PARAMETRIC MODELING

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The term **parametric modeling** denotes the use of parameters to control the dimensions and shape of CAD models. Think of a rubber CAD model that can be stretched and deformed through various controls, but cannot be ripped or torn. The manipulation of a CAD model of a single part could be through overall part dimensions or through the dimensions of features. Things get considerably more interesting if a parameterized assembly model is constructed. Changes in assembly dimensions or in part dimensions can cause changes in assembly and part shapes or in parts' assembled positions. Generally, it can be very useful to explore design spaces by manipulating parametric CAD models - creating multiple instantiations of a design and analyzing their properties.

There are two broad approaches parametric modeling:

- variational geometry
- parametric geometry

Sorry for the dual usage of **parametric**, but the terminology in this field resulted from an *ad hoc* process.

In general, the term parametric geometry refers to a 1-way evaluation of parametric relationships, much like a spreadsheet. On the other hand, the relationships in variational geometry models can be bi-directional. Variational geometry solvers are typically nonlinear, simultaneous equation solvers. The underlying mathematics suggests that variational geometry is more general and powerful, but in practice it is the command set in CAD systems that really controls modeling generality and power.

How to Control Geometry

The idea behind parametric modeling is that CAD users may want to adjust model dimensions, for example to explore the effects of different feature sizes, without recreating model geometry. In fact, parametric modeling enables a new CAD model construction methodology. But let's start at the beginning.

Parametric modeling utilizes several different types of primitive elements, basically dimensions, datums, and constraints.

- **Dimensions** can be linear and angular.
- **Datums**. Different CAD systems provide various types of datums, but typically datum planes and datum coordinate systems are provided. Datum lines and points are also possible. Generally, datums are coordinate systems, or parts of coordinate systems, that are used to control other coordinate systems or geometric entities.
- **Constraints** can be geometric or algebraic relationships that the designer wants to impose on the geometry of CAD models. For example, typical **geometric constraints** are parallel, perpendicular, offset, tangent, and alignments. These constraints can be applied to many different types of geometric entities, such as lines, planes, and surfaces. Alignments are used to constrain parts relative to one another when constructing assembly models. **Algebraic constraints** are equations that the designer adds to ensure that features sizes meet design requirements. For example, a part cross-section may have to be a certain area.

By carefully laying-out datums and geometry, then constraining them with dimensions and constraints, parametric models can be constructed that enable designers to explore a wide range of product sizes and shapes. However, poorly constructed parametric models can result in designer frustration caused by limited CAD model flexibility.

Constructing a Parameterization Scheme

Different parameterizations applied to a CAD model imply different responses to changes in dimensions. In order to construct a good parametric model, several items should be considered:

- Identify top-level variables. In other words, which dimensions are the real design variables and which ones are subordinate?
- Decide how your CAD model should change when one of these top-level dimensions is changed.
- Add those dimensions, datums, and constraints that allow your CAD model to change accordingly.

Of course, this recipe is easier to type than to actually implement. The bottom line is that your CAD model should embody the flexibility that is of interest in your design project. Evaluation criteria for parametrization schemes include:

Use natural top-level parameters - the natural design variables.

Allow your major components (or part features) to be positioned using their dominant mating relationships.

Model using a top-down hierarchy.

Allow major part and subsystem interfaces to be directly controlled.

Enable your components to be progressively refined. That is, allow black-box components to be added to your assemblies; these components can be detailed later, while still being part of an assembly.

Role of Parametric Models in Design

A parametric model embodies a space of designs. This design space is defined by the dimensions in the CAD model. By varying dimension values, the designer can explore the design space, identifying good regions of the space or selecting specific points of the space as representative of good designs. This activity is generally considered to be parametric or detailed design. I consider the act of constructing a parametric model to be layout, configuration, or preliminary design.

Parametric modeling CAD systems are good at supporting parametric design. Given a parametric model, the design space can be explored by changing variable values. In effect, the design space is a subset of R^n, where n is the number of design variables. CAD models can be linked to optimization codes to support the solution of optimization problems. The variables in a parametric model should be linked to the design variables in the optimization problem. In this way, whenever the optimization code changes a design variable value, the CAD model can be updated.

Support for configuration design problems, on the other hand, is only provided to the extent that the designer is able to construct parametric CAD models. Small configuration changes usually necessitate the designer having to undo several commands, then redoing similar commands. Consider the substitution of a bolted-joint with a snap-fit connection. The bolt and nut parts must be deleted from the assembly model. Then, one or more parts must be modified. The snap feature must be added to one part and other changes (e.g., changing holes to have circular cross-sections to having square cross-sections) may be necessary as well.

We have done research here at Georgia Tech on the fastener instantiation and substitution problems that have some promise in supporting aspects of configuration design, but a general solution will require very different CAD technologies. One technology that would be useful is a computational model of behavior, such that behaviors distributed throughout geometric objects can be modeled. Finite element models are one example of such a distributed behavior model (behavior in terms of displacement throughout a spatial domain). However, only a handful of behaviors can be readily modeled using FEM.

Example

The example that will be used to illustrate parametric modeling was constructed in ProEngineer. It is a blank injection mold insert. The way that parametric modeling CAD systems typically work is the user starts by sketching the part's cross-section, adding constraints, then specifying dimension values.

I followed the ProEngineer guidelines of first setting up 3 datum planes and a datum coordinate system that coincides with the intersection of the 3 planes. Datum planes DTM2 and DTM3 can be seen in Figures 1 and 2, along with coordinate system CS0. All of these datums are parents of the part to be created.

DTM3 was chosen as the sketch plane (XY). The mold insert cross-section was created with positive Y coordinates. Insert geometry consisted of two polylines and two 90 degree arcs. The arcs are tangent to the coincident line segments (constraints that ProE assumes correctly). After adding these geometric entities, I aligned the top line segment with DTM2. ProE assumes that line segments are horizontal or vertical, if nearly so, and are parallel or perpendicular to one another. In this case, these assumptions are appropriate. It is important to note that these assumptions are implemented internally by ProE as constraints.

All parametric modelers are really uptight about properly constraining the geometric entities. This is where the choice of parameterization schemes comes into play. I chose to dimension everything from the datum planes. Figure 1 shows the dimensions with default ProE values. Note that the height of the insert is controlled by a dimension from the DTM2 datum. The width is controlled by the dimension with default value of 799.13. Note that the horizontal location of the insert is controlled by a dimension from DTM1, the vertical datum plane (dimension value of 120.4). Also, the circular arcs have their radii dimensioned.

Figure 2 shows the mold insert with correct dimensional values specified. Note the change in shape. Since ProE correctly changed the shape, it means that the cross-section is completely parameterized. Each of these dimensions can be changed, which of course is the whole idea behind parametric modeling.

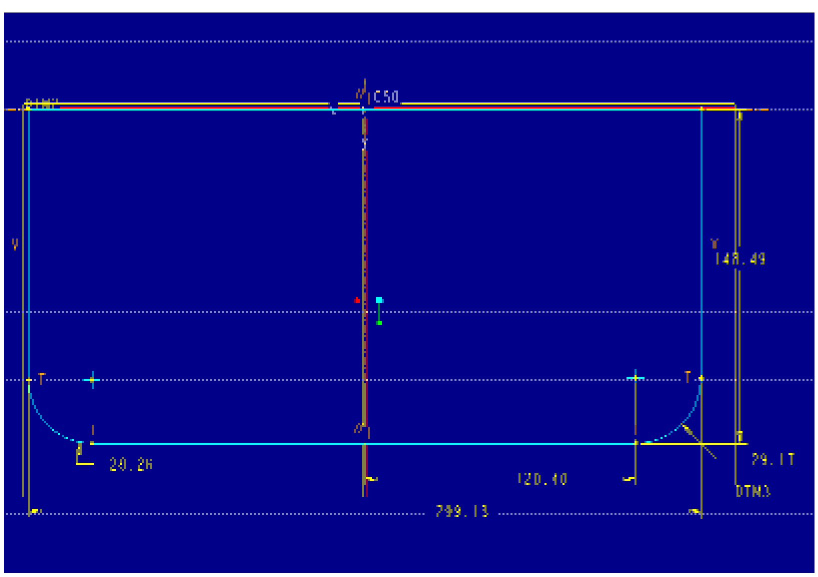

Figure 1 Mold Insert Cross-Section Geometry and Dimensions.

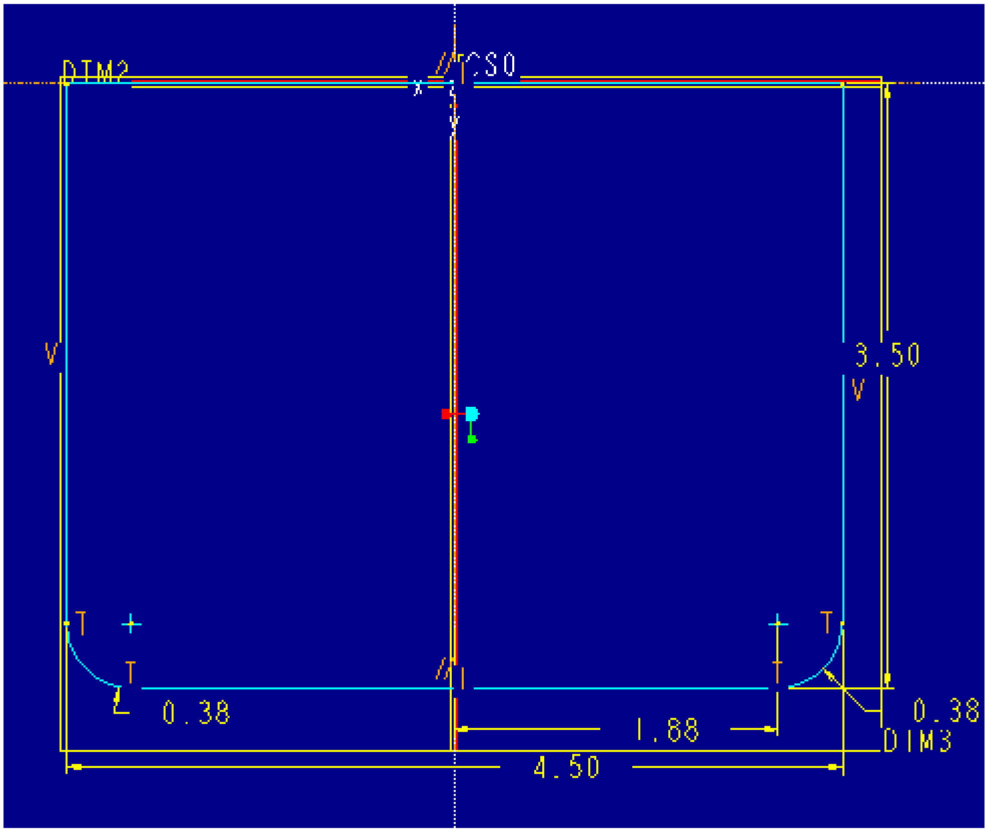

Figure 2 Mold Insert Cross-Section with Correct Dimensional Values.

After completing the cross-section, a solid model can be created by extruding the cross-section. I set things up to extrude this cross-section along the positive Z axis. After creating the solid model, it is displayed by ProE, along with the dimensions, as shown in Figure 3.

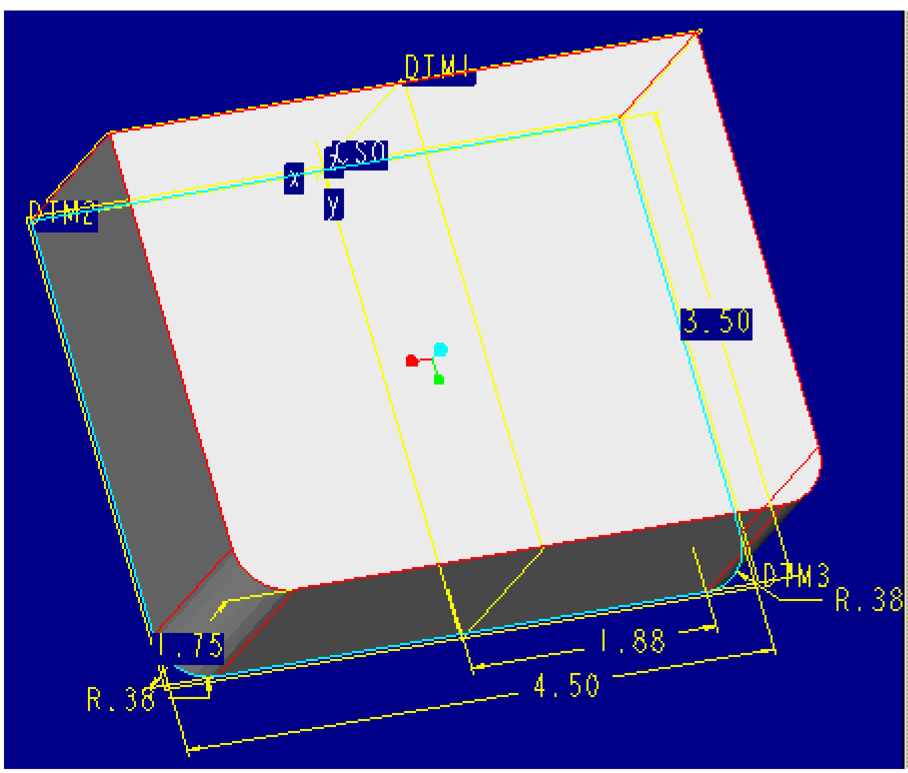

Figure 3 Solid Model of Mold Insert.

Figure 4 shows the result of changing the insert width dimension from 4.5 inches to 5.5 inches. Note that the insert geometry is no longer centered in the CS0 coordinate system. This is because the dimension to the right arc was not changed (1.88). With a different parameterization scheme, the insert could have remained centered. Recall that I dimensioned everything from the datums, rather than dimensioning entities relative to one another, which would be necessary in order for automatic centering to work. Which is correct? Both are - it really depends upon what design freedom the designer intends to embody in the design.

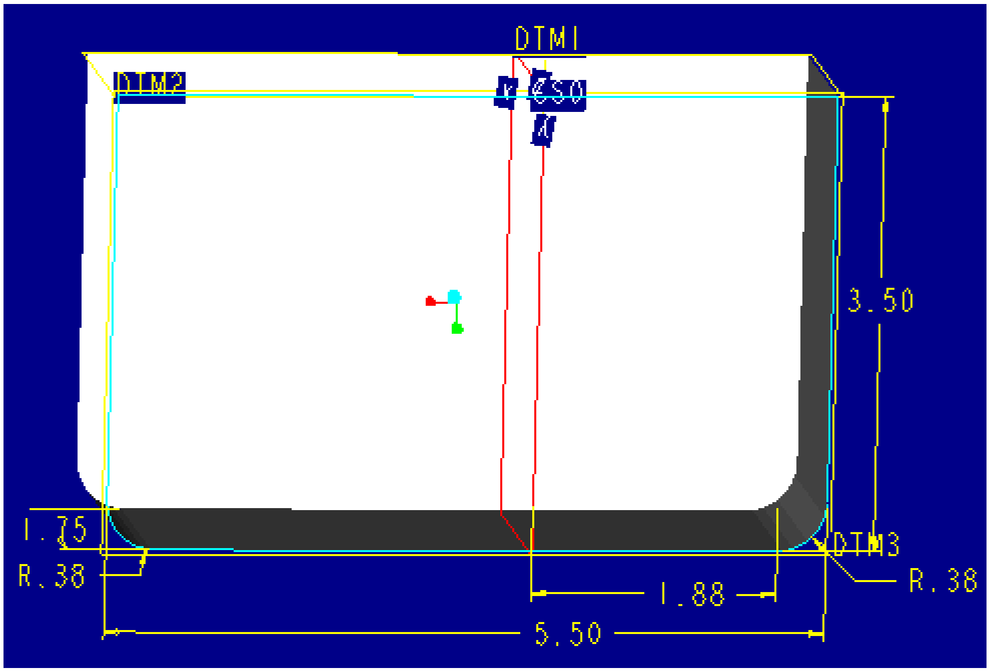

Figure 4 Modified Mold Insert.