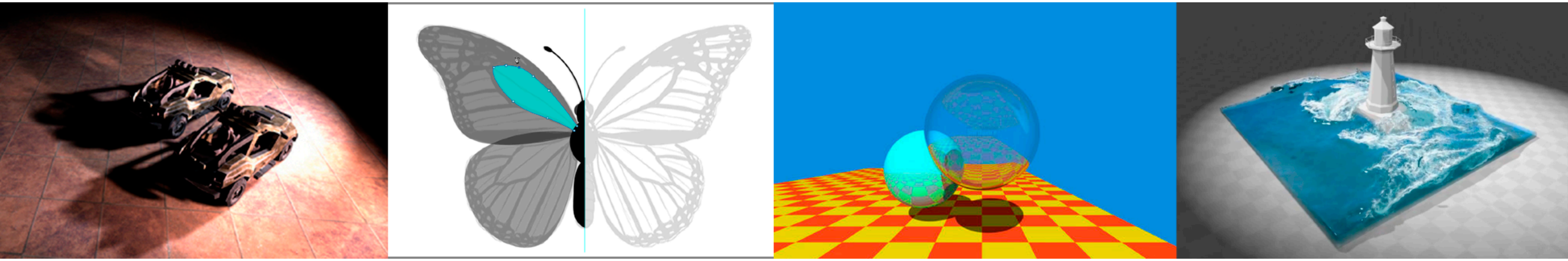
Introduction to Computer Graphics

GAMES101, Lingqi Yan, UC Santa Barbara

Lecture 10:

Geometry 1 (Introduction)



http://www.cs.ucsb.edu/~lingqi/teaching/games101.html

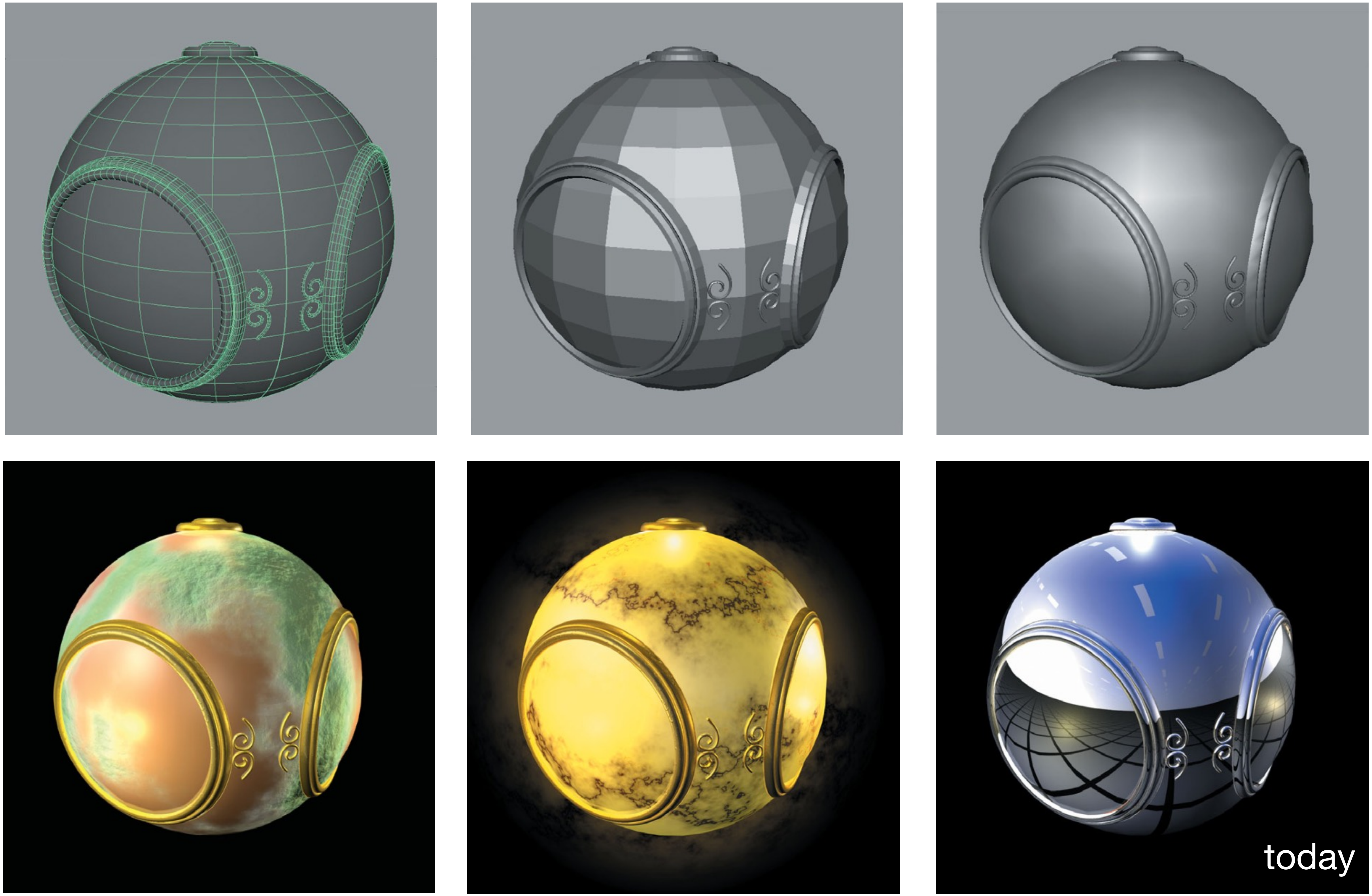
Announcements

- Homework 3
  - The framework has been updated
  - Together with an “FAQ” section in the BBS
- New TAs
  - Peng Yu (禹鹏)，BUAA，y2505418927@gmail.com
  - Wenxian Guo (郭文鲜)，ZJU，wxguojlu@hotmail.com

Last Lectures

- Shading 1 & 2
    - Blinn-Phong reflectance model
    - Shading models / frequencies
    - Graphics Pipeline
    - Texture mapping
- Shading 3
    - Barycentric coordinates
    - Texture antialiasing (MIPMAP)
    - Applications of textures

Last Lectures



Today

- Applications of textures
- Introduction to geometry (2nd part of this course!)
  - Examples of geometry
  - Various representations of geometry

Applications of Textures

Many, Many Uses for Texturing

In modern GPUs, texture = memory + range query (filtering)

- General method to bring data to fragment calculations

Many applications

- Environment lighting
- Store microgeometry
- Procedural textures
- Solid modeling
- Volume rendering
- …

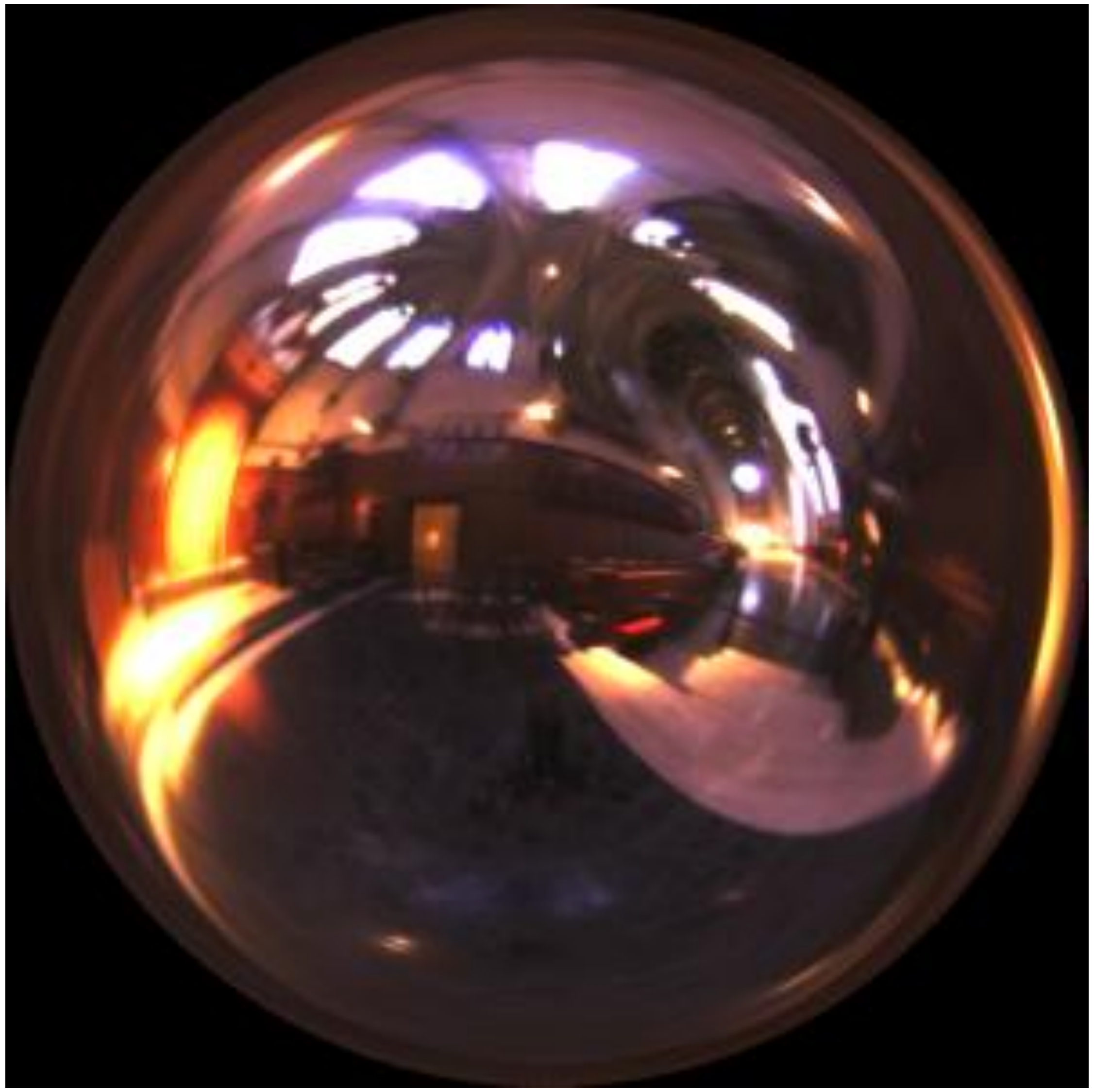
Environment Map

Light from the environment

[Blinn & Newell 1976]

Rendering with the environment

Environmental Lighting



Environment map (left) used to render realistic lighting

Spherical Environment Map

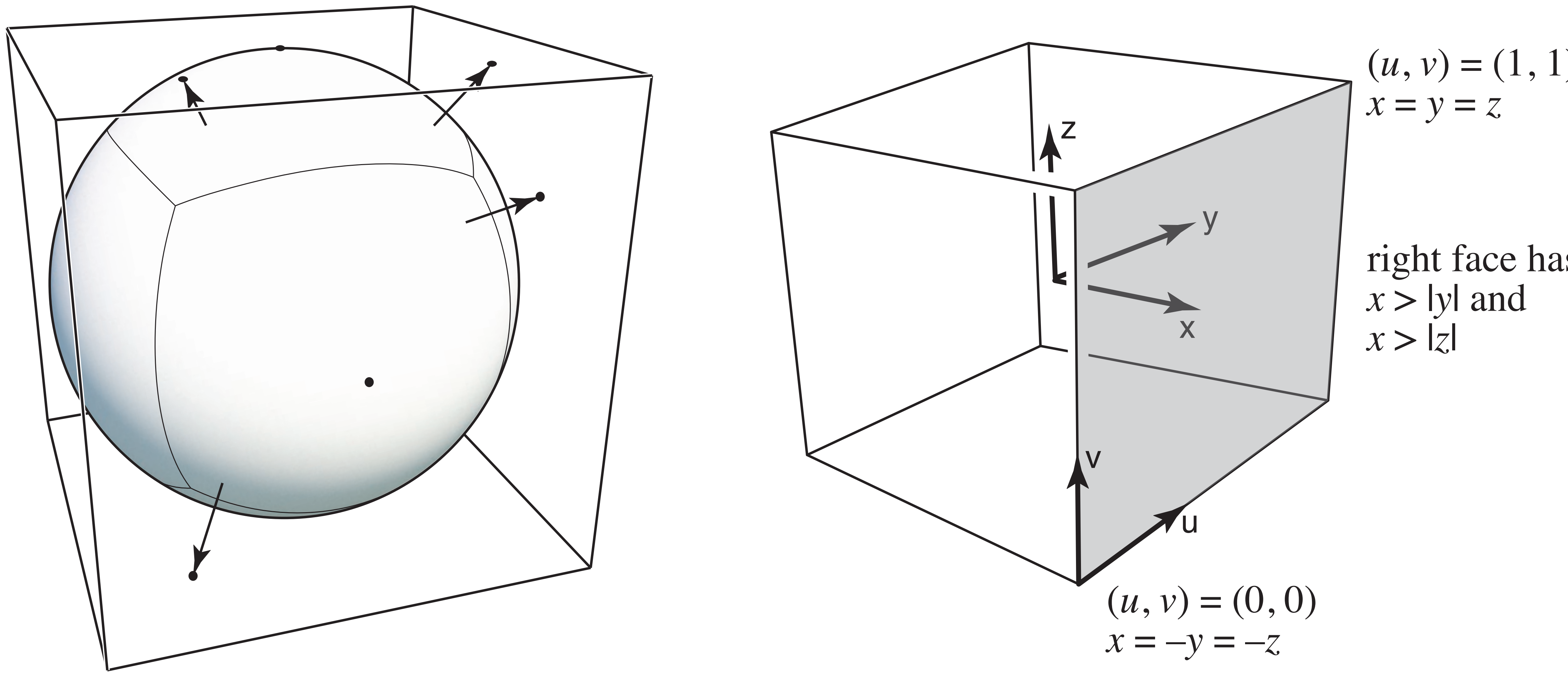
Hand with Reflecting Sphere. M. C. Escher, 1935. lithograph

Light Probes, Paul Debevec

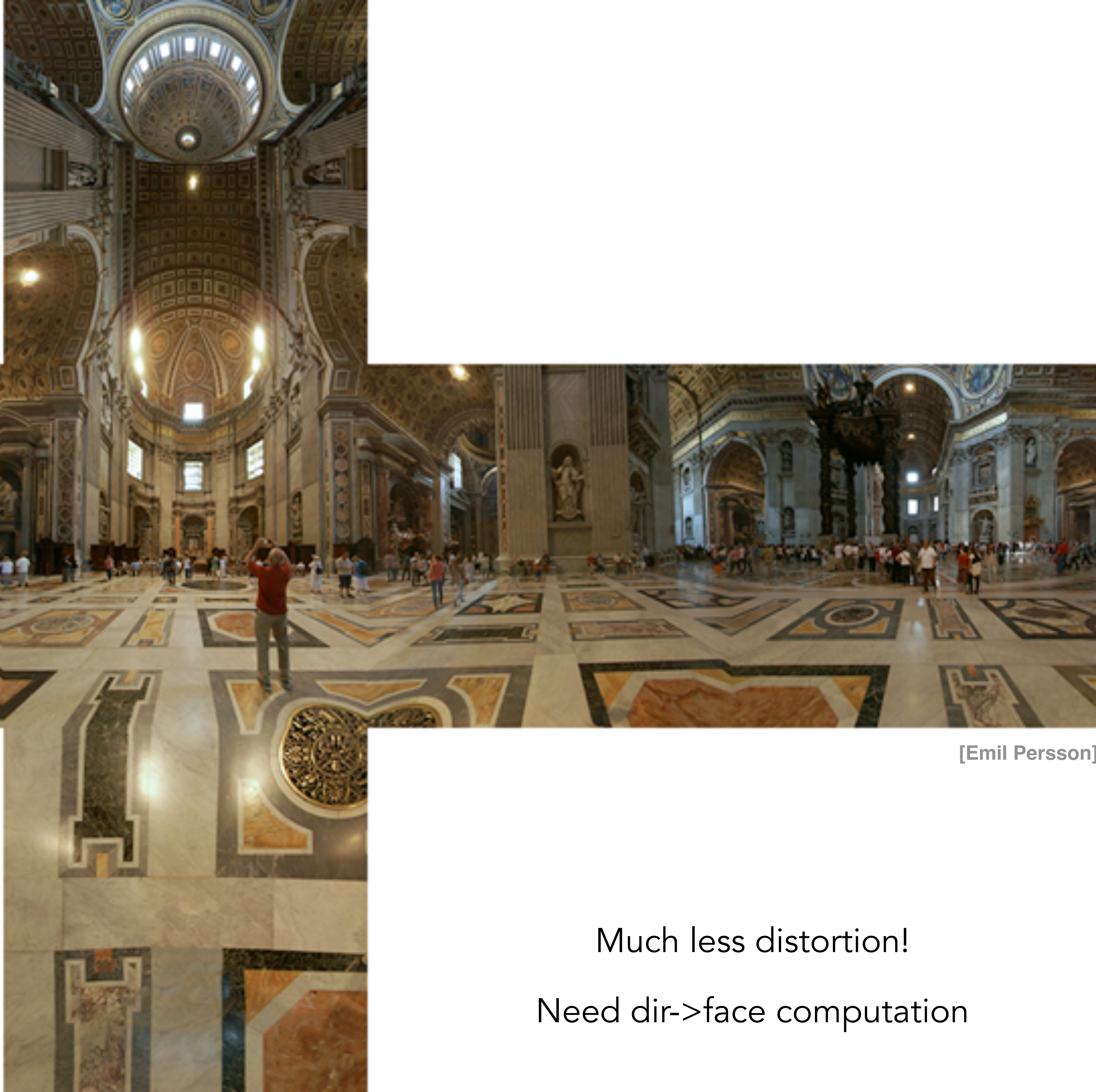
Spherical Map — Problem

Prone to distortion (top and bottom parts)!

Cube Map



A vector maps to cube point along that direction.
The cube is textured with 6 square texture maps.



[Emil Persson]

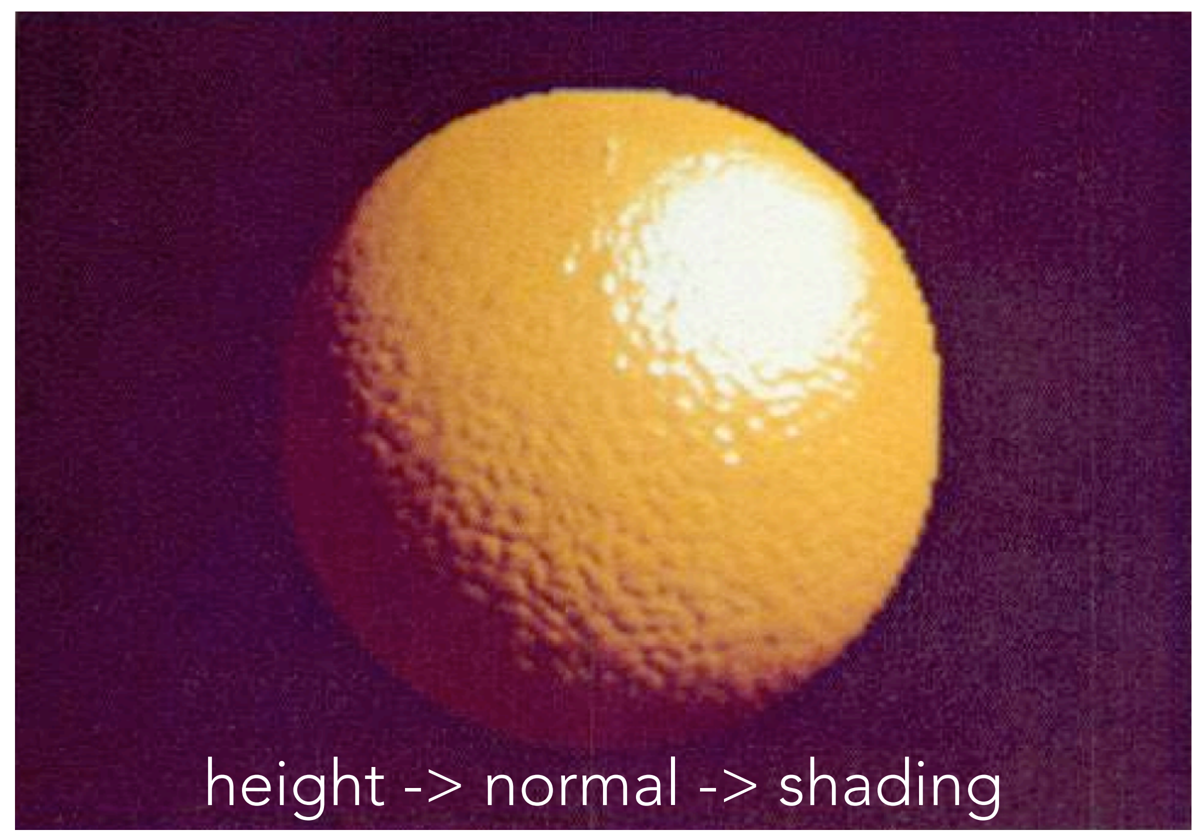
Much less distortion!

Need dir->face computation

Textures can affect shading!

- Textures doesn't have to only represent colors
  - What if it stores the height / normal?
  - Bump / normal mapping
  - **Fake** the detailed geometry

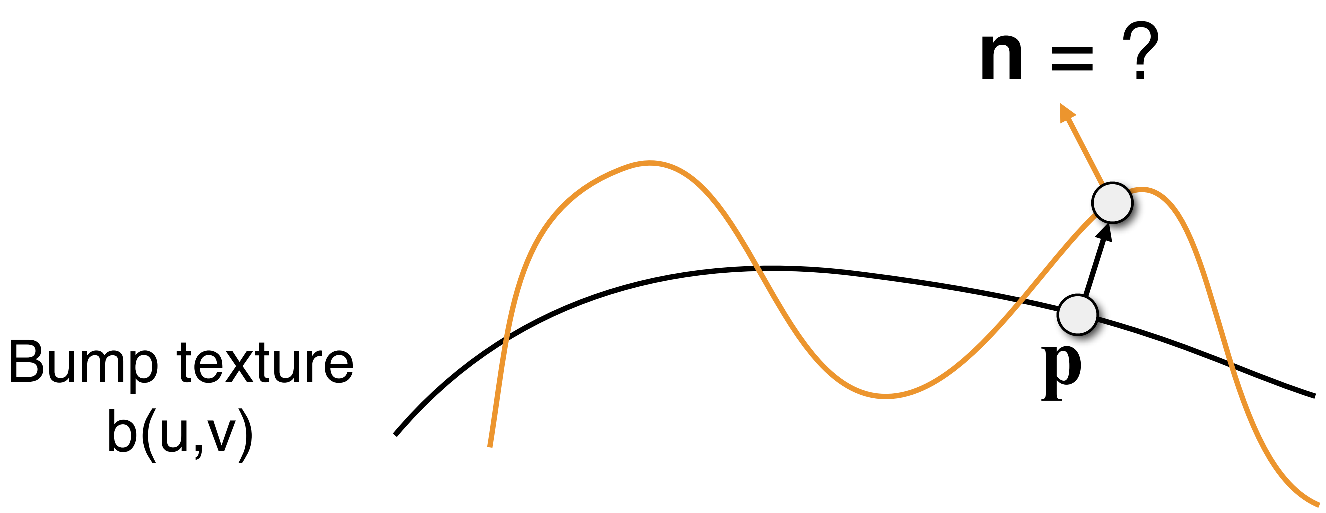
Relative height to the underlying surface



Bump Mapping

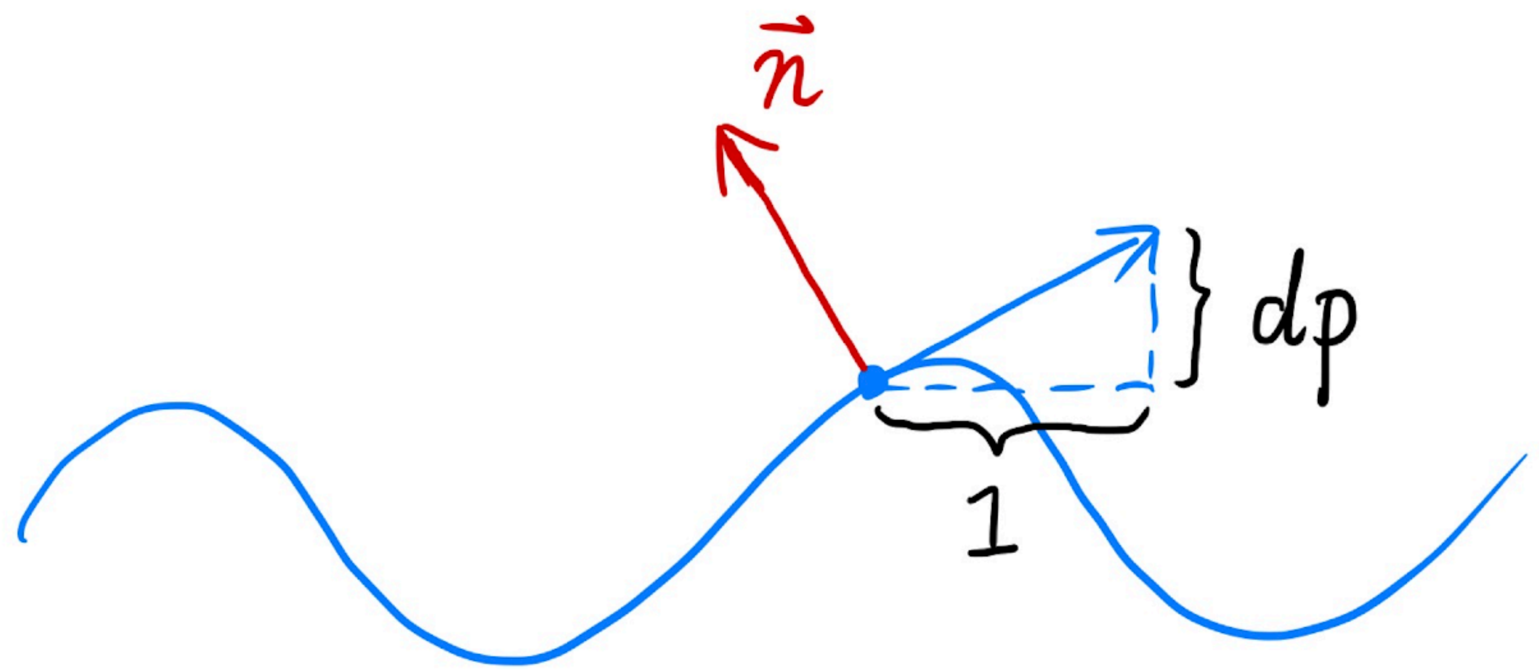
Adding surface detail without adding more triangles

- Perturb surface normal per pixel (for shading computations only)
- "Height shift" per texel defined by a texture
- How to modify normal vector?



How to perturb the normal (in flatland)

- Original surface normal n(p) = (0, 1)
- Derivative at p is dp = c * [h(p+1) - h(p)]
- Perturbed normal is then n(p) = **(-dp, 1)**.normalized()

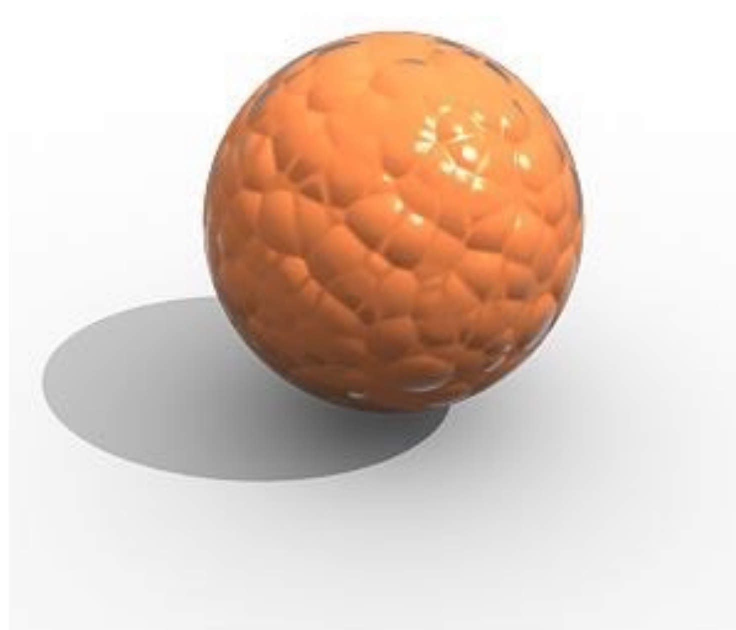


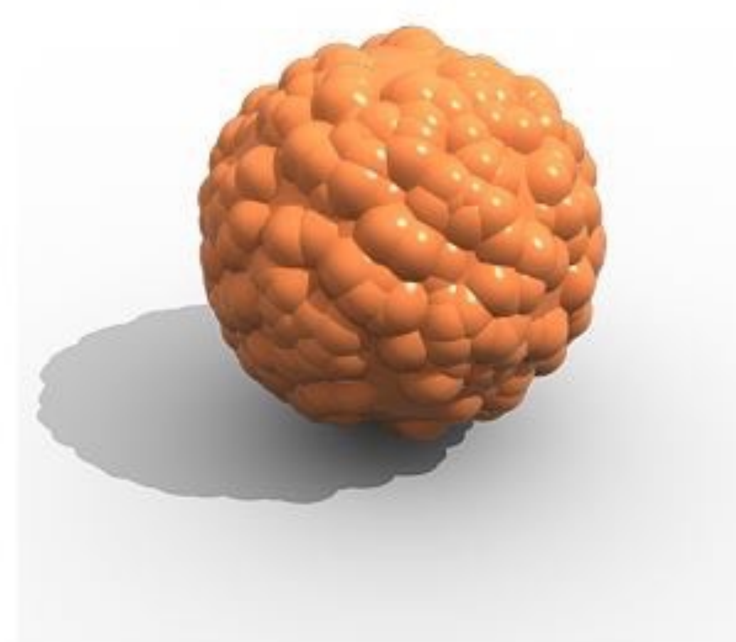
How to perturb the normal (in 3D)

- Original surface normal n(p) = (0, 0, 1)
- Derivatives at p are
  - dp/du = c1 * [h(**u**+1) - h(**u**)]
  - dp/dv = c2 * [h(**v**+1) - h(**v**)]
- Perturbed normal is n = **(-dp/du, -dp/dv, 1)**.normalized()
- Note that this is in **local coordinate**!
  More will be elaborated in FAQ of HW3

Textures can affect shading!

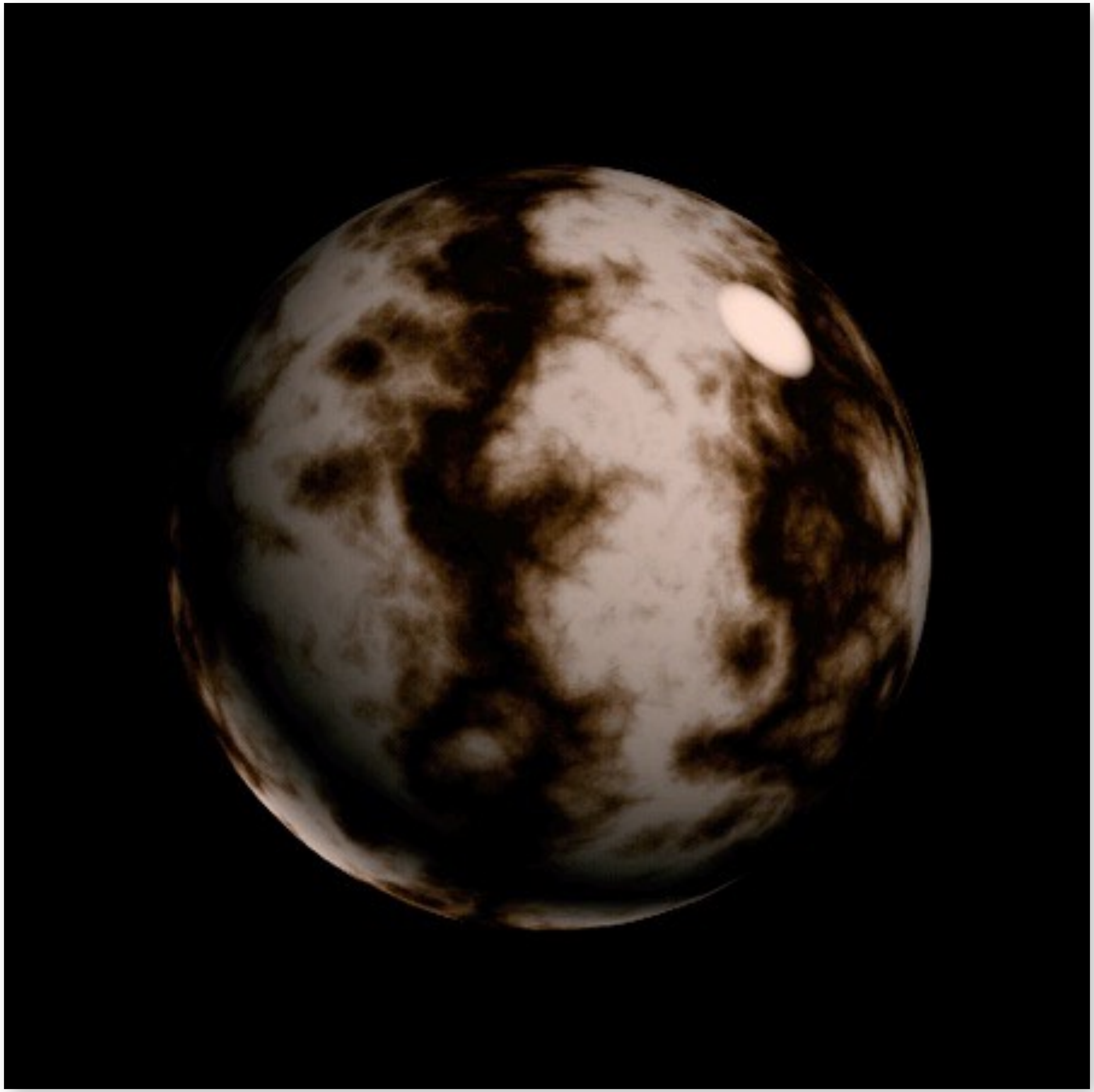
- **Displacement mapping** — a more advanced approach
  - Uses the same texture as in bumping mapping
  - Actually **moves the vertices**

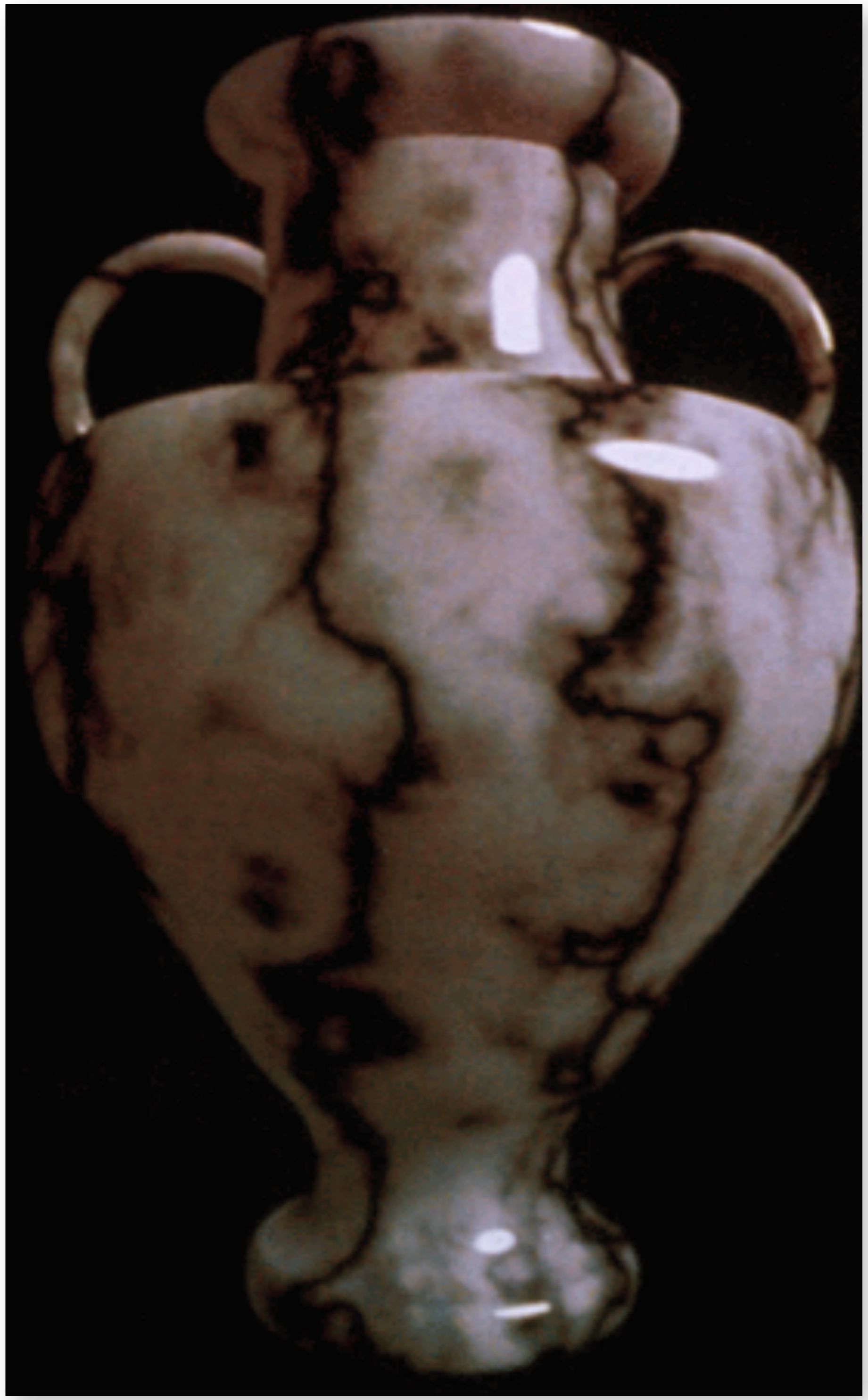




Bump / **Normal** mapping   Displacement mapping

3D Procedural Noise + Solid Modeling





Perlin noise, Ken Perlin

Provide Precomputed Shading

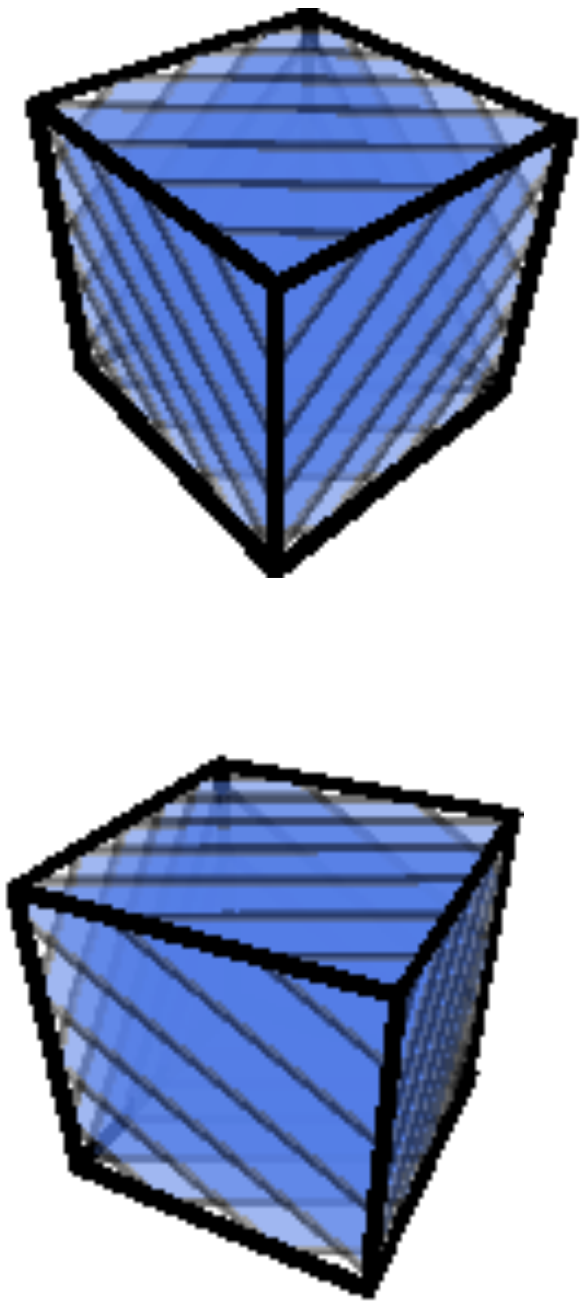
Simple shading

Ambient occlusion texture map

With ambient occlusion

Autodesk

3D Textures and Volume Rendering



Marc Levoy

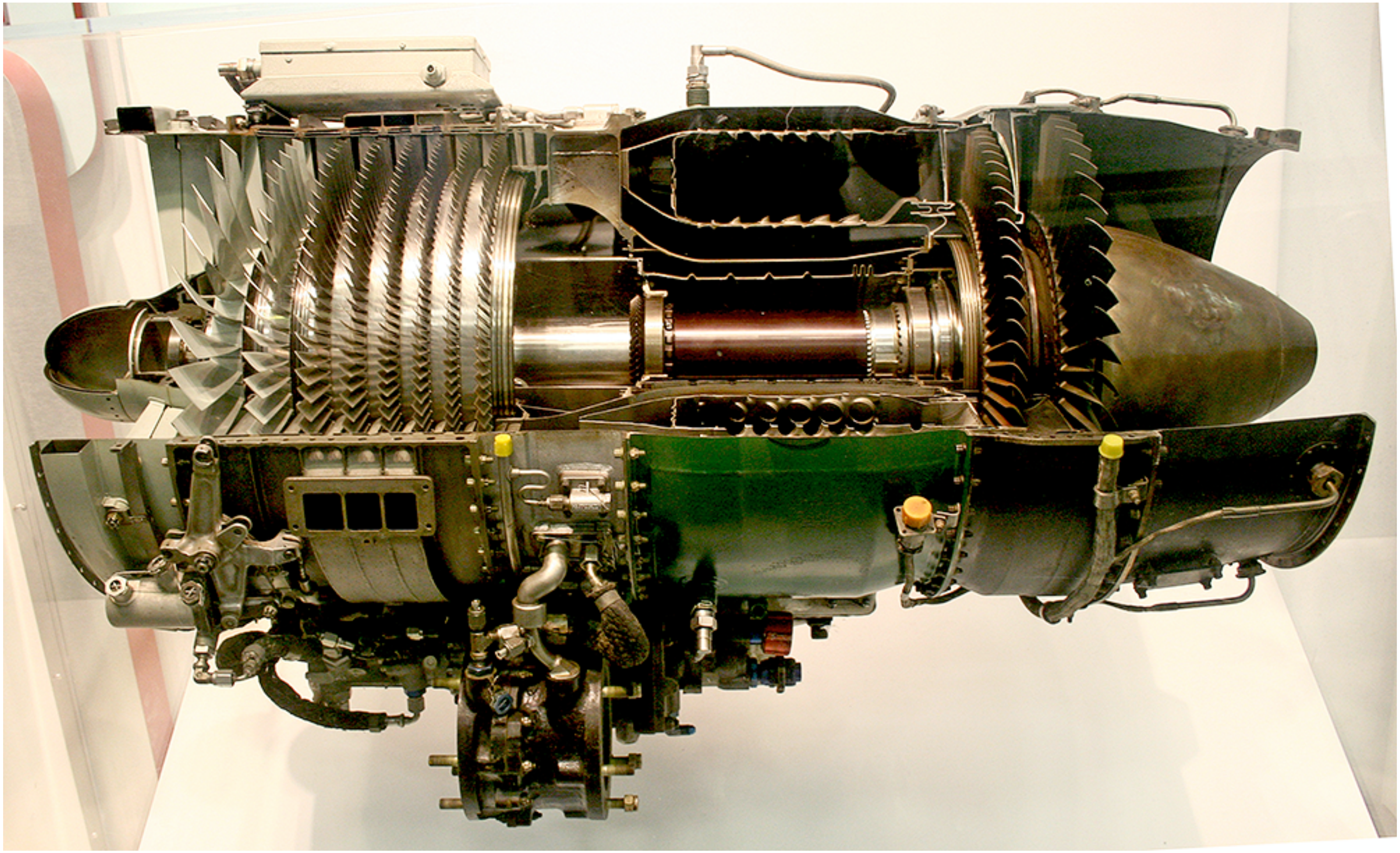
Today

- Shading 3
  - Applications of textures
- Introduction to geometry
  - Examples of geometry
  - Various representations of geometry

Examples of Geometry

Examples of Geometry

Examples of Geometry



Examples of Geometry

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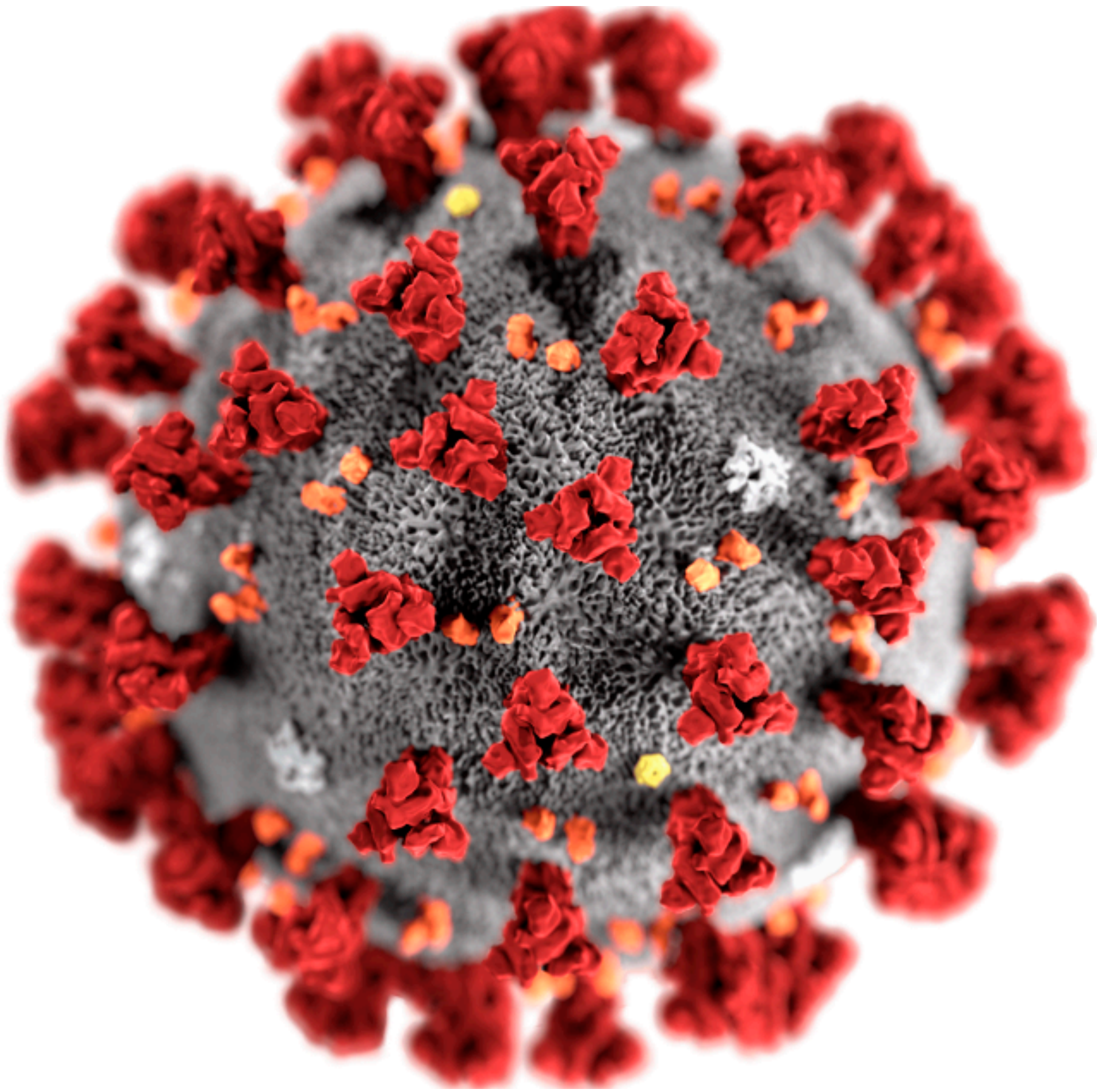
Examples of Geometry



COVID-19

I will call it
“Trump Virus”
forever.

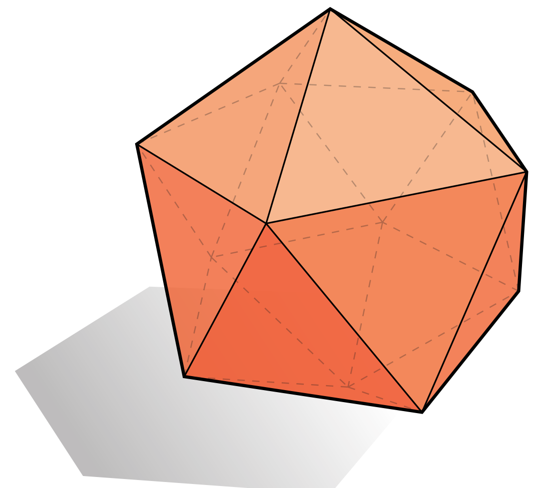
Examples of Geometry

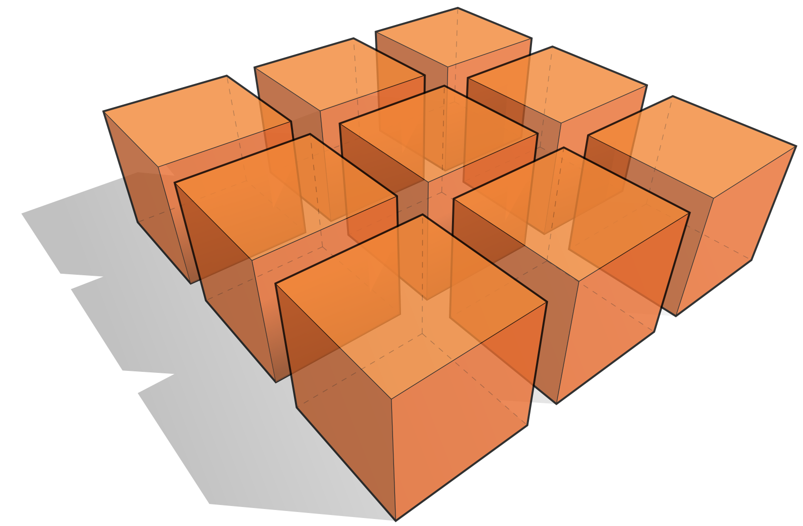
Adriana Franco, National Geographic

Many Ways to Represent Geometry

Implicit

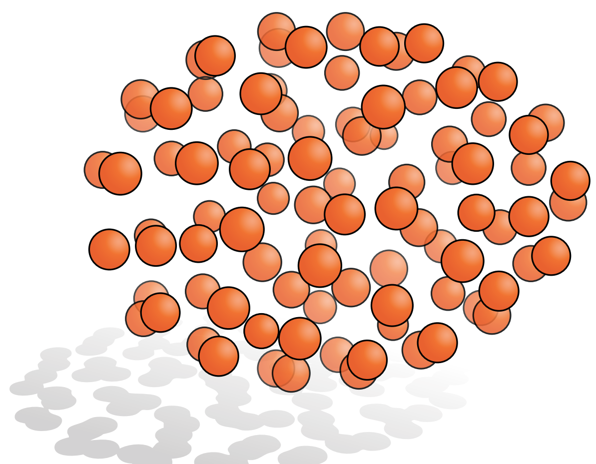
- algebraic surface
- level sets
- distance functions
- …

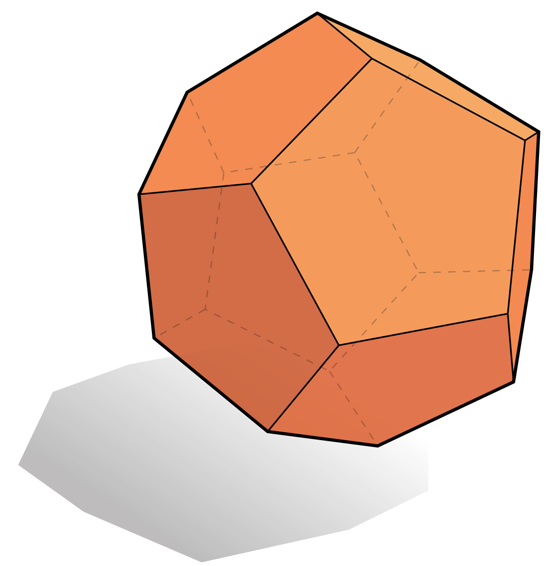


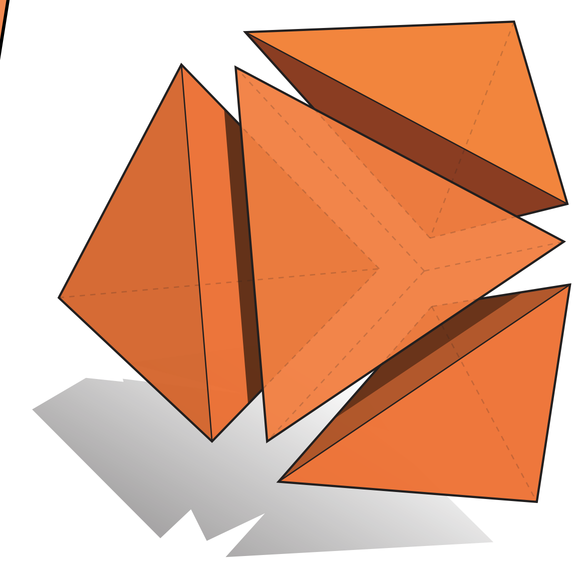


Explicit

- point cloud
- polygon mesh
- subdivision, NURBS
- …







Each choice best suited to a different task/type of geometry

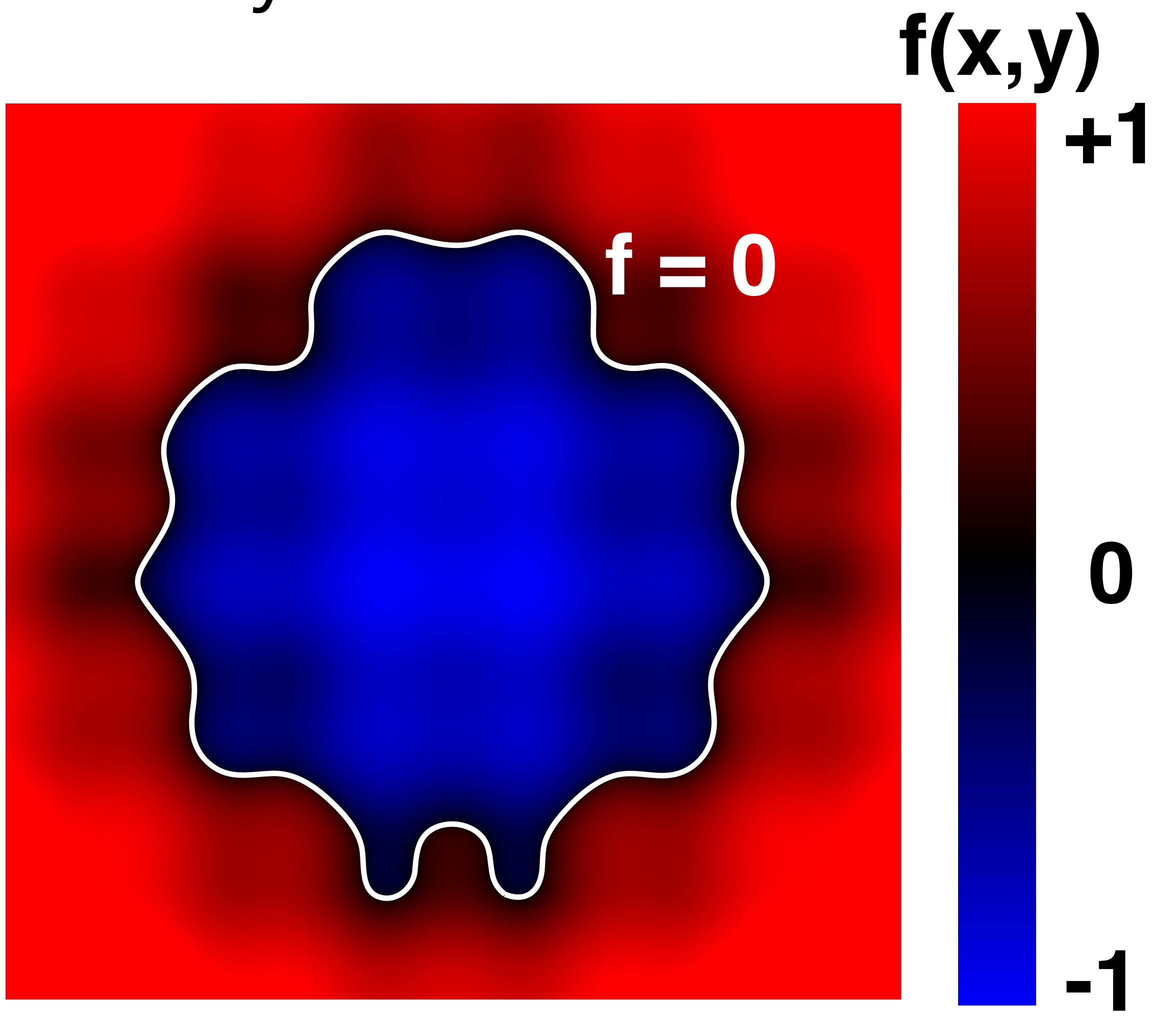
“Implicit” Representations of Geometry

Based on classifying points

- Points satisfy some specified relationship

E.g. sphere: all points in 3D, where $x^2+y^2+z^2 = 1$

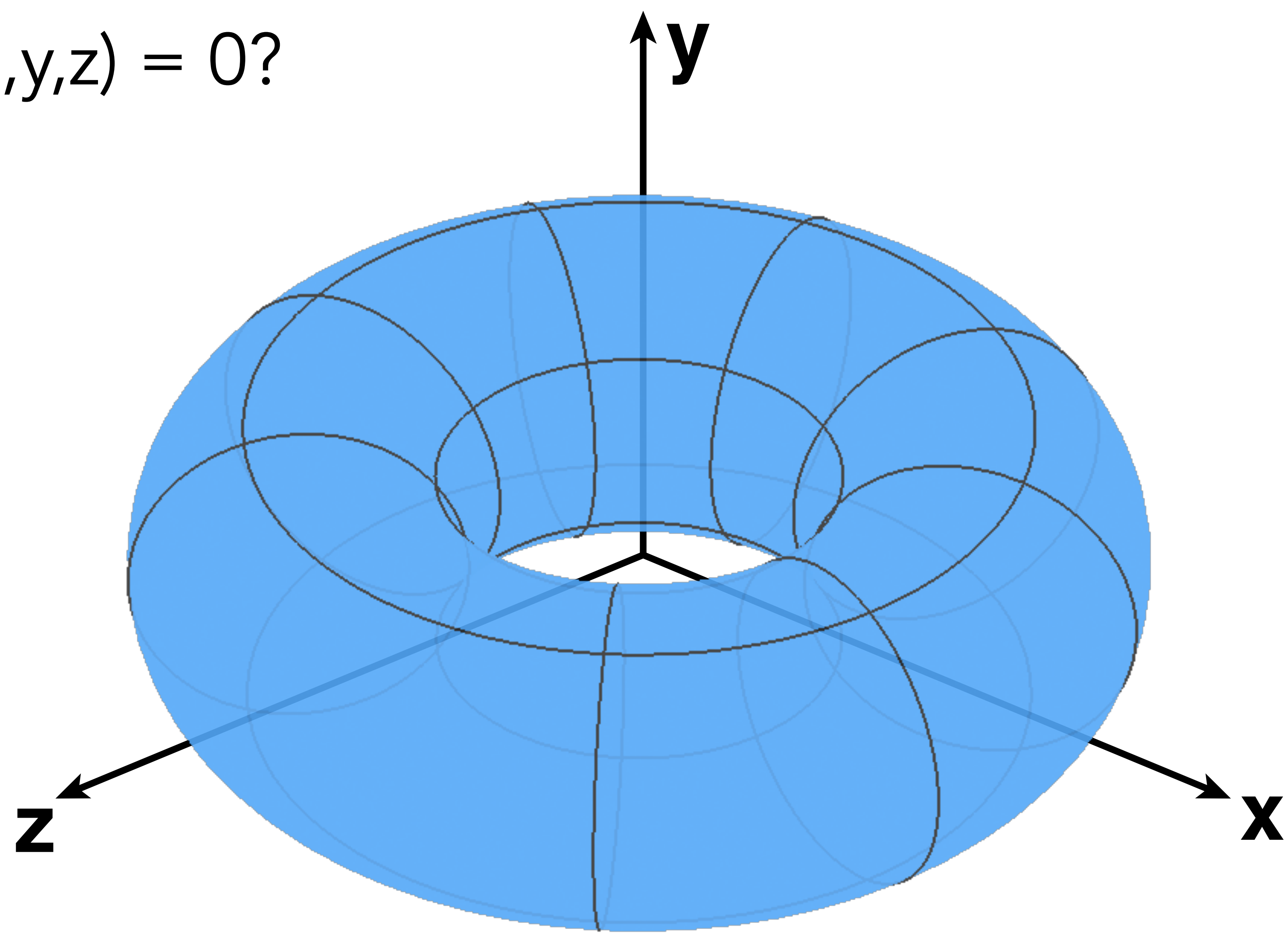
More generally, $f(x,y,z) = 0$



Implicit Surface – Sampling Can Be Hard

$$f(x, y, z) = (2 - \sqrt{x^2 + y^2})^2 + z^2 - 1$$

What points lie on f(x,y,z) = 0?



Some tasks are hard with implicit representations

Implicit Surface – Inside/Outside Tests Easy

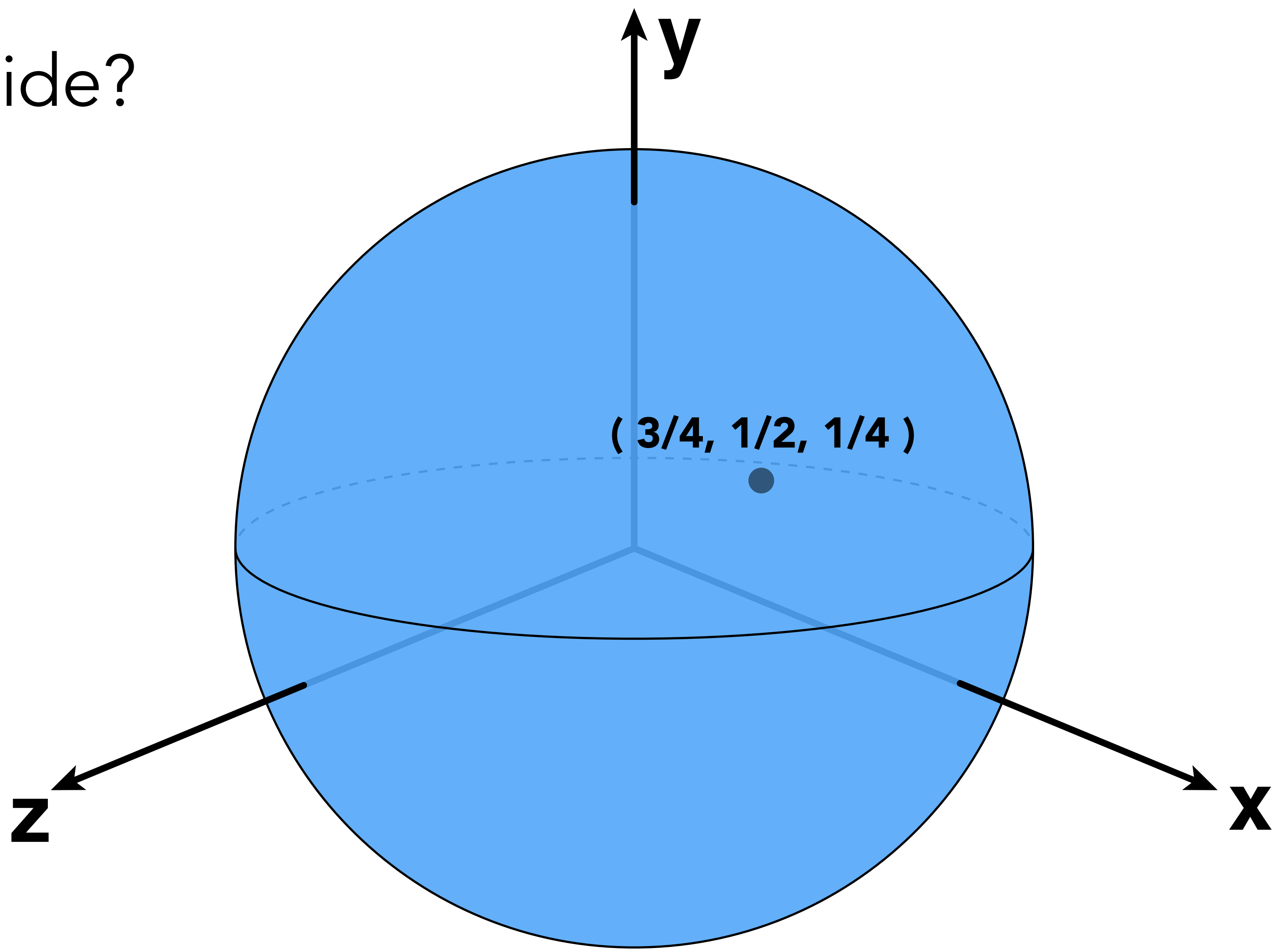
$$f(x, y, z) = x^2 + y^2 + z^2 - 1$$

Is (3/4, 1/2, 1/4) inside?

Just plug it in:

f(x,y,z) = –1/8 < 0

Yes, inside.

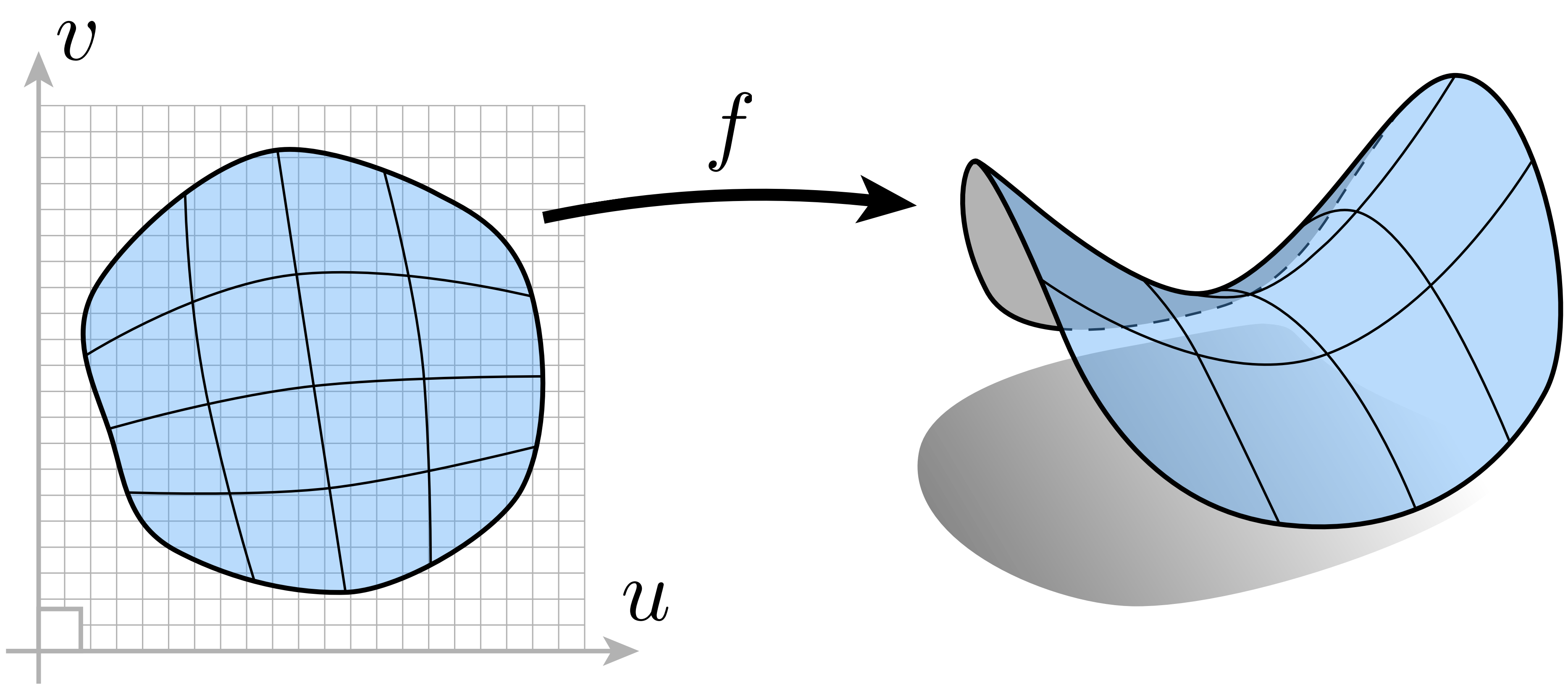


Implicit representations make some tasks easy

“Explicit” Representations of Geometry

All points are **given directly** or **via parameter mapping**

Generally: $f : \mathbb{R}^2 \to \mathbb{R}^3; (u, v) \mapsto (x, y, z)$

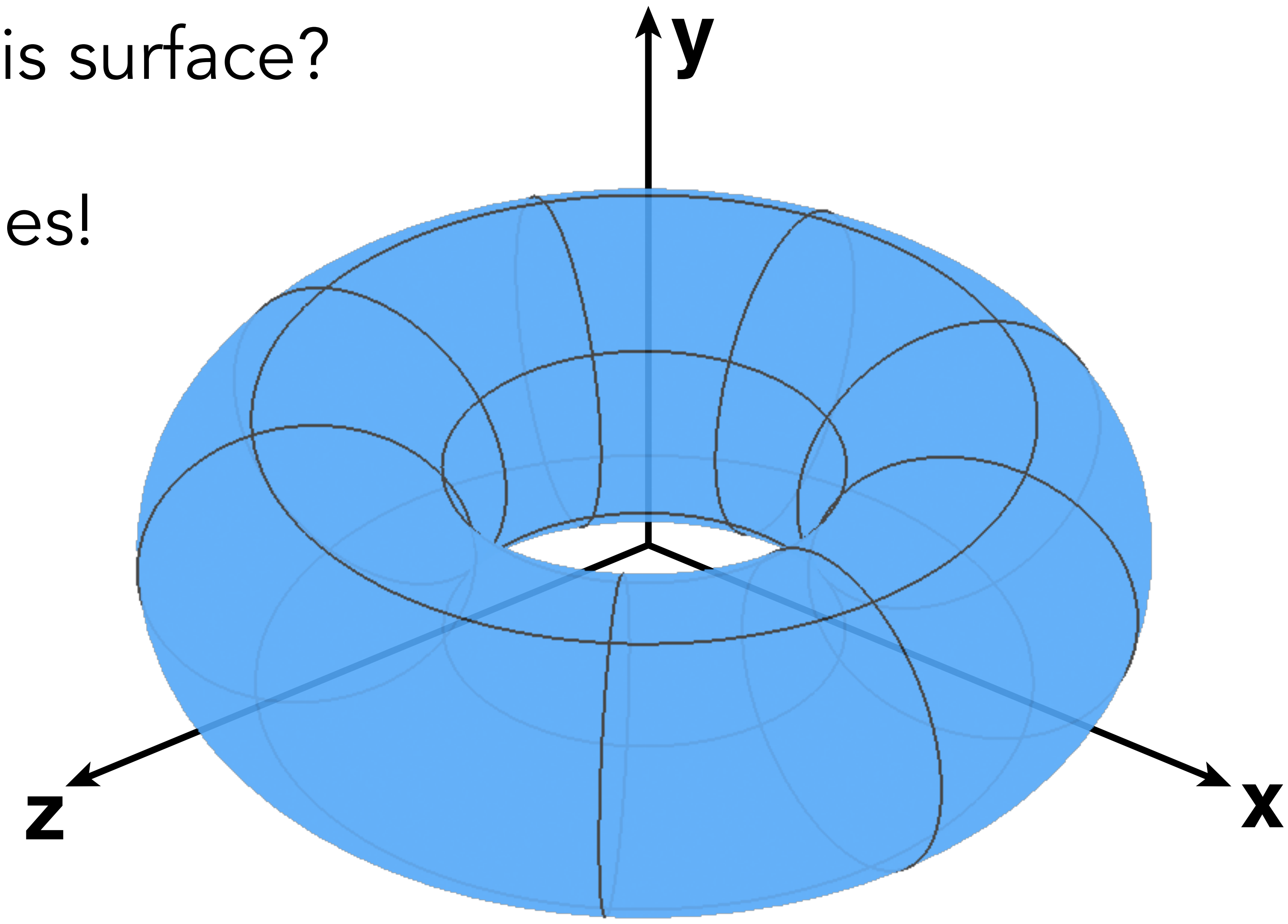


Explicit Surface – Sampling Is Easy

$$f(u,v) = ((2+\cos u)\cos v, (2+\cos u)\sin v, \sin u)$$

What points lie on this surface?

Just plug in (u,v) values!

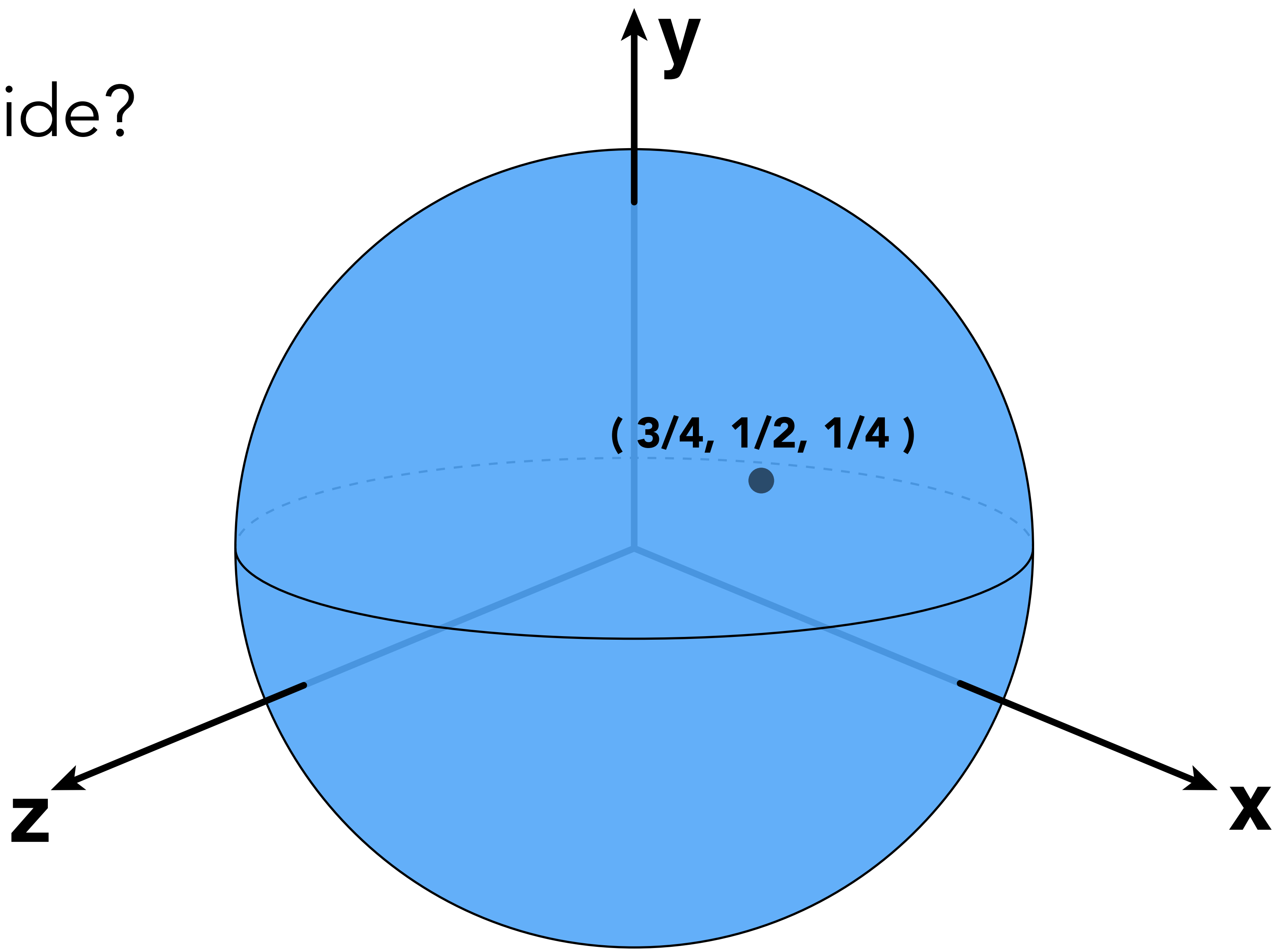


Explicit representations make some tasks easy

Explicit Surface – Inside/Outside Test Hard

$$f(u,v) = (\cos u \; \sin v, \sin u \; \sin v, \cos v)$$

Is (3/4, 1/2, 1/4) inside?



Some tasks are hard with explicit representations

No “Best” Representation – Geometry is Hard!

“I hate meshes.
I cannot believe how hard this is.
Geometry is hard.”

— David Baraff
Senior Research Scientist
Pixar Animation Studios

Slide cribbed from Keenan Crane, cribbed from Jeff Erickson.

Best Representation
Depends on the Task!

More Implicit Representations in Computer Graphics

Many Implicit Representations in Graphics

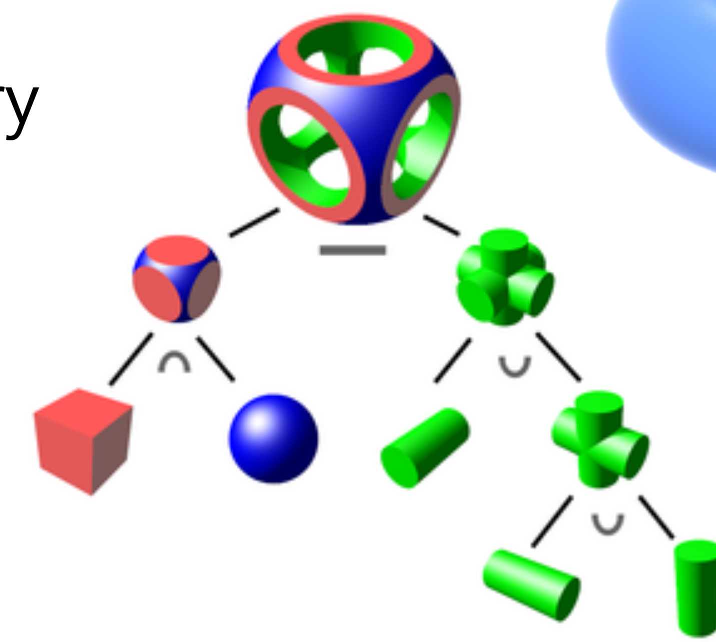
Algebraic surfaces

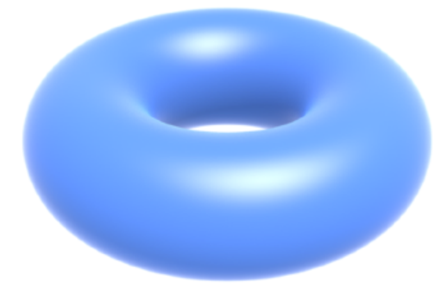
Constructive solid geometry

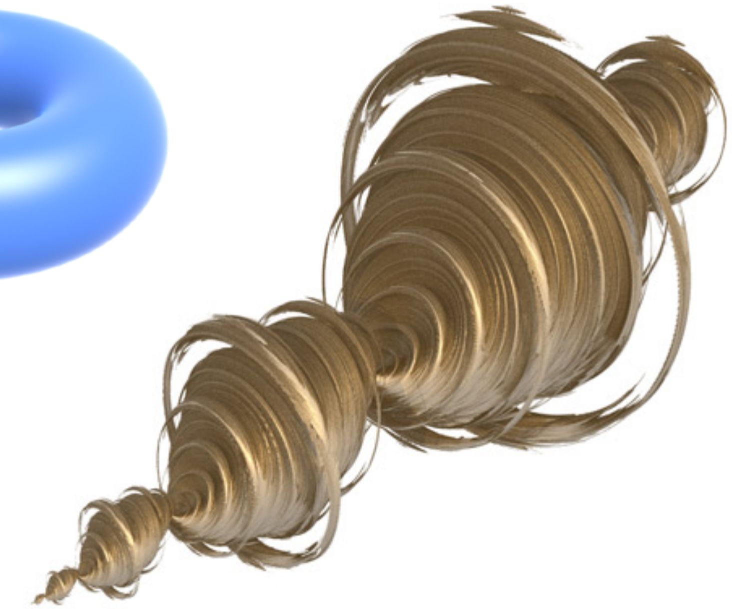
Level set methods

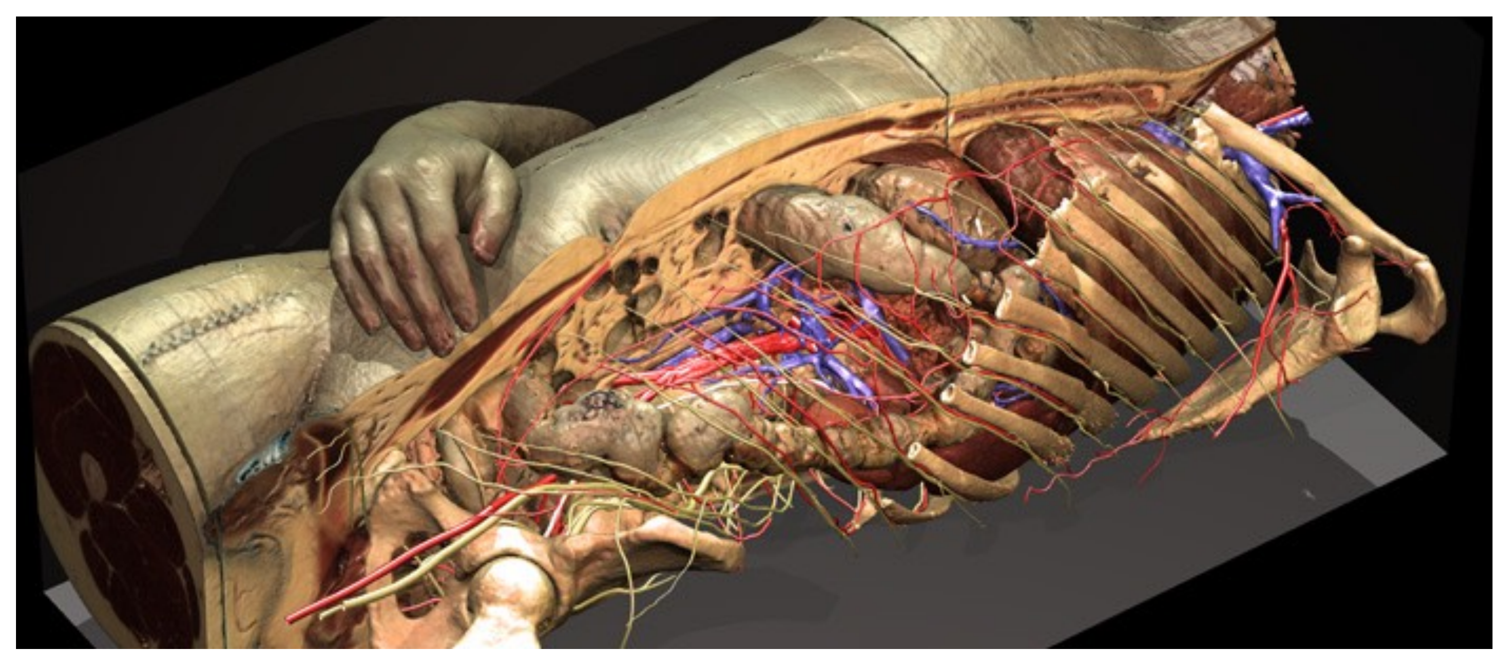
Fractals

…



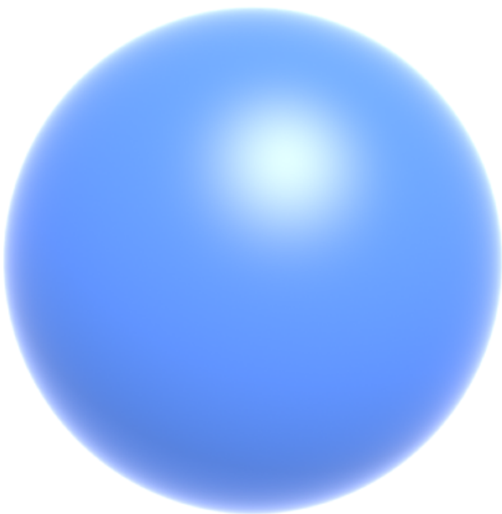




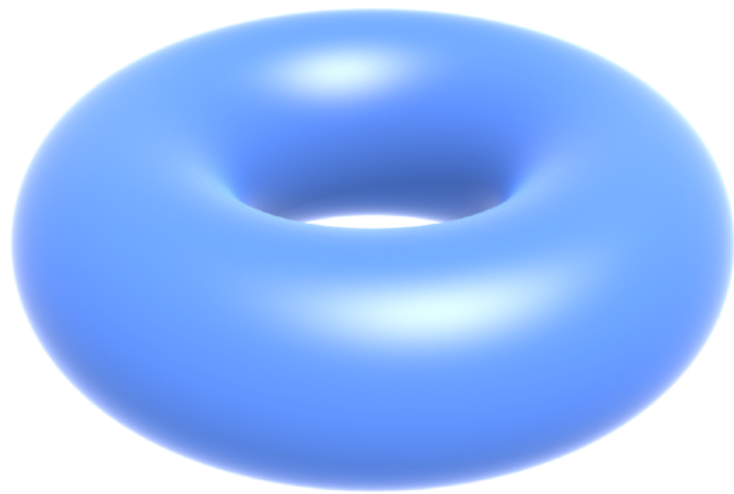


Algebraic Surfaces (Implicit)

Surface is zero set of a polynomial in x, y, z



$$x^2+y^2+z^2=1$$



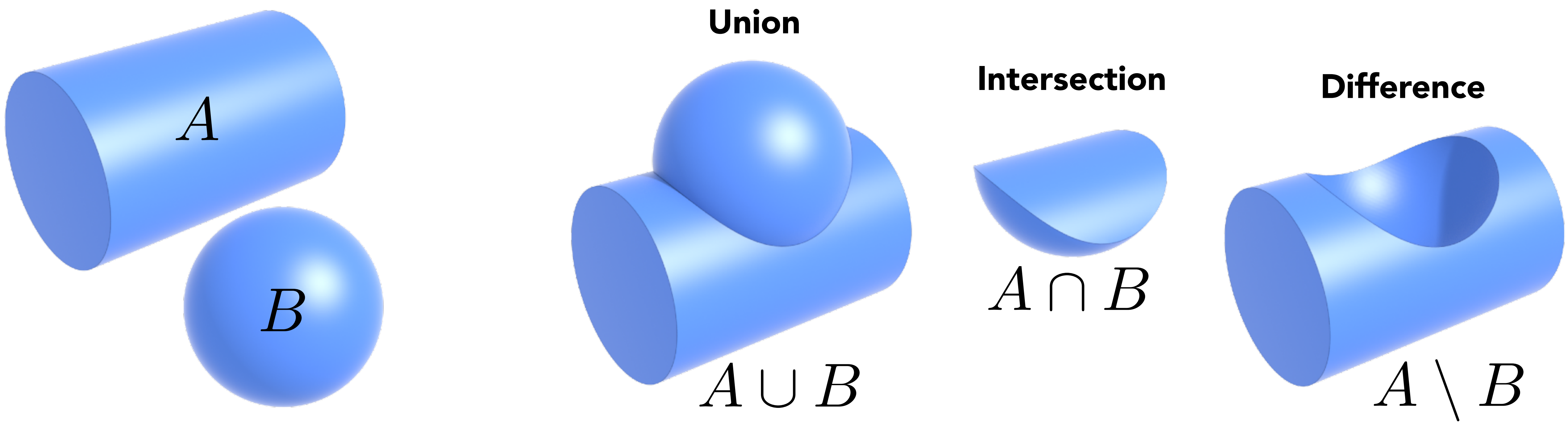
$$(R-\sqrt{x^2+y^2})^2+z^2=r^2$$

$$(x^2+\frac{9y^2}{4}+z^2-1)^3=x^2z^3+\frac{9y^2z^3}{80}$$

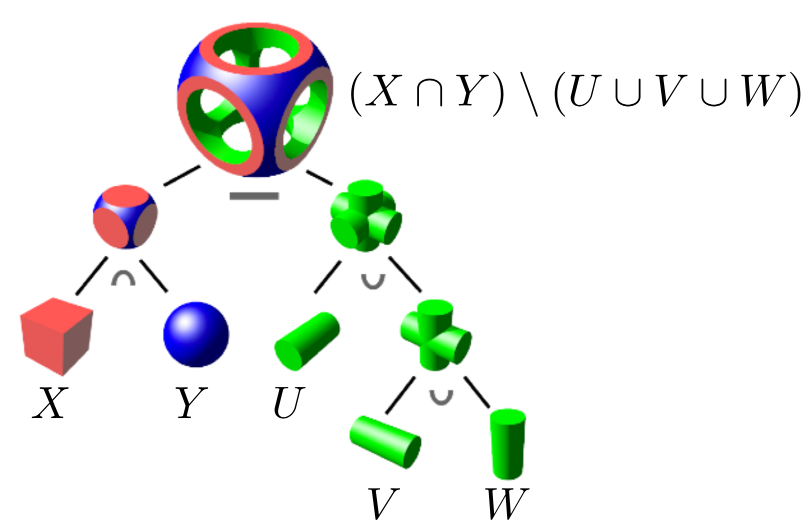
More complex shapes?

Constructive Solid Geometry (Implicit)

Combine implicit geometry via Boolean operations



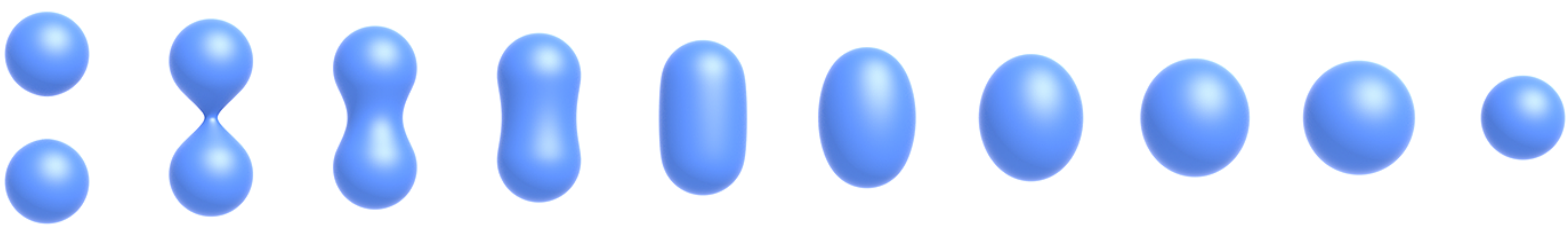
Boolean expressions:



Distance Functions (Implicit)

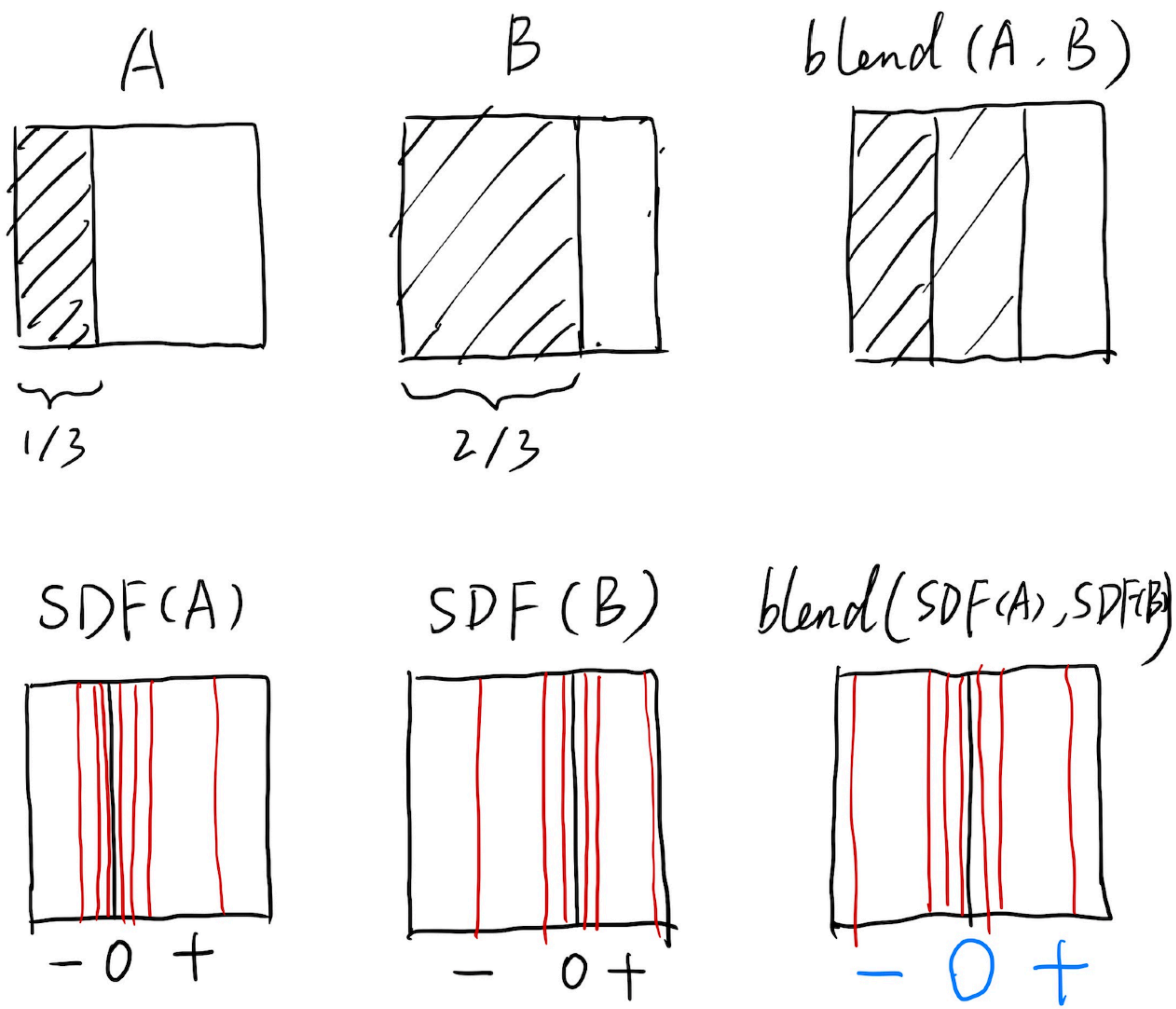
Instead of Booleans, gradually blend surfaces together using

Distance functions:
giving minimum distance (could be **signed** distance)
from anywhere to object



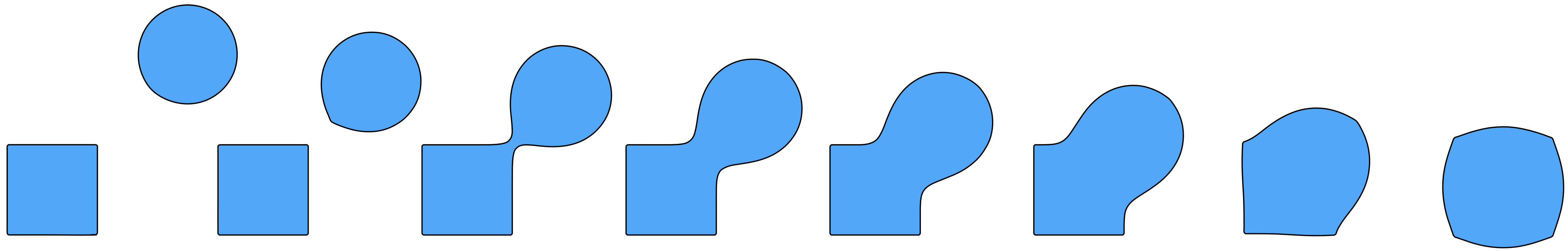
Distance Functions (Implicit)

An Example: Blending (linear interp.) a moving boundary



Blending Distance Functions (Implicit)

Can blend any two distance functions d1, d2:



Scene of Pure Distance Functions

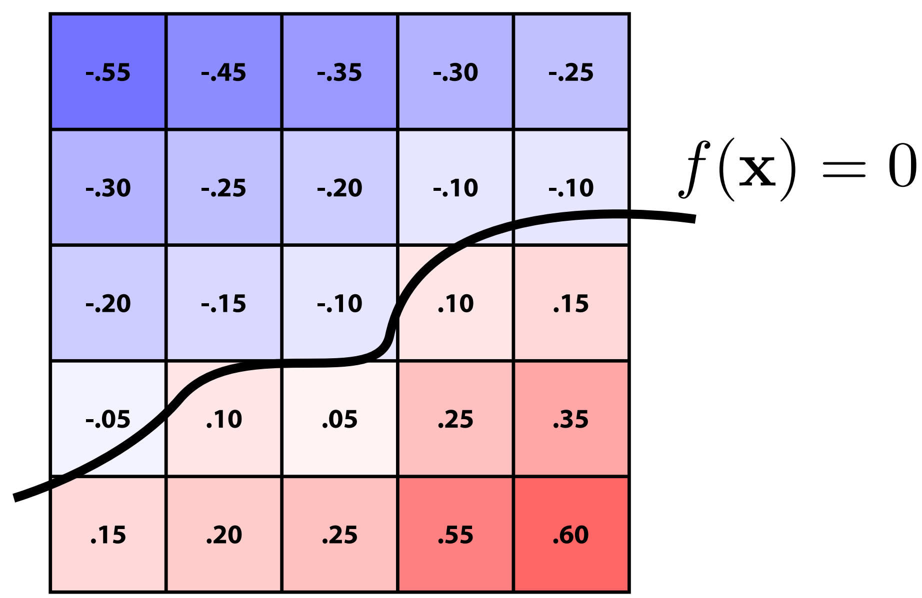
See https://iquilezles.org/www/articles/raymarchingdf/raymarchingdf.htm

Level Set Methods (Also implicit)

（水平集）

Closed-form equations are hard to describe complex shapes

Alternative: store a grid of values approximating function

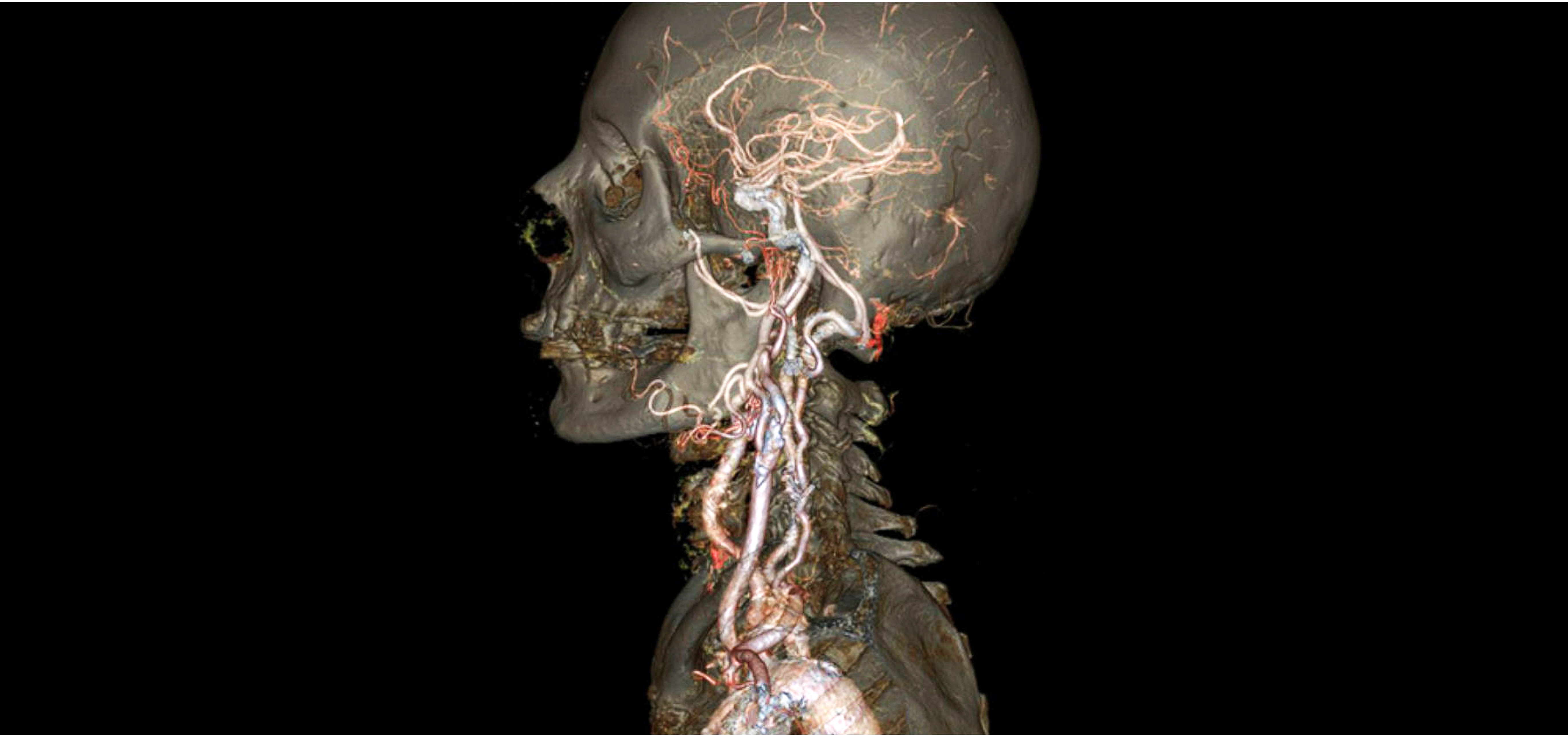


Surface is found where interpolated values equal zero

Provides much more explicit control over shape (like a texture)

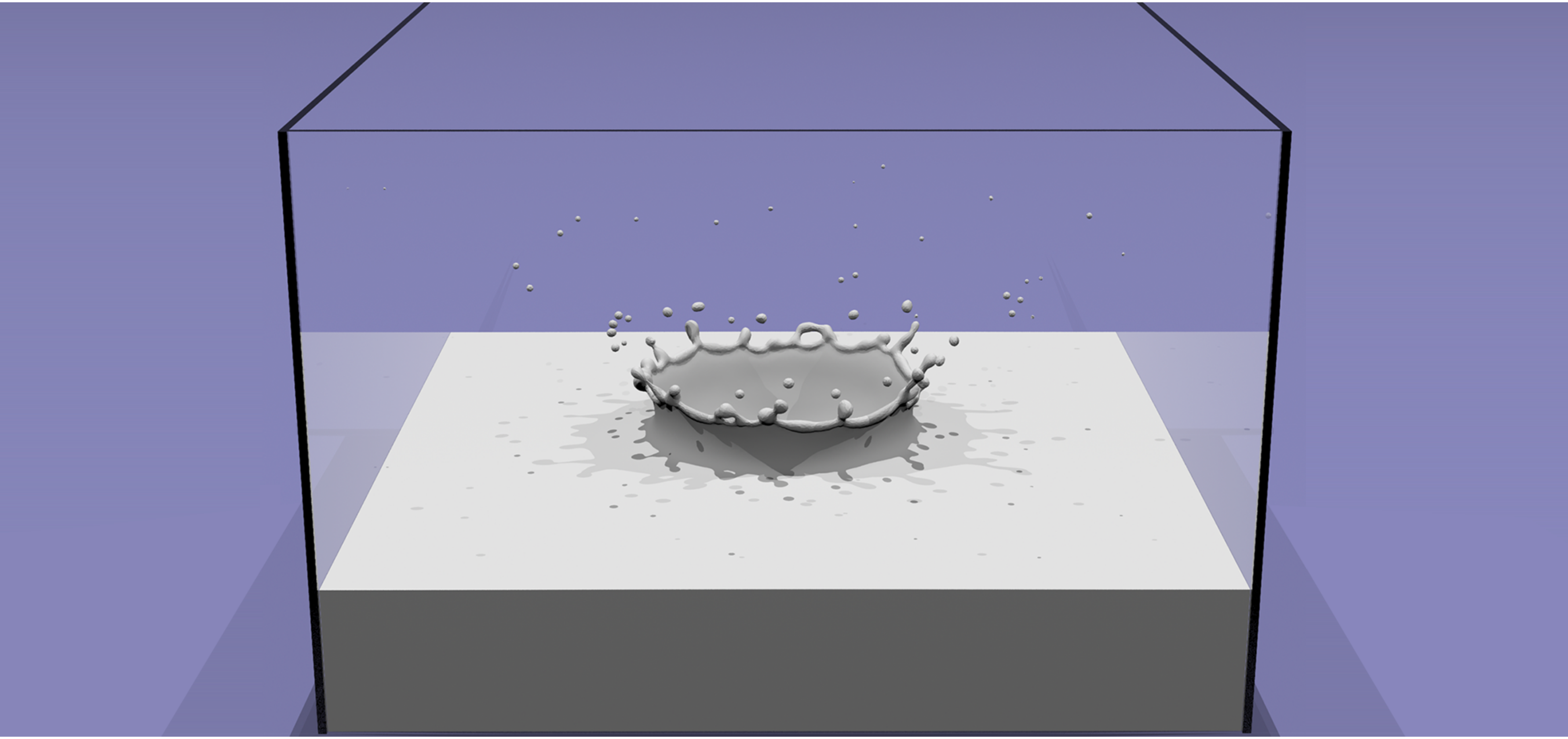
Level Sets from Medical Data (CT, MRI, etc.)

Level sets encode, e.g., constant tissue density



Level Sets in Physical Simulation

Level set encodes distance to air-liquid boundary



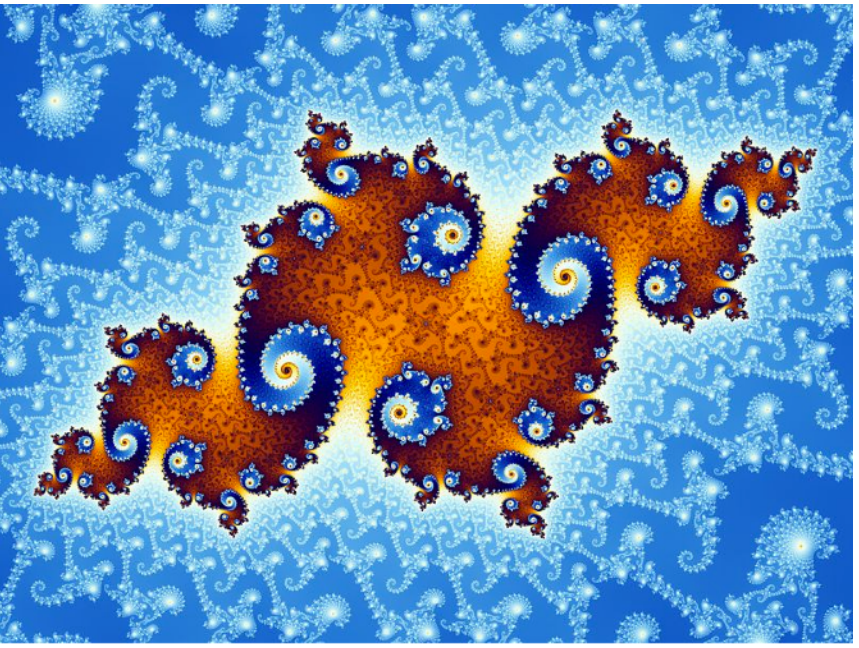
See http://physbam.stanford.edu

Fractals (Implicit)

Exhibit self-similarity, detail at all scales

“Language” for describing natural phenomena

Hard to control shape!



Implicit Representations - Pros & Cons

Pros:

- compact description (e.g., a function)
- certain queries easy (inside object, distance to surface)
- good for ray-to-surface intersection (more later)
- for simple shapes, exact description / no sampling error
- easy to handle changes in topology (e.g., fluid)

Cons:

- difficult to model complex shapes

Thank you!

(And thank Prof. Ravi Ramamoorthi and Prof. Ren Ng for many of the slides!)