CITS3003 Graphics & Animation

Lecture 21: 3D Modelling
Objectives

• Modelling complex 3D objects
  - How to get 3D model

• Techniques used by 3D modelling software
  - Subdivision surfaces
    • Catmull Clark algorithm
Why do we need 3D modelling?

• So far we’ve mainly been concerned with drawing complex 3D models while mostly ignoring where the models are coming from

• Models need to come from somewhere

• 3D Models can come from three main sources
  1. Scanning real objects
  2. Non-rigid deformation of real object scans
  3. Making synthetic models in 3D modelling softwares (CAD)
Scanning Real Objects

• Many 3D scanners are available in the market. Price depends on the resolution of the scan. Examples are
  - Minolta Vivid laser scanner & 3dMD face scanner
  - Microsoft Kinnect ($200), PrimeSense, Realsense etc

• To cover complete 360°, we must scan the object from multiple directions and then stich them together

• Real scans need a lot of post-processing to remove noise, spikes and cover holes
Non-Rigid Deformation of Models

- Deformable models are formed by curves or surfaces defined that can be deformed by changing parameter.
- By changing the parameters of the deformable model, we get different 3D shapes.


SMPL: a skinned multi-person linear model: [link](#)
Computer Generated Models

• Scanning real objects or making deformable models are beyond the scope of this unit

• We will look into how to generate 3D models using computer software
Computer Generated Models

- Blender
  - Blender includes many different tools useful for different kinds of modelling.
  - You can import real animations (motion capture) into Blender to animate a model.

We’ll focus only on a couple of fundamental techniques: subdivision surfaces and animation via skinning.
3D modelling can be tedious and time consuming.

– Even positioning a single point in 3D is tricky – Mice and displays are 2D devices

– OpenGL (and DirectX) is based mostly on drawing many triangles.

– So objects must be constructed from many vertices, edges and faces,

– Placing each vertex/edge/face individually is not usually feasible!

– How can we do this quickly and easily?
Can we easily model natural shapes?

We can quickly model “blocky” objects – with only a few faces.

– But most natural shapes aren’t blocky.
  We can use prebuilt common shapes like spheres, cylinders, ellipsoids, ...
– But these still don’t allow us to create “natural” shapes – most shapes in the real world aren’t perfect spheres, etc.

– Can we generate shapes with many vertices by controlling just a few?
Subdivision Surface Method

*Subdivision surface method* is a method for producing smooth surfaces that can be adjusted easily.

- The idea is to specify a blocky surface, with a manageable number of faces and to calculate a smooth surface that roughly follows it.
- The smoothing process needs to be predictable.
Subdivision Surface Method

Subdivision surface

Shading
Subdivision Surface Method
Subdivision Surface Method
Subdivision Surface Method

- The basic idea is to start with a single control mesh.
- This mesh can represent a closed surface.
- We then use a set of rules to refine the mesh, resulting in a higher resolution control mesh.

Foundations of 3D Computer Graphics
S.J. Gortler
Subdivision Surface Method
Subdivision Surface Method
Subdivision Surface Method
• Using smooth shading with subdivision surface can help in smoother surface (low memory and time consumption)
One can typically design surfaces using splines in a geometric modelling package.

“Spline is a flexible strip used to produce a smooth curve or a curve that is defined by two or more points.”

“We can specify a spline curve by giving a set of control points, which indicate general shape of the curve.”

Subdivision Surface Method

• *Subdivision surface* is related to earlier techniques, like NURBS (Non-Uniform Rational B-Splines) which also use a small number of control points.
  - Subdivision surfaces is better for 3D modelling because it doesn’t have as strict requirements, such as the points forming a grid of quadrilaterals.
  - It is also useful to be able to edit the mesh at the different levels of subdivision, which isn’t possible with NURBS and similar techniques.

• Subdivision surfaces have proven to be simple, useful, and general

Catmull-Clark subdivision surface technique is often the preferred technique for generating smooth surfaces from a “control mesh” with a relatively small number of points, because it is simple, predictable and has desirable properties such as:

- **Each original point affects only a small part of the surface** – roughly up to each neighbour.

- **The 1-st derivative is always continuous** – i.e., the normals never change suddenly.

- **The 2-nd derivative is nearly always continuous**, i.e., the curvature (rate of change of the normals) doesn’t change suddenly. The exception is at extraordinary vertices – where the mesh is "irregular”, i.e., not a grid of quadrilaterals
Subdivision Surfaces: technical details

[From Catmull & Clark]

\[ o = \text{old vertices } (p_{ij}) \]
\[ x = \text{new vertices } (q_{ij}) \]

After one subdivision step, there is a new vertex for:
- Each old face
- Each old edge
- Each old vertex

Figure 1. Standard bicubic B-spline patch on a rectangular control-point mesh
Subdivision Surfaces: technical details

[From Catmull & Clark]

\[ o = \text{old vertices } (p_{ij}) \]
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After one subdivision step, there is a new vertex for:

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*Figure 1. Standard bicubic B-spline patch on a rectangular control-point mesh*
There is a new vertex for:
- Each old face

On the old surface, there are 9 faces. So there are 9 new vertices marked as

(e.g. \(p_{11}p_{12}p_{22}p_{21}\) is a face on the old surface)

*Figure 1. Standard bicubic B-spline patch on a rectangular control-point mesh*
Subdivision Surfaces: technical details

[From Catmull & Clark]

There is a new vertex for:
• Each old edge

On the old surface, there are 12 edges. So there are 12 new vertices marked as

Figure 1. Standard bicubic B-spline patch on a rectangular control-point mesh
Subdivision Surfaces: technical details

[From Catmull & Clark]

There is a new vertex for:

• Each old vertex

On the old surface, there are 4 vertices: $p_{22}, p_{23}, p_{33}, p_{32}$. So there are 4 new vertices marked as ●.

Figure 1. Standard bicubic B-spline patch on a rectangular control-point mesh
Subdivision Surfaces: technical details

[From Catmull & Clark]

\( o = \text{old vertices } (p_{ij}) \)
\( x = \text{new vertices } (q_{ij}) \)

After one subdivision, there is a new vertex for:

- Each old face
- Each old edge
- Each old vertex

So, in total, the new surface has 9+12+4=25 vertices.

Figure 1. Standard bicubic B-spline patch on a rectangular control-point mesh
Subdivision Surfaces: technical details

Let’s refer to the new vertices as points and the old vertices as vertices

[From Catmull & Clark]

- New “face” points are at the average of the vertices for the face

- New “edge” points are at the average of the two vertices on the edge and the two face points on either side of the edge

- The placement of new “vertex” points is a bit complicated (see next slide)

*Figure 1. Standard bicubic B-spline patch on a rectangular control-point mesh*
Let’s refer to the new vertices as points and the old vertices as vertices

[From Catmull & Clark]

For the vertex $P$, a new point is placed at

$$F + 2E + (n - 3)P \over n$$

Where $F$ is the average of the face points, $E$ is the average of the edge points and $n$ is the number of edges

The faces and edges are the original ones that touch the original $P$

Figure 1. Standard bicubic B-spline patch on a rectangular control-point mesh
Other important properties of *Catmull & Clark* subdivision:

- When the control points form a simple grid topology (as in Figure 1) the surface tends towards a bicubic B-Spline, a standard kind of surface used when smoothness is required.

- Unlike other techniques for generating such surfaces (like NURBS), the technique naturally extends to other topologies, giving 3D modellers much freedom.

- Properties like texture coordinates can be smoothly generated in a similar way to the vertex positions: by averaging them with the same weights during subdivision.

*Figure 1. Standard bicubic B-spline patch on a rectangular control-point mesh*
Catmull & Clark subdivision surface method on closed surfaces

• Counting the number of new vertices for open surfaces after one subdivision step can be a bit confusing. For closed surfaces, the counting is easier and more intuitive.
Catmull & Clark subdivision surface method on closed surfaces

For a cube, initially

There are 8 vertices, 6 faces, and 12 edges.
\[ V_0 = 8 \]
\[ F_0 = 6 \]
\[ E_0 = 12 \]

- After one subdivision step, how many vertices are there?

There are 26 vertices, 24 faces, and 48 edges.
\[ V_1 = V_0 + F_0 + E_0 = 26 \]
\[ F_1 = 4F_0 = 24 \]
\[ E_1 = 2E_0 + 4F_0 = 24 + 24 = 48 \]

- In general, after \( n \) subdivision steps,

\[ V_n = V_{n-1} + F_{n-1} + E_{n-1} \]
\[ F_n = 4F_{n-1} \]
\[ E_n = 2E_{n-1} + 4F_{n-1} \]
As the Catmull & Clark subdivision surface method constrains the surface to be smooth, the cube would approach the shape of a sphere after a few subdivisions.
Further Reading

  - Catmull-Clark subdivision Ch-10 Section 10.12

The slides are partially based on “The Guerrila CG Project of guerrilla.org”, topic Subdivision surfaces: Overview.

- Other Resources/ References
  Foundations of 3D Computer Graphics, S.J. Gortler
  - Chapter 22
  https://learnopengl.com/Model-Loading/Assimp