Direct Modeling: Easy Changes in CAD?

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Abstract

Direct Modeling is an emerging CAD technology that uses direct manipulation of the geometry to effect changes in the part model, and is based on a boundary representation database. This paper highlights the differences between Direct Modeling and conventional history-based solid modeling, compares emerging technologies, and discusses what this means for engineering graphics educators.

Introduction

Direct Modeling (DM), a.k.a. synchronous modeling or dynamic modeling, is an alternative approach to feature-based parametric solid modeling that has gained popularity in the past few years. Many of the major CAD software vendors have added direct modeling capabilities to their offerings: PTC Creo Elements/Direct, AutoDesk Fusion, and SolidWorks Direct Editing to name a few. Software vendors claim that Direct Modeling solves numerous problems that are inherent with the use of history-based systems.

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 – 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 of the solid. The model is regenerated based on a set of constraint equations rather than the sequential reconstruction of feature history (Ushakov, 2008).

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 greatly

simplified. 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 same Microsoft derived principles, which means the user can simply cut and paste elements from an existing design and start building an entirely new model (PTC, 2011).

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 (PTC, 2011). 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 will not have to understand the modeling strategy used to create the model, and will 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 is about quickness and responsiveness-to-change, making it an ideal approach where speed and flexibility are important (Brunelli, 2014).

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, ACIS, etc. 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 (Ushakov, 2008).

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.

Comparison of Technologies

As the major engineering CAD vendors begin to integrate Direct Modeling methods into their products, significant differences in implementation and functionality are currently observed. These differences result from the need to merge the capabilities of the history-based systems with the

new direct approach. The result is a number of hybrid systems that exhibit the features of both history-based parametric solid modelers and the push/pull user interface and boundary representation database of direct modeling. These differences in implementation are as follows:

PTC Creo Direct uses Push / Pull technology to create new geometry or modify existing 3D CAD design, regardless of file format. Direct interaction with the geometry makes it easy to learn and use. Part files created in Creo Direct or Creo Parametric can be read and manipulated using the tools in either software package, but the feature tree shows that the history-based structure is maintained in both files, although it is hidden from the user in Creo Direct. Figure 1 shows a simple part created in Creo Direct by extruding a square, adding a blind hole, moving the bottom face of the hole with the push/pull interface, then adding a round on one edge and a draft on the front face. Note that the feature tree shows only the datum planes and the original sketch for the square extrusion. There are no other features available to the designer for modification, even though the software provides tools to create the hole and draft. Figure 2 shows the same file imported into Creo Parametric. Note that the model tree for the part includes all of the feature operations that would be used to create the part in Creo Parametric (extrude, hole, round, draft), as well as an additional feature representing the Move operation that was applied to the bottom of the hole. Manipulating the model in Creo Direct results in the creation of additional features in the Creo Parametric feature tree, such that the tree can become quite long after a few modifications (Menezes, 2011). The parametric features can be edited within the Creo Parametric software; however, changing the Hole feature from a blind depth to a through hole causes the Move feature to fail. This demonstrates that the software is most suited for tasks such as generating proposals, defining the initial design for tooling fixtures or capturing design input from customers in the field.
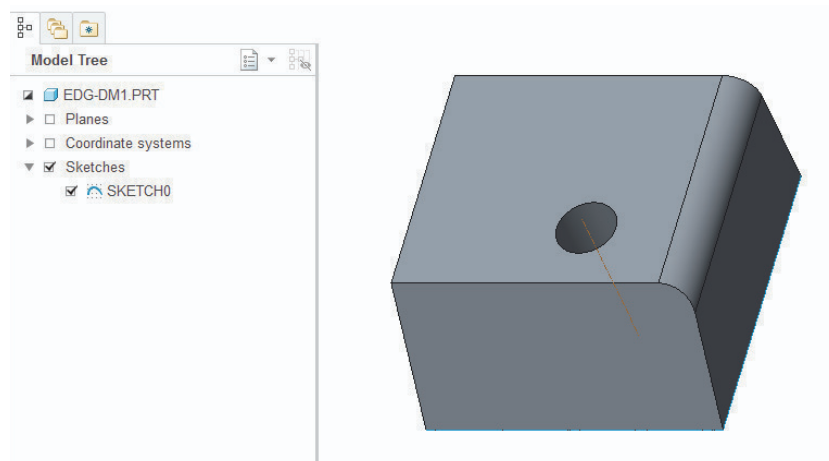

Figure 1. A simple part modeled in Creo Direct
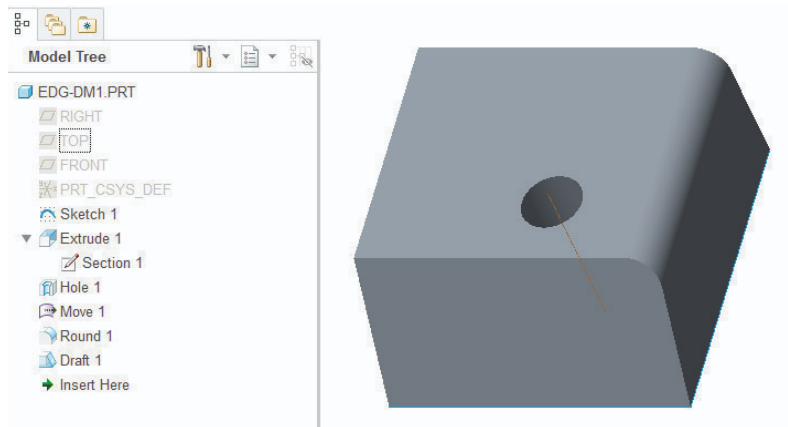
Figure 2. Creo Direct part opened in Creo Parametric

SolidWorks Direct Model Editing is not Push/Pull; this is a feature-based parametric tool. Direct editing enables the user to copy, move, split, replace, offset, push, and drag geometry to create the desired result. Patterning creates features, faces, and solid bodies by clicking directly on the geometry to be patterned. Direct Edit capabilities automatically convert non-native, imported model geometry into intelligent SolidWorks features that can be modified parametrically or through direct geometry manipulation. Similar to Creo, SolidWorks adds Direct Edit features to the model tree, as shown in Figure 3.
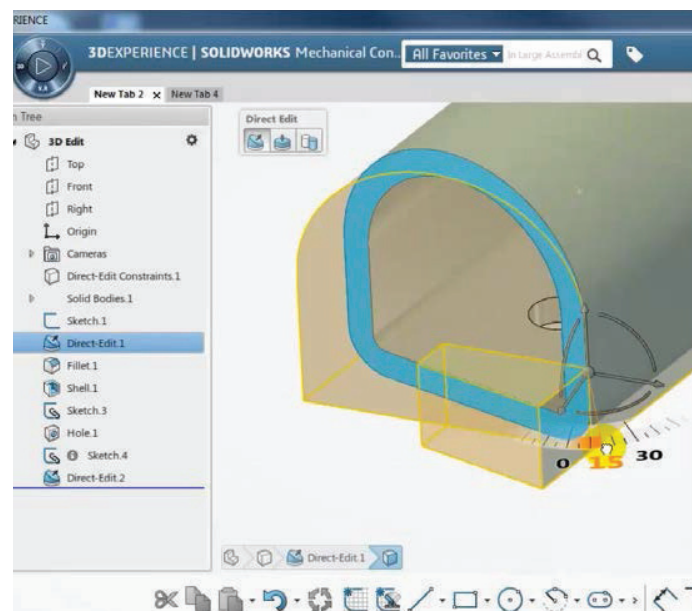
Figure 3. SolidWorks Direct Edit adds features to history-based model (Vargatu, 2014)

Catia Live Shape is a feature based system, similar to SolidWorks' Direct Model Editing, which makes sense since both are Dassault products. Live Shape is called "declarative modeling." It looks like direct modeling, but with declarative modeling, specifications can be "declared" or assigned. This is a free modeling approach, but with a precise modeling capability that captures design intent. The focus of this product is on sketching ideas freely and improving collaboration between design and simulation or manufacturing.

AutoCad Inventor Fusion is a Push / Pull system with a parametric component that enables designers to combine parametric, history-based modeling with the more freeform productivity of direct modeling. Freeform creates smooth and precise surfaces with T-Splines technology or with sketch curves, patches, and extrusions.

NX Synchronous Technology is a Push/Pull system that has a parametric component. The user can easily modify complex 3D models without understanding how the model was constructed, and without knowing the feature relationships and dependencies. The user applies modifications directly to the model faces, edges and cross-sections using simple, direct "push-and-pull" tools. Direct modeling with synchronous technology automatically finds and recognizes collections of faces representing functional features, and enables the designer to modify them quickly and easily. Freeform design with simple push-and-pull shaping techniques begins with solid or surface, analytic or B-rep geometry, and the user can then insert isoparametric curves and model organic forms by moving constraint points, surface poles and handles.

Impact on Engineering Education

Direct interaction afforded by Direct Modeling offers a large 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 Modeling 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' of a feature-based model and concern for causing regeneration failures from the changes being made. Not only is it easier to create and modify simple geometries such as those commonly modeled in introductory CAD courses, but students can also create more complex shapes using freeform modeling of NURBS surfaces, such as the beverage containers shown in Figure 4. These models were created with Creo freestyle using a push/pull interface after a two hour introductory lab session.
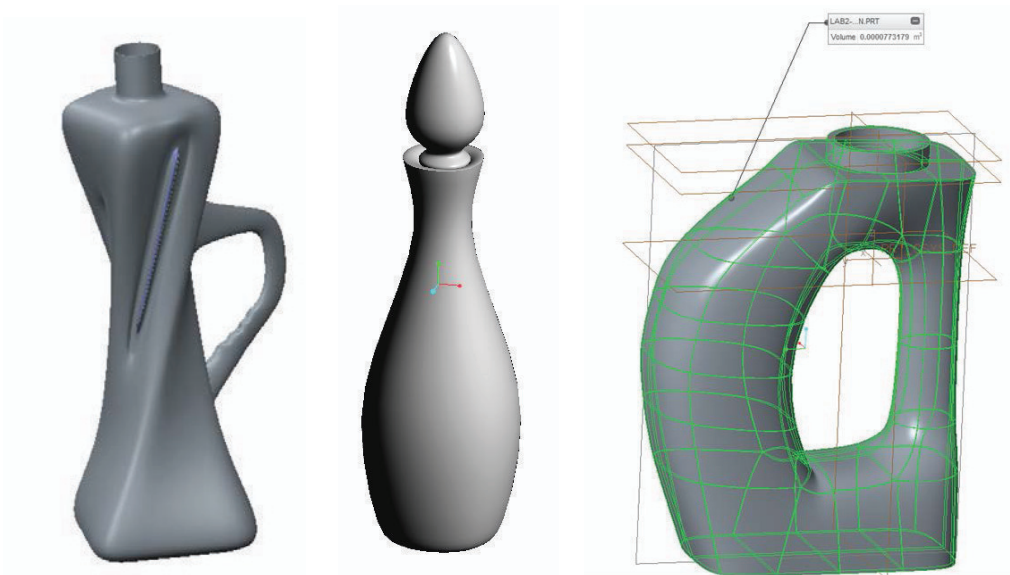
Figure 4. Freeform beverage containers designed by students

Current history-based CAD users and educators need to modify their mindset and thinking to incorporate this new modeling methodology into their existing design strategies and teaching or training approaches. Currently, 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 (Krish, 2010). Although the use of Direct Modeling, as yet an emerging technology, 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 the 2D detail drawing phase (Bodein et al., 2014).

The creative 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, andinteract with the developing model of the product (Gaughran, 2002). New teaching methods will be needed to develop skills to properly incorporate design intent into these new DM and hybrid models while maintaining the flexibility that is inherent in the use of direct methods. Effective use of DM systems, on the other hand, 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 (Wang et al., 2015).

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", knowledge that enables the operator to execute the necessary commands and "Strategic 3D CAD knowledge", knowledge that includes a range of metacognitive processes including planning, monitoring and revising (Chester, 2007).

It appears that the major CAD vendors are 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, but it appears that these hybrid systems are not yet sufficiently robust, and modeling strategies for using the direct modeling tools are not well developed. Therefore it will be important to provide students with a thorough understanding of both technologies in the near term, while developing cognitive models for the use of direct modeling systems.

Conclusions

Various implementations of Direct Modeling have become embedded in mainstream 3D CAD software. As these new tools are adopted by industry, CAD educators will need to develop ways to teach relevant new concepts to engineering students.

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