DesignMentor: A Pedagogical Tool for Computer Graphics and Computer–Aided Design

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Motivation

⬤ **Teaching curves and surfaces is a challenging task**

    Major obstacles: formidable mathematics
                        lack of pedagogical tools

⬤ **Learning curves and surfaces is also a difficult task**

    The concepts are abstract and difficult to visualize; without knowing the details, writing programs to experiment is not easy; and some concepts and algorithms are simply too difficult to implement.

⬤ **There is virtually no tools**

    Yes, there are tools. Most of them are libraries for programming or packages (*e.g.*, MAPLE and Mathematica). These tools are not very helpful for illustrating the fundamentals.

⬤ **So, we designed DesignMentor!**

What DesignMentor Is?

- **DesignMentor** provides students with an interactive environment for learning, practicing, and visualizing most fundamental concepts and algorithms in curves and surfaces
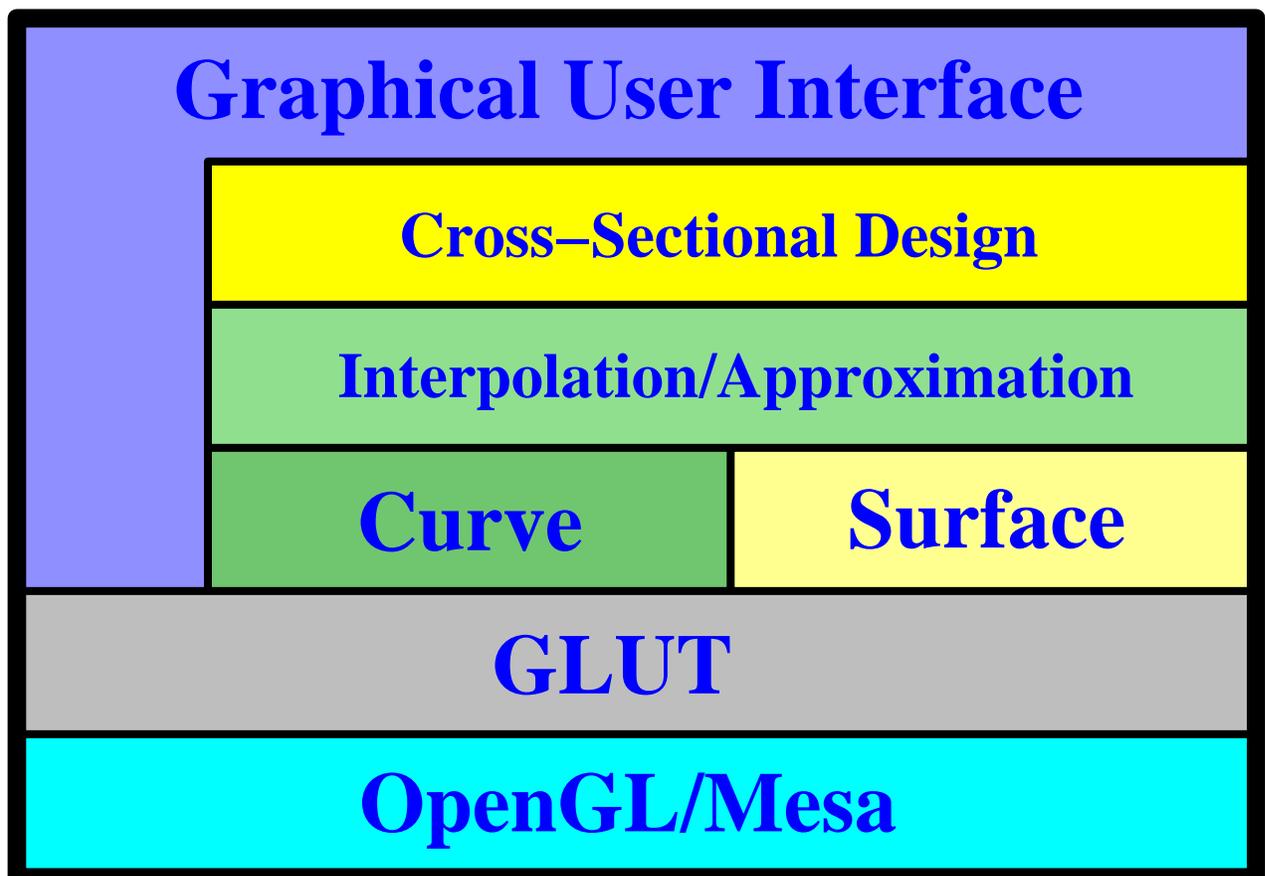
What DesignMentor Is Not?

- **DesignMentor** is *not* a production system for helping students learn design issues and practice design skills.
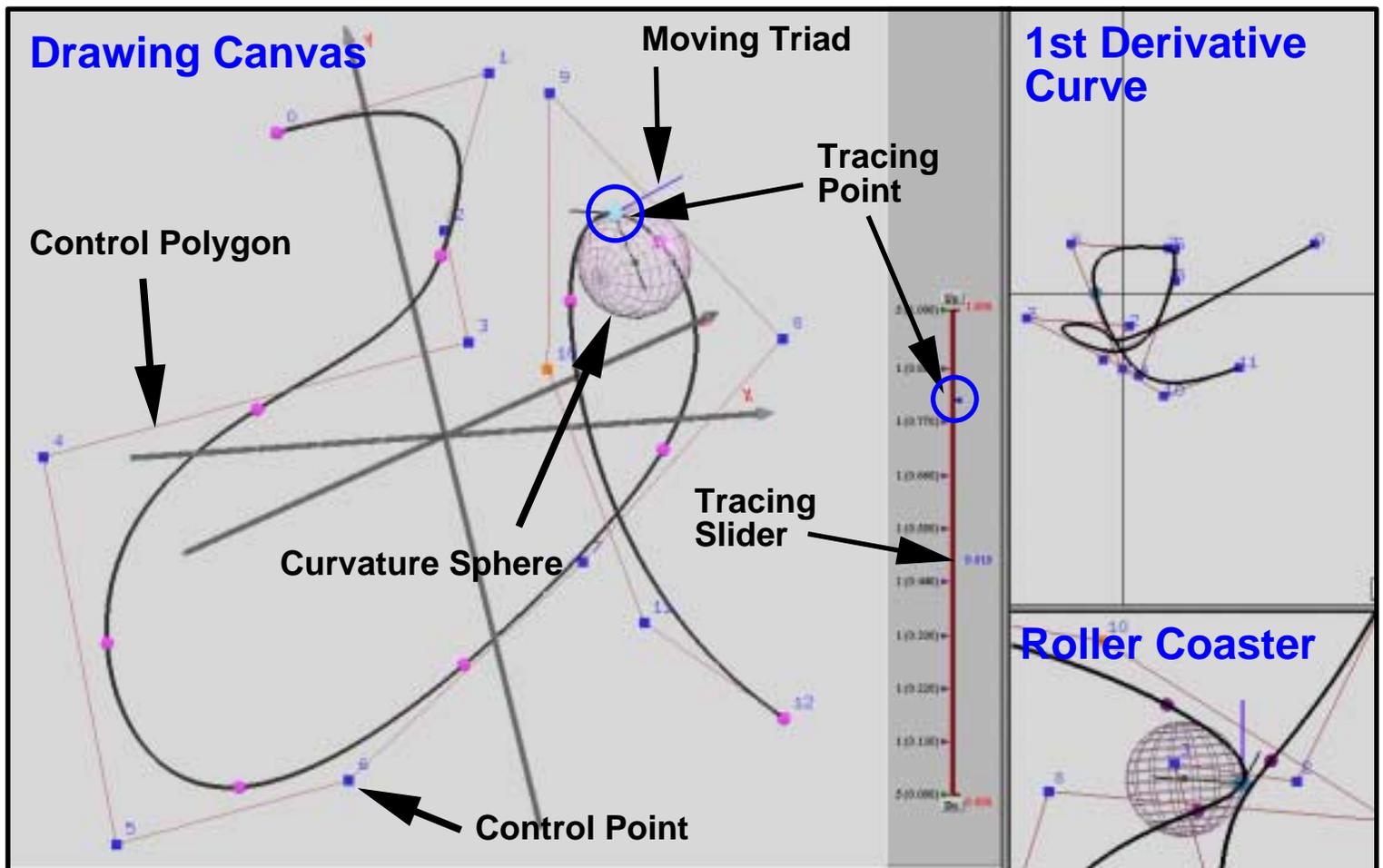
Overview of DesignMentor

- **DesignMentor** supports Bezier, rational Bezier, B–spline and NURBS curves and surfaces

- **DesignMentor** is portable and supports Windows 95/98/NT, SGI and Sun platforms
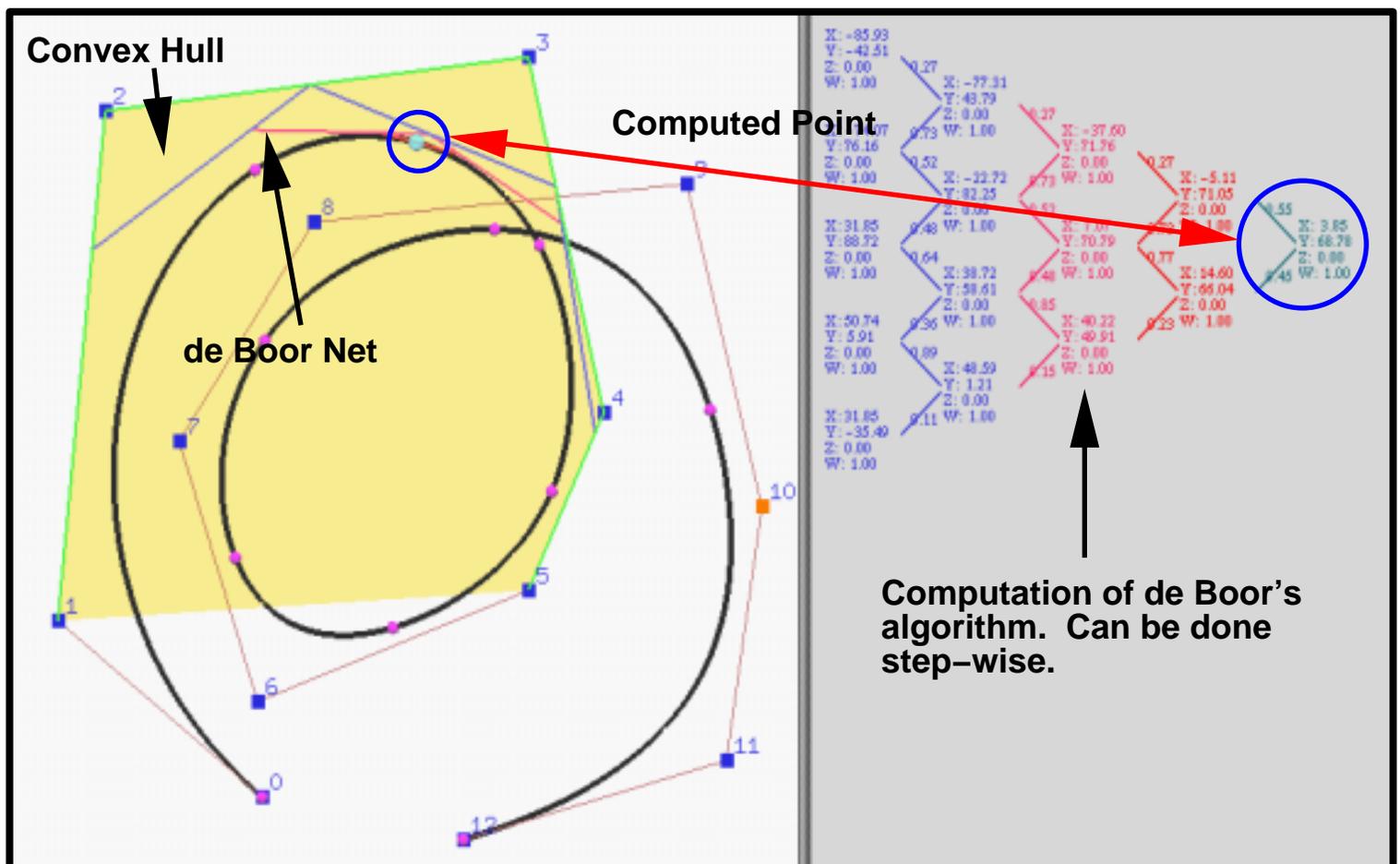
System Architecture of DesignMentor

Graphical User Interface
Cross–Sectional Design
Interpolation/Approximation
Curve / **Surface**
GLUT
OpenGL/Mesa

DesignMentor's Curve System

- ⬤ **A student can click on the canvas for creating a number of *control points* and select a curve type (*e.g.*, Bezier).**

- ⬤ **DesignMentor generates the curve**

- ⬤ **DesignMentor can display many important geometric properties**

Drawing Canvas

Moving Triad

1st Derivative Curve

Tracing Point

Control Polygon

Curvature Sphere

Tracing Slider

Roller Coaster

Control Point

De Casteljau's and de Boor's Algorithms

- **DesignMentor** can display the convex hull and a step–wise execution of de Casteljau's/de Boor's algorithm

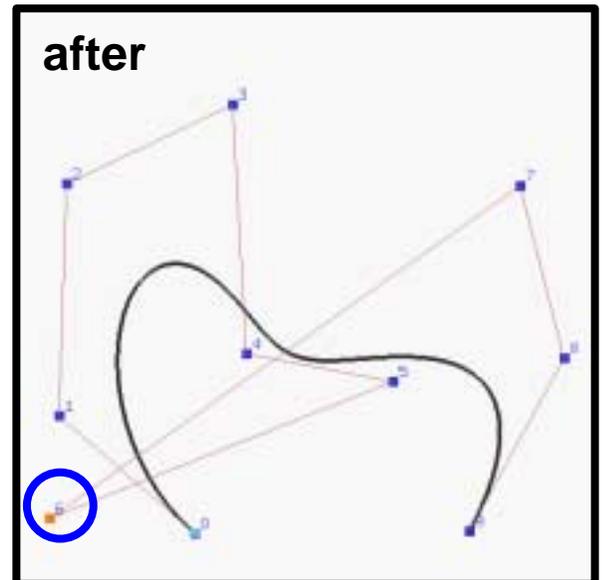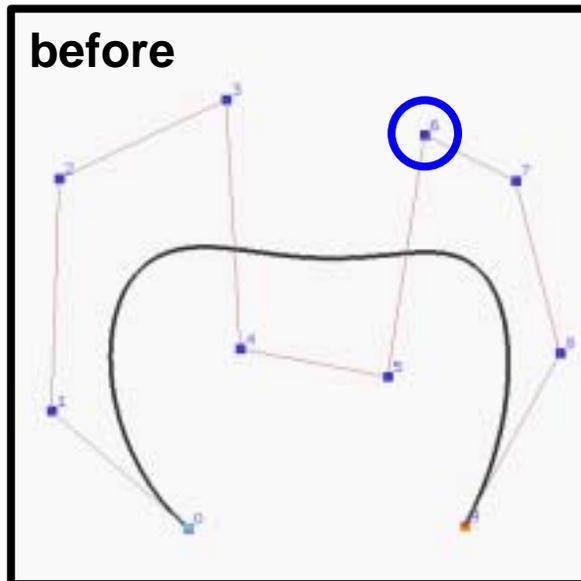- The computation and visualization are updated on–the–fly as the curve is being traced

Shape Editing

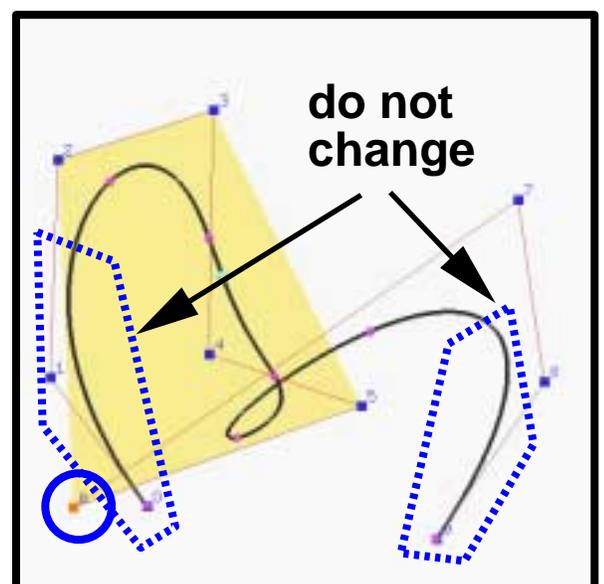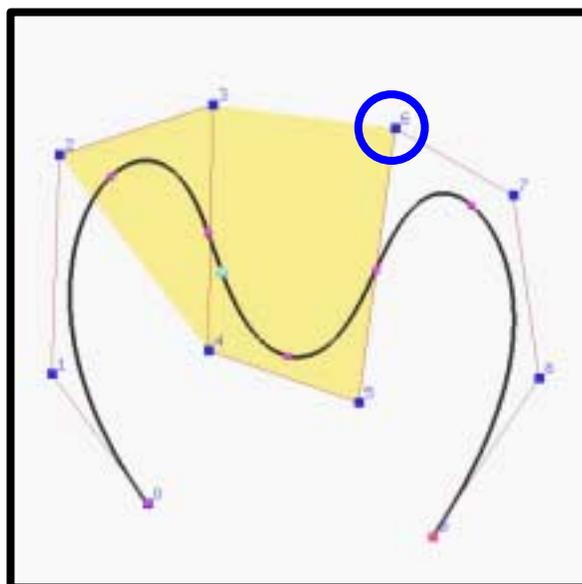🟡 **DesignMentor** supports shape editing

- 🟩 **Moving control points: all curves**
- 🟩 **Changing weights of control points:**
  Rational Bezier and NURBS
- 🟩 **Modifying knots: B−spline and NURBS**

🟡 **Shape editing is *global* for Bezier and rational Bezier curves**
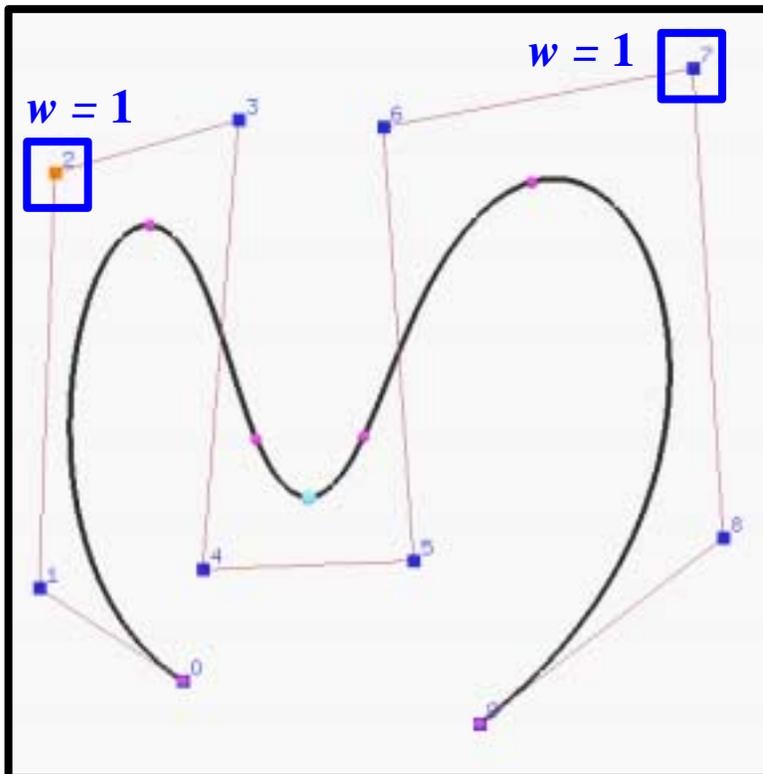
Bezier

B−spline

Modifying Weights (NURBS)

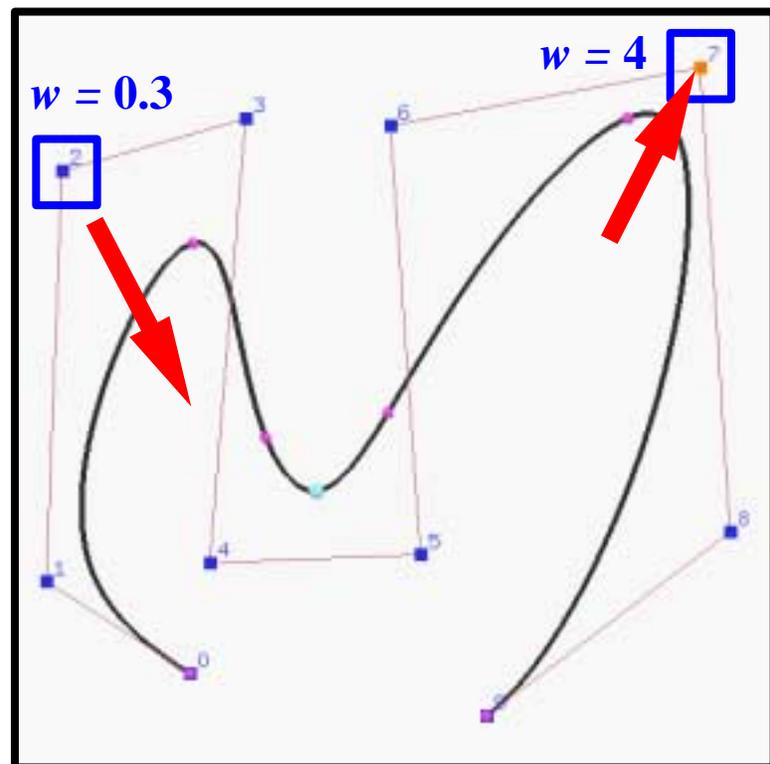- **Weights can also be modified for rational Bezier and NURBS curves**

  Increasing (resp., decreasing) the weight of a control point pulls (resp., pushes) the curve toward (resp., away from) that point

- **A user selects a control point and changes its weight. The effect is shown on–the–fly.**
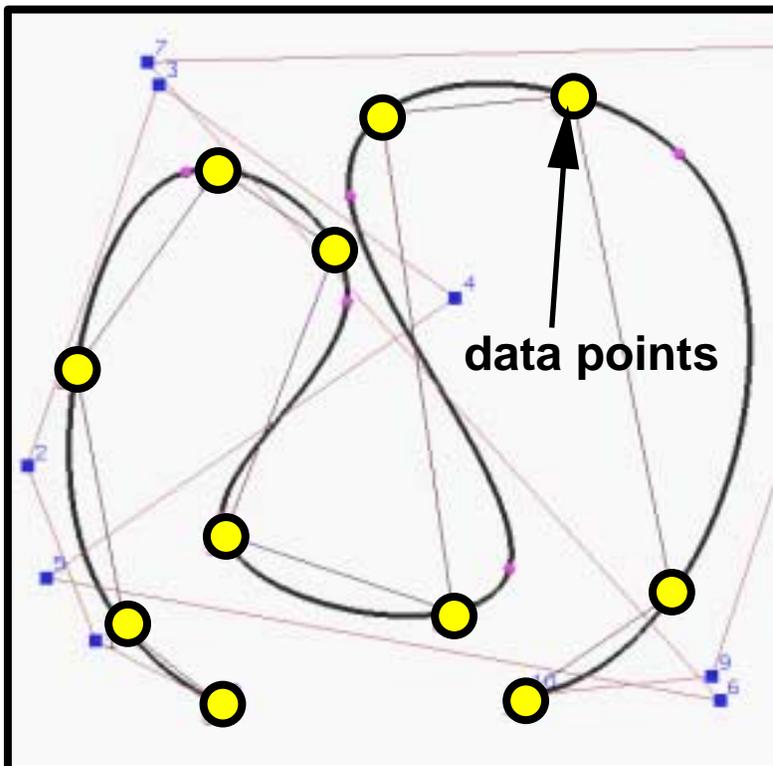
Before

After

$w = 1$

$w = 1$

$w = 0.3$

$w = 4$

NURBS curve of degree 5

Advanced Geometric Algorithms

🟡 **DesignMentor** supports 3 advanced algorithms for B–spline and NURBS:

🟩 **Knot insertion:** inserting a new knot
🟩 **Subdivision:** dividing a curve into two
🟩 **Degree Elevation:** increasing the degree by 1

Before insertion

knots

new control points

new knot

corners cut

B–spline of degree 5

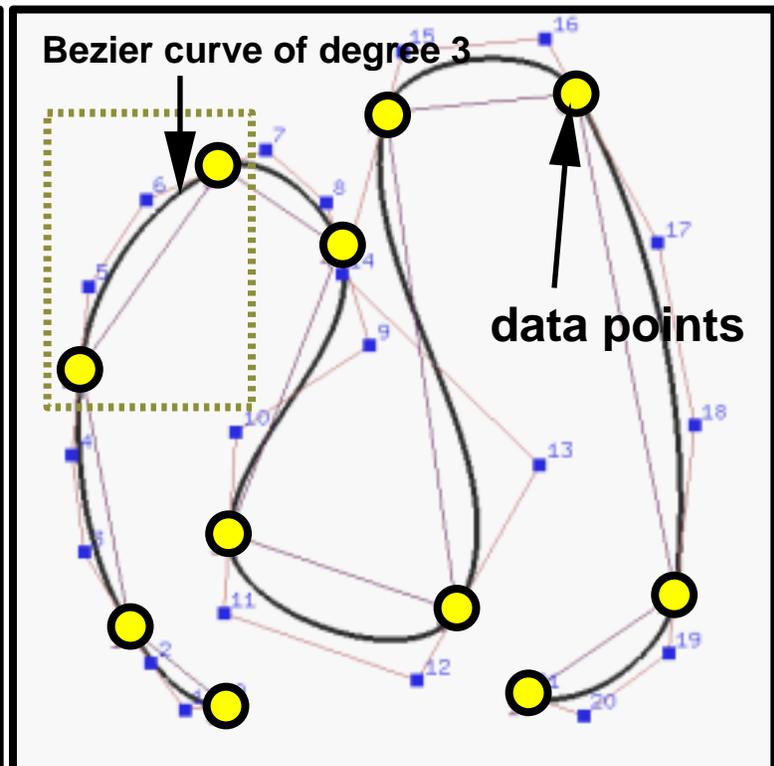**After insertion**

new knot

Curve Interpolation

⬤ **DesignMentor** also supports curve interpolation and approximation

🟩 A user clicks data points on the canvas and **DesignMentor** constructs a B–spline curve that contains all points in the given order

🟩 Under *Global Interpolation* modifying a data point changes the curve globally.
Under *Local Interpolation* modifying a data point only affects the curve locally.
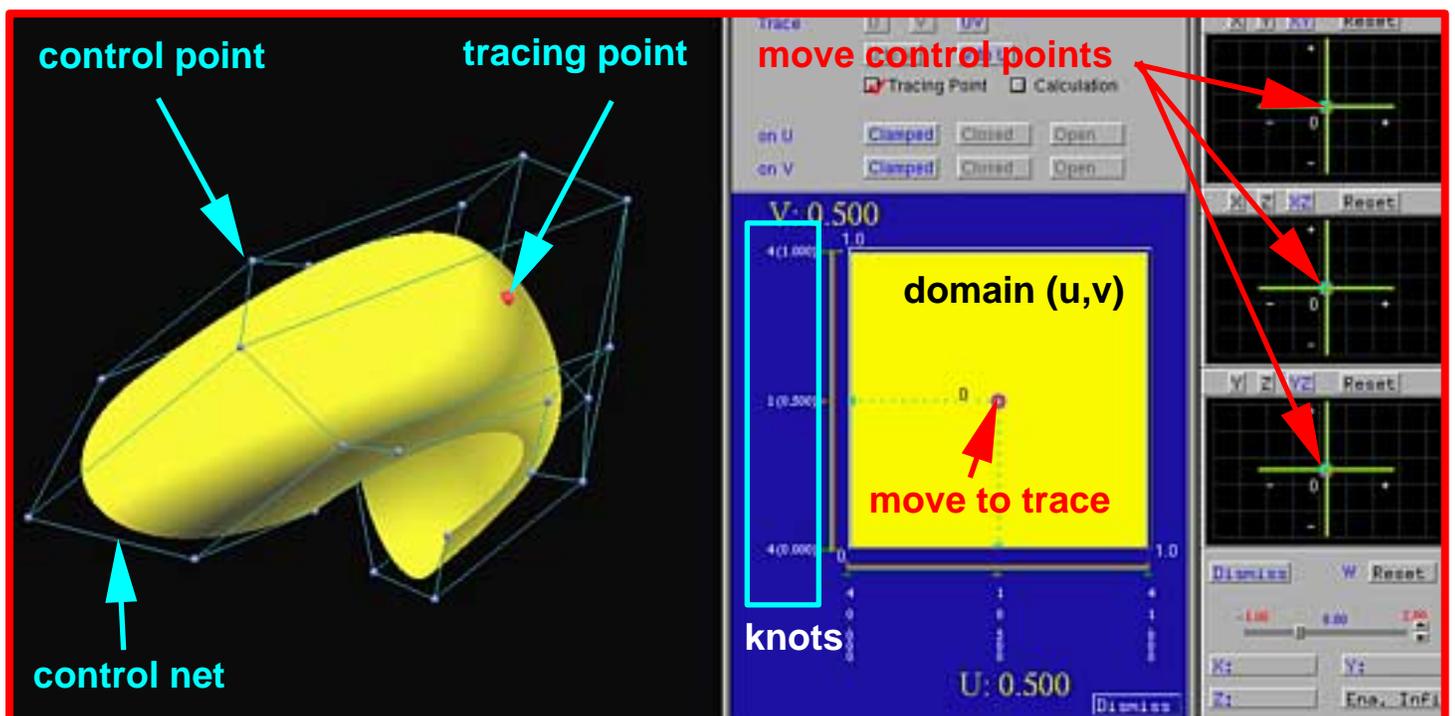
Global Interpolation

Local Interpolation

data points

Bezier curve of degree 3

data points
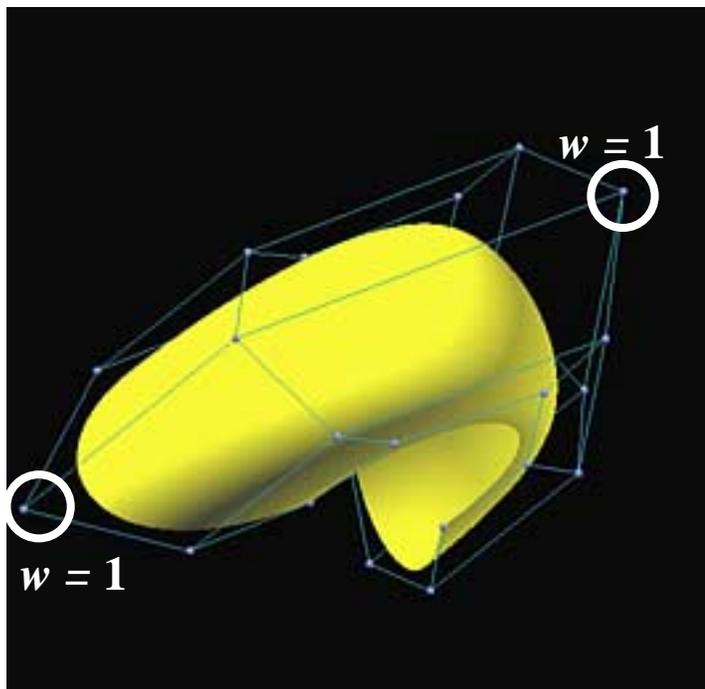
DesignMentor's Surface System

- **DesignMentor** supports Bezier, rational Bezier, B–spline and NURBS surfaces.

- A user indicates the type of a surface and its degrees. **DesignMentor** generates a flat surface.

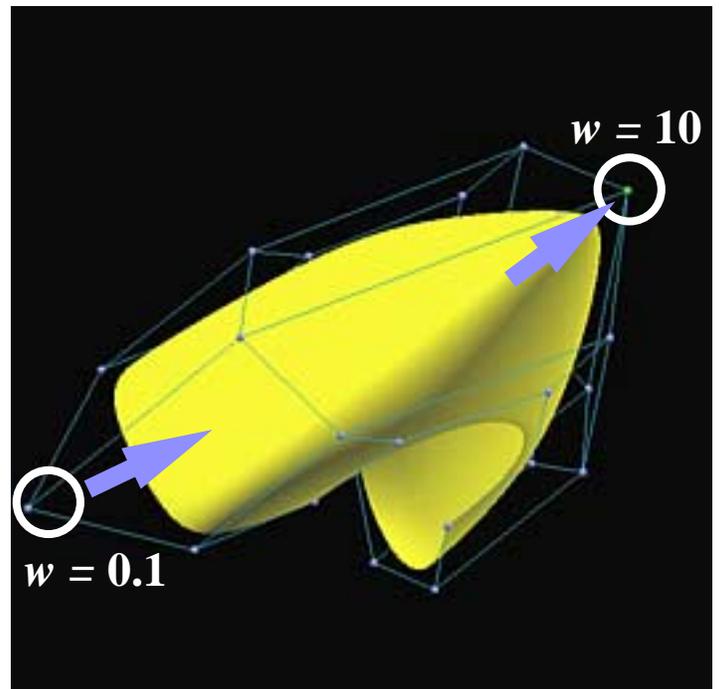- Then, a user create the desired surface with shape editing operations.

Surface Shape Editing

⬤ **To change the shape of a surface, a user can**

- ☐ **move control points (all surfaces)**
- ☐ **modifying knots (B–spline and NURBS)**
- ☐ **change weights (rational Bezier and NURBS)**

⬤ **A zero weight means no contribution to the creation of the surface**

before weight change

w = 1

w = 1

after weight change

w = 10

w = 0.1
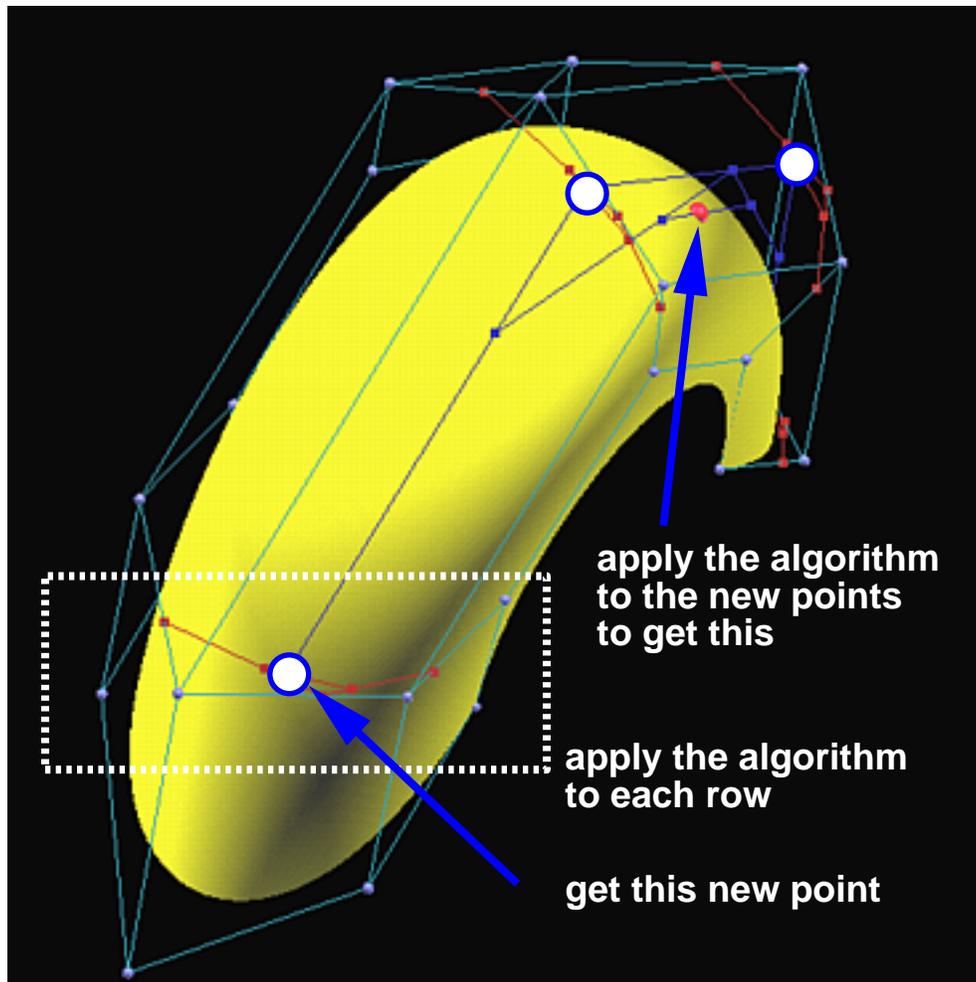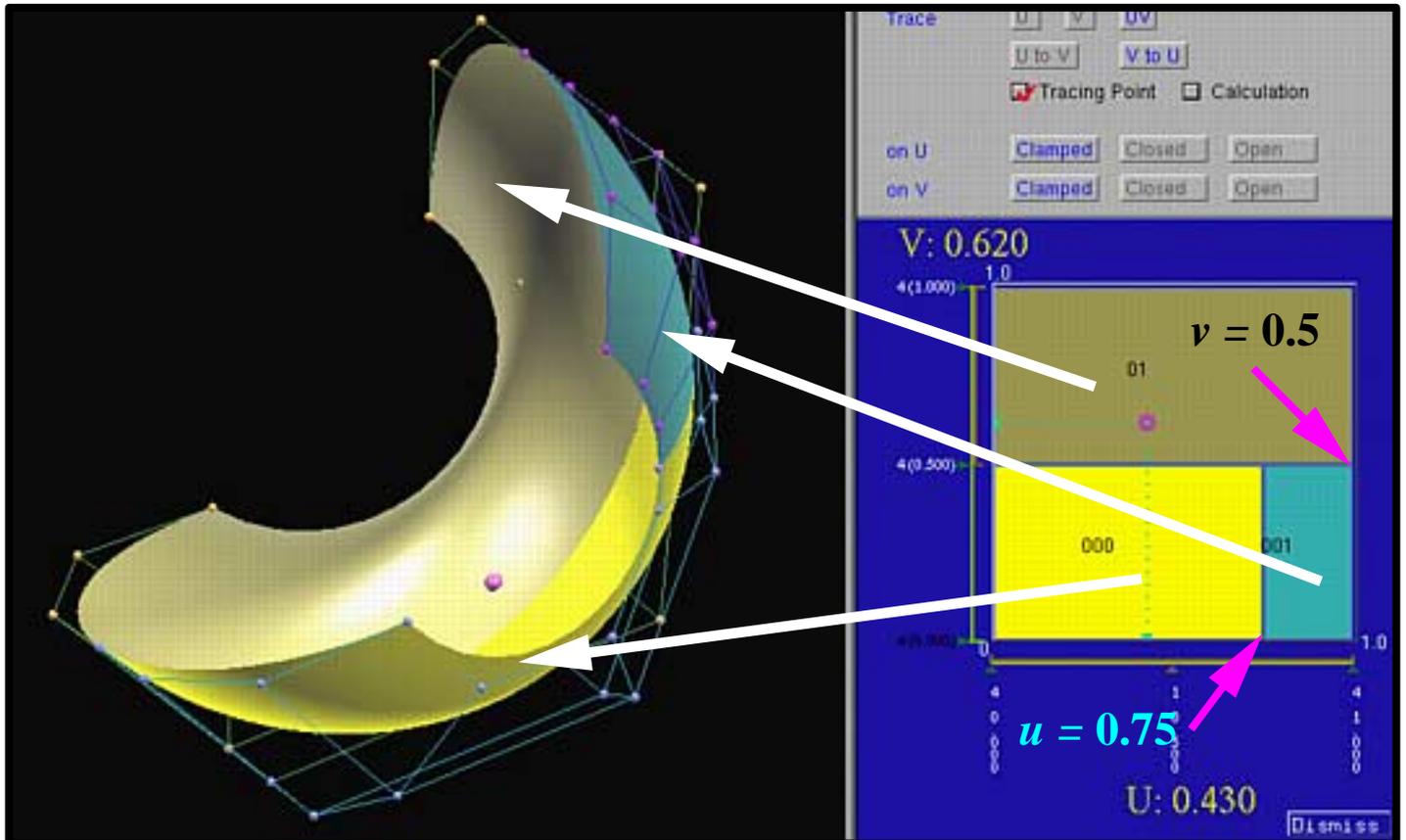
De Casteljau's and de Boor's Algorithms

- **De Casteljau's/de Boor's algorithm for curves can be extended to surfaces**

- **Apply the algorithm to each row of control points creating a set of new points, followed by one application of the algorithm to the new points.**

apply the algorithm
to the new points
to get this

apply the algorithm
to each row

get this new point

Advanced Geometric Algorithms

- ⬤ **DesignMentor** supports knot insertion, degree elevation and surface subdivision both *u* and *v* directions.

- ⬤ Each subpatch is color coded

Cross–Sectional Design

○ **Cross–Sectional Design is a technique of surface design using a number of curves (*i.e.*, profile – cross section and trajectory curves)**
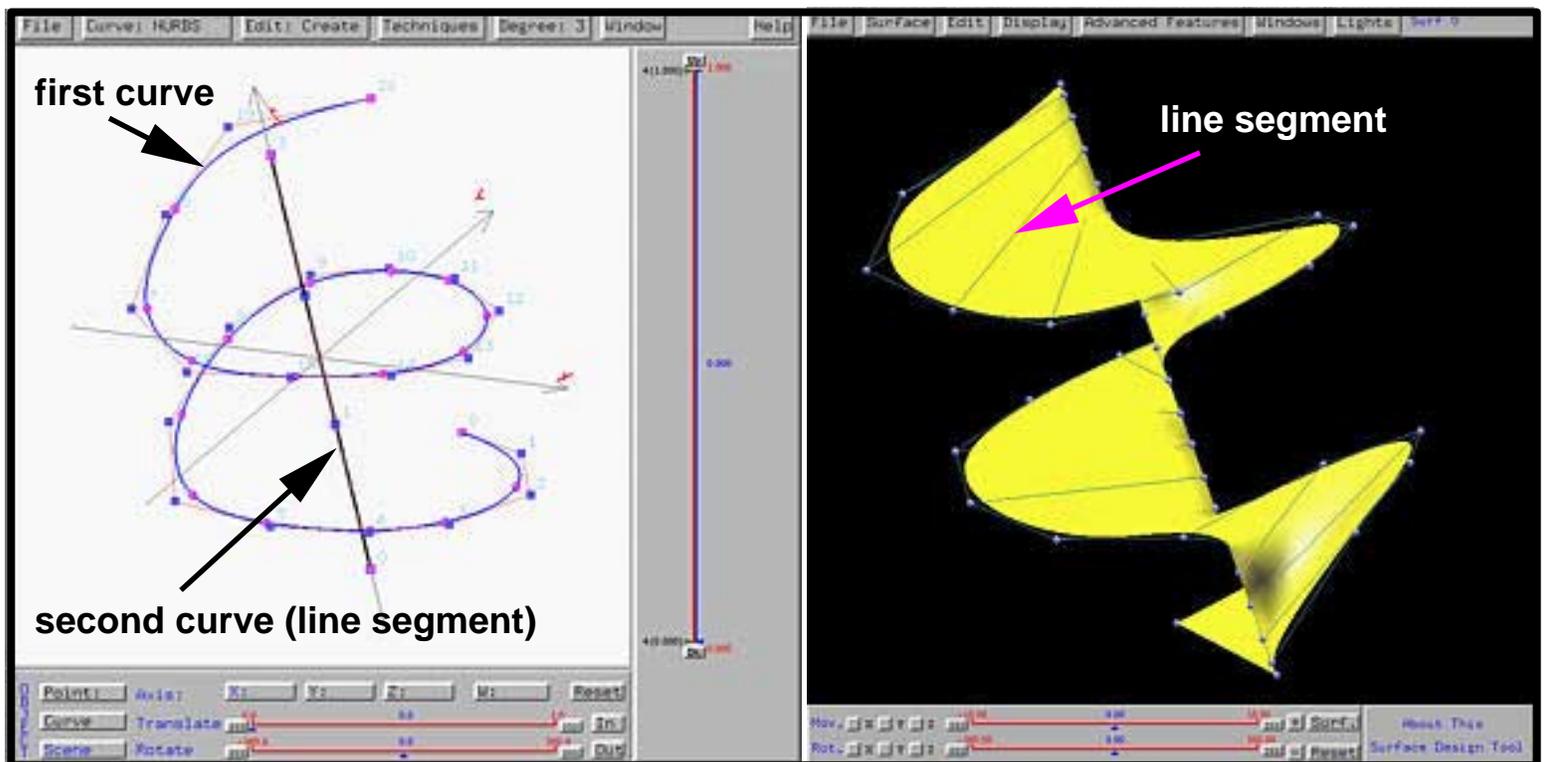
DesignMentor supports the following surface types:

- ◻ **Ruled surface: two curves**
- ◻ **Surface of revolution: one profile curve**
- ◻ **Swung surface: one profile and one trajectory curve**
- ◻ **Simple swept surface: one profile and one trajectory curve**
- ◻ **Skinned surface: a number of profile curves**
- ◻ **Swept by skinning: one trajectory and a set of (transformed) profile curves**

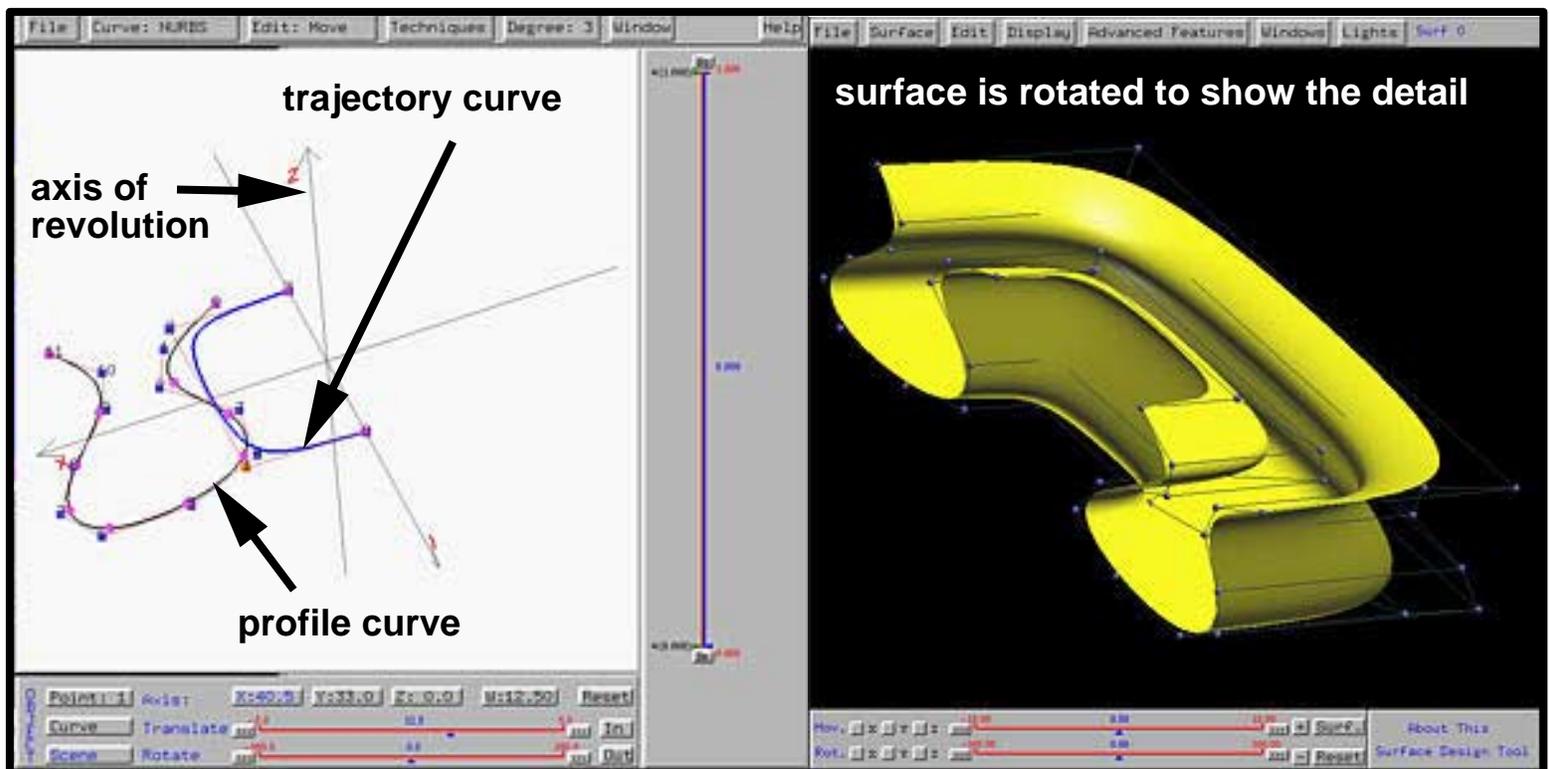○ **The surface system activates the curve system for designing profile and trajectory curves**

Ruled Surfaces

⭘ **It takes two curves for designing a ruled surface.**

⭘ **The surface is created by joining corresponding points on curves with line segments.**

first curve

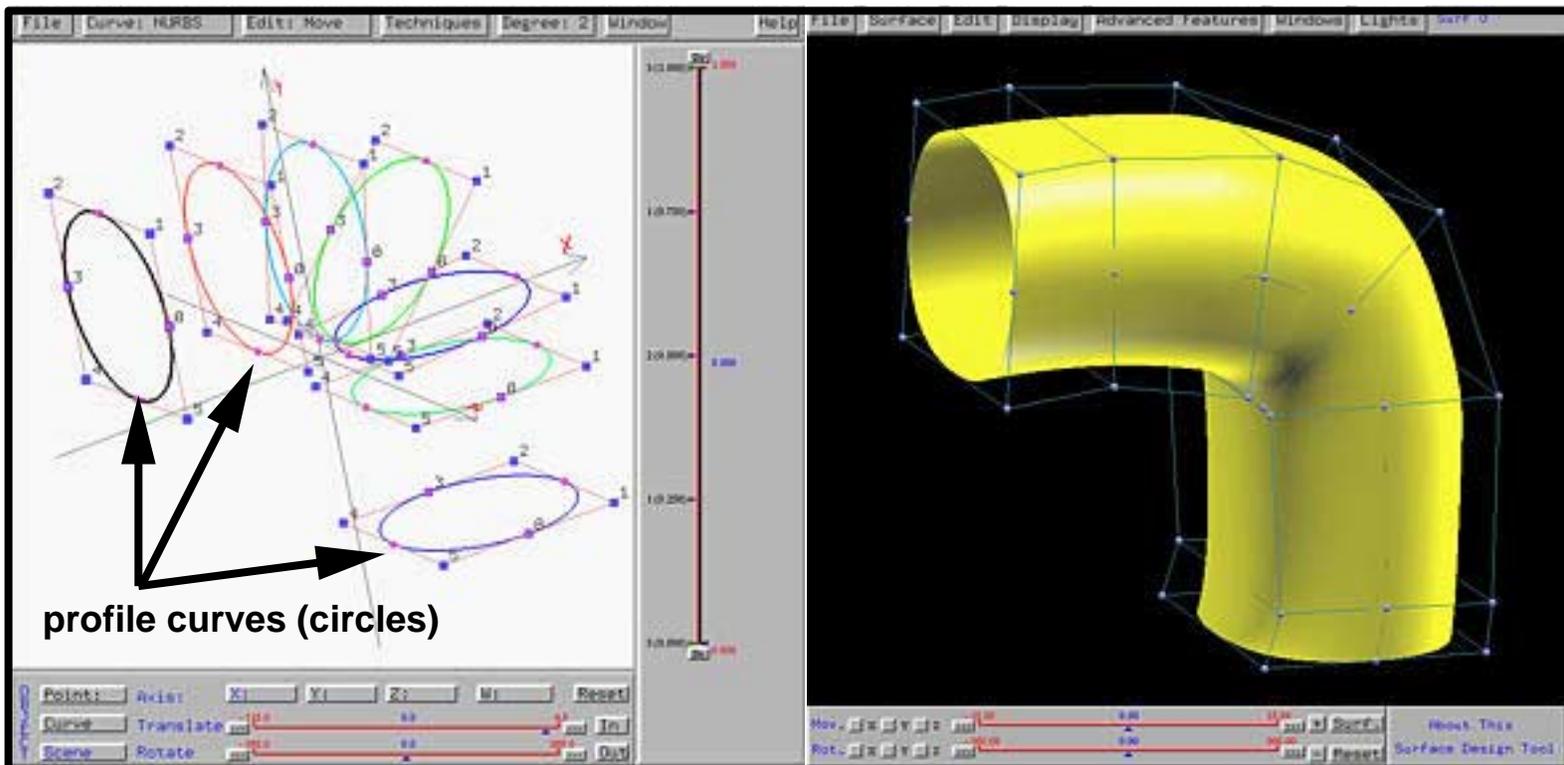second curve (line segment)

line segment

Swung Surfaces

○ **A swung surface is very similar to a surface of revolution**

○ **In addition to an axis of revolution, a trajectory curve is required**

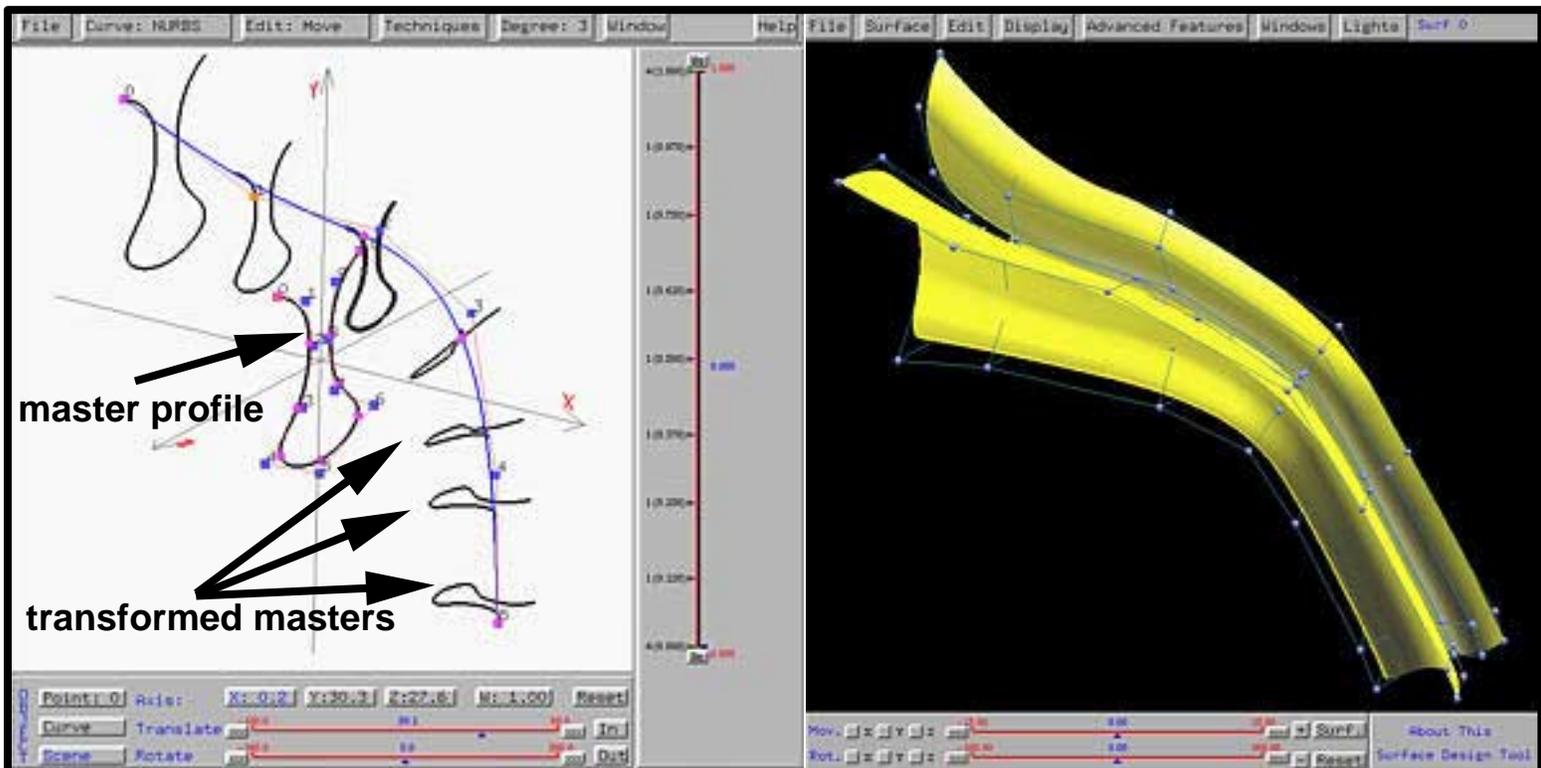○ **As the profile curve rotates about the axis, it is *scaled* by the trajectory curve**

trajectory curve

axis of revolution

profile curve

surface is rotated to show the detail

Skinned Surfaces

- ⬤ **A skinned surface requires a set of *profile* curves**

- ⬤ **DesignMentor constructs a B–spline surface to contain all given curves**

- ⬤ **Thus, skinning is a form of inter–polation (of curves)**

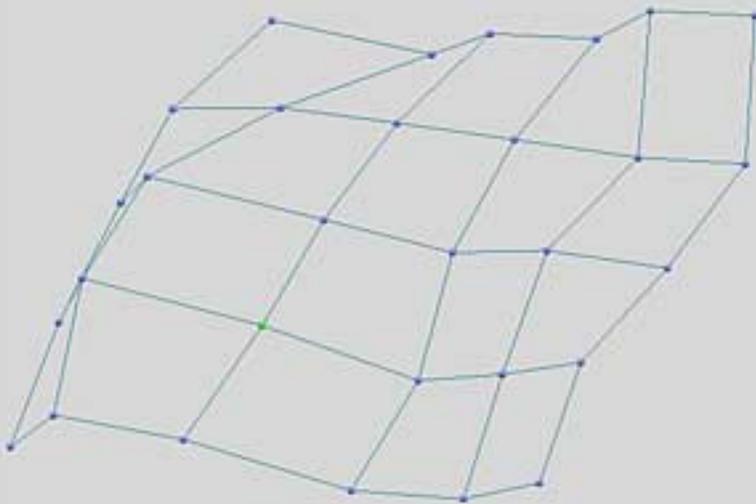profile curves (circles)

Swept by Skinning

- ⬤ **DesignMentor** can construct complex swept surfaces via skinning

- ⬤ A master profile curve is required

- ⬤ Instances of this master curve are placed along the trajectory curve and can be rotated and scaled

- ⬤ Then, skinning is applied
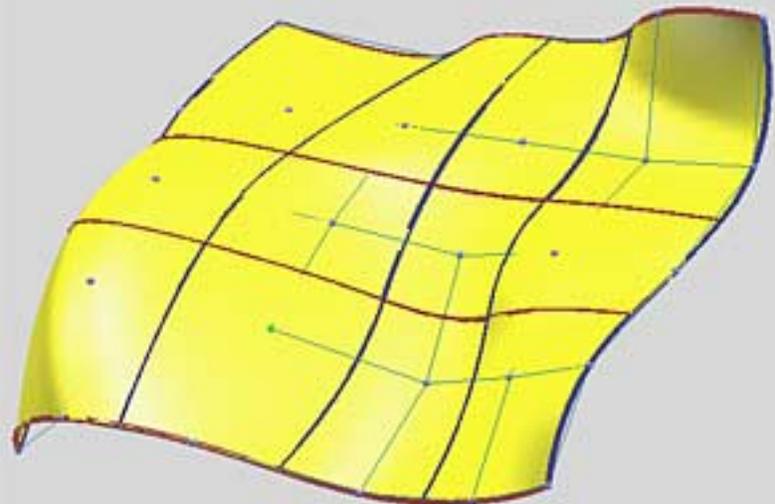

master profile

transformed masters

Interpolation and Approximation

⦿ **DesignMentor** supports global and local interpolation and global approximation for regular grid
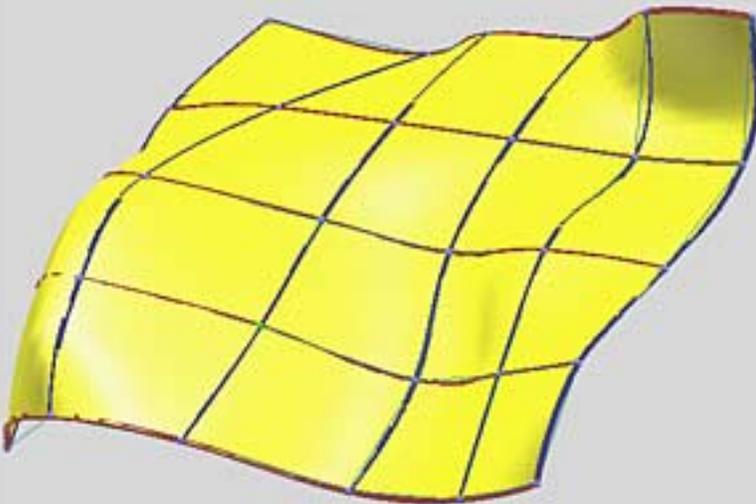

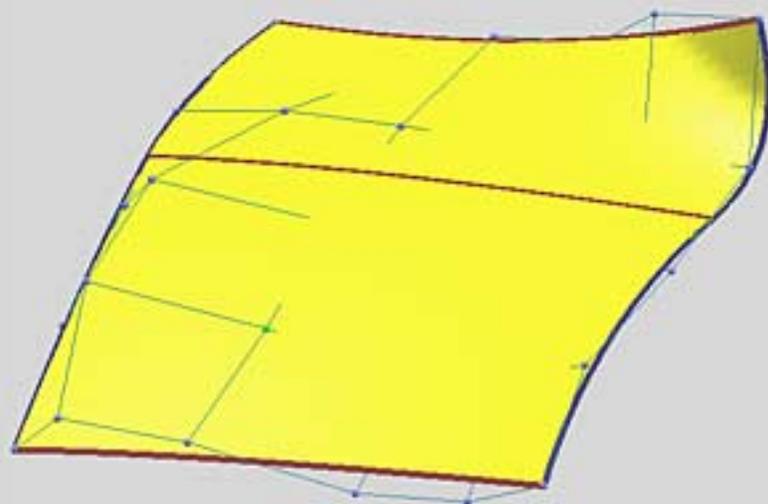data point grid

global interpolation

compare the resulting surfaces

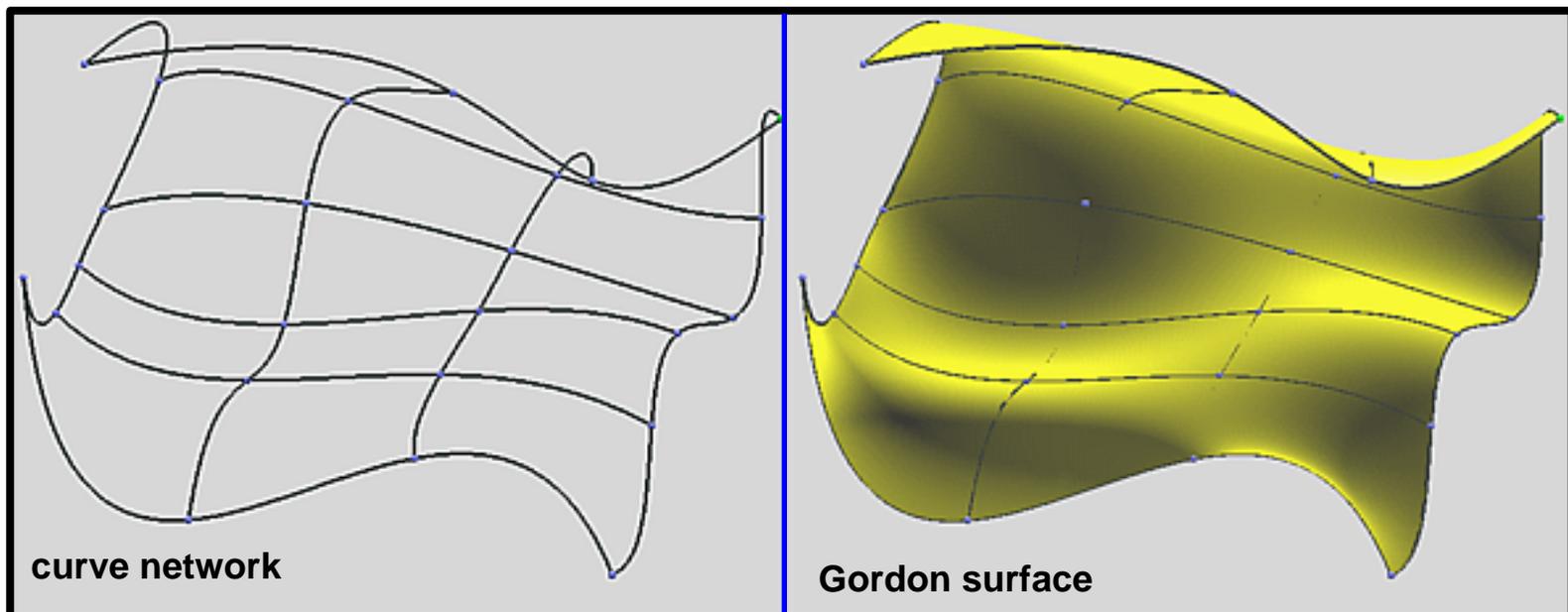local interpolation

compare the resulting surfaces

global approximation

compare the resulting surfaces

Curve Network Interpolation

- **DesignMentor** supports interpolation on a curve network

- A user can design a curve network with **DesignMentor** or other system

- Then, **DesignMentor** interpolates the curve network with a surface, the *Gordon Surface*

curve network | Gordon surface

Future Work

- More visualization of geometric properties (*e.g.,* tangent plane, normal vector, curvature sphere, umbilic, Dupin indicatrix, ...)

- Triangular and multi–sided patches

- Curve and surface interrogation

- Subdivision scheme

- *The Blossoming Principle*

- Irregular data interpolation and approximation