Synchronous Technology

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A White Paper Prepared by

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for

Siemens PLM Software

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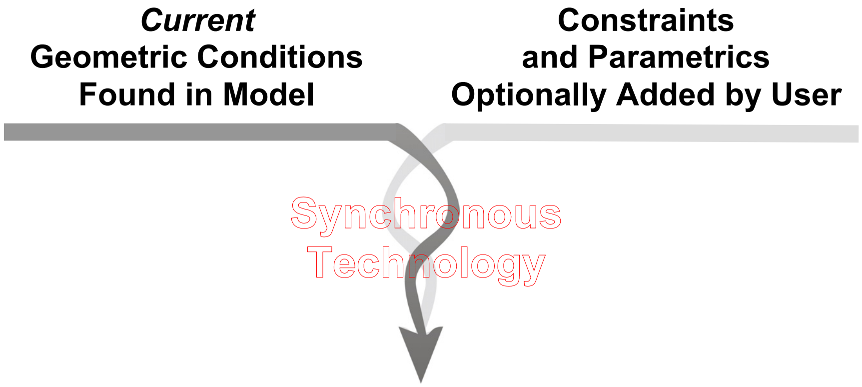
TECHNOLOGY BREAKTHROUGH

The year 2008 will record a milestone event in the history of 3D CAD design.

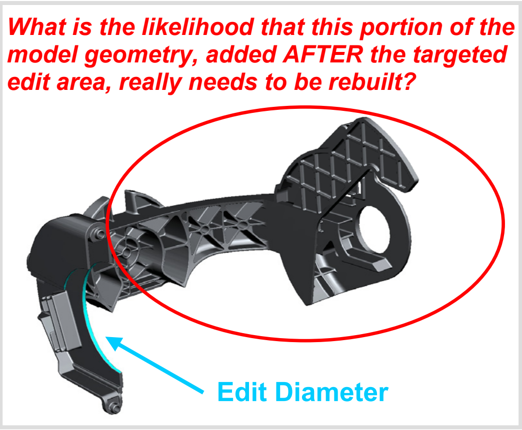
Siemens PLM Software introduces **SYNCHRONOUS TECHNOLOGY** – a groundbreaking maturity leap in interactive 3D solids modeling. The new technology delivers a major advancement above parametric, history-based modeling, yet co-exists in synergy with it. Synchronous technology examines a product model's current geometric conditions in real-time and combines them with parametric and geometric constraints added by the designer to evaluate and perform new geometry construction and edit of the model without the need for full history replay.

FIGURE 1
Synchronous Technology Merges Current Geometric Conditions with Persistent Constraints at Run Time



Imagine the performance impact and design flexibility of making an edit without the need to regenerate the entire model because synchronous technology discovers, localizes, and resolves dependency relationships in real time. Envisage the positive benefits to product development complexity when a designer no longer has to study and unravel complicated constraint relationships in order to understand how to approach a model edit, nor worry about the edit's downstream implications. Designers will begin to ask, "Why must we overtly constrain two model faces to be either co-planar or tangent, when the modeling application can instantaneously recognize those strong geometric conditions and preserve them under edit?"

FIGURE 2
A Common Model Edit and Its Implications in a History-based System



Courtesy of Siemens PLM Software

Synchronous technology breaks through the architectural barrier inherent in a history-based design system that cannot fully determine dependency implications and must therefore rely on a full re-execution of the sequential modeling history. Figure 2 above poses the relevant question. In today's ordered history-based systems, whenever a change is required to a feature in the history list, the system needs to roll back the model to that feature by deleting all subsequent geometry, make the change, and then re-execute the subsequent feature commands to rebuild the model. In large, complex models the performance penalty can be enormous depending on how far back in the history the target feature lies. Synchronous technology does not have this problem – the system recognizes in real time where these conditions exist and localizes model rebuild to only what is necessary to keep the geometric conditions in the model correct.

A QUANTUM JUMP IN MODELING EVOLUTION

The evolution of Computer Aided Design has seen numerous advances in its forty-five year history. CAD was born in 1963 with Ivan Sutherland's SKETCHPAD implementation at MIT. It began as a 2D digital drafting media, and then made its first revolutionary leap into 3D in the 1970s, with 3D wireframe technology, and soon after 3D surface modeling. CAD technology remained classified as *explicit modeling* due to limitations that required users to directly modify geometry shape by edits to the outer boundaries of the 3D model composed of lines and curves.

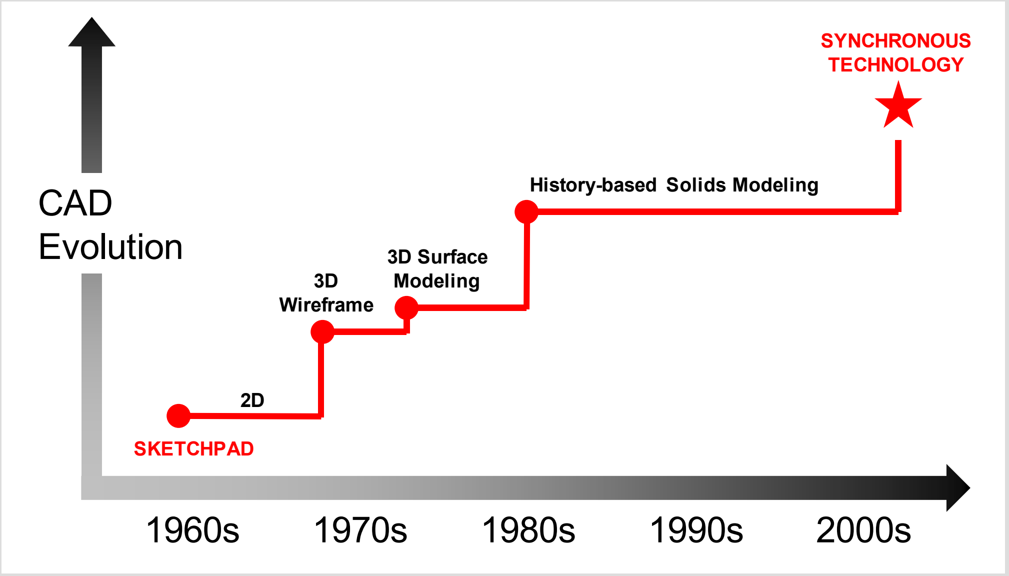
The introduction of commercial solutions in solids modeling in the early 1980s remained explicit in nature due to their reliance on Boolean operations of union, subtract, and intersection. In the mid-1980s, CAD design underwent its second revolution with the emergence of parametric modeling and the concepts of model features embedded in a sequential history-based architecture. Through the 1990s and into the recent past, the vast majority of commercial CAD application adopted the parametric, feature, history-based approach, although a few notable exceptions remained based on explicit modeling technology.

Both approaches have their benefits and their detriments. Explicit modeling allows designers to make direct edits to model geometry without the need to worry about any ripple effect of the edit. The designer controls what and only what changes. That, however, can also be considered a drawback. Because until recently an explicit modeler could not recognize that a collection of model faces may represent a form feature, such as a hole or a slot, it was up to the designer to carefully select all the proper solid faces as part of any edit. In addition, explicit modelers have for the most part an inability to record and remember user-imposed geometric constraints and parametric dimensional formulas.

On the opposite side of the modeling spectrum, history-based, parametric, feature-driven applications excel at capturing intellectual property and user-imposed constraints. Changes to the CAD model automatically update all dependent portions of the geometric shape. That blessing, however, can also be a nightmare to which many designers can testify – understanding the complexity of relationships embedded in a large model to determine the effect of a change can be daunting. Often only the original author can remember the design strategy used to create the model and then only if it was designed recently. Finally, designers must accept the performance penalty of full model regeneration from the point of an edit in the sequential construction history.

Recently, major advances in the ability of CAD systems to do real time "mining" of intelligence found in generic solid-model geometry have resulted in an expansion of "direct geometry" edit capabilities, even within history-based, parametric systems. These improvements lay the foundation for the next revolutionary leap in technology – synchronous technology. By combining a deep, insightful examination of the current geometry conditions of a model, joining that information together with any user-defined constraints and parametrically driven dimensions, and then localizing dependencies in real time, synchronous technology offers the best of both approaches.

FIGURE 3
CAD Evolution



Synchronous technology is a history-free, feature-based modeling system that combines the best of dimension- and constraint-driven techniques for full control and repeatability, with the flexibility of direct modeling.

BUSINESS IMPACT

The performance improvements realized by synchronous technology for edits on history-based and non-history-based models will result in dramatic development process gains. In addition, as users of synchronous technology become comfortable with its intelligent model interaction, their reliance on persistent geometric constraints embedded in the model will lessen. A designer will chose to author the original model without such embedded constraints, knowing that obvious geometric conditions will be recognized by synchronous technology and will be managed intelligently. The impact of that evolution will produce fundamental changes in the product development process.

Product manufacturing companies will see:

- Decreased time-to-revenue based on reduced development cycles
- Increased ease to cope with expected and unexpected product change
- The ability to work on a product model they did not originally author
- Dramatic improvement working with the supply chain because of intelligent interaction with CAD models transferred between different CAD systems using an industry standards format such as STEP, or Siemens PLM Software's JT format
- Increased capabilities to explore more design alternatives rapidly
- More potential to reuse designs without a remodel, as users can edit independent of creation methods (i.e., edit a cylinder as an extruded circle or a revolved rectangle)
- An ability to react faster to market requirement changes later in the development cycle, while at the same time reduce and control the impact of a change on the product model

Those changes will have far reaching implications, in that more rapid revisions to existing products will result in cheaper products and faster time to market. CAE analysts will be able to more easily prepare models for analysis and do quick "what-if" scenarios. Companies will streamline efforts to generate manufacturing process plans and gain the ability to rapidly suggest changes based on manufacturing tooling and process issues.

PROOF OF TECHNOLOGY

A deeper look with an example-by-example basis is needed to understand the power of synchronous technology and to appreciate a complete sense of the impact it will have on the industry.

FEATURE TREE BECOMES FEATURE COLLECTION

Examination of any history-based CAD design application will find an ordered feature tree containing rigidly sequential structure that captures the step-by-step operations the designer used to build the model. The ordered tree is the history (or recipe) of the model's construction. Each entry in the tree is called a *model feature* (not to be confused with form features, such as holes and bosses, although they are also model features) and each represents a particular modeling construction operation. For example, when the designer performs a simple extrusion of a planar sketch, it is added to the feature tree as the next sequential model feature entry.

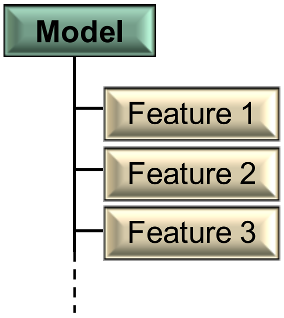
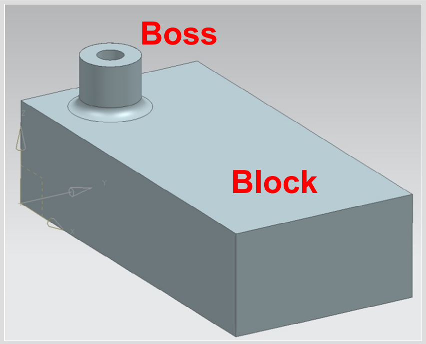


FIGURE 4
History-based Feature Tree

The feature tree begins to nest to deeper levels when the designer explicitly imposes constraints on a new feature by referencing an existing feature in the tree. This is commonly called a parent/child relationship between the two. The child depends upon the existence of the parent feature. Figure 5 presents a classic example of the nuances for this parent/child dependency.

If the designer picks the underside of the block and creates the hole up through the boss, the hole becomes a child of the block and does not rely on the boss. If, however, the designer picks the top of the boss and creates the hole down through the boss and block, the hole becomes a child of the boss and relies on its existence.

FIGURE 5
History-based Model's Parent/Child Relationships Depend on User Selection



Courtesy of Siemens PLM Software

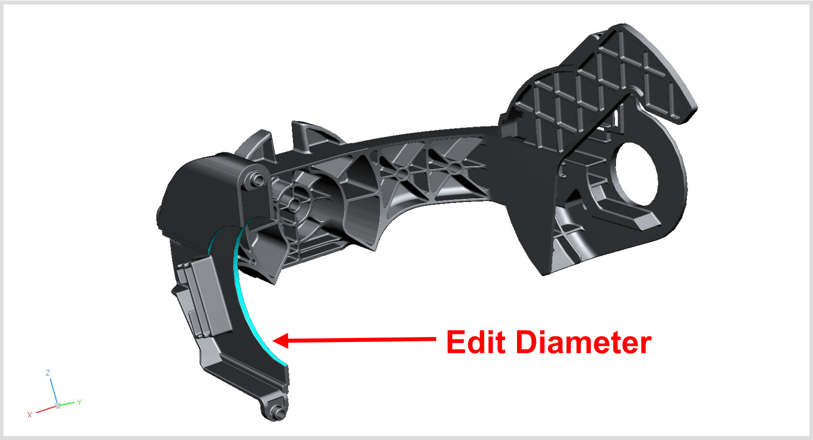
If the designer now selects the boss and deletes it, the resultant model is contingent upon which dependency exists in the model based on its creation history. If the hole is a child of the block, the hole remains; if, however, the hole is a child of the boss, it is deleted along with the boss. In such a commonly implemented history-based modeling application, the burden is placed on the designer to know and understand the embedded dependencies. Synchronous technology removes this need to understand the creation method because it allows the designer to control the relationship at edit time.

Today's history-based CAD systems do not scan the geometric model and attempt to localize the impact of an edit. They rely solely on a replay of history to propagate the change. Synchronous technology changes that assumption.

Synchronous technology explores and localizes dependencies in real time, then executes only the change propagation that is necessary. Consider the immediate impact: in a commonly implemented ordered, history-based application, the system needs to roll back the model to the feature undergoing a change by deleting all subsequent geometry, make the change, and then re-execute the subsequent feature commands to rebuild the model. The earlier in the sequential history the target feature lies, the greater the impact on performance. In many cases, designers often perform unruly workarounds or avoid these types of changes altogether.

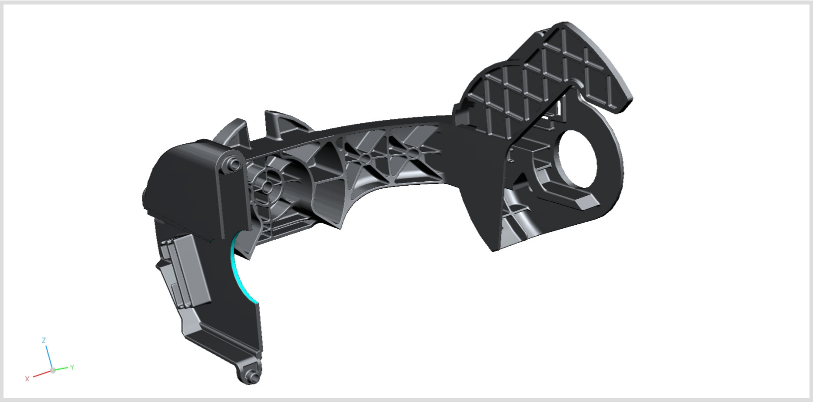
Figure 6 below depicts a model constructed in a common history-based system. It contains 950 features in its history tree. In a common history-based application, a parametric edit to the diameter of the highlighted face takes approximately 63 seconds to complete.

FIGURE 6
History-based Model Composed of 950 Features



Courtesy of Siemens PLM Software

FIGURE 7
History-based Model Edit to Reduce Size of Diameter



Courtesy of Siemens PLM Software

The result of the edit is seen in Figure 7. The edit is lengthy due to the fact that much of the model detail in the center area and on the right side of the model was constructed *after* the area containing the feature undergoing edit. A full history-based system cannot determine that other portions of the model have no dependencies on the selected feature, and thus must blindly follow sequential history order. If the same history-based model was edited using synchronous technology, the edit operation takes only approximately 1.5 seconds to complete. Synchronous technology scans the model in real time, localizes the dependencies, and solves only those necessary dependencies for the correct solution.

In current history-based systems the feature tree has an order dependency. Changing the order of the history tree can result in significant model changes or in model failure. With synchronous technology, the tree displayed becomes a FEATURE COLLECTION that enables designers to quickly select and manipulate parts of their model. However, it does not affect the way the model is constructed. That opens a number of advantageous possibilities to the designer. The collection can be sorted by type of feature, e.g., all rounds collected together, if that provides a needed insight into the model.

Initial reactions to the power promised by synchronous technology often result in a long list of *"Yes, but what if…?"* questions. Historically, the same held true when parametric technology was introduced to the market in the 1980s. A case-by-case examination of how synchronous technology operates on varied types of models is needed.

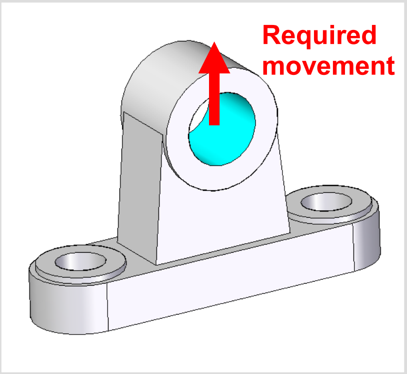
CONTROLLED EDITS ON AN UNCONSTRAINED MODEL

On one end of the spectrum, a model may be fully unconstrained. Sometimes called *dumb* solids, these models most often result from a data exchange translation from one proprietary CAD system to another. An unconstrained model contains no persistent geometric constraints and no parametric values assigned to geometry dimensions.

Given an unconstrained pillow block model depicted in Figure 8, the user must perform an edit that moves the highlighted (cyan colored) cylinder upward to a geometric position that matches the position of a mating shaft (not shown). Because the model is unconstrained, there are no driving dimensions associated with the cylinder that the user can identify and modify parametrically.

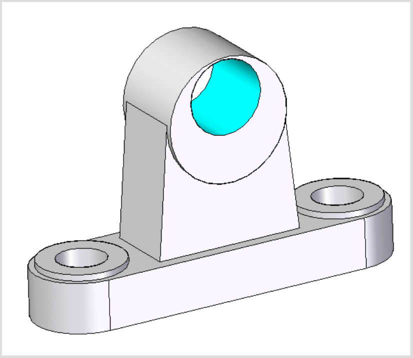
Due to the non-constrained system, only the selected cylinder moves (Figure 9). This result is highly undesirable since the obvious *unwritten* intent of the model shape is lost. Any designer would recognize that the inner mounting hole should remain concentric with the outer cylinder surface and the side tapered faces should remain tangent. The user could have added the outer cylinder to the selection in order to maintain concentricity by moving them together, but without any persistent constraints embedded in the model, the taper on the side faces would not have been maintained (Figure 10).

FIGURE 8
Selection on Unconstrained Pillow Block



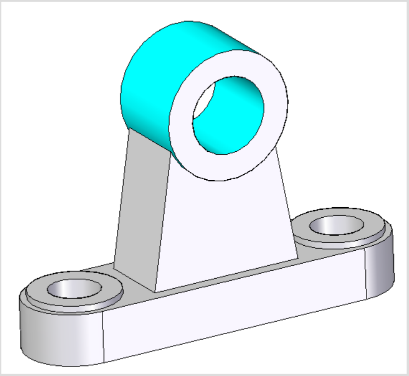
Courtesy of Siemens PLM Software

FIGURE 9
Single Selection Edit WITHOUT Synchronous Technology



Courtesy of Siemens PLM Software

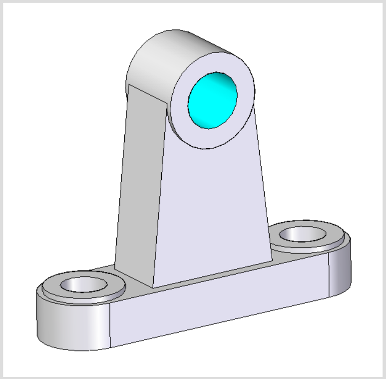
FIGURE 10
Double Selection Edit WITHOUT Synchronous Technology



Courtesy of Siemens PLM Software

With synchronous technology the same edit operation can be made on the unconstrained model, but now the system automatically recognizes these **strong geometric conditions** in real-time and preserves both the concentric cylinders and the tapered tangencies (Figure 11). Note this edit was made by selecting only the inner face of the cylinder, but synchronous technology will produce the same result if only the outer cylinder is selected and moved.

FIGURE 11
Edit WITH Synchronous Technology



Courtesy of Siemens PLM Software

This simple example underscores both the power of synchronous technology and the wide ranging implications it offers users in how they approach design problems. First, when a user is given a component model without embedded constraints, as is often the case when working with a supplier – either because the model was transferred using an industry standard such as STEP or because the supplier consciously removed embedded constraints in order to protect its intellectual property – the user can still easily perform intelligent edits without the burden of having to add geometric relationships for obvious conditions.

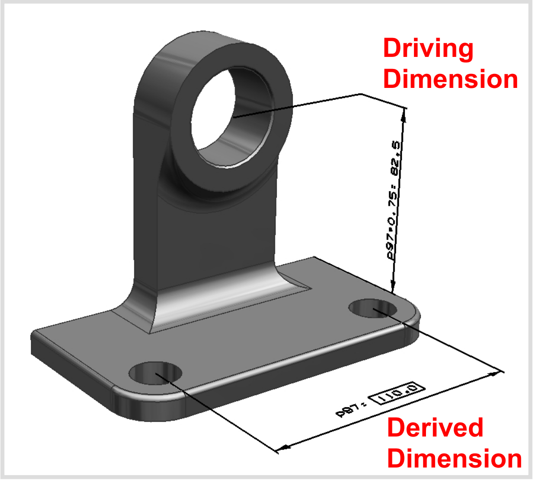
Second, and more fundamental to the nature of design modeling, because the system requires fewer overtly defined relationships embedded in the model (none in this case) to solve intelligently, a designer may choose to author the original model without such embedded constraints, knowing that obvious geometric conditions will be recognized and managed. Design authoring workflow can be dramatically simplified. No longer will a designer have to study and unravel complicated constraint relationships in order to understand how to approach an edit, nor worry about the edit's downstream implications. Synchronous technology discovers and resolves those relationships in real time.

EDITS ON A PARAMETRICALLY CONSTRAINED MODEL

We now turn our attention to the opposite side of the modeling specturm and investigate the impact of synchronous technology on a parametric constrained model.

Figure 12 below illustrates a model with a reference dimension between the two holes in the base. A reference dimension is sometimes also called a derived dimension. It is not a user-imposed constraint. This distance, however, is referenced in a controlling dimension (or driving dimension) that controls the height of the pivot point with an equation that makes it 0.75 of the distance between the base holes. This then represents a parametric formula constraint that must be preserved whenever the model undergoes an edit.

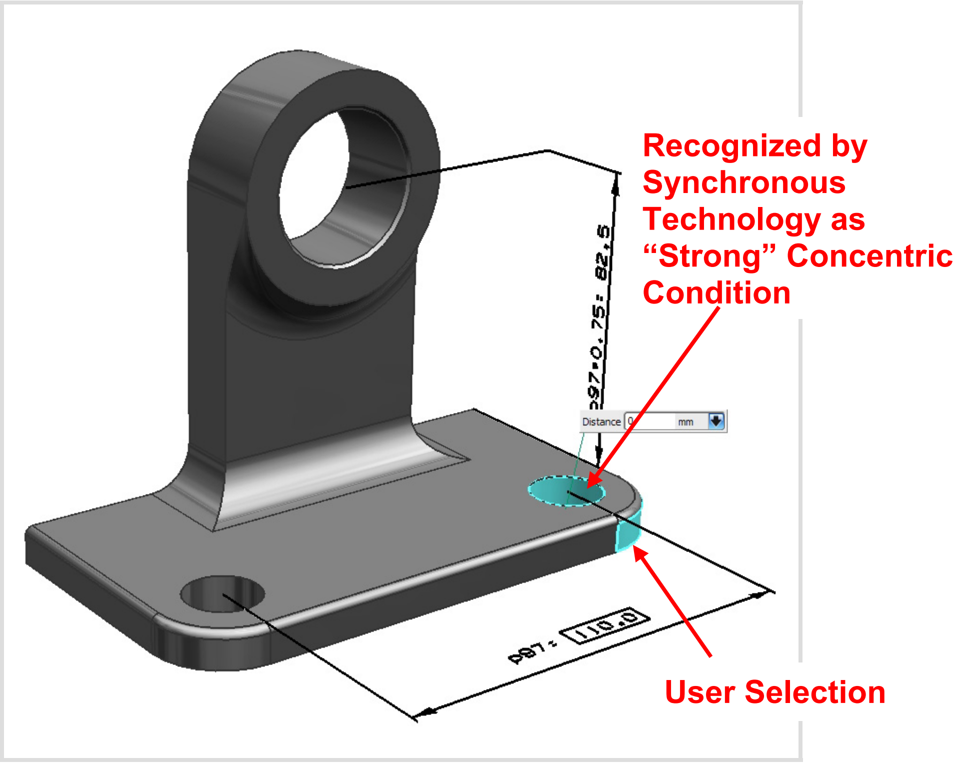
FIGURE 12
Model WITH Parametric Formula Constraint



Courtesy of Siemens PLM Software

Figure 13 shows that a designer may use a direct move on the end of the base. Synchronous technology recognises in real time that the base hole on the right is concentric to the selected arc at the end of the base. It is automatically added to the edit. The move is a direct model edit using a *move face* operation. As the base block gets longer, the base hole on the right is moved with the base; the reference dimension between the two base holes is changed, and the distance to the pivot point is updated based on its parametric formula constraint.

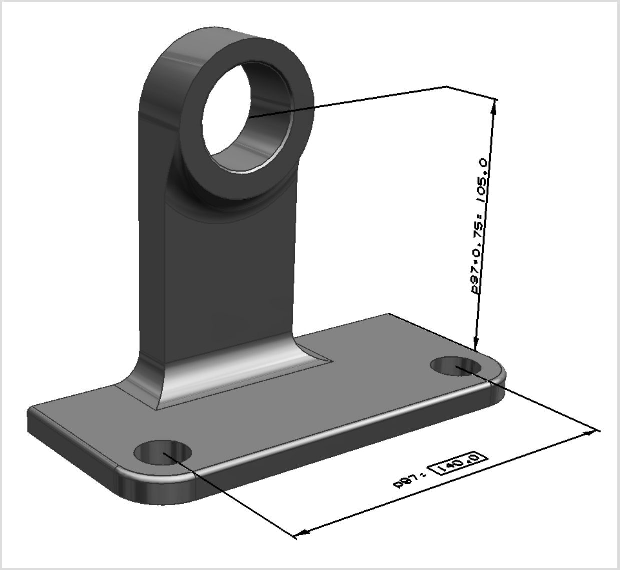
FIGURE 13
Model WITH Parametric Formula Constraint Undergoing a Direct Geometry Edit



Courtesy of Siemens PLM Software

Figure 14 shows the final outcome after dragging the end of the block an extra 30 mm. Note the parametric formula constraint is preserved. Thus synchronous technology coexists with user-imposed parametric constraints.

FIGURE 14
Resultant Model

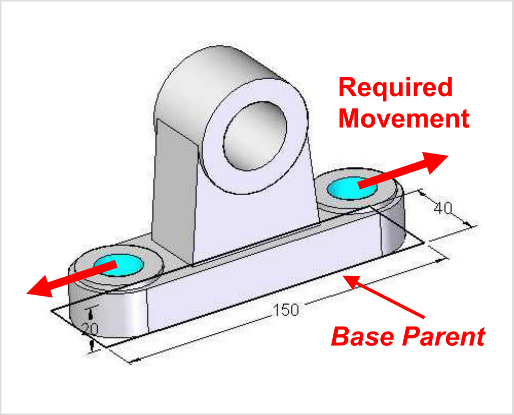


Courtesy of Siemens PLM Software

PARENT / CHILD

If we return to our pillow block model, we can explore the impact of synchronous technology on parent/child relationships. Figure 15 depicts the approach a designer would typically use to construct the model in a common history-based system. First a 2D sketch of the base rectangle 150 units by 40 units is defined. The sketch profile is then extruded upward 20 units to create the solid base. The ends of the base are rounded. Two holes are added to the base. The holes are children of the base parent block.

FIGURE 15
Edit on History-based Model

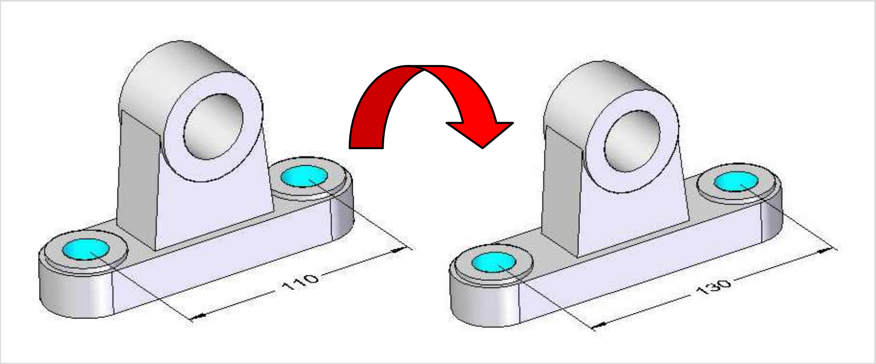


Courtesy of Siemens PLM Software

To positionally mount the pillow block model in a larger assembly, the user must now perform an edit to move the base holes further apart to meet alignment mating conditions with another (unseen) component. While the most natural operation would be to select the base holes and move them into their required positions, the designer cannot operate directly on the holes in this constrained system. Due to the structure in the constrained model, holes are driven from *parent* geometry. They cannot exist until the base parent geometry is created. They require an ordered history. As a result the parent must be changed for the holes to move – a completely unnatural and cumbersome method. Further, only by manually computing the overall shape taking into account the hole clearances, can the overal distance of the base geometry be correctly changed.

With synchronous technology, the user can simply place a dimension between the base holes and drive the movement directly. Synchronous technology maintains concentricity between the modified holes and all concentric cylinders. Again tangencies are automatically preserved. An added benefit is that synchronous technology also maintains the correct concentric position of the small caps surrounding the base holes. Such added dimensions can be saved with the part.

FIGURE 16
WITH Synchronous Technology, Edit by Placing and Updating a Dimension



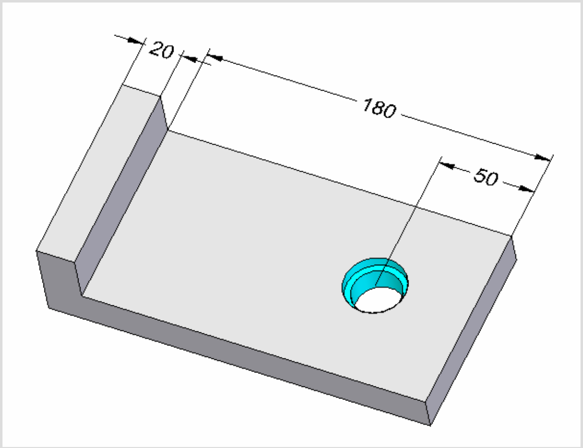
Courtesy of Siemens PLM Software

DIMENSIONAL DIRECTIONAL CONTROL

Synchronous technology opens up a wealth of new possibilities in user interaction with the product model.

The next example illustrates **DIMENSIONAL DIRECTIONAL CONTROL** available with synchronous technology. The user's task is to modify the location of the hole in the component model depicted in Figure 17. Two scenarios are possible.

FIGURE 17
Component Model for Dimensional Directional Control



Courtesy of Siemens PLM Software

The first edit approach is to simply move the hole around while keeping the part model size the same. The red directional arrow shown in Figure 18 indicates that the hole geometry will move in that direction. The geometry tied to the other side of the dimension remains fixed. The original "50" value is modified to "100," while the "180" dimension is maintained.

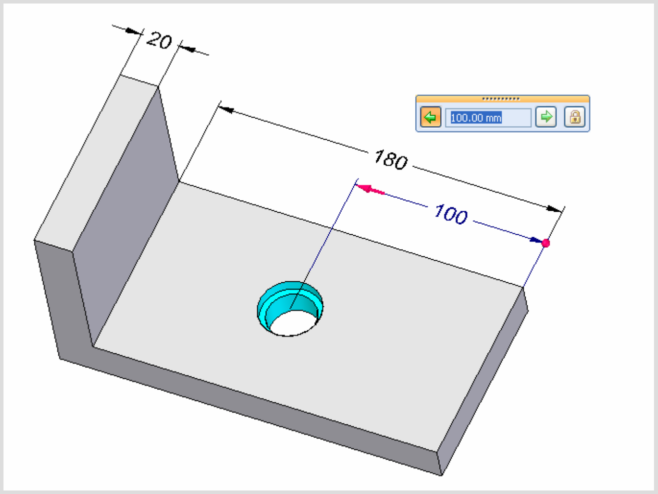


FIGURE 18
Hole Moves while Part Size Remains Fixed

Courtesy of Siemens PLM Software

The second possible approach is to fix the distance between the hole and the right edge of the part. Note that any edit to the hole's position in that direction (denoted by the red arrow in Figure 19) will cause the part to grow in size. In a common history-based system without synchronous technology this edit approach is not even possible. Such edits must be made in the order of creation. In a common history-based system the hole can not drive geometry created before the hole feature itself, much less in a controllable direction.

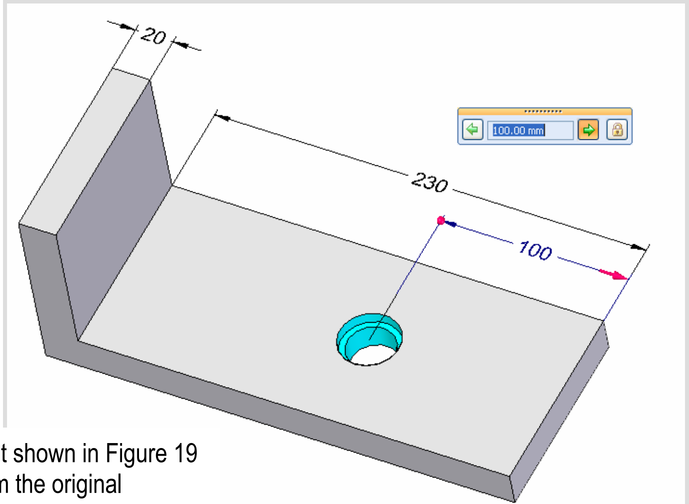


FIGURE 19
Hole Moves AND Part Size Adjusts

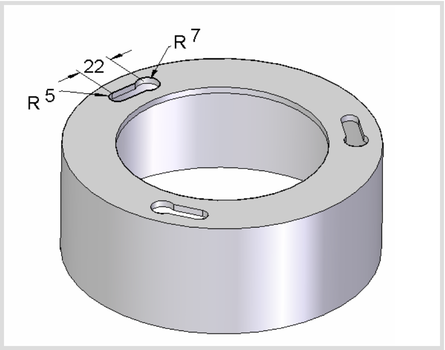
Note the edit shown in Figure 19 is made from the original illustration, Figure 17, and not from Figure 18.

Courtesy of Siemens PLM Software

PROCEDURAL FEATURES

In this next example, the user needs to make edits to the pattern of key slot-shaped holes, either to change the instance count or the geometric shape of the *seed* feature. In common history-based systems, pattern edits must roll the model back to the seed feature(s); only then are edits made; and the model is rebuilt from that point on (model regeneration) for all subsequent operations to take effect. The further back in the history the seed feature exists, the more significant computation must happen to rebuild the model.

FIGURE 20
Pattern Feature

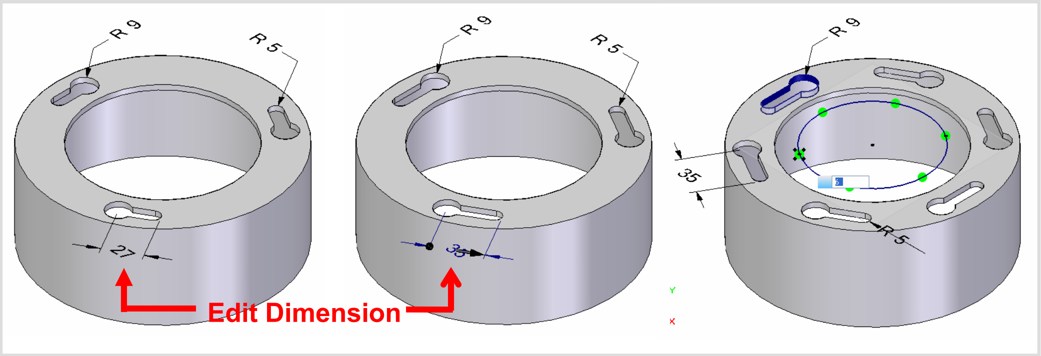


Courtesy of Siemens PLM Software

Synchronous technology introduces a concept call **PROCEDURAL FEATURES**. These features are specifically designed to operate in a system where no ordered solve takes place. A feature must be able to *regenerate itself* to be considered a procedural feature. Not all features can nor need to be of this type; holes and patterns, however, observe this behavior. Thinwall (shell) is similar because it contains special knowledge of how to behave correctly, but it manages change within localized areas of the thinwall.

With synchronous technology, first notice how a series of dimensions can be applied to any of the pattern instances, and edits to *any* cause *all* instances to update. While a dimensional change will cause the pattern to update, any operations created *after* the pattern need not regenerate (since the pattern is self-contained), and the potential resulting performance gains are tremendous. The right-most image below shows a change to the instance count. Again only the geometry associated with the pattern is modified.

FIGURE 21
Pattern Feature
Edit Results



Courtesy of Siemens PLM Software

MODEL CREATION

While the previous examples illustrate model edit capabilities with synchronous technology, many new and interesting geometry creation facilities become available:

- Coordinated 2D sketching solvers and 3D geometry solvers allow sketching in 3D where both solve simultaneously. In this next sequence of three images, sketching in 3D (Figure 22) is done and upon sketch closure (Figure 23), dynamic pull handles appear to allow the user to manipulate the solid extrusion. Runtime logic determines when material is added or removed. (In this illustration material can only be added, as shown in Figure 24.) Dimensions or drag to other geometry key points can be used to set the distance of push/pull operations.

FIGURE 22
Sketching

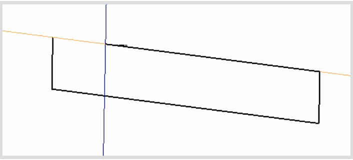


FIGURE 23
Sketch Rectangle Closed

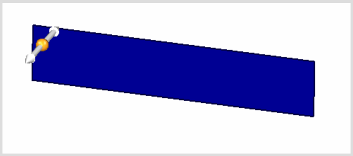
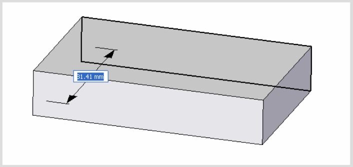


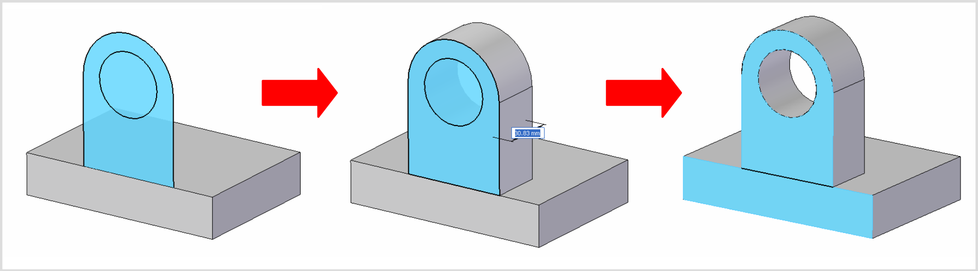
FIGURE 24
Sketch Extruded



Images Courtesy of Siemens PLM Software

- Open profiles are used to simplify drawing to simple sketches where the 2D is connected directly to 3D. Again a simple push or pull creates the upper shaft support seen in the image sequence (Figure 25).

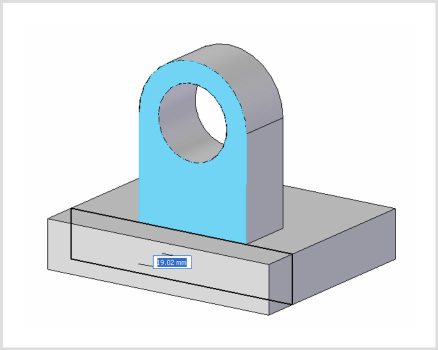
FIGURE 25
Open Profile Extrusion



Images Courtesy of Siemens PLM Software

- Regions can also be created by simple lines across a face. In Figure 26, one line splits the face and allows direct modification of the face.

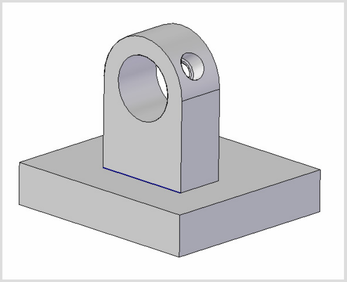
FIGURE 26
Regions



Courtesy of Siemens PLM Software

- Holes are typically placed on planar faces. However, adding a grease fitting as seen in Figure 27 requires a hole at some point of tangency. Built into synchronous technology is the ability to add a hole to a curved face where the hole's normal vector automatically matches the face normal.

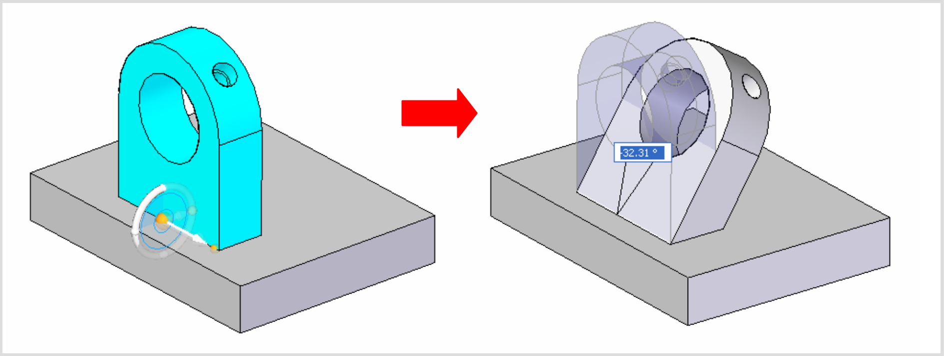
FIGURE 27
Hole Tangent to Surface Normal



Courtesy of Siemens PLM Software

- Material can also be added, removed, or rotated by directly selecting a face set and manipulating a geometric control. The following sequence illustrates how faces can be quickly rotated.

FIGURE 28
Rotating Faces



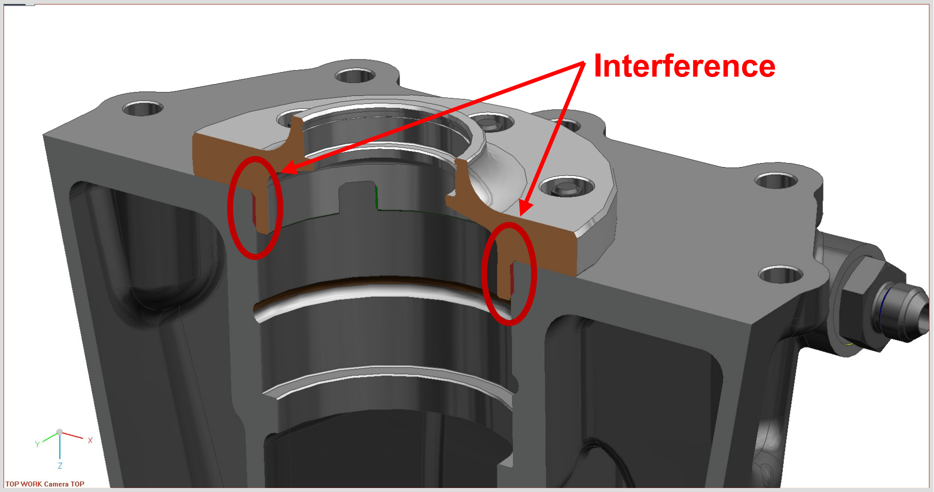
Courtesy of Siemens PLM Software

FAST WHAT-IF CHANGES

One of the most useful capabilities that design organizations would like to have available is the ability to do quick *what-if* design changes as they debate the best product design. In a common history-based system, edits to the model can be cumbersome and require the designer to fully understand the history sequence, in order to determine where in the sequence to make the edit, and then predict what ripple effect that change will cause.

Consider a traditional design review where an assembly has been cut with a plane to look for interferences. Figure 29 shows the interference circled in red that obviously continues around the circular well.

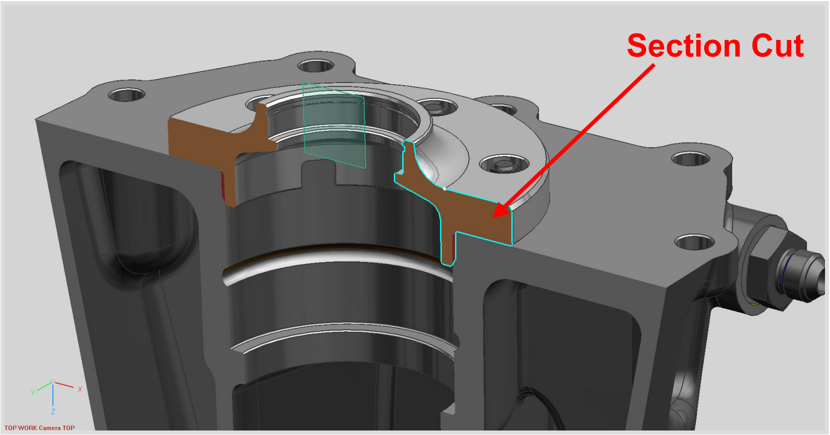
FIGURE 29
Section Cut Showing Interference



Courtesy of Siemens PLM Software

This design problem would normally require a downstream user to mark up (red-line) the view and feed the image back to the authoring designer to seek a resolution. With synchronous technology, using section-based editing the reviewer could easily suggest some possible model changes to fix the problem. First, section-based editing cuts a planar section through the model and generates sketch curves that will drive the model (Figure 30).

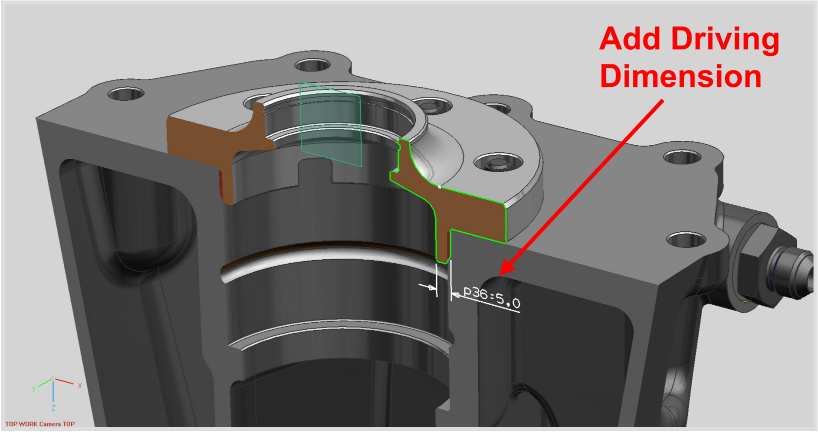
FIGURE 30
Section Cut Showing Generation of Sketch Curves



Courtesy of Siemens PLM Software

The reviewer can then either drag the curves or add 2D dimensions to the profile and modify their values as shown in Figure 31.

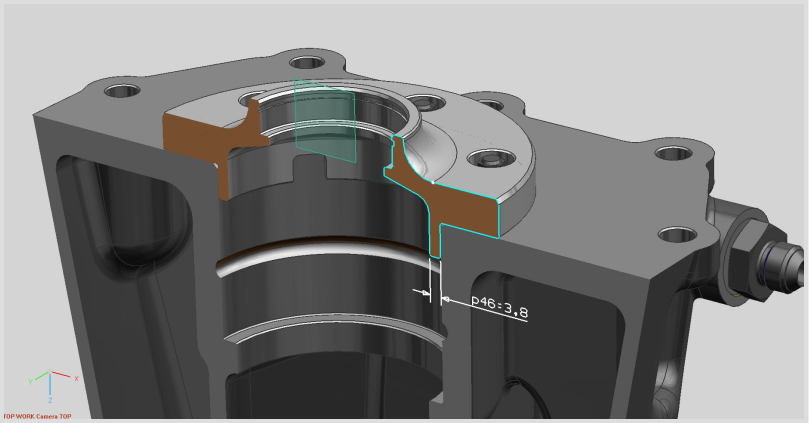
FIGURE 31
Dimension Added



Courtesy of Siemens PLM Software

In this case the thickness can be changed from 5 mm to 3.8 mm, giving the result shown in Figure 32, and the interference is eliminated.

FIGURE 32
Dimension Changed to Eliminate Interference



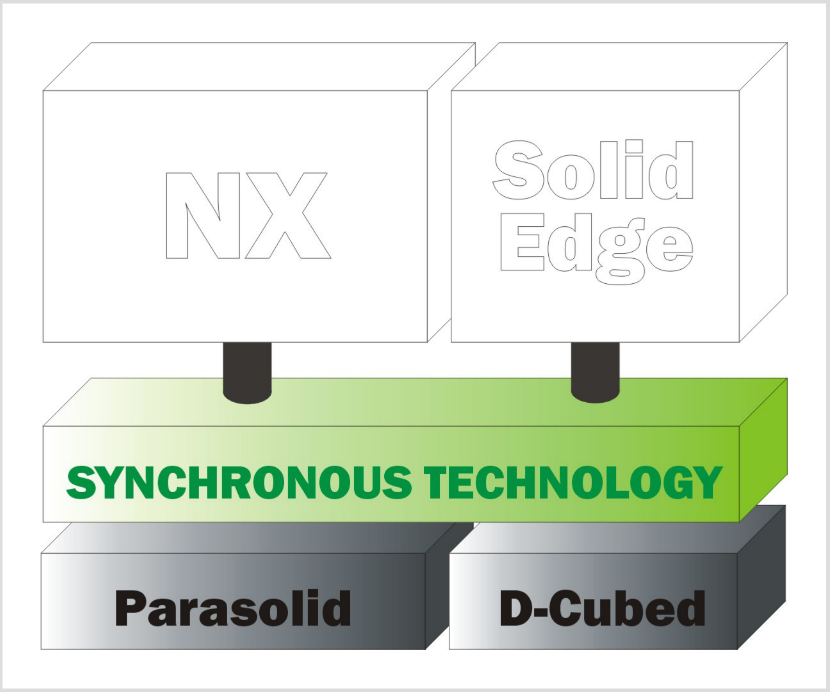
Courtesy of Siemens PLM Software

TECHNOLOGY ROLL-OUT

Synchronous technology software acts as a design application layer that sits between the operational logic of design create/edit commands in the CAD application, and the basic geometry support services of a geometry kernel and other utilities. During execution it draws information from both the current state of the geometric model and any persistent constraints that the user imposed on portions of that model. It deals intelligently with a broad spectrum of models from fully unconstrained to heavily constrained.

Initial research seeds for synchronous technology were discovered in the UGS R&D labs by Siemens during its acquisition due diligence process. Because Siemens recognized the potential value and fostered accelerated development, Siemens PLM Software now indicates that the first commercial release of synchronous technology will occur in the summer of 2008 for both of its CAD applications, NX and Solid Edge.

FIGURE 33
Software Architecture



SUMMARY AND OPINION

The CAD world is about to change dramatically.

In much the same manner as CAD users were exposed to parametric modeling in the 1980s and came to understand and value its impact over time, synchronous technology will find an equally appreciated role in product modeling across all industry verticals. Because the real-time power delivered by synchronous technology to recognize the current geometric conditions in a solid model coexists synergistically with user-imposed constraints and parametric dimensions, the user transition to take increasing advantage of the new breakthrough capabilities will progress smoothly.

As product development companies leverage the power and performance of synchronous technology, the competitive advantages they realize will fuel its adoption. There will be *no going back* to flooding a product model with user-defined geometric constraints. Synchronous technology will automatically discover geometric conditions apparent in the model and preserve them during edits. The new intelligence of CAD modeling will virtually blast from their desktop screens.