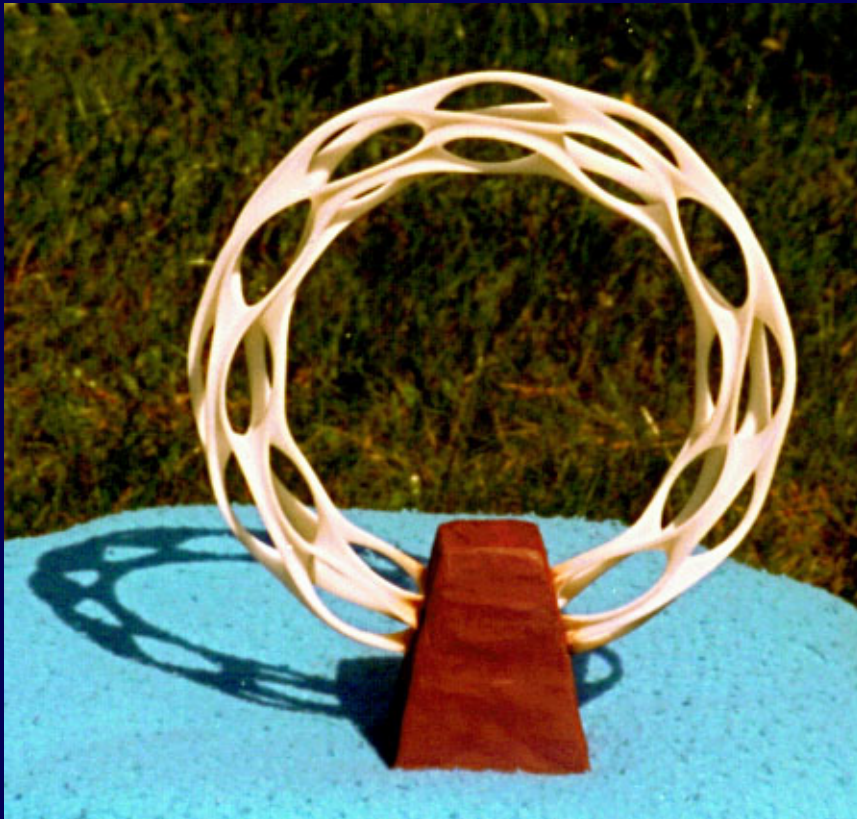


Parametric Geometric Modeling



“Solar Circle”



“Pax Mundi”

- ◆ How would you create CG models for these two abstract sculptures ?
- ➔ Huddle and discuss with your neighbors!

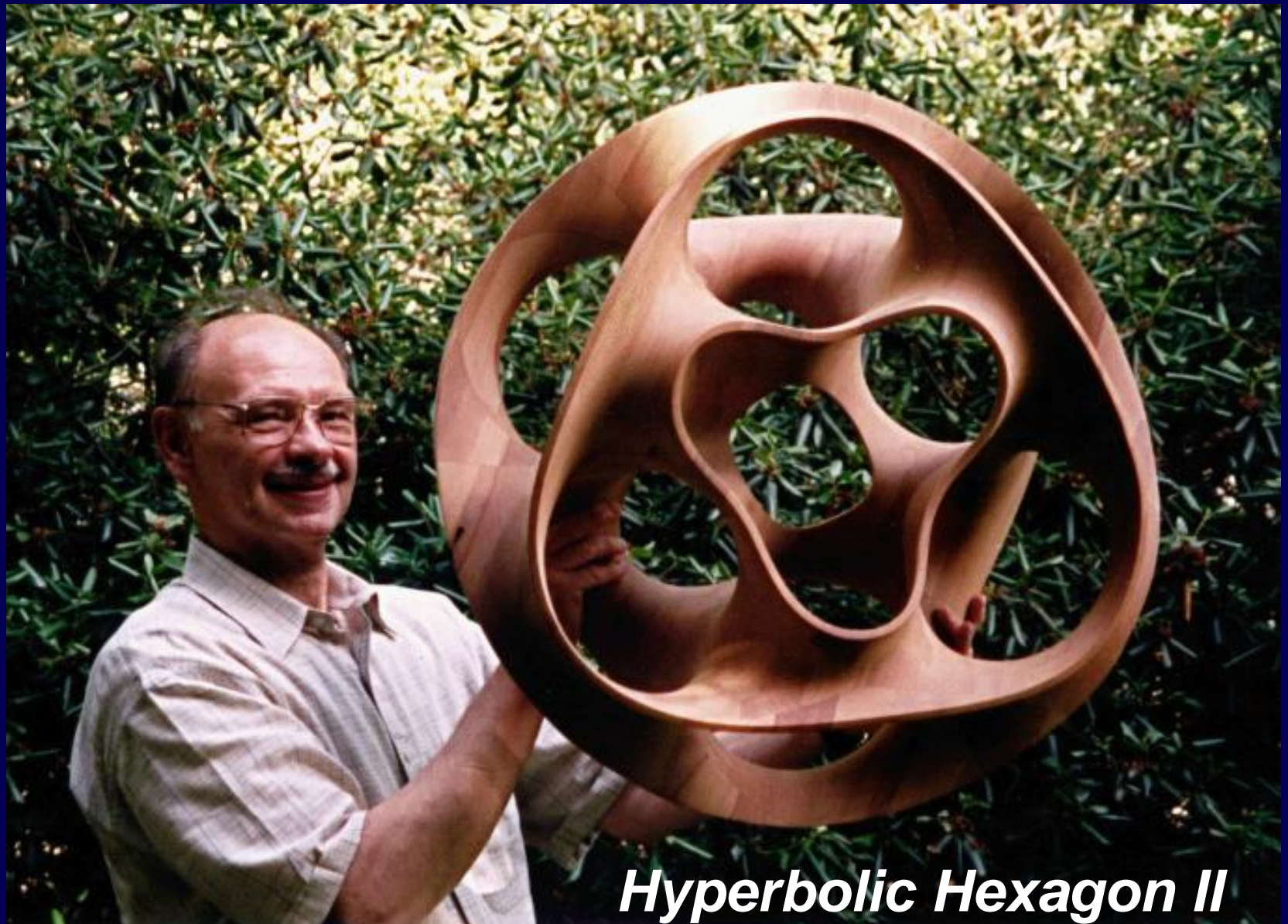
CS 184 Guest Lecture, Nov. 26, 2008

by Carlo H. Séquin

Parametric Geometric Modeling

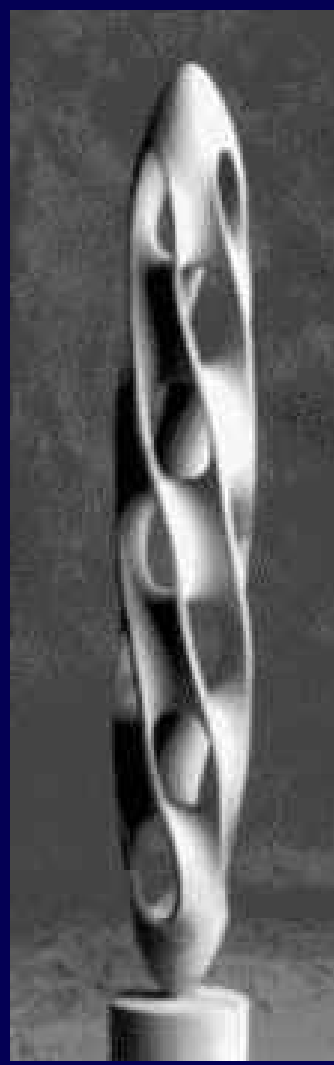
- ◆ Sculpture Generator I
- ◆ Minimal surfaces
- ◆ Generalized sweeps
- ◆ The SLIDE framework
- ◆ Design and implementation of a large sculptures

Brent Collins

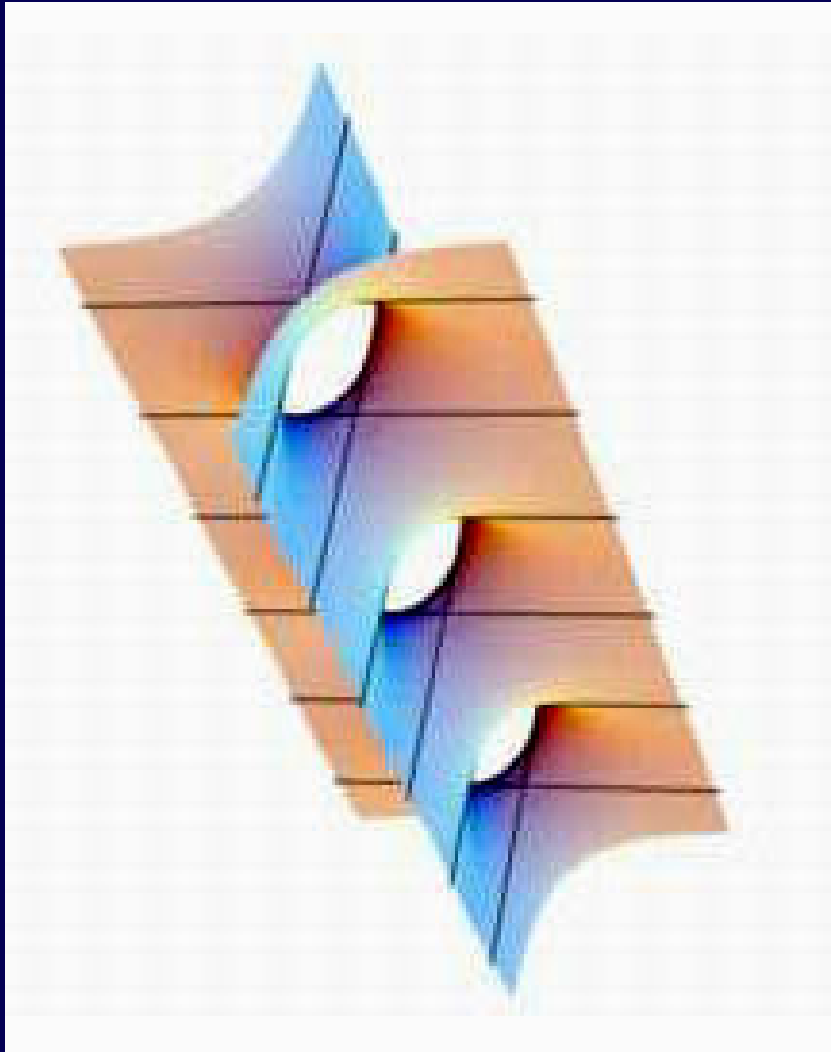


Hyperbolic Hexagon II

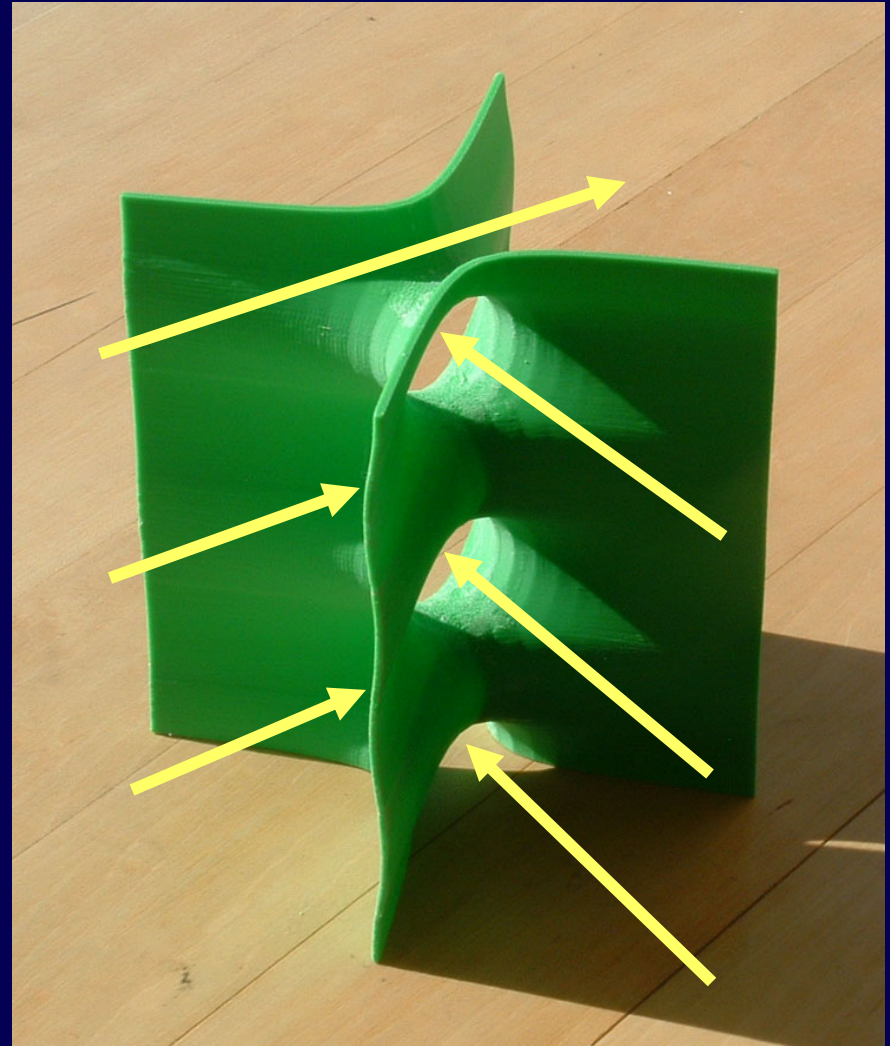
Brent Collins: Stacked Saddles



Scherk's 2nd Minimal Surface

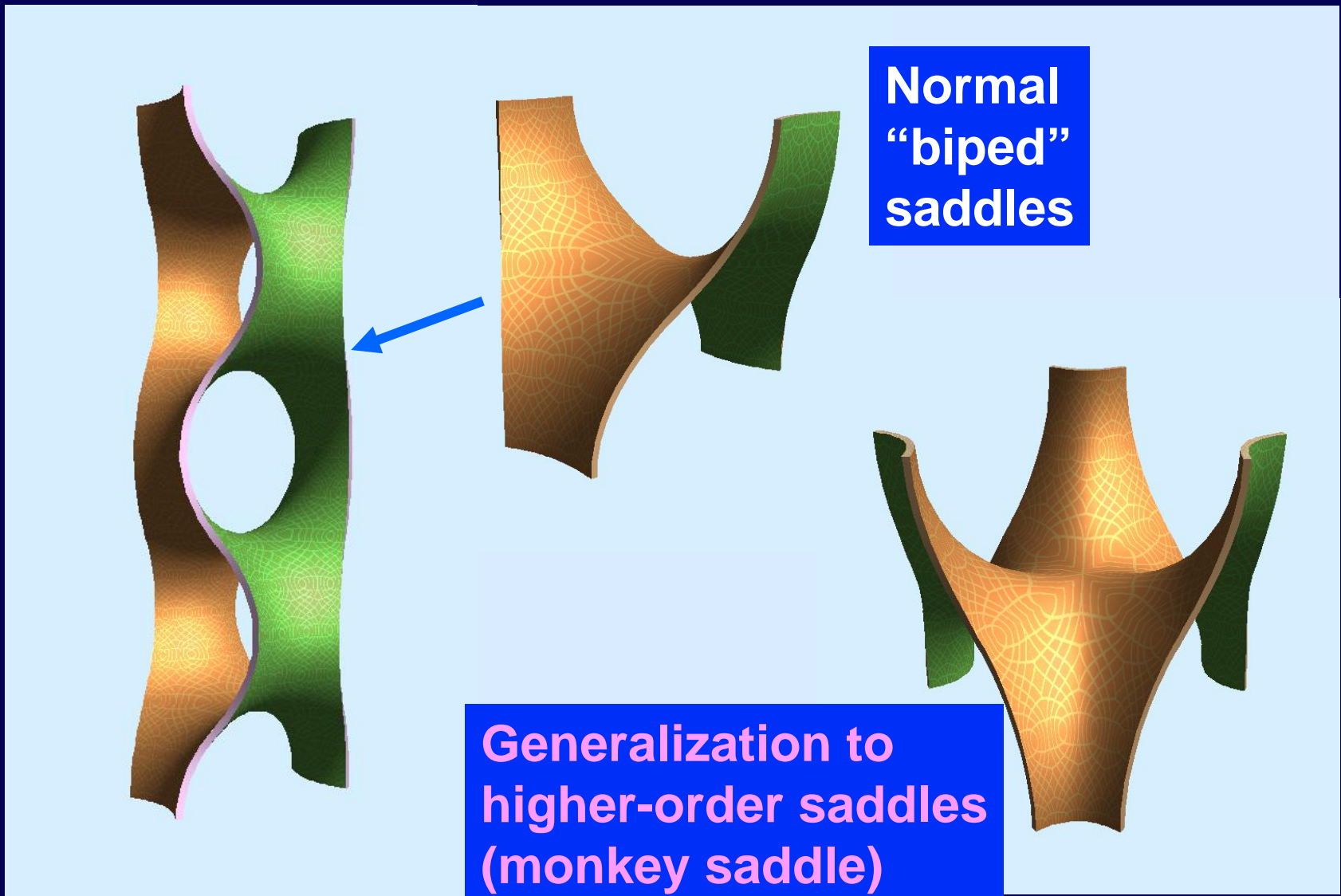


Zero mean curvature everywhere



Alternating Tunnels

Scherk's 2nd Minimal Surface → Art





Scherk Tower

- ◆ 5-story core
- ◆ Monkey saddles
- ◆ Thick surface
- ◆ “Flare” added

Hyperbolic Hexagon by B. Collins



- ◆ 6 saddles in a ring
- ◆ 6 holes passing through symmetry plane at $\pm 45^\circ$
- ◆ = “wound up” 6-story Scherk tower
- ◆ **Discussion:** What if ...
 - we added more stories?
 - or introduced a twist before closing the ring?

Solar Arch

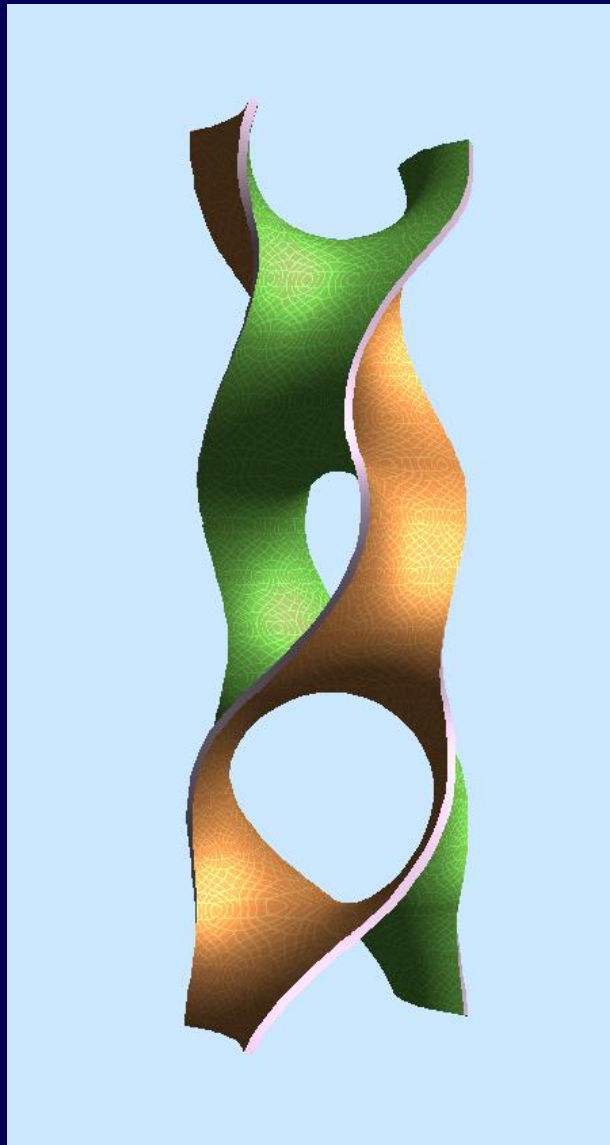


◆ 12 stories

◆ 4th-order
saddles

◆ 270° twist

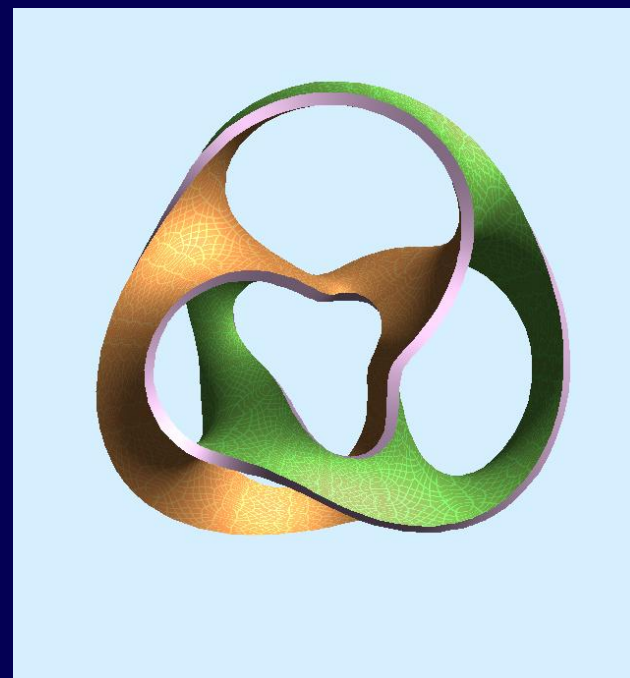
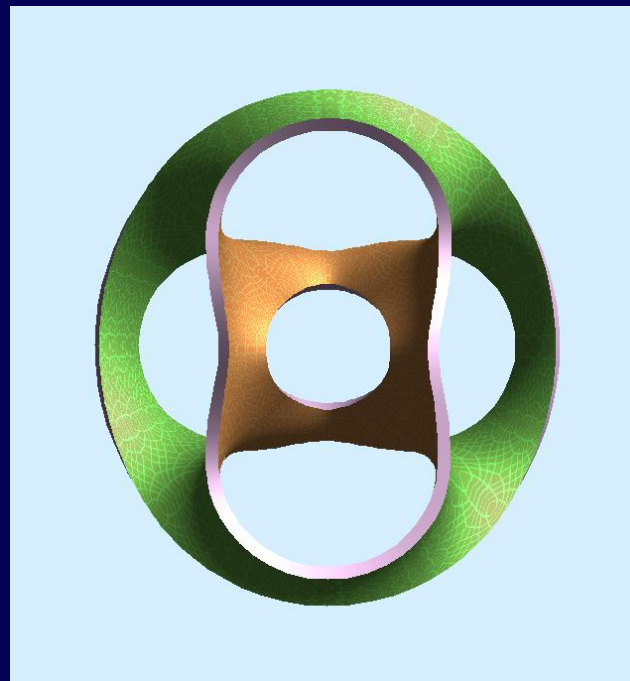
Closing the Loop



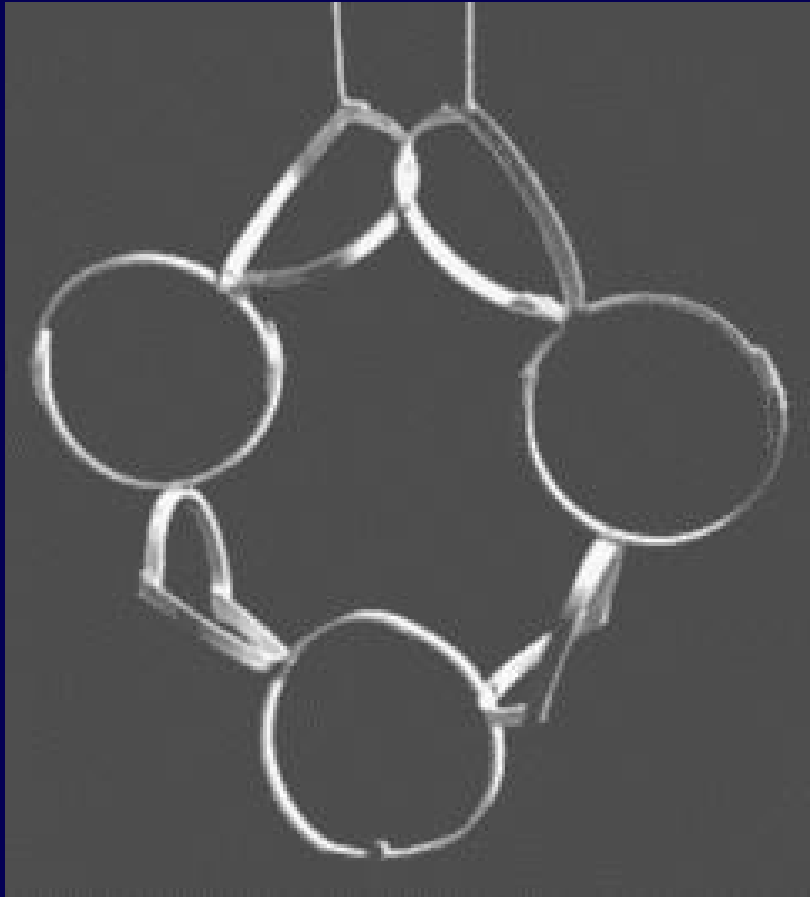
straight

or

twisted



Brent Collins' Prototyping Process



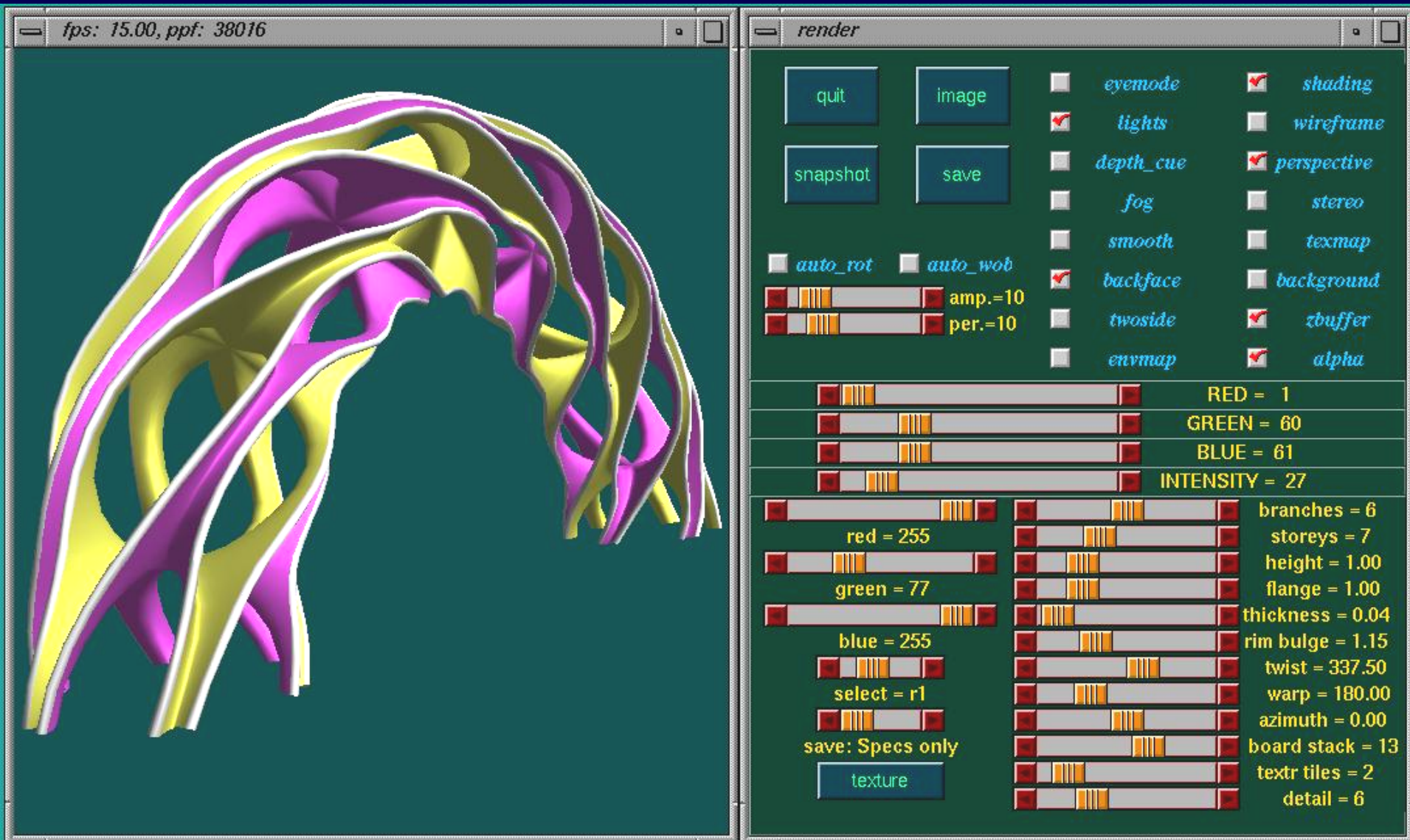
**Armature for the
*Hyperbolic Heptagon***



**Mockup for the
*Saddle Trefoil***

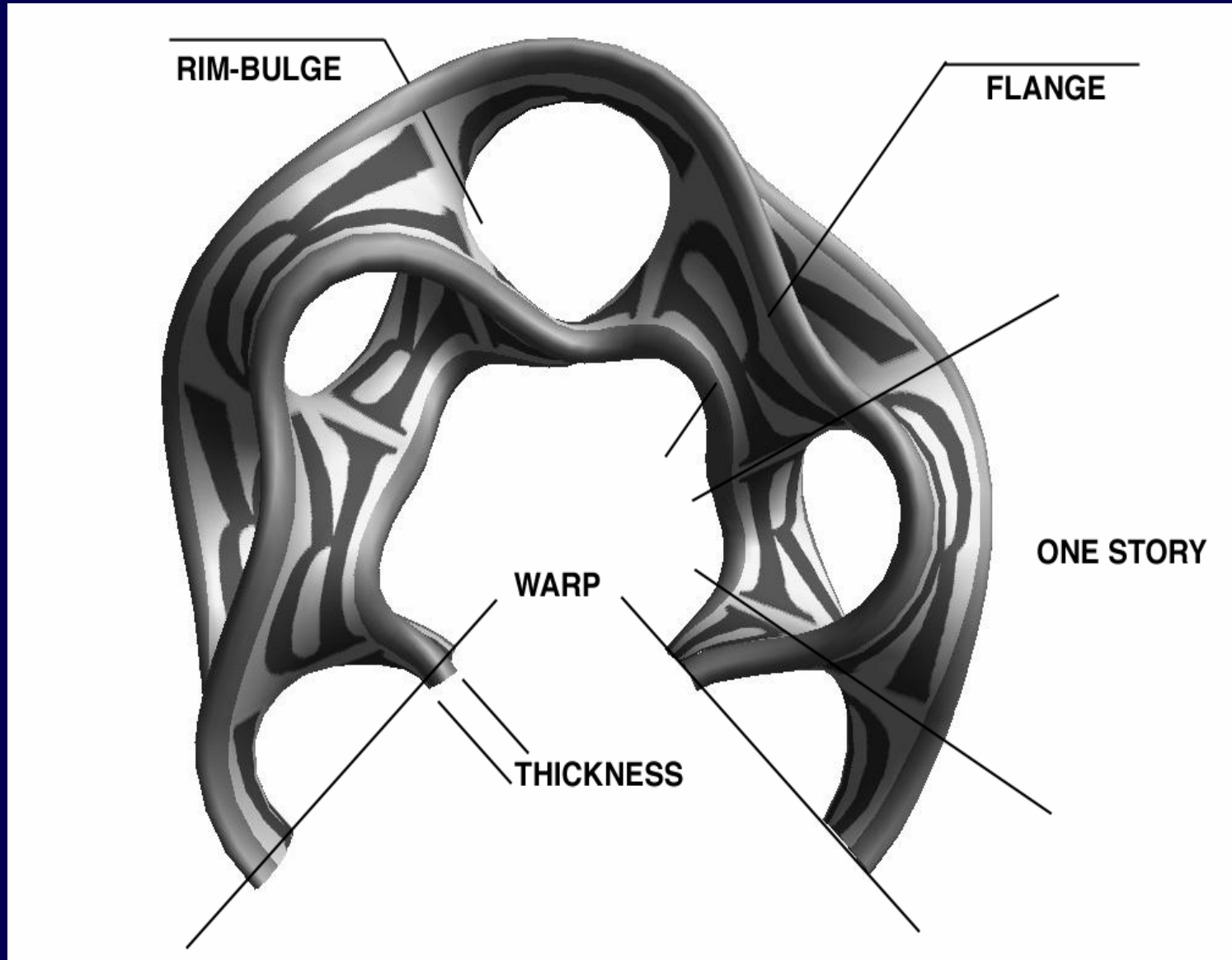
Time-consuming ! (1-3 weeks)

Sculpture Generator I, GUI



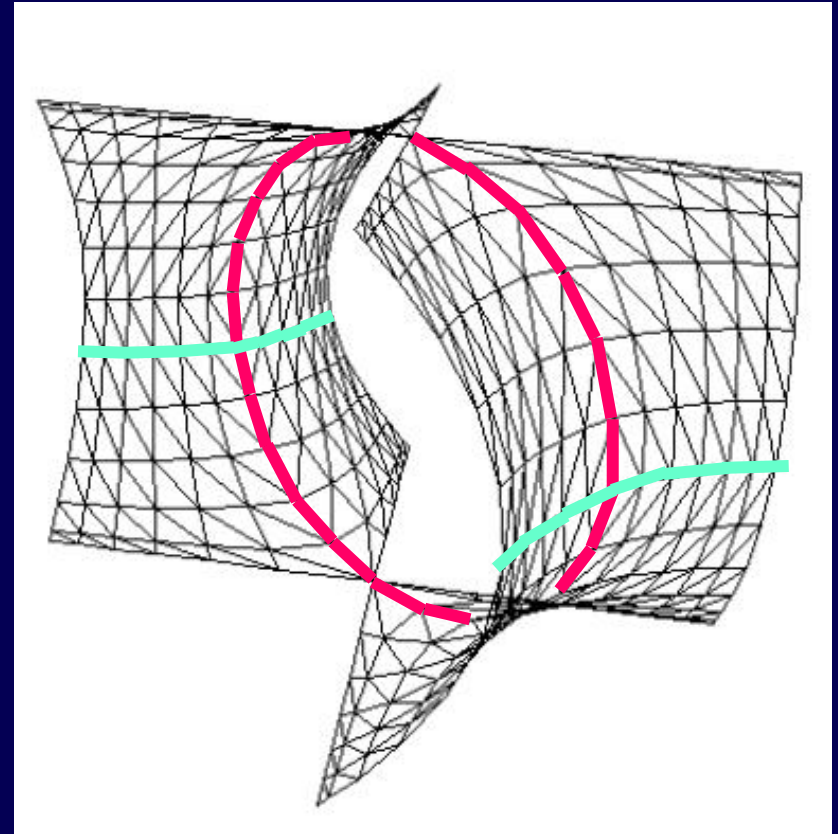
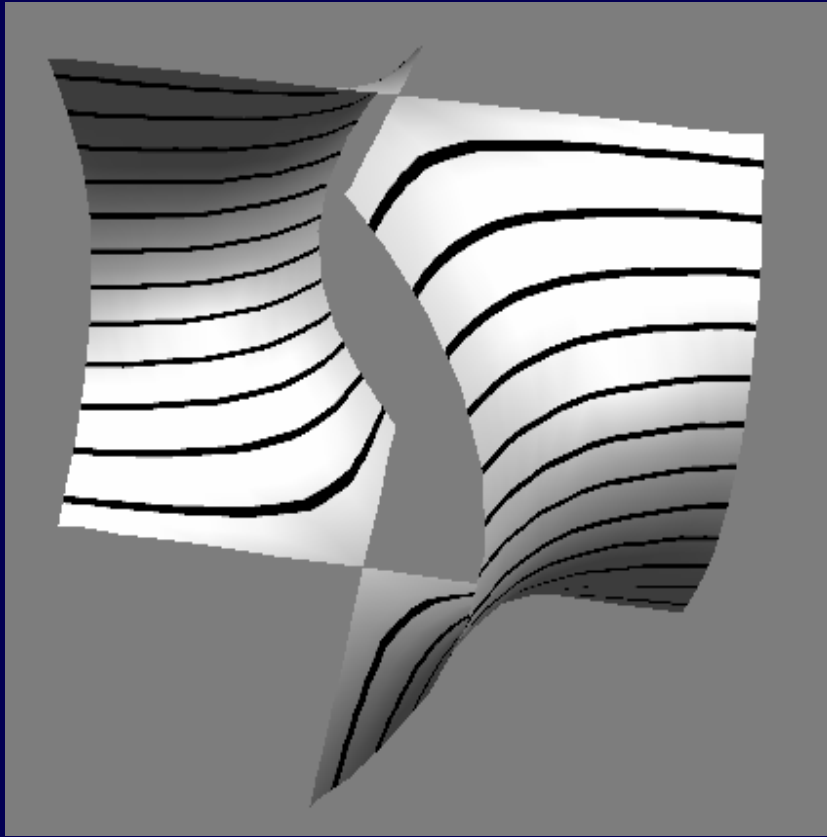
Creates a family of highly specialized, parameterized shapes

Some of the Parameters in “SG1”



Base Geometry: One “Scherk Story”

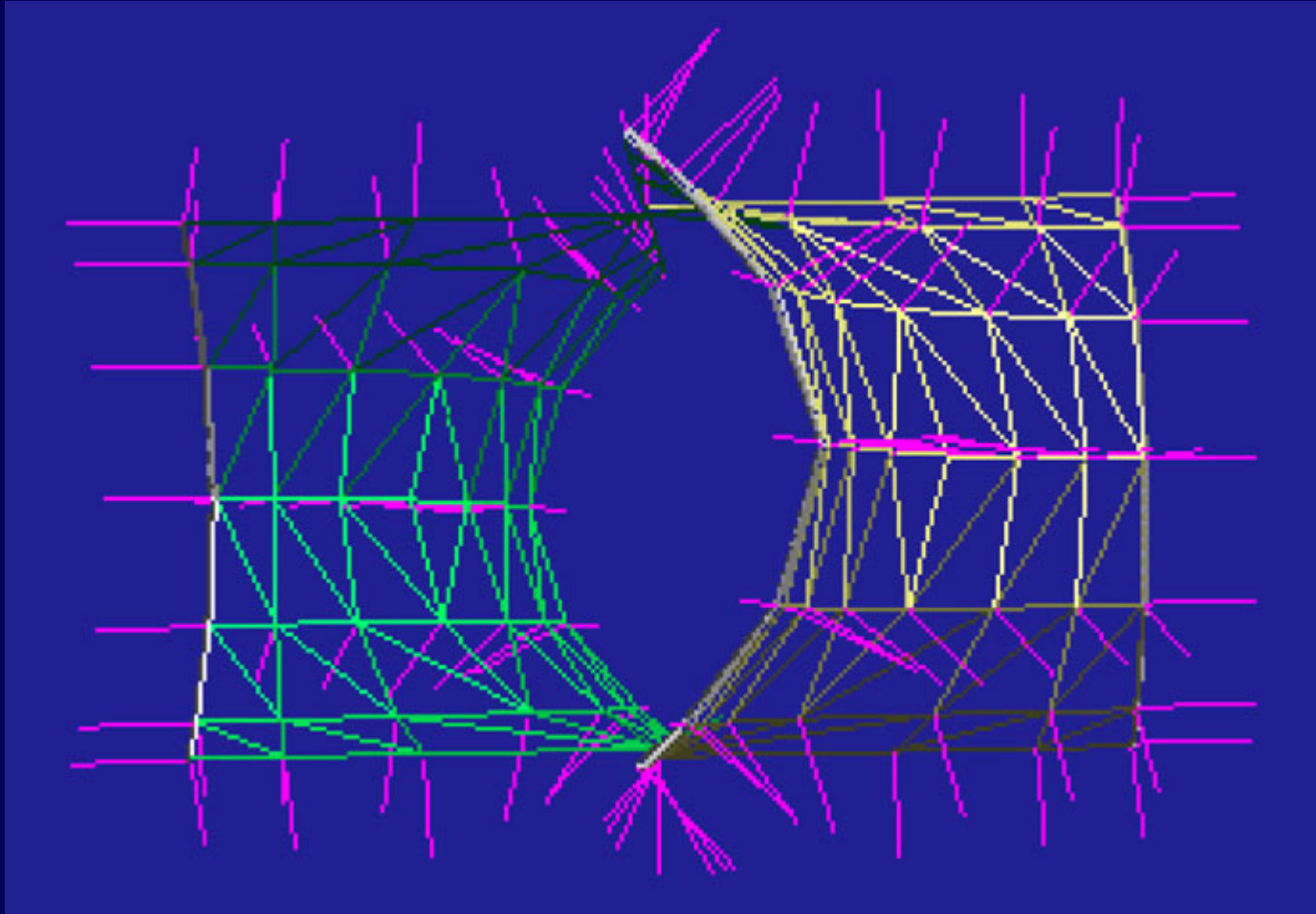
- ◆ Taylored **hyperbolas**, hugging a **circle**



- ◆ **Hyperbolic Slices** → **Triangle Strips**

The Basic Saddle Element

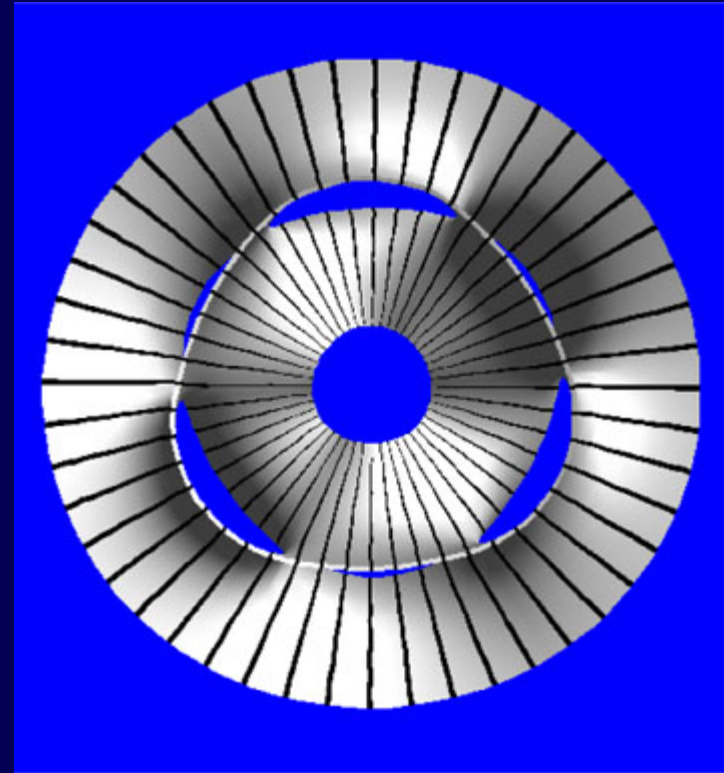
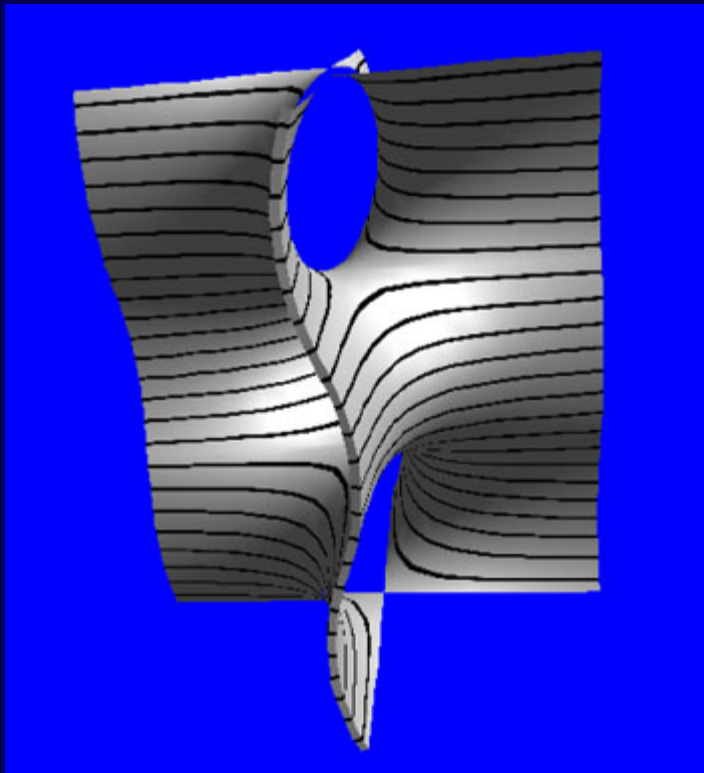
with surface normals



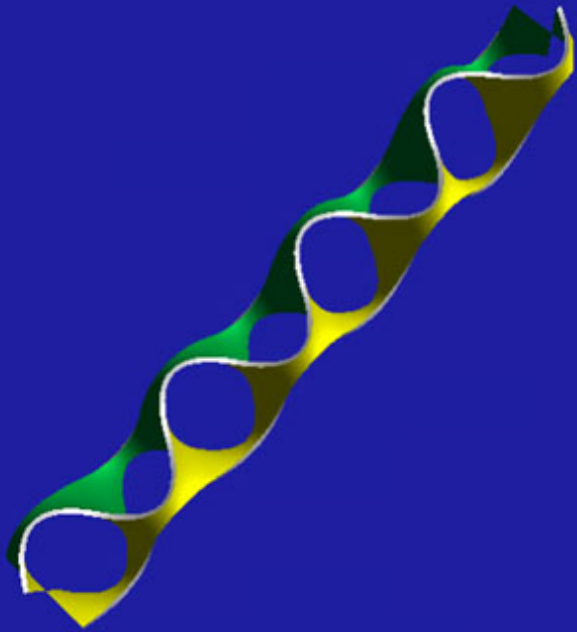
◆ precomputed -- then warped into toroid

Shape Generation:

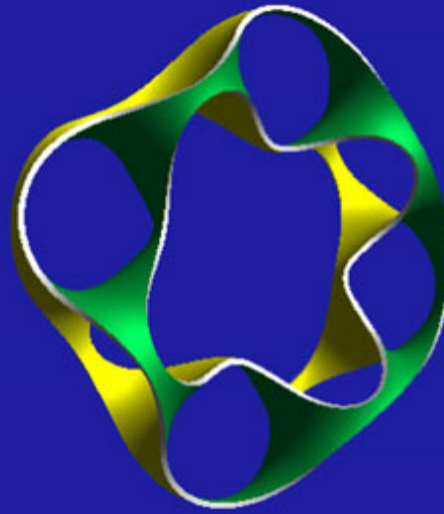
- ◆ by stacking this basic hyperbolic element,
- ◆ twisting that stack along z-axis,
- ◆ bending (warping) it into an arch or loop.



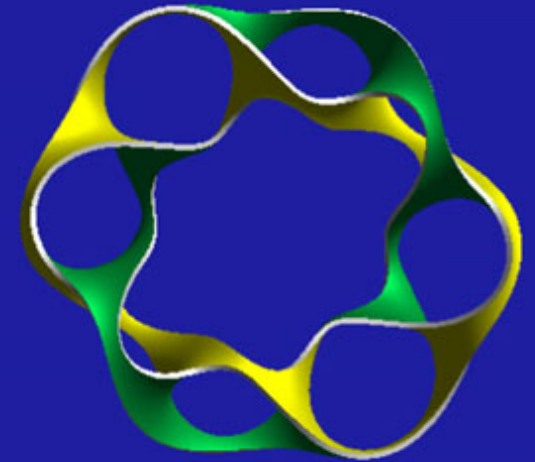
Toroidal Warp into Collins Ring



8-story tower

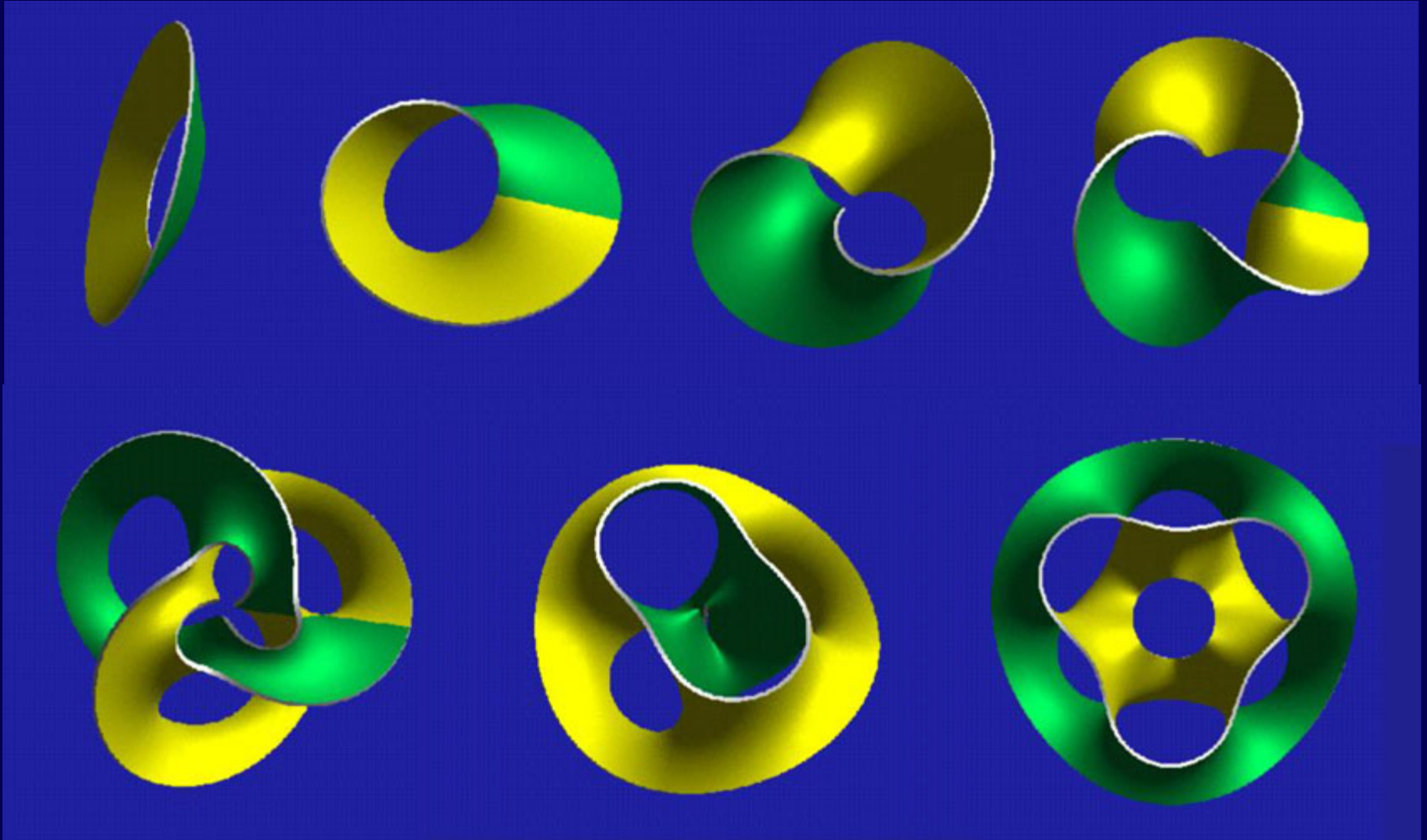


warped into a ring



360° twist added

A Plethora of Shapes





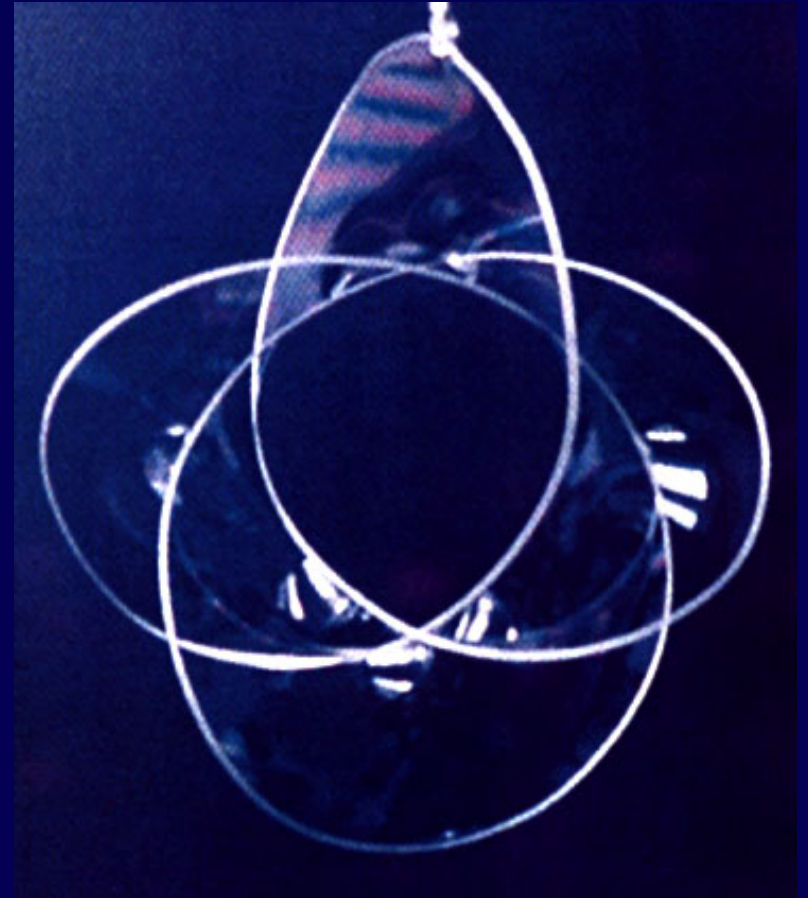
V-art

**Virtual
Glass
Scherk
Tower
with
Monkey
Saddles**

**(Radiance
40 hours)**

Jane Yen

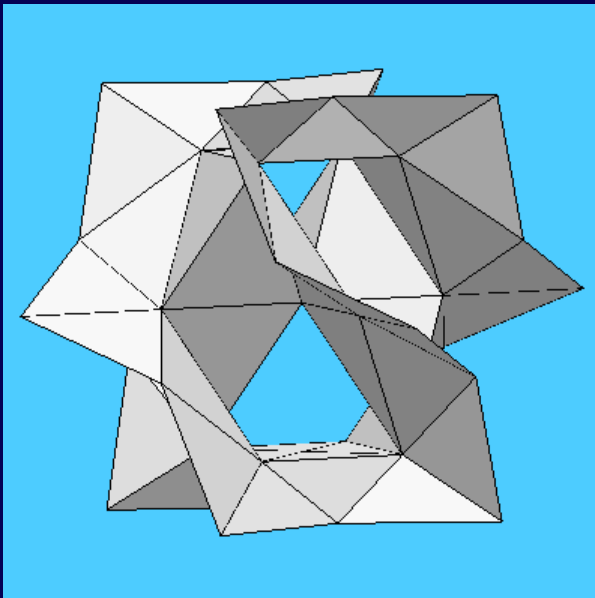
True Minimal Surfaces ?



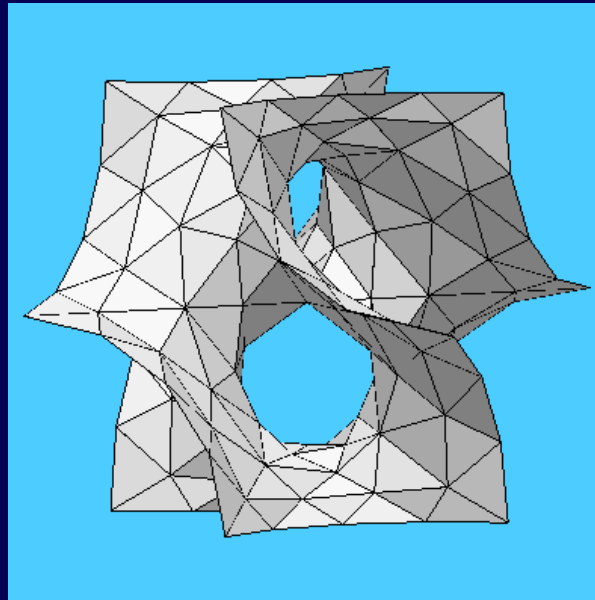
- ◆ Not a true “minimal surface” (like a soap film)!

Ken Brakke's *Surface Evolver*

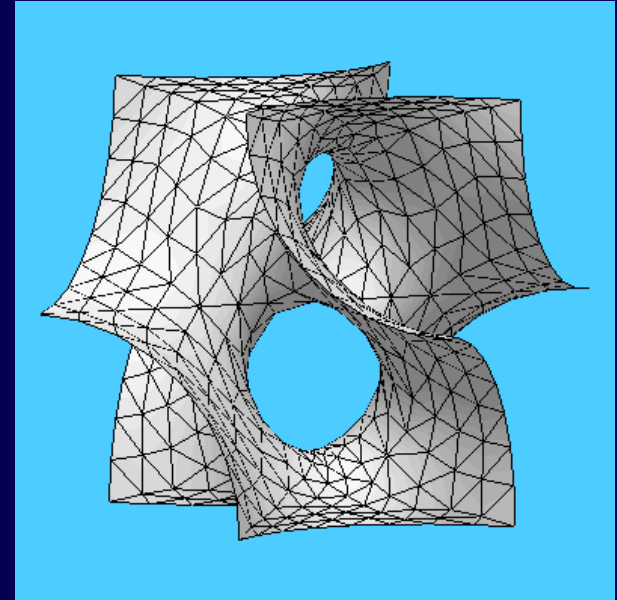
◆ For approximating minimal surfaces:



Start with a crude polyhedral object



Subdivide triangles
Optimize vertices



Repeat the process

Minimality and Aesthetics

Are **minimal surfaces** the most beautiful shapes
spanning a given edge configuration ?

“Whirled White Web” Séquin 2003

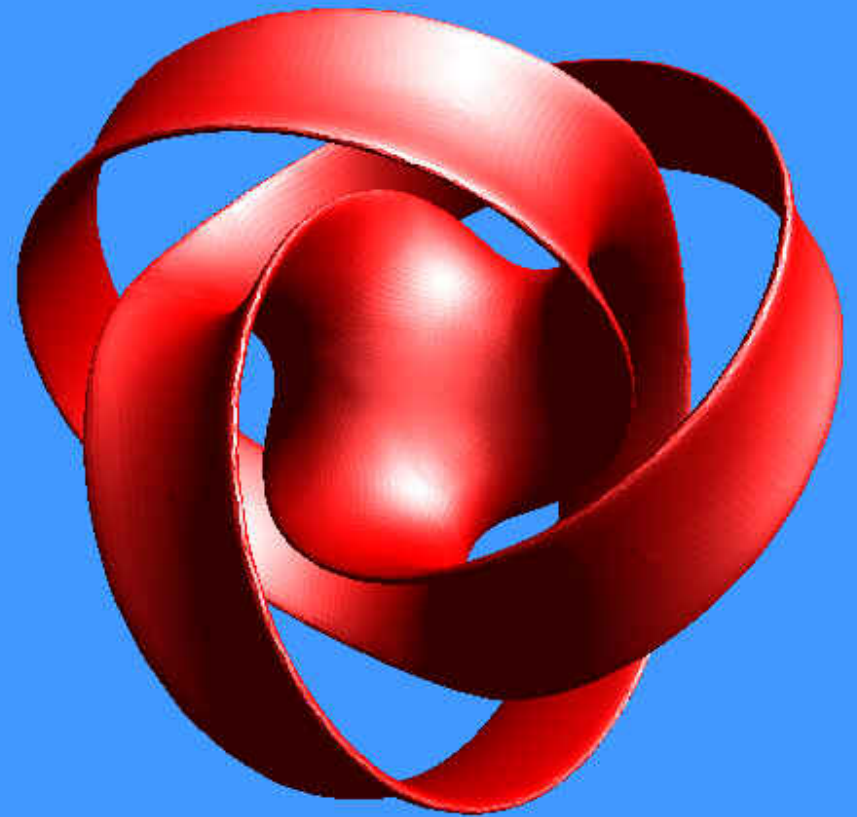


Maquette made with
Sculpture Generator I



Minimal surface spanning
three $(2,1)$ torus knots

“Atomic Flower II” by Brent Collins



Minimal surface in smooth edge
(captured by John Sullivan)

Volution Surfaces (twisted shells)



Costa Cube



Ico-Vol 4

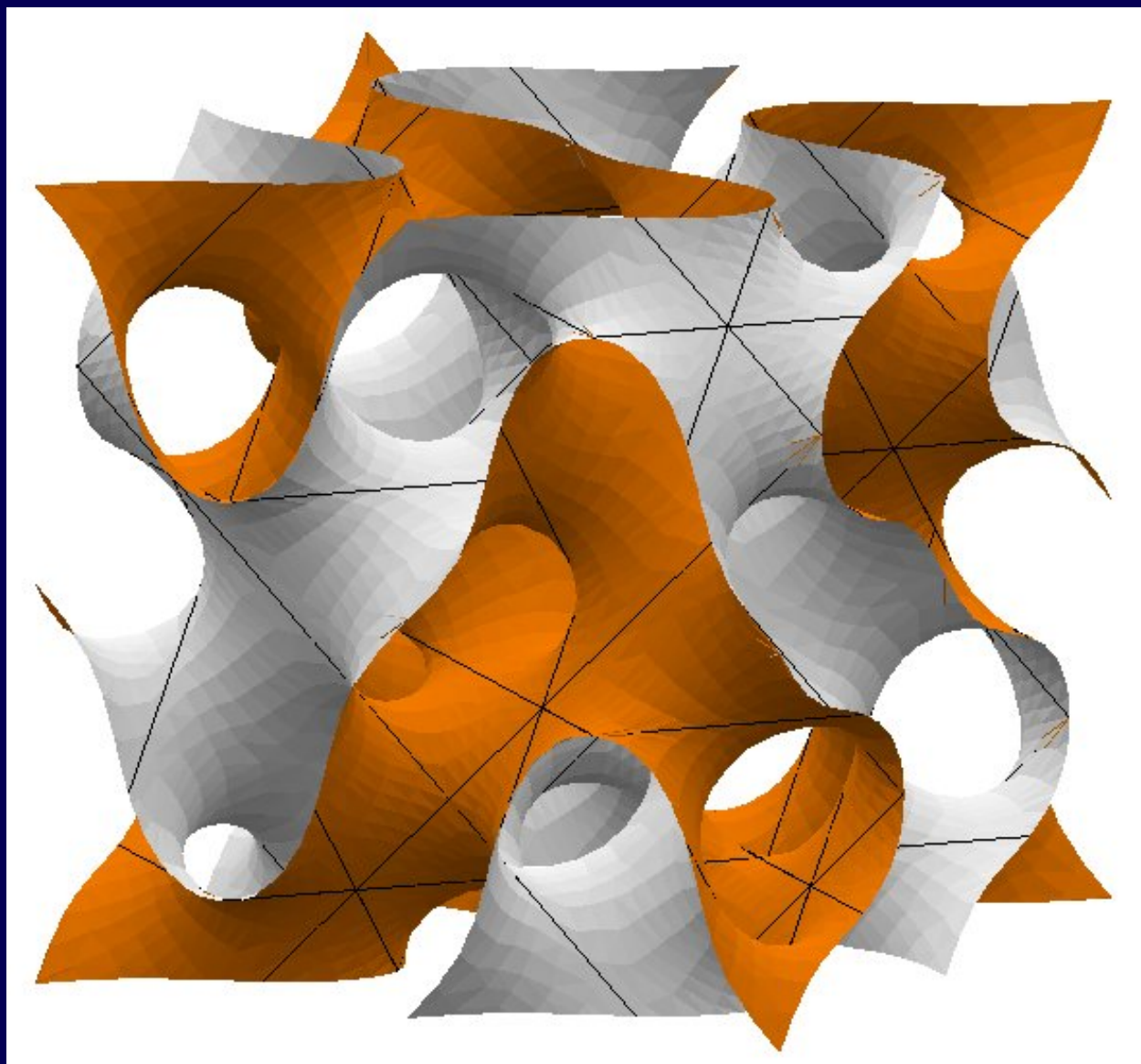
Here, minimal surfaces seem aesthetically optimal.

**To Make a Piece of Art,
It also Takes a Great Material Finish**



PATINA BY STEVE REINMUTH

Balanced Triply Periodic Surface

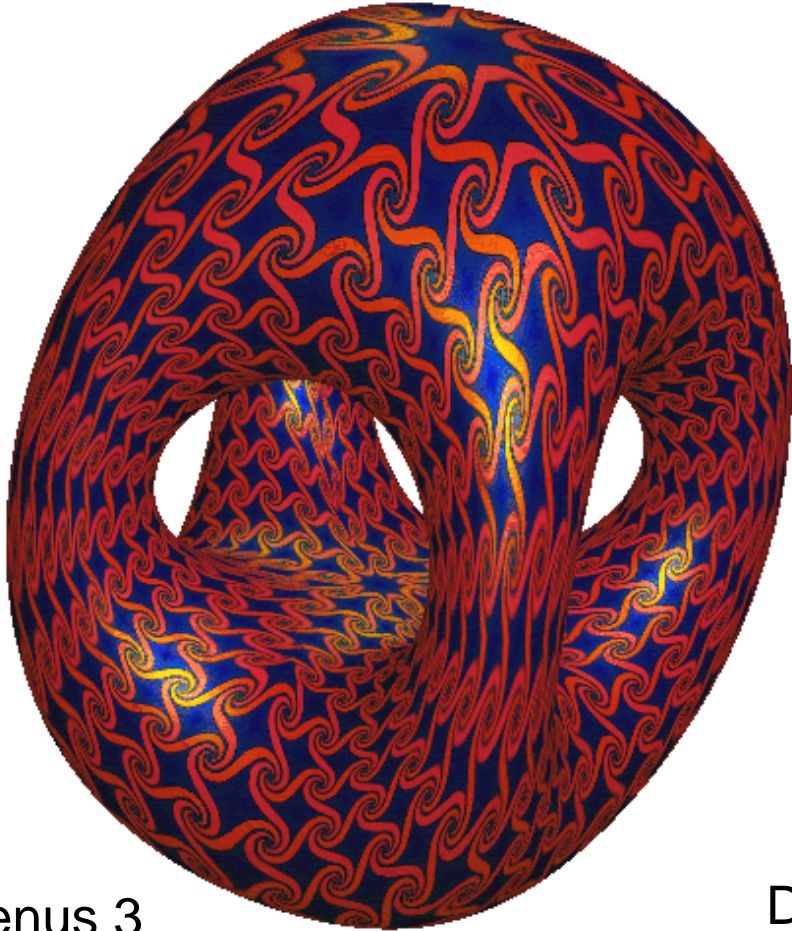


www.nada.kth.se/~asa/ray.html

"Minimal Surface City"

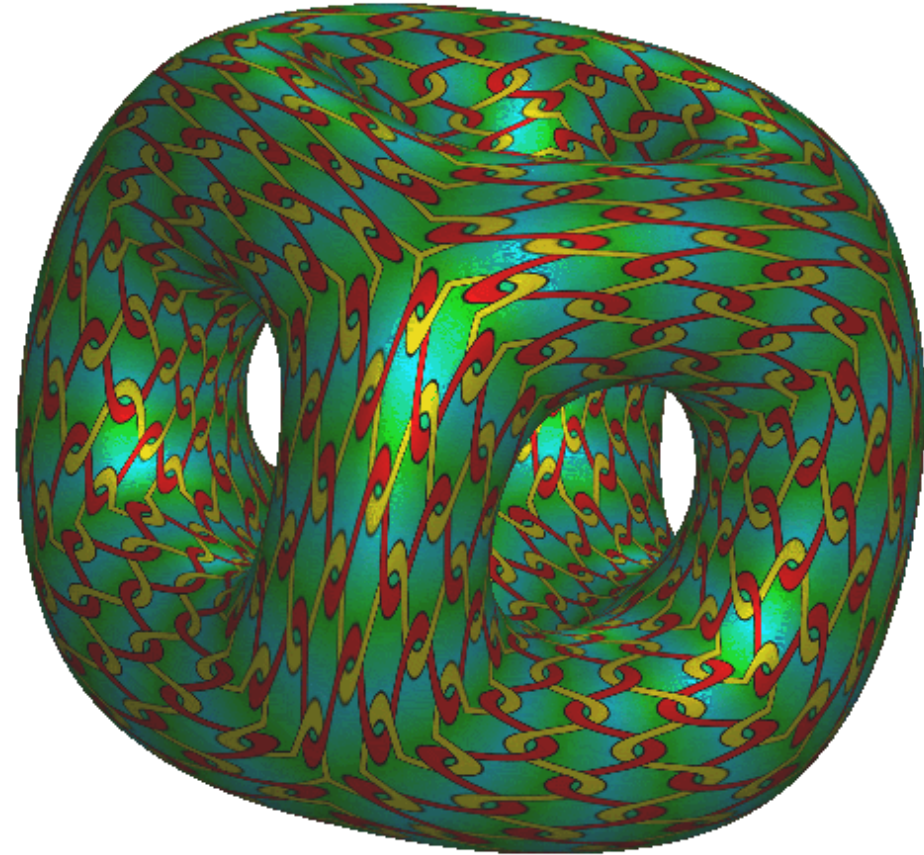


Minimum-Variation Surfaces (→CS284)



Genus 3

D_{4h}



Genus 5

O_h

- ◆ The most pleasing smooth surfaces...
- ◆ Constrained only by topology, symmetry, size.

Collins' Fabrication Process



Layered laminated main shape

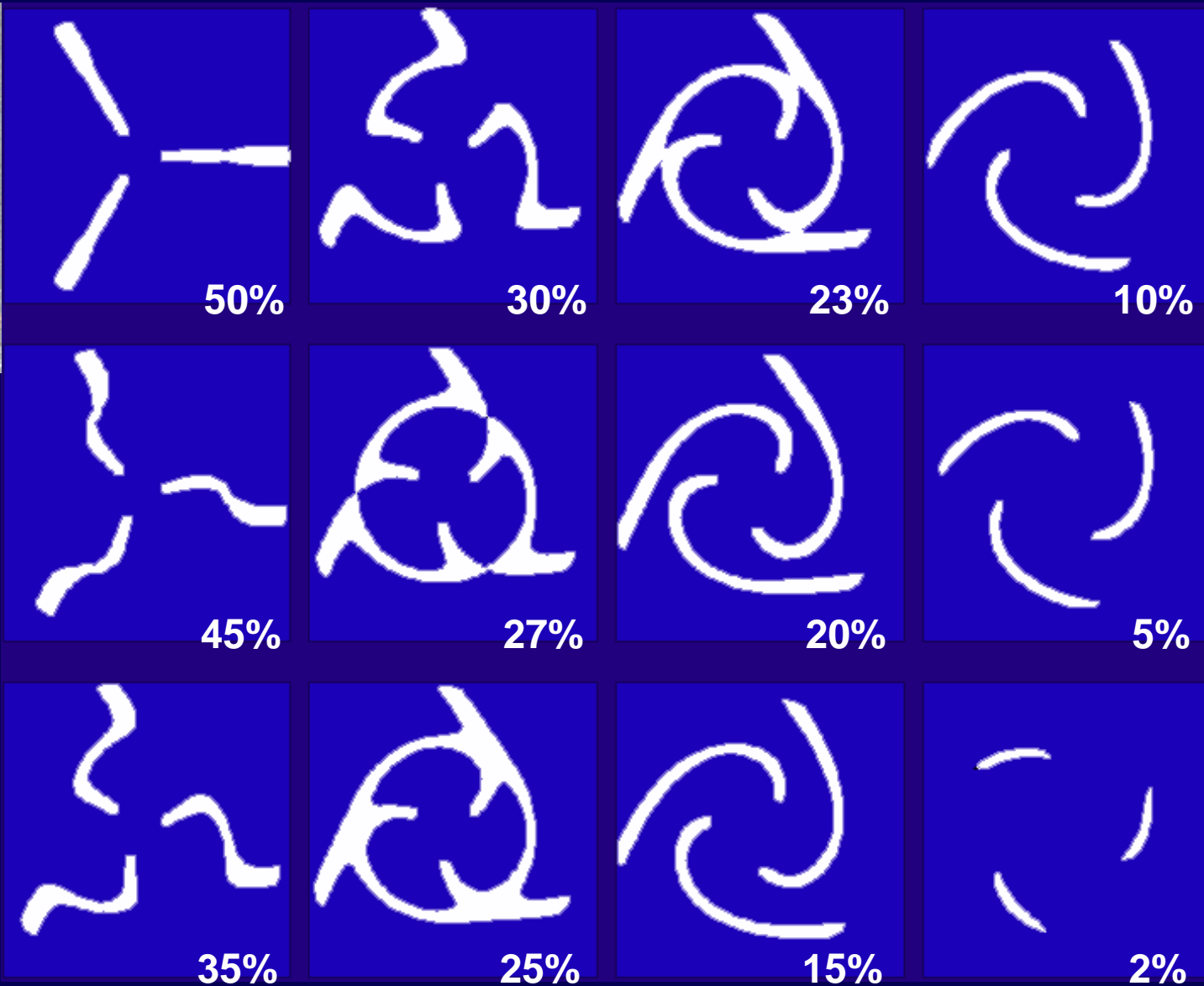


Wood master pattern
for sculpture

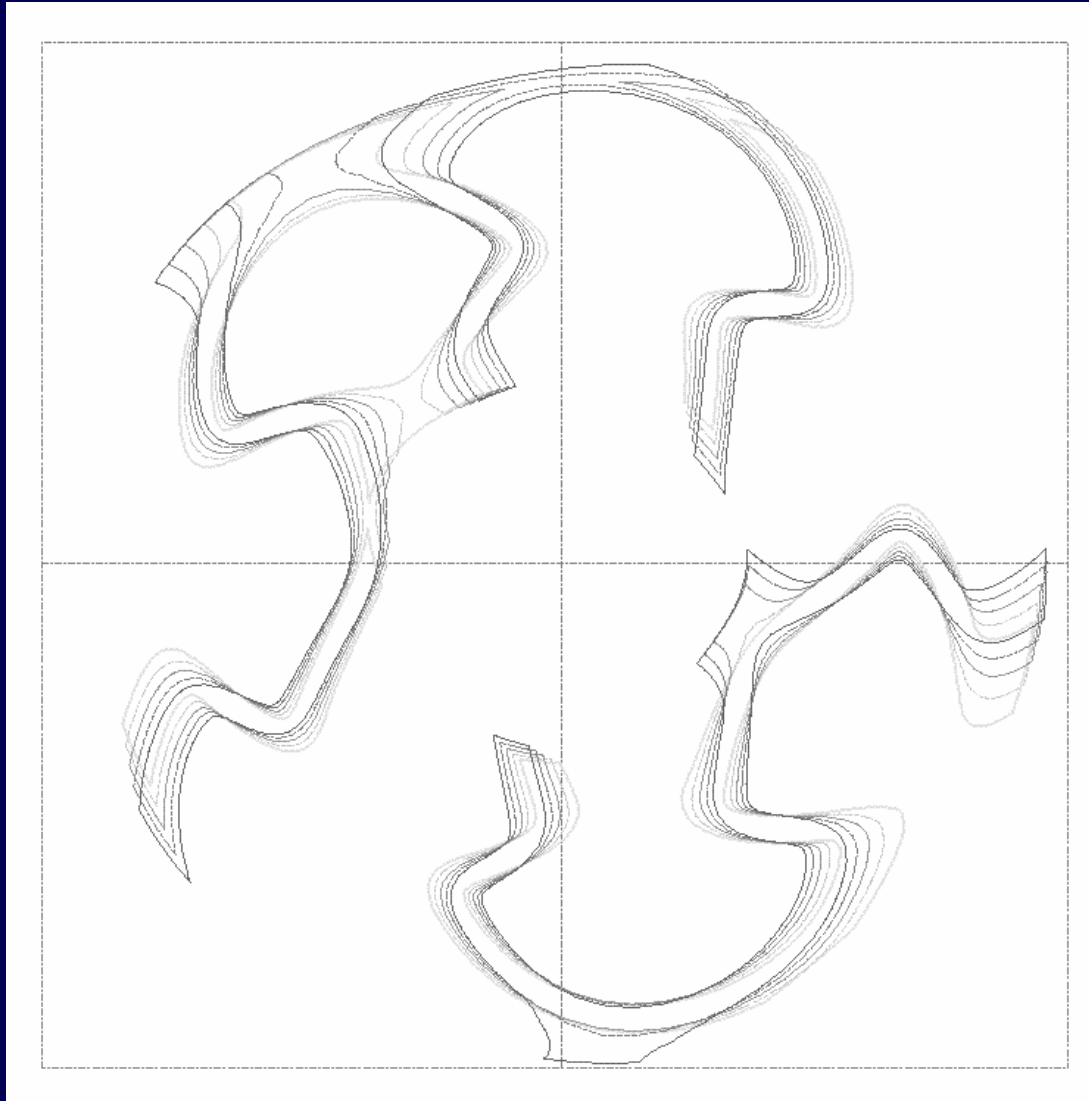


Example: *Vox Solis*

Slices through *Minimal Trefoil*



Profiled Slice through *Heptoroid*



- ◆ One thick slice thru sculpture, from which Brent can cut boards and assemble a rough shape.
- ◆ Traces represent: top and bottom, as well as cuts at $1/4$, $1/2$, $3/4$ of one board.

Emergence of the *Heptoroid* (1)



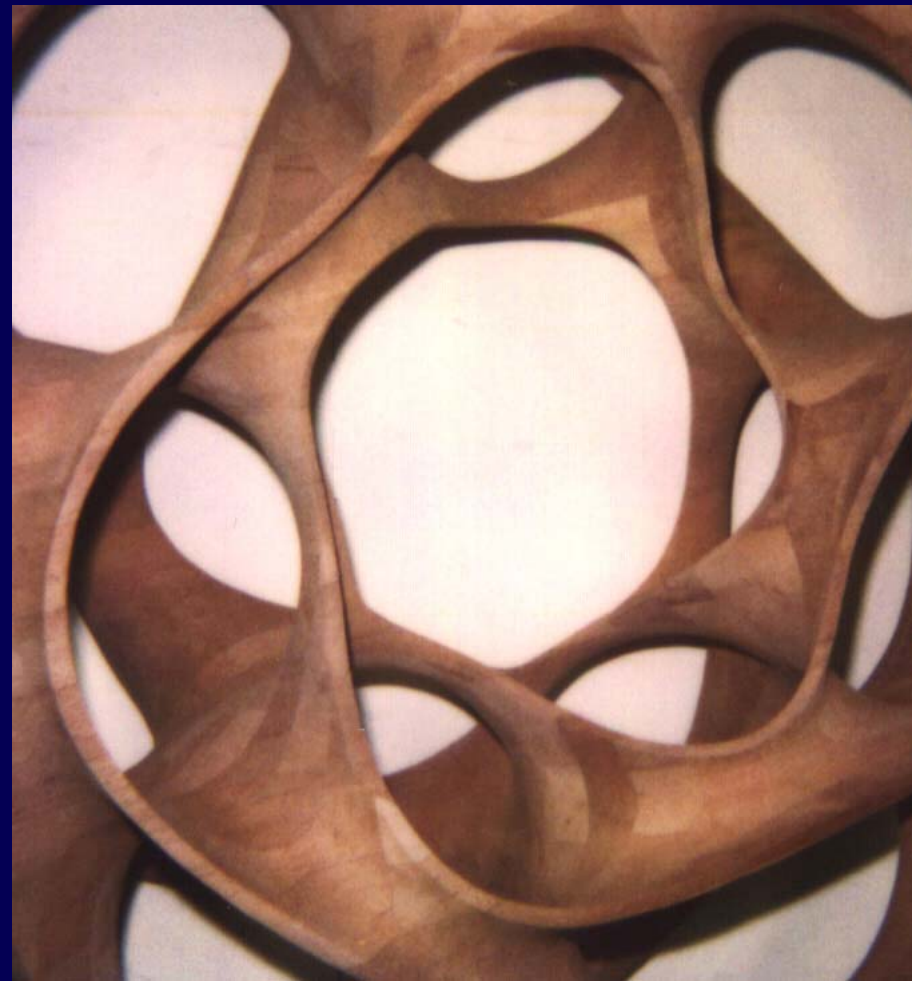
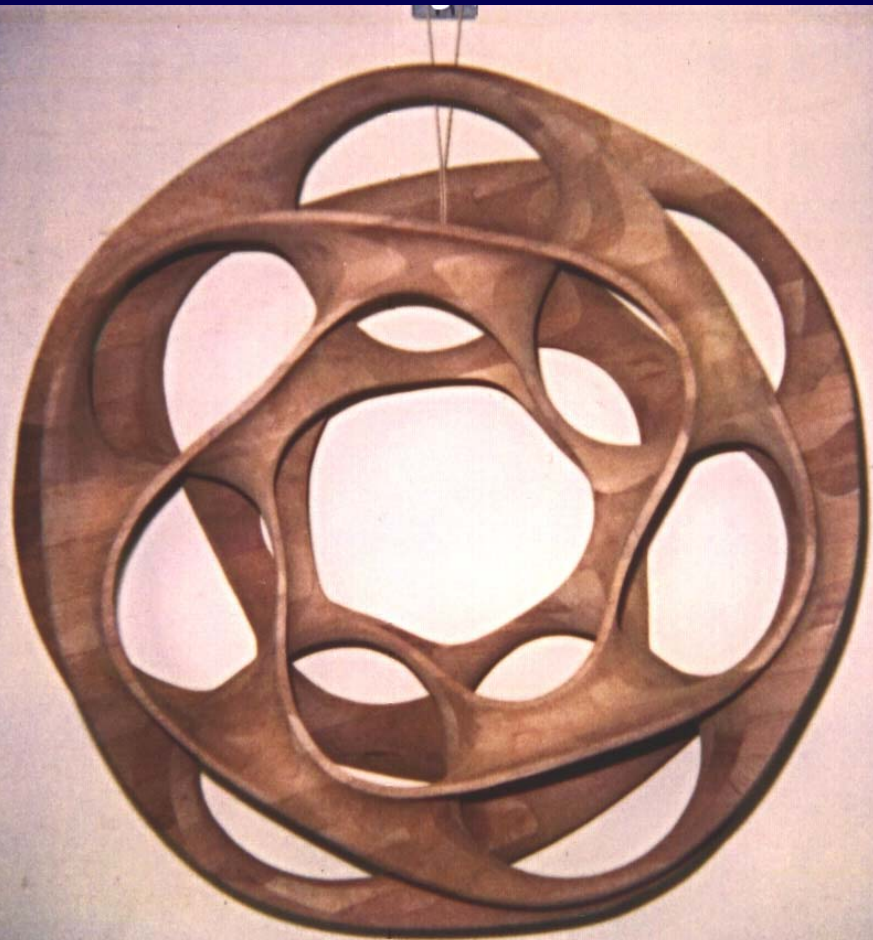
Assembly of the precut boards: Heavy “staircasing”

Emergence of the *Heptoroid* (2)



Forming a continuous smooth edge

Emergence of the *Heptoroid* (3)



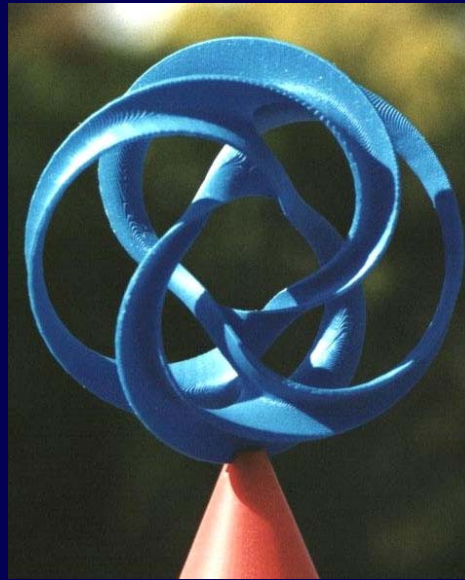
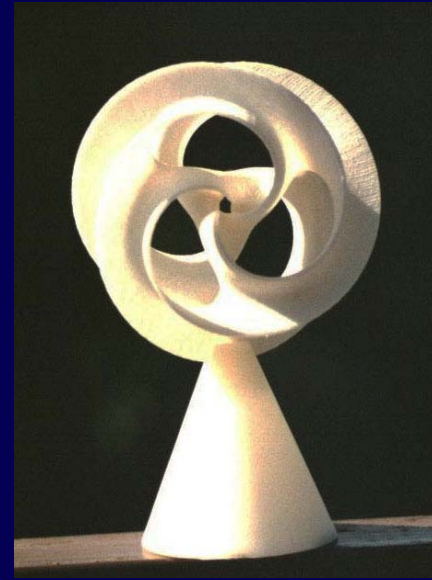
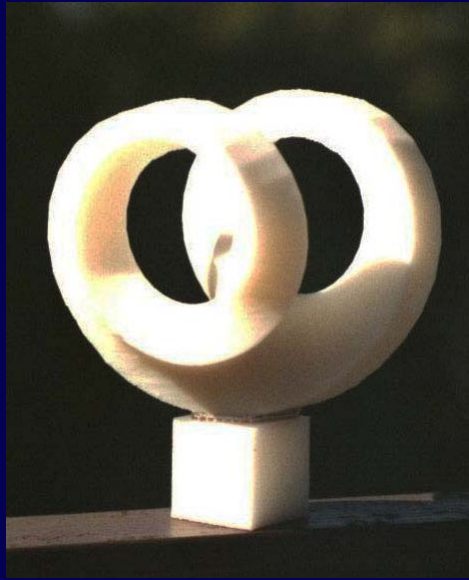
Smoothing the whole surface



The Finished *Heptoroid*

- ◆ at Fermi Lab
Art Gallery (1998)

“Scherk-Collins” Sculptures (FDM)



Hypersculpture: *Family of 12 Trefoils*



B=1

B=2

B=3

B=4

W=2

W=1

Extending the Notion of a “Saddle”



$B=1$



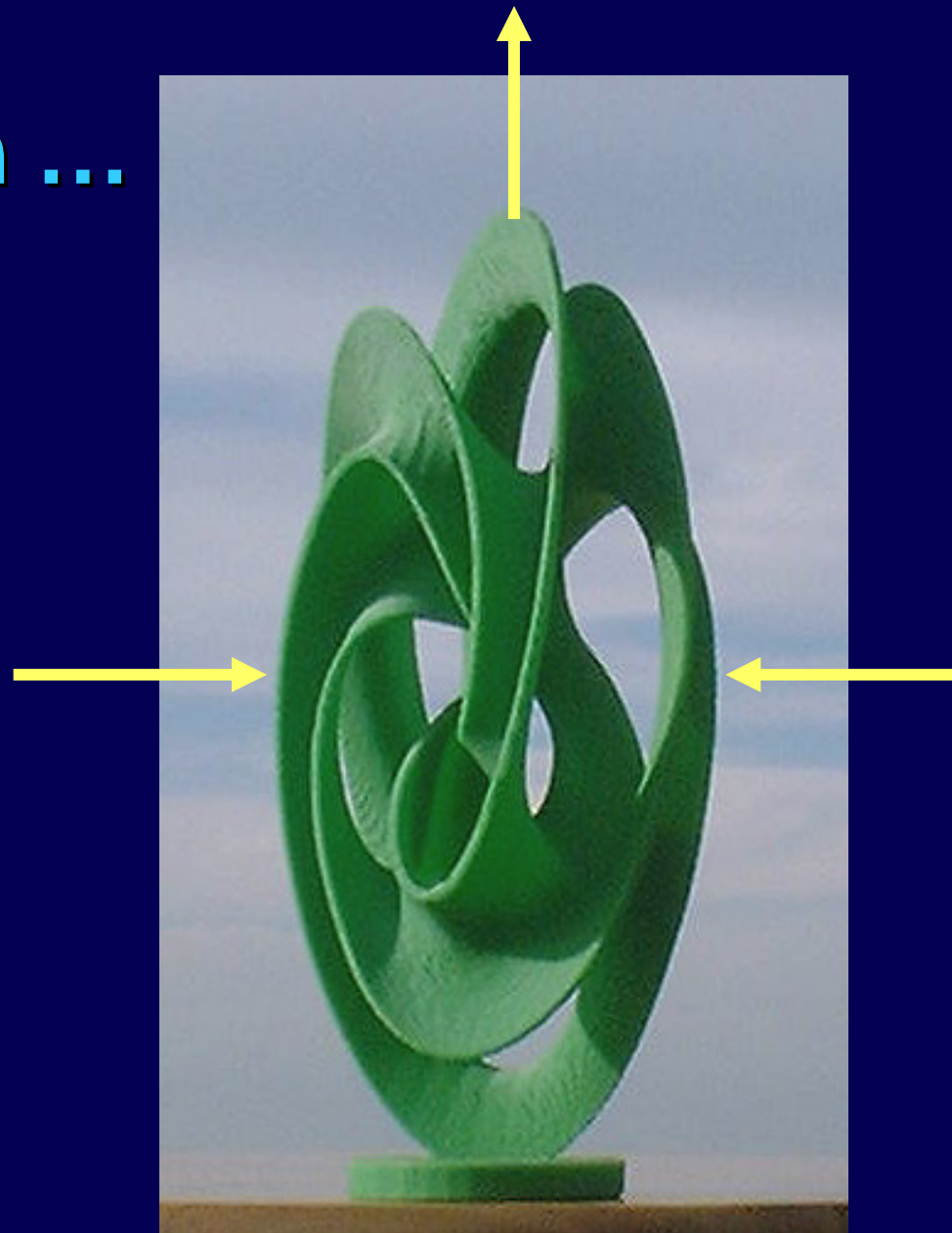
$B=2$



$B=3$

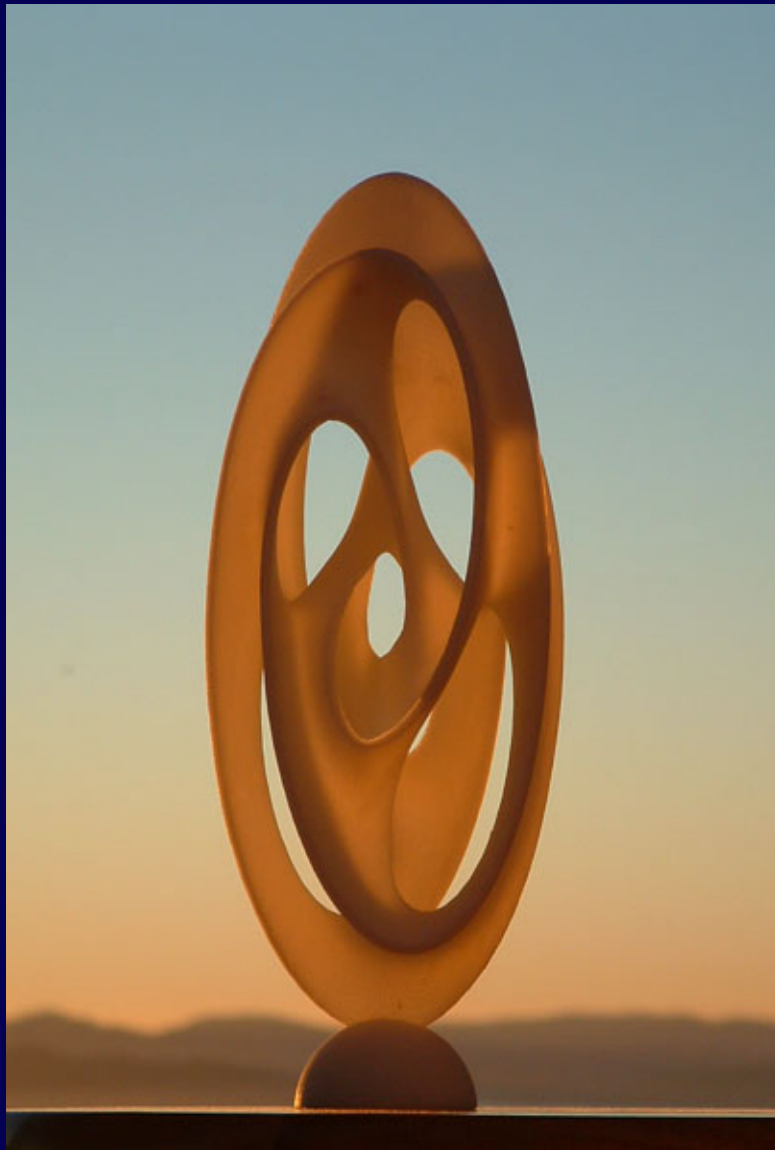
**B = number of branches = the order of the saddles.
 $B = 1$: A “one-leg saddle”? → just a simple band.**

Another Extension ...



**Allow different kinds of
“stretching” ...**

Extending the Paradigm: *Totem 3*



Bronze Investment Cast



Totem-4

Bronze, Dec. 2007

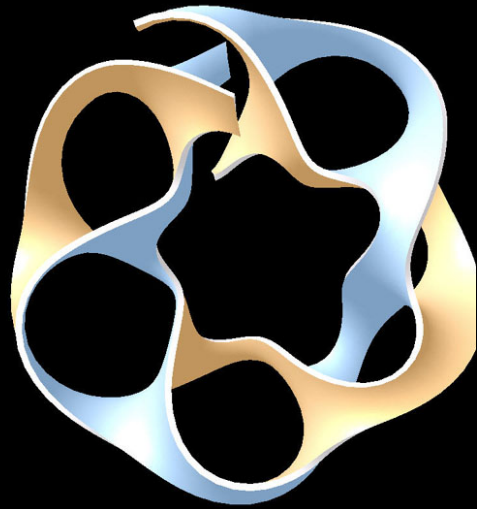
Carlo Séquin

Cohesion

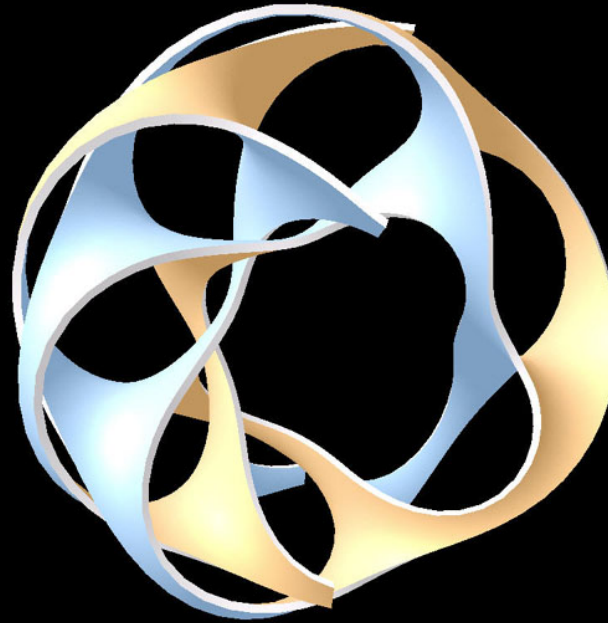


SIGGRAPH'2003 Art Gallery

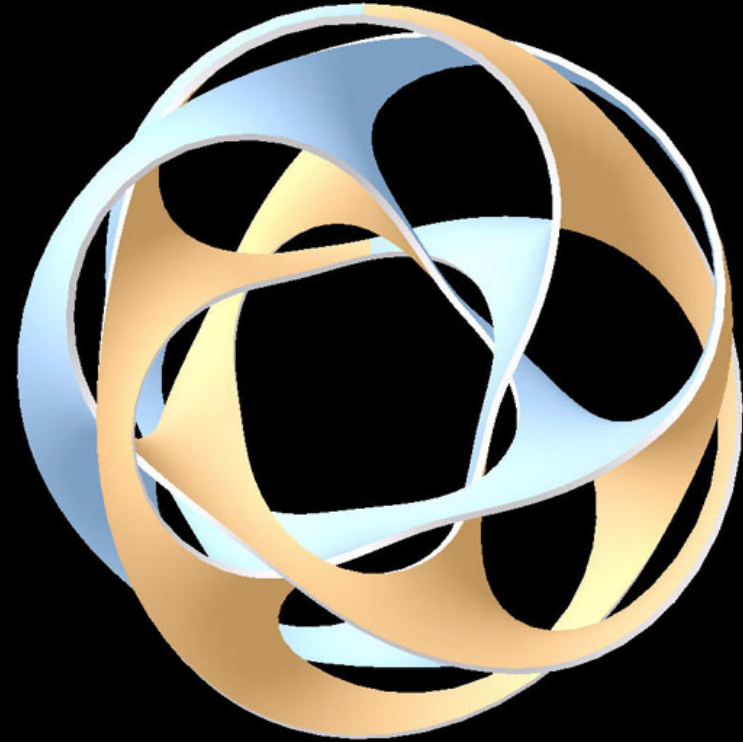
Going more than once around the loop ...



$w = 380^\circ$



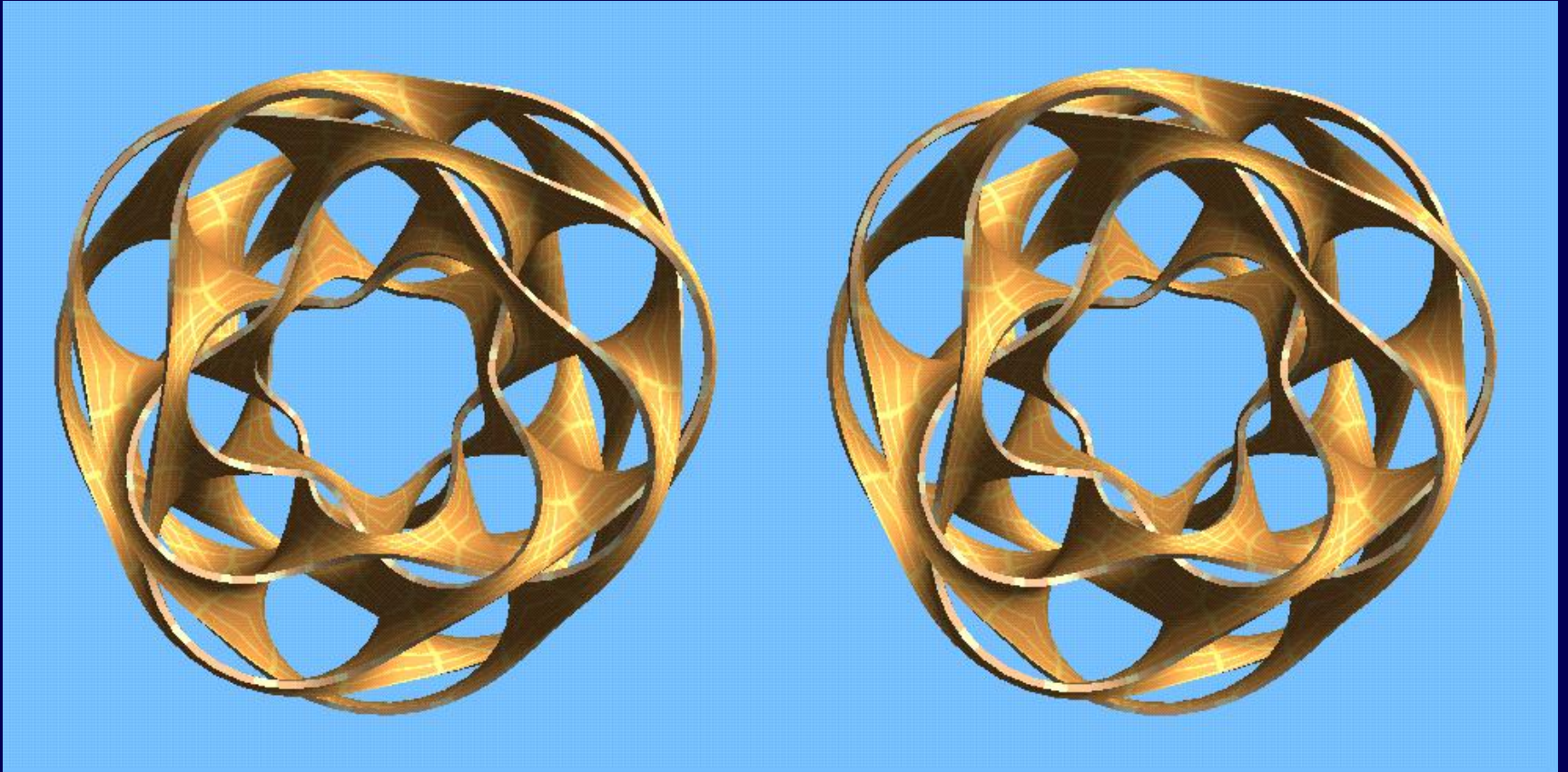
$w = 560^\circ$



$w = 720^\circ$

... results in an interwoven structure.

11 Stories, Monkey-Saddles, $w=2$:



cross – eye stereo picture

9-story Intertwined Double Toroid



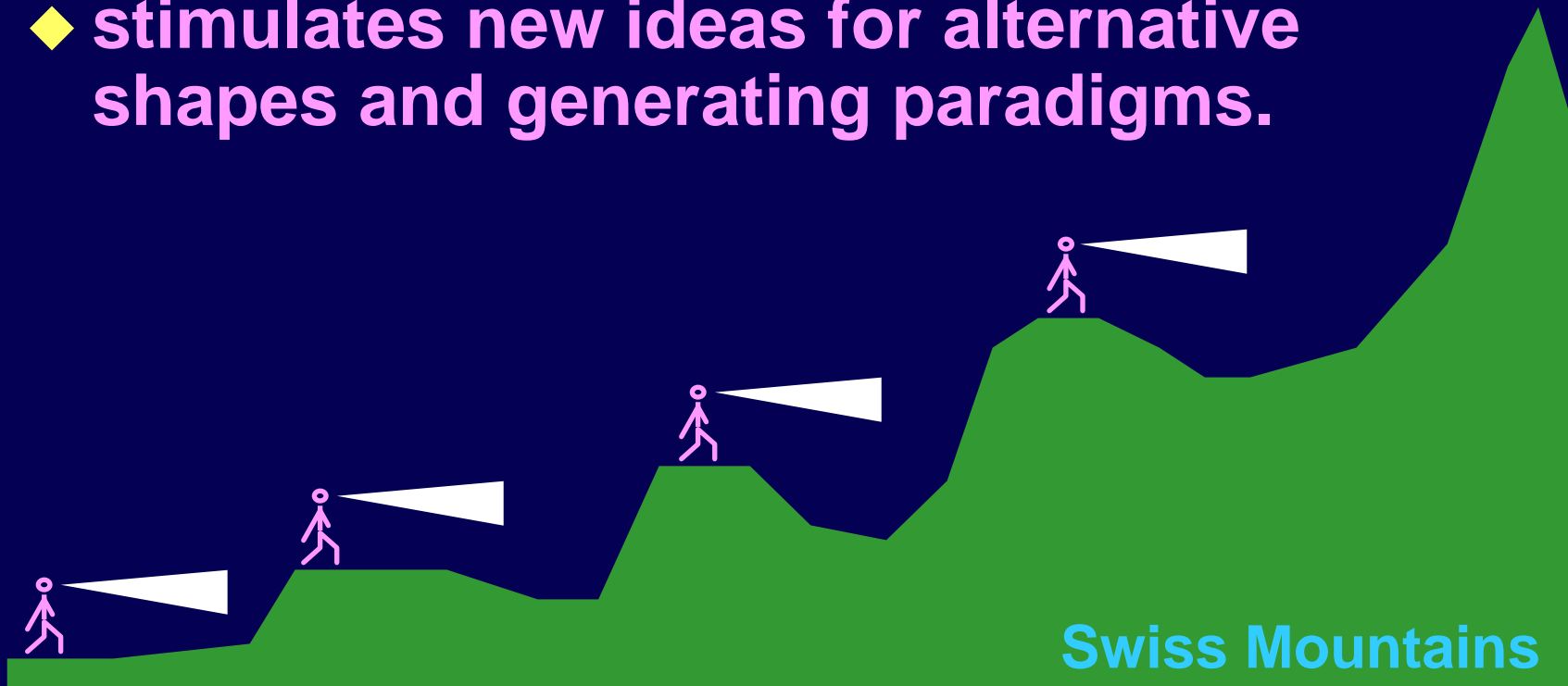
**Bronze
investment
casting**

**from
wax original**

**made on
3D Systems'
*Thermojet***

Stepwise Expansion of Horizon

- ◆ Playing with many different shapes and
- ◆ experimenting at the limit of the domain of the sculpture generator,
- ◆ stimulates new ideas for alternative shapes and generating paradigms.



Sculpture Generator 1 as a Playground

**The computer becomes
an amplifier / accelerator
for the creative process.**

**Another occasion where
Sculpture Generator 1
became invaluable ...**

Breckenridge, CO, January 2003



Snowsculpting Championships: “Whirled White Web”
(C. Séquin, S. Wagon, D. Schwalbe, B. Collins, S. Reinmuth)

Day 1

Removing lots of snow ...





Day 2: Making a Torus



End of Day 2



The Torus

Day 3, am: Drawing Flanges



Day 3, pm: Carving Flanges, Holes



Day 4: Geometry Refinement





End of Day 4: Desired Geometry



Day 5, am: Surface Refinement



Official Team Photo



Judgement Time: *Whirled White Web*



12:40 pm -- 42° F



12:41 pm -- 42° F



“WWW” Wins Silver Medal



Large and Durable Sculpture !

- ◆ Need a material
more permanent than snow ...

2006: Commission for a Big Sculpture!

- ◆ Scale up original “Pax Mundi” (to 6ft diam.)
- ◆ Less than 1500 pounds
- ◆ Budget 50'000 \$
- ◆ Due in 4 months (→ Nov. 2006)
- ◆ Collaboration: Collins, Reinmuth, Séquin
- ◆ **My task:**
Create the digital file for a mold master



**Another
Inspiration:**

**Brent Collins'
Pax Mundi
(1997)**

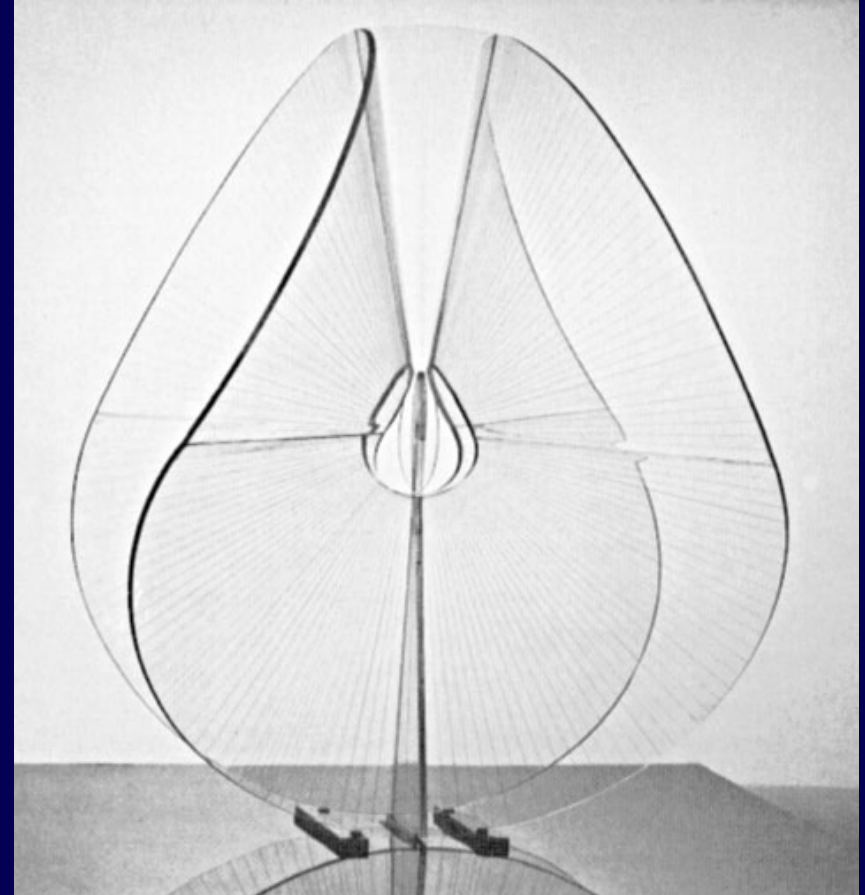
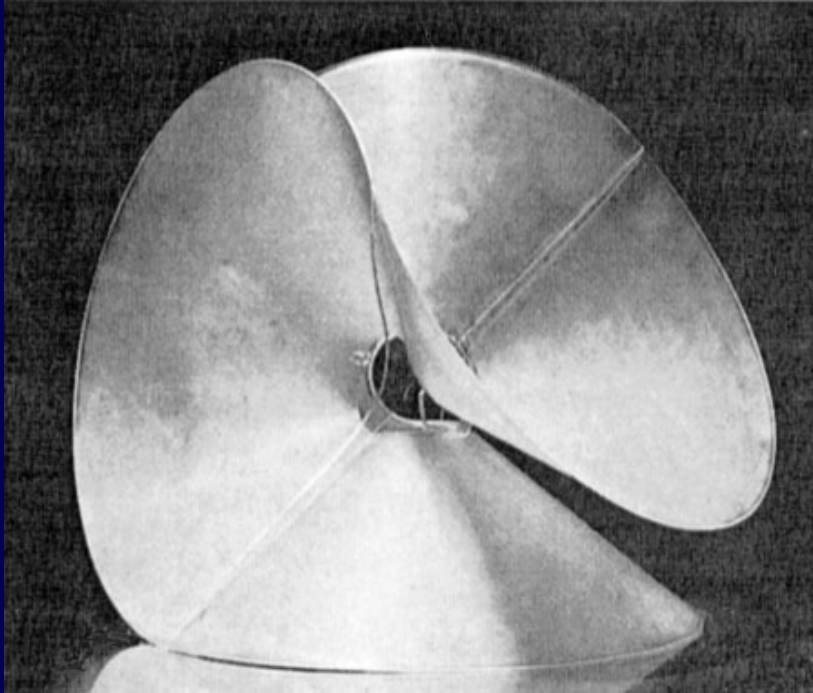
How Would You Model This ?

- ◆ Conceptual associations ?
- ◆ Potentially useful modeling paradigms ?
- ◆ Generating principle ?
- ◆ Use of geometrical parameters ?

Keeping up with Brent ...

- ◆ *Pax Mundi* cannot be done with *Sculpture Generator I*
- ◆ Needs a more general program !
- ◆ First:
Need to understand what is going on → →

Sculptures by Naum Gabo

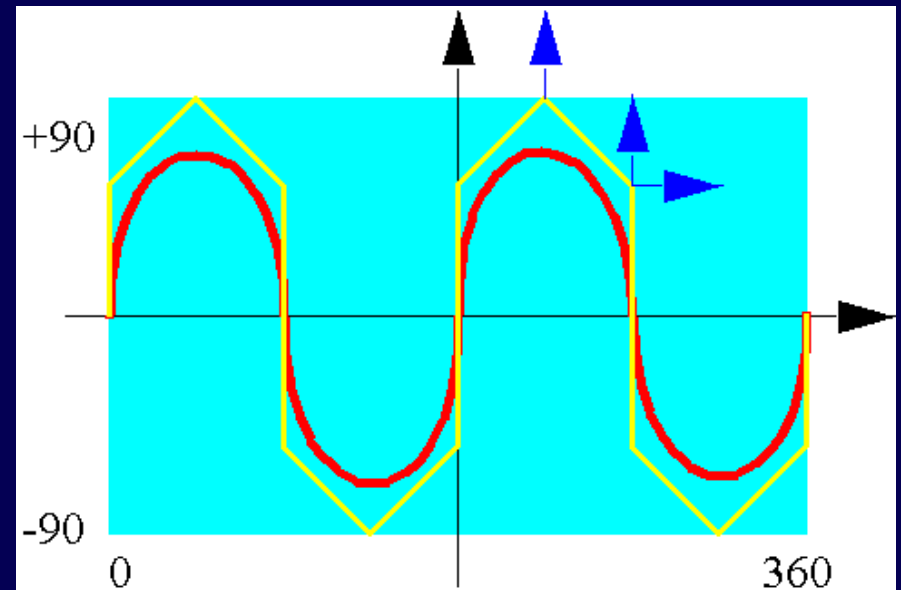


Pathway on a sphere:

Edge of surface is like seam of tennis- or base-ball;

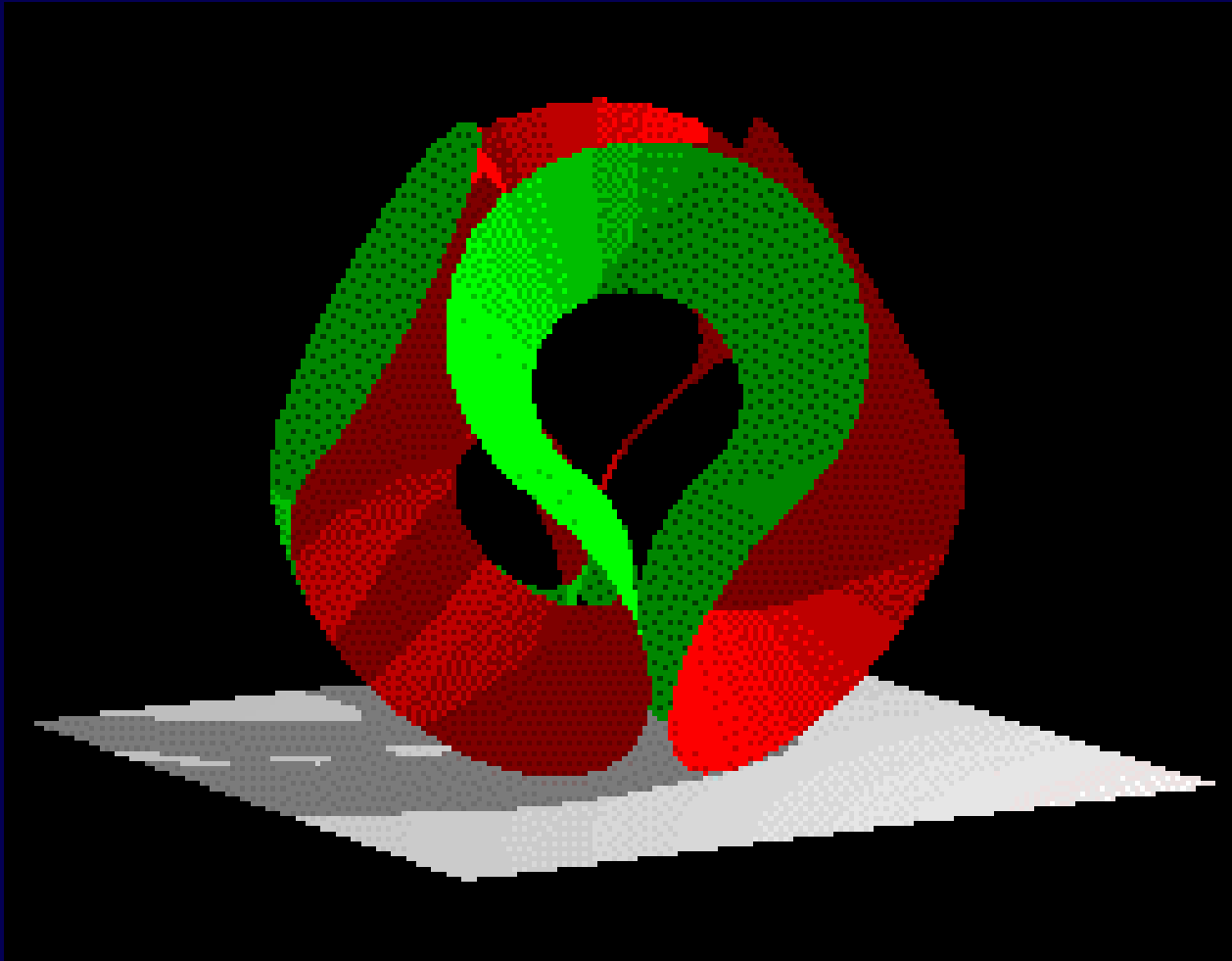
==> 2-period Gabo curve.

2-period “Gabo Curve”



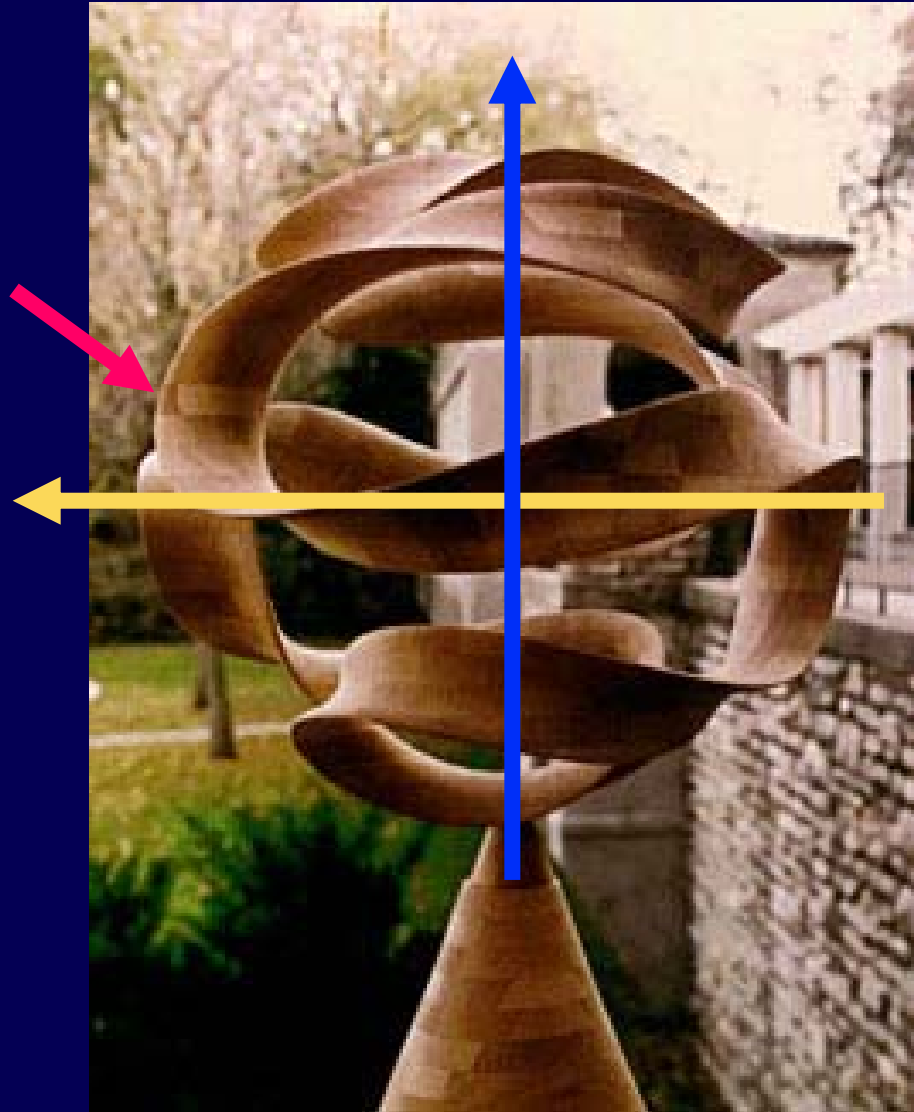
- ◆ Approximation with quartic B-spline with 8 control points per period, but only 3 DOF are used (symmetry!).

4-period “Gabo Curve”



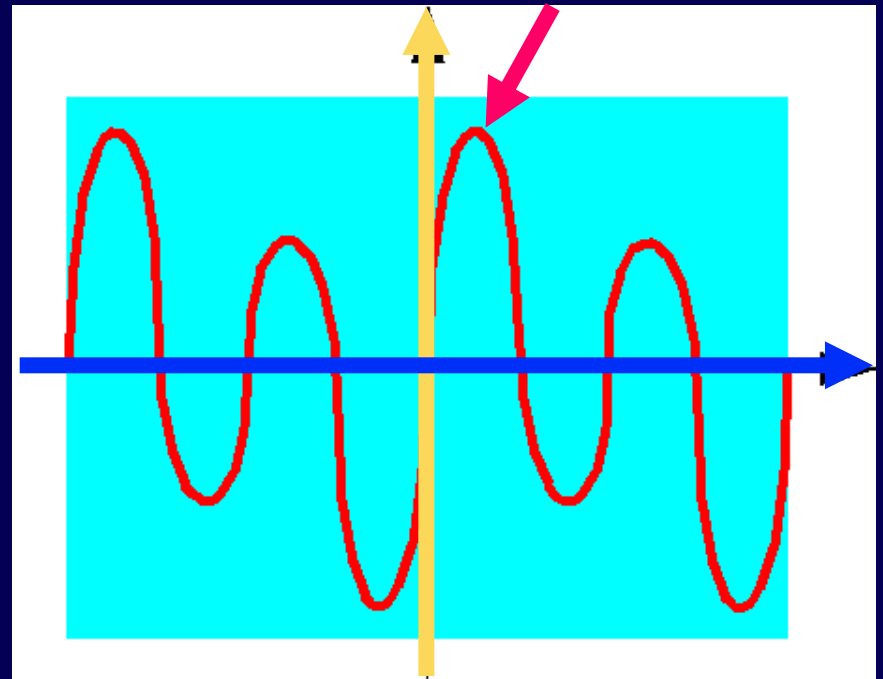
Same construction as for as for 2-period curve

Pax Mundi Revisited



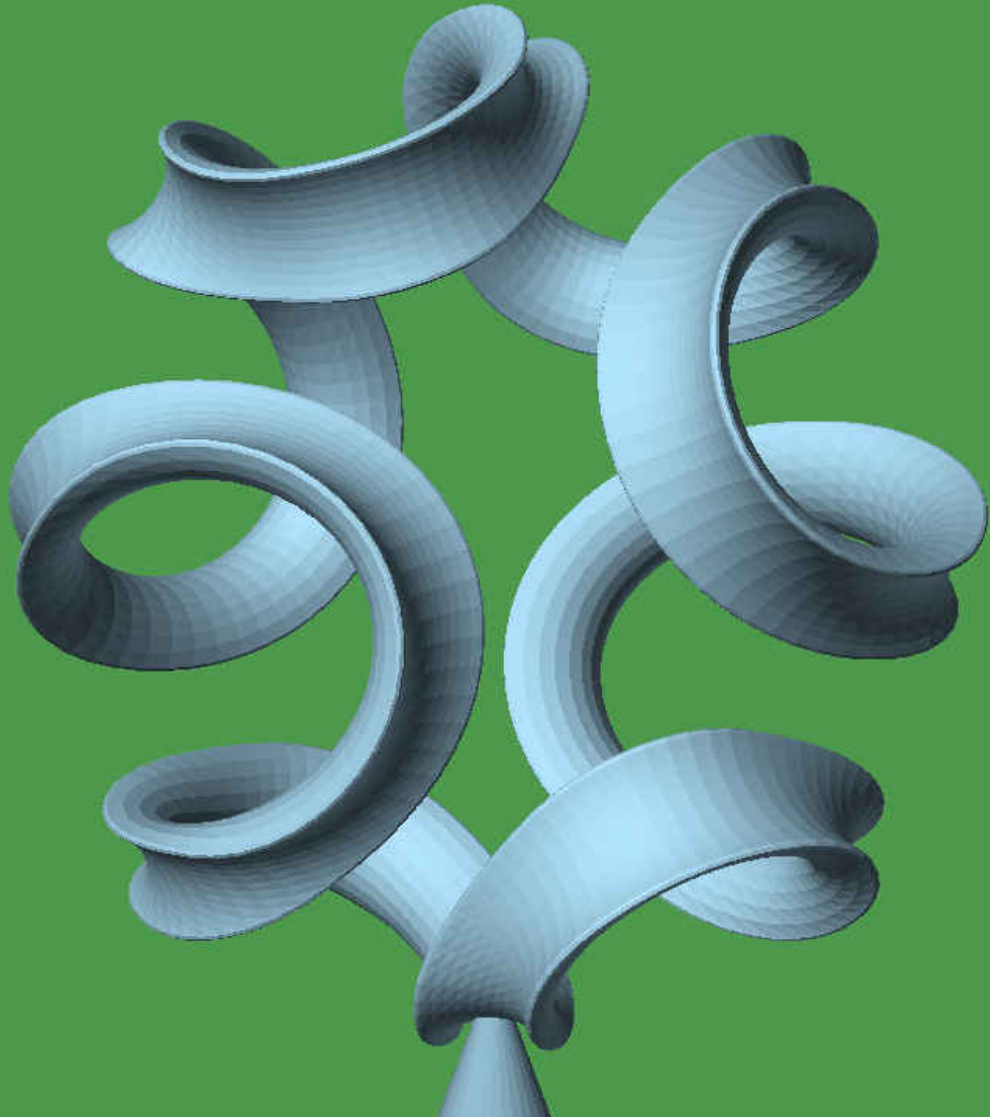
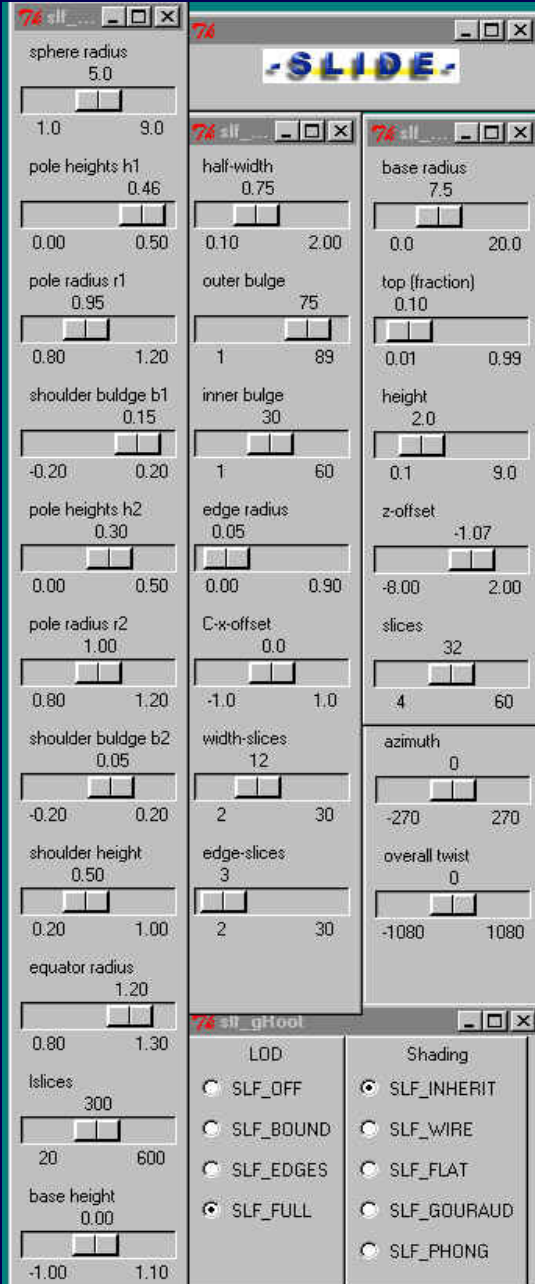
◆ Can be seen as:

Amplitude modulated,
4-period Gabo curve

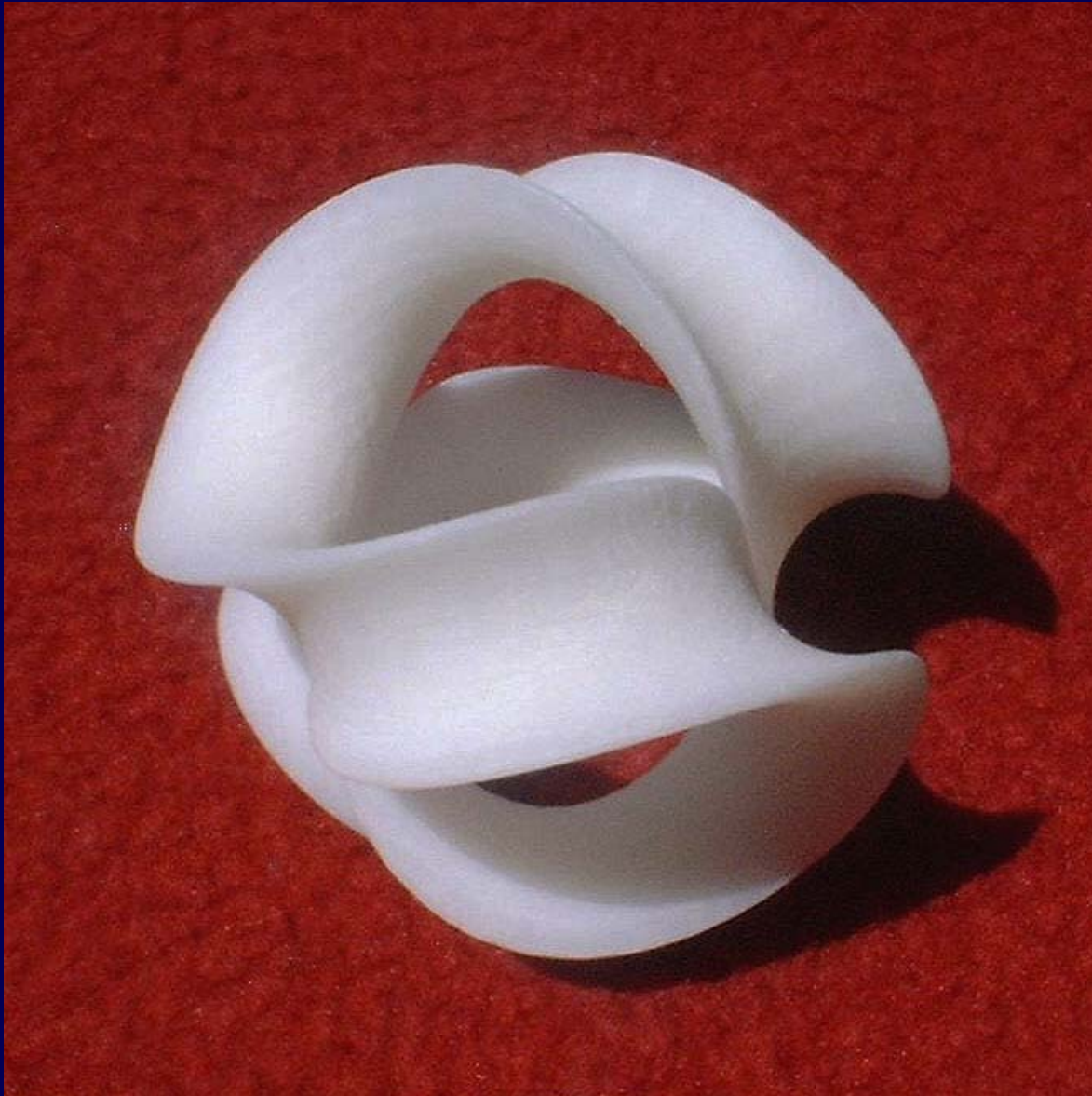


SLIDE-GUI for “*Pax Mundi*” Shapes

Good combination of interactive 3D graphics and parameterizable procedural constructs.



2-period Gabo Sculpture



Tennis ball –
or baseball –
seam
used as
sweep curve.

Viae Globi Family (Roads on a Sphere)



2

3

4

5

periods

Via Globi 5 (Virtual Wood)

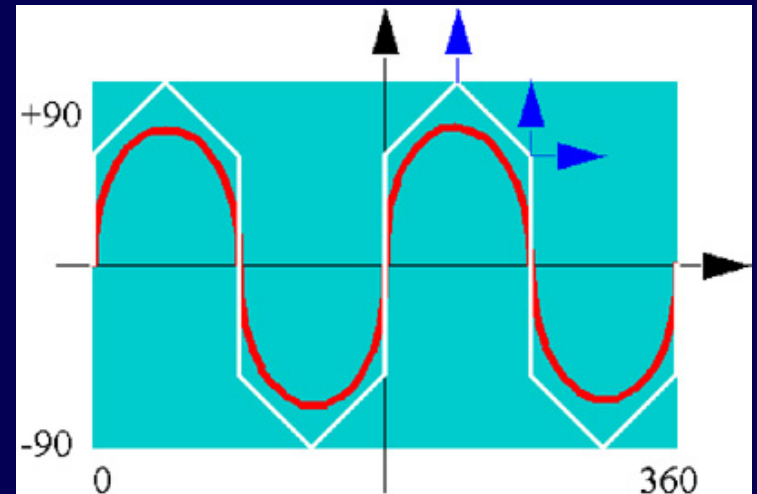


Wilmin Martono

Modularity of *Gabo Curve Generator*

◆ Sweep Curve Generator:

- Gabo Curves as B-splines



◆ Cross Section Fine Tuner:

- Paramerized shapes

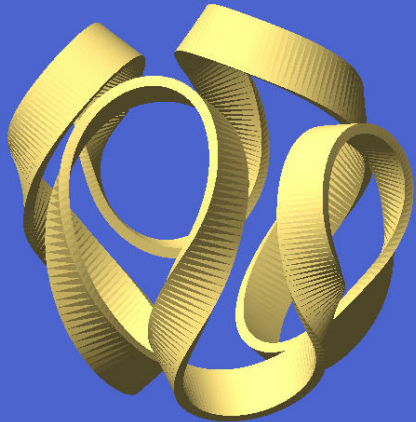


◆ Sweep / Twist Controller

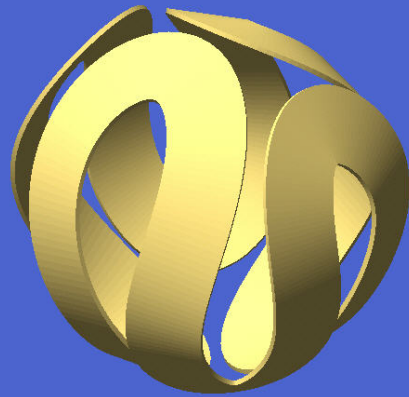


Sweep / Twist Control

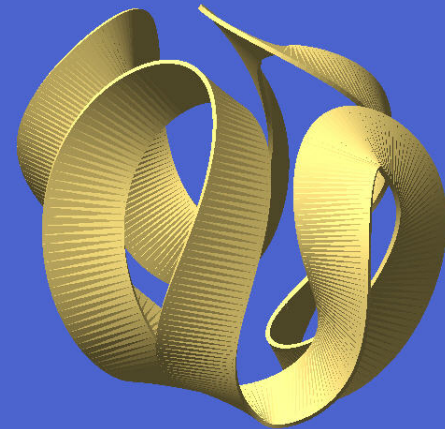
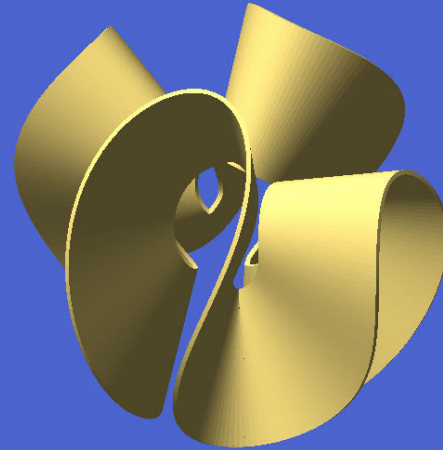
- ◆ How do we orient, move, morph ...
the cross section along the sweep path ?



**Natural orientation
with Frenet frame**



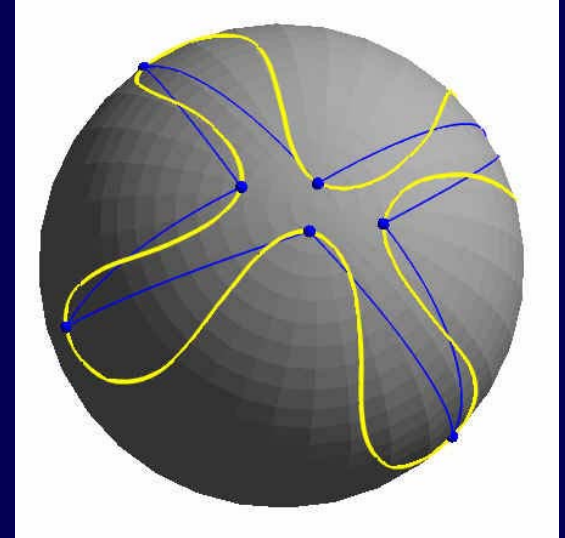
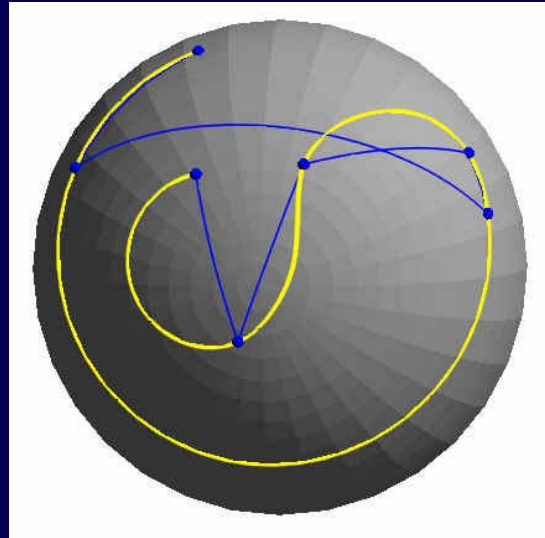
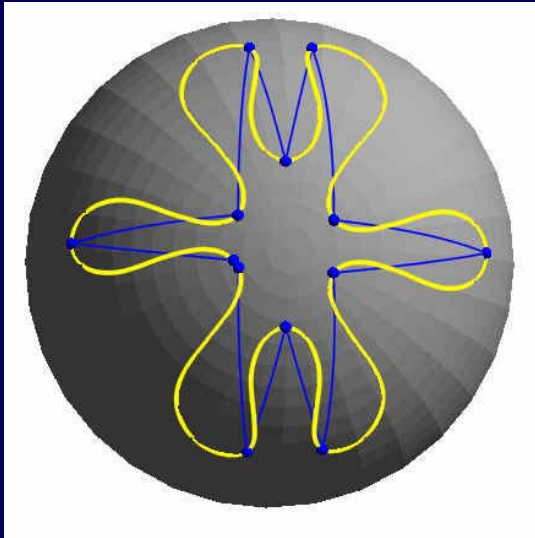
**Torsion Minimization:
Azimuth: tangential / normal**



**90° of twist
added.**

Extension: Free-form Curve on a Sphere

Spherical Spline Path Editor (Jane Yen)

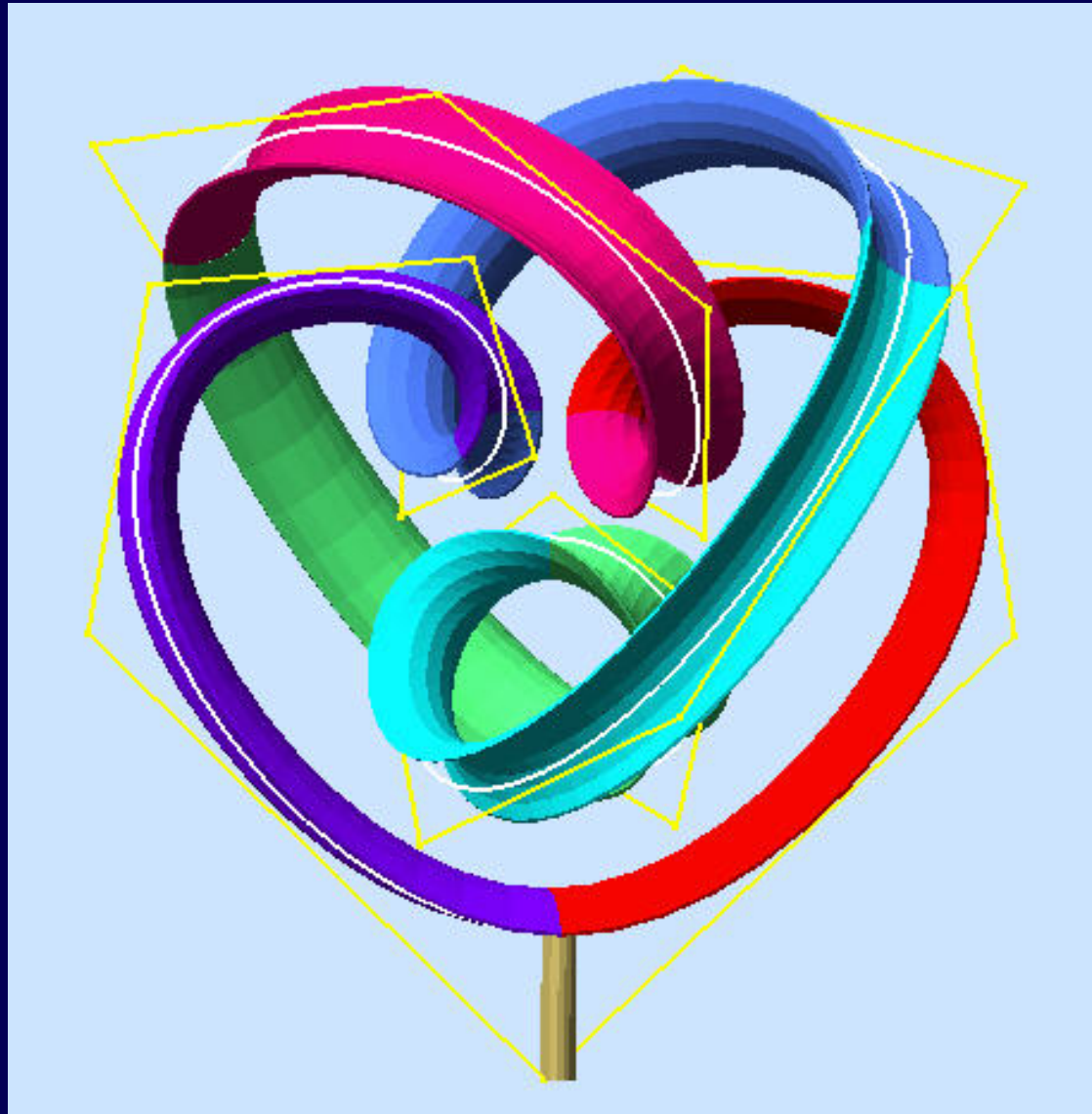


Nice smooth interpolating curves through sparse data points

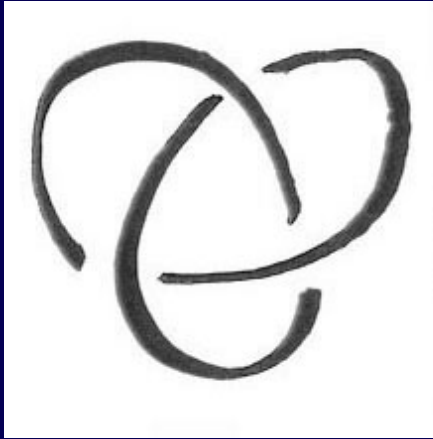
Many Different *Viae Globi* Models



Paradigm Extension: Sweep Path is no longer confined to a sphere!



The Beauty of Knots

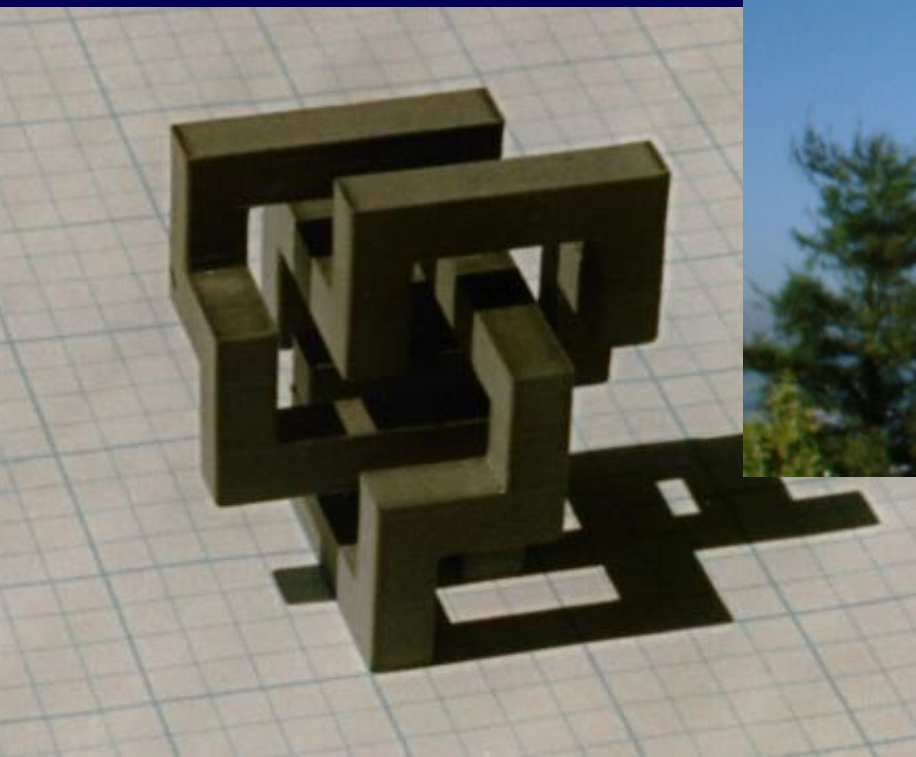
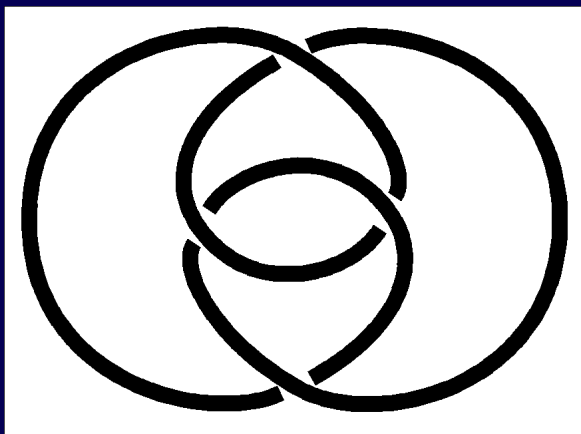


Trefoil Knot



Music of the Spheres (Brent Collins)

Figure-8 Knot



Free-form 3D Space Curves

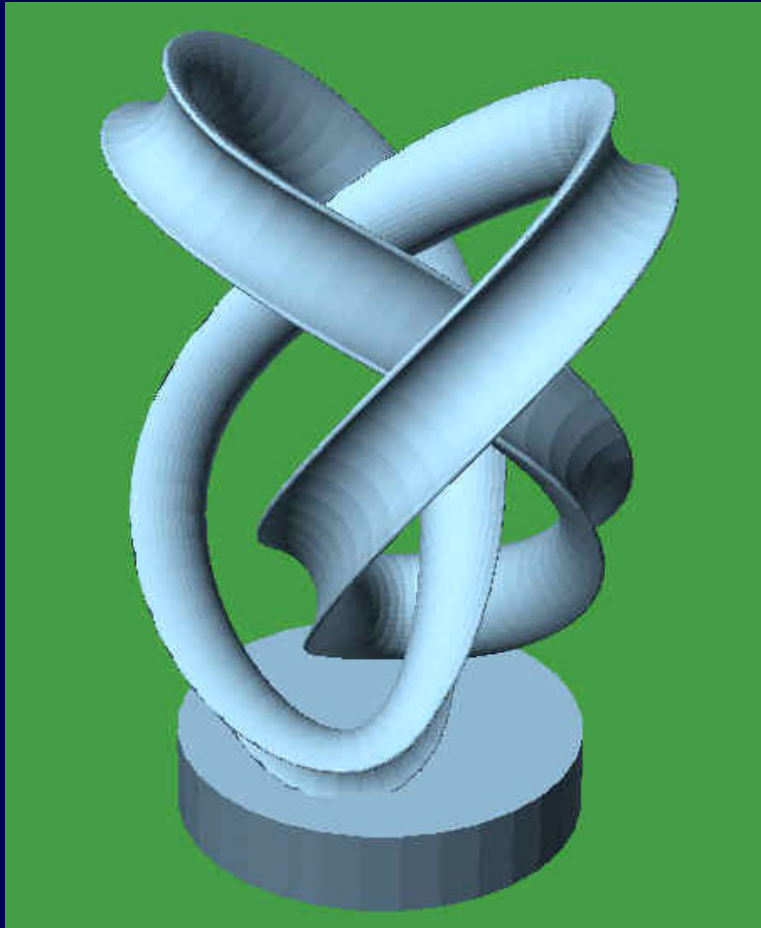


Figure-8 knot



Figure-8 Knot

Bronze, Dec. 2007

Carlo Séquin

Chinese Button Knot (9_{40})



9₁



9₁₁



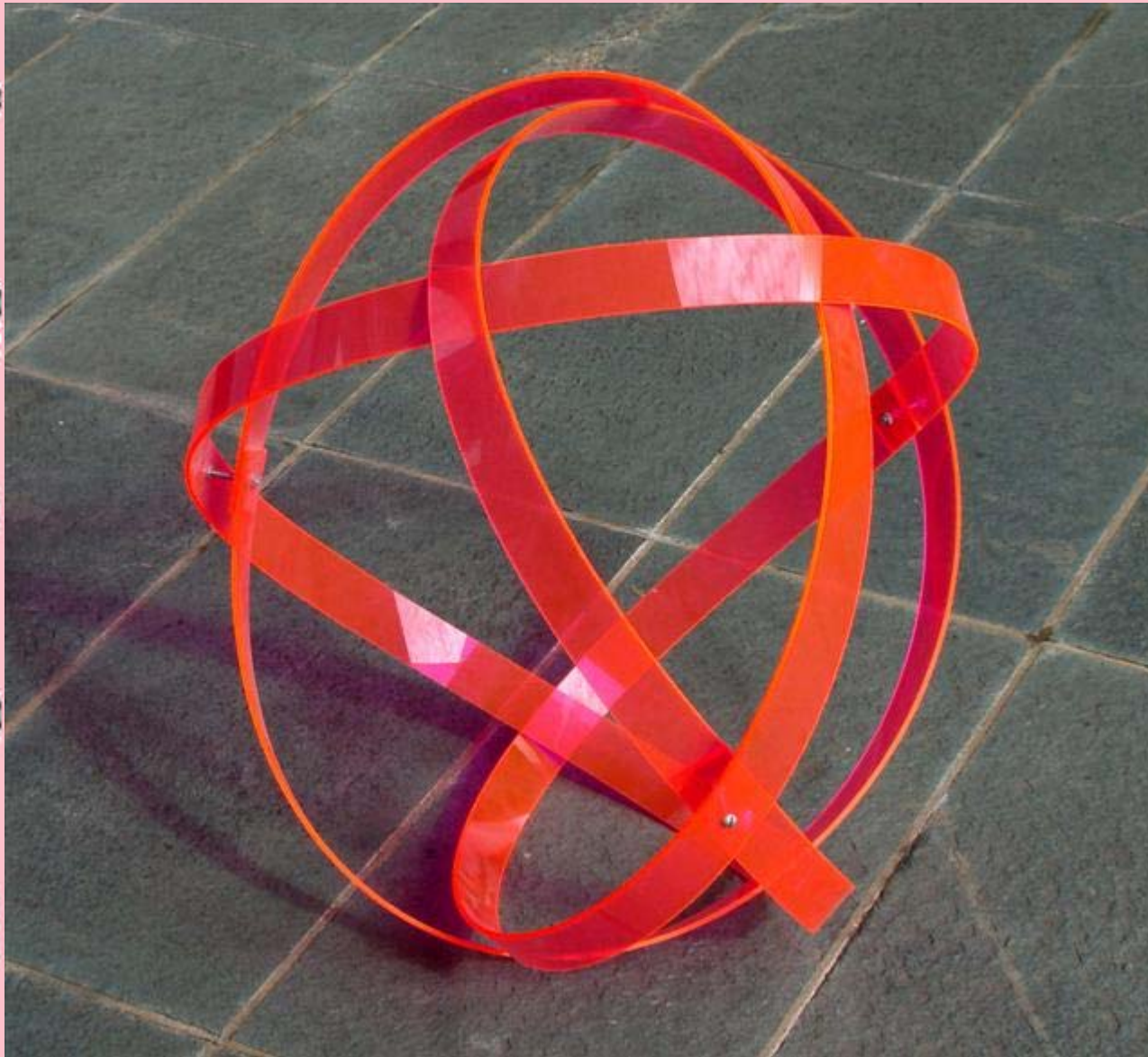
9₂₁



9₃₁



9₄₁



9₉



9₁₀



9₁₉



9₂₀



9₂₉



9₃₀



9₃₉

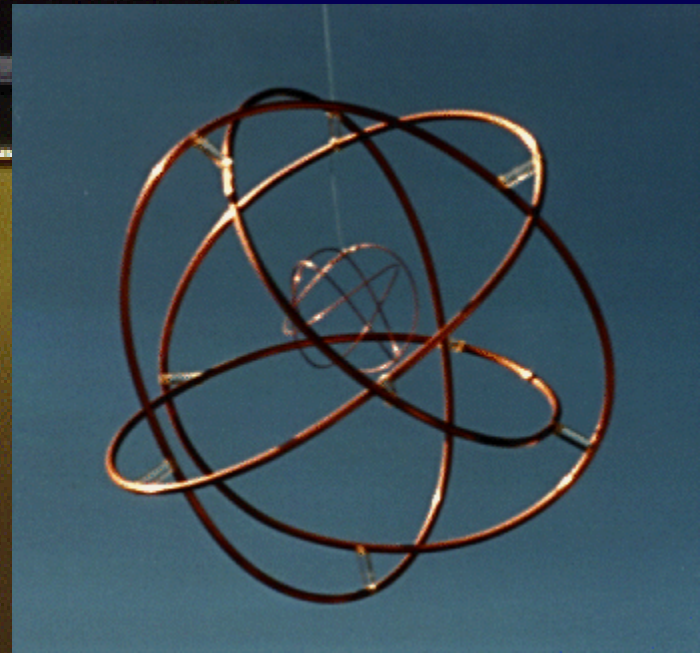
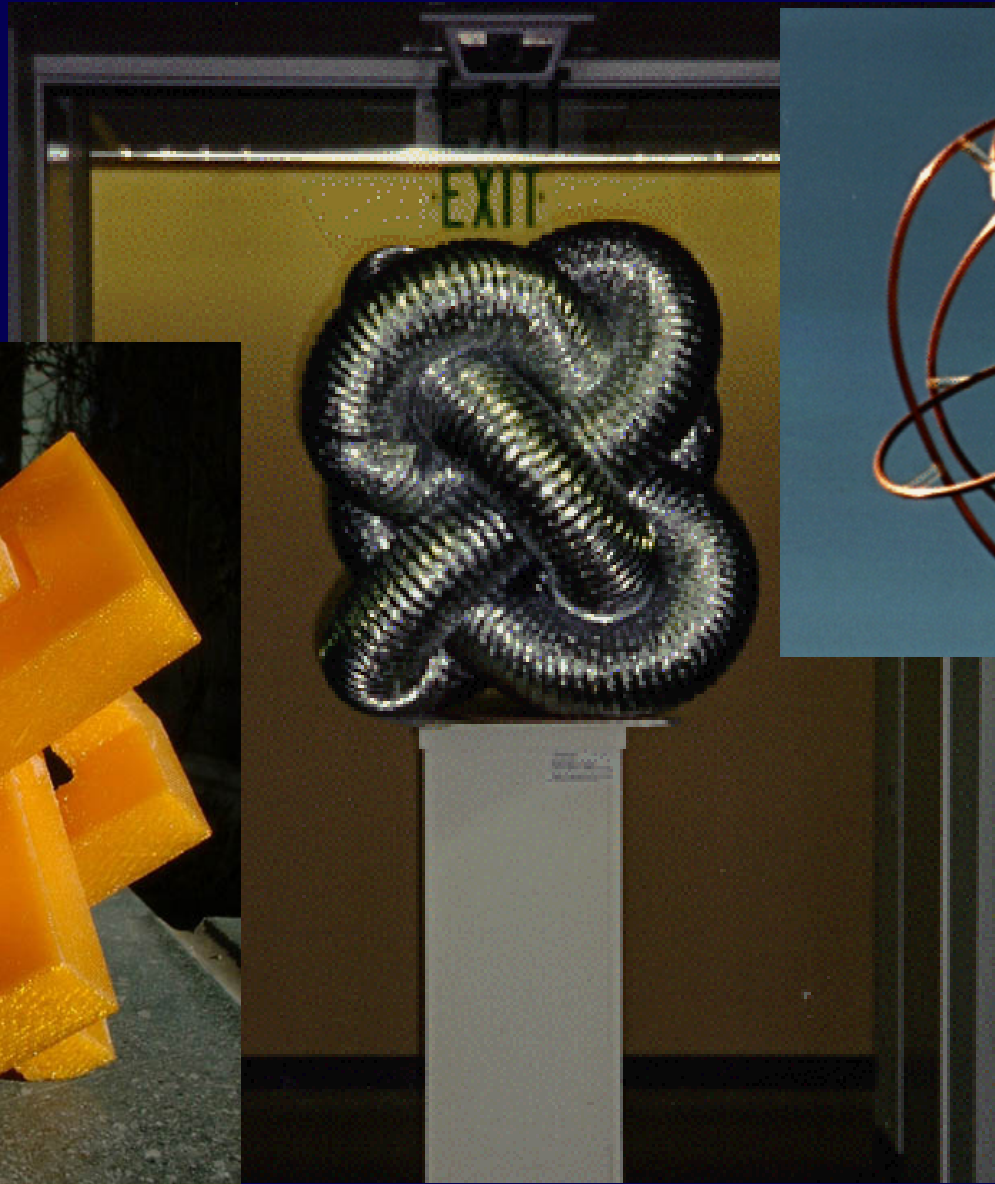
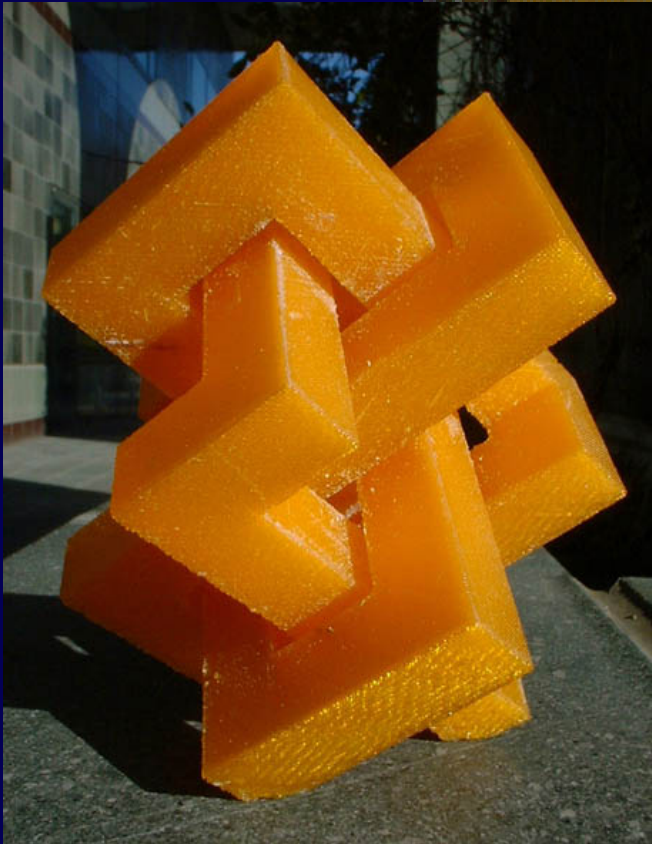


9₄₀



9₄₉

Chinese Button Knot 9_{40}





**Chinese
Button Knot**

Bronze, Dec. 2007

Carlo Séquin

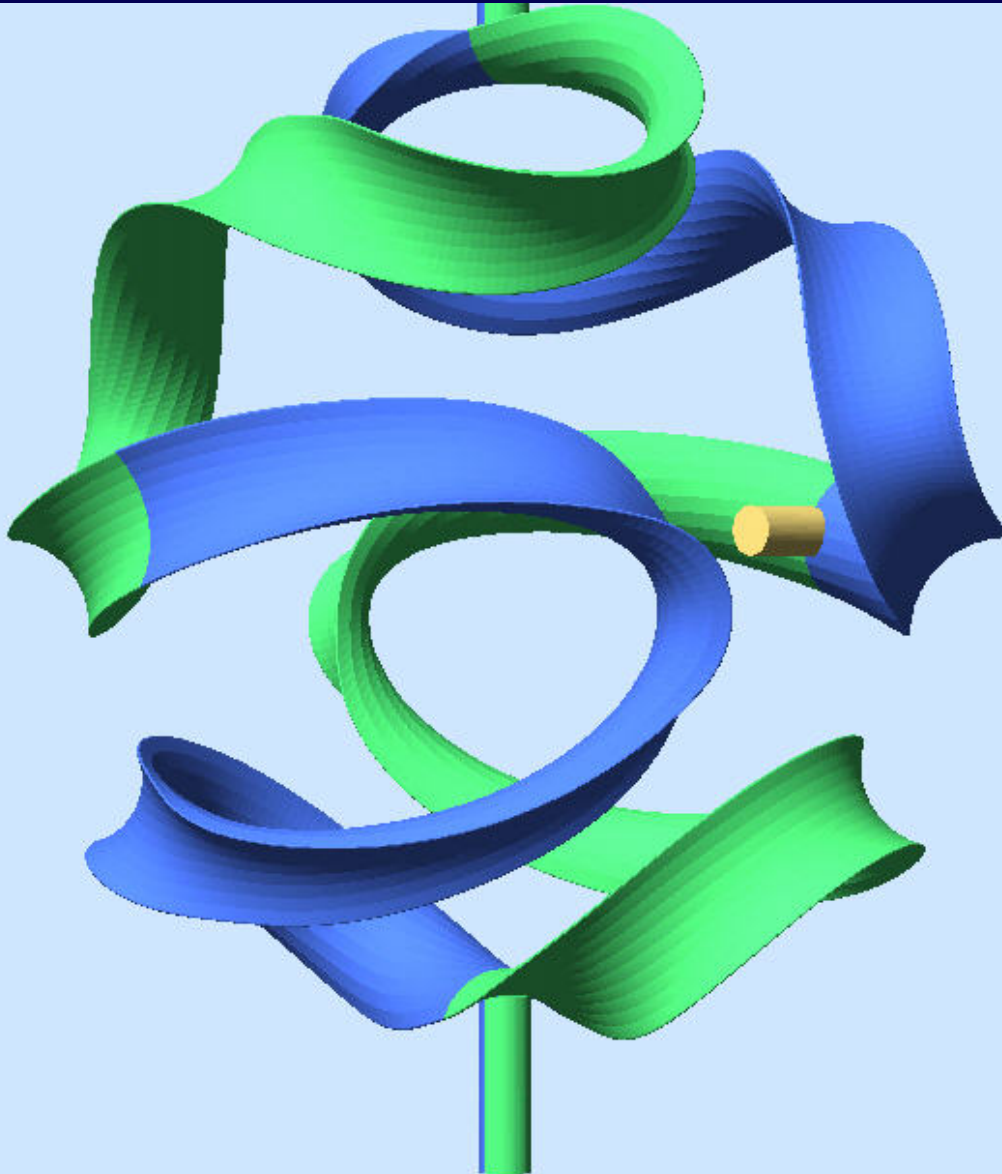
2006: Commission for a Big Sculpture!

- ◆ Scale up original “Pax Mundi” (to 6ft diam.)
- ◆ Less than 1500 pounds
- ◆ Budget 50'000 \$
- ◆ Due in 4 months (→ Nov. 2006)
- ◆ Collaboration: Collins, Reinmuth, Séquin
- ◆ **My task:**
Create the digital file for a mold master

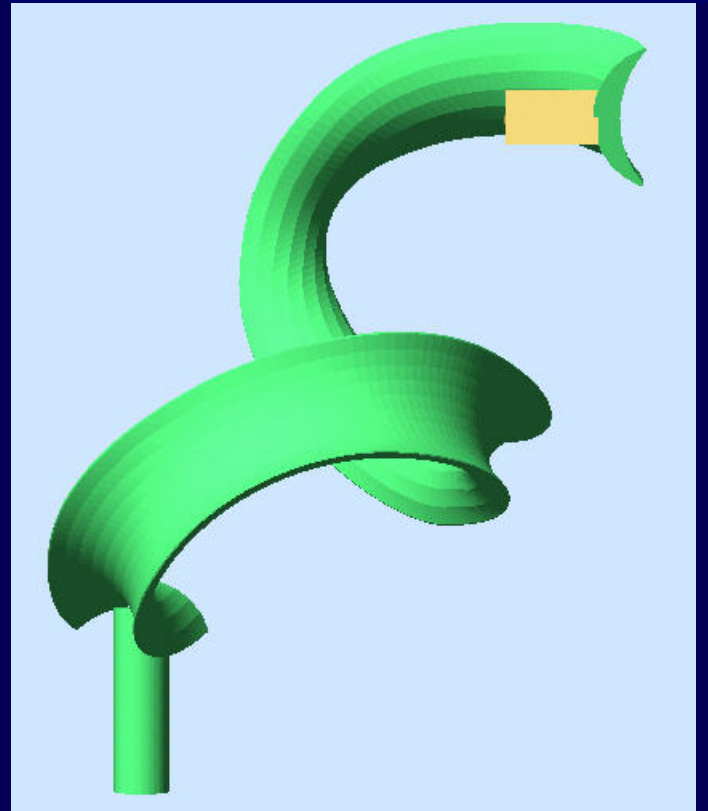
Target Geometry



Emulation; Define Master Pattern



◆ Master to make a mold from.



◆ Use 4 copies.

Subdivide into Two Master Segments



Joe Valasek's CNC Milling Machine



Machined Master Pattern #2



(Cut) Master → Silicone Rubber Mold



Mold → Several (4) Wax Copies



Spruing the Wax Parts for Casting



Ceramic Slurry Shell Around Wax Part



Shell Ready for Casting



Casting with Liquid Bronze



Bronze Cast Slowly Cooling Off



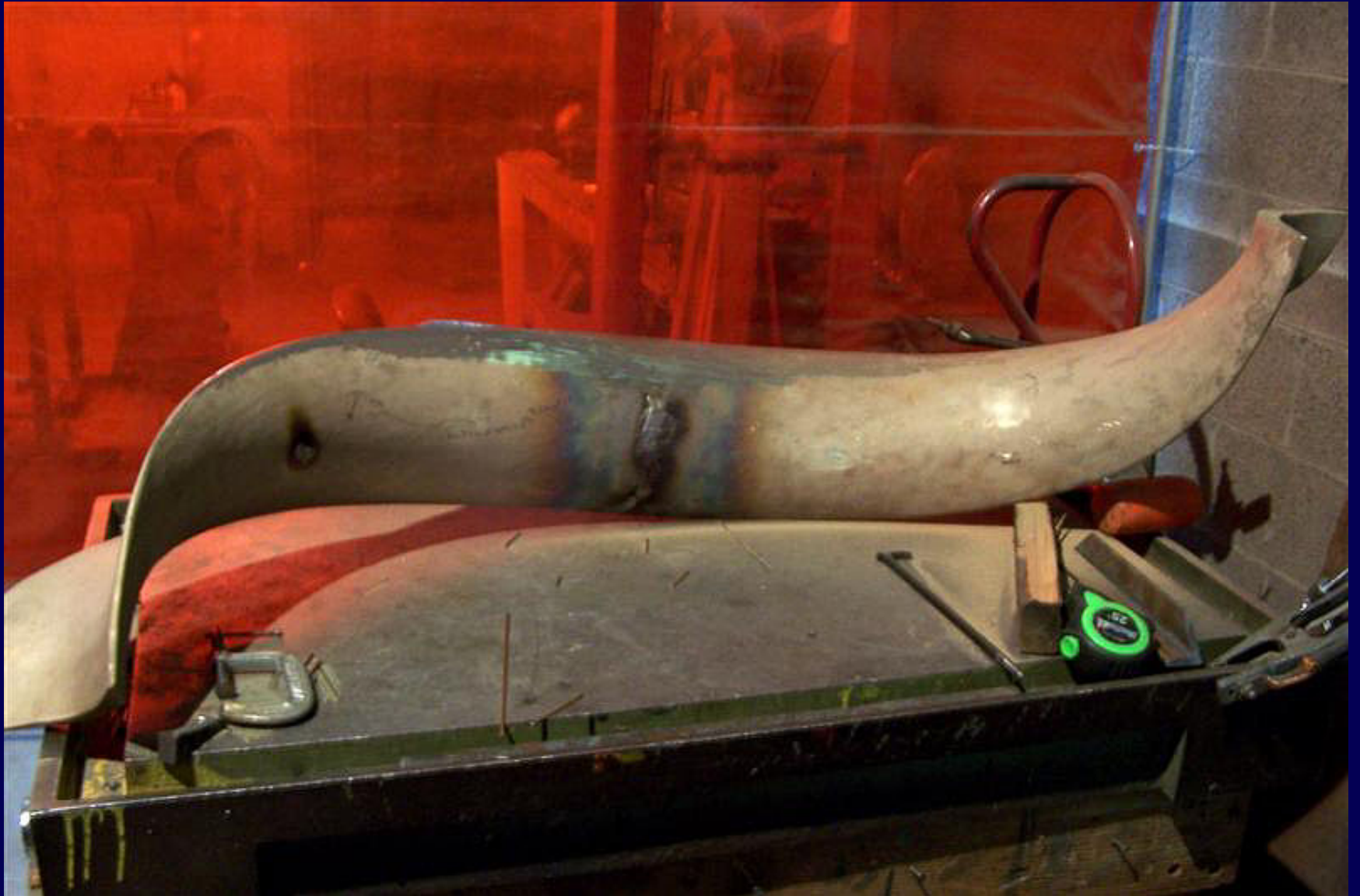
Cracking the Ceramic Shell



The Freed Bronze Cast



Assembly of Pieces



Grinding the Welded Seams, Polishing the Surface





Applying Patina

Front Door



H&R Block Building



The Final Destination



Steve Tightening the Bolts



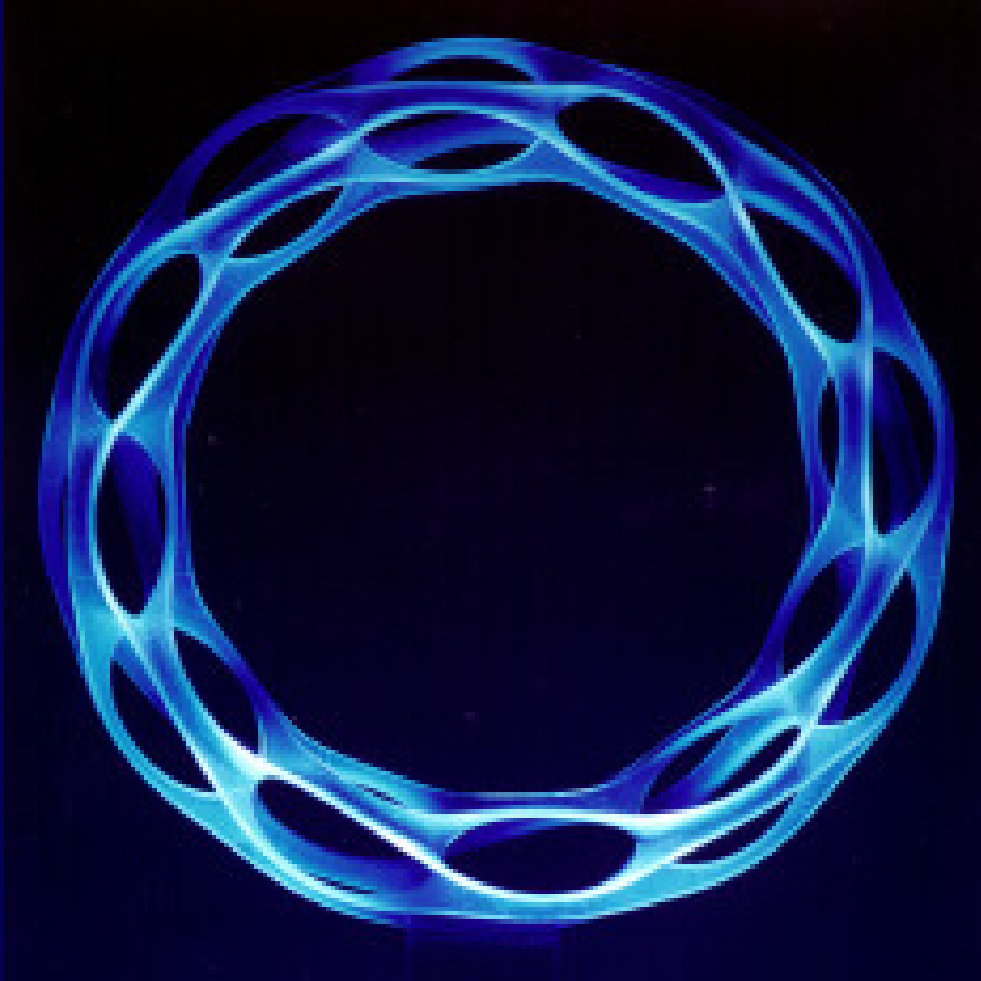
Brent Polishing Our Baby







A New Commission ...



- ◆ 10 ft diameter
- ◆ amber-tinted polyester resin
- ◆ to be hung in an atrium below skylight

Sculpture Design



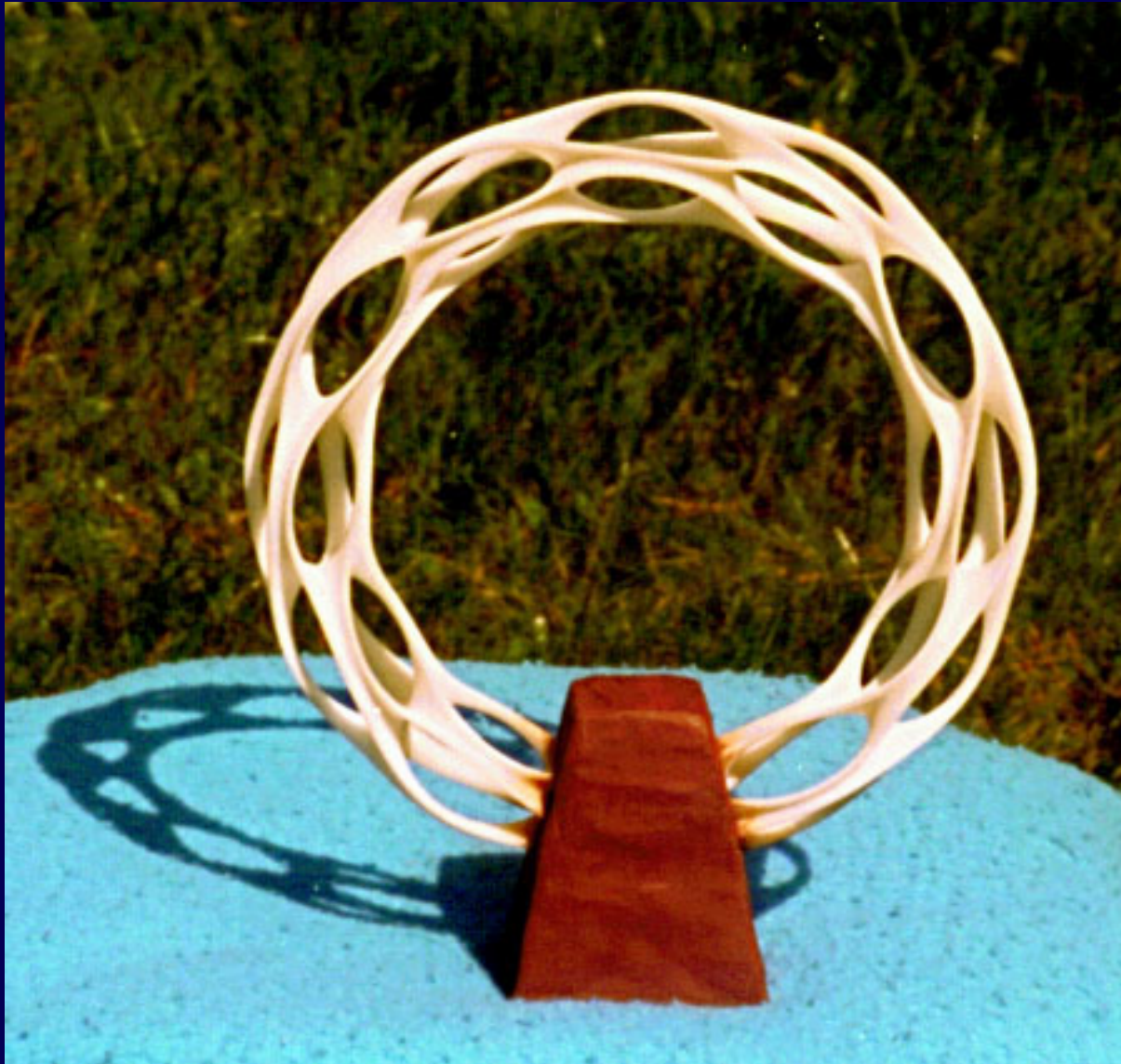
- ◆ branches = 4
- ◆ storeys = 11
- ◆ height = 1.55
- ◆ flange = 1.00
- ◆ thickness = 0.06
- ◆ rim_bulge = 1.00
- ◆ warp = 330.00
- ◆ twist = 247.50
- ◆ azimuth = 56.25
- ◆ mesh_tiles = 0
- ◆ textr_tiles = 1
- ◆ detail = 8

- ◆ bounding box:
- ◆ xmax= 6.01,
- ◆ ymax= 1.14,
- ◆ zmax= 5.55,
- ◆ xmin= -7.93,
- ◆ ymin= -1.14,
- ◆ zmin= -8.41

Breckenridge Competition (1997)



FDM Maquette of *Solar Arch*

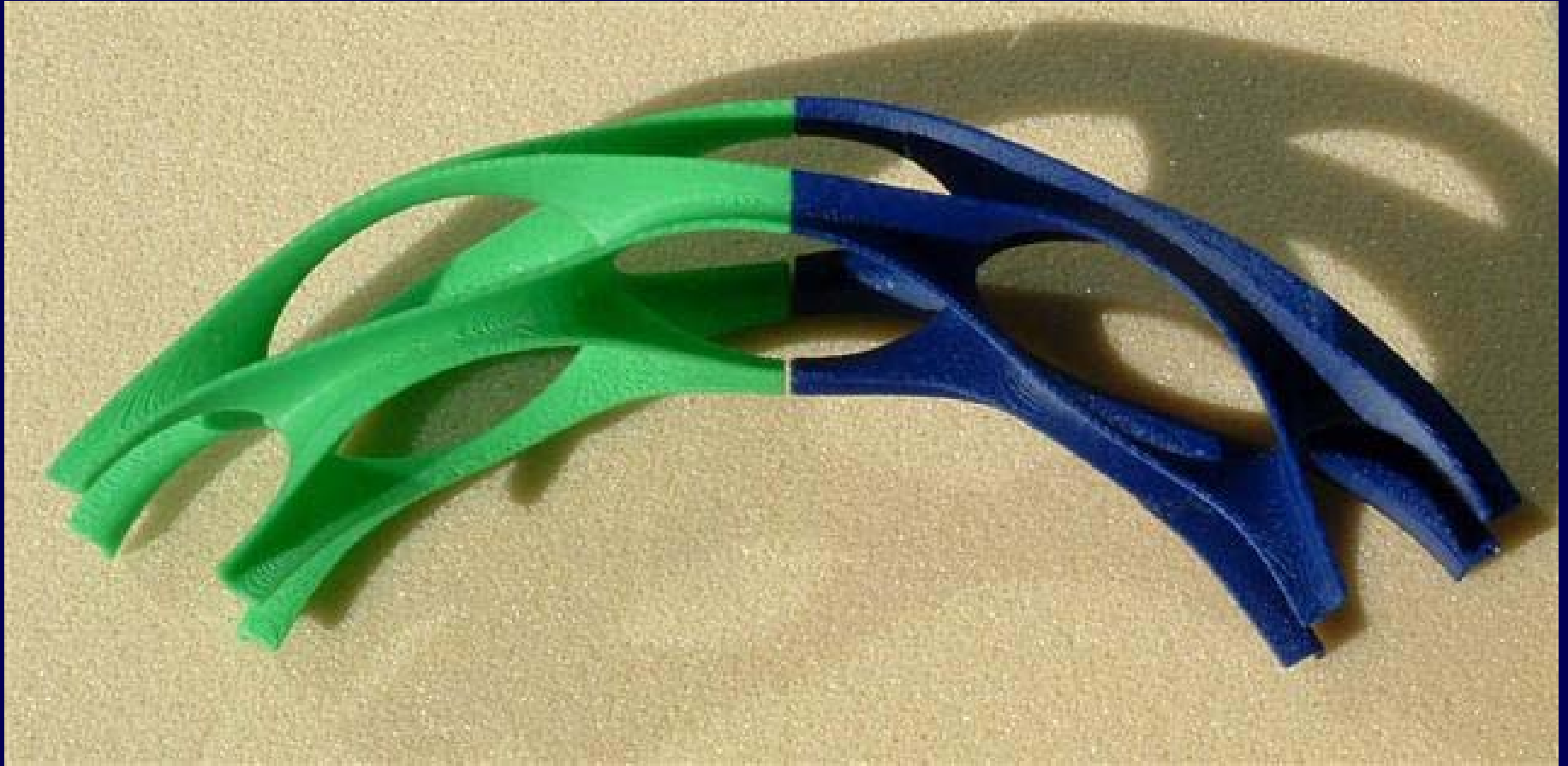


◆ 2nd place

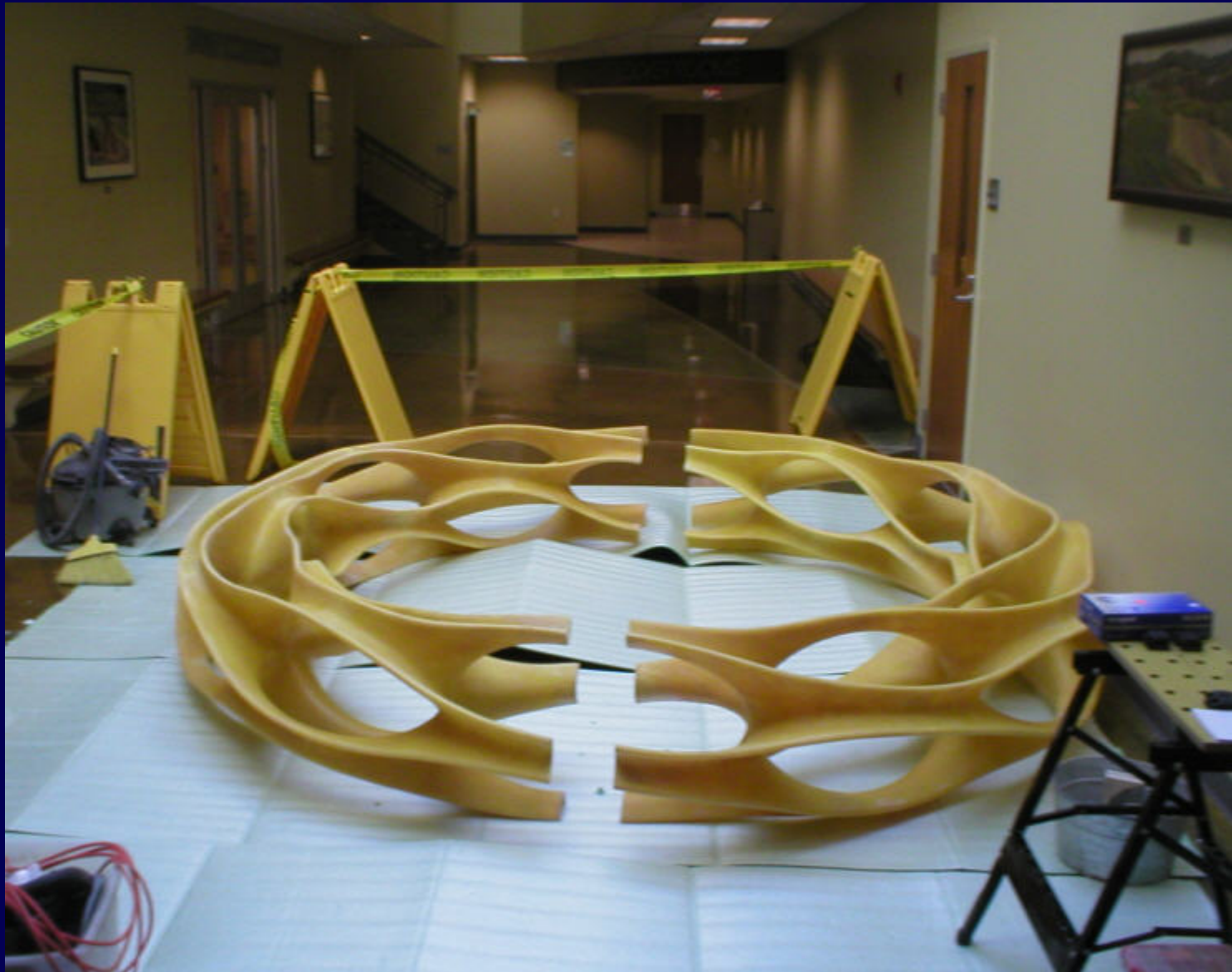
Solar Arch – Small Bronze



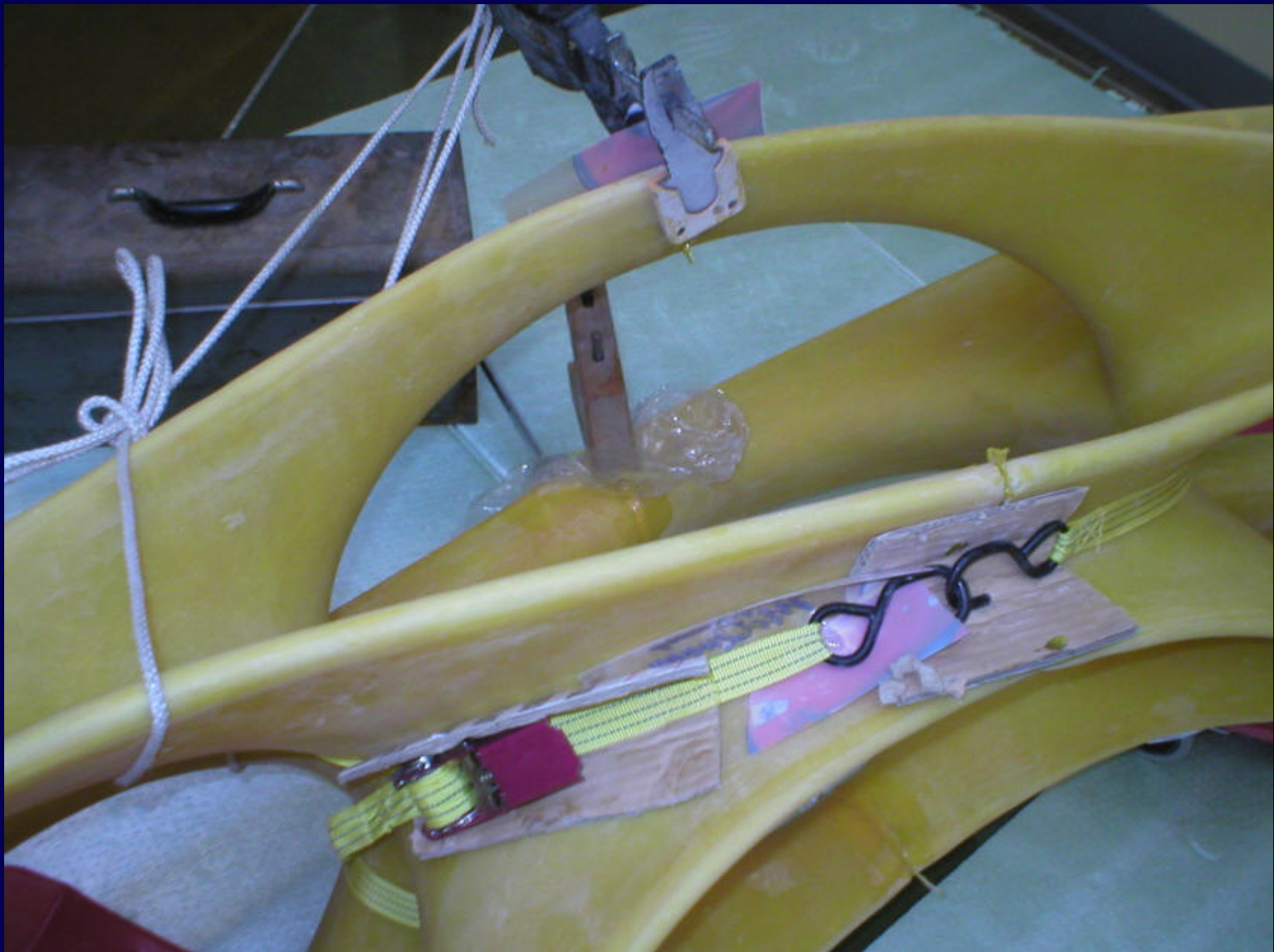
Two Modules Assembled



Two times Three Modules



Merging the Two Half-Circles





Brent Collins with “*Millennium Arch*”





Always Some Tense Moments ...



Millennium Arch by Day



Millennium Arch by Night



Some Observations

- ◆ **Interactive graphics ==> enhanced creativity**
- ◆ **Speed is not my primary concern.**
- ◆ **I would like a more expressive user interface – particularly for the first stages of capturing an idea and getting it into the computer.**
- ◆ **I am still using paper, wire, styrofoam, etc ... to explore new ideas.**

QUESTIONS ?

