

8. Applying Constraints and Dimensioning In Solid Modelling

The solid model stores more than just the final geometry—it stores the “design intent” rules that govern what will happen when geometry changes. This makes it easy to make flexible design changes to part models. These rules are described as “constraints” on wireframe geometry used to extrude and revolve parts, and as “relations” when parts are cut, joined, or intersected. Part dimensions and constraints can also contain user-written equations. These relations and constraints allow a design philosophy of “shape then size.”

8.1. WHAT ARE CONSTRAINTS?

You include constraints on your 2-D sketch to control how the geometry will behave when modifications are made to the sketch or to the model that you create. In this way, your design intent will be preserved even as modifications are made to the size of the part later on. There are two major types of constraint-based modeling systems available on the market today: **variational** geometry and parametric modeling.

8.1.1. Variational Geometry

With *variational geometry*, constraints are applied to the 2-D shape in terms of degrees of freedom. A *degree of freedom* exists if there is currently no constraint applied to control a specific feature of the geometry of your sketch.

Variational-geometry modelers consider the total number of degrees of freedom that a sketch contains, and as you add constraints, degrees of freedom are removed from consideration. Variational solvers work on systems of equations. Therefore, if there are initially 20 degrees of freedom for your sketch, you will need 20 constraints in order for your geometry to be fully constrained. The resulting system of 20 equations (each time you apply a constraint, you are creating an equation for the system) must be able to be solved simultaneously, or your geometry is not valid.

Another feature of variational geometry is that you do not have to work with fully constrained geometry. Certain degrees of freedom can be left unspecified on the sketch, and you can still extrude or revolve the shape to form a solid.

This concept is best described by a simple example. Start with a simple 4-sided polygon, defined by 4 points, 1 through 4, as shown below. What do we want to happen if point 3 is translated to the right? Two possible solutions are shown in Figure 8.1:

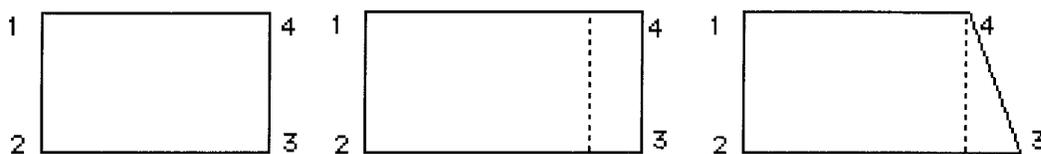


Figure 8.1. Simple 4-sided polygon

A way to solve this ambiguity is to constrain the right hand end so that it must remain vertical. What is happening in the software when this constraint is applied can best be described in terms of simultaneous equations. In a two dimensional plane, the four-sided polygon shown has eight degrees of freedom (DOF),

since the location of each corner is described by an X and a Y location. To constrain the right end to remain vertical, a simple equation can be written:

$$X_3 = X_4$$

When this equation is applied, the number of DOF in the section is reduced by one. Other equations could be written to enforce other geometric constraints. For example, to constrain the top and bottom lines to be horizontal, the equations could be written:

$$Y_1 = Y_4 \qquad Y_2 = Y_3$$

Applying a dimensional constraint, such as to place a vertical dimension between points 1 and 2 to some value, say 100 for this example, is the same as writing an equation

$$Y_1 = Y_2 + 100$$

Other equations can be written to express other geometric relations such as perpendicular and parallel. The equation to ensure that an arc remains tangent to a line may be more complicated, but the concept is the same. As we apply geometric constraints, the software is writing a system of equations that will be solved to determine the unknowns if any value is changed.

Uses of Variational Geometry

The tools available with variational geometry can be used in different ways. For example, rather than creating a section to exact dimensions as you would in a drafting system, you could sketch the section approximately on the workplane, and then add variational constraints to “drive” the section into the configuration you want.

Variational geometry can also be used to study kinematic linkages. Constraining a point to point dimension on a line constrains the line to have a fixed length, like a linkage of a mechanism. Angular dimensional constraints can be applied, and modified to “drive” the mechanism to see its allowable configurations.

When a constrained section is used to create a part by revolving or extruding, the resulting part will also contain the constraining “rules.” Constraints which are applied to the section will be displayed as dimensions on the solid part when you pick the extrude or revolve feature used to create the part. Like other dimensions, they can be picked and modified to change the part.

How Many Constraints do You Need?

Some mathematically-inclined readers may have a question at this point about how many constraints can be applied to a section. Normally, to solve a set of simultaneous equations, the number of equations must equal the number of unknowns.

What happens if fewer than this number are applied, and a change is made to a value?

There could be more than one possible solution. If you were using a general-purpose symbolic math package, it might not let you try to solve a set of equations where there were more unknowns than there were equations. The solver used to solve variational geometry is not just a simple simultaneous-equation solver. It looks at the geometry, and attempts to make the minimum change if more than one solution is possible.

8.1.2. Parametric Modeling

Parametric modeling is a subset of variational geometry. Parametric modeling allows for a flexible design in much the same way that variational modeling does. That is, you are able to add constraints to your sketch to control how the geometry will behave as modifications are made. However, parametric modeling does not work on a system of simultaneous equations. Instead, parametric modelers solve the equations specifying your constraints in the order that they were applied. Thus, if conflicting constraints were specified, then the most recent constraint that was added to the geometry would govern the behavior of the 2-D shape as modifications were made.

In general, you need to have a fully constrained shape before you can use parametric modeling to create a 3-D solid. Your resulting shape may have more than one constraint that defines the same degree of freedom; however, you cannot have any degrees of freedom that are undefined.

As you work with your solid-modeling software, it is important that you understand whether you are working in a variational-geometry or parametric environment. The results that you achieve may vary greatly, depending upon the software system that is available to you.

8.2. TYPES OF CONSTRAINTS

Constraints enable you to preserve the original design intent even as changes are made to the model you have created. Constraints allow for a great deal of flexibility in the design, but it is important that you apply the constraints properly so that the integrity of the design is maintained. It is also important for you to realize, first, that at the current level of software development, constraints can be applied only between 2-D geometric entities on your sketch and, second, that you are constraining one entity relative to another one. There are three major categories of constraints:

- Geometric
- Dimensional
- Ground

8.2.1. Geometric Constraints

Geometric constraints control the shape of the profile. When you profile your sketch, the sketch is analyzed and geometric constraints are added to suit the sketch. If a line is within 4 degrees of being horizontal, it will be altered to be horizontal. The same thing applies to vertical. You also add your own constraints to solve a profile completely.

You can add geometric constraints to control the shape of different objects in your profile. Limit the use of geometric constraints where possible and use dimensional constraints to give you the freedom of size changes.

Geometric constraints are used to define the *shape* of your 2-D geometry. Figure 8.2 illustrates the types of geometric constraints you can use to define the shape of your 2-D profile.

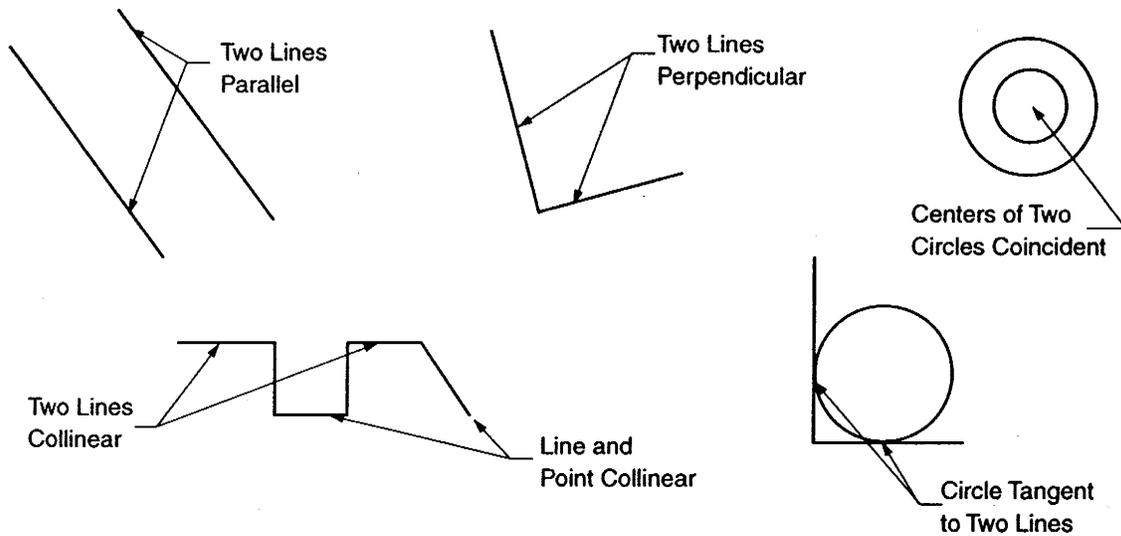


Figure 8.2. Types of geometric constraints

The following is an explanation of the different geometric constraints listed in the order. Beside each name is the corresponding identification letter. If the constraint requires two objects, the first object is the control object and the second has the constraint applied to it.

Parallel (P) With this constraint, you define one line parallel to a second line on the sketch. If the angular orientation of one line changes, then the angular orientation of the second line will change accordingly.

Perpendicular (L) This type of constraint is used to restrict the orientation of one line so that it always meets a second line at a right angle. Again, if the angular orientation of one of the lines changes, then the orientation of the second line will be modified so that perpendicularity is maintained.

Collinear (C) This constraint is used to establish collinearity either between two separate lines or between a line and an indicated point.

Coincident (N) This constraint is used to indicate that two points on a sketch coincide with one another. For example, two circles may be constrained to be concentric with one another.

Tangent (T) With this constraint, you establish a relationship between an arc (or a circle) and a line such that the two entities will always remain tangent to one another. If you create a predefined filler on a sketch, chances are that a tangency constraint was internally applied for you by the software.

Horizontal (H) Lines are forced to run parallel to the X axis.

Vertical (V) Lines are forced to run parallel to the Y axis.

Project (J) Objects are forced to be projected until they touch a specified object.

Join A gap between two objects is closed. Because it is more of an operation than a constraint, there is no constraint letter.

Xvalue (X) The center points of arcs and circles are forced to use the same X coordinate. This will also work with the endpoints of lines.

Yvalue (Y) The center points of arcs and circles are forced to use the same Y coordinate. This will also work with the endpoints of lines.

Radius (R) Arcs are forced to use the same radius.

Equal (E) Lines are forced to have the same length.

Mirror (M) Lines, arcs, circles, ellipses, and spline segments are forced to become mirror images about a specified axis.

Fixed (F) The endpoint of a sketch segment, or the segment itself is forced to be in a fixed position.

Figure 8.3 shows a 2D sketch that has geometric constraints applied to it as listed underneath it. Note that the shape of the geometry is now well defined. You can then add ground or dimensional constraints to the sketch to define the exact size and orientations of the features that make up its geometry.

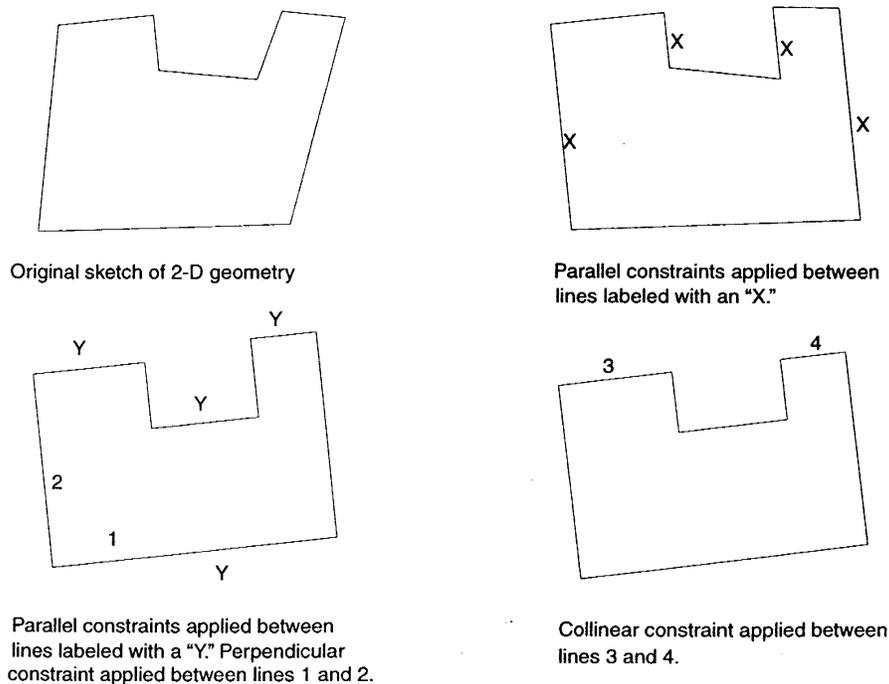


Figure 8.3. Application of geometric constraints to a 2D shape

8.2.2. Dimensional Constraints

Dimensional constraints specify the length, radius, or rotation angle of the geometric elements in your sketch. Geometric constraints force the profile to conform to a specific shape. Dimensional constraints, on the other hand, add the parametric characteristic to the profile. You can change a dimension at any time and its new value will be immediately reflected in the design.

Dimensional constraints define the *size of* your 2-D shape. Sometimes, when you apply this constraint, you will define a size that is inconsistent with other dimensions or with other geometric constraints on your sketch. The type of dimensional constraints that are available to you typically are as follows:

Linear This constraint is used to define - the linear distance between two lines, between a line and a point, or between two points. The constraint is sometimes further subdivided into either vertical, horizontal, or aligned dimensions. A *vertical* dimension is the vertical distance between two entities, a *horizontal* dimension is the horizontal distance between two entities, and an *aligned* dimension is the actual distance between two points. Aligned dimensions can be used only to define the distance between two points.

Angular Angular dimensions are used to define the angle between two lines on your sketch. The lines between which the constraint is applied do not need to intersect on the sketch itself; however, you cannot define an angular dimension between two parallel lines.

Diametral & Radial Diametral constraints are used to control the diameter of any circles on your sketch. Radial dimensions control the radius of any arcs on your sketch.

Two-Dimensional Constraints

As you made your sketches, you did not necessarily create all of the individual 2-D geometric entities in their final sizes or shapes. Furthermore, design is iterative, and you will likely make many changes to your initial design throughout the process. The earliest versions of solid-modeling software provided little opportunity for you to change your geometry in an easy manner. Designers were forced to start over from the beginning in order to incorporate even the smallest change in creating a part. Fortunately, software today is very flexible, and you are able to effect changes in your design as necessary. The source of this flexibility stems from the use of constraints within the software. This chapter focuses on these constraints: what they are, why they are useful, and the types of constraints typically found in solid-modeling software. You will also learn how to apply and modify constraints to assist you in creating parts that are the correct size *and* shape. Figure 8.4. illustrates the various dimensional constraints that you can use to define the size of your 2-D geometry.

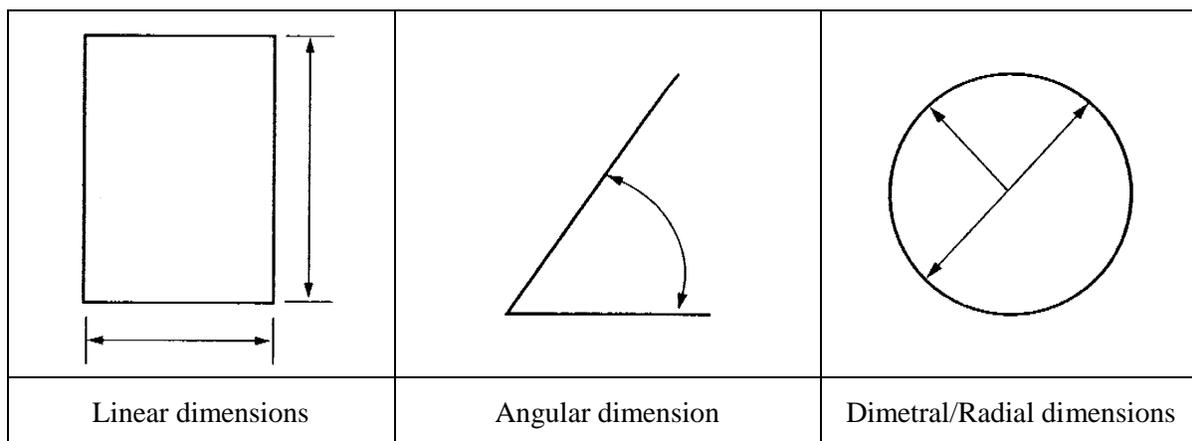


Figure 8.4. Types of Dimensional Constraints

With the combination of geometric, ground, and dimensional constraints attached to the geometry, this shape is now fully constrained—there are zero degrees of freedom remaining. Note that if any of the dimensional constraints are modified, the geometric and ground constraints will maintain the *shape* of the geometry, but the *size* will change according to the newly input dimensional value.

Method of Entry and Display of Dimension Values

Dimensions can be shown and entered as either numeric constants or as equations. You can even use a combination on one profile (see Figure 8.5). Part (a) shows the profile with numeric dimensions and Part (b) shows it with equations. Using equations on the profile can add to its versatility because when you modify one dimension, a series of dimensions will change in relation to it (see Figure 8.5(b)). Note the formula $d3 = d4/2$. Whenever you change the dimension $d4$, dimension $d3$ will change to always be **1/2** the value of $d4$. Using formulas, you can easily customize parts that have dimensions that are specifically related to each other. The rule of thumb for using numeric values versus equations is:

Use numeric values when the size of an object is not related to another object and use an equation when the size of an object is directly related to another object.

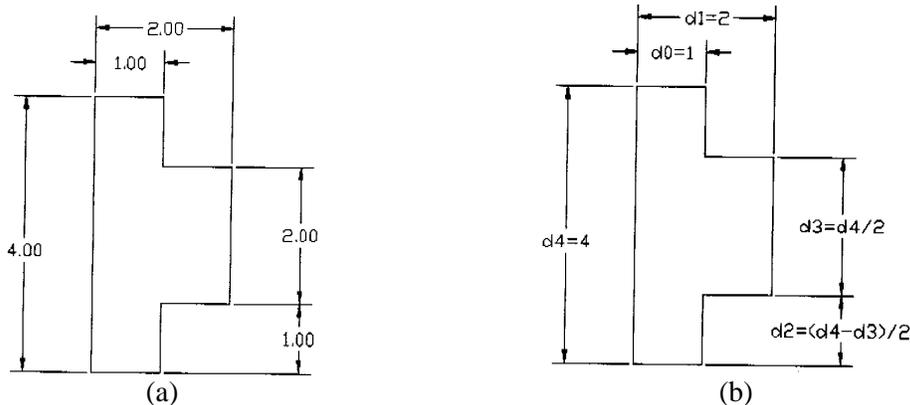


Figure 8.5. Numeric values and equations of dimensions

You can enter an equation whenever you are asked to enter a dimension value. You should usually dimension the larger objects first. This will help to keep the sketch from distorting during dimensioning. Remember that you're using a combination of geometric and dimensional constraints to solve the profile. You do not necessarily have to dimension every object in the profile. Some of the objects may be constrained by other objects. It is important to review the geometric constraints before dimensioning the object (see Figure 8.6(a)). This profile requires only three dimensions because most of the geometry is controlled by geometric constraints. Review the various constraints in Figure 8.6(b). If you add too many geometric constraints, you may get the message that the profile is overconstrained and you will need to remove some. Usually the program will notify you if you try to add a dimension that will overconstrain or conflict with another previously placed dimension.

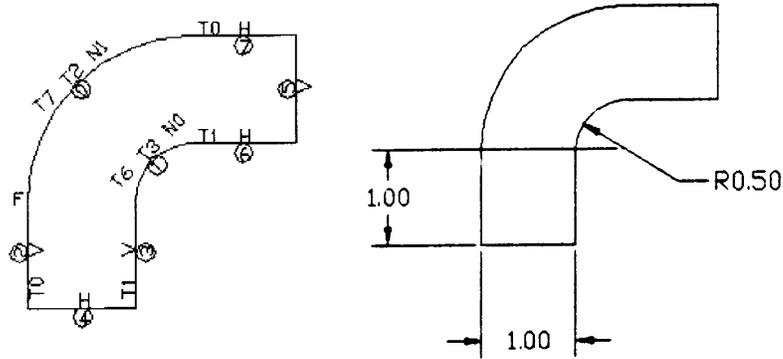


Figure 8.6. Dimensioned profile and its constraints

8.2.3. Ground Constraints

When you constrain your sketch, you establish relationships that must be maintained as modifications are made to its geometry. Sometimes, the constraints dictate that one line must move relative to another line on the sketch. For example, if you include a parallel constraint between two lines that are not initially parallel, then one of the two lines will have to move in order to satisfy this new geometric constraint—Ground constraints are added to your sketch to define which of the pair of lines involved is the movable line. There are basically four types of ground constraints:

- Vertical** This constraint fixes one line so that it is oriented vertically on your sketch.
- Horizontal** This constraint fixes a line so that it is always horizontal on your sketch.
- Angular** This constraint fixes the angular orientation of a line in space—for example, 30 degrees relative to the horizontal.
- X,Y** This constraint is used to fix the X or Y location (or both) of a specific point on your sketch. If a point is fixed in space, then all lines and curves will move relative to that point as you modify your 2-D shape.

Figure 8.7 illustrates the various ground constraints you can use to fix the location of your sketch in space. Be careful not to apply too many ground constraints to your sketch, because, if you do, your geometry will be too rigidly defined, and there will not be enough flexibility in your design. A good rule of thumb is to apply only one constraint that is *either* vertical or horizontal and to fix the location of only one point in space when you ground your sketch.

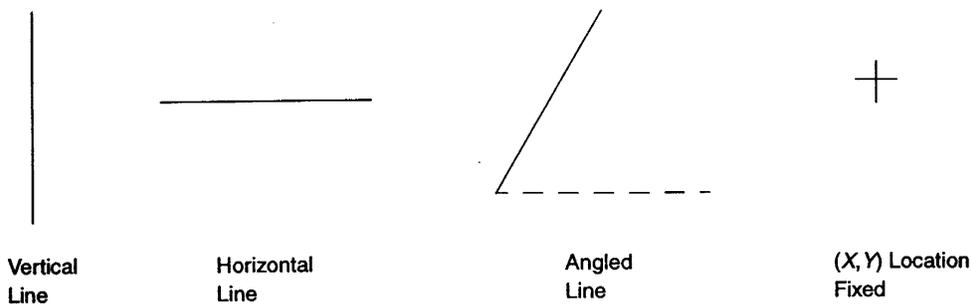


Figure 8.7. Types of ground constraints

8.3. APPLYING CONSTRAINTS TO SKETCHES ON 3-D GEOMETRY

It is possible to sketch directly on a surface of a 3-D object. You can also apply and modify dimensional constraints to the sketch on the face of an object in the same way that you added and modified constraints to stand-alone 2-D shapes. The types of dimensional constraints that can be added in this way include setting the distance between the centerpoint of a circle and an edge of the object and setting the parallel distance between a line on the sketch and an edge of the object. Many times, you can also add geometric constraints between edges of the object and portions of your 2-D sketch on the surface. Depending on the software you are using, these geometric constraints may be applied automatically for you as you sketch. Figure 8.8 shows a 3-D object with a 2-D sketch on one surface. Note the presence of the dimensional and geometric constraints defining the geometry of the sketch relative to the object. When constraining 2-D geometry on 3-D objects, remember to add the dimensions *before* extruding to cutout or to protrude because constraints cannot be added as a portion of the definition of the 3-D part.

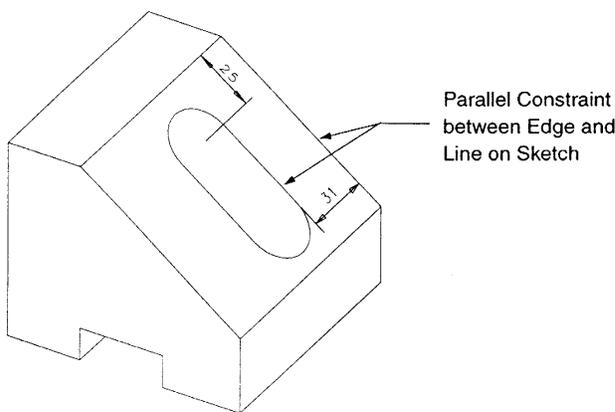


Figure 8.8 Constrained 2D shape on surface of a 3D object

Questions

1. List and describe five types of geometric constraints used during the sketch construction process of a parametric design package.
2. How many constraints do you need?
3. What happens if fewer than this number are applied, and a change is made to a value?

References

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2. S.A. Sorby, **Solid Modeling with I-DEAS**, Prentice Hall, 2000.
3. N.N. **I-DEAS Master Series Student Guide**, SDRC, 1998.
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