Objectives

- Introduce fundamental techniques for creating 3D models, in particular subdivision surfaces for easily creating curved surfaces.

Why do we need 3D modelling?

- So far we've seen how to draw 3D models while mostly ignoring where they come from,
- but models need to come from somewhere.
- The most common source is 3D modelling using special software
- We'll use the main open source 3D modelling software: Blender
  - Blender includes many different tools useful for different kinds of modelling.
  - We'll focus only on a couple of fundamental techniques: subdivision surfaces and animation via "skinning".

How can we easily model in 3D?

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.
• It is related to earlier techniques, like NURBS (Non-Uniform Rational B-Splines) which also use a small number of control points.
  - But it 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.

Catmull-Clark subdivision surface technique

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:
- Each original point affects only a small part of the surface – roughly up to each neighbour.
- The 1st derivative is always continuous – i.e., the normals never change suddenly.
- The 2nd 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 (marked in blue in the figure.)

Working with subdivision surfaces

Meshes should usually have mostly quadrilaterals
- Having mostly a grid around the mesh makes it easy to adjust.
- It also tends to smooth well.
- One way to create meshes like these is by “extruding a cube” as in the youtube tutorial in part 2 of the project (also see other blender tutorials).

To keep things manageable, we work with relatively few control points.
- Just enough to accurately create the desired smooth shape.
- Loop subdivisions are often an easy way to add a few points when needed.
- To add many new vertices, subdivide the whole mesh one level.
- You can also select edges to subdivide, although this can cause irregularity. (It’s better to do whole areas or loops at once.)
- Apply the smoothing subdivision just before exporting, or before adding an armature for skinning animation.
- To easily swap between different levels of subdivision, use the multiresolution modifier, which remembers fine detail while editing earlier subdivision levels.
- For 3D detail, try the sculpt tool.
See the following two papers:

These papers cover more detail than is required for this unit. We’ll focus on the main aspects of the design of the technique, and why it works well.
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. These 12 new vertices are marked as ○.

New “face” vertices are at the average of the vertices for the face
New “edge” vertices are at the average of the two vertices on the edge and the two faces on either side of the edge
New “vertex” vertices are more complicated (PTO)

So, in total, the new surface has 9 + 12 + 4 = 25 vertices
Subdivision surfaces: technical details

Other important properties of Catmull & Clark subdivision:
- Where 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.

NURBS = Non-Uniform Rational Basis Spline

Exercise (answer): 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,
\[ V_n = V_{n-1} + F_{n-1} + E_{n-1} \]
\[ F_n = 4F_{n-1} \]
\[ E_n = 2E_{n-1} + 4F_{n-1} \]

Exercise:
- After one subdivision step, how many vertices are there?
- After two subdivision steps, how many vertices are there?
Verify your result using the program blender.

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.

Exercise: Consider a cube.
- After one subdivision step, how many vertices are there?
- After two subdivision steps, how many vertices are there?
Verify your result using the program blender.

Thus, after two subdivision steps:
there are \( V_2 = V_1 + F_1 + E_1 = 26 + 24 + 48 = 98 \) vertices.

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 subdvisions.

The result above can be verified in the software blender.
Subject 18 – 3D Modelling: Subdivision Surfaces

Subdivision Examples in Blender

Starting with a cube, after 1 subdivision step (left figure) and after 2 subdivision steps (right figure).