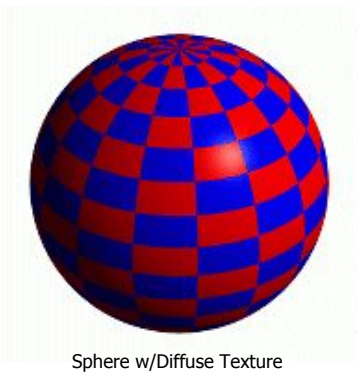
Procedural Modeling

From Last Time

- Many “Mapping” techniques
  - Bump Mapping
  - Displacement Mapping
  - Environment Mapping
  - Light Mapping
  - Normal Mapping
  - Parallax Mapping
  - Parallax Occlusion Mapping

Bump Mapping

- Use textures to alter the surface normal
  - Does not change the actual shape of the surface
  - Just shaded as if it were a different shape



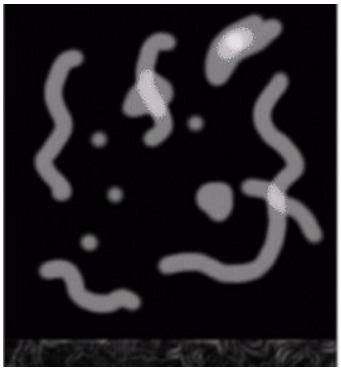
Sphere w/Diffuse Texture

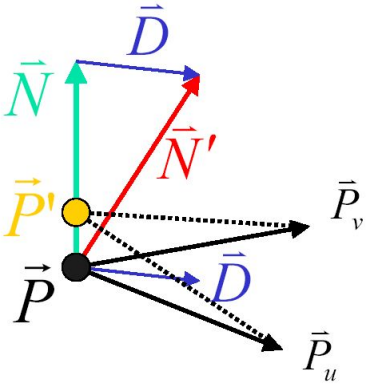
Swirly Bump Map

Sphere w/Diffuse Texture & Bump Map

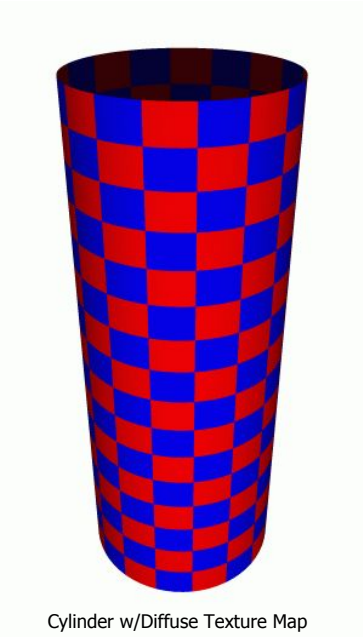
Bump Mapping

- Treat a greyscale texture as a single-valued height function
- Compute the normal from the partial derivatives in the texture

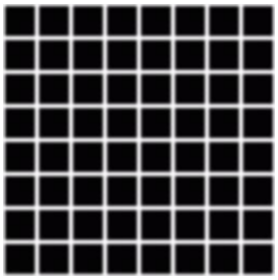




Another Bump Map Example



Cylinder w/Diffuse Texture Map

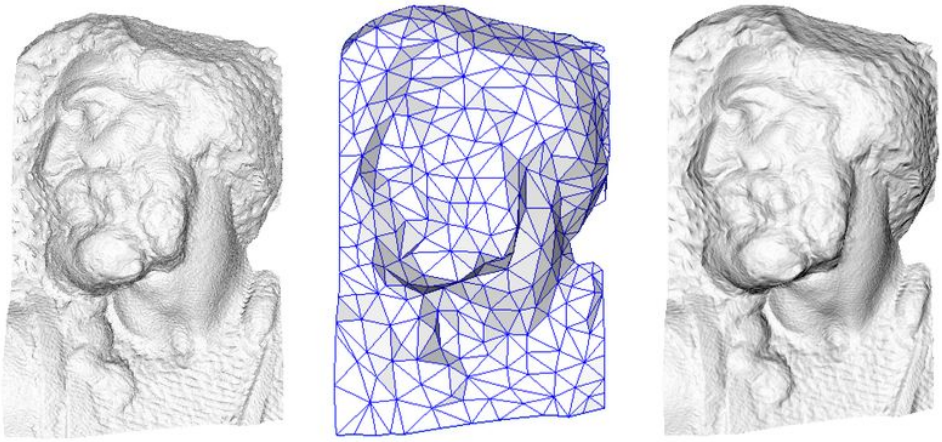


Bump Map

Cylinder w/Texture Map & Bump Map

Normal Mapping

- Variation on Bump Mapping:
  Use an RGB texture to directly encode the normal



original mesh
4M triangles

simplified mesh
500 triangles

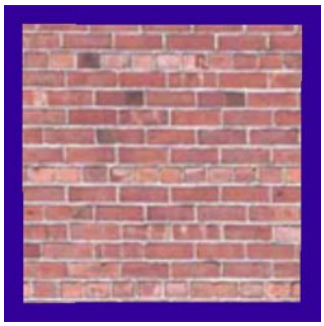
simplified mesh
and normal mapping
500 triangles

http://en.wikipedia.org/wiki/File:Normal_map_example.png

What's Missing?

- There are no bumps on the silhouette of a bump-mapped or normal-mapped object

- Bump/Normal maps don't allow self-occlusion or self-shadowing



From Last Time

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  - Environment Mapping
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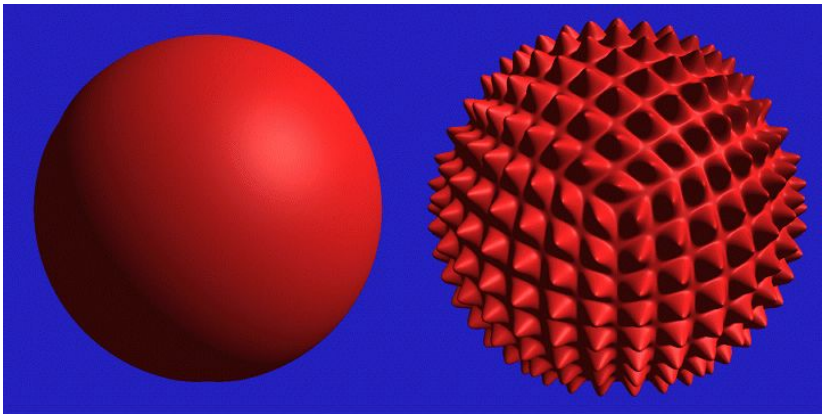
  - Parallax Occlusion Mapping

Displacement Mapping

- Use the texture map to actually move the surface point
- The geometry must be displaced before visibility is determined



Displacement Mapping

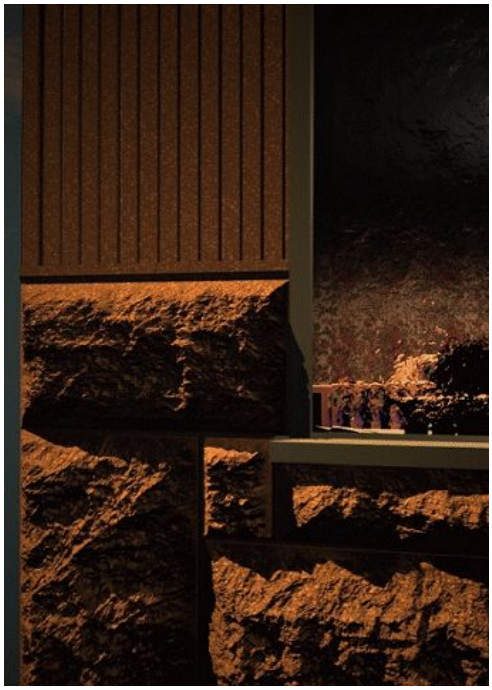


Image from:

Geometry Caching for Ray-Tracing Displacement Maps
EGRW 1996
Matt Pharr and Pat Hanrahan

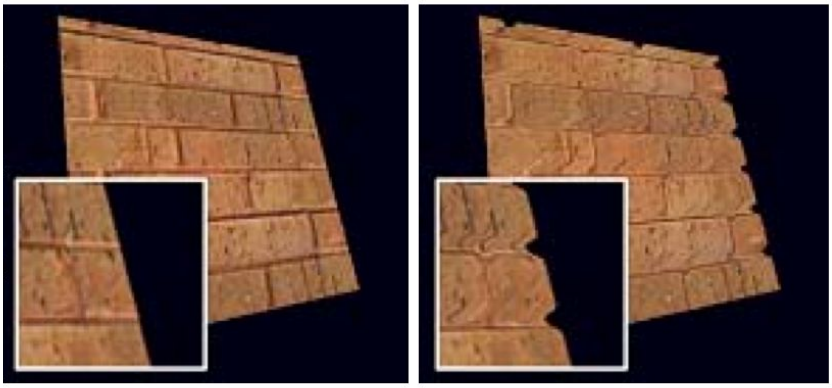
note the detailed shadows cast by the stones

Displacement Mapping

Ken Musgrave

Parallax Mapping a.k.a. Offset Mapping or Virtual Displacement Mapping

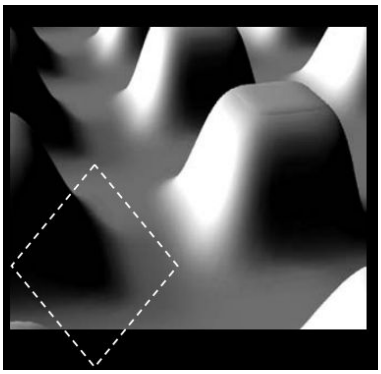
- Displace the texture coordinates for each pixel based on view angle and value of the height map at that point
- At steeper view-angles, texture coordinates are displaced more, giving illusion of depth due to parallax effects



"Detailed shape representation with parallax mapping", Kaneko et al. ICAT 2001

Parallax Occlusion Mapping

- Brawley & Tatarchuk 2004
- Per pixel ray tracing of the heightfield geometry
- Occlusions & soft shadows



http://developer.amd.com/media/gpu_assets/
Tatarchuk-ParallaxOcclusionMapping-Sketch-print.pdf

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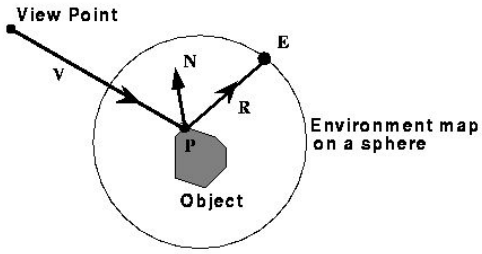
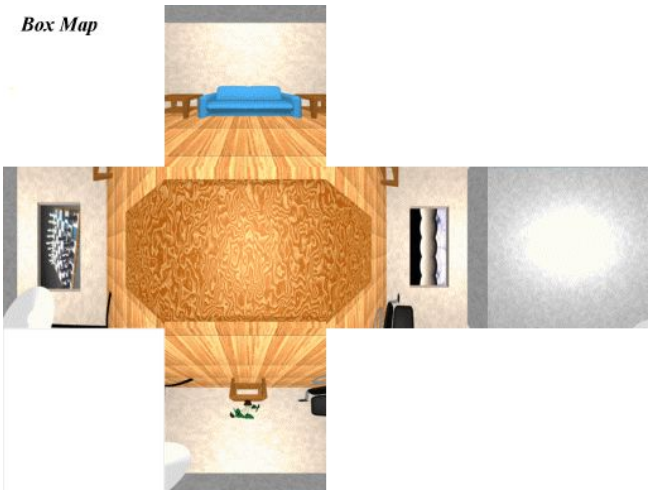
Environment Maps

- We can simulate reflections by using the direction of the reflected ray to index a spherical texture map at "infinity".
- Assumes that all reflected rays begin from the same point.



What's the Best Chart?



Environment Mapping Example

Terminator II

Texture Maps for Illumination

- Also called "Light Maps"

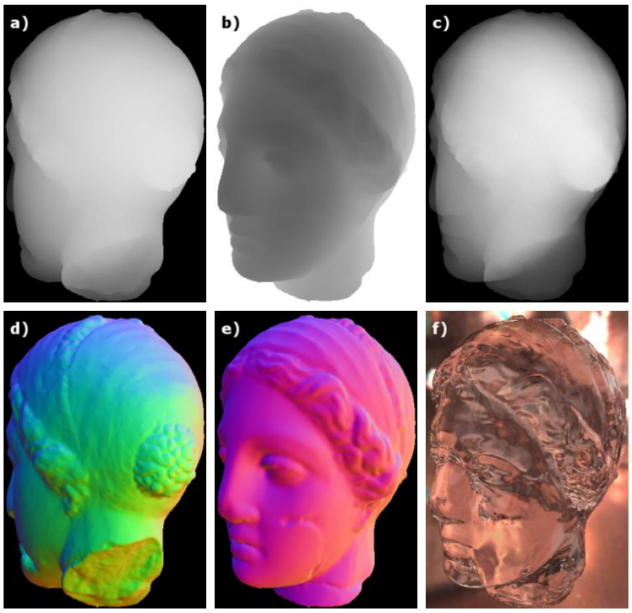
Quake

Questions?

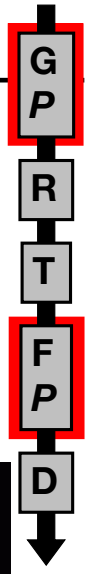
Image by Henrik Wann Jensen
Environment map by Paul Debevec

Reading for Today

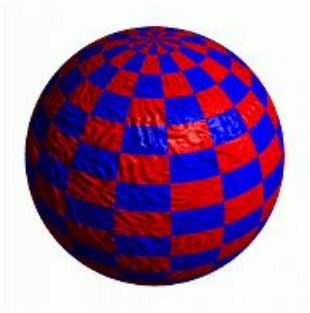
- Chris Wyman, "An Approximate Image-Space Approach for Interactive Refraction", SIGGRAPH 2005

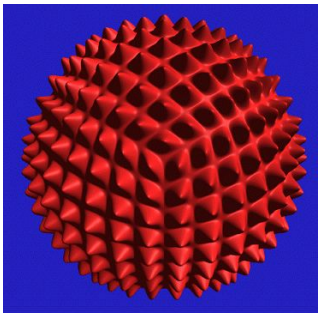


Last Time?



- Modern Graphics Hardware
- Cg Programming Language
- Gouraud Shading vs.
  Phong Normal Interpolation
- Bump, Displacement, & Environment Mapping

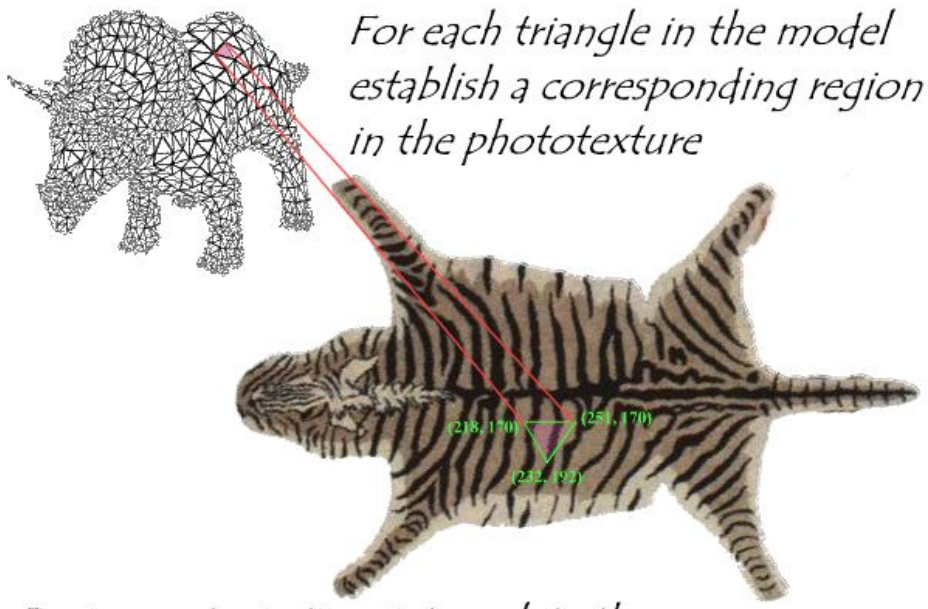




Today

- Texture Mapping
- Common Texture Coordinate Mappings
- Solid Texture
- Procedural Textures
- Perlin Noise
- Procedural Modeling
- L-Systems

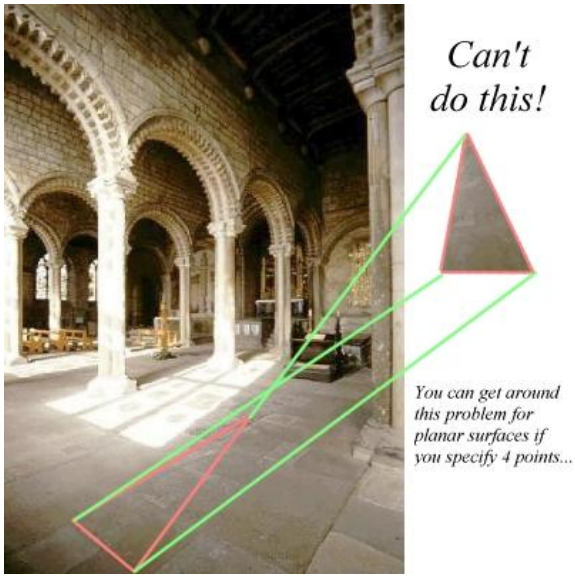
Texture Mapping



During rasterization interpolate the coordinate indices into the texture map

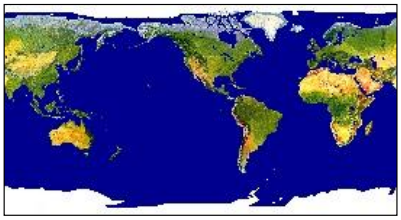
Texture Mapping Difficulties

- Tedious to specify texture coordinates
- Acquiring textures is surprisingly difficult
  - Photographs have projective distortions
  - Variations in reflectance and illumination
  - Tiling problems



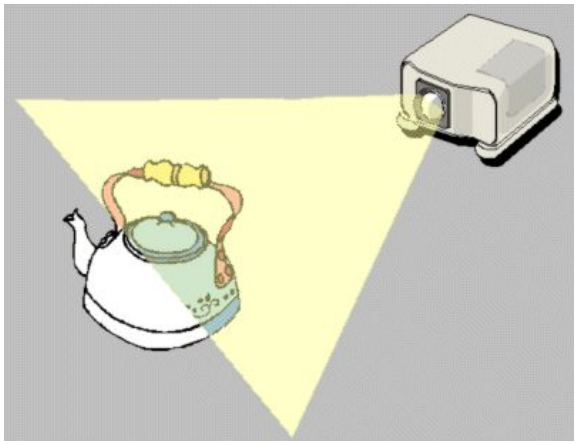
Common Texture Coordinate Mappings

- Orthogonal
- Cylindrical
- Spherical
- Perspective Projection
- Texture Chart



Projective Textures

- Use the texture like a slide projector
- No need to specify texture coordinates explicitly



Projective Texture Example

- Modeling from photographs
- Using input photos as textures

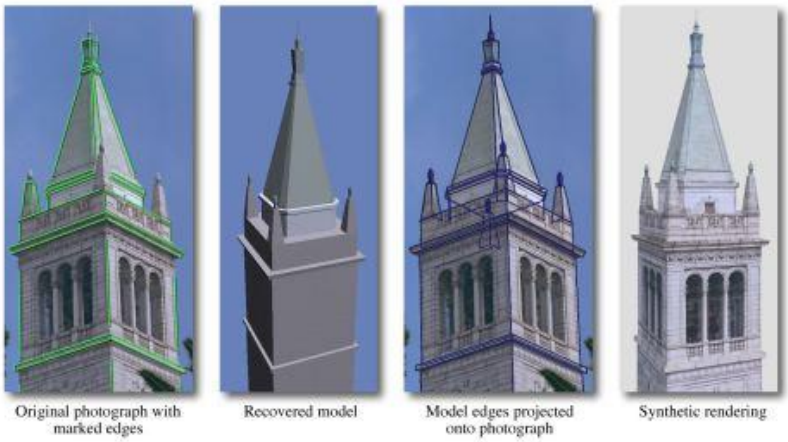
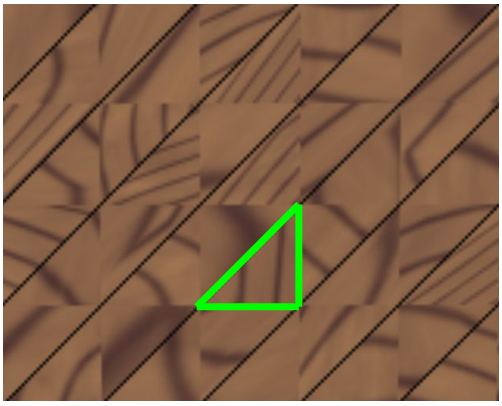
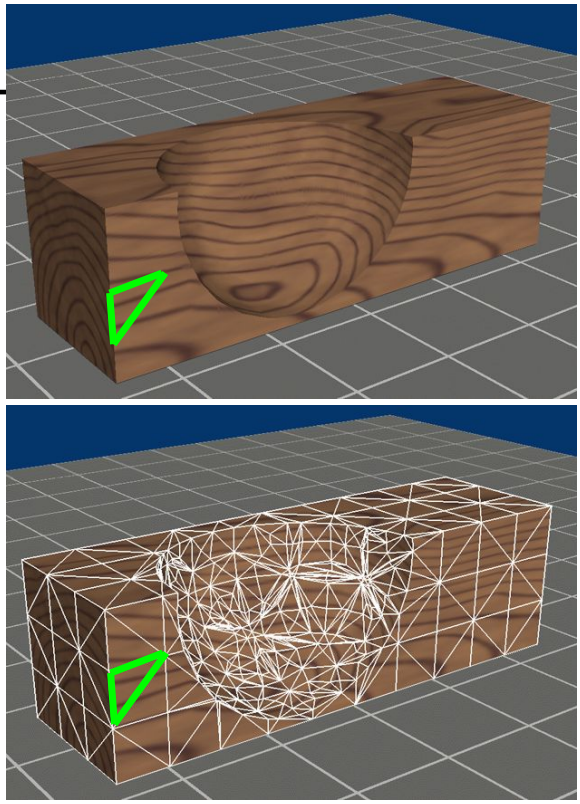


Figure from Debevec, Taylor & Malik
http://www.debevec.org/Research

Texture Chart

- Pack triangles into a single image





Questions?

Today

- Texture Mapping
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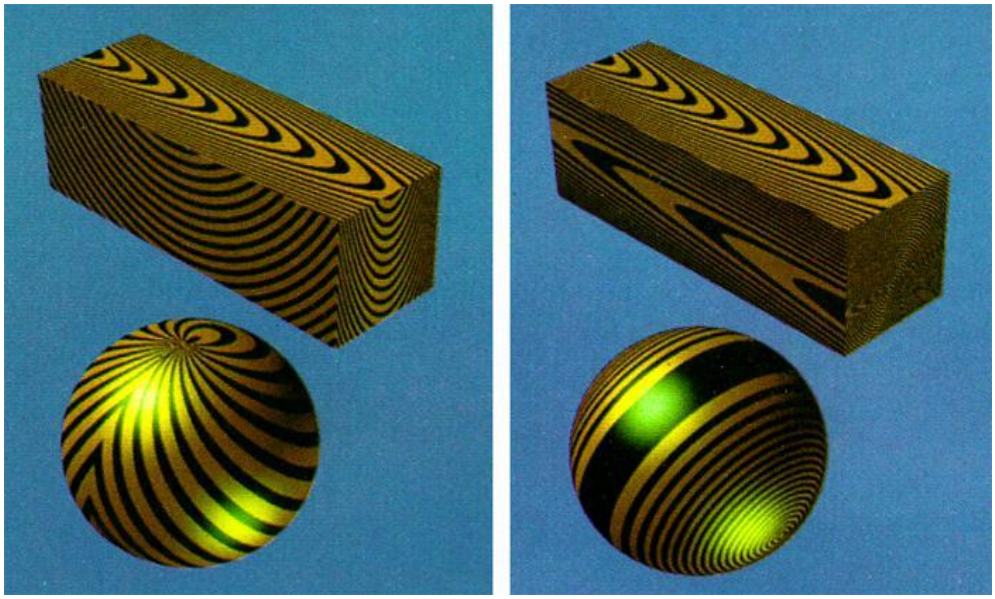
- Solid Texture
- Procedural Textures
- Perlin Noise
- Procedural Modeling
- L-Systems

Texture Map vs. Solid Texture



"Solid Texturing of Complex Surfaces",
Peachey, SIGGRAPH 1985

Procedural Textures

$f(x,y,z) \rightarrow \text{color}$

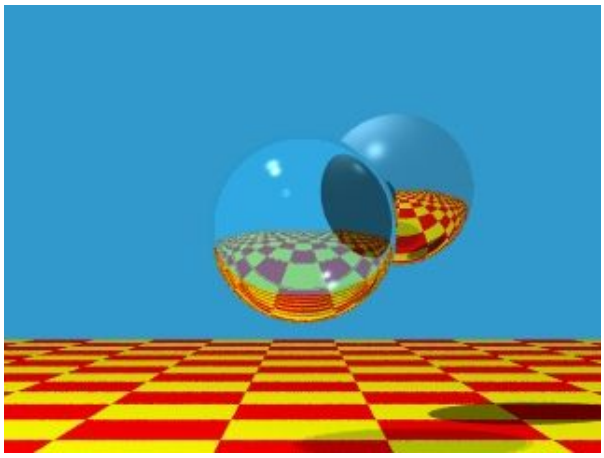
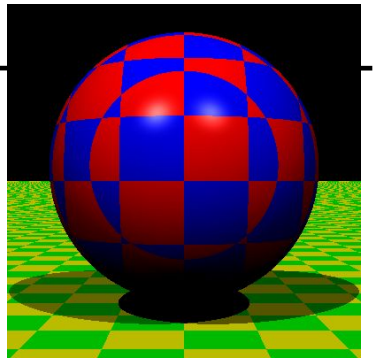
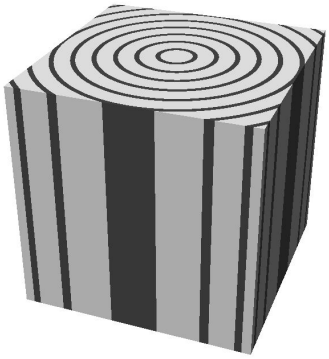


Image by Turner Whitted

Procedural Textures



- Advantages:
  - easy to implement in ray tracer
  - more compact than texture maps (especially for solid textures)
  - infinite resolution

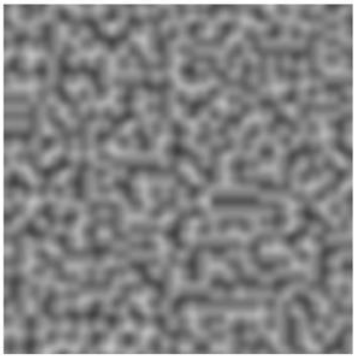


- Disadvantages
  - non-intuitive
  - difficult to match existing texture

Reading for Today

- "An Image Synthesizer", Perlin, SIGGRAPH 1985 & "Improving Noise", Perlin, SIGGRAPH 2002

Perlin Noise



- Properties:
  - Looks “random”, but is deterministic (always returns the same answer for a specific coordinate)
  - Small memory footprint & fast to compute
  - Known amplitude & frequency
  - Smooth interpolation when zoomed in
- Can be combined/layered:
  - Add multiple noise functions w/ different frequencies and amplitudes
  - Simple arithmetic operations (thresholding, sine waves, etc.)

“Shade Trees”, Cook, SIGGRAPH 1984

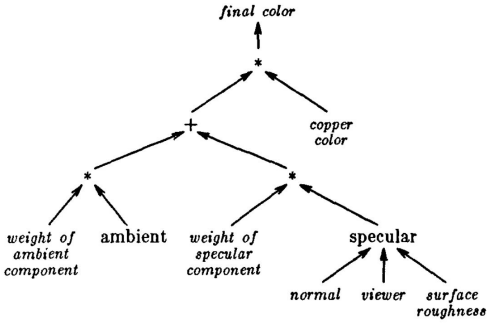


Figure 1a. Shade tree for copper.

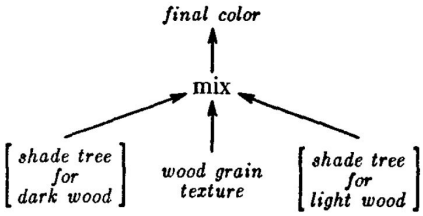
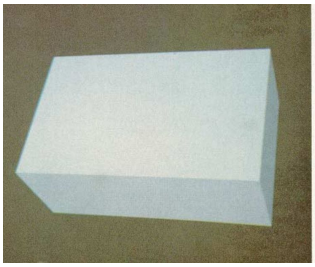
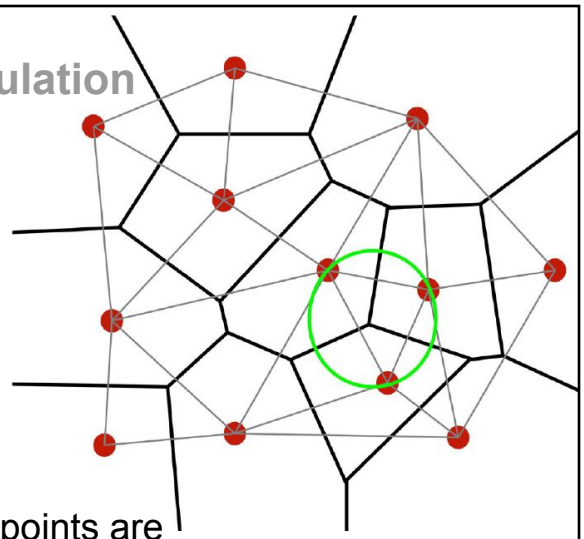


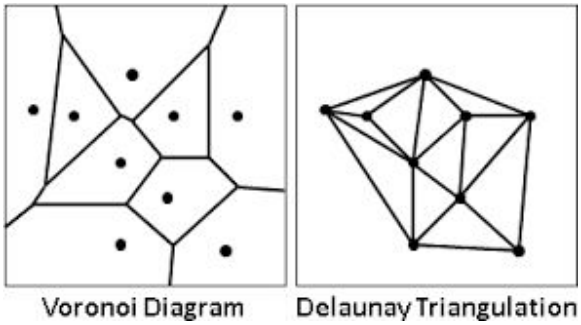
Figure 1b. The mix node in a shade tree for wood.

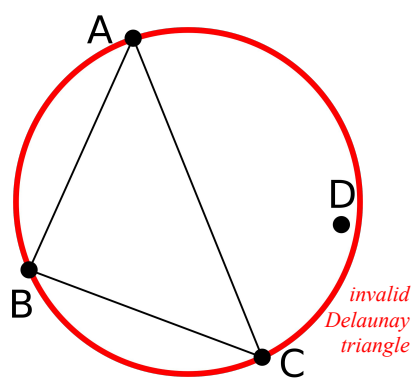


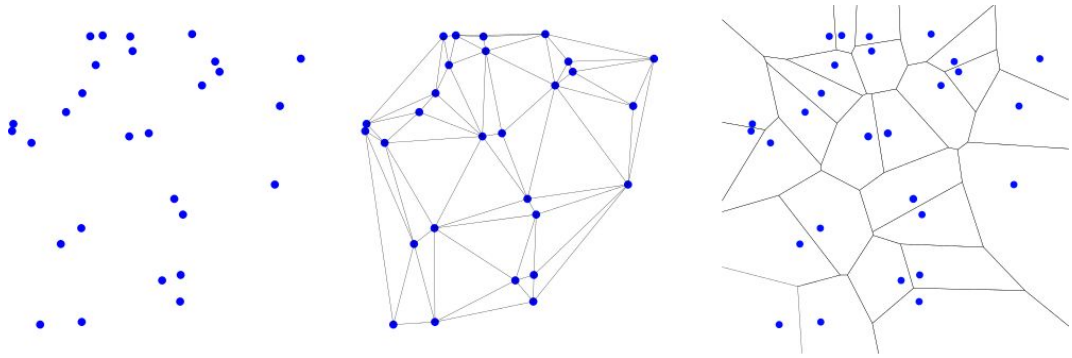
- **Grey: Delauney Triangulation**
  - "Best" triangulation of the red dots (most equilateral)
  - A specific triangle is in the Delauney Triangle *if and only if* the circle defined by those 3 points *does not* contain any other red dot
  - Note: Well defined when points are random. If points are on a uniform grid, we have ties…



- **Black: Voronoi Diagram**
  - Each cell is the set of all points in the plane that claim that cell's red dot as the closest
- Note: The black edges perpendicularly bisect the grey edges

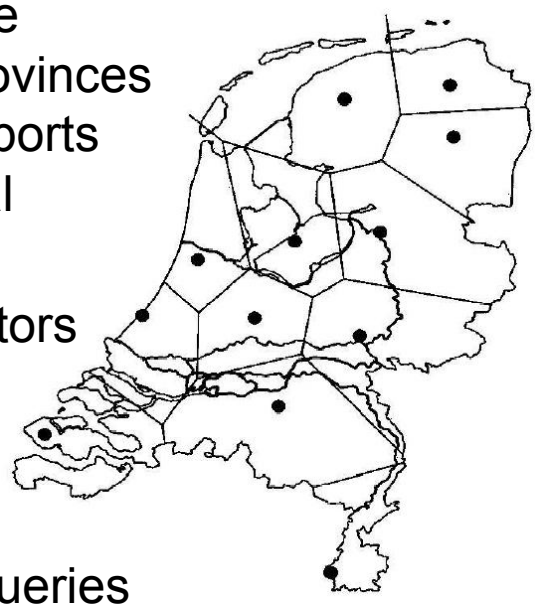






Voronoi Diagram/Cells/Regions

- How to re-district the Netherlands into provinces so that everyone reports to the closest capital
- Cell edges are the perpendicular bisectors of nearby points
- 2D or 3D
- Supports efficient *Nearest Neighbor* queries

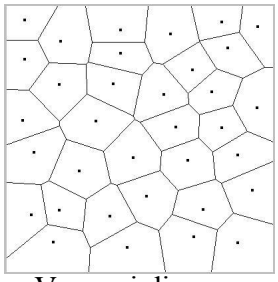


http://ccc.inaoep.mx/~rodrigo/robotica/Trigui.pdf

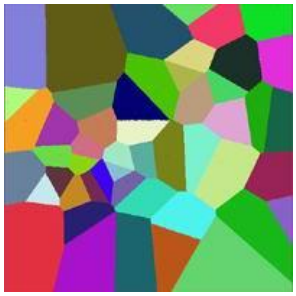
"Optimally" site the next Starbucks

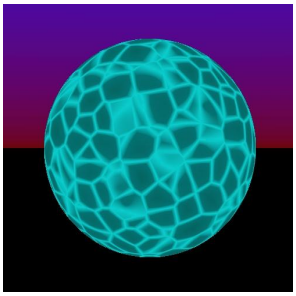
http://findbyclick.com/coffee_s.html

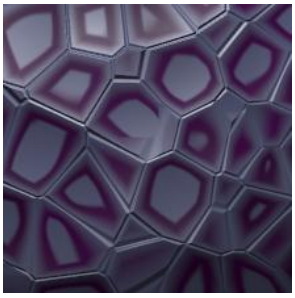
Cellular Textures



Voronoi diagram

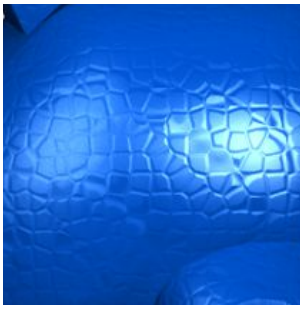






"A Cellular Texture Basis Function", Worley, SIGGRAPH 1996

www.worley.com



Questions?

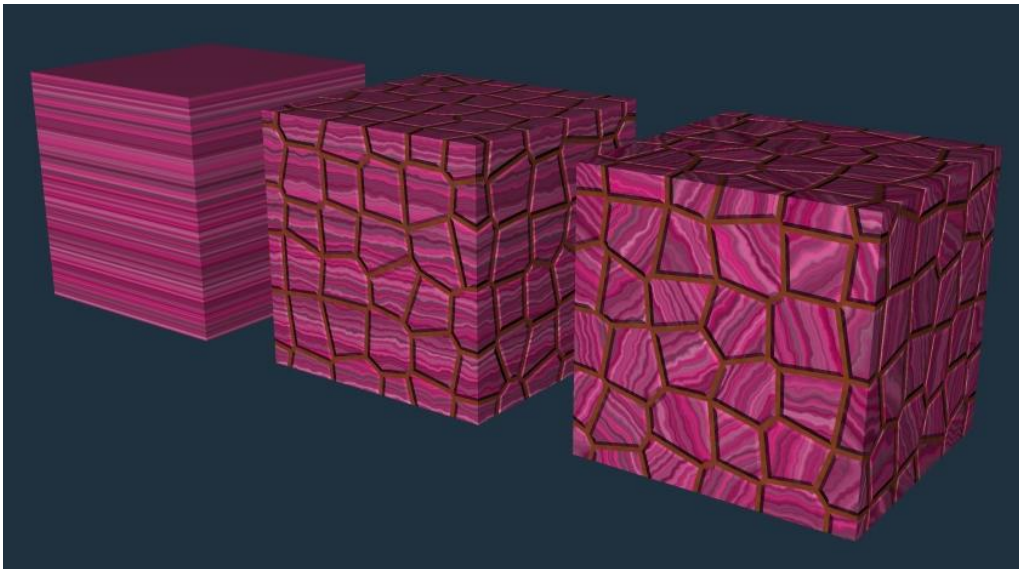
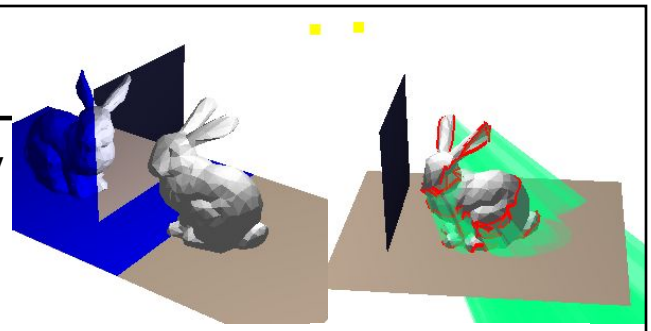
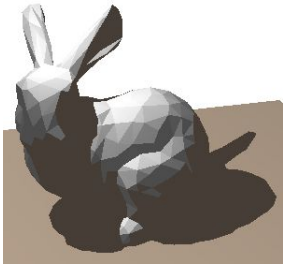


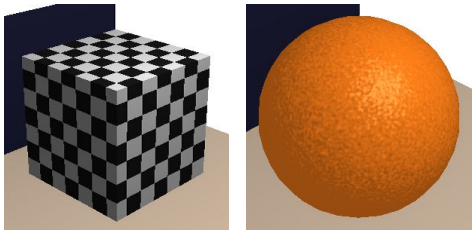
Image by Justin Legakis

Homework 4



- Create some geometry
  - Reflected object & floor
  - Silhouette edges
  - Shadow polygons
    - Make sure your polygons aren't doubled up
    - Make sure your polygons are oriented consistently
- Mess with the stencil buffer
  - Don't just blindly copy code from the tutorial
  - Use the web to read the man page for each instruction & its parameters
- Be creative with shaders
  - Hopefully everyone can get the examples to compile & run





Today

- Texture Mapping
- Common Texture Coordinate Mappings
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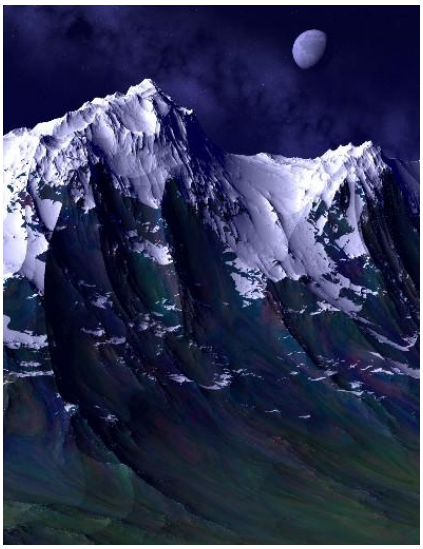
- Perlin Noise
- Procedural Modeling
- L-Systems

Procedural Displacement Mapping

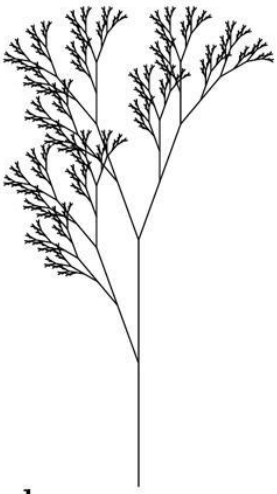


Ken Musgrave
www.kenmusgrave.com

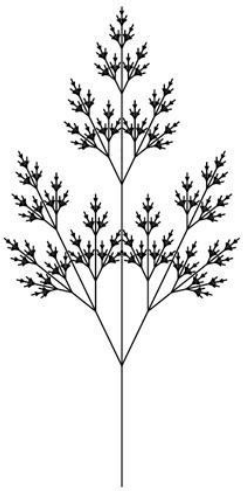
L-Systems

alphabet: {a,b}
initiator: a
production rules:
- a -> b
- b -> ba

generations:
- a
- b
- ba
- bab
- babba
- babbabab
- babbababbabba
- babbababbabbababbabab



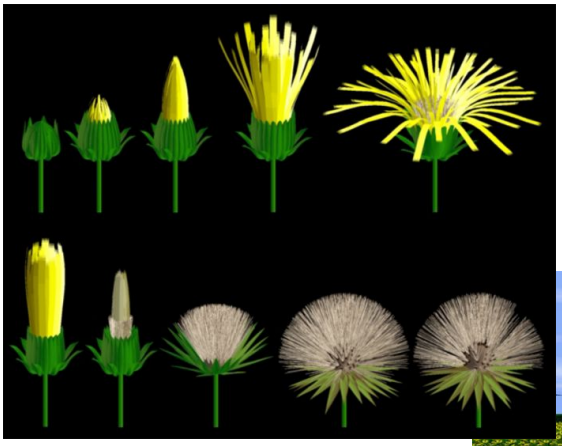
d
n=7, δ=20°
X
X →F[+X]F[-X]+X
F →FF



e
n=7, δ=25.7°
X
X→F[+X][-X]FX
F→FF

Prusinkiewicz & Lindenmayer,
The Algorithmic Beauty of Plants, 1990
http://algorithmicbotany.org/

L-Systems

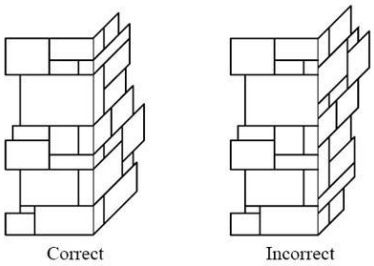


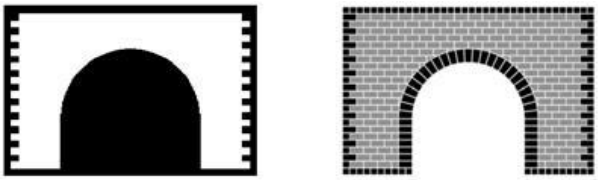
Animation of Plant Development
Prusinkiewicz et al., SIGGRAPH 1993

Prusinkiewicz & Lindenmayer, *The Algorithmic Beauty of Plants,* 1990
http://algorithmicbotany.org/

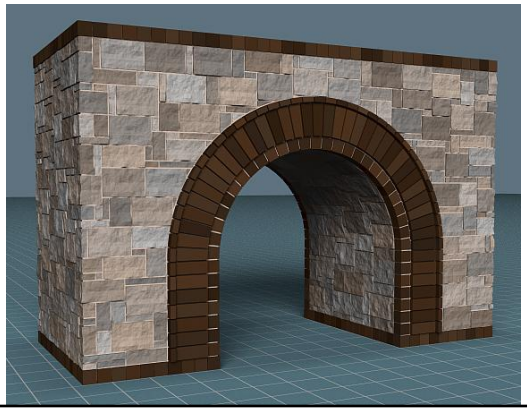
"Synthetic Topiary", Prusinkiewicz, James, and Mech, SIGGRAPH 1994

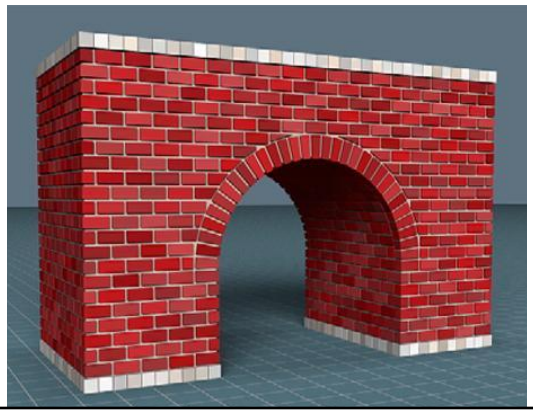
Cellular Texturing for Architecture





"Feature-Based Cellular Texturing for Architectural Models", Legakis, Dorsey, & Gortler, SIGGRAPH 2001



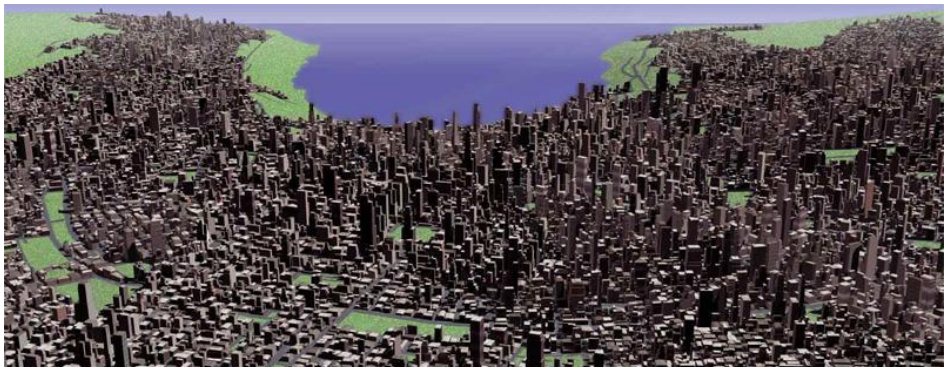


Procedural Modeling Advantages

- Small representation
- Generate detail as needed ("infinite"? resolution)
- Great for natural mathematical patterns and man-made engineering and design
- Trivial to make many duplicate objects with small variations

L-Systems for Cities

"Procedural Modeling of Cities",
Parish & Müller, SIGGRAPH 2001



Procedural Modeling of Buildings

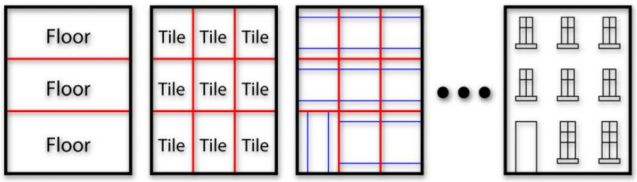
- "Procedural Modeling of Buildings", Mueller, Wonka, Haegler, Ulmer & Van Gool, SIGGRAPH 2006

Applications

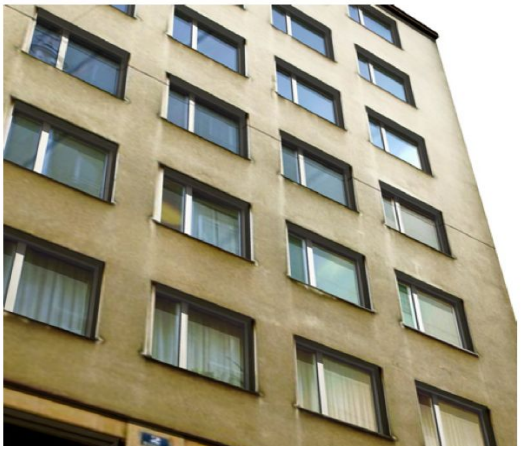
- Entertainment – Gaming
- Education – Studying botanical variation
- Archeological reconstruction
- Realism for Training
- Predicting the future (how will things grow over time)
- Urban planning (preparing for traffic)
- Accommodate for that growth/change

Image-based Procedural Modeling of Facades

- Mueller, Zeng, Wonka, & Van Goo SIGGRAPH 2007



Input Photograph



Reconstructed 3D Geometry

Questions about Procedural Modeling

- Number of rules necessary?
- Cost in human designer time of creating procedural model?
- Re-useability of procedural model?
- Validation
- Can you build a procedural model that produces a specific target?
  - *From a photo of a specific rare wood grain, can you create a procedural model that creates texture that looks like it came from a different location of the same/similar tree?*

Questions?

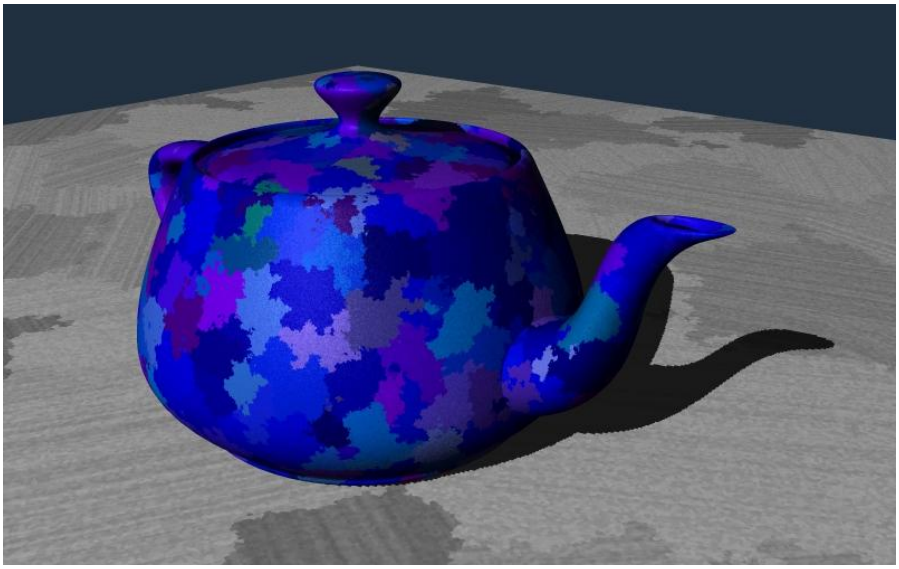


Image by Justin Legakis