

We've broken the process of creating a 3D surface from sketching into three conceptual stages. The first step is just drawing curves in 2D. The second step adds the complexity of drawing curves in 3D. While this is very similar to 2D drawing, controlling what happens in the third dimension is non-trivial, and often requires additional props in the form of drawing planes and drawing surfaces. The third stage involves cleaning up the curves (making sure that they actually intersect) and adding additional surface information in the form of surface normals for the curves. Obviously, it's possible to go back and forth between the different stages.

Sketching in 2D Basics of drawing strokes, how strokes are accumulated into curves, and some tips and tricks for getting it to do what you want.

Sketching in 3D Controlling drawing surfaces and the camera.

Curve networks and surfaces Snapping curves together and ensuring they're oriented the correct way.

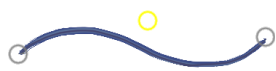
2D Sketching instructions

The interface tries to mimic a natural pencil-and-paper feel while still accomplishing the desired goal, which is creating curves. As you sketch, the interface is making guesses about how you want your strokes to interact with existing strokes. It tries to join together strokes into continuous curves when it can. It will, of course, get it wrong sometimes. There is a (hopefully) light-weight way to tell the interface what you really wanted to do through an in-screen menu. In-screen menus are also used to edit the curve in more traditional ways (dragging, smoothing, erasing) and to control the image plane size and location.

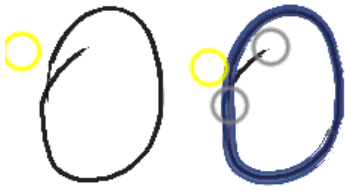
There is a button in the upper middle labeled "2D drawing". This button puts the interface in the default 2D drawing mode, which uses a stroke-like rendering and no additional scene geometry.

Sketching and strokes

To make strokes, just draw. Strokes are drawn in black, with the resulting curve(s) show in blue over the strokes. The interface will do one of the following with your stroke:



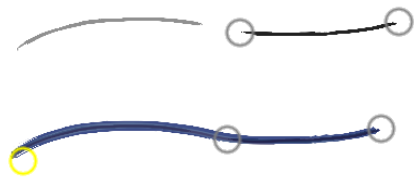
Creating a new curve by drawing a stroke. The blue circles indicate the end of the stroke. (Yellow circle is cursor location.)



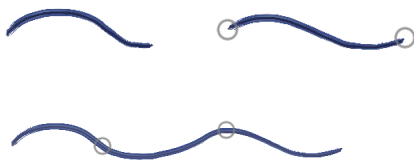
Creating a new closed curve by drawing a stroke that loops back on itself. The left-most image shows the raw stroke, the right-most image shows the resulting closed curve.



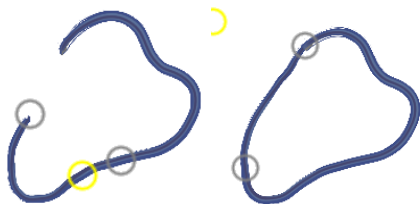
Two strokes that overlap at their ends are merged into a single curve).



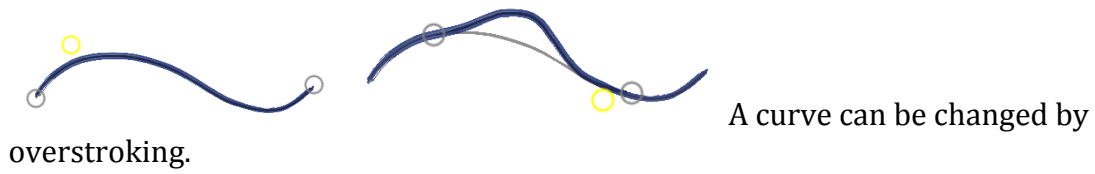
Two strokes that look like they should join are merged into a single curve.



Two strokes can be merged into a single curve by drawing from the end of one to the start of the next.

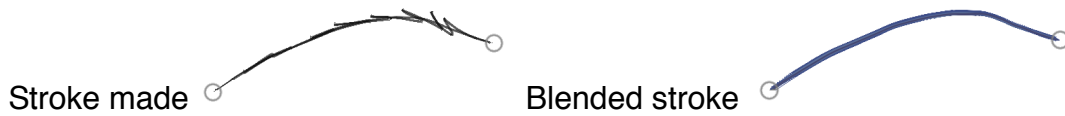


Similarly, an open curve (left) can be closed by drawing from one end to the other



An overstroke itself can consist of multiple strokes merged together.

Additionally, you can create a stroke by scratching back and forth. The scratches are taken out to create a smooth stroke, which is then used as if it were the original stroke.



Stroke menu (changing what the interface does with the stroke)

If the interface chose the wrong action, you can tell it to do a different one by clicking/tapping on one of the grey circles at the ends of the strokes. This brings up the stroke menu:



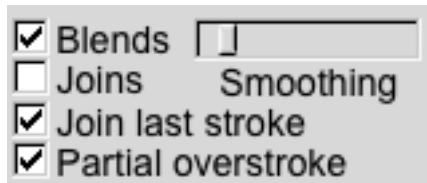
The stroke menu items can be picked by 1) Moving the cursor out of the menu over the desired wedge. 2) Clicking/Tapping in the desired item (wedge or center). 3) Clicking down in the desired item then dragging to select a curve to apply the action to (only valid for some items). To dismiss the menu without doing anything, move the cursor out of the menu between the wedges.

Clockwise from the top, the actions are:

- C: Combine two curves with the stroke. Assumes the stroke was merged or joined with one of the existing curves; mouse drag to pick the second curve
- Jc: Close the curve with the stroke. Mouse drag to pick the curve.
- J: Join or merge the stroke to a curve. Mouse drag to pick the curve.
- B: Doesn't do anything right now.
- X: Delete the stroke.
- Nc: Create a new, closed curve.
- O: Apply the stroke as an overstroke. Mouse drag to pick the curve.
- S: Smooth the join. Mouse drag to smooth more, ie, click down then keep moving the mouse/pen until it's smooth enough. Then release the mouse/pen.
- N: (located at the center of the menu). New curve. Ie, a double tap in the stroke circle creates a new curve.

A note on the options that require a selected curve: If you don't select a curve it will use the one you were last editing.

In addition to these per-stroke edits, you can globally set what actions are available using a few check boxes in the upper middle part of the window.



- Blends: Should the system look for scratching back and forth and smooth the result for you?
- Joins: Should the system look for joins at all? This is off by default.
- Join last stroke: Look for joins, but only to the last stroke.
- Partial overstrokes: Allow a stroke that starts in the middle of the curve and doesn't hang off the end (basically gets treated as an overstroke)

Moving the drawing surface around

There are in-screen controls for rotating the drawing surface, changing it's size, and panning it left and right. There are also standard camera controls (upper left): zoom changes the size of the canvas. The in-screen controls are invoked by clicking in the background (shift click will force the camera menu up). Most of these are 3D controls: the ones that are of interest for 2D drawing are the rotate zoom (at 9:00 o'clock) and the pan (at 4:30 o'clock).



- (9:00 o'clock) Rotate zoom. The paper is pinned to the upper-left hand corner. Moving in an arc around the pin point causes the paper to rotate. Moving in and out from the pin point zooms in and out.
- (4:30 o'clock) Pan. Mouse/pen down in the wedge and move.
- (6:00 o'clock) Center (C). To center the camera on all of the curves, pass through the bottom wedge. To center the camera on a single curve, mouse/click down and drag to the desired curve.
- (Center of menu) Undo.

If you accidentally change the 3D camera you can "snap" the camera back to the nearest orthogonal view point by selecting the "A" option (7:30 o'clock) on the menu. Passing the cursor out of the menu snaps it to the closest view; if you tap then you'll get six arrows to choose from. You can also hit shift-Z to return to the default starting view.

Dragging, erasing, smoothing, deleting, and undoing

The center of the camera menu has a global undo; double tapping in the background will cause an undo. There is also a menu for editing curves in a more traditional manner. The curve menu is invoked by clicking on a curve.



Clockwise from the top, the actions are:

- P: Pin two curves together. Mouse drag to pick the second curve. It will drag the two curves together then add a point constraint to pin them together.
- G: Not implemented.
- S: Smooth the curve. Passing through the menu item will smooth the entire curve. Mouse down and drag along the curve to select a region to smooth. To repeat the smoothing action, mouse down in one of the blue circles and drag until the desired amount of smoothing is achieved.
- A: For aligning 3D drawing planes; see 3D curve drawing instructions.
- X: Delete the curve. Passing through the menu will delete the entire curve. Mouse down and drag along the curve selects a region to erase.
- U: Curve-specific undo. Will undo the last action applied to that stroke.
- H: Show/hide the curve. Hidden curves are not considered when applying strokes.
- N: Add a normal constraint; see 3D curve drawing instructions.
- D: (located at the center of the menu). Dragging the curve. Passing through the menu will select the entire curve. Mouse down and drag will select a subset of the curve to drag.

Tips, tricks, and options

- You can turn off joining a stroke to a curve when there's a gap between the stroke and the curve (Joins check box at the top).
- There are show all and hide all buttons at the top. When curves are hidden they can still be selected, but they will not be considered for joining with new strokes. If the screen is getting crowded and it's hard to get the stroke to merge with the right curve (or it merges all the time and you don't want it to) try hiding some (or all) of the curves. Individual curves can be hidden/shown by clicking on them and selecting the "H" menu option. See also selection size below.
- There's also a show closed button. If you're unsure if a curve is closed, click this button. Note that closed curves have a tiny blue bar where the join is, but this can be hard to see sometimes.
- The interface considers curves and strokes close enough to be merged if they lie within the yellow circle around the cursor. You can change the size of this circle using the slider at the bottom. You can also draw/undraw the selection circle ("Select circle" under "Scene geometry" on the left).
- There are a variety of geometries and shading styles under the Curve geometry and Curve shading menus on the left; see 3D curve drawing for more details.
- The global undo has a limited stack size; however, the curves do not.
- If things are getting a bit slow/crowded, you might try the "finalize" button at the top. This deletes the stroke history for each curve (which means, as a consequence, that you can't do a per-curve undo anymore, although global undo will still work).

Known issues and future work

- Currently doesn't fade-out strokes appropriately - it should fade them out/erase them if they don't lie under the current curve.
- Stroke textures pretty much suck :). Would be nice to have something more painterly/nice.

Future work:

- Grouping curves to apply the same operation to all of them
 - Sketch an axis and deform the axis
 - Multi-touch style ala As-Rigid-As-Possible editing

3D curve drawing

This section assumes you have already read the 2D sketching instructions and have played around with the executable a bit. The actual sketching part of 3D drawing is pretty much the same as drawing in 2D, but there are some additional controls to help the system figure out exactly where in space you want curves to go. The first control is simply the camera; by moving the camera around you change the viewpoint. Unless otherwise specified, new curves get placed on the film plane, curves are dragged parallel to the film plane, and over sketching edits the curve in the film plane direction (leaving the into-the-screen component alone as much as possible). By moving the camera around you can draw and edit curves in space. You will, however, quickly discover that this is hard to control. Which is why there are three additional way to control 3D drawing: The shadow box, extrusion surface, and the inflation surface.

Overstroking and merging happen a little differently in 3D as well. Overstroking only changes two dimensions (the ones in the film plane), the third dimension (into the screen) is kept from the original version of the curve. So if you sketch a curve, turn the view 90 degrees, and oversketch, you can control what happens in all three dimensions. Similarly, if you draw a stroke that joins two existing curves the system will interpolate the third dimension of the original curves so they join nicely both in the film plane and in the "into the screen" direction.

Merging behavior depends on whether or not the drawing plane is visible. If there is no drawing plane the system continues the current direction. Ie, if the curve you're merging with is coming toward you then the added bit will also come towards you. If the drawing plane is visible then the system will place the new part of the curve on the drawing plane and blend from the existing curve to the new one.

Dragging behavior also depends on whether or not the drawing plane is visible. If it is, it drags in the drawing plane. If not, in the film plane.

Drawing plane

Click the 3D drawing button at the top of the screen. This brings up the shadow box with its drawing plane. The drawing plane can be positioned in space in a variety of ways; when the drawing plane is visible new curves will be placed on it. By moving both the drawing plane and the viewpoint it is usually possible to find a combination that is comfortable to draw on and where you can see what you're doing.

If the draw plane is visible drags will move the curve parallel to the drawing plane. Otherwise, drags are parallel to the film plane. You can move and draw/undraw the film plane while drawing.

Clicking on the draw plane handles on the edges causes the camera to rotate to look down the draw plane normal. Clicking again flips the view direction to be on the other side of the film plane.

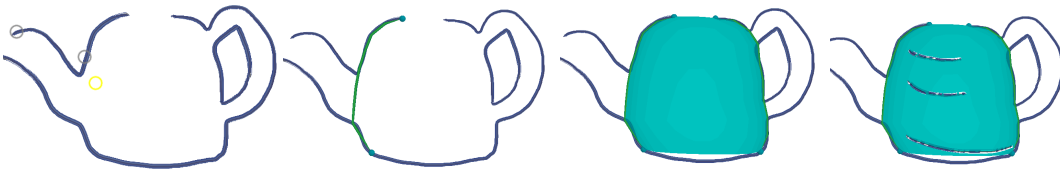
Inflation and extruded surfaces

The inflation surface is made from two roughly parallel curves. The surface passes through the curves on the edges and is "inflated" towards the viewer in the interior.

An extruded surface is made by taking a curve and extruding it in one direction.

If an inflation or extruded surface exist, you can draw on them. The curve will lie in the surface.

From left to right, drawing the first curve on the left, the second one, then drawing on the surface.



From left to right, clicking on the curve to bring up the axes. Clicking on the axes produces an extrusion surface. Drawing on the extrusion surface.



Click the inflation surface button on the left under Surface Geometry to start the process. The only real change you'll see is that the cursor no longer has the yellow selection surface drawn around it.

- 1) Inflation surface. Draw over existing curves to create the left side. Repeat for the right side.
 - a) You don't need to draw exactly over a single curve. You can have gaps, draw over part of a curve, etc.
 - b) The spheres at the end of the curve let you pick that curve to edit
 - c) If there are no spheres at the end of the curve, that's the one you'll be editing when you draw again.

- d) To go back to creating a different inflation surface, click the spheres on the left curve.
 - e) Toggling between normal drawing and inflation surface drawing:
 - f) Click in the background to stop drawing.
 - g) Click on the sphere on the top edge of the inflation surface to start drawing.
 - h) If the sphere is not there, then you're already in draw on the inflation surface mode.
 - i) You can also turn the inflation surface off using the menu on the left. Note that this will erase/destroy the inflation/extrusion surface.
- 2) Extrusion surface. Click on a curve. This brings up the axes of the curve. Click on one of the arrows; the curve will be extruded in that direction
- a) See above for toggling between normal and inflation surface drawing
 - b) Clicking on the curve should bring the axes back up again
 - c) If you click on a curve and you get the curve menu, click again on the "A" option.
 - i) Make sure the drawing plane is not visible or this will set the drawing plane, not an extrusion surface

Some caveats:

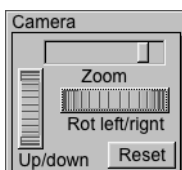
- You need to draw two curves before you get an inflation surface.
- This is highly modal behavior (left curve, then right curve, then draw on surface). If it gets wonky, just click on the inflation surface check box, turning it off than on again to start over.

In general, use the drawing plane to create new curves and turn it off when you're sketching over new curves. Use the inflation surface to add contouring curves.

One other thing you can do is create a sequence of parallel cross sections by moving the draw plane forward in increments. Work from back to front.

Camera

There are four ways to control the camera viewpoint.



- There are two dials in the upper left hand corner that rotate the view left-right and up-down.

- There is an in-screen camera menu invoked by tapping on the background.
- If the shadow box is visible then it has controls to move the camera as well.
- The letters x,X,y,Y,z,Z will position the camera looking down the corresponding axes (plus and minus).

If the shadow box is visible, you can use it to control the camera, too.

- Cylinders on the middle of the outer sides rotate the camera in an axis-aligned way.
- Balls at the outer corners of the cube (with the exception of the lower left) start a trackball rotation.
- The lower left outer corner is a zoom



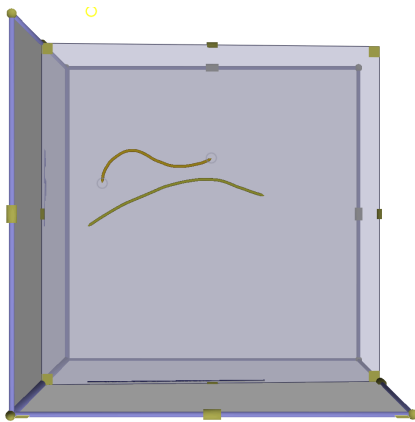
Clockwise from the top, the camera actions on the camera menu are:

- 1) (up-down arrows): Rotate the camera up and down. Mouse down in the wedge and move the mouse up and down. Release the mouse to stop.
- 2) (I shape): Dolly plus zoom (changes perspective). Mouse down in the wedge and move the mouse up and down. Release the mouse to stop.
- 3) (Arrow and dots): Zoom plus rotation. Pin point is the upper left corner. Moving in and out from the corner changes the zoom, moving in an arc around the corner rotates the film plane.
- 4) A: Align the camera. Three options:
 - a) Pass the mouse out of the wedge. The camera will snap to the closest x,y,z axis.
 - b) Tap in the wedge. This will bring up six arrows (the x,y,z axes). Click on the arrow.
 - c) Drag from the wedge to a curve. This will bring up six arrows based on the curve's tangent and normal. Click on the arrow.
 - d) Note: To snap the camera to the draw plane, tap on the A option on the curve menu. The camera will rotate to look down the drawing plane normal (placing the drawing plane parallel to the view plane).

- 5) C: Center the camera. Two options:
 - a) Passing through the menu will center on all of the curves.
 - b) Mouse down and drag to a curve to center on that curve.
 - c) Mouse down, drag over selections, then drag back to the center menu option will center on all the points drawn over.
- 6) (four arrows): Pan. Will pan the camera left and right.
- 7) (left-right arrows): Rotate the camera left and right. Mouse down in the wedge and move the mouse up and down. Release the mouse to stop.
- 8) (angled arrows): Trackball rotation. Mouse down in the wedge and move the mouse around. Release the mouse to stop.
- 9) U: (located at the center of the menu). Tap again to undo the last action. (Ie, double tap in the background is an undo).

Drawing plane

Shadow box and draw plane



The drawing plane can be manipulated directly by:

- ❖ Pulling it backwards and forwards (small squares at the corners)
- ❖ Rotating it using the cylinders on the edges.
 - Pulling toward the middle rotates the plane
 - Pulling along the edge spins the plane.
- ❖ Clicking on any of the controls snaps the camera to the draw plane
- ❖ There are two small squares at the front of the shadow box.

- The right-most one turns the drawing plane on and off
- The left-most one re-centers the drawing plane in the shadow box

You can also align the drawing plane to one or two curves. To align it to a single curve, tap on the curve to bring up the curve menu. Tap on the "A" option. This will bring up three arrows. Click on the arrow that you want to be the new drawing plane normal.

To align to two curves, tap on the first curve to bring up the curve menu. Drag from the "A" option to the second curve. The drawing plane will be positioned so that it passes through the two points and is perpendicular to both curves (as much as possible).

To align the camera to the drawing plane, click on any of the drawing plane controls. Clicking again will flip the camera to the other side.

The drawing plane can be re-centered by clicking on the square in the lower left that sticks out from the shadow box.

To show/hide the drawing plane, click on the square that sticks out from the bottom right of the shadow box.

Dragging

If the draw plane is visible, dragging drags the curve in the drawing plane direction. If not, it uses the view plane.

To drag perpendicular to the drawing/view plane, move the cursor to the top or bottom arrow of the drag icon. The icon will get skinny. Mouse down and drag; this drags perpendicularly.

Shadow box controls work while dragging. To get the camera menu, do a shift click. Click in the background to stop dragging.

To select a region to drag, click on the curve to bring up the curve menu. Click down and drag, scrubbing the mouse down over the curve, to select the region. Release the mouse.

Tips and tricks

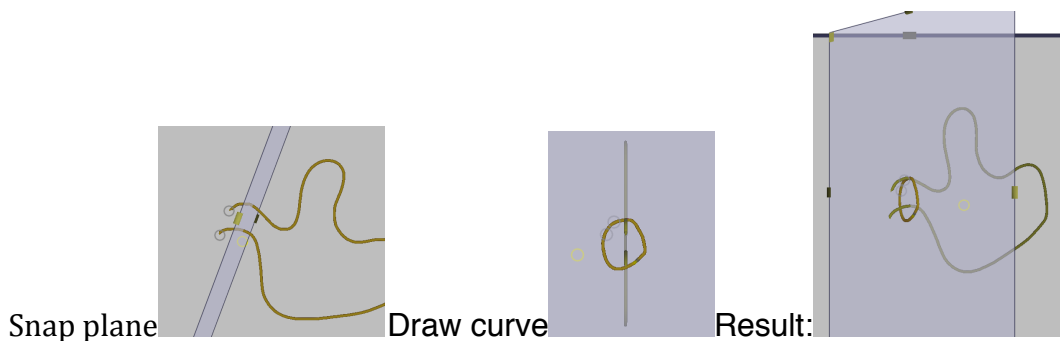
You can change the camera and the draw plane while dragging. This lets you select the part of the curve you want to drag from one view, rotate the camera, then drag the curve from a different view. To bring up the camera menu, use shift-click (the camera controls on the shadow box and upper left work as-is).

It gets pretty messy pretty fast. Use the show and hide all buttons on the top to hide most of the curves, then show just the ones you want to edit (tap on the curve and pick the "H" option).

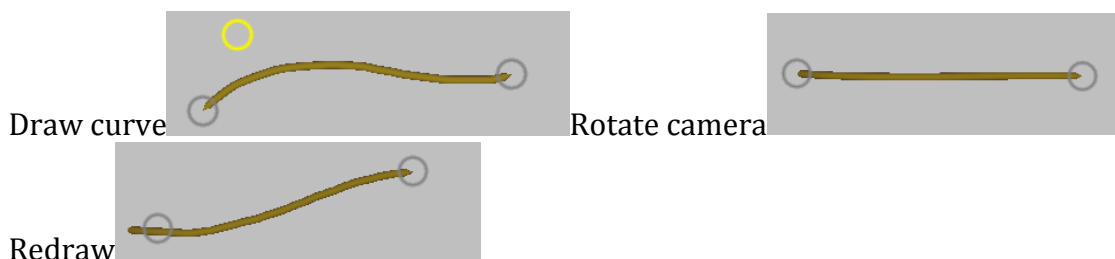
You can draw contours at different depths by moving the drawing plane. Turn on grid spacing (under 3D geometry on the left) to get some feedback on how much to move the drawing plane.

There are three ways to get a curve that's not in the film plane. The first is to use an inflation or extrusion surface as illustrated above. The second is to snap the drawing plane and then draw on it. The third is to draw, then re-draw from another direction.

Using the drawing plane: 1) Click on one curve where you want one end of the cross section to be. 2) Pick the "A" option (lower left). 3) Drag from the "A" option to where you want the other end of the cross section to be (must be on a curve). 4) Click on one of the draw plane handles to align the camera with the draw plane. 5) Draw the cross section.



Using re-draw: Draw, then rotate the camera 90 degrees and oversketch. Note: This doesn't work very well when there are a lot of curves in the scene. Try hiding all but the one you want to over sketch.



Known bugs and future work

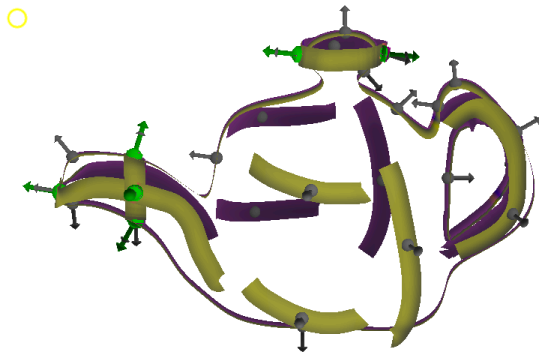
* Automatically drop a collection of curves representing a basic shape (eg sphere, cube, etc) into the scene * Editing a group of curves * Scale, rotate of a curve or group of curves

Surface construction

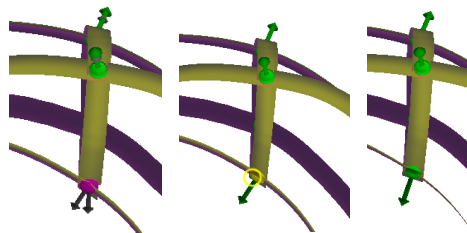
This stage is primarily concerned with making curves actually intersect and orienting them correctly. The default view (3D surfacing button) draws the curves as ribbons (yellow side is "out") and shows explicit point and normal constraints. The goal is to snap curves together wherever they are close and orient the ribbons so they all face out. Once this looks ok, you can generate a surface. The surface may not look so great; there's tips at the bottom for fixing some common problems.

It's best to snap curves together first, then fix the normals. Mostly because snapping the curves together will fix a lot of the normal problems.

Visuals: The curves are drawn as ribbons. The green circles at the curves are snapped intersections. The big green arrows are the normals at those intersections. The gray normals are additional normal constraints.



From left to right: Purple is a potential intersection. Clicking on it snaps the curves together and adds a normal constraint. Editing the normal constraint rotates the curves.



Snapping curves together

There are two ways you can snap curves together. One is to manually snap them together using the curve menu (top option, "P"). The other is a global search process, which shows all the potential intersections. You can then click to fix them, or fix them all at once.

Global search and snap: The slider under "Intersections" in the bottom left "Surface" menu. controls how close things have to be before they're considered intersections.

Clicking "Find all" will actually find the intersections. Intersections that are snapped already are drawn as green spheres. Intersections that can potentially be snapped are shown as purple spheres connected by cylinders. Click on an intersection to snap it (the sphere will turn yellow if you are over it). There is a "Fix all" button which will fix all purple intersections.

Start with the slider all the way to the left, fix, move the slider a bit to the right, fix, and so on. When you think you have everything snapped, slide the slider all the way to the left and do a last "Find all".

Whenever you snap curves together it will automatically add both point and normal constraints for those curves. All of the normals for the intersecting curves can be controlled at once using the intersection normal (make sure Intersect norms is checked, ie, you can see the green arrows). These are shown as green arrows. Clicking on the arrow head will flip the normal the other way. You can also mouse down and drag it.

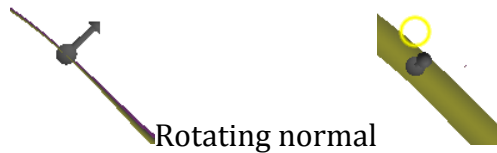
Fixing normals/orienting ribbons

First fix all of the normals for the intersection points (see above). At this point you may need to add additional normal constraints to orient the curves the right way. To add a normal constraint, click on the curve location you want to orient to bring up the curve menu, then pick the "N" option. This adds a normal constraint. These constraints can be rotated around by dragging on them. More specifically:

- Passing out of the "N" option or clicking will just add a constraint
- Mouse down in the "N" option to start dragging the normal
- To select an existing normal constraint, put the cursor over the base of the arrow until it turns yellow. Click down, bringing up the curve menu. Mouse down and drag to edit.
- Deleting a normal constraint: Select it as above, but instead of dragging, either pass out of the "N" option or click in it.

If there's a lot of wiggles in the ribbon it's probably a good idea to smooth it.

Adding and editing a normal constraint



Point constraints

Mostly you shouldn't have to edit these by hand. But if you do, they behave just like normal constraints, except use the "P" option to add and delete instead of the "N" one. The "P" option is the same as the snap option; if you just click instead of dragging you add/remove the point constraint (no snapping to another curve).

Building a surface.

Click "calc" in the bottom left menu. This takes a few minutes. The slider underneath controls the size of the polygons; move to the left to get smaller/more polygons (which takes longer). You can draw/undraw the surface in the upper left menu.

Tips and tricks

Sometimes when you snap one constraint (or smooth or edit) it will undo an existing one. Which is why it's a good idea to re-check.

The surface building code is a bit flakey. If the surface is bulging out, try adding more normal constraints. If you get something really crazy, you probably have a normal backwards somewhere. You can see what it's actually using for generating the surface by clicking the "Constraints" box. Also check for curves that look closed, but aren't, and dangling edges.

For checking that curves are closed, there's a show all closed curves button in the top menu.

In general there's two ways to fix the surface. The first is to add more normal constraints. The second is to add additional curves, or to extend ones that already exist. If the surface has actual topological problems (holes where you don't want them, filled surfaces where you do) adding curves is usually the best way to go. Particularly curves that are perpendicular to existing ones.

Known bugs and future work

* Snapping constraints (or editing curves) sometimes undoes other ones * If you can't select a purple sphere, try turning off curve point and normal constraints * To do: automatically snap curves together as you draw them