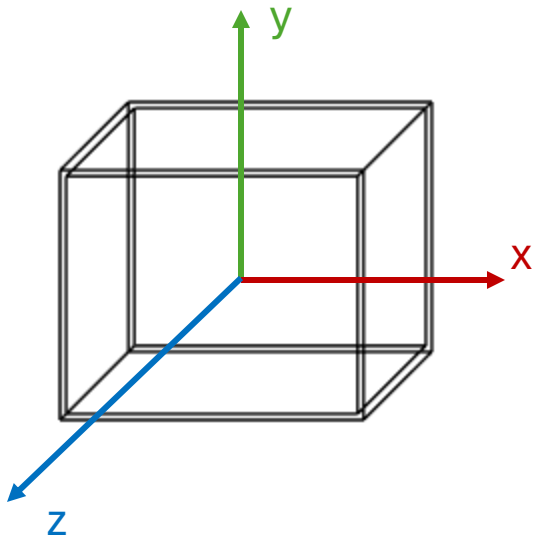
3D Modeling

CSU44052 Computer Graphics

Binh-Son Hua

3D Data

Manually specify 3D data



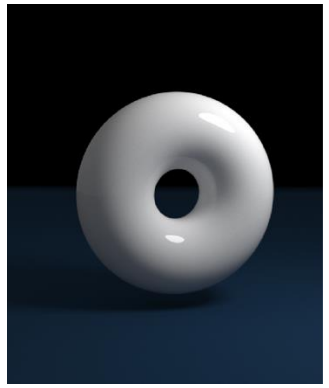
=

(-1, -1, -1)
(1, -1, -1)
(1, 1, -1)
(-1, 1, -1)
(-1, -1, 1)
(1, -1, 1)
(1, 1, 1)
(-1, 1, 1)

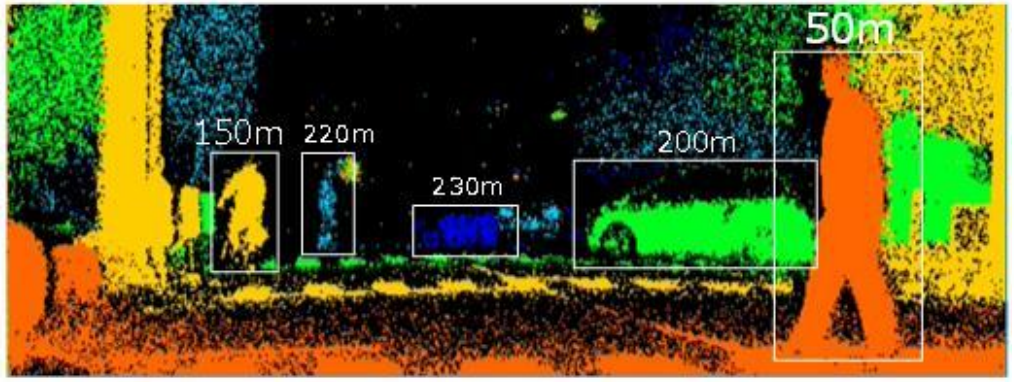
3D Data

Too complicated
for manual construction!

Different Types of 3D Data

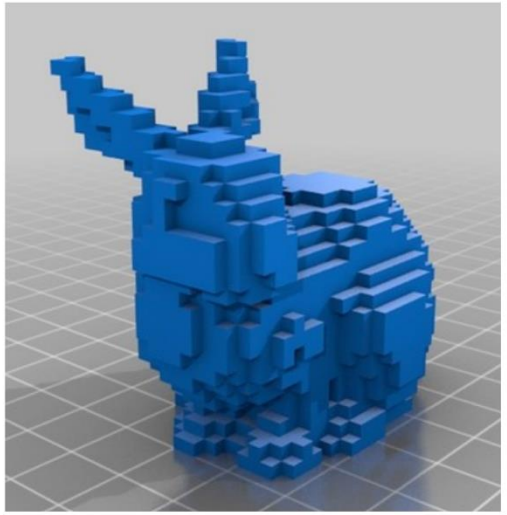


Parametric

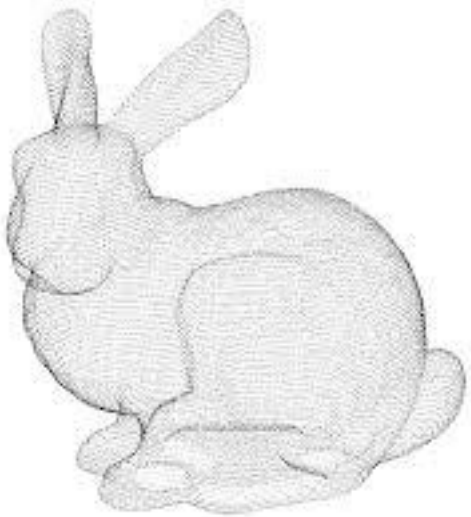


Depth

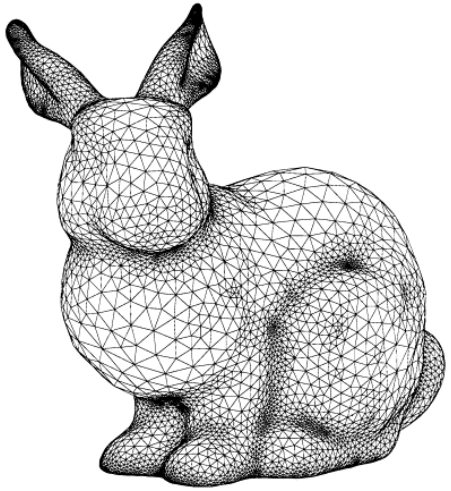
Multiple images



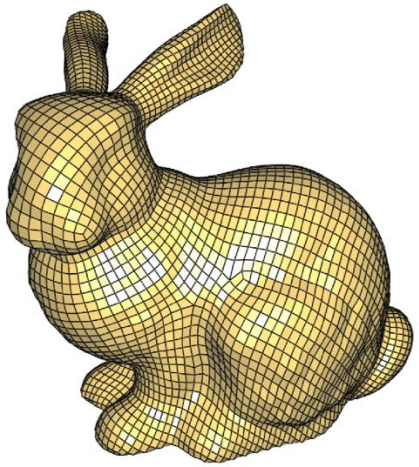
Voxel



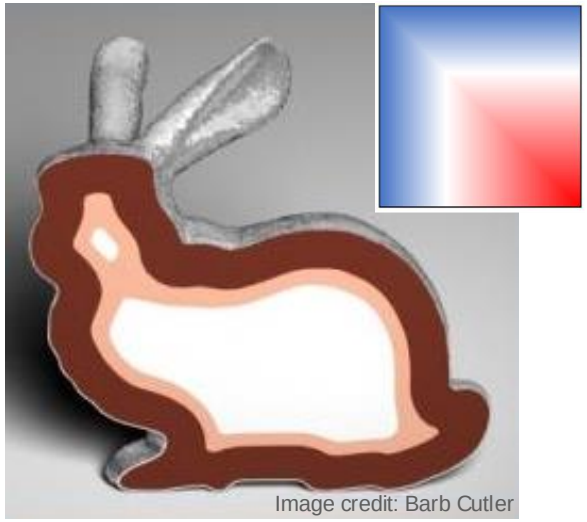
Point cloud



Triangle mesh



Quad mesh



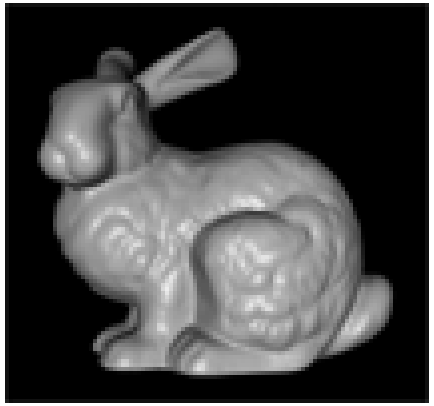
Implicit surface

Objectives

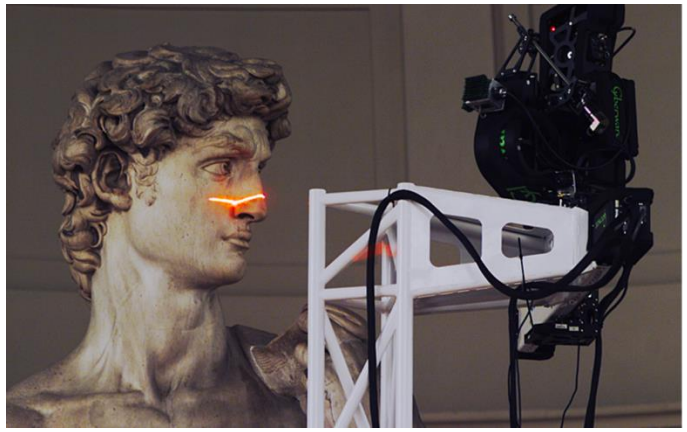
- Take a detour from OpenGL to discuss how 3D models are created
- 3D modeling software
- Scanning technologies
- Geometry processing
- Procedural textures
- Generative AI for 3D modeling

3D Modeling

- 3D modeling is the process for creating geometry and appearance for 3D objects and 3D scenes



- CAD modeling
- Photogrammetry



- Motion capture

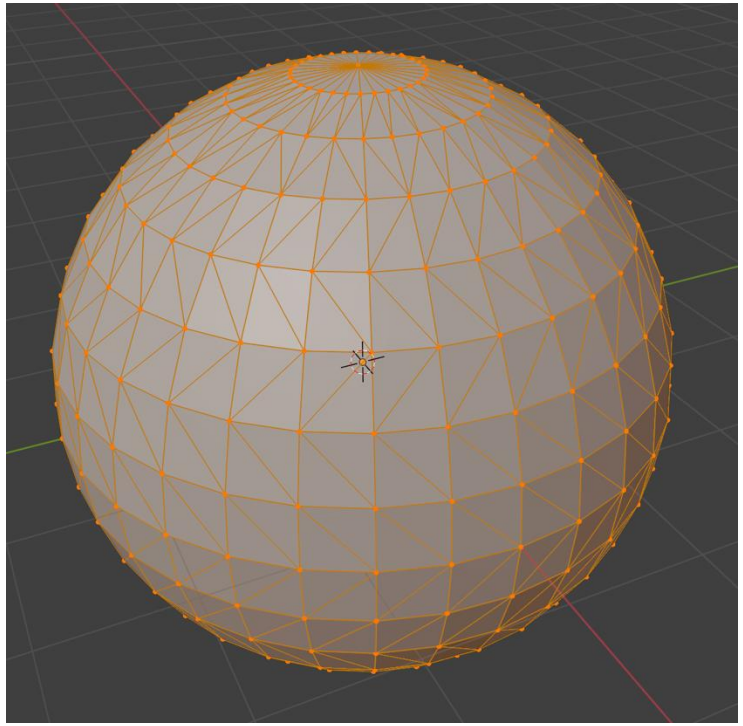
Modeling the Earth

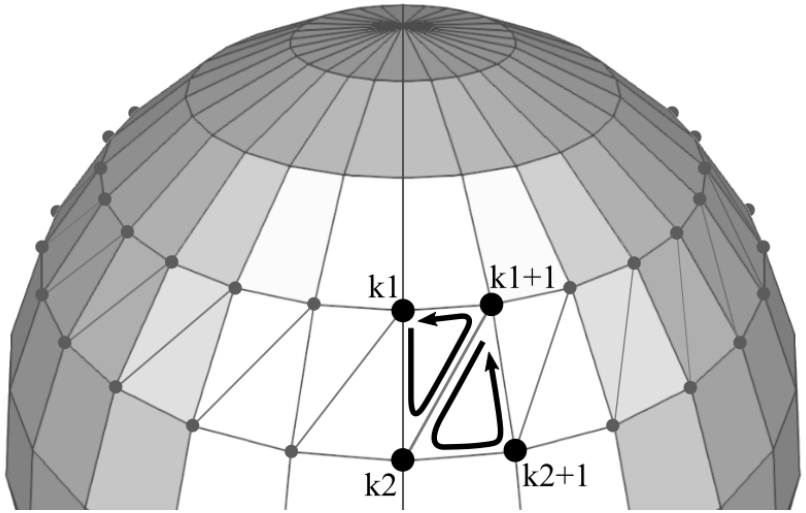
- Sphere equation

$$x = r \sin\theta \cos\phi$$

$$y = r \sin\theta \sin\phi$$

$$z = r \cos\theta$$



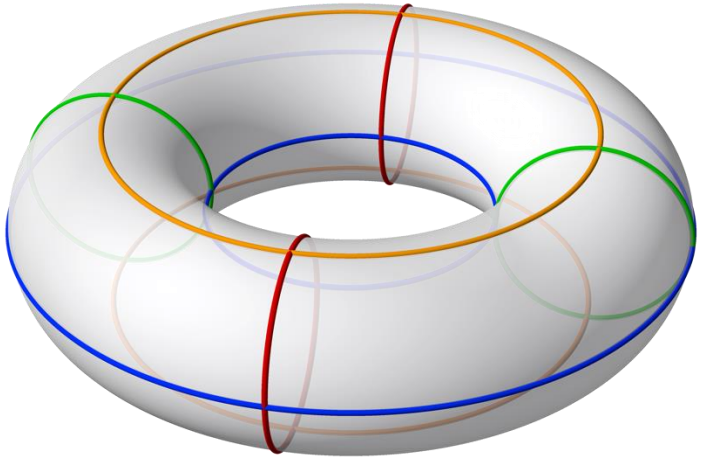


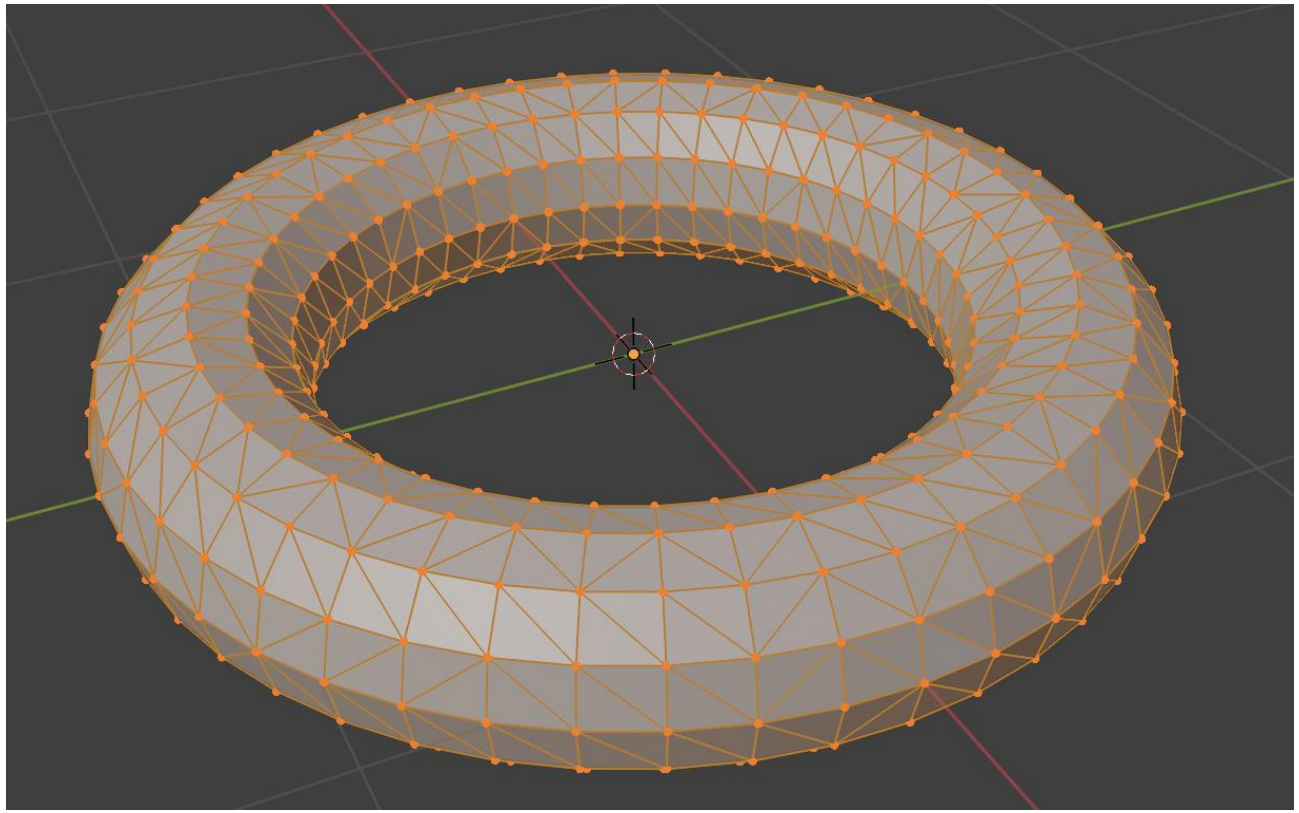
https://www.songho.ca/opengl/gl_sphere.html

Modeling a Donut

- Torus equation

$$x(\theta, \varphi) = (R + r\cos\theta)\cos\varphi$$
$$y(\theta, \varphi) = (R + r\cos\theta)\sin\varphi$$
$$z(\theta, \varphi) = r\sin\theta$$





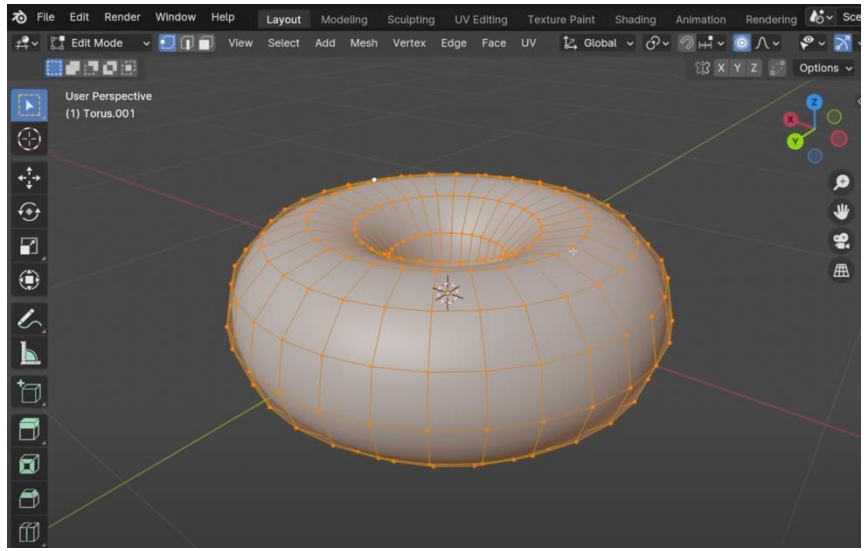
https://en.wikipedia.org/wiki/Torus

Modeling Programs

- Blender, 3DS Max, Maya, Softimage, AutoCAD, Mudbox, etc.

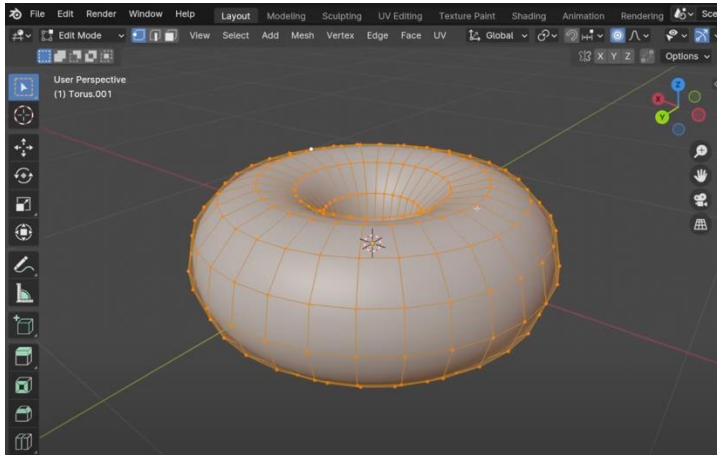
https://www.autodesk.com/education/free-software/all

Creating a Donut using Blender

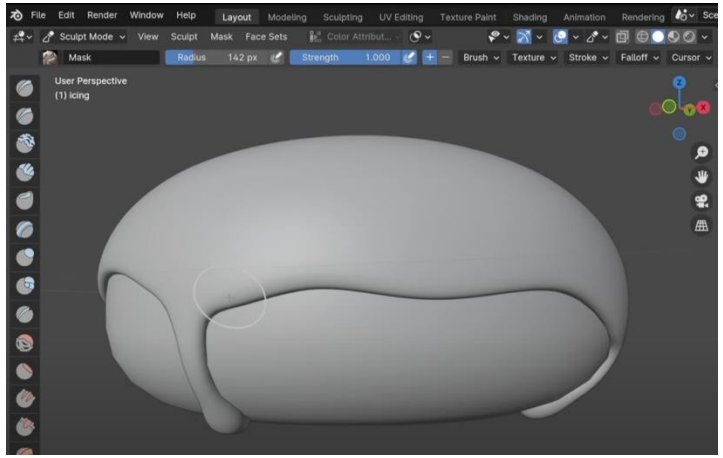


“Donut” - Blender 4.0 Tutorial by Andrew Price
https://www.youtube.com/watch?v=B0J27sf9N1Y

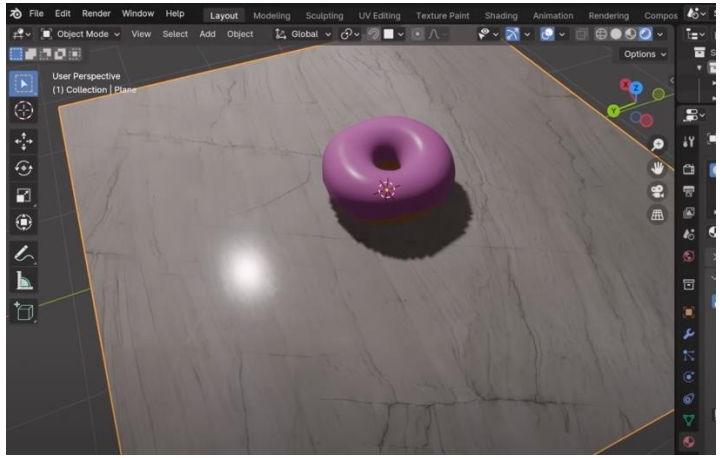
Creating a Donut using Blender



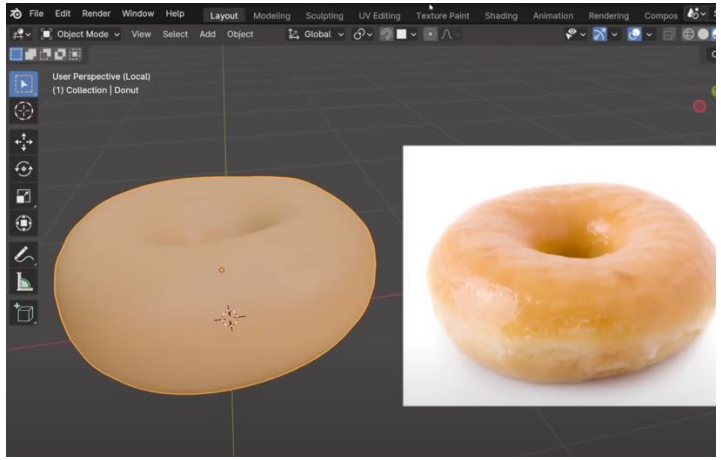
Create a basic donut shape



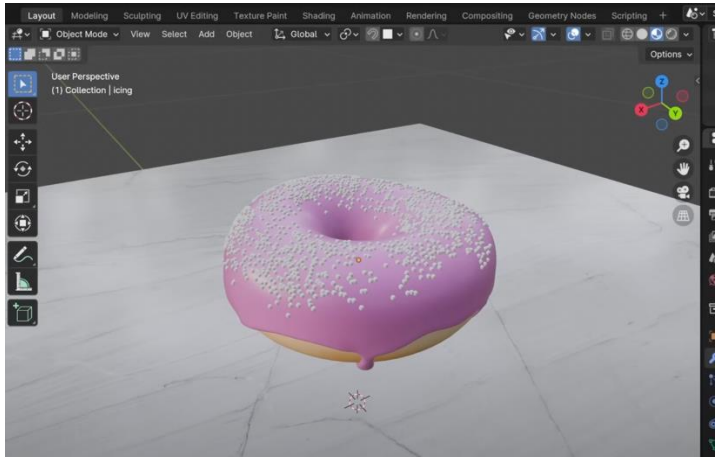
Sculpt the cream layer



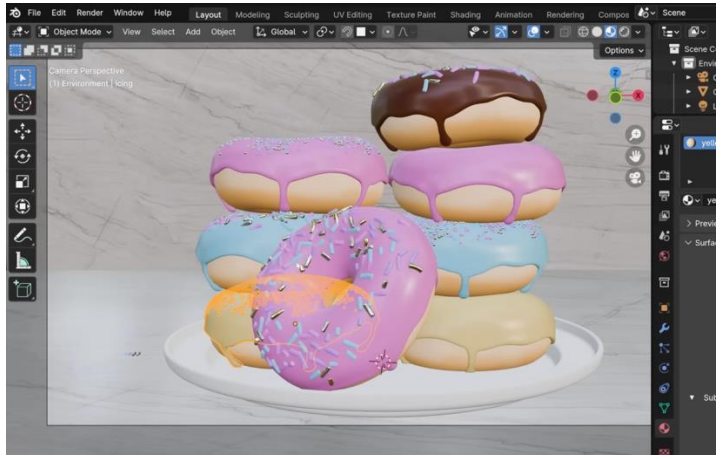
Shading



UV texture



Model sprinkles



Layout and render

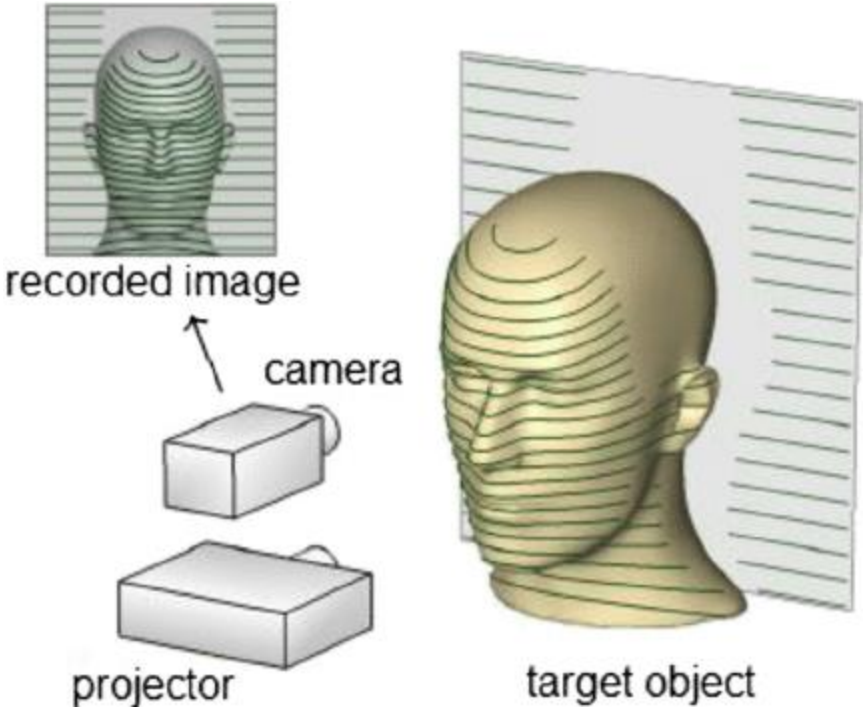
Scanning Technologies

1. Photogrammetry

https://www.capturingreality.com/
https://itseez3d.com/

Scanning Technologies

2. Structured light scanning

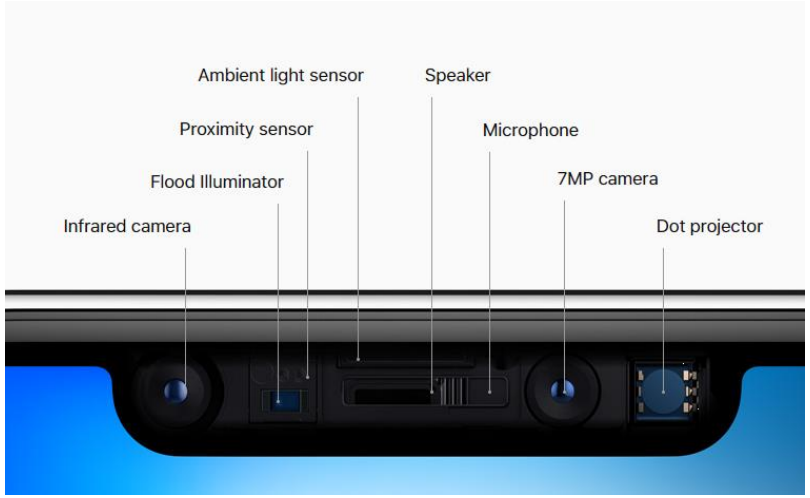


Structured Infrared Light Scanning

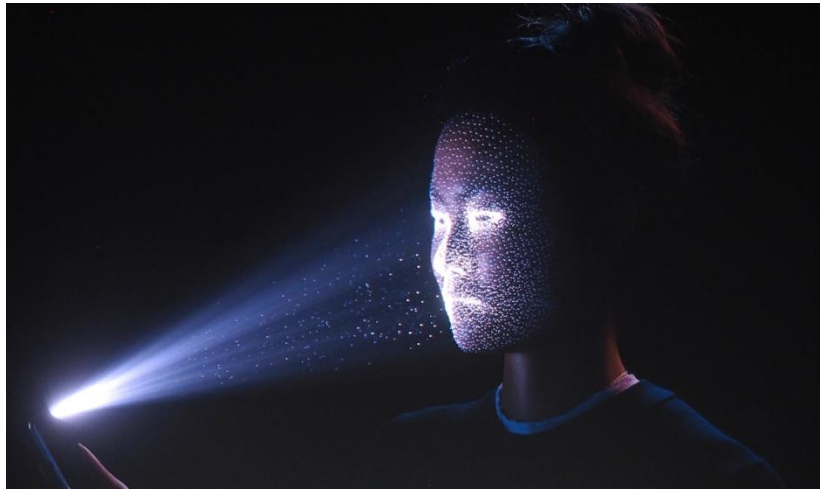
Microsoft Kinect v1

Asus Xtion Pro

http://bbzippo.wordpress.com/2010/11/28/kinect-in-infrared/



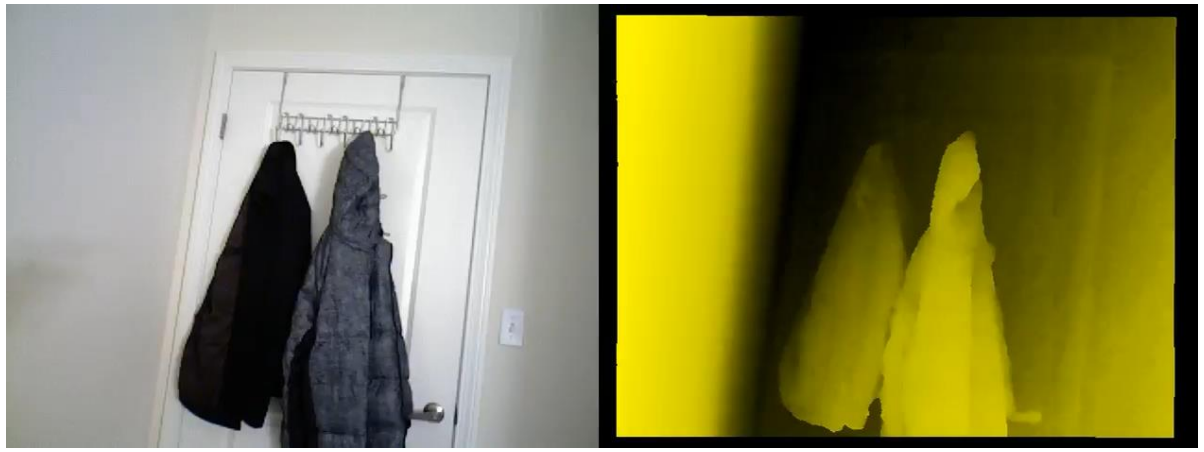
Apple TrueDepth camera and FaceID



https://www.cnet.com/news/apple-face-id-truedepth-how-it-works/

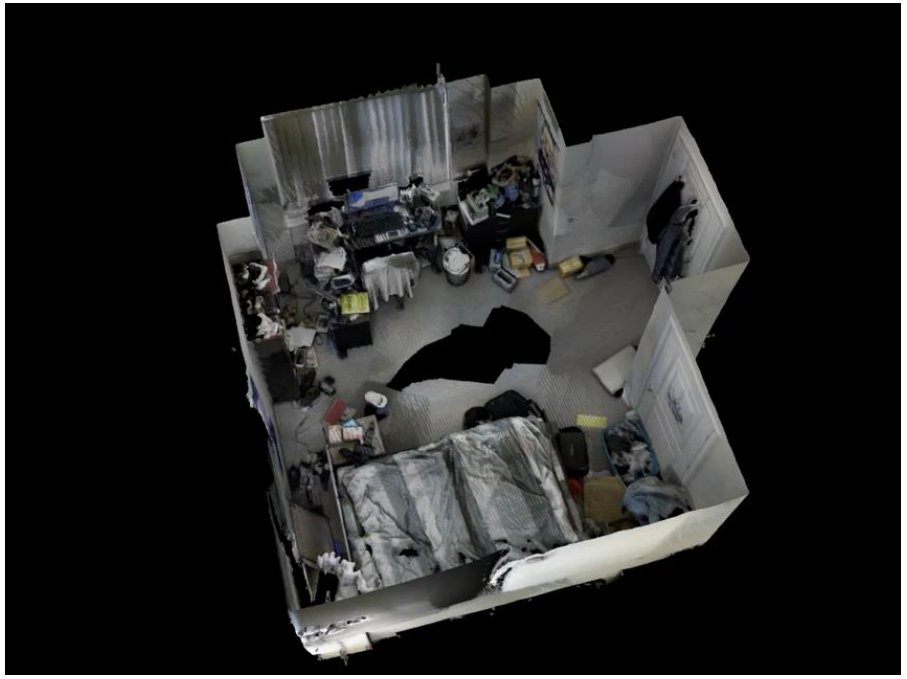
RGB-D Scanning

Capture



- ❑ RGB-D sensors: IR, time-of-flight
- ❑ Handheld camera movement 0.1m/s

Reconstruction



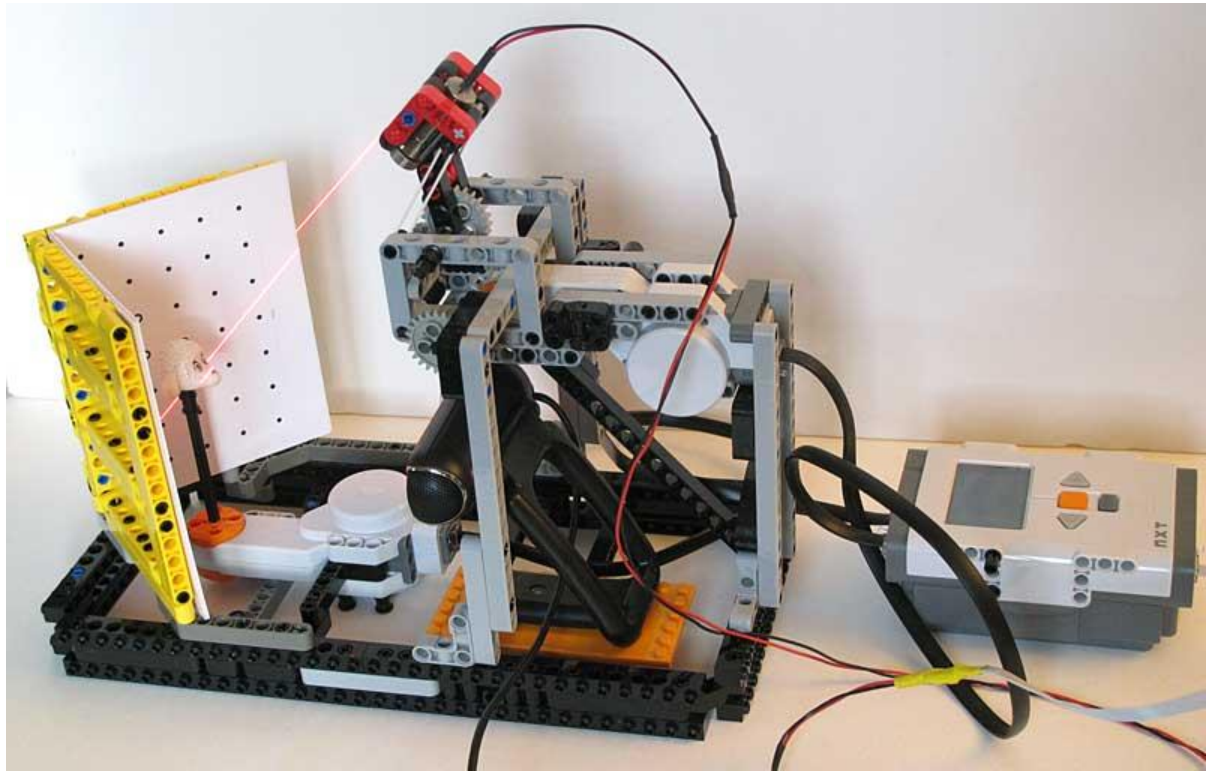
- ❑ Align geometry fragments
- ❑ Remove unreferenced/noisy vertices
- ❑ Median colour for texturing

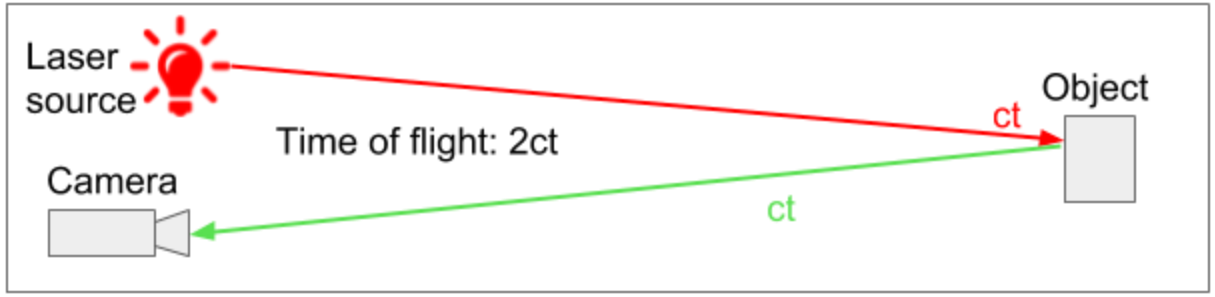
3D reconstruction

https://youtu.be/JMnoVxBmgig?feature=shared

Scanning Technologies

3. Laser scanning





Laser Scanning

- High-quality 3D shape of real-world objects

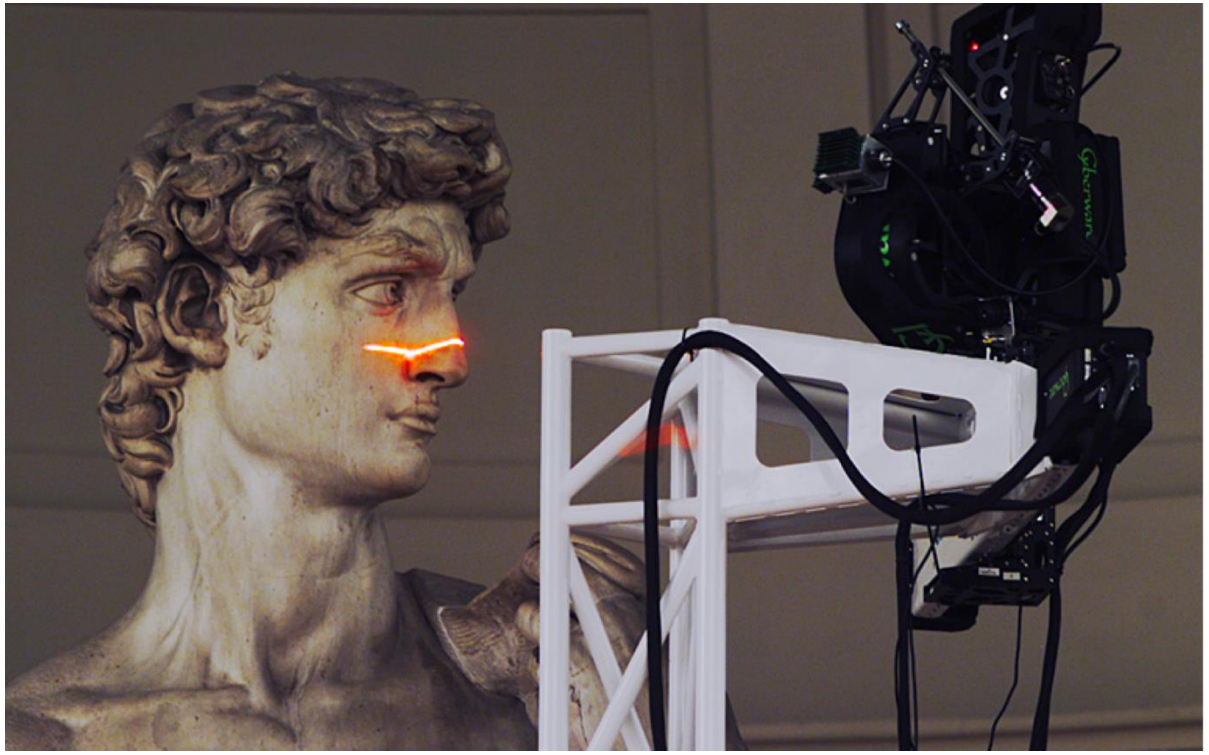


Photo credit: The Digital Michelangelo Project

LiDAR Scanning

- Emit multiple laser pulses and measure **time-of-flight** to estimate distance
- Available on consumer devices since iPad Pro and iPhone 12 (2020).
- Mapping applications for 360-degree look around.
- Depth sensing in autonomous driving applications.

https://twitter.com/iPhonedo/status/1243071065946910721

https://mothership.sg/2022/04/apple-maps-backpack/

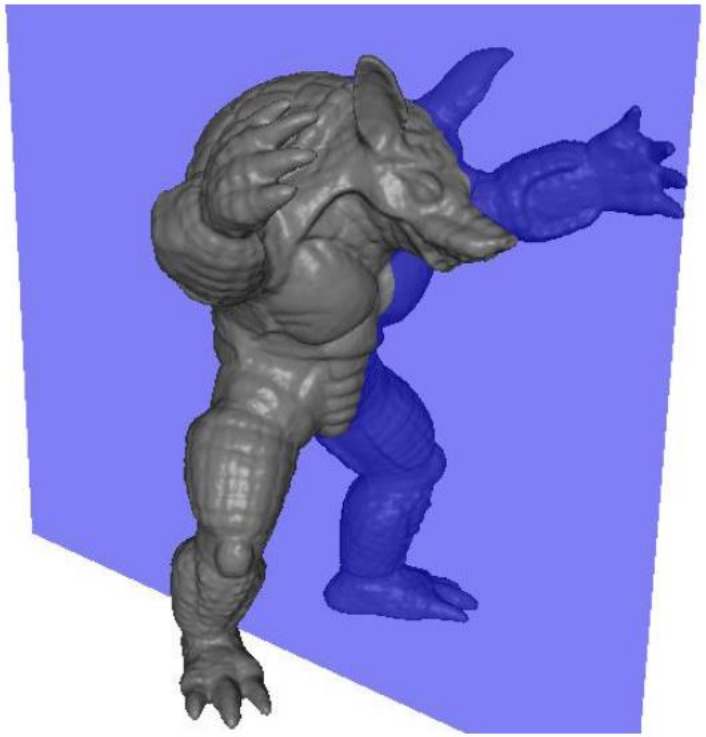
DDAD dataset

Geometry Processing

- After acquiring 3D meshes, some further processing might be required.

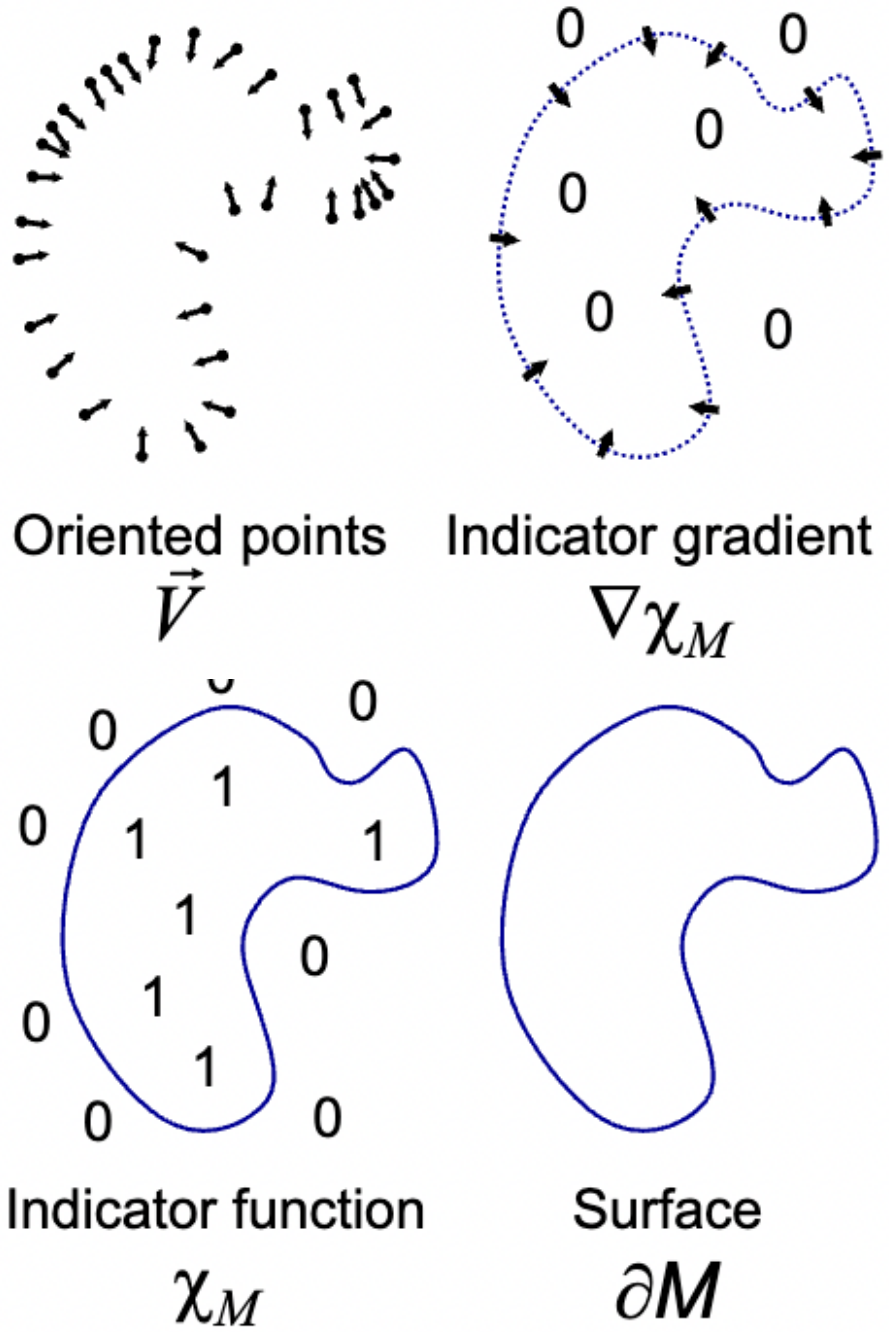
Geometry Processing

- Surface reconstruction from points with normal vectors



Poisson Surface Reconstruction

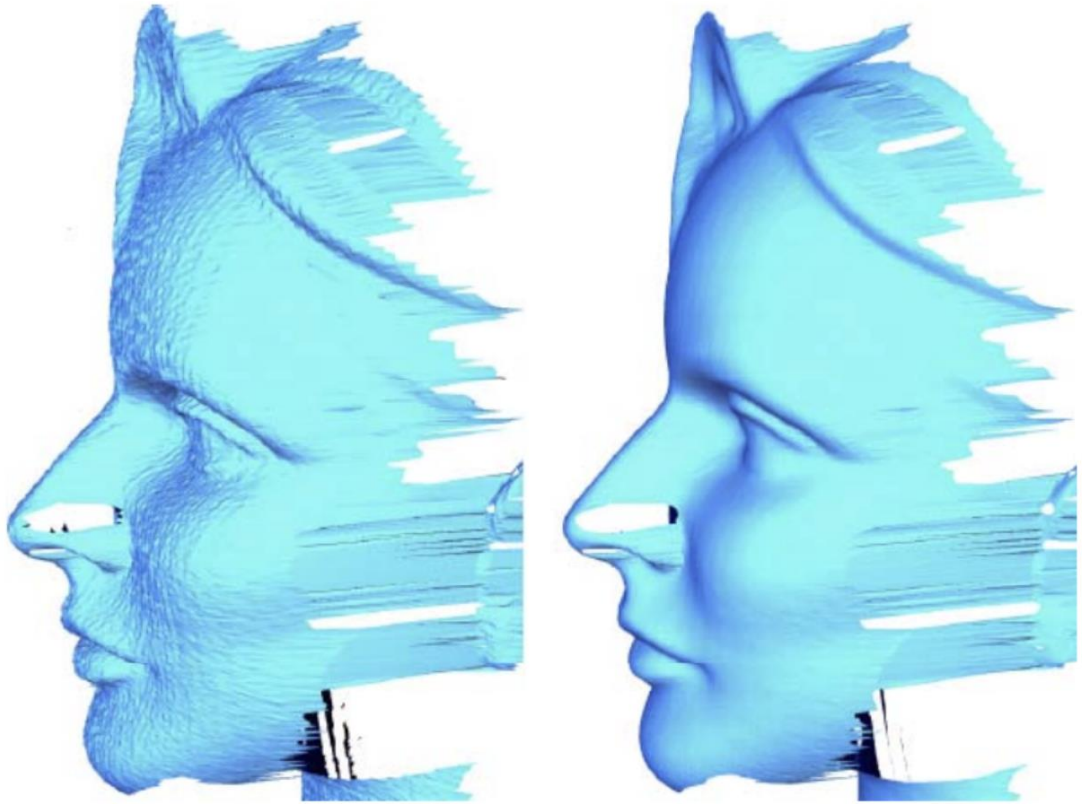
- Compute the **indicator** function (1 inside, 0 outside) from the input point set and extract the surface.
- View the points as the **gradient** samples of the indicators.
- Finding the surface becomes solving a standard Poisson problem



Geometry Processing

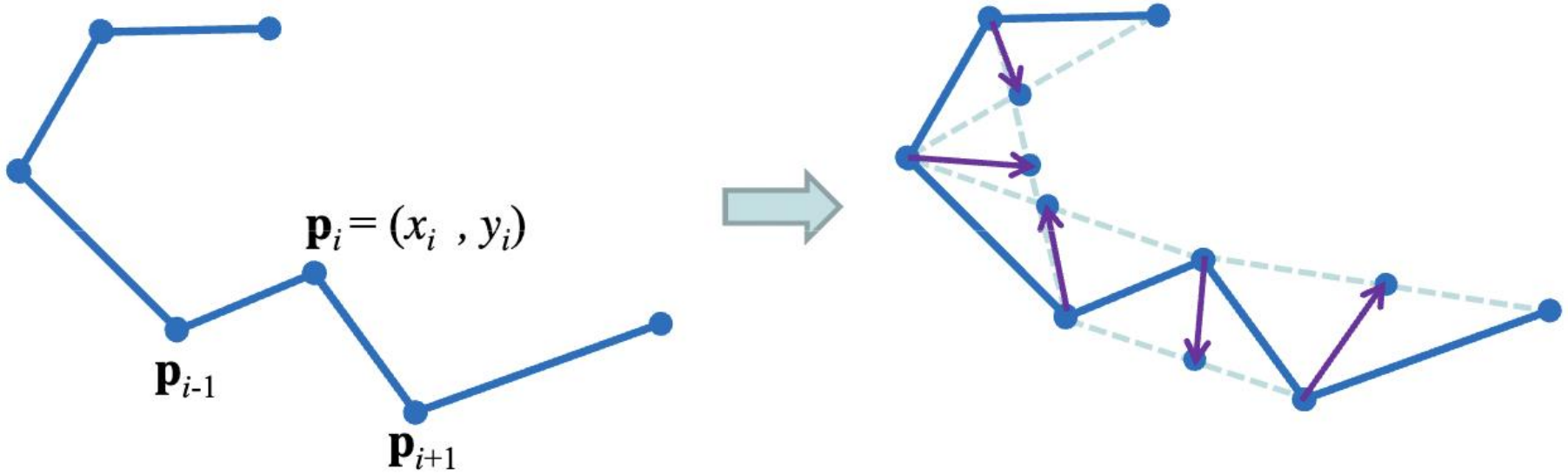
- **Mesh smoothing** to reduce noise

- Filter out high-frequency noise



Laplacian Smoothing

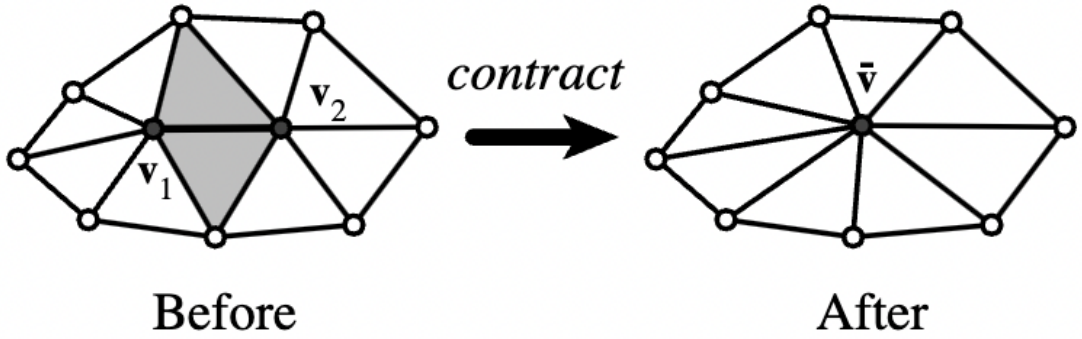
- Take the average of neighbor vertices

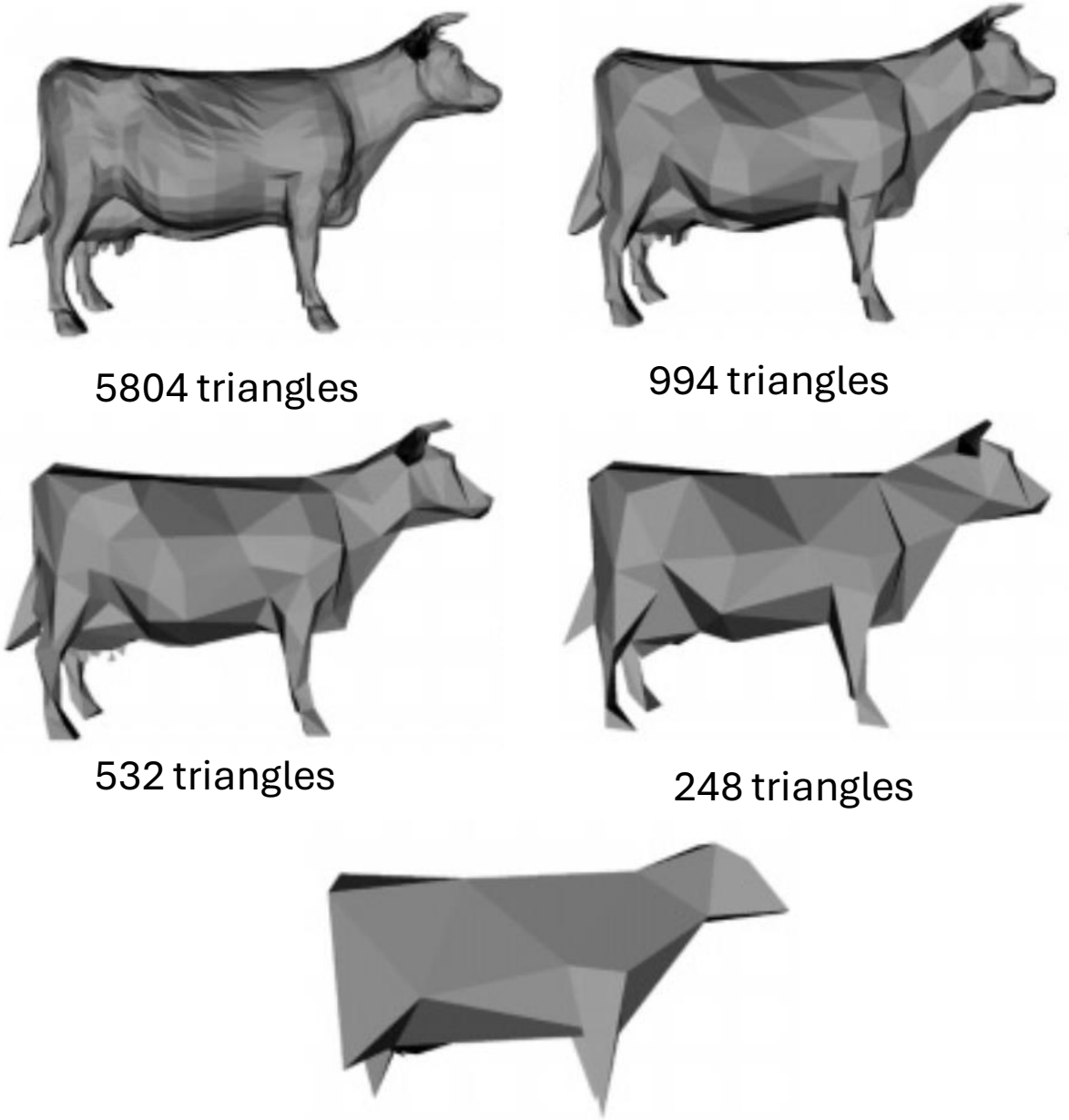


https://graphics.stanford.edu/courses/cs468-12-spring/

Geometry Processing

- **Mesh simplification** to reduce number of triangles for faster rendering

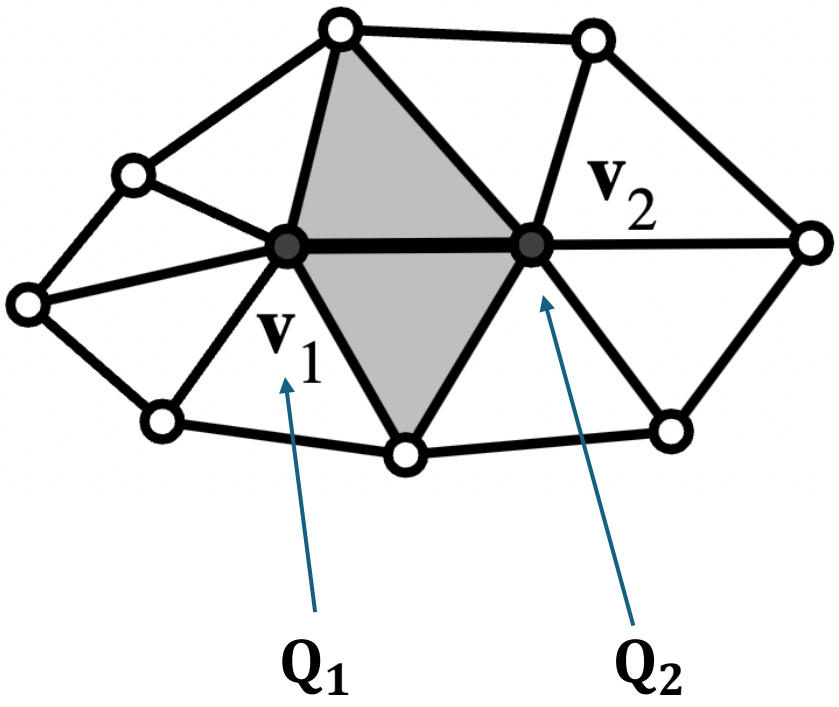




Garland and Heckbert,
Surface Simplification Using Quadric Error Metrics, 1997

Mesh Simplification

- Assign a symmetric 4x4 matrix Q to each vertex
- The error at a vertex **v** due to simplification is defined by $\mathbf{v}^{\mathbf{T}}\mathbf{Q}\mathbf{v}$
- The error of contracting **v1** and **v2** into a vertex **v** is therefore $\mathbf{v}^{\mathbf{T}}(\mathbf{Q_1} + \mathbf{Q_2})\mathbf{v}$
- Keep all errors in a heap and contract the edge with the smallest error

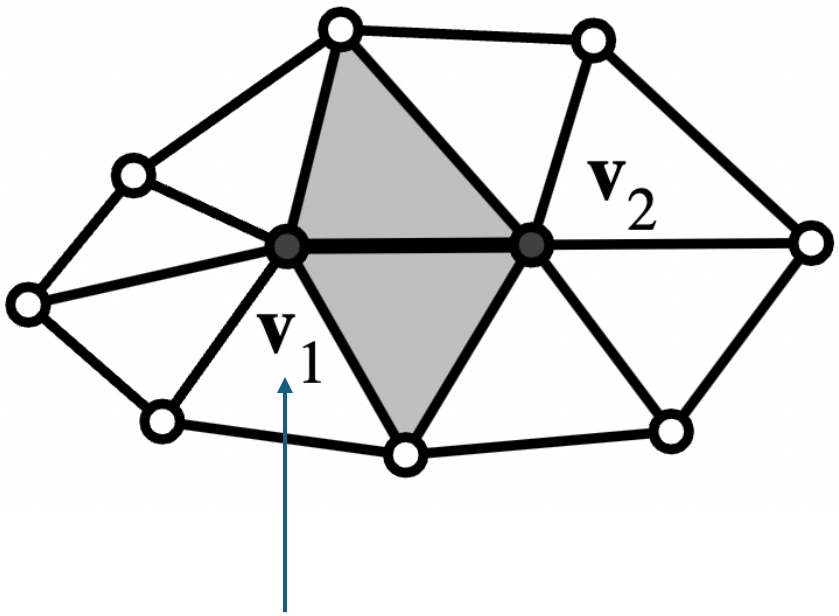


Mesh Simplification

- How to define matrix Q?

- Idea: each vertex in the original 3D model, before simplification, is the intersection of its neighboring planes

- Define Q such that $\mathbf{v}^{\mathbf{T}}\mathbf{Q}\mathbf{v}$ is the sum of squared distances of $\mathbf{v}$ to these planes



6 planes

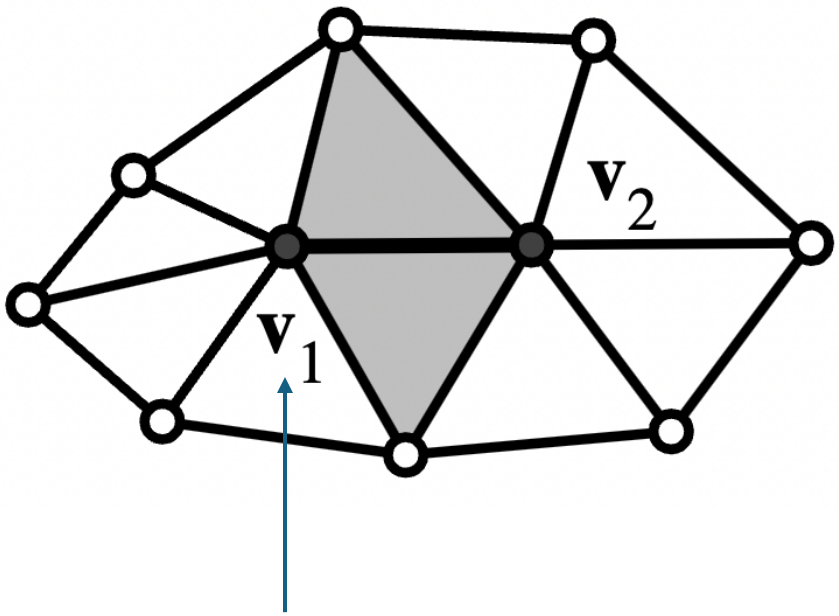
Mesh Simplification

- Parameterize a plane using a vector **p** = [a, b, c, d] such that

$$\boldsymbol{p}^T \boldsymbol{x} = 0$$

for **x** = [x, y, z, 1] is a point on the plane.

- $\boldsymbol{p}^T \boldsymbol{x}$ measures the (signed) distance from point **x** to the plane **p**.



6 planes

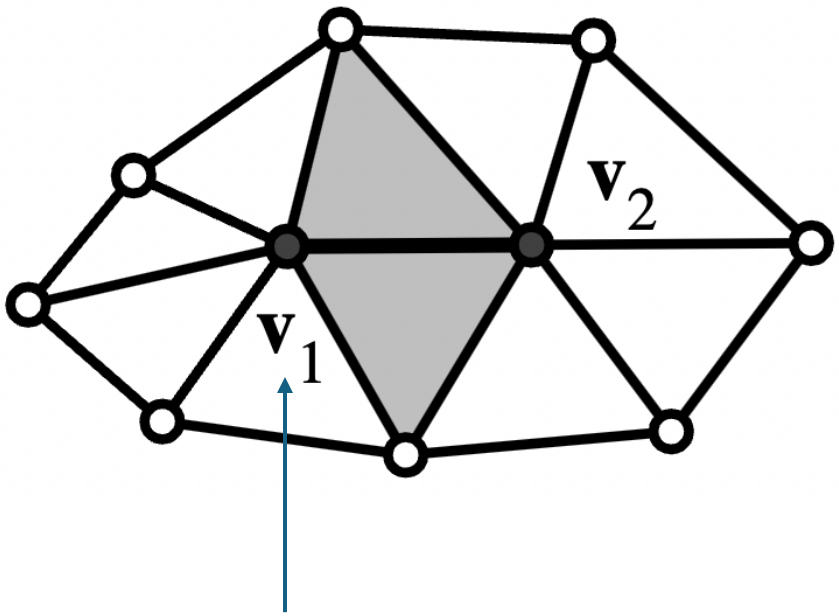
Mesh Simplification

- Derive Q:

$$\text{error(v)} = \sum_{p \in planes(v)} (v^T p)(p^T v)$$

$$\text{error(v)} = v^T \left(\sum_{i \in planes(v)} (pp^T) \right) v$$

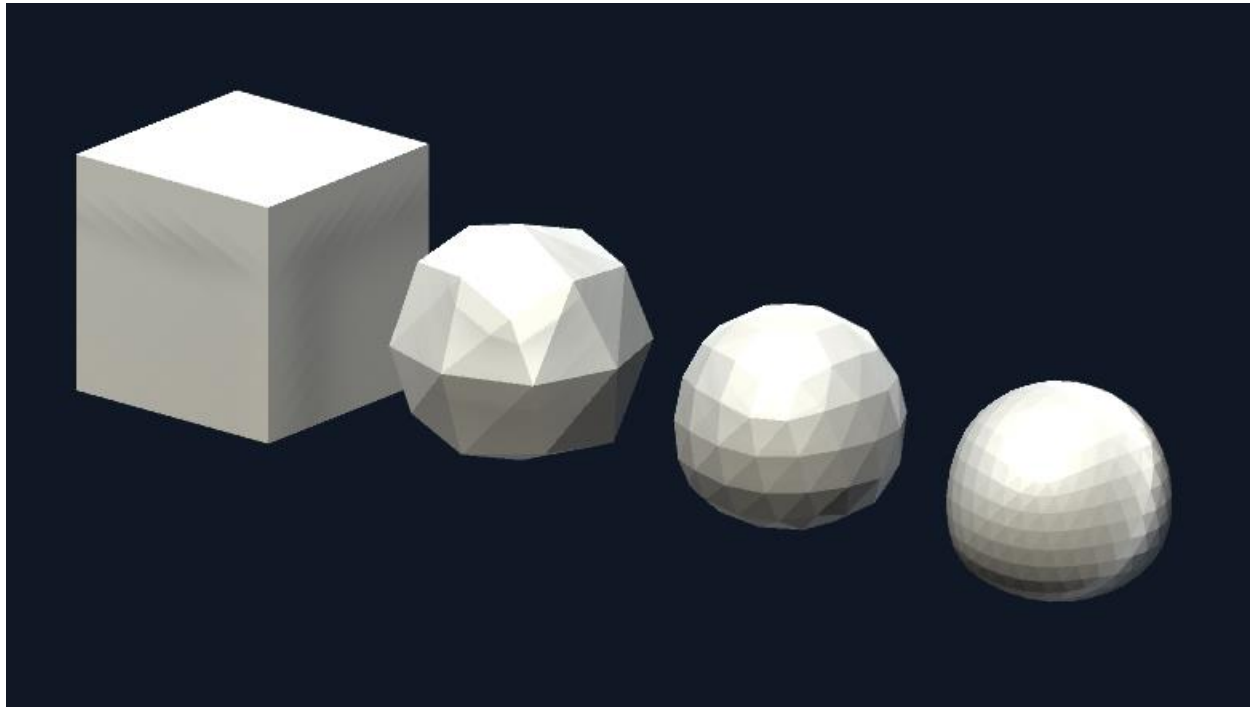
4x4 matrix Q



6 planes

Geometry Processing

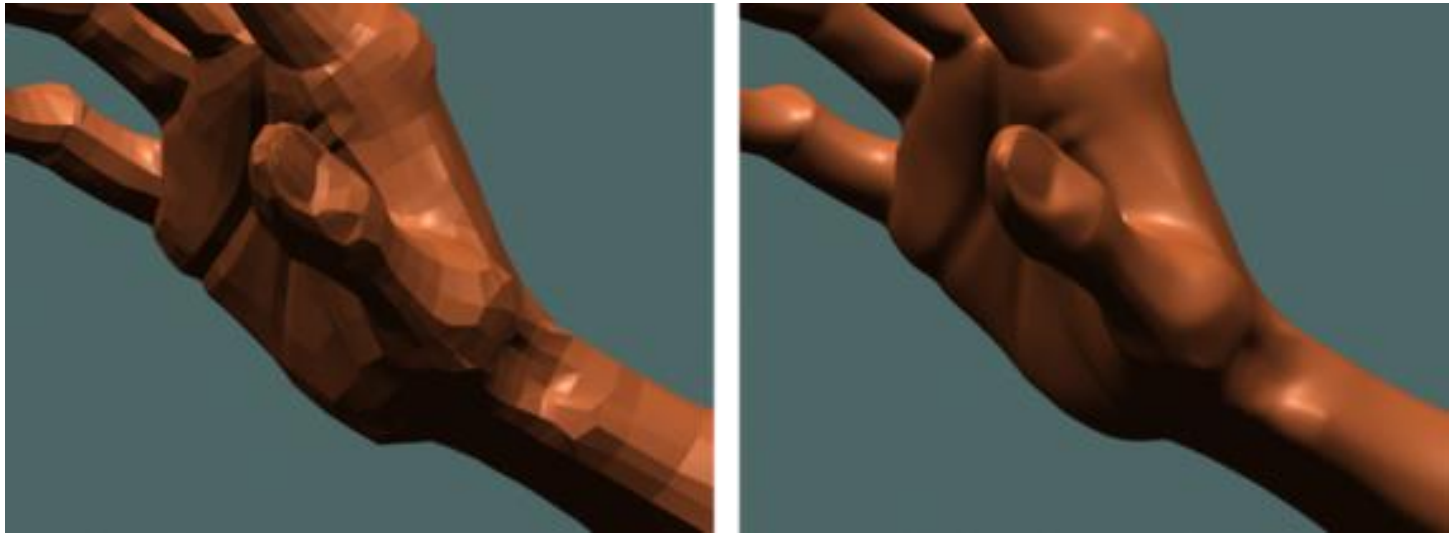
- **Mesh subdivision** defines a smooth curve or surface as the limit of a sequence of successive refinements



Catmull and Clark, Recursively generated B-spline surfaces on arbitrary topological meshes, 1978
Charles Loop, Smooth Subdivision Surfaces Based on Triangles, 1987

Mesh Subdivision

- The very first application of Catmull-Clark subdivision to animation production



Geri's Game, 1997 by Pixar
Subdivision Surfaces in Character Animation, 1998

Mesh Subdivision

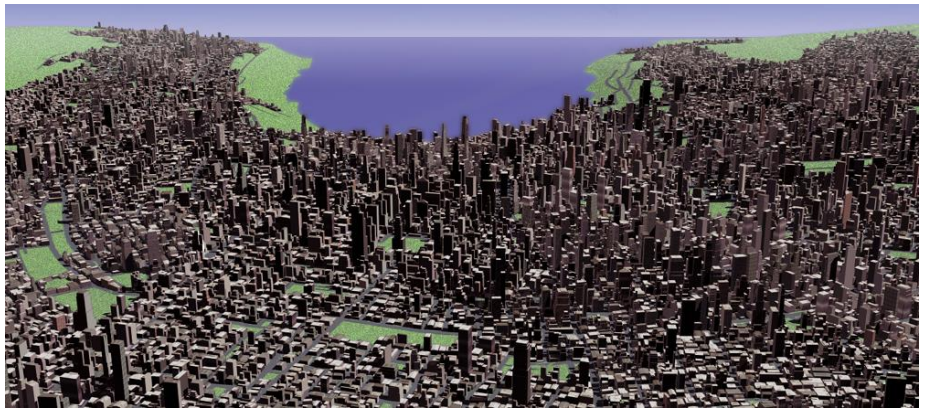
- The very first application of Catmull-Clark subdivision to animation production

https://artsandfood.com/2020/04/exhibition-the-science-behind-pixar.html/

Procedural Modeling

- Good for repetitive structures
- Trees / Plants
- Terrains
- Buildings
- Cities
- Gears

Procedural Modeling of Buildings, SIGGRAPH 2006



Procedural Modeling of Cities, SIGGRAPH 2001

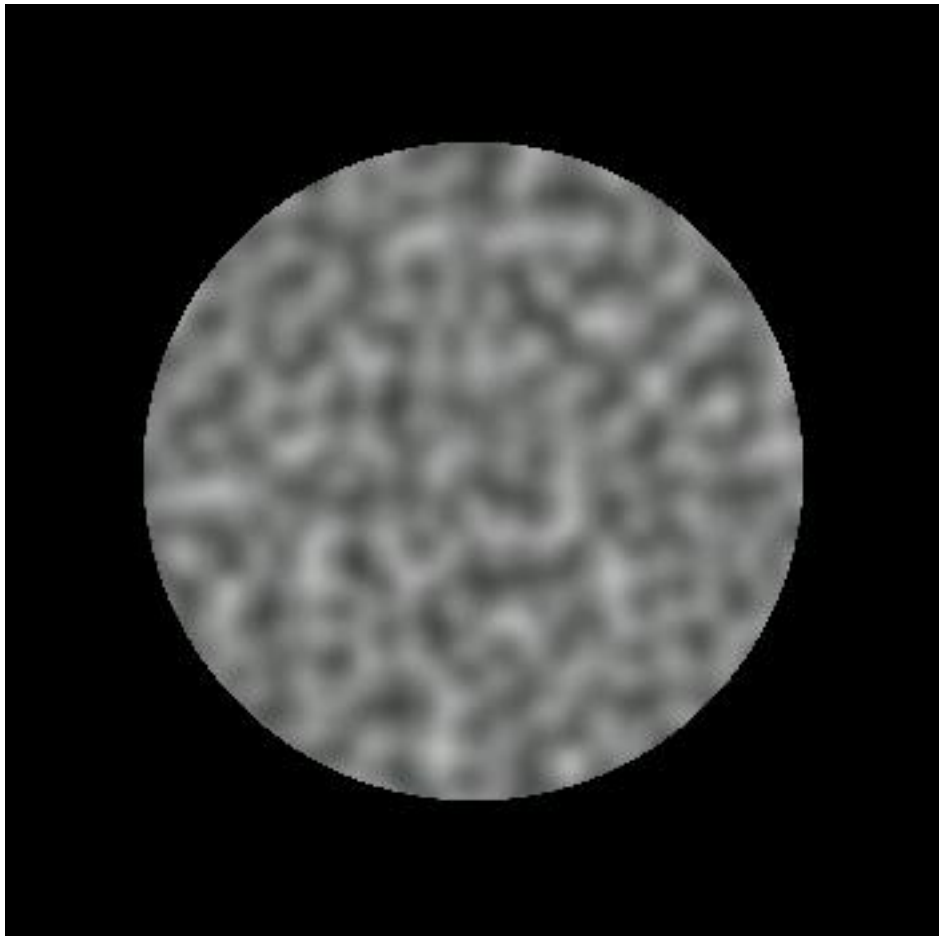
Procedural Textures

Unlike texture mapping, procedural texture is created from noise.

Noise + mathematical expressions = procedural textures.

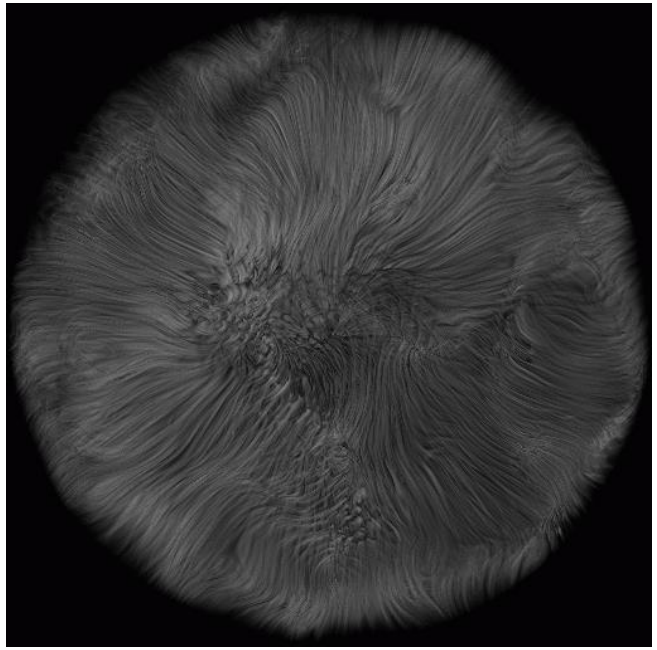
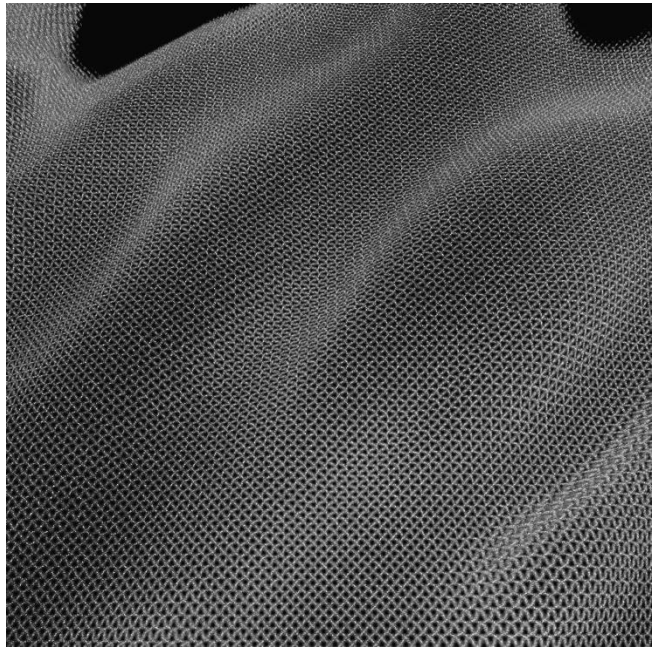
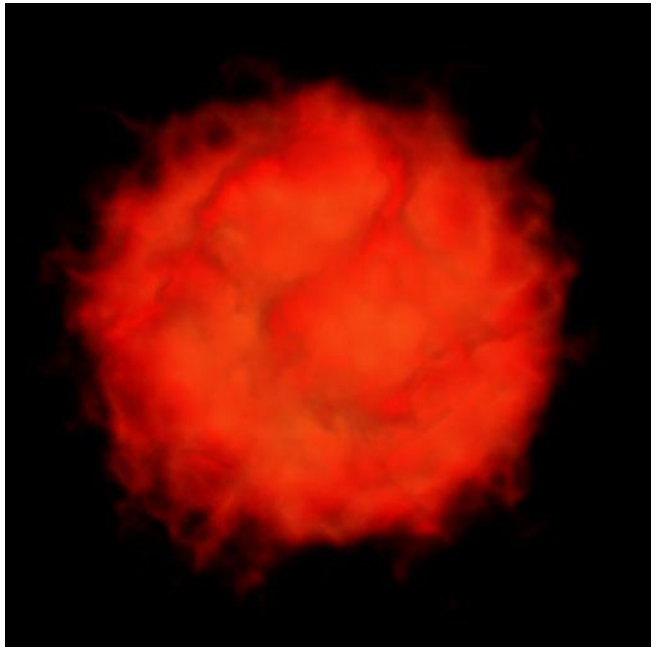
No memory or bandwidth requirements

No mapping problem



https://web.archive.org/web/20160309022253/http://noisemachine.com/talk1/6.html

Procedural Textures

https://mrl.cs.nyu.edu/~perlin/doc/hypertexture/

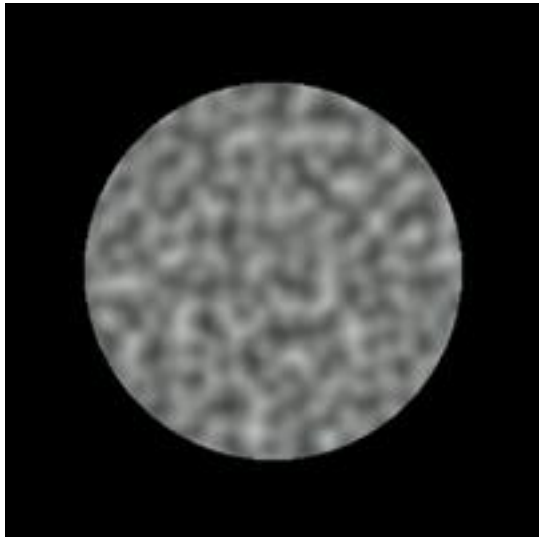
Perlin Noise

- Academy Award for Technical Achievement technique

“To Ken Perlin for the development of Perlin Noise, a technique used to produce natural appearing textures on computer generated surfaces for motion picture visual effects.”

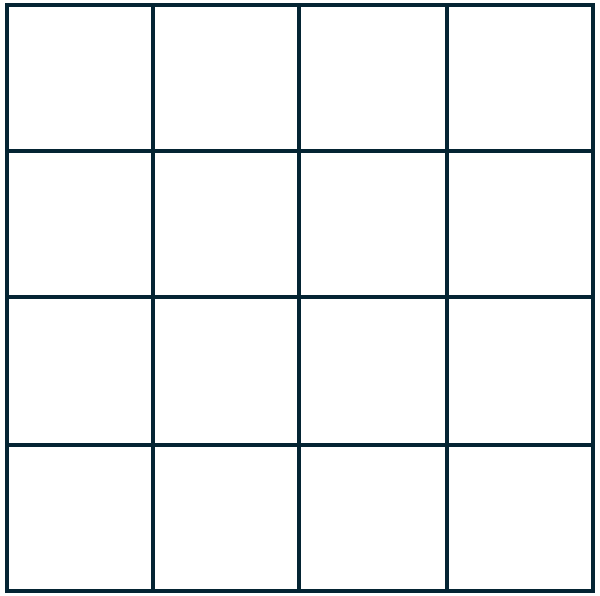
Perlin Noise

- Repeatable, pseudo-random signal in 1D, 2D, 3D that is band-limited and visually isotropic.
- It looks like a random signal (white noise) where all high spatial frequencies are removed.



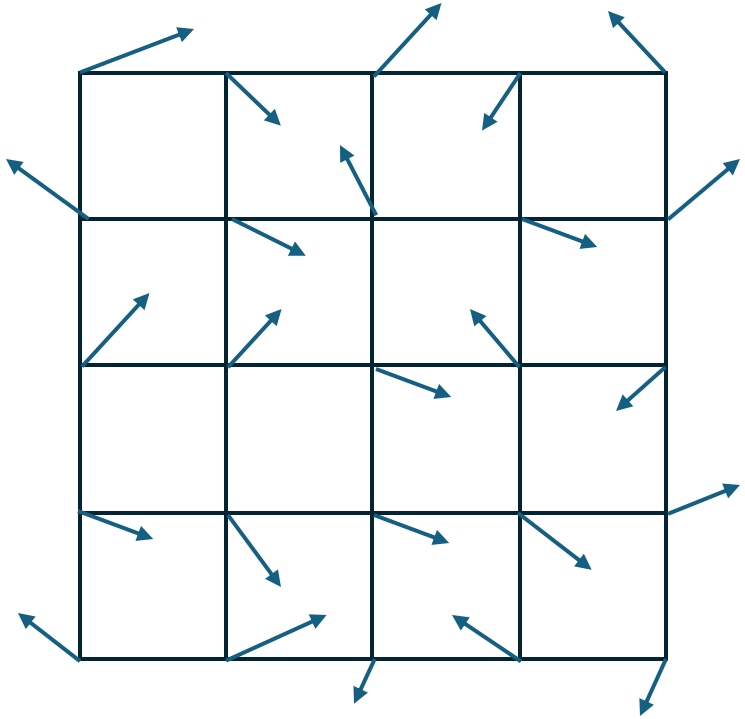
2D Perlin Noise

- Define an initial grid



2D Perlin Noise

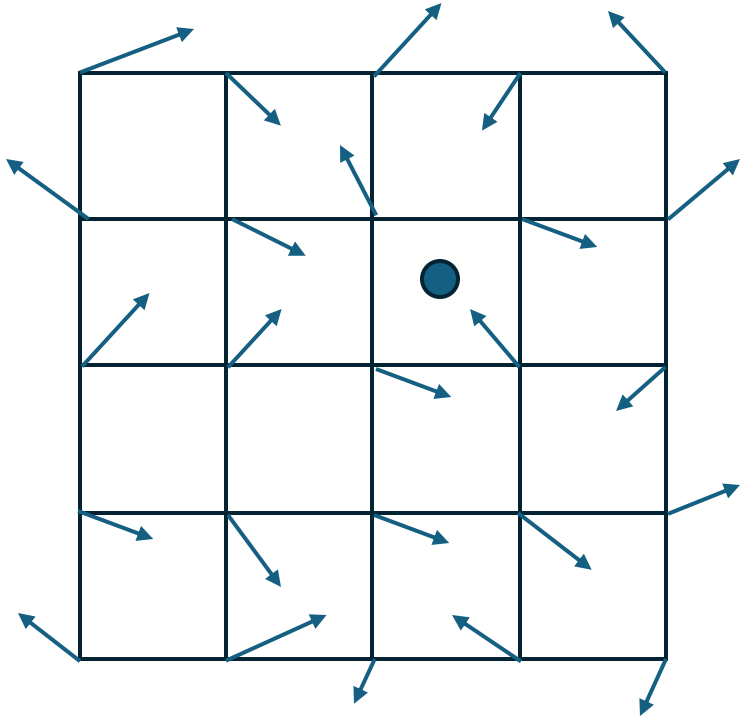
- Random gradient vectors at grid corners

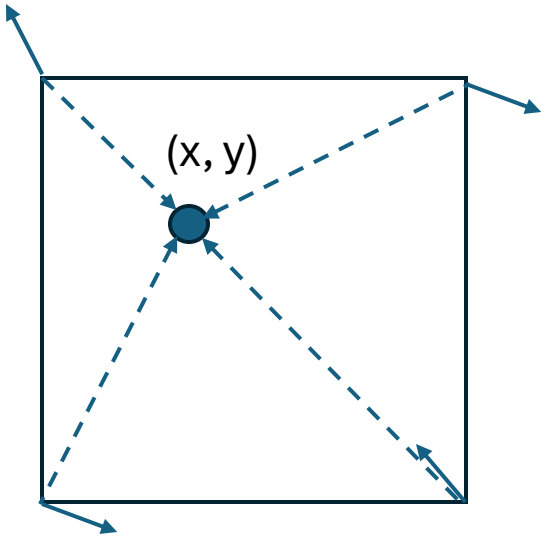


Think of a terrain where the vectors model its slopes

2D Perlin Noise

- For each point (x, y), interpolate from four neighboring corners





- Take the dot product of the gradient vector and the dashed vector at each corner
- Noise(x, y) = interpolated values of the dot product results

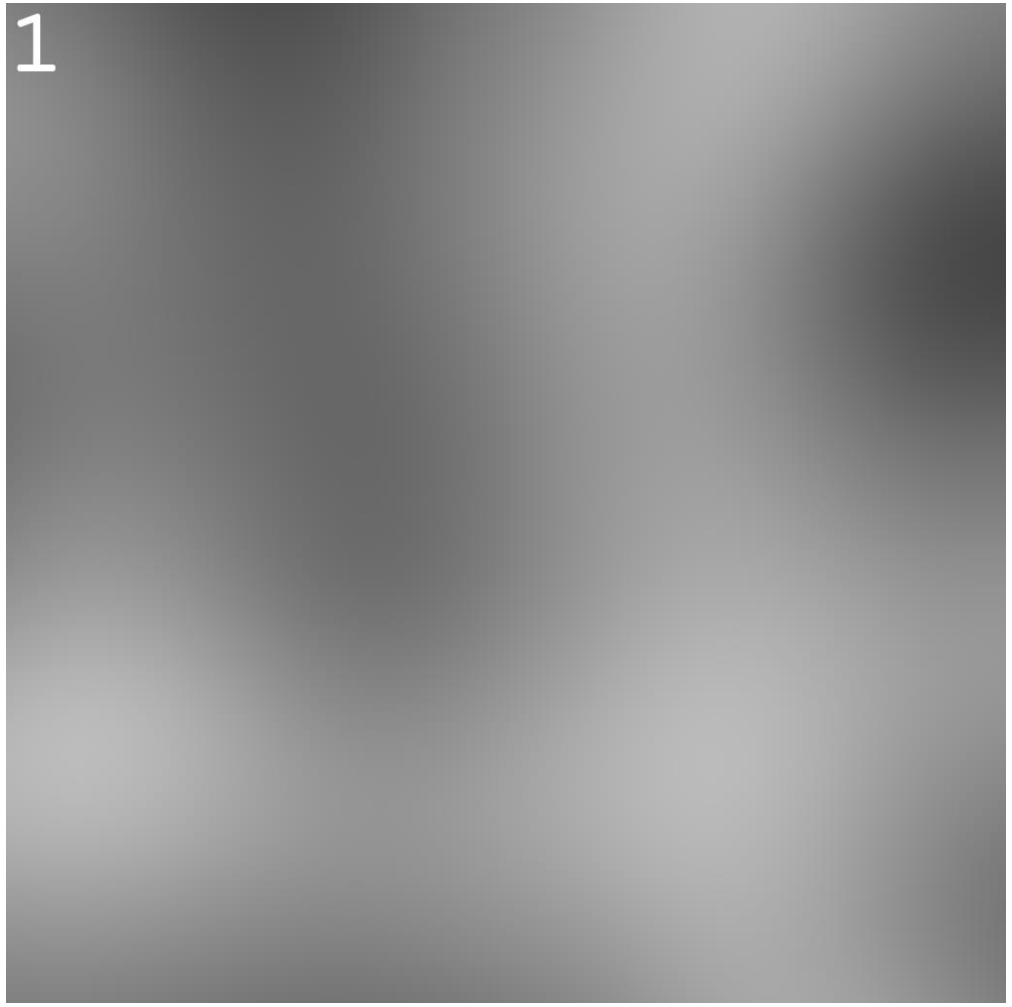
2D Perlin Noise

- Add self-similarity by

$$noise(x, y)$$

$$+\frac{1}{2}noise(2x, 2y)$$

$$+\frac{1}{4}noise(4x, 4y) + \ \ldots$$



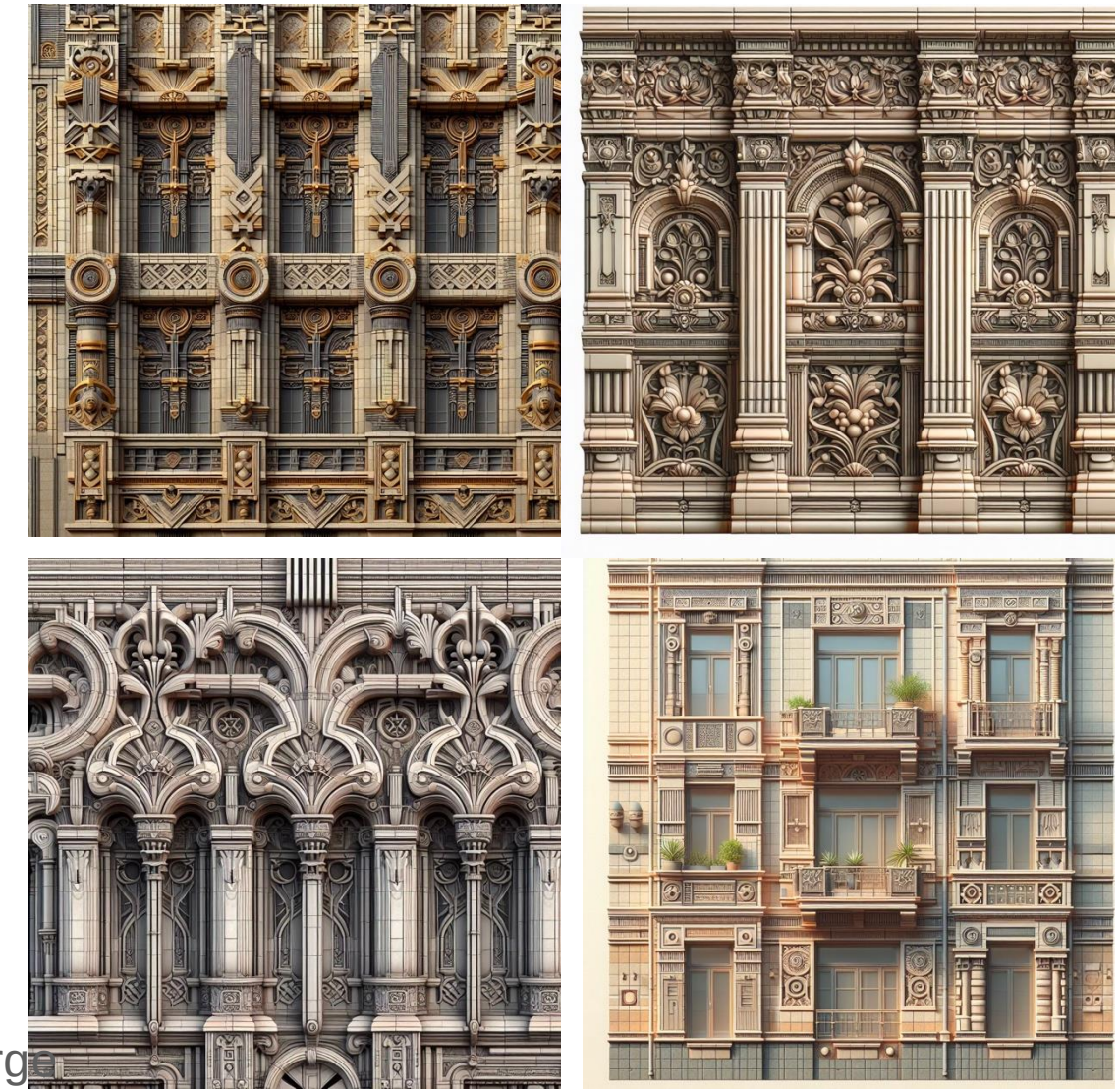
Animation of Perlin noise in which 6 octaves of 2-D noise are added together. The result is fractal noise.

Source: Wikipedia

Generative Modeling

- A fast-evolving research area is to use neural networks to synthesize 3D models
- Generate images from text prompts
- Generate 3D models from text prompts
- Generate 3D models from reference images

Text-to-Image Generation



A photo of a large, grinning, twelve-legged cat with a large bushy tail and a hollow body that serves as a bus, with windows and seats covered with fur (Studio Ghibli)

"A texture map for building facade"

Text-to-3D Generation

A blue jay standing on a large basket of rainbow macarons.

Credit: ProlificDreamer

Text-to-3D Generation

A 3D model of an adorable cottage with a thatched roof

A birthday cake rendered in 3D

Text-to-3D generation

A flower in a hand crafted vase

Tran et al., DiverseDream: Diverse Text-to-3D Synthesis with Augmented Text Embedding, ECCV 2024

Image-to-3D Generation

Voleti et al., SV3D: Novel Multi-view Synthesis and 3D Generation from a Single Image using Latent Video Diffusion
https://sv3d.github.io/ and https://huggingface.co/stabilityai/sv3d ECCV 2024

Further Reading

- Implementing Improved Perlin Noise: https://developer.nvidia.com/gpugems/gpugems/part-i-natural-effects/chapter-5-implementing-improved-perlin-noise

- High-Resolution Image Synthesis with Latent Diffusion Models https://arxiv.org/abs/2112.10752

- Text-to-3D generation: https://dreamfusion3d.github.io/