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New Directions in Solid Modeling - What Direct Modeling Means for CAD Educators

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Abstract

Direct modeling is a little known CAD technology that has been around for many years. It uses direct manipulation of the geometry to effect changes in the part model, and is based on a boundary representation database. This paper discusses the industry's perception and the value of every day usage of direct modeling, the future of this technology, and implications for engineering graphics educators.

Introduction

Direct modeling (DM), a.k.a. synchronous modeling or dynamic modeling, is an alternative approach to parametric, history-based solid modeling. Direct modeling is used as the core technology in a limited number of software systems such as SolidEdge and Co-Create, but none of these systems have been widely adopted by industry. Common solid modeling systems have recently added functionality within their software that mimics the user interface of direct modeling, including PTC Creo Elements/Direct, NX Synchronous Modeling, Catia Live Shape and SolidWorks Direct Editing. Software vendors claim that direct modeling solves numerous problems that are inherent with the use of history-based systems and facilitates model interoperability.

What is Direct Modeling?

Direct modeling is an intuitive approach to creating geometry without the burden of history-based dependencies. History-based (procedural) parameterization of models requires the user to thoughtfully consider the important model input/output parameters; independent dimensions are identified and defined by the user during model creation while dependent dimensions are calculated based on procedure (history tree rebuild). However, instead of storing the sequence of feature creation, a direct model is based on the boundary representation (b-rep) of the solid. The model is regenerated based on a set of geometric constraint equations rather than the sequential reconstruction of feature history. This is a simple but powerful method of specifying design intent, although implemented differently than in history-based models[15].

Construction methods are similar to those used in conventional solid modeling; the user can design a 2D profile and then develop the model using commands like extrude, revolve, mill, bore, etc. Without the presence of a parameterized history tree, manipulation of the geometry is simplified, a major advantage of DM. Local geometry and topology changes can be made using both direct "push-pull" interactions or using dimension-driven methods. Users can directly manipulate model geometry without needing to know how that geometry was created by simply grabbing, pulling and dragging faces, edges and features. Direct modeling also utilizes everyday software methods such as "copy/paste" and "drag/drop". Direct modeling closely follows these Microsoft derived principles, which means the user can simply cut and paste elements from an existing design and start building an entirely new model[11].

Advantages of Direct Modeling

Direct modeling creates geometry rather than features so it is perfect for conceptual modeling where the designer doesn't want to be tied down with the interdependencies of features and the ramifications making a change might have. The direct modeling approach to 3D CAD provides an environment where users can design directly on the model's geometry. This is especially beneficial when creating one-off designs or facing unexpected and late changes in the design process[13]. The direct modeling approach simplifies the design process, so pre-planning a modeling strategy is not necessary as compared to history-based modeling. Users working on existing models do not need to understand the modeling strategy used to create the model, and do not need to search through the feature tree to identify specific feature parameters in order to make a change to the geometry. The direct modeling approach facilitates quickness and responsiveness-to-change, making it an ideal approach where speed and flexibility are important[3].

Due to the absence of the history tree, models created using the direct modeling approach exhibit greater interoperability. Files can be saved in standard formats such as STEP, Parasolid, or ACIS, and imported into other CAD packages without loss of information. Direct modeling is an ideal tool for manipulating imported geometry from other systems that generate a simple closed volume from these conversion formats. Variational direct modeling technology can automatically recognize design intent of a “dumb” geometry in the form of geometric and dimensional constraints between boundary elements[16].

In applications that require interoperability between different CAD packages, some solid modeling systems can perform feature recognition, either automatically or through user interactions, thereby facilitating decomposition and simplification of neutral b-rep models in STEP, ACIS or Parasolid formats into features for analysis or manufacturing[6]. These neutral file formats are representative of the direct modeling b-rep data structures. However, automatic feature recognition results in a sequence of features that seldom mimics the original features created by the designer, except for the simplest of parts. A moderately complex model of a chair, Figure 1 (left), contains a variety of features including extrusions, fillets, draft, sweep and loft, as well as a mirrored feature. The STEP file of this model, when imported using automatic feature recognition, yields fewer fillets, two revolves, two draft features, and a large volume of material that could not be featurized, shown as “Imported3”, Figure 1 (right). No extrusions or pattern features were recognized. Only the geometry that is transformed into features can be edited in a conventional history-based solid modeling system. This would pose problems in making changes to the model for most regions within the geometry. With direct modeling, changes could be made to any surface or edge, whether on the recognized features or the unfeaturized volume.

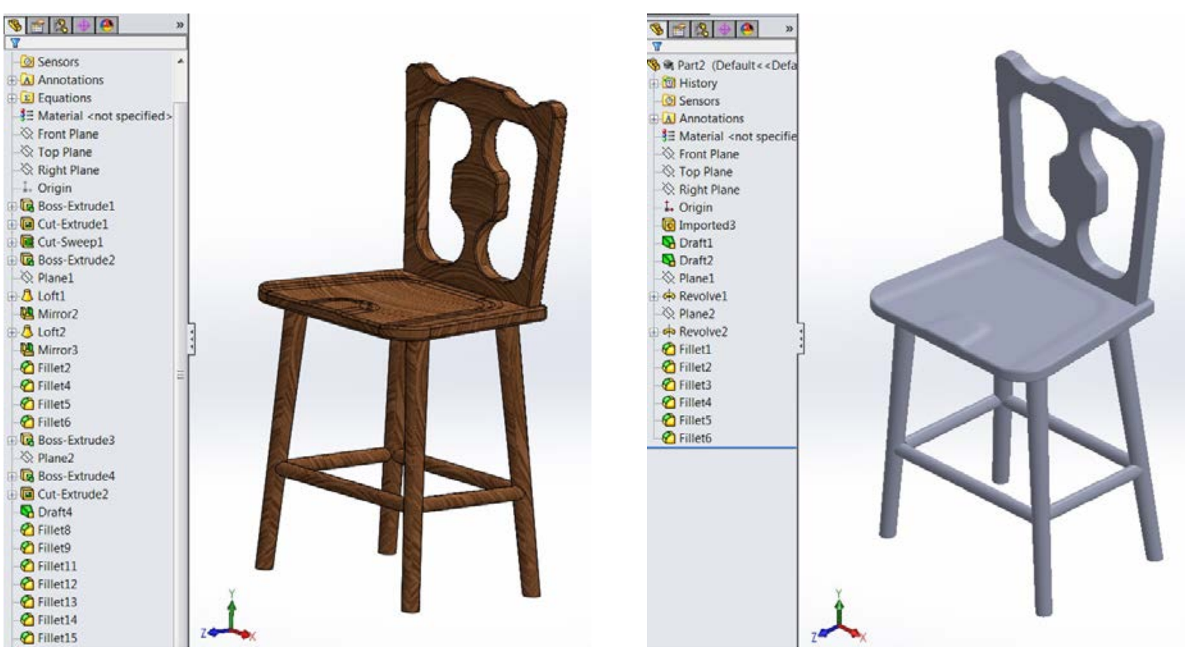

Figure 1. Conventional history-based model (left); featurized neutral STEP file (right).

Direct modeling is ideal for freeform ergonomic parts and parts with complex surface geometry. Freeform manipulation of NURBS surfaces using push-pull operations is similar to modeling with clay. Ergonomic shapes can be easily combined with standard features to facilitate the creation of concept designs. Students and designers can create complex shapes using freeform modeling of NURBS surfaces, such as the beverage containers shown in Figure 2. These models, incorporating both freestyle NURBS-based features and conventional sketch-based features were created with Creo Parametric using a push/pull interface after a two hour introductory lab session.

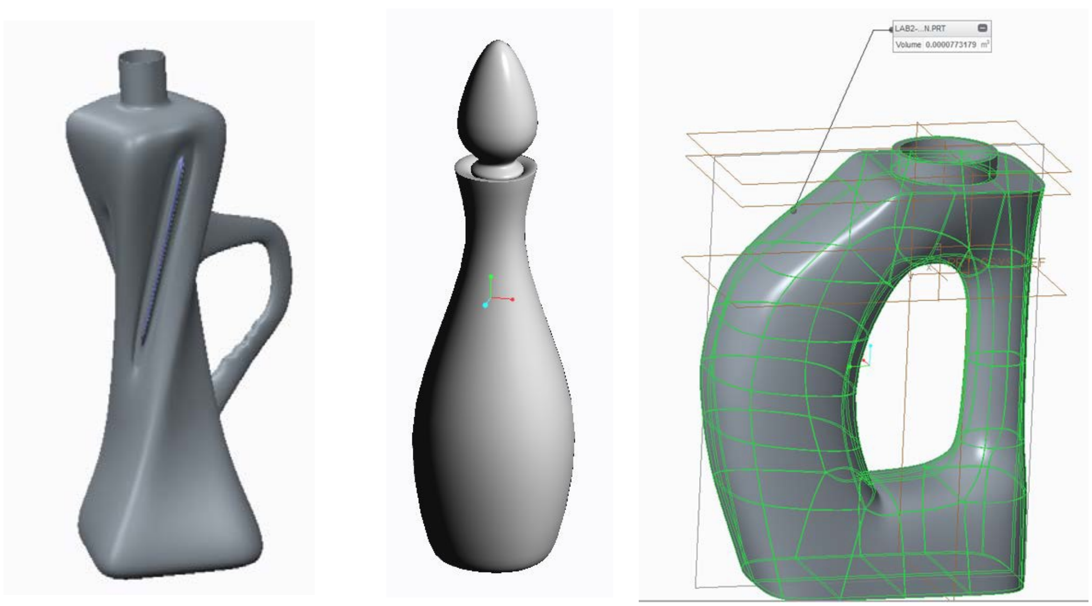

Figure 2. Freeform beverage containers designed by students

Usefulness in Industry

The concept of direct modeling has been around for more than 20 years yet only in the last few years have CAD vendors been marketing its capabilities[8]. Although the major engineering CAD vendors have started to integrate direct modeling methods into their products, significant differences in implementation and functionality are currently observed. While some CAD vendors claim to incorporate direct modeling into their products, these implementations are in the form of a hybrid system, which mimics the user interface and manipulation modes of DM, but retains the history-based data structure[8].

In these hybrid systems, the geometry manipulations appear in the model tree as “move”, “copy” or “direct” features, alongside the conventional solid features[1], as shown in Figure 3.

The user interface supports direct manipulation of the part geometry and push-pull interactions. NX Synchronous offers an option to convert a history-based model with a history-free one but cautions users that all the history will be deleted. It is not recommended for highly engineered production parts[13]. It's unclear if the part history is truly deleted or just "hidden". These hybrid systems may facilitate user interaction with the model while making design changes, but tend to complicate the history tree, resulting in less robust models[1].

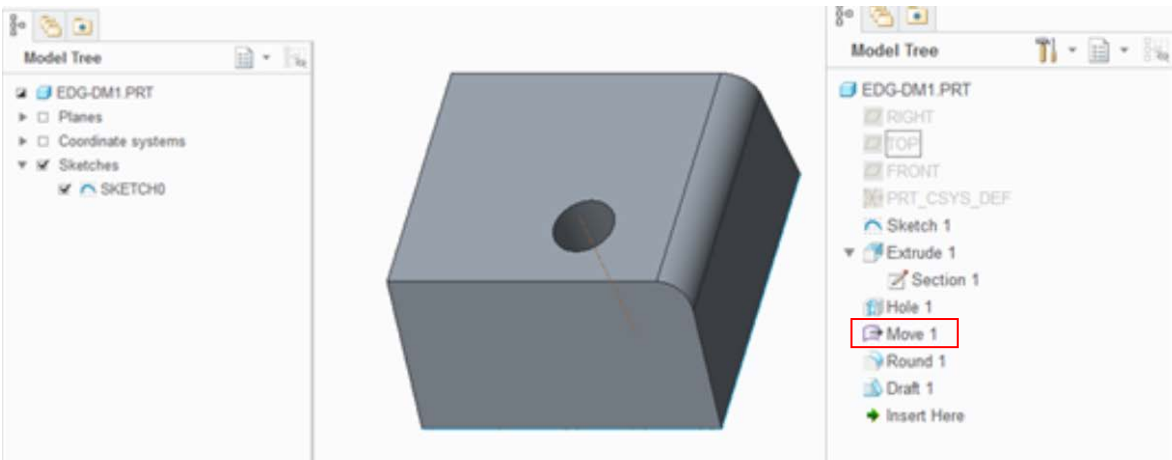

Figure 3. Part with featureless model tree (left) and "move" feature in conventional feature-based model tree (right)[1].

A limited survey of industry users has shown that many design engineers do not utilize the direct modeling functionality and in some cases users do not even know that the direct modeling add on modules exist. Interviews (teleconferencing, emailing and in-person) yielded the following testimonials by experienced CAD professionals working in various industries.

"After hearing about the Direct Editing feature in SolidWorks, I did some research and started playing around with it. It's fun to play with but seems to be a novelty and has no real use in the design / manufacturing of our product"[9].

"We use PTC Creo and SolidWorks, but no one here uses any part of the Creo Direct or [SolidWorks] Direct Editing modules"[4].

"UTC is using PTC Creo, but we don't do anything with direct modeling that I have seen"[14].

We have been using SolidWorks for many years and have never heard of the Direct Editing feature"[12].

Parametric, history-based CAD is considered to be unsuitable for use in the concept phase due to the lack of knowledge regarding suitable parameterization of the model and feature dependencies. Conceptual design development is a process where many threads of possibilities are developed in parallel[10]. Although the use of direct modeling has been limited in industry, it is primarily being used in the concept / prototype phase for new projects where producing multiple "quick and dirty" concepts is necessary. After the concept has been adequately defined, companies are transferring the project to the history-based modeling packages to create assemblies and to document the design through to the 2D detail drawing phase[2].

Direct modeling may also be used in manufacturing, where interoperability is necessary due to the use of different software between designers and manufacturing, either within the same company or with outside customers and vendors. Files in neutral formats such as ACIS or STEP can be imported and modified using direct modeling functionality without the need for history-based features[6].

The Future of Direct Modeling

Although not currently fully implemented in most mainstream CAD systems, vendors seem to be moving towards DM to address the need for improved functionality, particularly in the areas of part modification and interoperability. However, full scale implementation of DM requires a complete overhaul of the core geometry engines and constraint systems used by most CAD software, and developers may take several years to transition to fully functional, robust, boundary-based constraint systems. Due to the drawbacks caused by the use of hybrid structure, some of the intended benefits of DM are not realized, and some vendors are opting to remove it from their platform[13], perhaps temporarily. Nonetheless, development of more robust geometric constraint algorithms and the potential benefits of DM suggest that its widespread use may be on the horizon.

Impact on Engineering Education

Current history-based CAD users and educators may need to modify their existing design strategies and teaching or training approaches to incorporate the new modeling functionalities of hybrid systems. The effective use of history-based parametric CAD software depends greatly on the user's cognitive ability to visualize the design, decompose the model into functional features, identify parameters that incorporate design intent, manage feature dependencies and constraints, and interact with the developing model of the product[7]. New teaching methods will be needed to develop skills to properly incorporate design intent into these new hybrid models while avoiding problems associated with the history-based structure that arise from using both feature-based methods and direct manipulation to modify the model[1].

In some cases the direct interaction afforded by these hybrid systems offers an advantage for non-CAD specialists in that it is generally more intuitive and very easy to learn, thus making it easier for students to develop more complex engineering designs quickly. Direct model manipulation eliminates many of the problems associated with traditional feature-based tools. Engineers and students that may not use CAD on a regular basis can easily make changes to models without having to fully understand all the constraints and feature dependencies of a feature-based model and concern for causing regeneration failures from the changes being made.

Whether teaching direct modeling or history-based modeling it is important to develop three elements necessary for obtaining CAD expertise. Declarative command knowledge is knowledge about the commands or algorithms that are unique to specific CAD software packages; specific procedural command knowledge enables the operator to execute the necessary commands; and strategic 3D CAD knowledge includes a range of metacognitive processes including planning, monitoring and revising[5]. Effective use of DM systems will require the user to have a deeper understanding of boundary representation and constructive solid geometry (Boolean) methods rather than history-based concepts such as parent-child relationships[16]. Modeling strategies for using the direct modeling tools are not well developed. Therefore, it will be important to develop cognitive models for the use of direct modeling systems.

Conclusions

It appears that the major CAD vendors are currently moving towards a hybrid of direct modeling and history-based parametric feature-based solid modeling systems. Educators need to be aware of these changes and future trends, including approaches for using these hybrid systems during the transition period. As these new tools are adopted by industry, CAD educators will need to develop ways to teach relevant new concepts to engineering students. These new concepts and methods include an understanding of feature recognition algorithms and variational constraint theory used in solving geometric systems. In the meantime, the advantages of direct model manipulation are expected to ease the use of CAD systems for novice users while facilitating conceptual design.

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