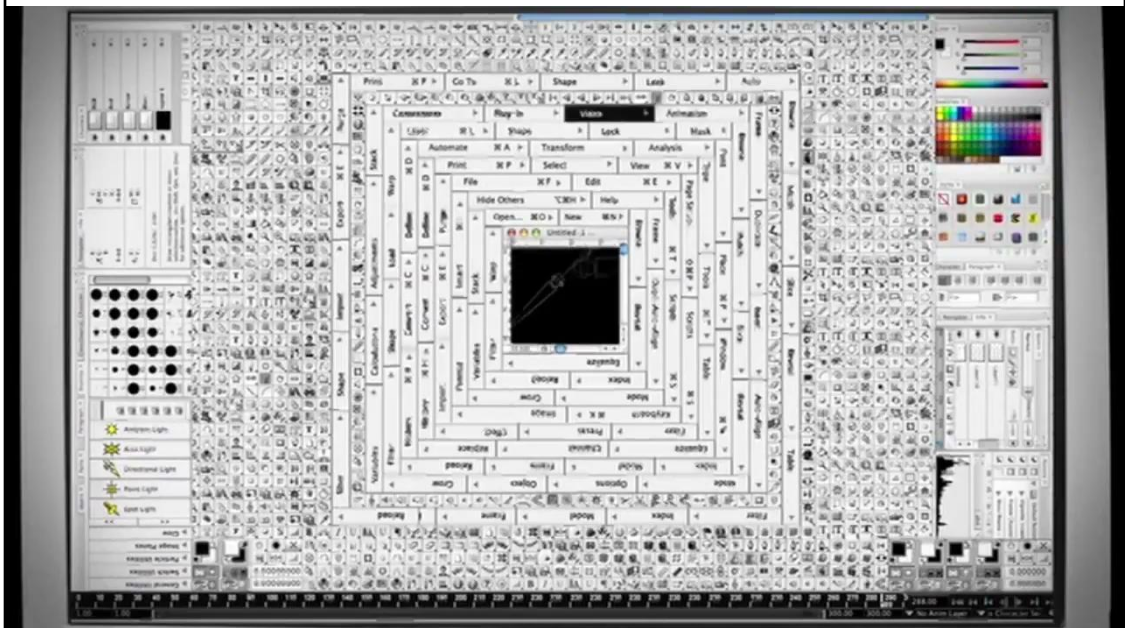


Procedural Modeling

Upgrades, Anya Belkina, 2010



Homework 4

- Create some geometry

- Reflected object & floor
- Silhouette edges
- Shadow polygons

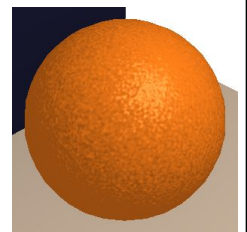
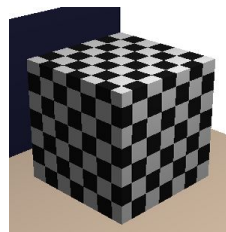
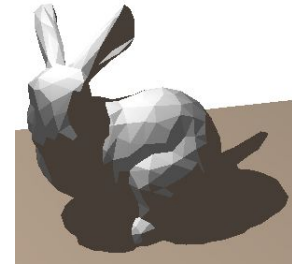
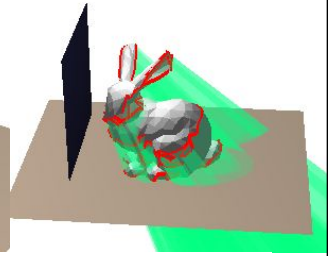
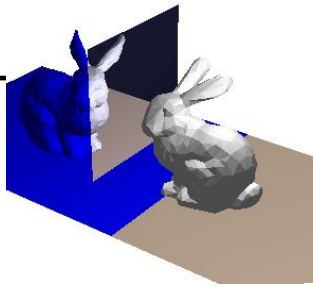
- Make sure your polygons aren't doubled up
- Make sure your polygons are oriented consistently

- 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

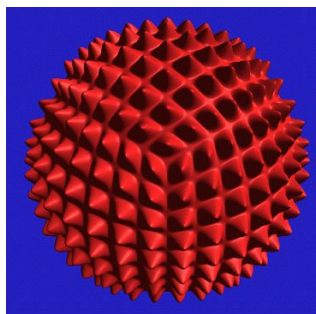
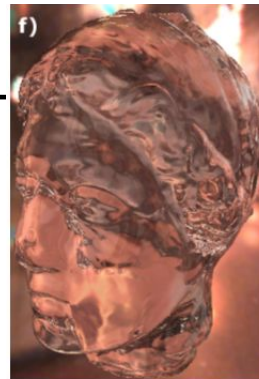
- Hopefully everyone can get the examples to compile & run



Last Time?

- Modern Graphics Hardware
- Cg Programming Language
- Gouraud Shading vs. Phong Normal Interpolation

- Bump, Displacement, & Environment Mapping

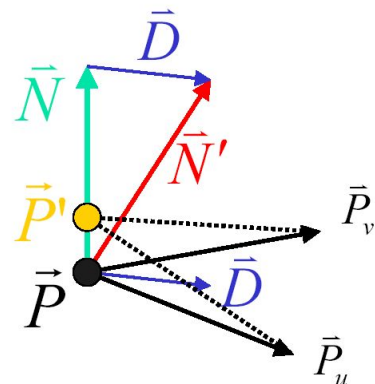
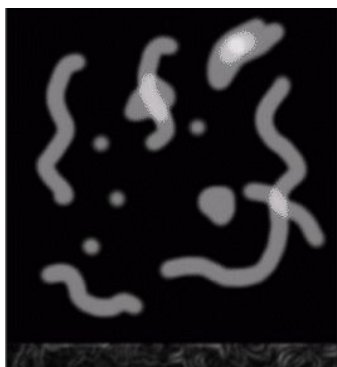


From Last Time

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

Bump Mapping

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

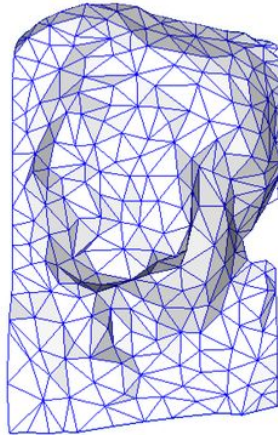


Normal Mapping

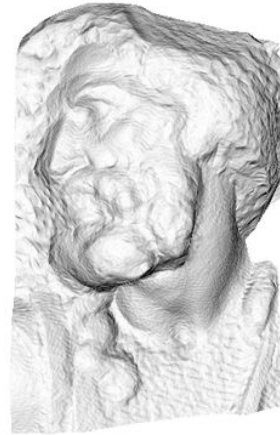
- Variation on Bump Mapping:
Use an RGB texture to directly encode the normal



original mesh
4M triangles



simplified mesh
500 triangles

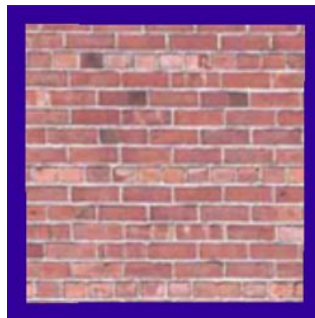


simplified mesh
and normal mapping
500 triangles

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



Today

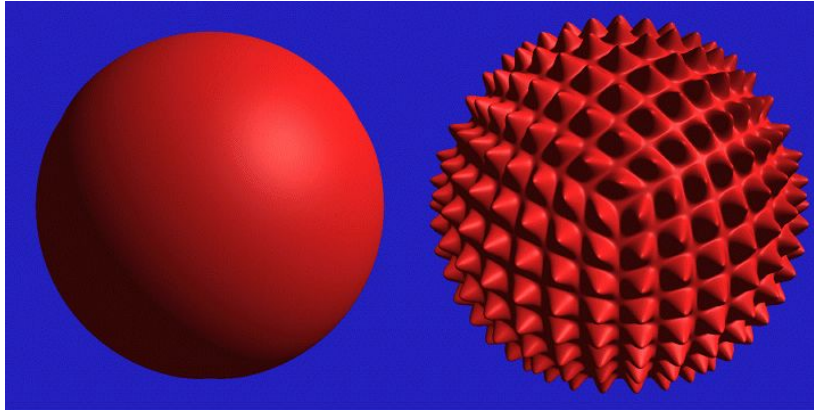
- Finish “Mappings” from Last Time
- Papers for Today
- Texture Mapping
- Common Texture Coordinate Mappings
- Solid Texture
- Procedural Textures
- Perlin Noise
- Procedural Modeling
- L-Systems
- Papers for Friday

From Last Time

- Many “Mapping” techniques
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 - Parallax Mapping
 - 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*

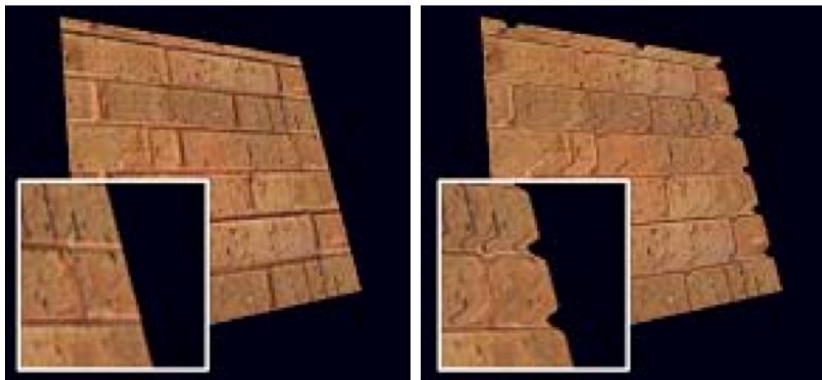
Displacement Mapping



Ken Musgrave

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

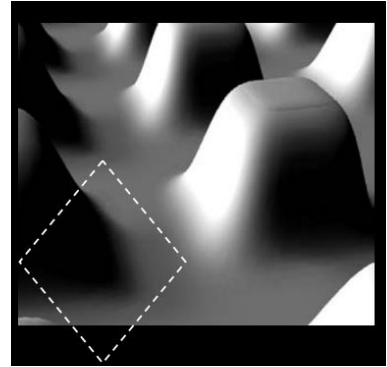
- Displace the texture coordinates for each pixel based on view angle and value of the height map at that point
- At steeper view-angles, texture coordinates are displaced more, giving illusion of depth due to parallax effects



“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



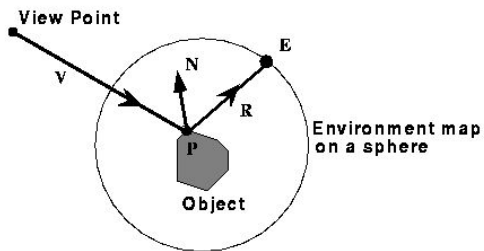
http://developer.amd.com/media/gpu_assets/Tatarchuk-ParallaxOcclusionMapping-Sketch-print.pdf

From Last Time

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

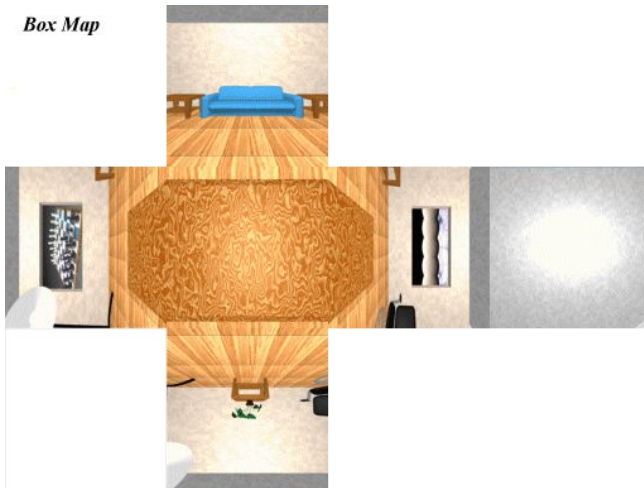
Environment Maps

- 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?

Box Map



Latitude Map



GL Map



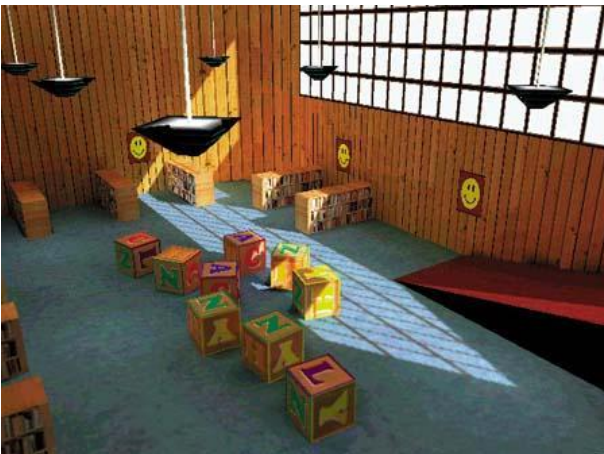
Environment Mapping Example



Terminator II

Texture Maps for Illumination

- Also called "Light Maps"



Quake

Questions?



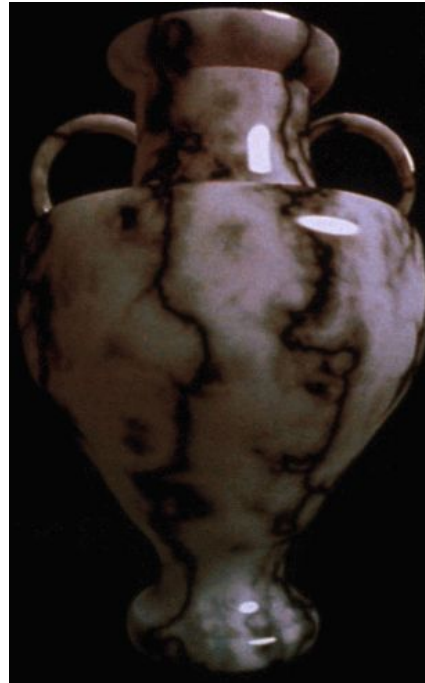
Image by Henrik Wann Jensen
Environment map by Paul Debevec

Today

- Finish “Mappings” from Last Time
- **Papers for Today**
- Texture Mapping
- Common Texture Coordinate Mappings
- Solid Texture
- Procedural Textures
- Perlin Noise
- Procedural Modeling
- L-Systems
- Papers for Friday

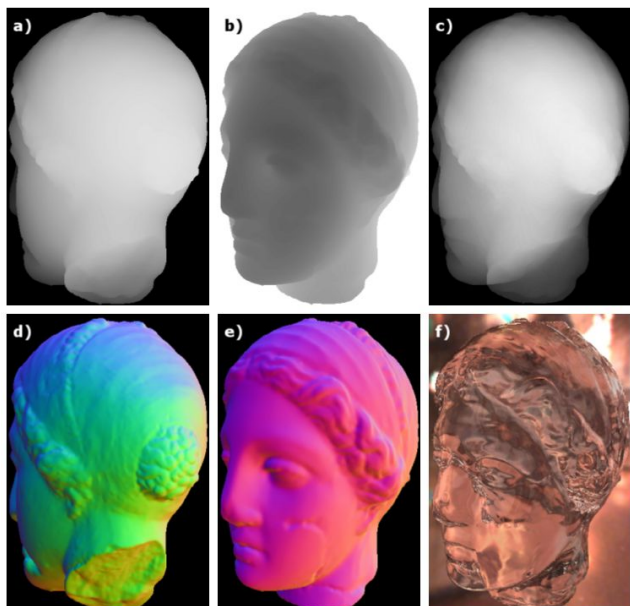
Reading for Next Time *(pick one)*

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



Reading for Today

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



Reading for Next Time *(pick one)*

“Hardware-Accelerated Global Illumination by Image Space Photon Mapping” McGuire & Luebke, HPG 2009



Direct Illumination Only

Direct + Constant Ambient

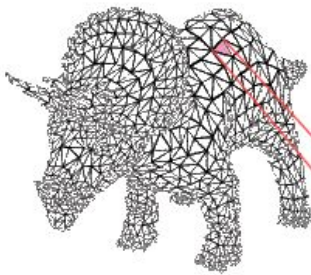
Image Space Photon Mapping

Figure 1: Image-space photon mapping can compute global illumination at interactive rates for scenes with multiple lights, caustics, shadows, and complex BSDFs. This scene renders at 26 Hz at 1920×1080 . (Indirect and ambient intensity are amplified for comparison in this image.)

Today

- Finish “Mappings” from Last Time
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- **Texture Mapping**
- **Common Texture Coordinate Mappings**
- Solid Texture
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- Papers for Friday

Texture Mapping



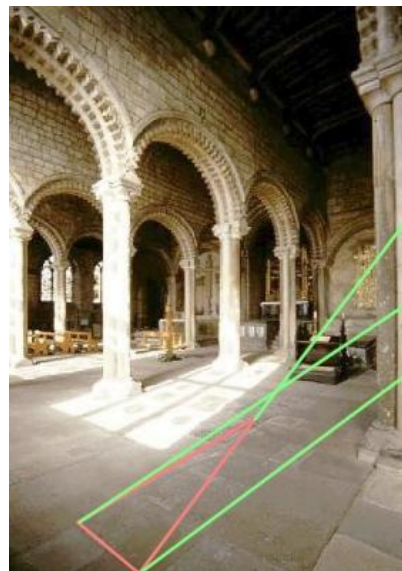
For each triangle in the model establish a corresponding region in the phototexture



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

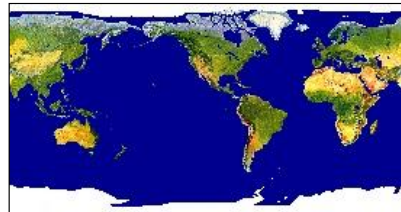
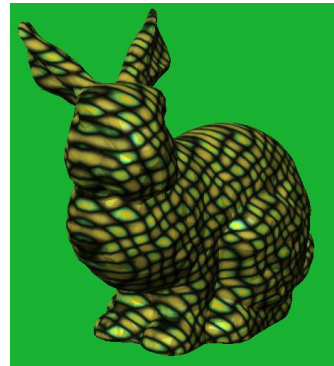


Can't do this!

You can get around this problem for planar surfaces if you specify 4 points...

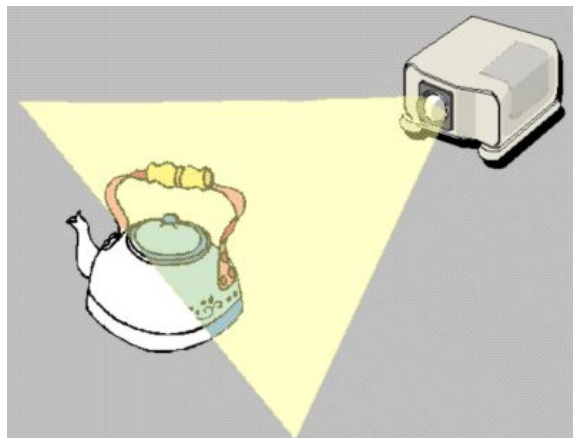
Common Texture Coordinate Mappings

- 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

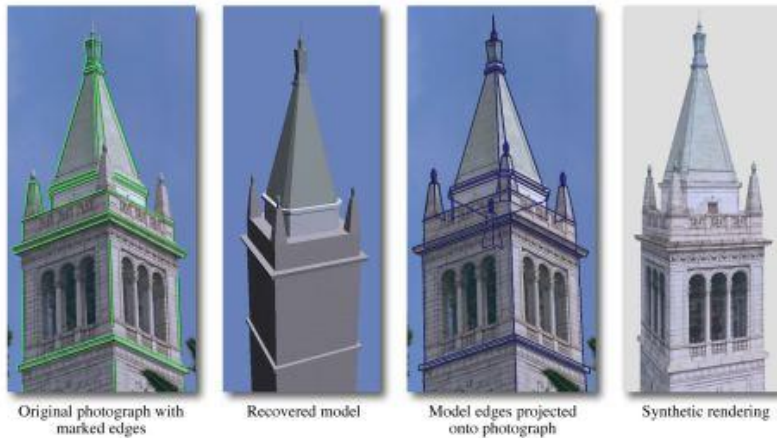
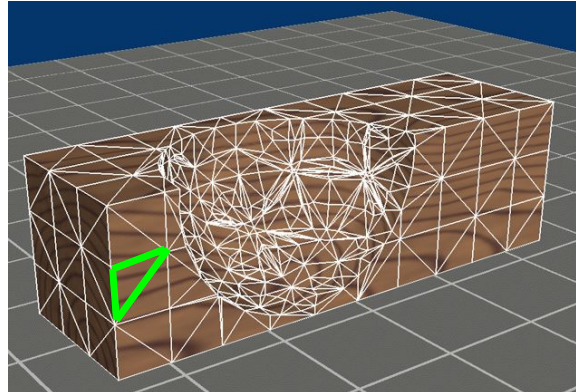
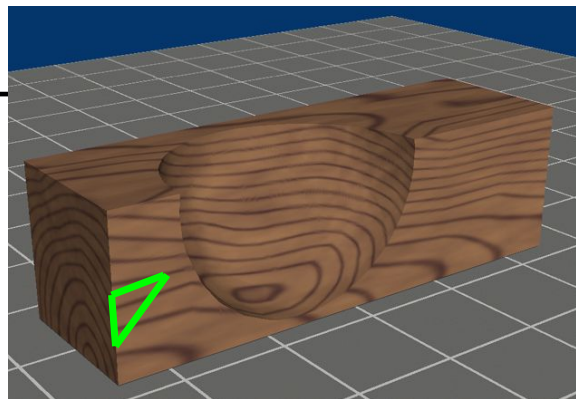
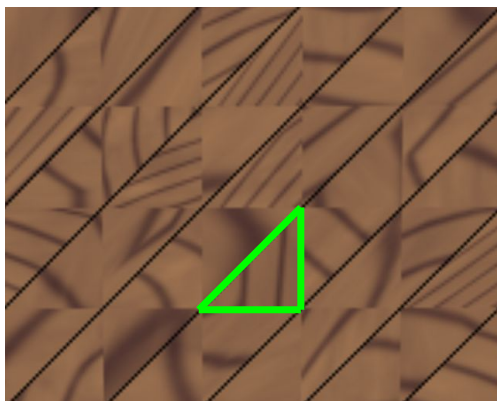


Figure from Debevec, Taylor & Malik
<http://www.debevec.org/Research>

Texture Chart

- Pack triangles into a single image

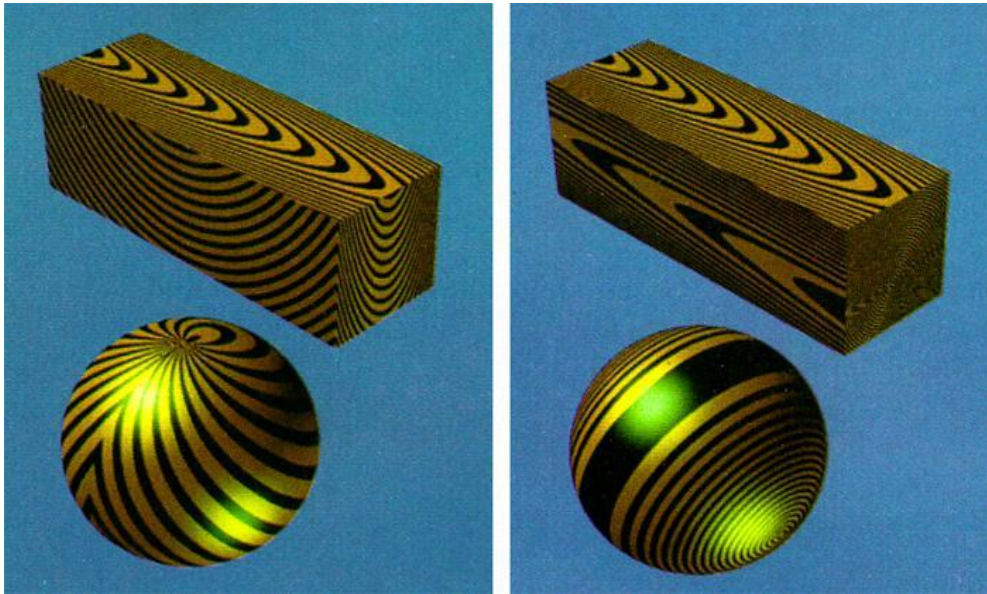


Questions?

Today

- Finish “Mappings” from Last Time
- Papers for Today
- Texture Mapping
- Common Texture Coordinate Mappings
- **Solid Texture**
- **Procedural Textures**
- **Perlin Noise**
- Procedural Modeling
- L-Systems
- Papers for Friday

Texture Map vs. Solid Texture



“Solid Texturing of Complex Surfaces”,
Peachey, SIGGRAPH 1985

Procedural Textures

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

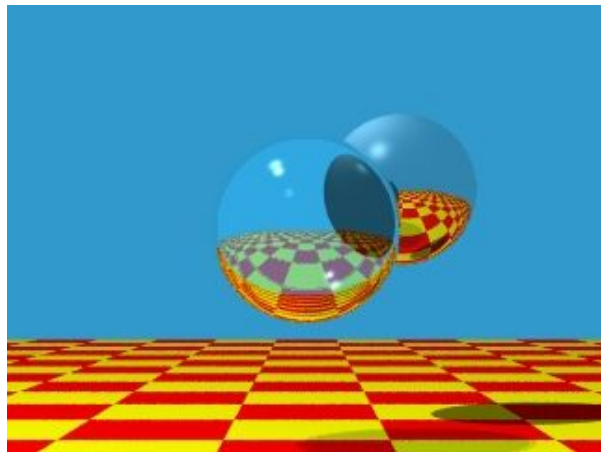
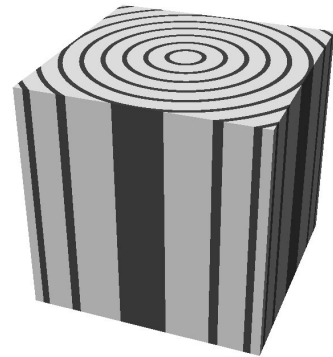
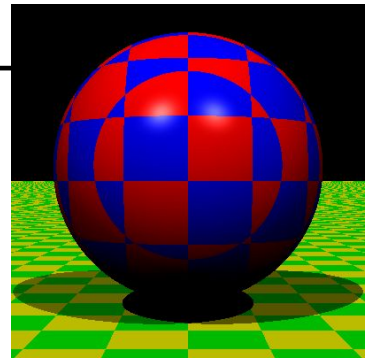


Image by Turner Whitted

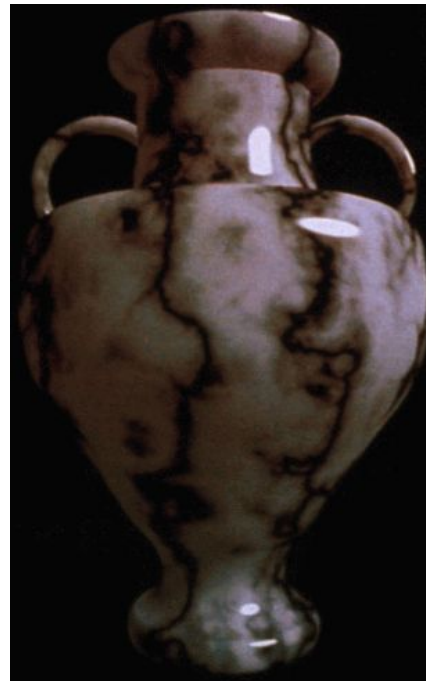
Procedural Textures

- 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

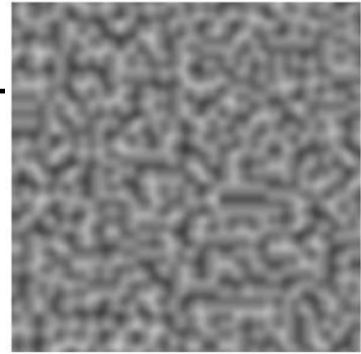


Reading for Today

- “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

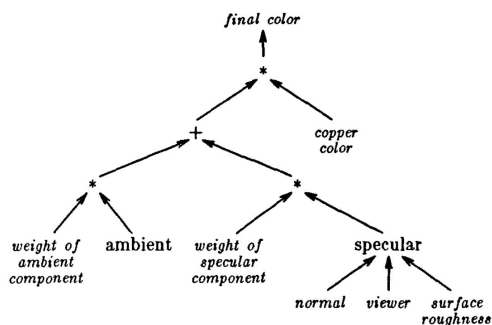


Figure 1a. Shade tree for copper.

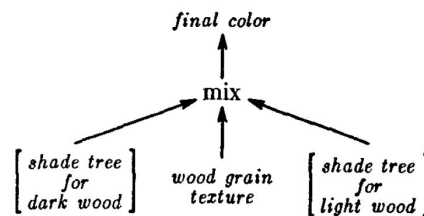
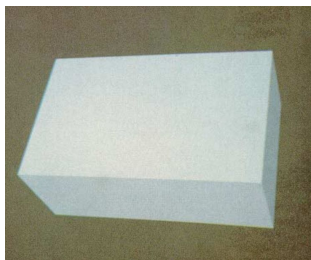
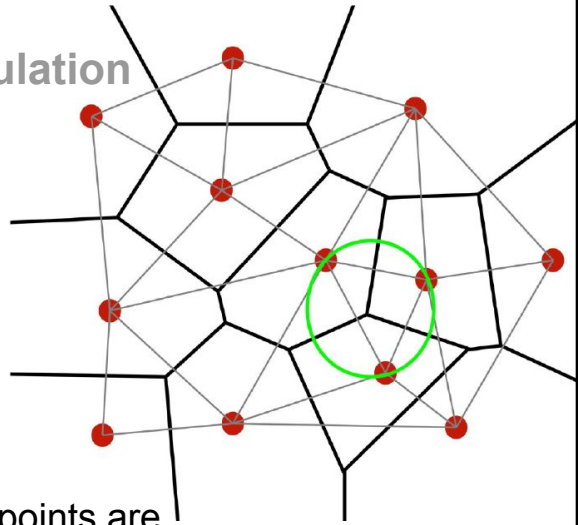


Figure 1b. The mix node in a shade tree for wood.



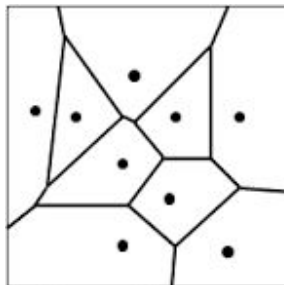
- **Grey: Delaunay Triangulation**

- “Best” triangulation of the red dots (most equilateral)
- A specific triangle is in the Delaunay 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...

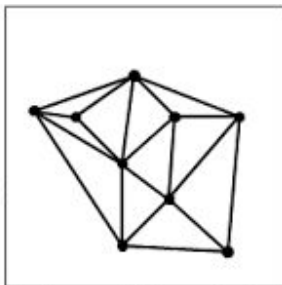


- **Black: Voronoi Diagram**

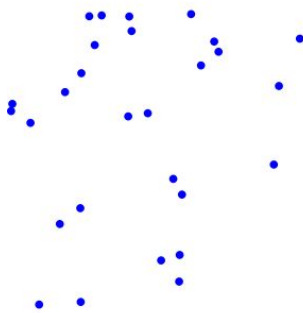
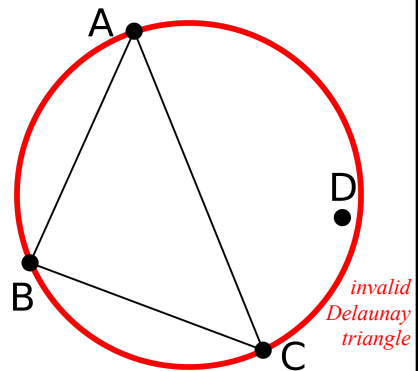
- Each cell is the set of all points in the plane that claim that cell’s red dot as the closest
- Note: The black edges perpendicularly bisect the grey edges



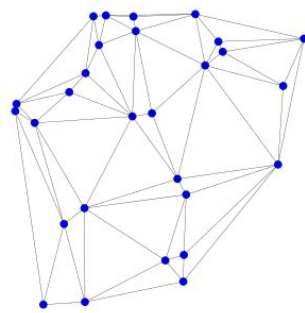
Voronoi Diagram



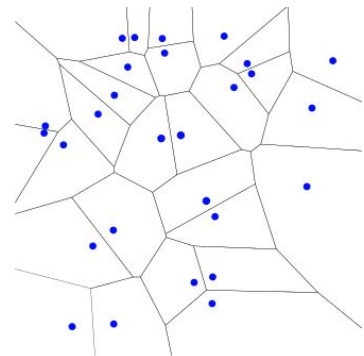
Delaunay Triangulation



Input



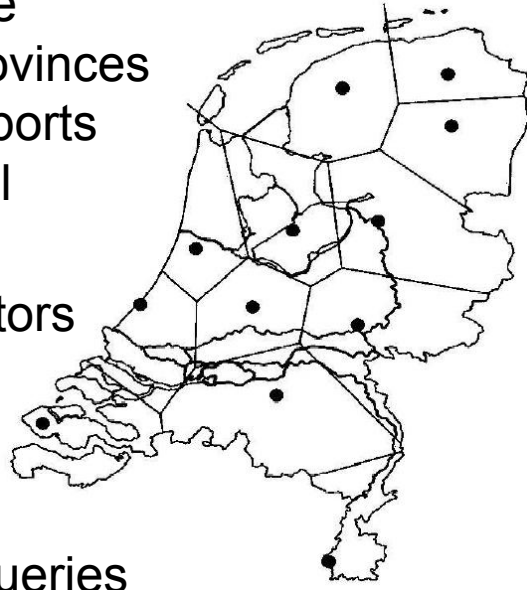
Delaunay Triangulation



Voronoi Diagram

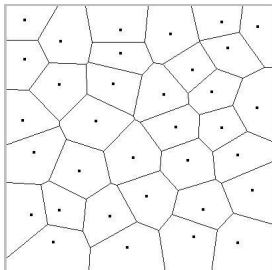
Voronoi Diagram/Cells/Regions

- 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

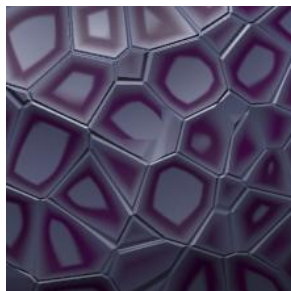
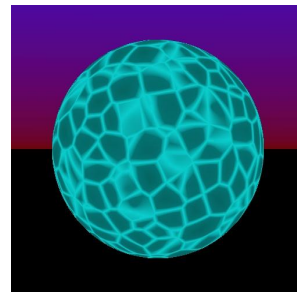


<http://ccc.inaoep.mx/~rodrigo/robotica/Trigui.pdf>

Cellular Textures

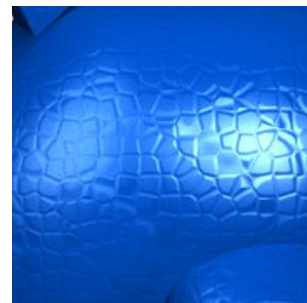


Voronoi diagram



“A Cellular Texture Basis Function”, Worley, SIGGRAPH 1996

www.worley.com



Questions?

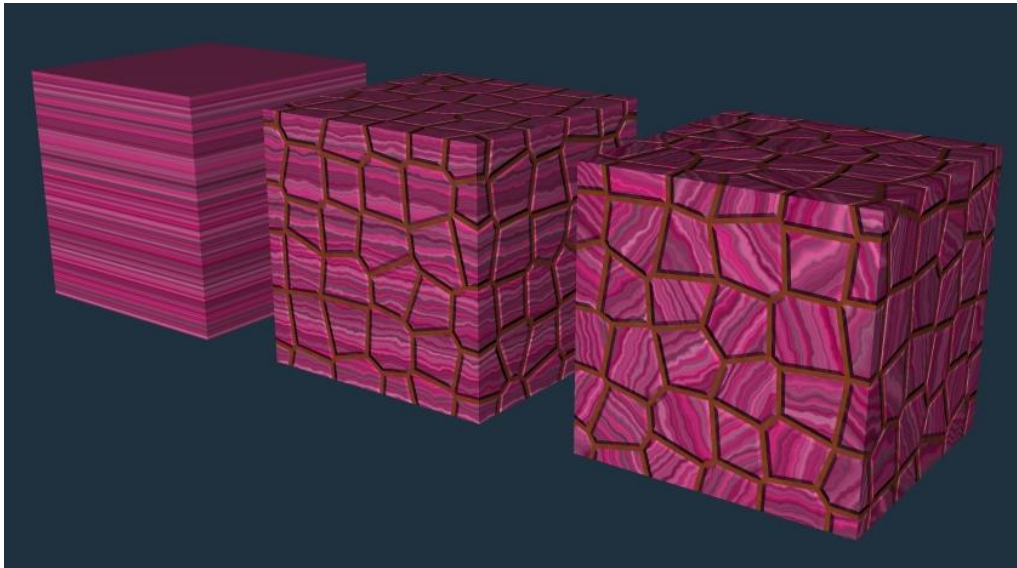
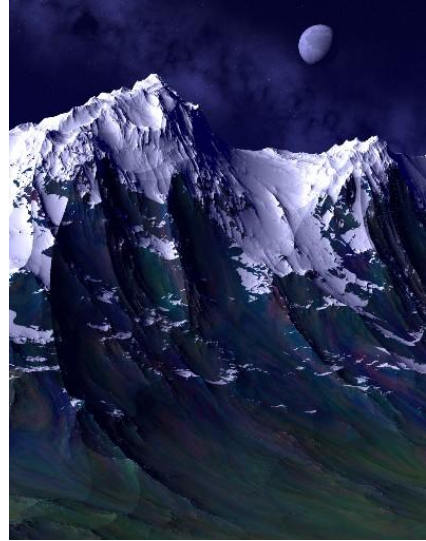


Image by Justin Legakis

Today

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- **L-Systems**
- Papers for Friday

Procedural Displacement Mapping



Ken Musgrave
www.kenmusgrave.com

L-Systems

alphabet: {a,b}

initiator: a

production rules:

a \rightarrow b

b \rightarrow ba

generations:

a

b

ba

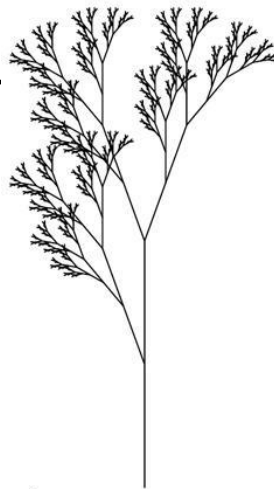
bab

babba

babbabab

babbababbabba

babbababbababbabab



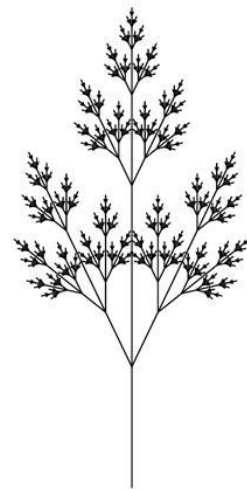
d

$n=7, \delta=20^\circ$

X

X \rightarrow F [+X] F [-X] +X

F \rightarrow FF



e

$n=7, \delta=25.7^\circ$

X

X \rightarrow F [+X] [-X] FX

F \rightarrow FF

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

L-Systems

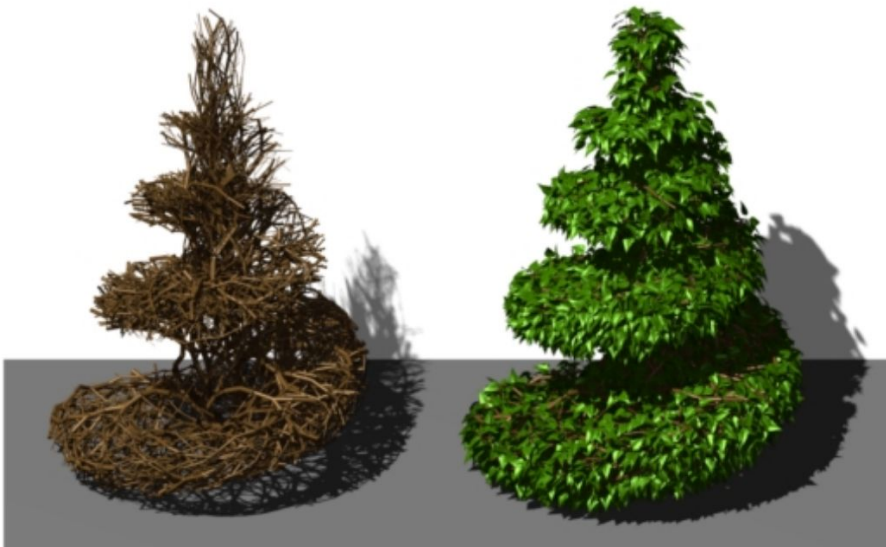


*Animation of Plant
Development*
Prusinkiewicz et al.,
SIGGRAPH 1993

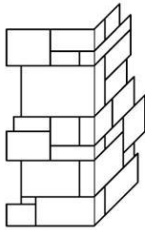
Prusinkiewicz & Lindenmayer,
*The Algorithmic Beauty of
Plants*, 1990
<http://algorithmicbotany.org/>



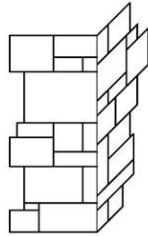
“Synthetic Topiary”, Prusinkiewicz,
James, and Mech, SIGGRAPH 1994



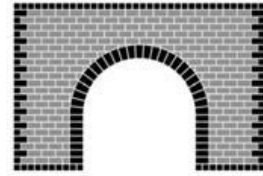
Cellular Texturing for Architecture



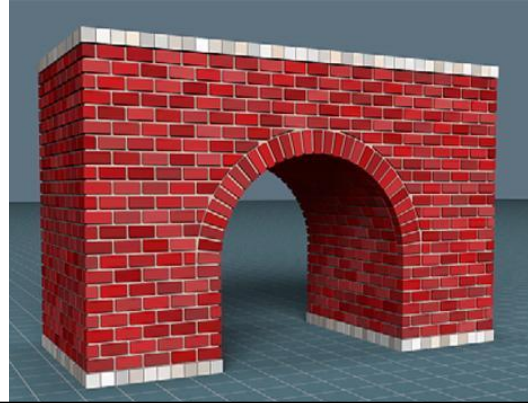
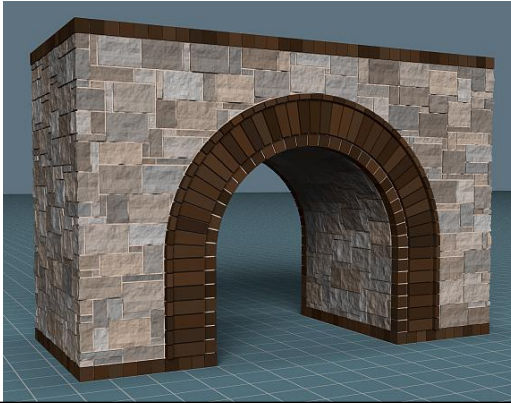
Correct



Incorrect



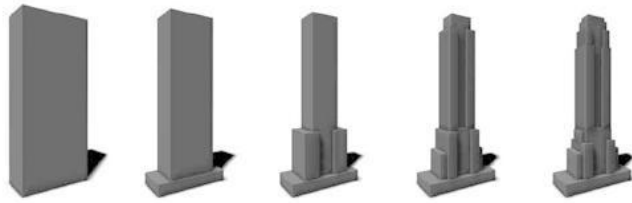
“Feature-Based Cellular Texturing for Architectural Models”, Legakis, Dorsey, & Gortler, SIGGRAPH 2001



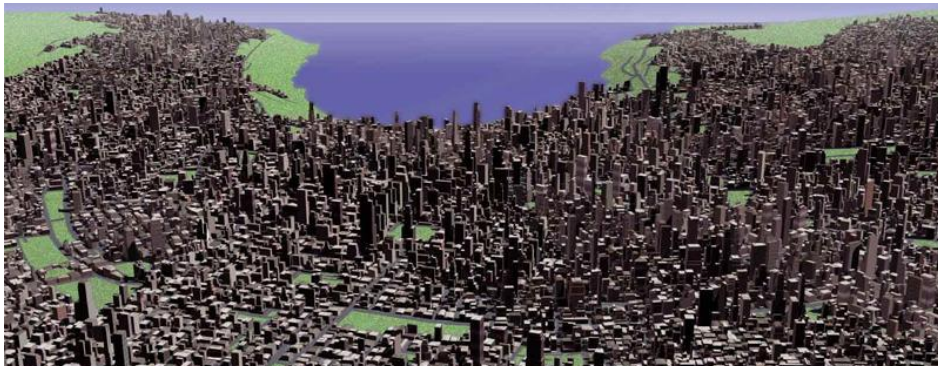
Procedural Modeling Advantages

- 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



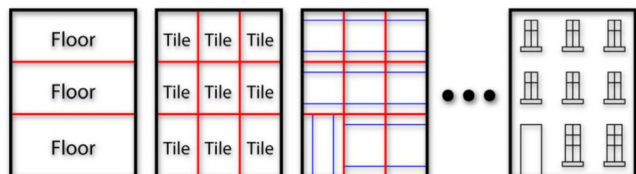
- “Procedural Modeling of Buildings”, Mueller, Wonka, Haegler, Ulmer & Van Gool, SIGGRAPH 2006

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?

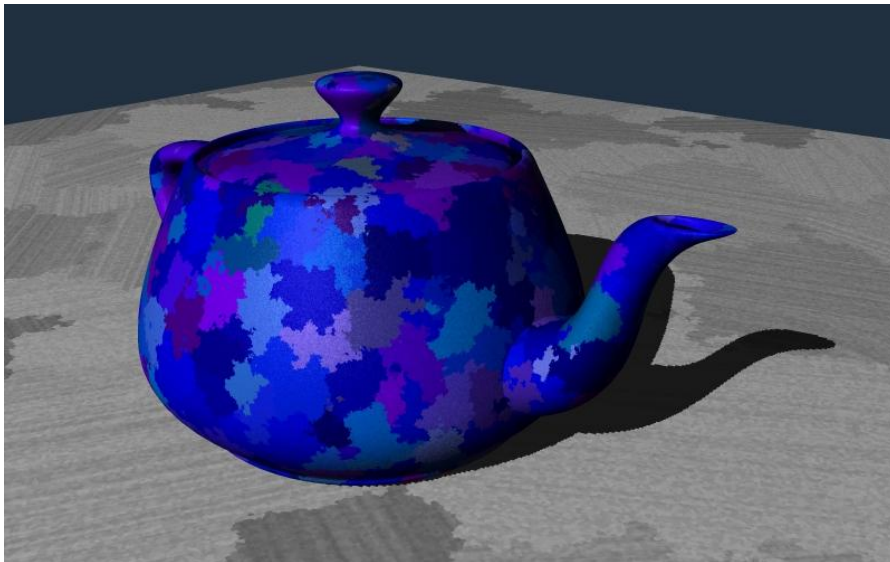


Image by Justin Legakis

Today

- Finish “Mappings” from Last Time
- Papers for Today
- Texture Mapping
- Common Texture Coordinate Mappings
- Solid Texture
- Procedural Textures
- Perlin Noise
- Procedural Modeling
- L-Systems
- Papers for Friday