



Xi'an Jiaotong-Liverpool University
西交利物浦大学

CPT205 Computer Graphics

Parametric Curves and Surfaces

Lecture 06
2024-25

Yong Yue and Nan Xiang

Topics for today



- Refresh of module delivery
- Why parametric – motivation
- Parametric curves
- Splines, interpolation and design curves
- Local control
- Revolved, extruded and swept surfaces
- Tensor product surfaces
- Summary

Module Team (Lecturers)

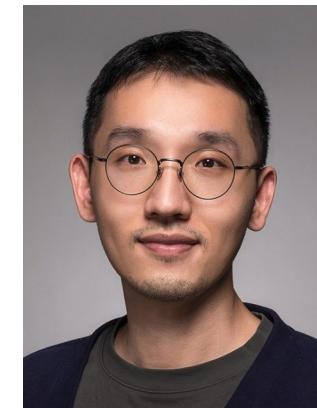


➤ Module Lecturers and Contact Details

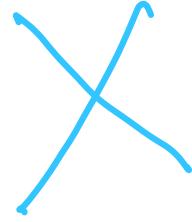
Name: *Yong Yue*
Email: yong.yue@xjtu.edu.cn
Office telephone: (0512) 8816 1503
Room number: SD523
Office hours: *17:00-18:00 Monday*
16:00-17:00 Tuesday
Preferred means of contact: *email*



Name: *Nan Xiang*
Email: nan.xiang@xjtu.edu.cn
Office telephone: (0512) 8916 5342
Room number: SD441
Office hours: *13:00-14:00 Monday*
13:00-14:00 Thursday
Preferred means of contact: *email*



Module Team (TAs)



➤ Teaching Assistance (TAs)

Qizhong Gao (qizhong.gao22@student.xjtu.edu.cn)

Xiaoyu Huang (xiaoyu.huang20@student.xjtu.edu.cn)

Yijie Chu (yijie.chu16@student.xjtu.edu.cn)

Yuhao Jin (yuhao.jin22@student.xjtu.edu.cn)

Zihan Ye (zihan.ye22@student.xjtu.edu.cn)

Zitian Peng (zitian.peng20@student.xjtu.edu.cn)

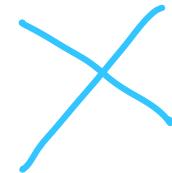
Depending on the demand for support, students may be divided into groups to receive support from dedicated TAs.



Teaching Plan

| Week (c/m) | Lecture | Topic | CW | Lecturer |
|---------------|--------------------------|---|---------|-------------------------|
| 01 (24.09.09) | Lecture 01 Lecture 02 | Introduction and hardware/software Mathematics for computer graphics | | Yong Yue |
| 02 (24.09.16) | Lecture 03 | Geometric primitives | | Nan Xiang |
| 03 (24.09.23) | Lecture 04 | Geometric transformations | CW1 out | Nan Xiang |
| 04 (24.10.07) | Lecture 05 | Viewing and projection | | Nan Xiang |
| 05 (24.10.14) | Lecture 06 | Parametric curves and surfaces | | Yong Yue |
| 06 (24.10.21) | Lecture 07 | 3D modelling | | Yong Yue |
| 07 (24.10.28) | | Reading week | CW1 due | |
| 08 (24.11.04) | Lecture 08 | Hierarchical modelling | CW2 out | Yong Yue |
| 09 (24.11.11) | Lecture 09 | Lighting and materials | | Nan Xiang |
| 10 (24.11.18) | Lecture 10 | Texture mapping | | Nan Xiang |
| 11 (24.11.25) | Lecture 11 | Clipping | | Yong Yue |
| 12 (24.12.02) | Lecture 12 | Hidden surface removal | CW2 due | Yong Yue |
| 13 (24.12.09) | Revision | Summary and highlights of topics covered / Past exam paper | | Nan Xiang / Yong Yue |

Delivery Schedule



➤ Delivery Schedule

- Lecture: *Monday 09:00-11:00 (EB138)*
- Lab: *D1/1: Tuesday 09:00-11:00 (SD554)*
D1/2: Tuesday 09:00-11:00 (SD546)
D1/3: Tuesday 11:00-13:00 (SD554)

➤ Attendance

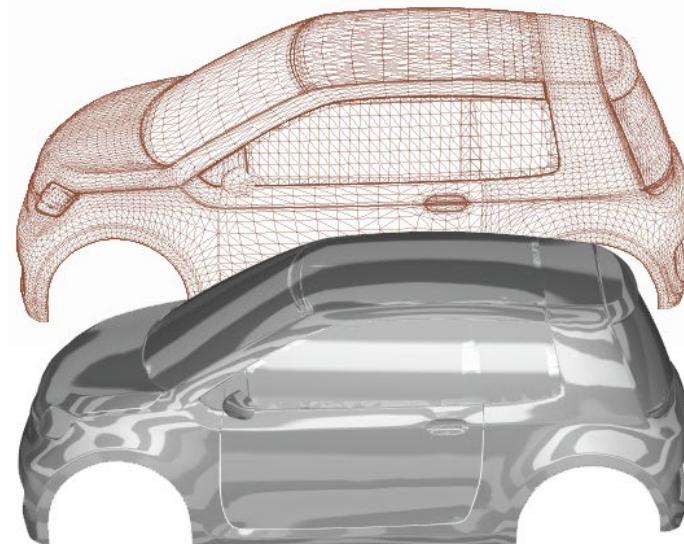
- Make sure you attend the lab session allocated to you, and sign in by scanning the QR code for each lecture and lab session that you attend
- Should any problem be encountered, let us or any TA know during / at the end of the session

Motivation

- More realistic 3D rendering of naturally curved objects

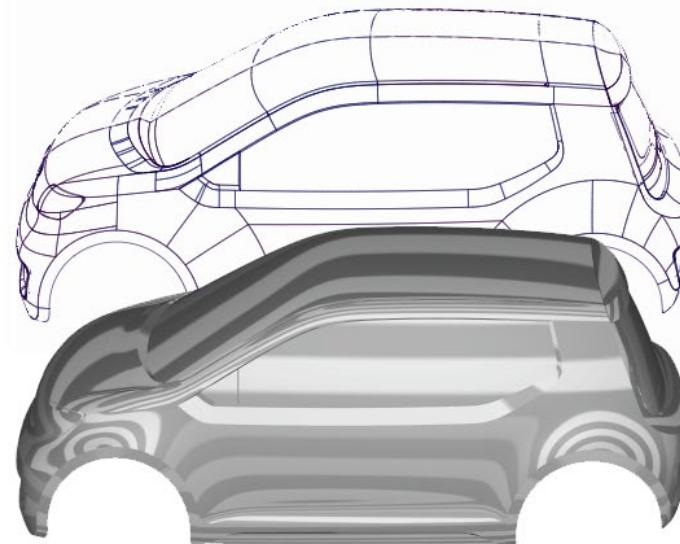
自然弯曲更容易3D渲染

Polygon Model



Poor surface quality

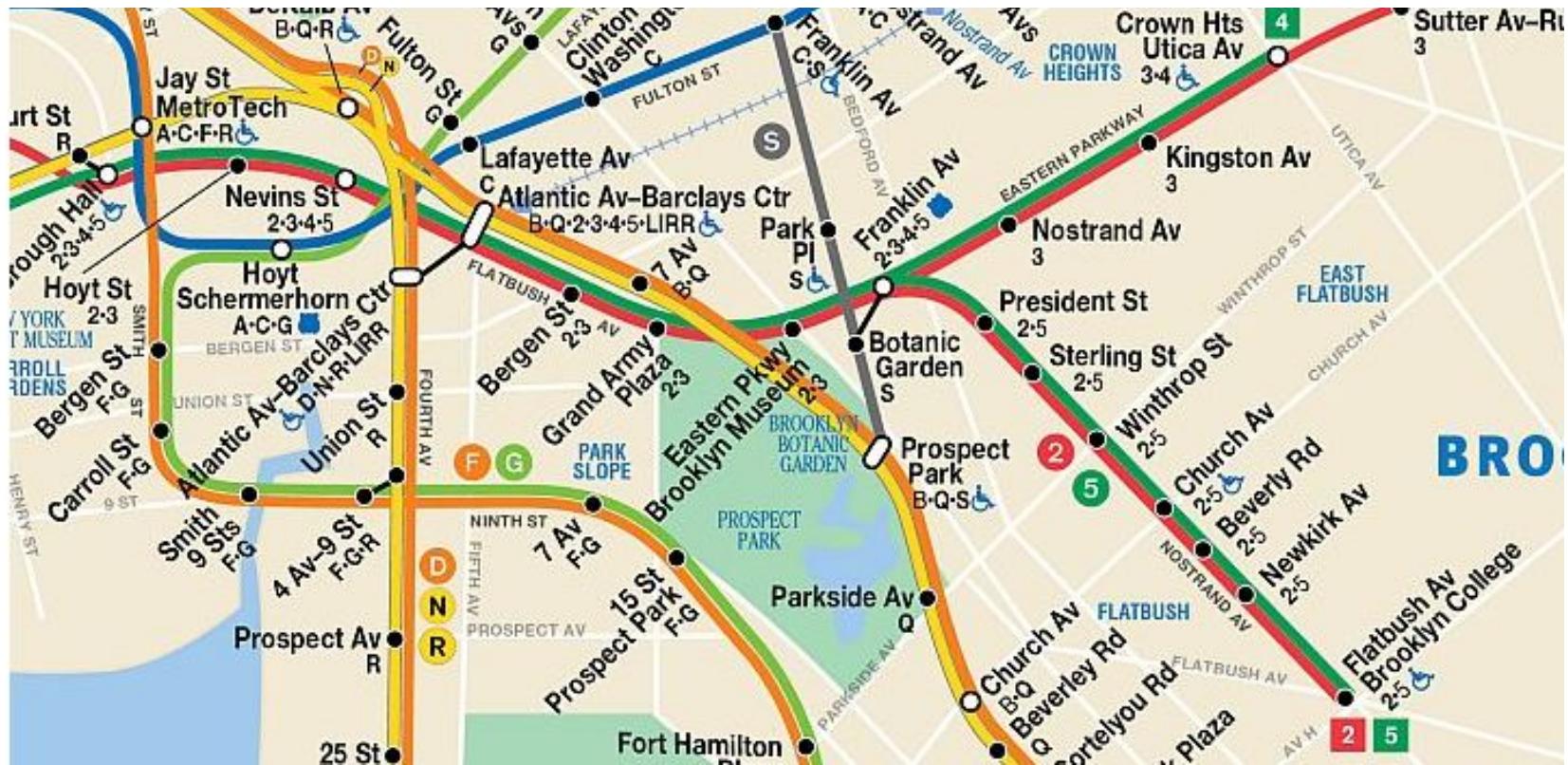
NURBS model



Pure, smooth highlights

Motivation

- Easier to follow than poly-lines



Why parametric?

- Parametric surfaces are surfaces that are usually parameterised with two independent variables.
- By parameterisation, it is relatively easy to represent surfaces that are self-intersecting or non-orientable.
自相交 / 不可定向
- It is impossible to represent many of these surfaces by using implicit functions.
- Even where implicit functions exist for these surfaces, the tessellated representation is often incorrect.

Parametric curves

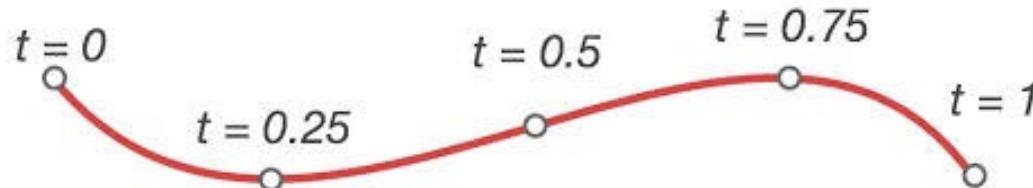
- A curve in a 2D (x, y) surface is defined as:

$$x = x(t)$$

$$y = y(t)$$

where t is a parameter in $[0, 1]$.

- In this way the curve is well defined, each value of t in $[0, 1]$ defining one and only one point.
- The curve description will not change when rotation occurs.

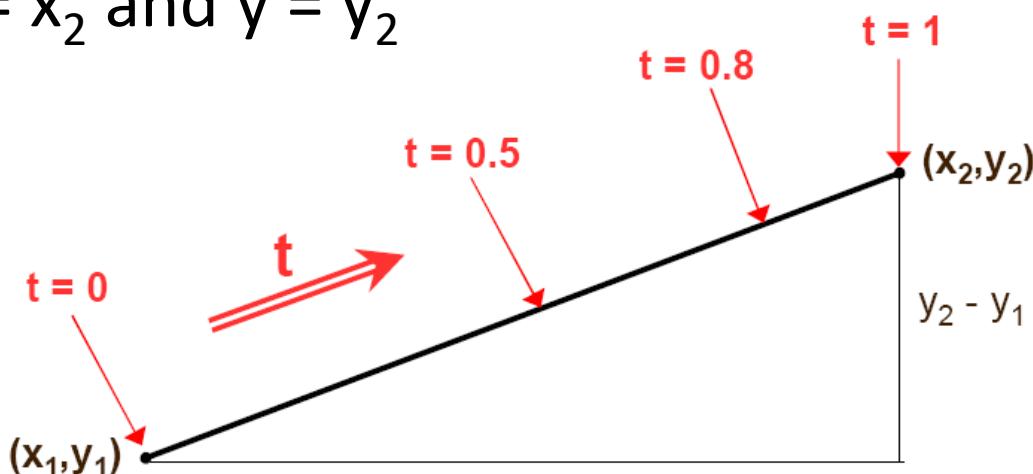


Parametric equation of a straight line

- Implicit representation: $y = a_0 + a_1x$ 隱式
- Parametric (explicit) representation:
 $x = x_1 + t(x_2 - x_1)$ $(0 \leq t \leq 1)$
 $y = y_1 + t(y_2 - y_1)$

when $t = 0$, $x = x_1$ and $y = y_1$

when $t = 1$, $x = x_2$ and $y = y_2$



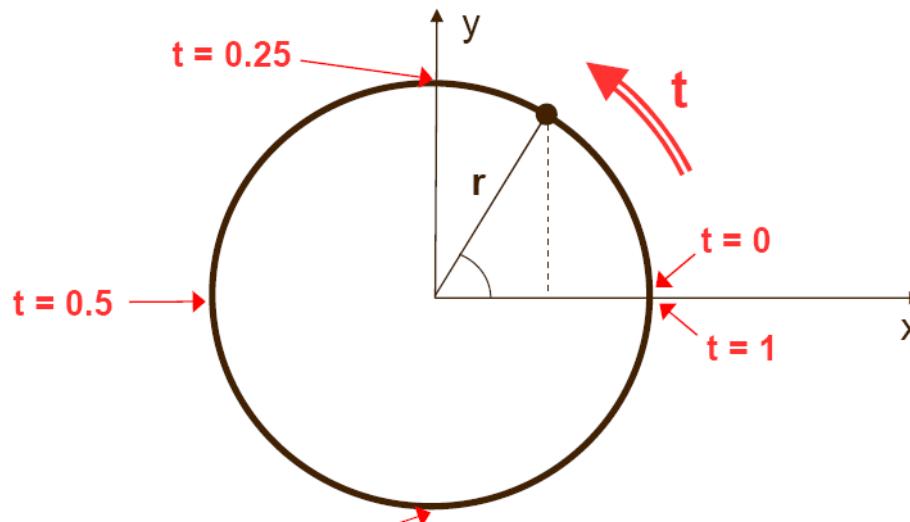
Parametric equation of a circle

- Implicit representation:

$$x^2 + y^2 = r^2 \quad (r = \text{radius})$$

- Parametric equation:

$$x = r \cos(360t), \quad y = r \sin(360t), \quad (0 \leq t \leq 1)$$



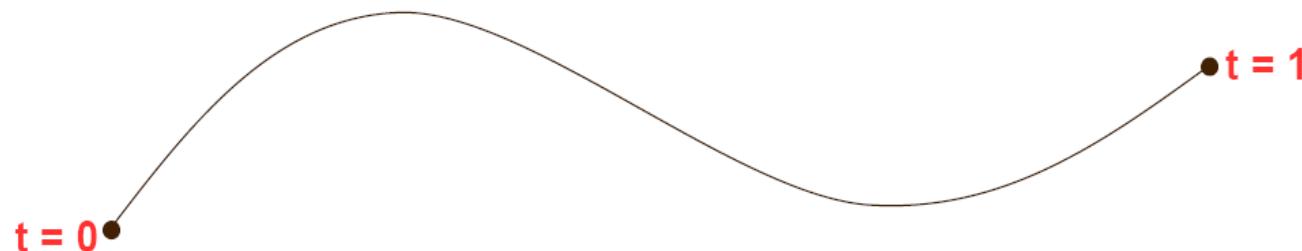
Parametric equation of a cubic curve

三次曲线

$$x(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \quad (0 \leq t \leq 1)$$

$$y(t) = b_0 + b_1 t + b_2 t^2 + b_3 t^3$$

where a_i and b_i terms are constants that vary from curve to curve.



What type of curve to use?

- A curve description should be used, which allows rapid computation (i.e. functions such as sin, cos, exp, log, and so on should be avoided).
- A polynomial can therefore be used

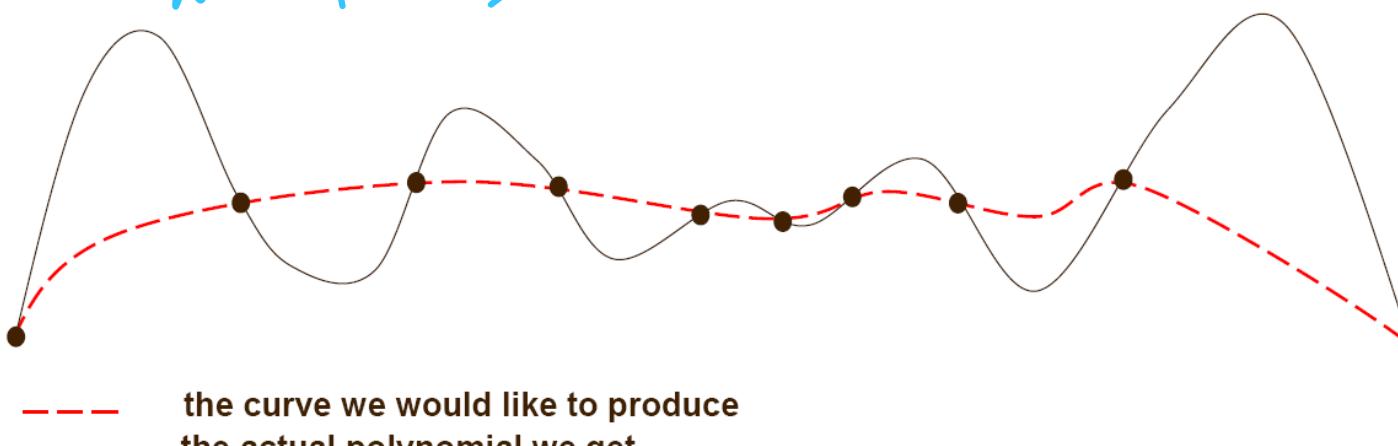
$$x(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + \dots + a_n t^n$$

- For interpolation, if there are k points, then $n = k - 1$ must be chosen, in order to find the correct values for a_i .

Interpolation through k points

- When $k = 2$, i.e. $n = k - 1 = 1$; a straight line can be fitted.
- When $k = 3$, i.e. $n = k - 1 = 2$; a parabola can be fitted.
- When k is large, n must be large, too; high-degree polynomials (i.e. with a large n) oscillate wildly, particularly near the ends of the line, and are not suitable.

$n = k - 1 \rightarrow$ 過誤差



低阶多项式曲线

Low-degree polynomial curves

- Polynomials have to be used for efficiency.
- High-degree polynomials are not suitable because of their behaviour.
- For curves of a large number of points
 - they can be broken into small sets (e.g. 4 points in each set).
 - a low-degree polynomial is put through each set (a cubic for 4 points).
 - these individual curves (cubics) are joined up smoothly.
- This is the basis of splines.

Splines 样条曲线

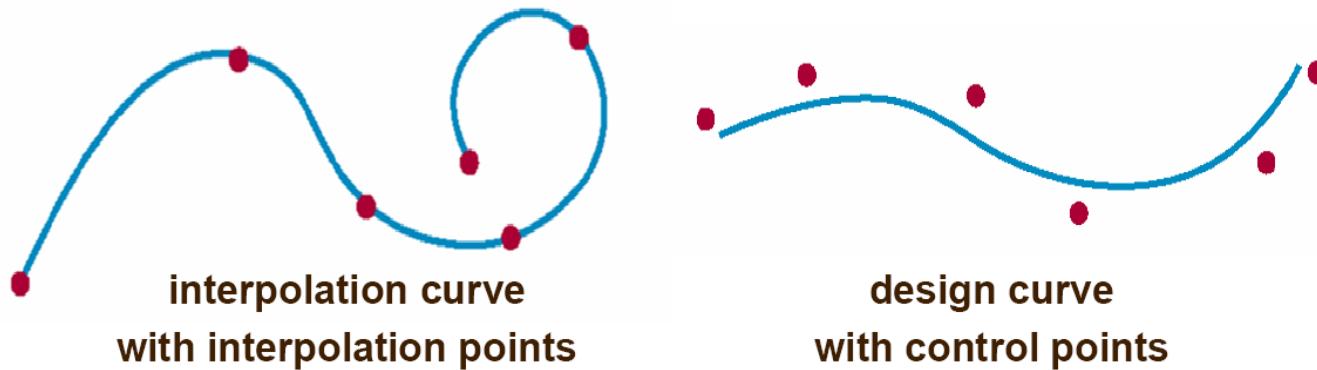
- A spline curve consists of individual components, joined together smoothly, looking like a continuous smooth curve.
- Different types of continuity exist and the following are generally required
 - continuity of the curve (no breaks) 曲线 / 剪线 / 曲率的连续
 - continuity of tangent (no sharp corners)
 - continuity of curvature (not essential but avoids some artefact from lighting)
- Each component is a low-degree polynomial, and for these continuities, cubic polynomials are generally needed.

Interpolation and design curves (1)

- **插值曲线** ↗ 关键帧
 - An interpolation curve defines the exact position (point) that the curve must pass through; e.g. in a keyframe animation, an object must be at a particular point at a particular time.
- **设计曲线**
 - A design curve defines the general behaviour of the curve, e.g. what the curve should look like, and tuning the shape is often needed. The method is often used by designers.

Interpolation and design curves (2)

- The shape of the interpolation curve depends on the data points provided. 必须全部经过
- The shape of the design curve depends on the control points, which do not lie on the curve, but allow adjustment of the shape by moving the points.



Design curves and local control

- The same approach is used in design curves; each consists of separate, but joined parts.
- An important feature is local control.
- When a curve is designed, if one part is done, it would be preferred to keep its current shape when another part of the curve is adjusted.
- So the adjustment should influence only a small / local part of the curve – this is local control.

Local control

➤ Curves without local control

- Natural splines
- Bezier curves (if continuity enforced)

➤ Curves with local control

- B-Splines
- NURBS (Non-Uniform Rational B-Splines)

➤ A cubic curve with local control

- Normally influenced by only 4 control points
- which are the control points most local to it

三次曲线 → 4个点..



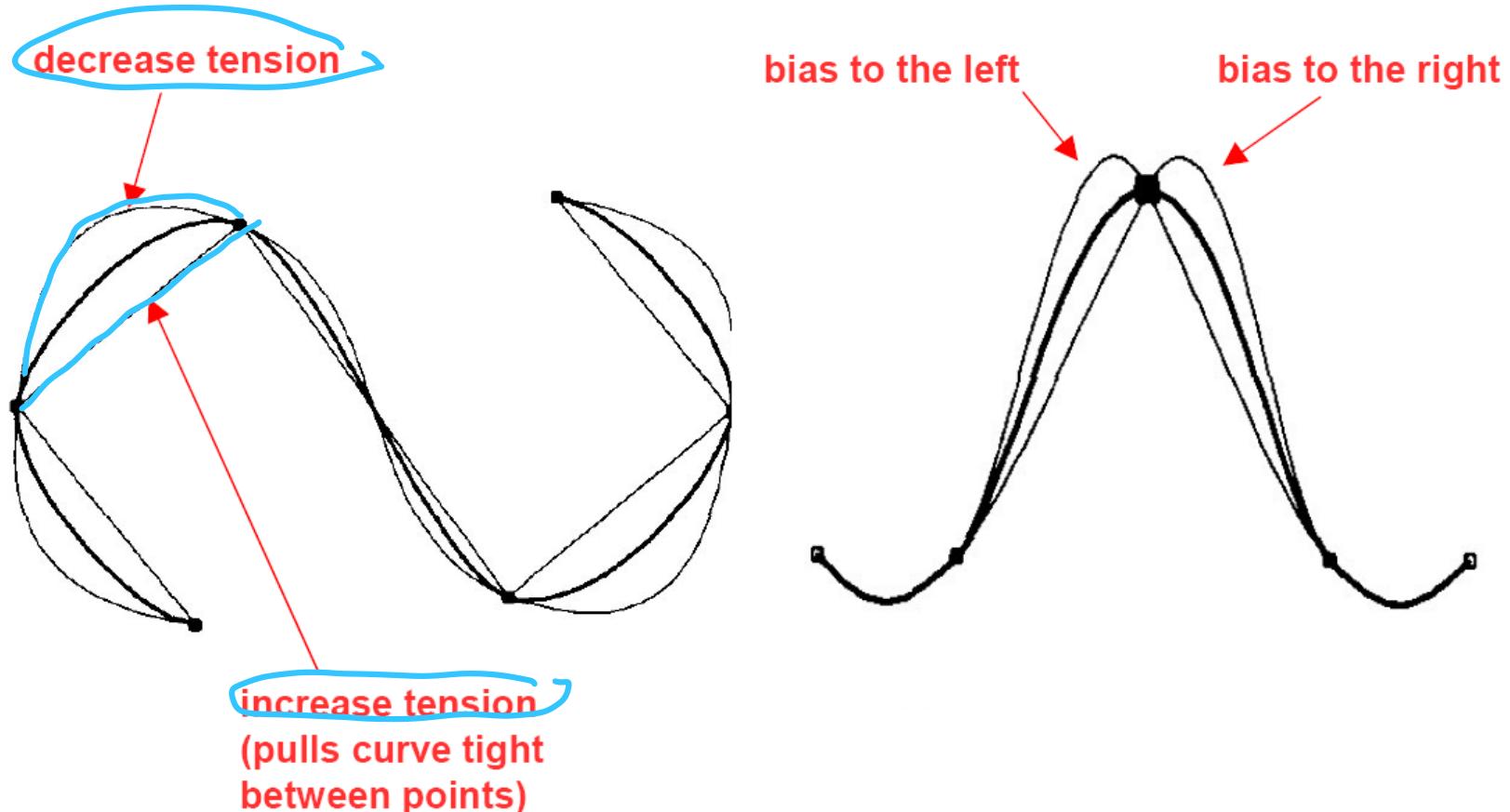
Pierre Etienne Bézier (1910-1999) – French engineer and one of the founders of the fields of solid, geometric and physical modelling as well as in the field of representing curves, especially in CAD/CAM systems. As an engineer at Renault, he became a leader in the transformation of design and manufacturing, through mathematics and computing tools, into CAD and 3D modeling. Bézier patented and popularized the Bézier curves and Bézier surfaces that are now used in most computer-aided design and computer graphics systems.

https://en.wikipedia.org/wiki/Pierre_B%C3%A9zier

Forms of local control

- So far we have considered controlling the design curve by only moving the control points.
- Some types of curve provide further parameters to allow some control while keeping the control points fixed – **important ones include tension and bias.**
张力 偏置
- Such control can apply to both interpolation and design curves.

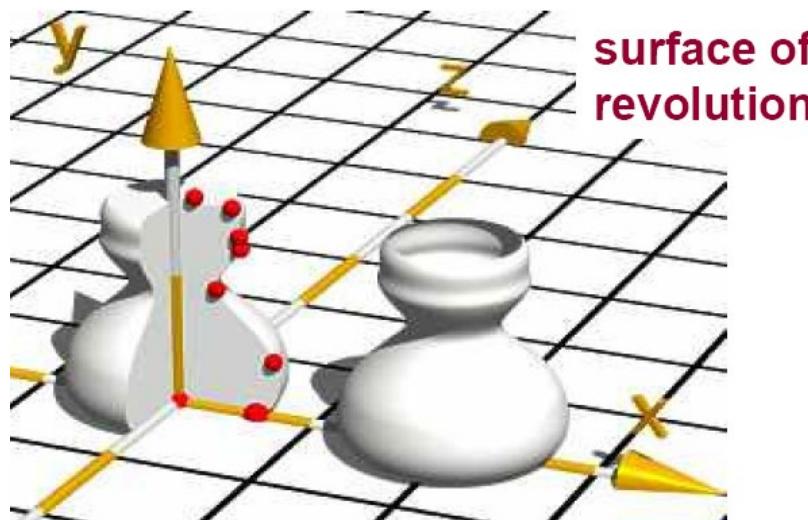
Tension and bias



Types of parametric surface

旋转曲面

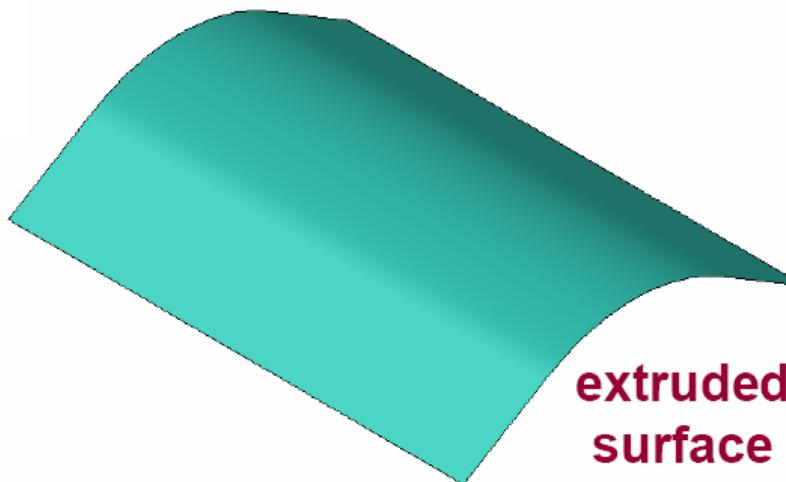
- Revolved surface – a 2D curve is revolved around an axis, and the parameter is the rotation angle.



Types of parametric surface

挤出曲面

- Extruded surface – a 2D curve is moved perpendicular to its own plane, and the parameter is the straight-line depth.

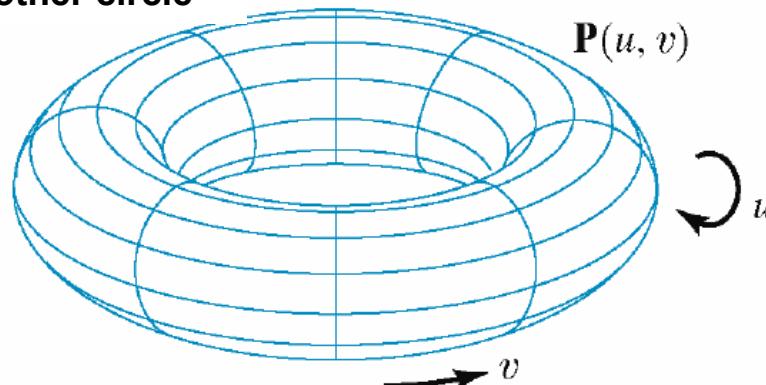


Types of parametric surface

扫描曲面

- **Swept surface** – a 2D curve is passed along a 3D path (which can be a curve), and the parameter is the path definition.

sweep surface produced
by sweeping a circle about
another circle





Tensor product surfaces

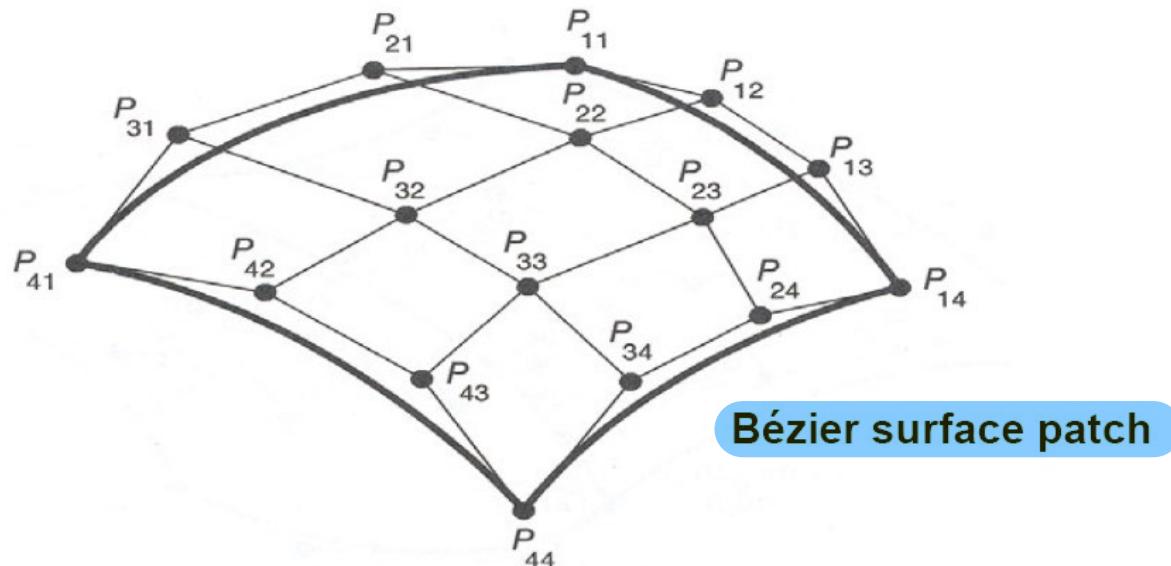
- They are the most widely used parametric surfaces.
- A tensor product surface combines two parametric curves (curves of curves such as the examples in the previous slides). Essentially these work in perpendicular directions.
- Parametric curves depend on 1 parameter (t) while parametric surfaces depend on 2 parameters (u, v).

Interpolation and design surfaces

- As for curves, there are interpolation and design surfaces, and the design form is more common.
- There is a control grid, normally a rectangular array of control points.
A blue callout bubble contains the text "There is a control grid, normally a rectangular array of control points." A handwritten blue arrow points from the word "grid" in the bubble to the character "网" in the handwritten annotation "网格".
- As the curve is broken into smaller curves, the surface is broken into surface patches.
- Local control becomes even more important.

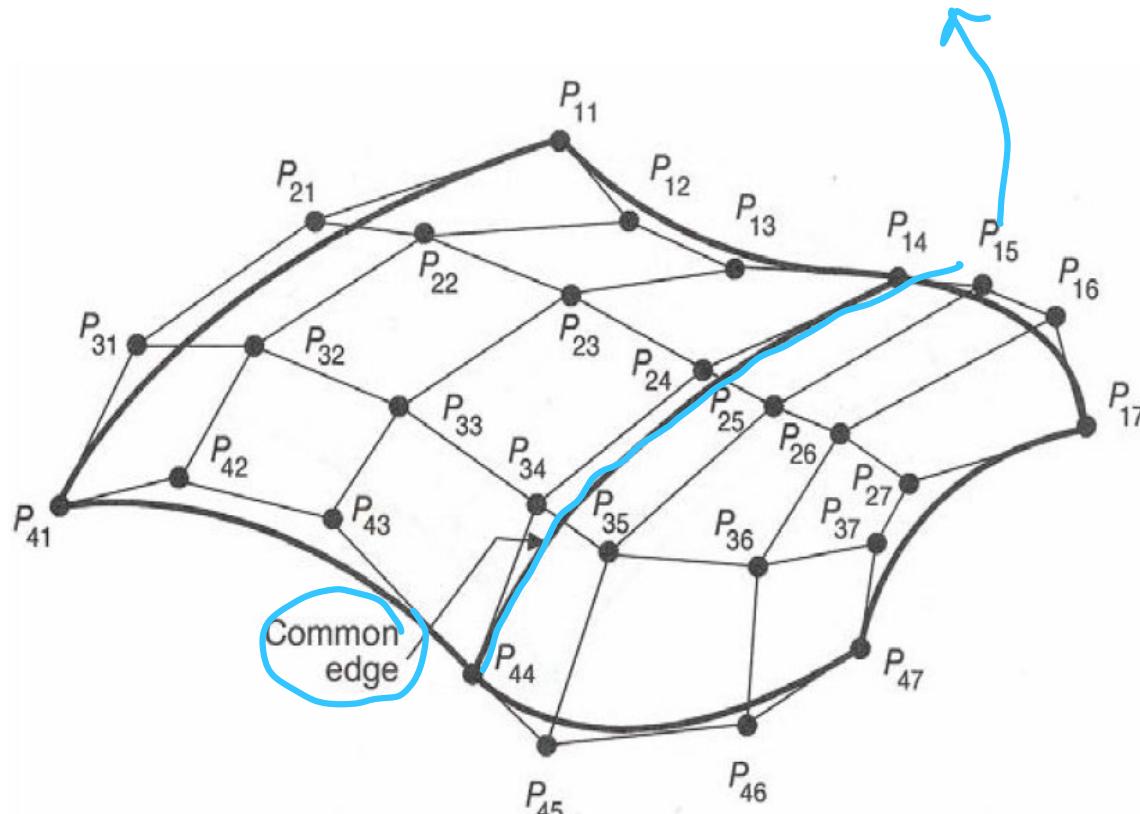
Control grid for a surface patch

- In a cubic curve with local control, a curve segment is normally affected by only 4 control points.
- In a cubic surface with local control, a surface patch is affected by 16 control points, these being in a 4x4 grid.



Joining patches

- The patches are joined, which is not always straightforward.
- Appropriate continuity at the boundaries must be ensured.

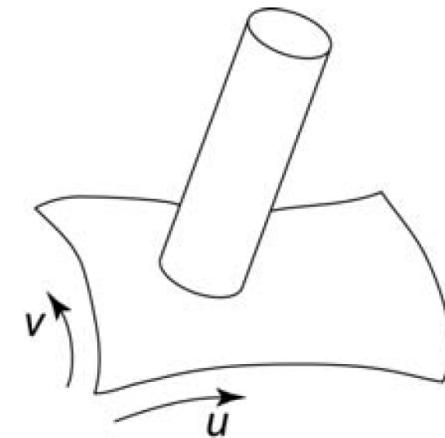


Trimming and control

- The control of the surface is performed as for curves

- the points in the control grid can be moved.

- some types of surface have tension and other parameters to use without having to move grid points.



- If not all of the surface is to be displayed → 切割线

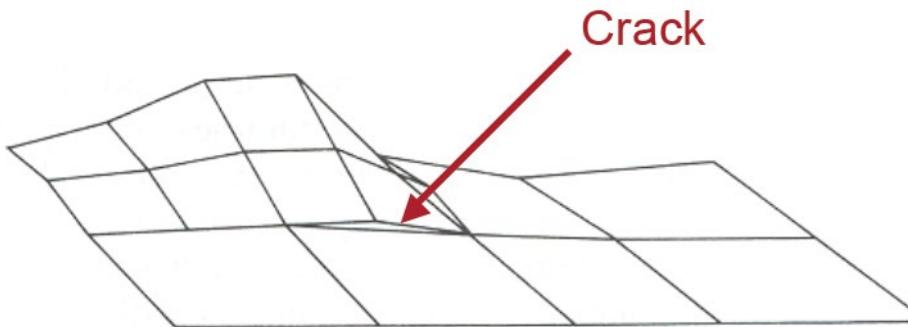
- a trim line cutting the surface can be defined.

- all parts of the surface on one side of this line are removed.

Improving resolution

- To obtain finer detail, the number of patches can be increased.
- It is possible to do this adaptively, i.e. only increase the number of patches where extra detail is needed.
- This can lead to cracks in the surface unless care is taken.

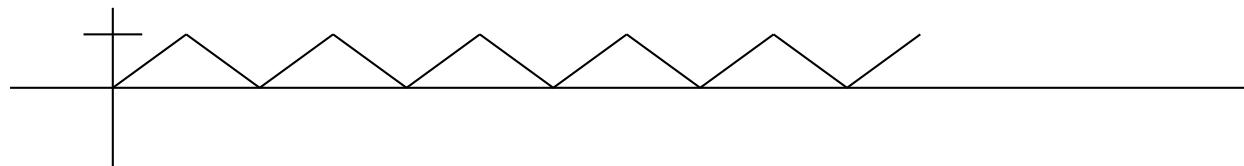
缝隙



Linear interpolation

Linear interpolation is useful (e.g. for animation) where t varies from 0 to 1 (and sometimes back again) over time.

```
float t = 0;  
float dt = 0.01;  
void onIdle(void)  
{  
    t = t+dt;  
    if (t>1) {t = 1; dt = -0.01;}  
    if (t<0) {t = 0; dt = 0.01;}  
}
```



Parametric functions

```
// Draw a sinewave

int i;
float x, y;
float d = 100.0;

glBegin(GL_POINTS);
for(i=0; i<=360; i=i+5)
{
    x = (float)i;
    y = d*sin(i*(3.1416/180.0));
    glVertex2f(x,y);
}
glEnd();
```

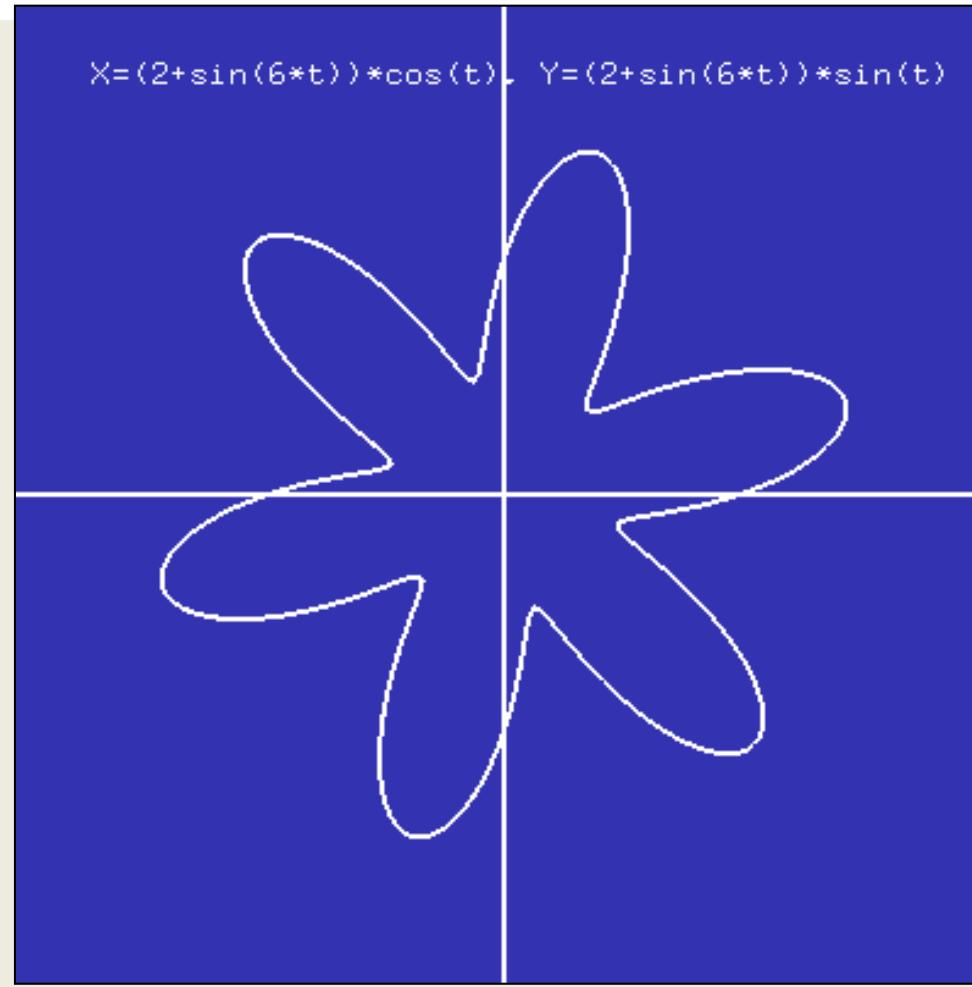
Parametric functions

```
// Draw a circle

double x, y;
double t;
double r = 100;

glBegin(GL_LINE_STRIP);
for(t=0; t<=360; t+=1)
{
    x = r*cos(t*3.1416/180);
    y = r*sin(t*3.1416/180);
    glVertex3f(x,y,0);
}
glEnd();
```

Parametric functions



Summary

- Parametric curves (cubics) and surfaces (tensor product) provide a flexible modelling tool.
- The number of parametric surface patches required for a model is far fewer than that of polygons for a similar model.
- Some modelling systems are based on such surfaces (NURBS being the most popular).
- Using such models produces an additional computational load on rendering the image (hidden-surface removal, shading calculations, collision detection and so on).