention is to make explicit the semantics designers associate with a model shape. In order to reach this goal, we have introduced the concept of functional dimensioning features. The novel framework is based on several assumptions as follows. The shape of a mechanical component is designed to fulfill elementary functionalities such as beat, shoulder, alignment, guide, stiffening, and fit. The geometric elements related to basic functions are the most critical, and therefore they are directly related to explicit dimensions and tolerance information. International standards exist (GPS and related standards) that define basic concepts and principles appropriate for the specification of dimensions and tolerances.

To successfully approach framework development using this new modeling paradigm within the context as outlined above, a viewpoint is required which is application independent, systematic and perhaps standardized, and which is based on the relationship between engineering function and geometric entities. Such a viewpoint should be suitable for both education and industrial practice. To direct principle formation and development regarding geometric entities and associated functional meaning in this direction, we propose to make reference to the concepts and definitions introduced by the GPS system of standards [3]. The aim of the GPS system of standards is to preserve the design intent from the ideal domain of design to the physical domain of the manufactured component, i.e. to ensure that the manufactured component will be able to provide the elementary functions as specified by the designer in a mechanical engineering drawing.

The ISO-TS 17450-1 [4] standard introduces the definition of a geometric feature as a point, line or surface. The concept of an ideal feature is used to identify nominal features belonging to the design domain. The concepts of intrinsic characteristics; situation characteristics and situation features are introduced additionally in order to manage the issue of relative location among features. In order to deal with issues defined at a higher level of abstraction, the ISO 14405-1 [5] standard defines the features of size to be cylinders, spheres, cones, wedges, or pairs of parallel surfaces. From a functional point of view, features of size are geometric entities providing function for coupling, such as centering holes and guides, as used in mechanical engineering. In order to cope with situations requiring elements beyond those of linear size, ISO 14405-2 [6] has been introduced.

Application of the GPS standards requires that dimensions and tolerances of functional elements are specified within the nominal representation of the component, i.e. the representation of the design solution. On the other hand, the explicit modeling approach allows the user to add geometrical constraints and dimensions directly to geometric elements, independently from the modeling sequence that leads to the model shape. It is in this context that we introduce the concept of a functional dimensioning feature (FDF). The structure of the FDF includes geometric entities in implicit and explicit form. These can be sized or invariance-class based, and either integrated or derived/referenced. The FDF also features spatial properties related to the explicit and implicit location, as well as the orientation of entities. The composition, structure, and semantics of the geometry and the spatial properties of the FDF are derived from principles and concepts used in geometric modeling. Such a structure allows functional dimensioning features to be employed as a means of integrating definitions and concepts such as features of size, situation features, and intrinsic characteristics. These arise from the GPS standards and are central to functional dimensioning, with functionalities as provided by the explicit modeling system.

Empirical work employing the framework developed and a commercially available parametric MCAD system with explicit modeling capability has been pursued in two directions. Firstly, it has been used to gain insight into both applicability and practice-related shortcomings, as well as to investigate the limits of the approach and framework developed. Various modeling situations within part and component design, considered representative examples typical for MCAD, have been replicated. This has been undertaken by employing the newly developed concept of functional dimensioning features and by explicit modeling to the extent permitted by the parametric MCAD system used during experimental work. Secondly, the empirical work has explored the definition of methodologies aimed at modeling and preserving the design intent within an explicit modeling approach. The results obtained in experimental work were then fed back to the development of methods for best practice, and those were applied to a selection of modeling situations and evaluated. The results and understanding obtained, in turn, provided input to improve the development of methods for best practice with a focus on the teaching of strategic knowledge.

Conclusions:

The framework proposed provides an integrative correspondence between concepts as specified by the

GPS standards and the operative framework as provided by explicit modeling. In particular, it enables rules defined by the standards, which relate to the traditional representation of mechanical design solutions specified in technical drawings to be applied on 3D models, while providing a conceptual base for the definition of best practices for explicit modeling. As the explicit modeling approach is independent of the logical sequence of applied operators and modeling entities, functional requirements in terms of geometrical constraints and dimensions can be added at any time, even after the final shape has been modeled. Here an interesting question, which invites further investigation, is to what extent the modeling of the shape and the definition of the functional constraints could be de-coupled and eventually delegated to different designers with various skills and expertise.

References:

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