Texture Mapping & Shaders

MIT EECS 6.837 Computer Graphics

BRDF in Matrix II & III

Spatial Variation

- All materials seen so far are the same everywhere
  - In other words, we are assuming the BRDF is independent of the surface point **x**
  - No real reason to make that assumption

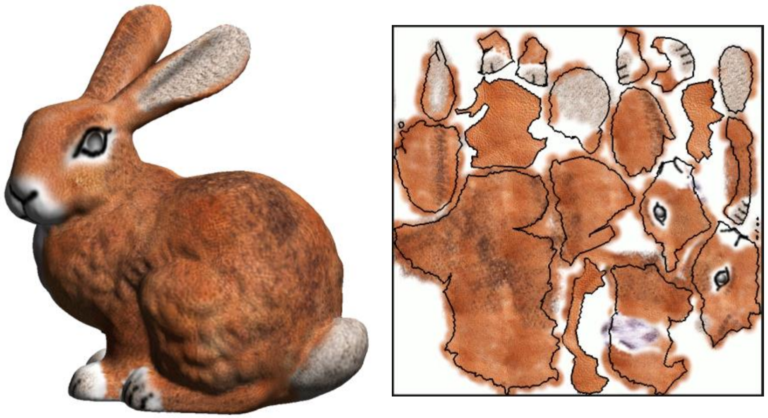
Spatial Variation

- We will allow BRDF parameters to vary over space
  - This will give us much more complex surface appearance
  - e.g. diffuse color k_d vary with x
  - Other parameters/info can vary too: k_s, exponent, normal

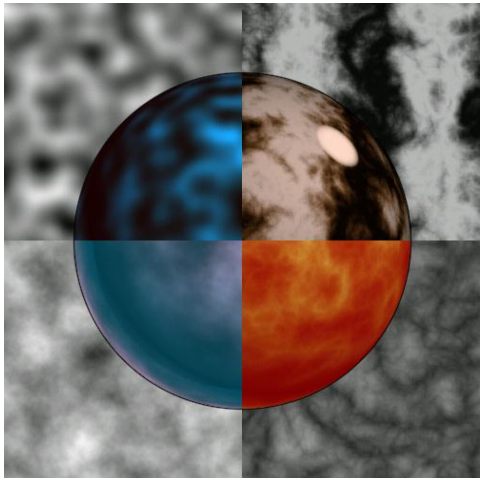
Courtesy of Fredo Durand. Used with permission.

Two Approaches

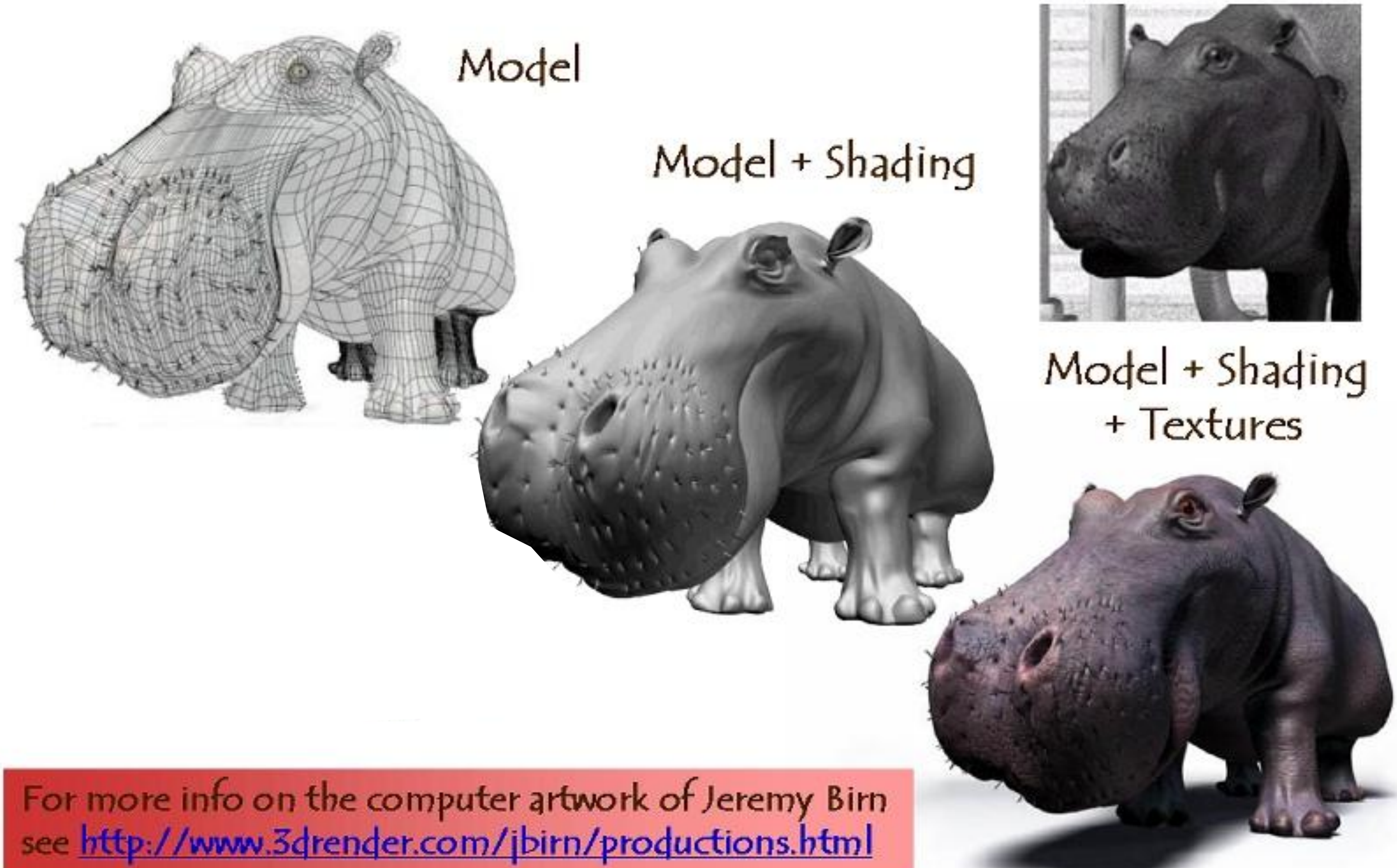
- From data : texture mapping
  - read color and other information from 2D images



- Procedural : shader
  - write little programs that compute color/info as a function of location



Effect of Textures



Courtesy of Jeremy Birn.

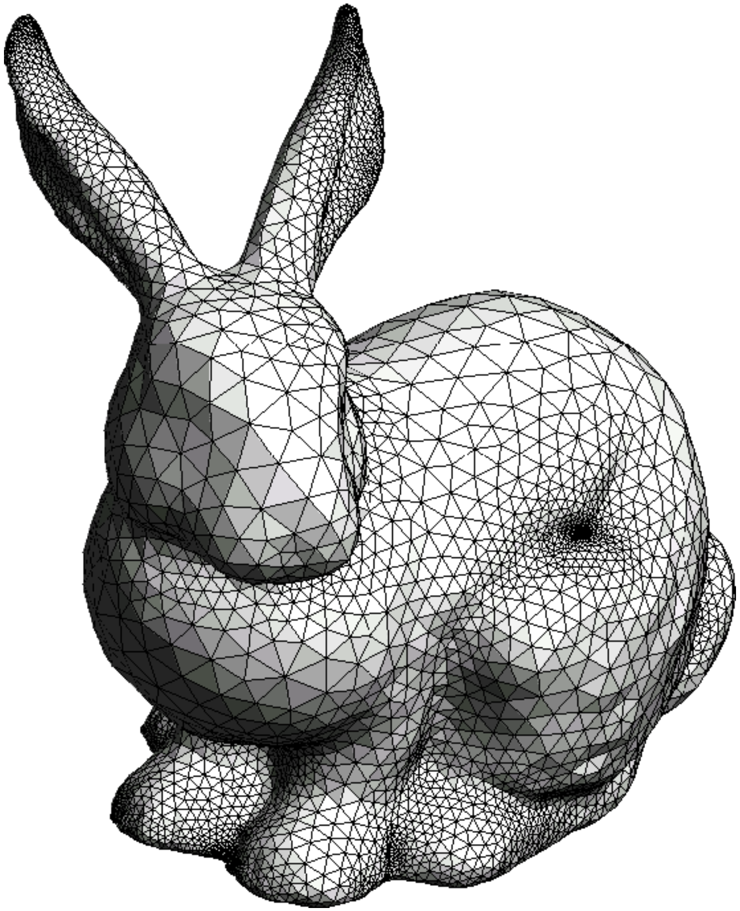
Texture Mapping

Image of a cartoon of a man applying wall paper has been removed due to copyright restrictions.

Texture Mapping

3D model

Texture mapped model



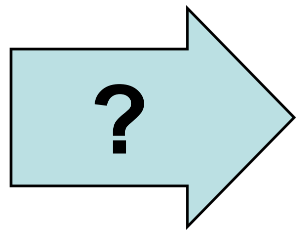


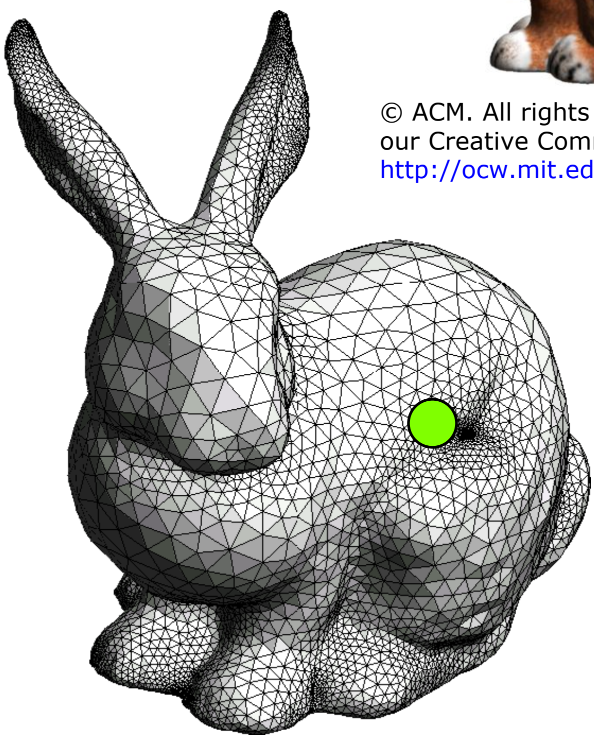
Image: Praun et al.

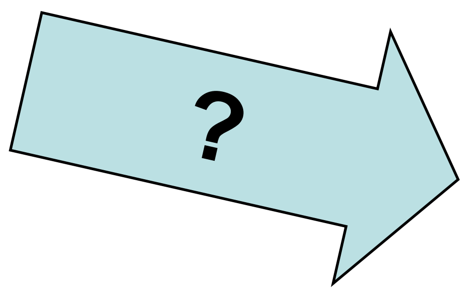
Texture Mapping

Image: Praun et al.

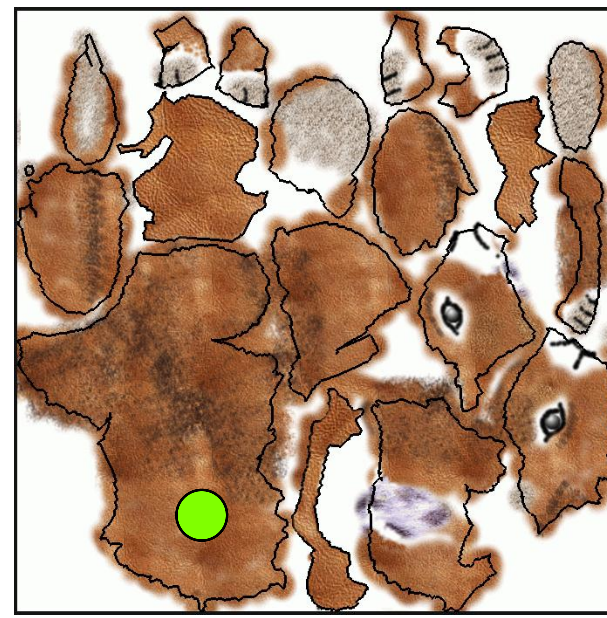
Texture mapped model

We need a function that associates each surface point with a 2D coordinate in the texture map





Texture map (2D image)

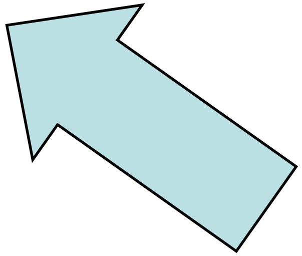


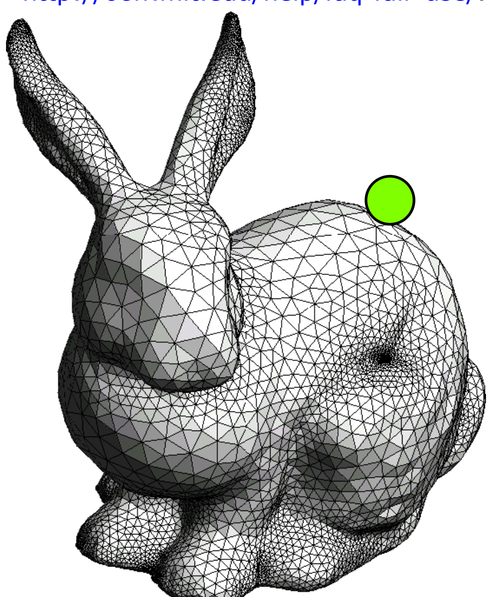
Texture Mapping

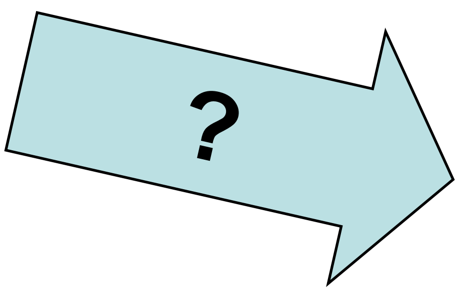
Image: Praun et al.

Texture mapped model

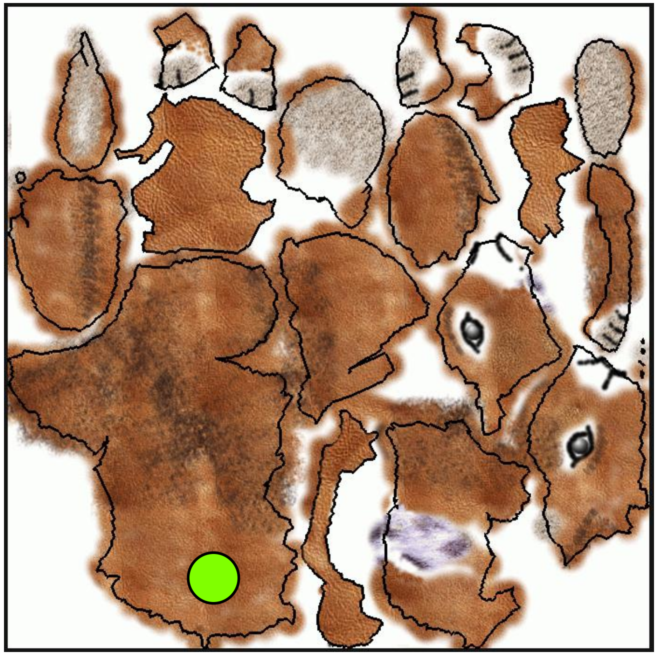
For each point rendered, look up color in texture map





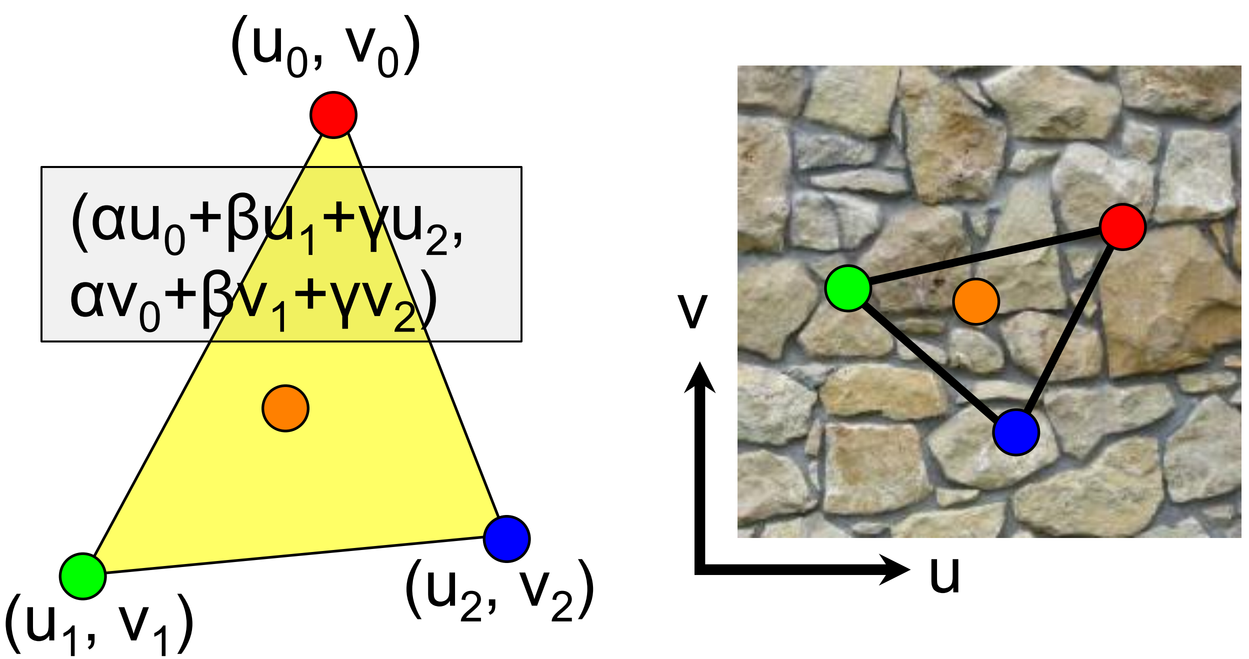


Texture map (2D image)



UV Coordinates

- Each vertex P stores 2D (u, v) “texture coordinates”
  – UVs determine the 2D location in the texture for the vertex
  – We will see how to specify them later
- Then we interpolate using barycentrics



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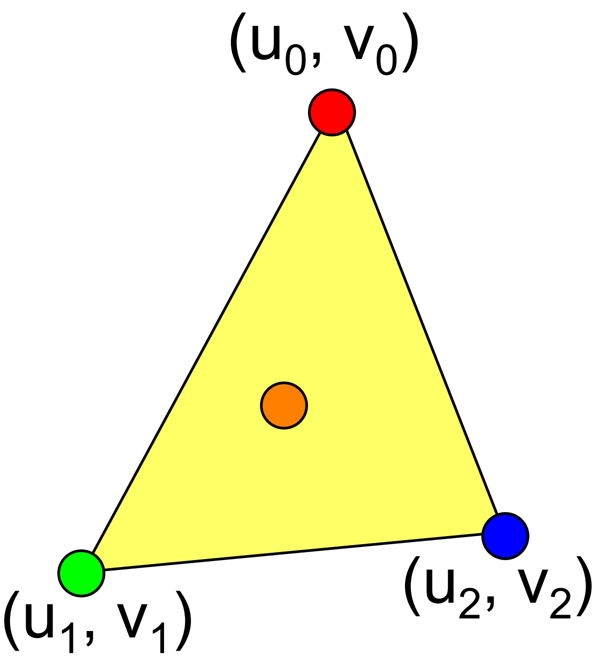
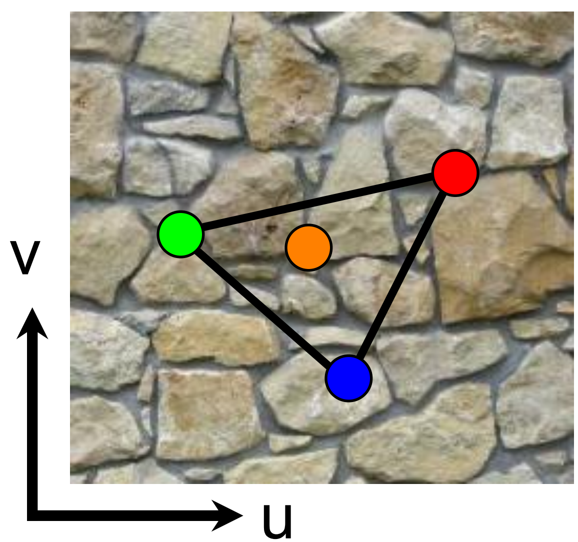
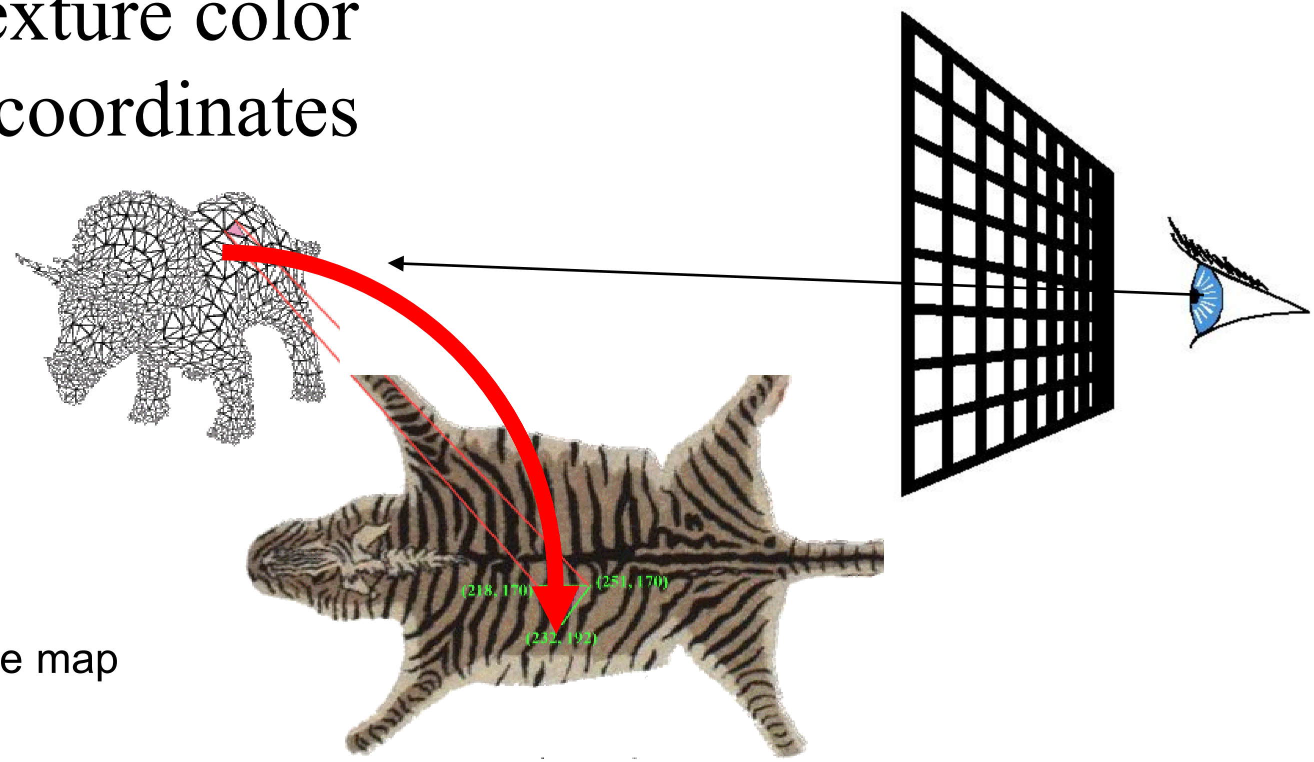




Pseudocode – Ray Casting

- Ray cast pixel (x, y), get visible point and α, β, γ
- Get texture coordinates (u, v) at that point
  - Interpolate from vertices using barycentrics
- Look up texture color using UV coordinates

Scene

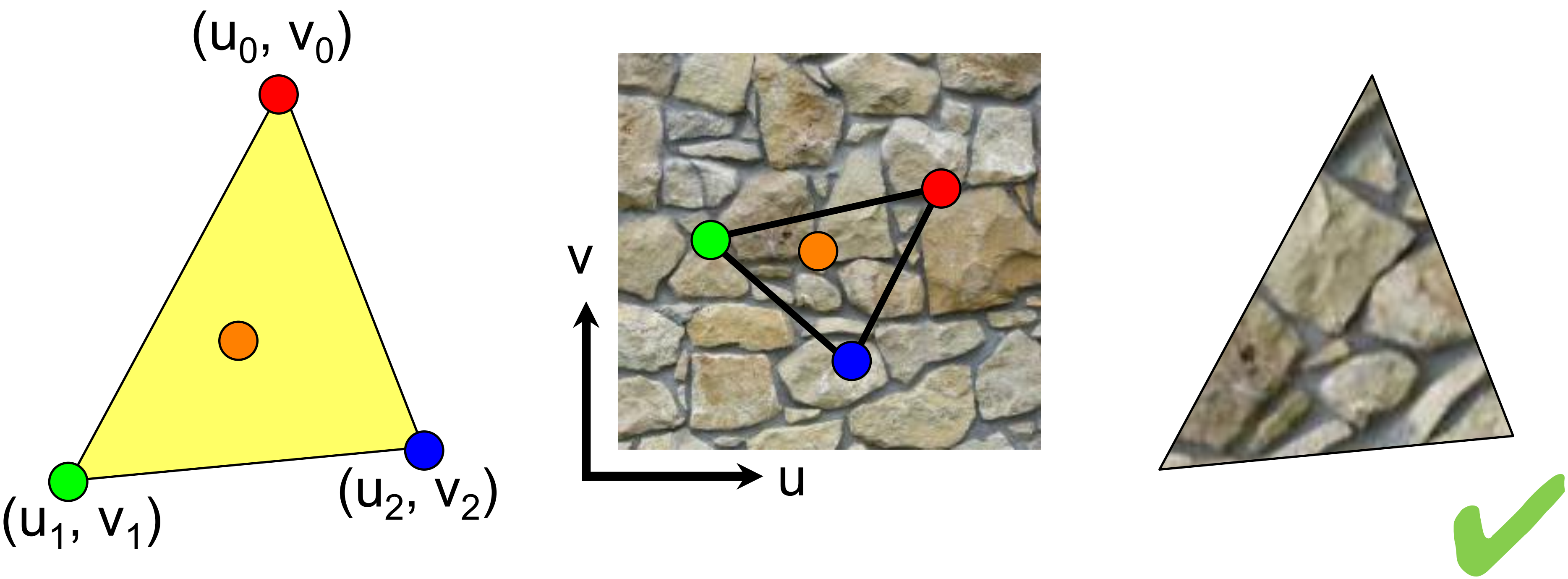


Texture map

Leonard McMillan, Computer Science at the University of North Carolina in Chapel Hill.

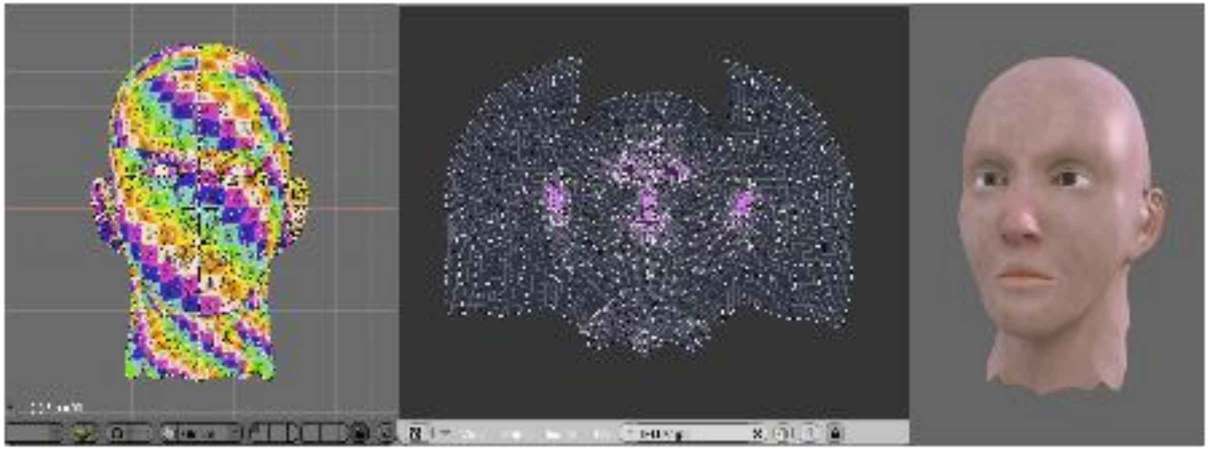
UV Coordinates?

- Per-vertex (u, v) “texture coordinates” are specified:
  - Manually, provided by user (tedious!)
  - Automatically using parameterization optimization
  - Mathematical mapping (independent of vertices)



Texture UV Optimization

- Goal : “flatten” 3D object onto 2D UV coordinates
- For each vertex, find coordinates U,V such that distortion is minimized
  - distances in UV correspond to distances on mesh
  - angle of 3D triangle same as angle of triangle in UV plane
- Cuts are usually required (discontinuities)

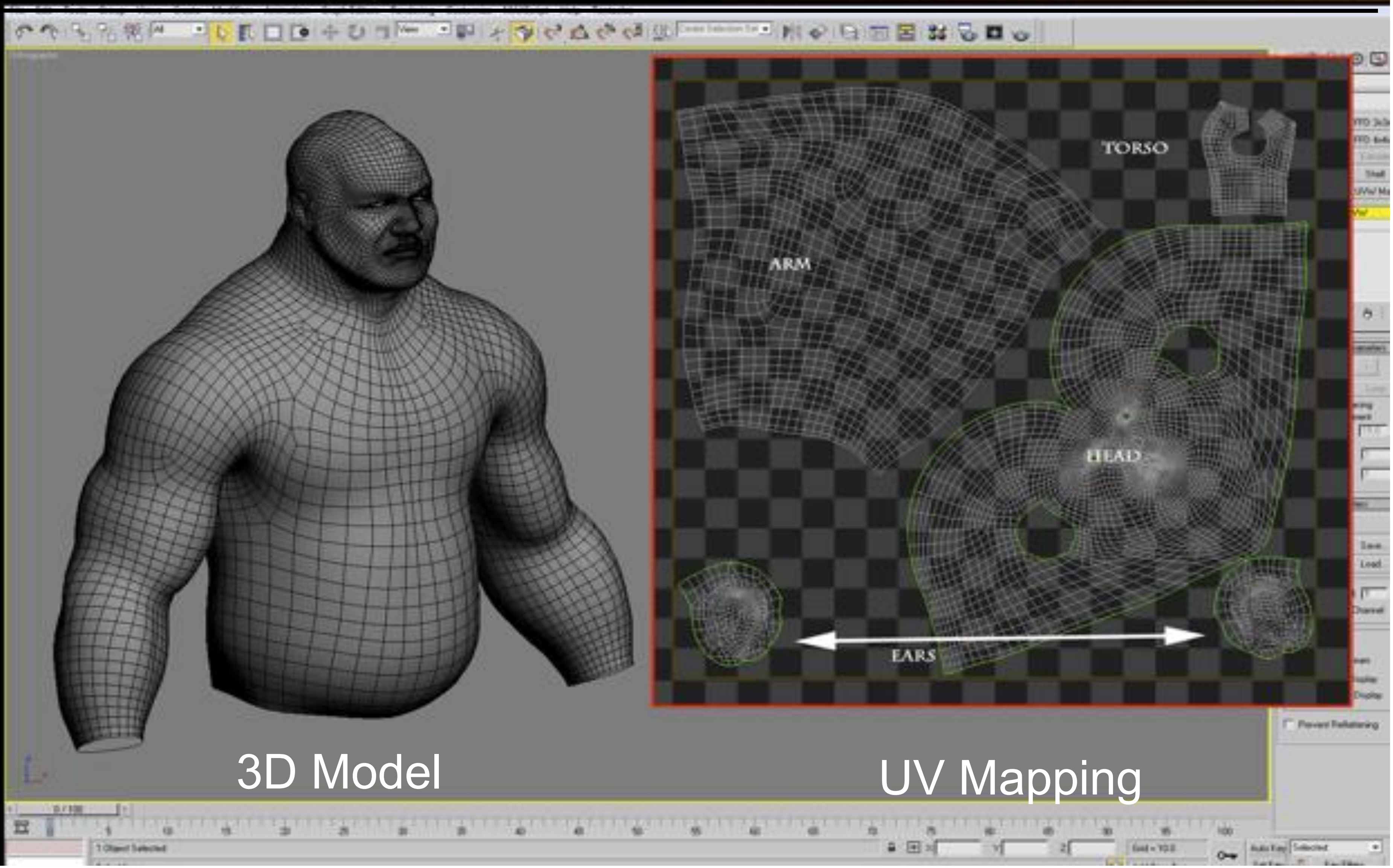


To Learn More

- For this course, assume UV given per vertex
- Mesh Parameterization: Theory and Practice”
  - Kai Hormann, Bruno Lévy and Alla Sheffer *ACM SIGGRAPH Course Notes, 2007*
- http://alice.loria.fr/index.php/publications.html?redirect=0&Paper=SigCourseParam@2007&Author=Levy

Slide from Epic Games

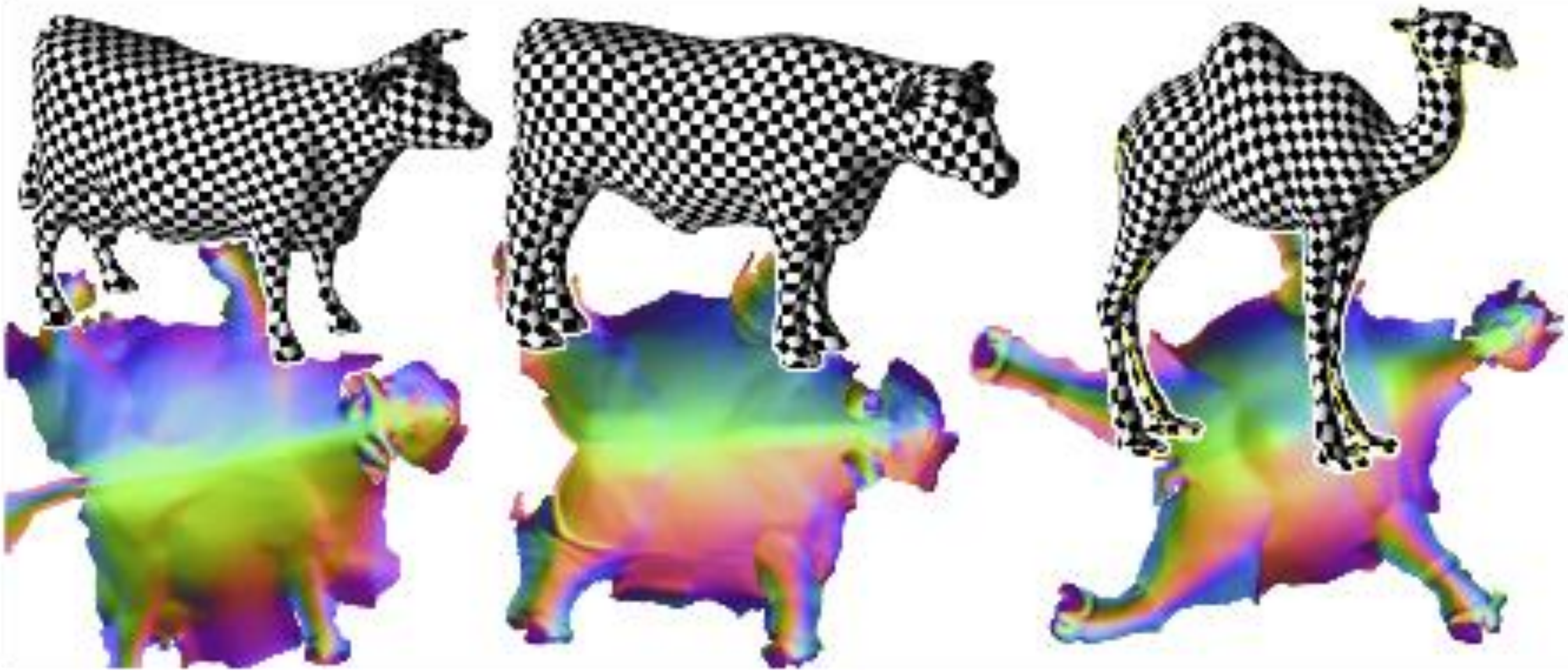
Creating Torso Portion in Max



3D Model

- Information we need:
- Per vertex
  - 3D coordinates
  - Normal
  - 2D UV coordinates
- Other information
  - BRDF (often same for the whole object, but could vary)
  - 2D Image for the texture map

Questions?



Some results computed by stretch L_2 minimization (parameterized models courtesy of Pedro Sander and Alla Sheffer).

Mathematical Mapping

- What of non-triangular geometry?
  - Spheres, etc.

- No vertices, cannot specify UVs that way!

- Solution: Parametric Texturing
  - Deduce (u, v) from (x, y, z)
  - Various mappings are possible....

Common Texture Coordinate Mappings

- Planar
  - Vertex UVs and linear interpolation is a special case!
- Cylindrical
- Spherical
- Perspective Projection

Images removed due to copyright restrictions.

Projective Mappings

- A slide projector
  - Analogous to a camera!
  - Usually perspective projection tells us where points project to in our image plane
  - This time we will use these coordinates as UVs
- No need to specify texture coordinates explicitly

Image removed due to copyright restrictions.

Projective Mappings

- We are given the camera matrix H of the slide projector
- For a given 3D point P
- Project onto 2D space of slide projector: HP
  - results in 2D texture coordinates

Image removed due to copyright restrictions.

Projective Texture Example

- Modeling from photographs
- Using input photos as textures

Original photograph with marked edges | Recovered model | Model edges projected onto photograph | Synthetic rendering

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

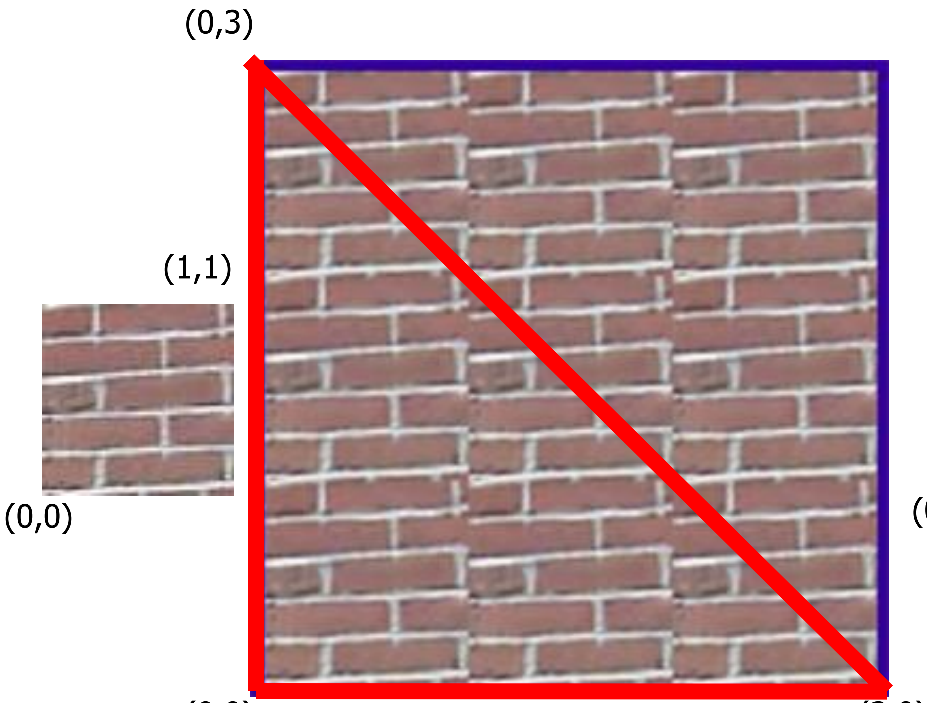
Video removed due to copyright restrictions. Please see http://www.youtube.com/watch?v=RPhGEiM_6lM for further details.

Questions?

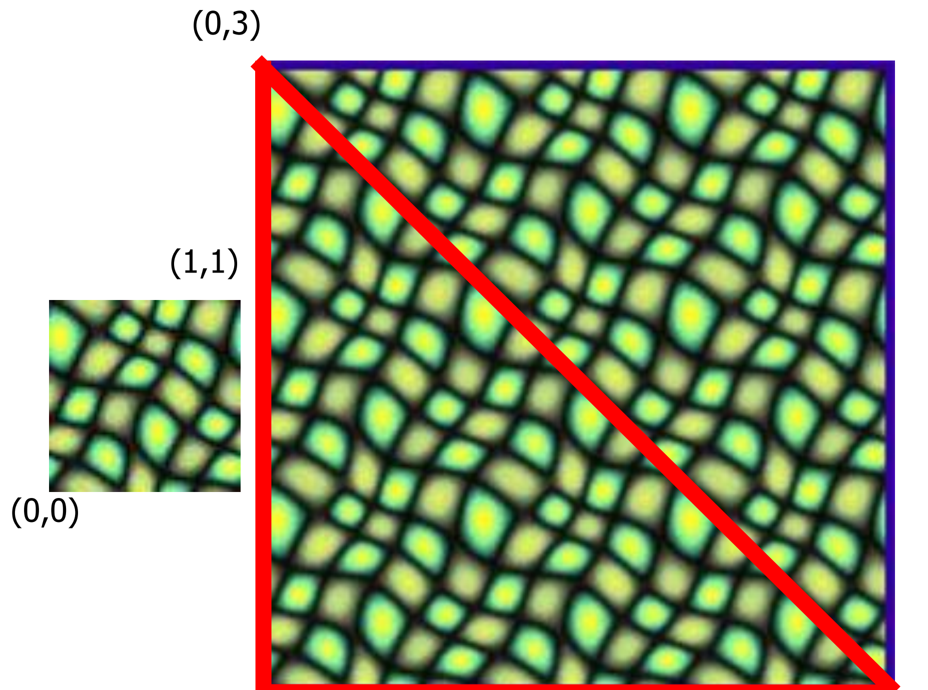
Texture Tiling

Note the range (0,1) unlike normalized screen coordinates!

- Specify texture coordinates (u,v) at each vertex
- Canonical texture coordinates (0,0) → (1,1)
  - Wrap around when coordinates are outside (0, 1)



tiles with visible seams



seamless tiling (repeating)

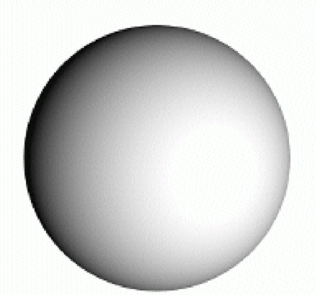
Questions?

Texture Mapping & Illumination

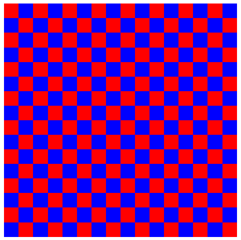
- Texture mapping can be used to alter some or all of the constants in the illumination equation
  - Diffuse color k_d, specular exponent q, specular color k_s...
  - Any parameter in any BRDF model!

$$L_o = \left[k_a + k_d \left(\boldsymbol{n} \cdot \boldsymbol{l} \right) + k_s \left(\boldsymbol{v} \cdot \boldsymbol{r} \right)^q \right] \frac{L_i}{r^2}$$

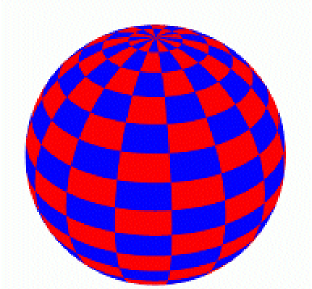
  - k_d in particular is often read from a texture map



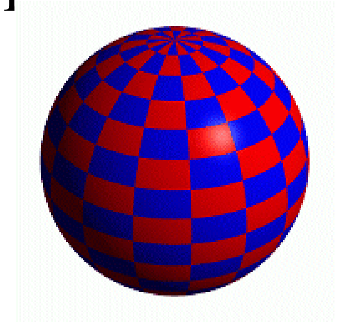
Constant Diffuse Color



Diffuse Texture Color



Texture used as Label



Texture used as Diffuse Color

Gloss Mapping Example

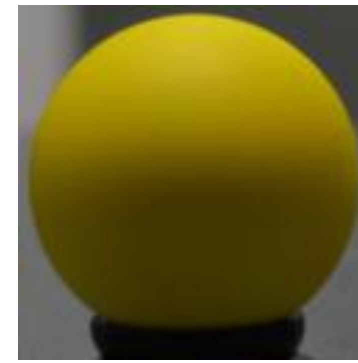
Ron Frazier

Spatially varying k_d and k_s

Questions?

We Can Go Even Further...

- The normal vector is really important in conveying the small-scale surface detail
  - Remember cosine dependence
  - The human eye is really good at picking up shape cues from lighting!



- We can exploit this and look up also the normal vector from a texture map
  - This is called "normal mapping" or "bump mapping"
  - A coarse mesh combined with detailed normal maps can convey the shape very well!

Normal Mapping

- For each shaded point, normal is given by a 2D image normalMap that stores the 3D normal

For a visible point

interpolate UV using barycentric

// same as texture mapping

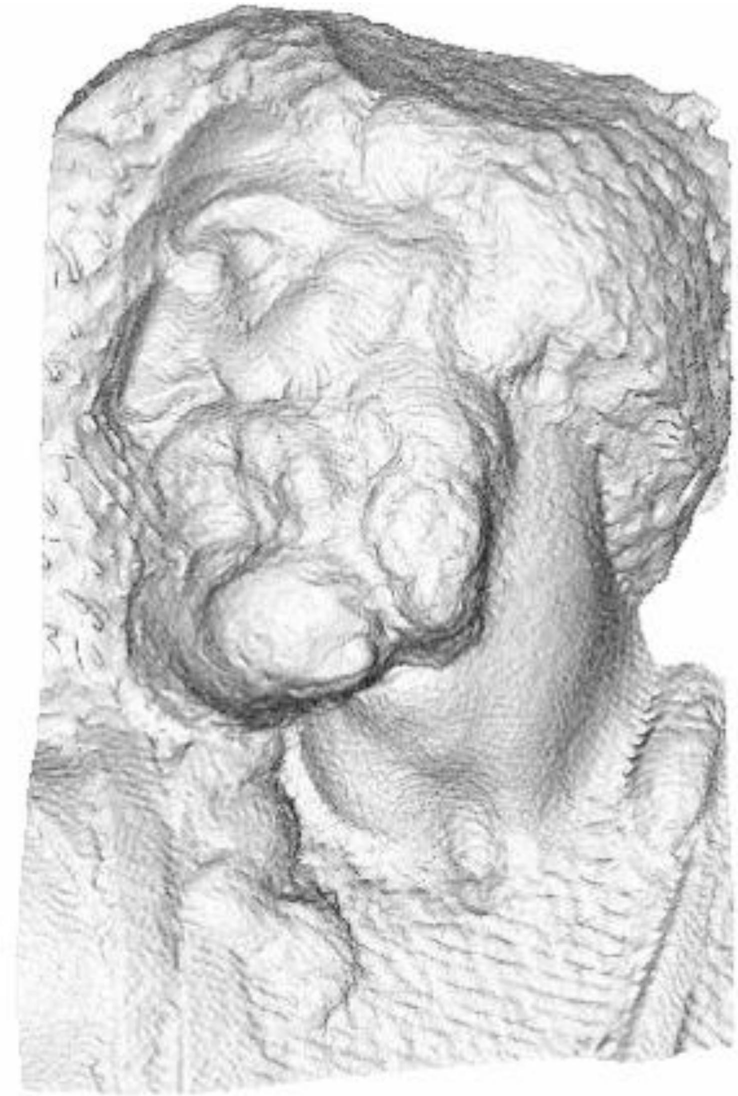
Normal = normalMap[U,V]

compute shading (BRDF) using this normal

$$L_o = \left[k_a + k_d\,(\boldsymbol{n} \cdot \boldsymbol{l}) + k_s\,(\boldsymbol{v} \cdot \boldsymbol{r})^q\right]\frac{L_i}{r^2}$$

Normal Map Example

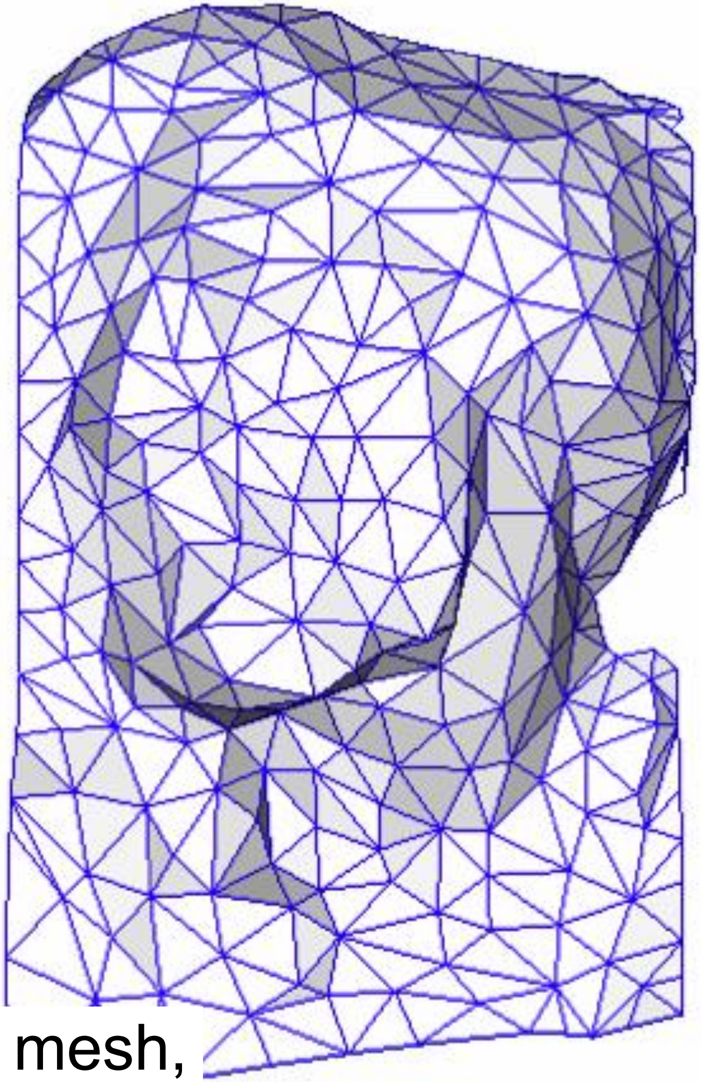
Paolo Cignoni



Original Mesh
4M triangles

Normal Map Example

Paolo Cignoni

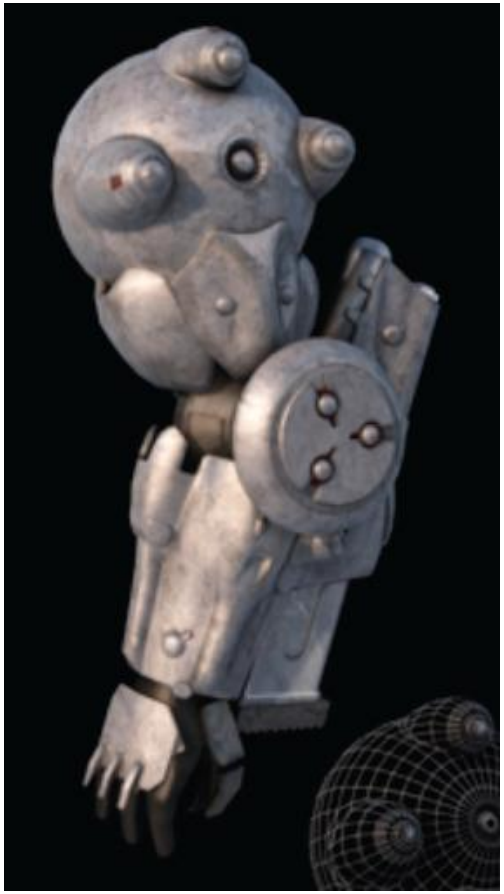


Simplified mesh,
500 triangles

Simplified mesh +
normal mapping

Normal Map Example

Models and images: Trevor Taylor



Final render

Diffuse texture k_d

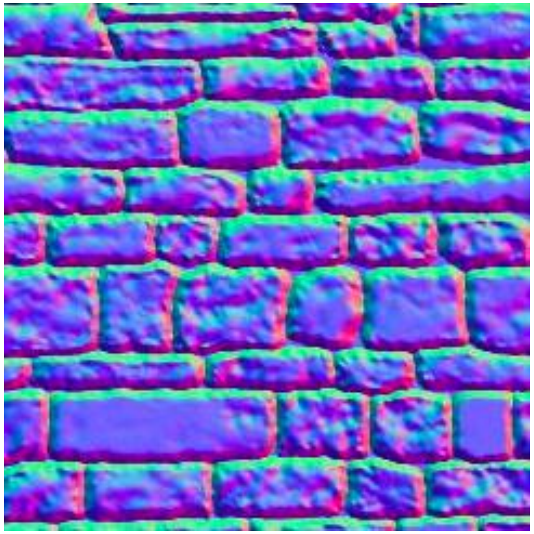
Normal Map

Generating Normal Maps

- Model a detailed mesh
- Generate a UV parameterization for the mesh
  - A UV mapping such that each 3D point has **unique** image coordinates in the 2D texture map
  - This is a difficult problem, but tools are available
    - E.g., the DirectX SDK has functionality to do this
- Simplify the mesh (again, see DirectX SDK)
- Overlay simplified and original model
- For each point **P** on the simplified mesh, find closest point **P'** on original model (ray casting)
- Store the normal at **P'** in the normal map. **Done!**

Normal Map Details

- You can store an object-space normal
  - Convenient if you have a unique parameterization
- ....but if you want to use a tiling normal map, this will not work
  - Must account for the curvature of the object!
  - Think of mapping this diffuse+normal map combination on a cylindrical tower
- Solution: Tangent space normal map
  - Encode a “difference” from the geometric normal in a local coord. system



Questions?

Shaders (`Material` class)

- Functions executed when light interacts with a surface
- Constructor:
  - set shader parameters
- Inputs:
  - Incident radiance
  - Incident and reflected light directions
  - Surface tangent basis (anisotropic shaders only)
- Output:
  - Reflected radiance

Shader

- Initially for production (slow) rendering
  – Renderman in particular
- Now used for real-time (Games)
  – Evaluated by graphics hardware
  – More later in the course

- Often makes heavy use of texture mapping

Questions?

Procedural Textures

- Alternative to texture mapping
- Little program that computes color as a function of x,y,z:

$f(x,y,z) \rightarrow color$

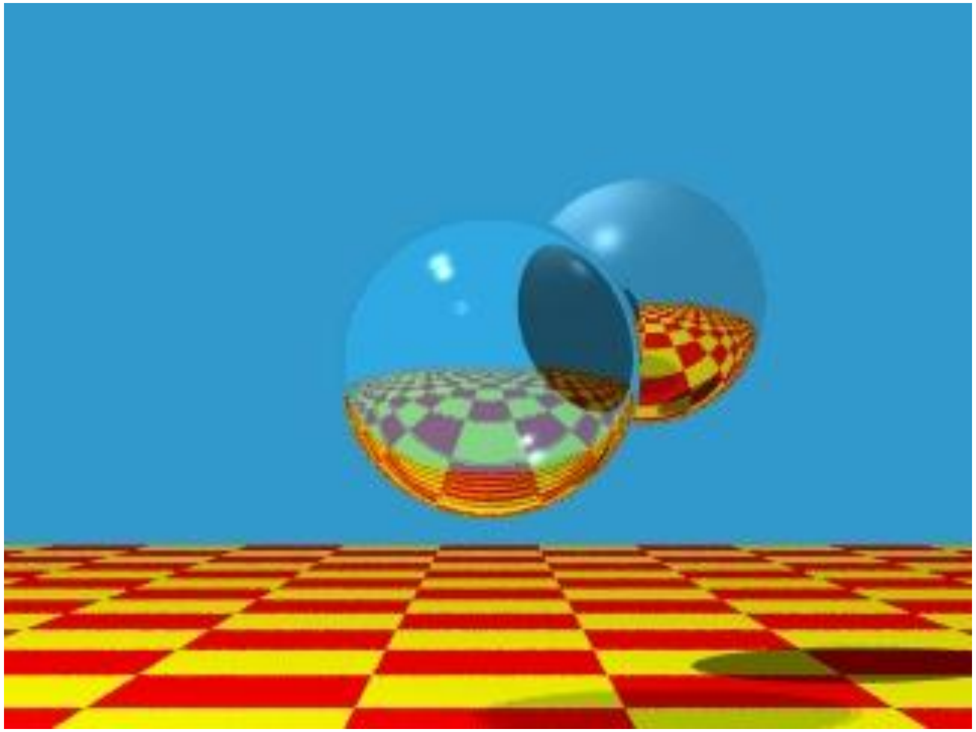
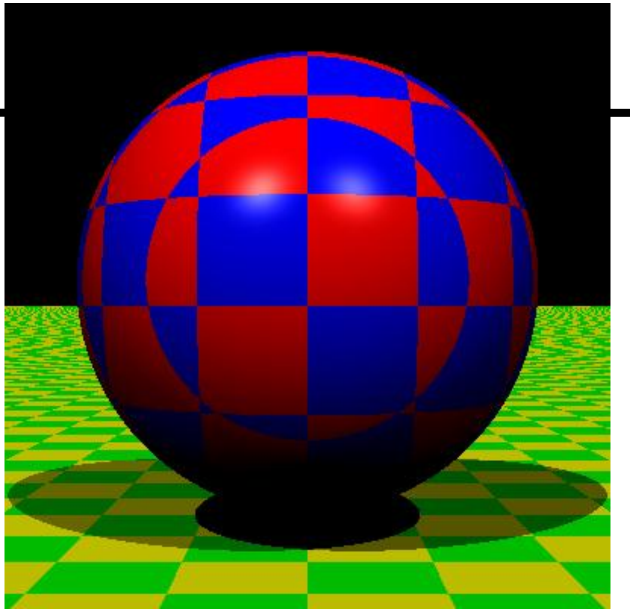
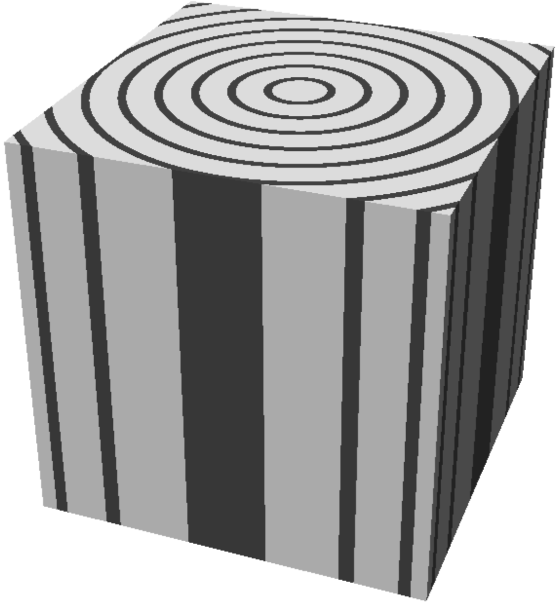


Image by Turner Whitted

Procedural Textures



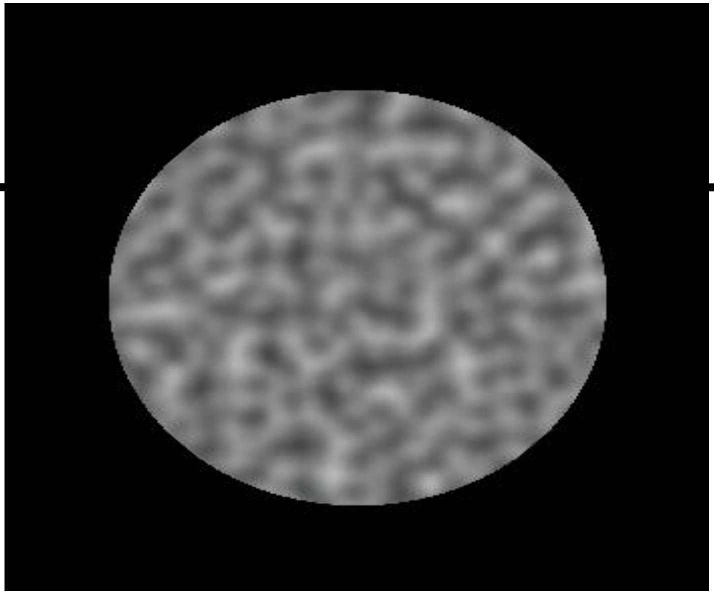
- Advantages:
  - easy to implement in ray tracer
  - more compact than texture maps (especially for solid textures)
  - infinite resolution



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

Questions?

Perlin Noise



- Critical component of procedural textures
- Pseudo-random function
  - But continuous
  - band pass (single scale)
- Useful to add lots of visual detail

http://www.noisemachine.com/talk1/index.html

http://mrl.nyu.edu/~perlin/doc/oscar.html

http://mrl.nyu.edu/~perlin/noise/

http://en.wikipedia.org/wiki/Perlin_noise

http://freespace.virgin.net/hugo.elias/models/m_perlin.htm

(not really Perlin noise but very good)

http://portal.acm.org/citation.cfm?id=325247

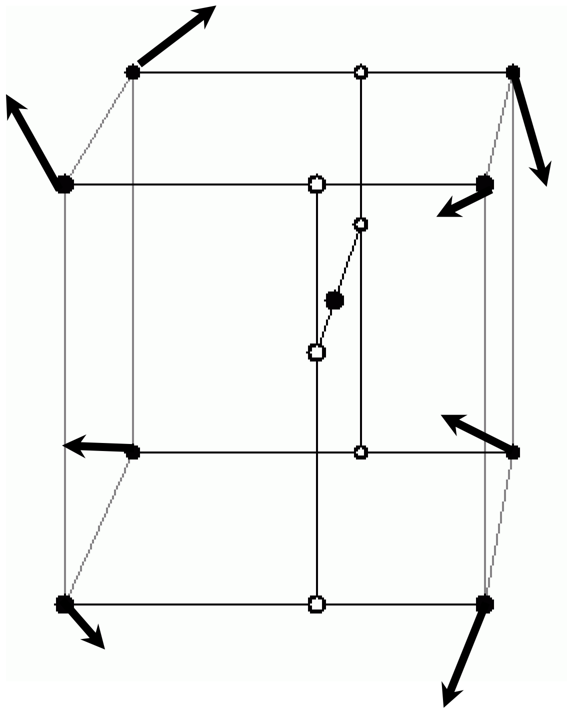
Requirements

- Pseudo random
- For arbitrary dimension
  - 4D is common for animation
- Smooth
- Band pass (single scale)
- Little memory usage

- How would you do it?

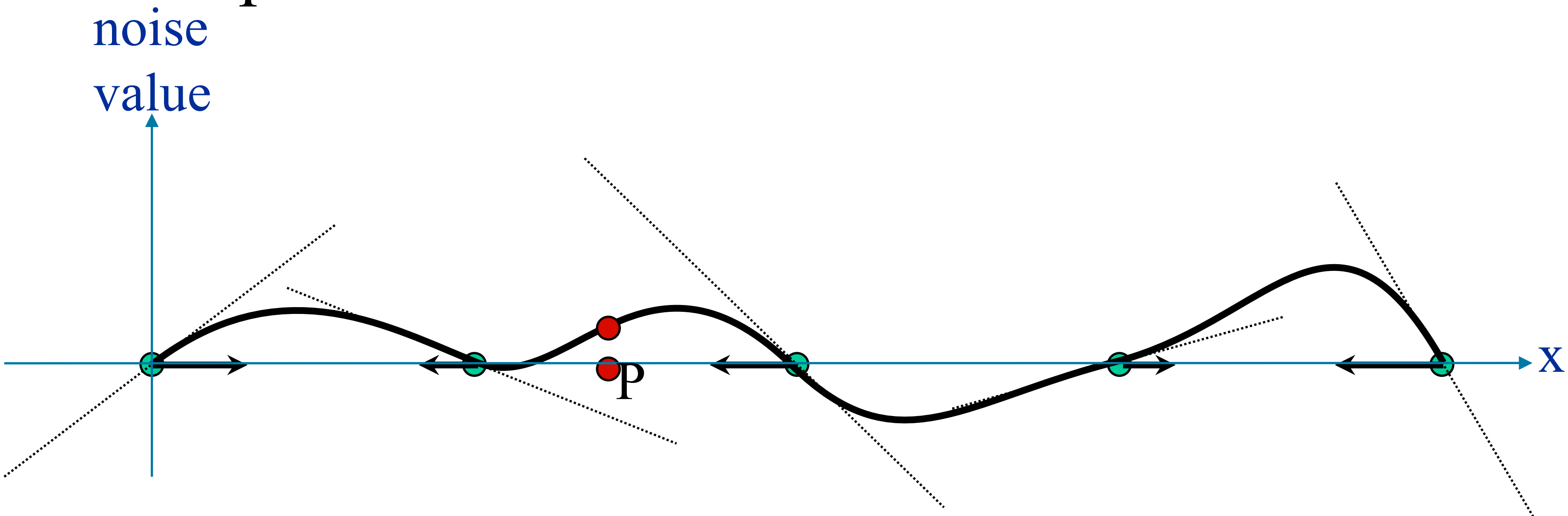
Perlin Noise

- Cubic lattice
- Zero at vertices
  - To avoid low frequencies
- Pseudo-random gradient at vertices
  - define local linear functions
- Splines to interpolate the values to arbitrary 3D points



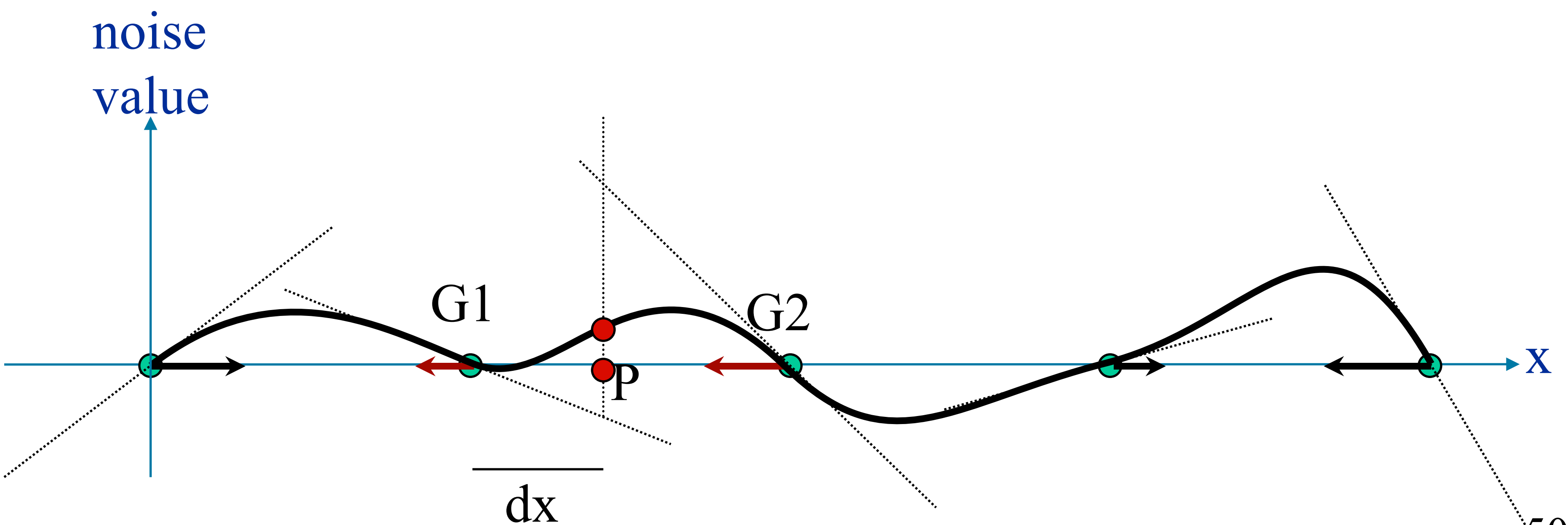
1D Noise

- 0 at integer locations
- Pseudo-random derivative (1D gradient) at integer locations
  - define local linear functions
- Interpolate at location *P*



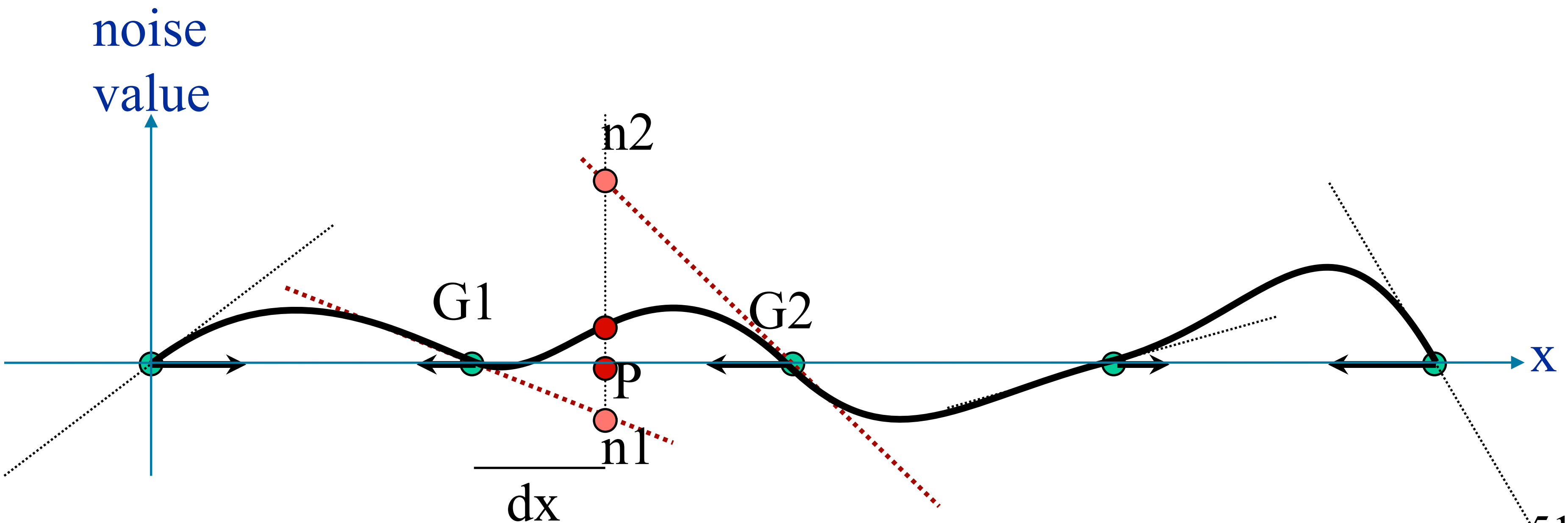
1D Noise: Reconstruct at *P*

- *dx*: fractional *x* coordinate
- Gradients G_1 and G_2 at neighboring vertices
  - Scalars in 1D. They are 3D vectors in 3D
- We know that noise is zero at vertices



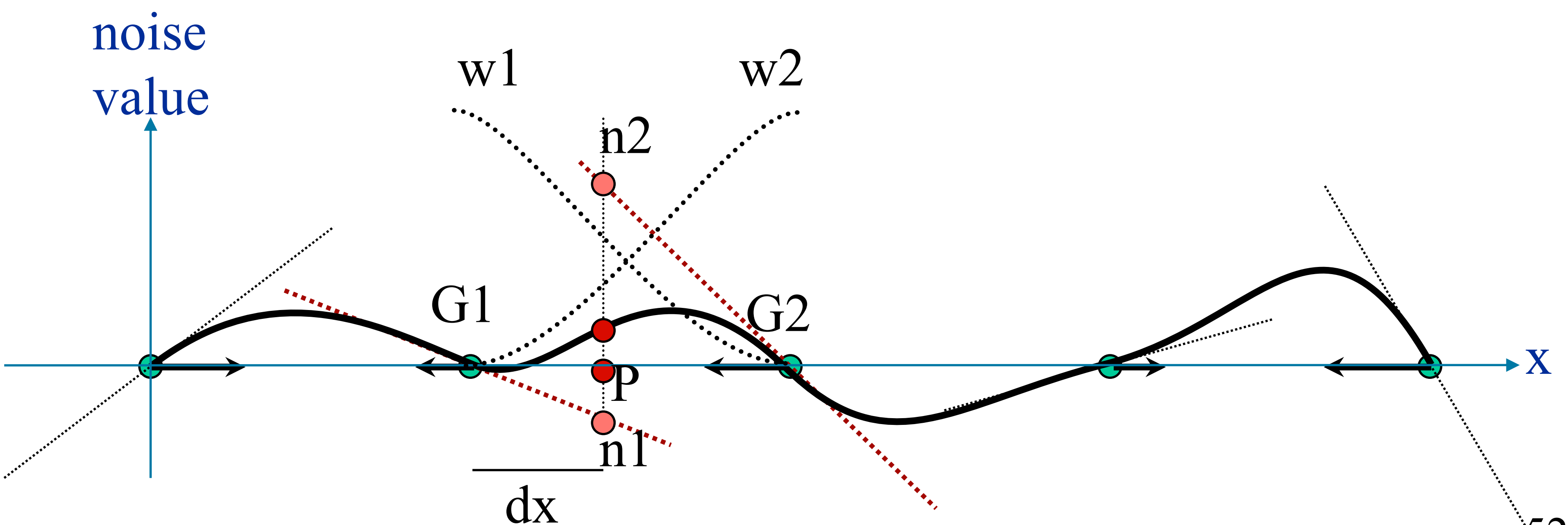
1D Noise: Reconstruct at *P*

- Compute the values from the two neighboring linear functions: $n1 = dx*G1;\ n2=(dx-1)*G2$
  - dot product in 3D.



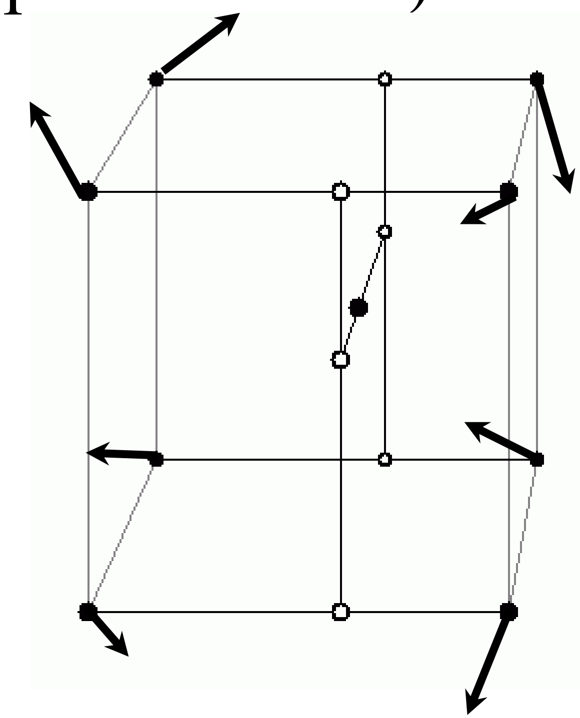
1D Noise: Reconstruct at *P*

- Compute the values from the two neighboring linear functions: $n1 = dx*G1$; $n2=(dx-1)*G2$
  - dot product in 3D
- Weight $w1=3dx^2-2dx^3$ and $w2=3(1-dx)^2-2(1-dx)^3$
  - ie: $noise=w1\ G1\ dx + w2\ G2\ (dx-1)$



Algorithm in 3D

- Given an input point *P*
- For each of its neighboring grid points:
  - Get the "pseudo-random" gradient vector *G*
  - Compute linear function (dot product $G \cdot dP$)
- Take weighted sum, using separable cubic weights
  - [demo in 2D]



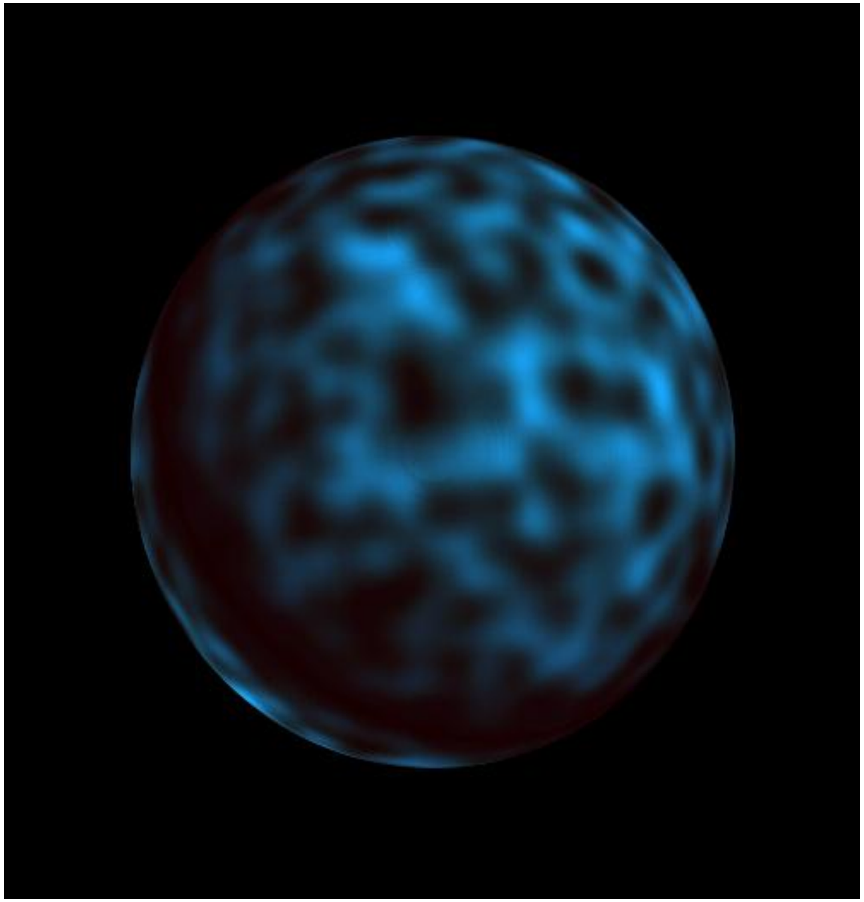
Computing Pseudo-random Gradients

- Precompute (1D) table of n gradients $G[n]$
- Precompute (1D) permutation $P[n]$
- For 3D grid point i, j, k :
  $G(i,j,k) = G[\ (\ i + P[\ (j + P[k]) \bmod n\ ]\ ) \bmod n\ ]$

- In practice only n gradients are stored!
  - But optimized so that they are well distributed

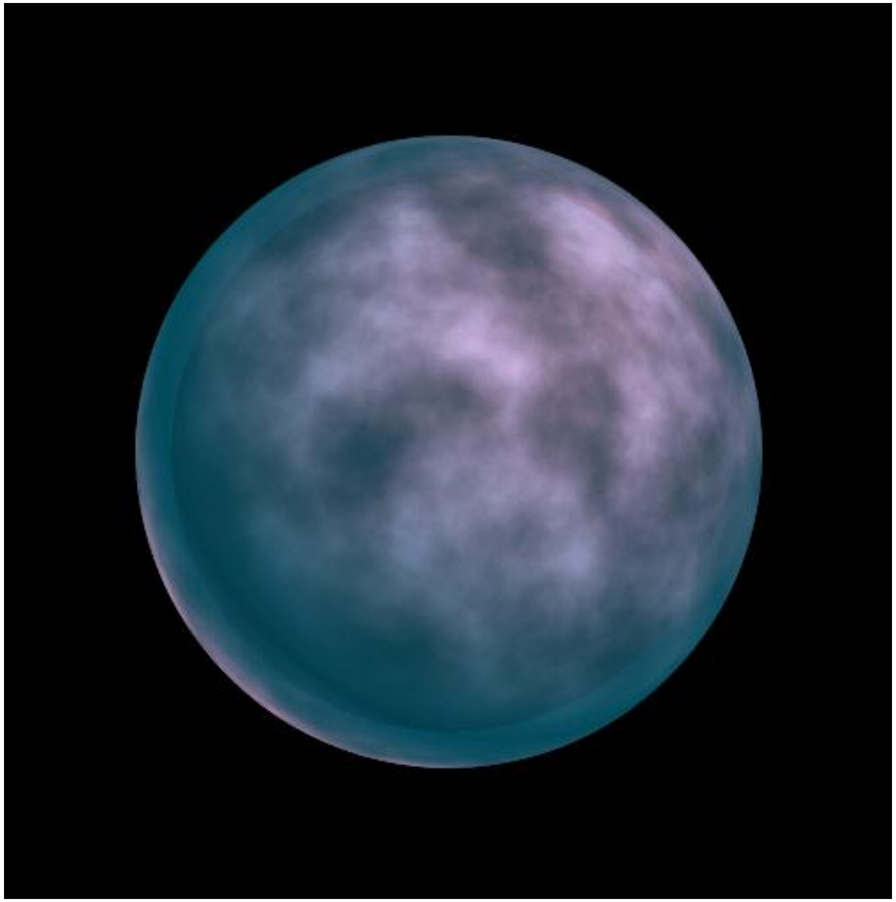
Noise At One Scale

- A scale is also called an octave in noise parlance



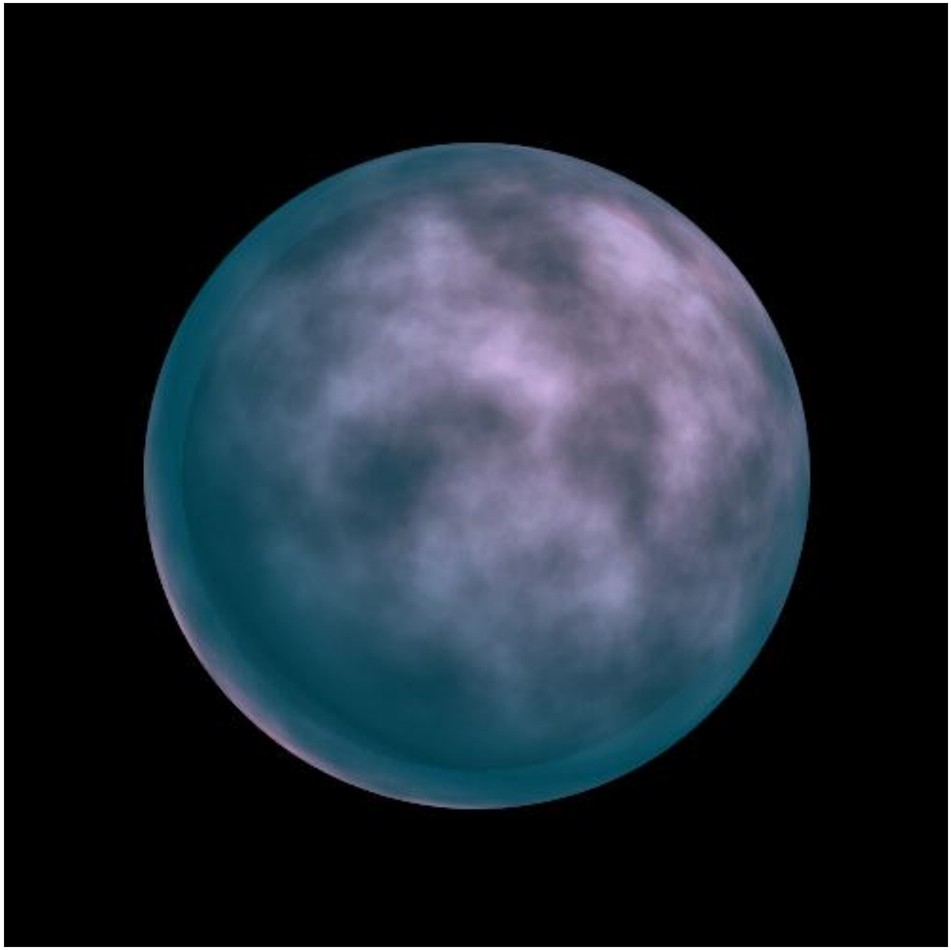
Noise At Multiple Scales

- A scale is also called an octave in noise parlance
- But multiple octaves are usually used, where the scale between two octaves is multiplied by 2
  - hence the name octave



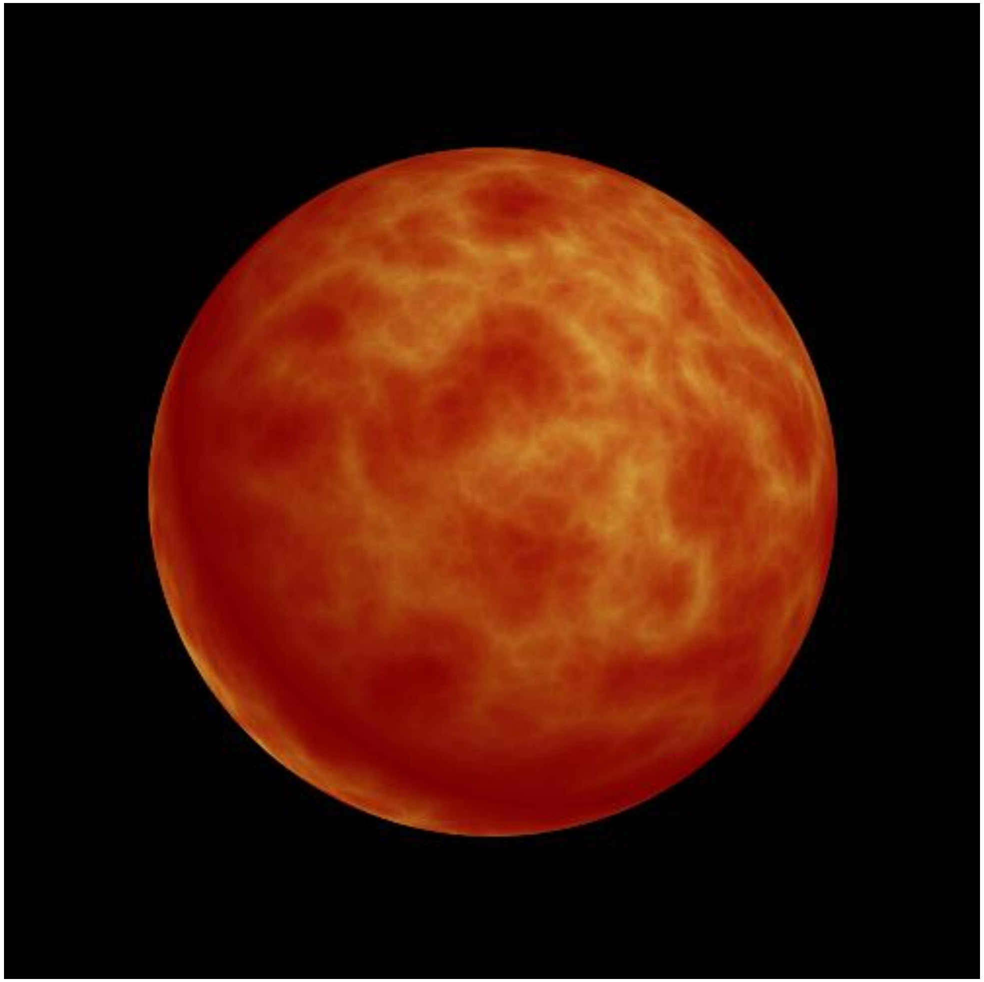
Sum 1/*f* noise

- That is, each octave *f* has weight 1/*f*



sum 1/*f* |*noise*|

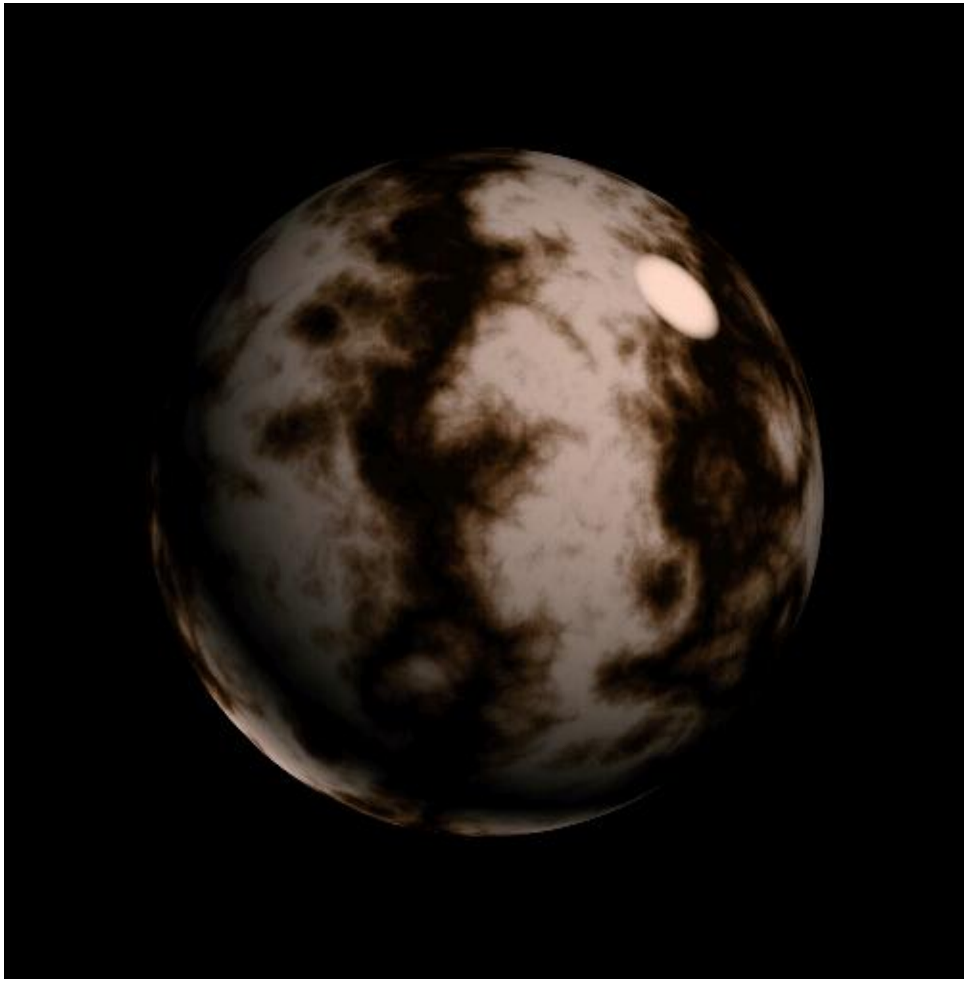
- Absolute value introduces *C1* discontinuities



- a.k.a. turbulence

$sin\ (x + \text{sum } 1/f\ |noise|)$

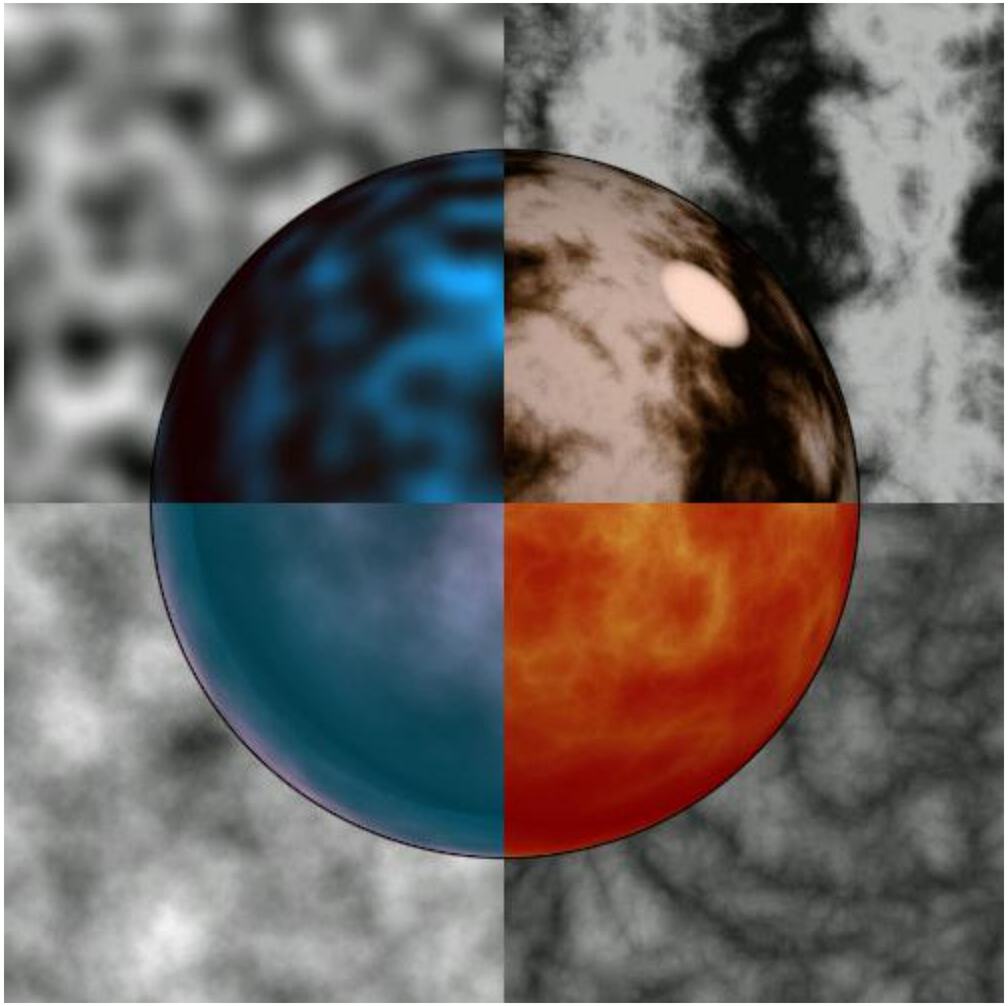
- Looks like marble!



Comparison

- *noise*

sin(*x* + sum 1/*f*(|*noise*|))

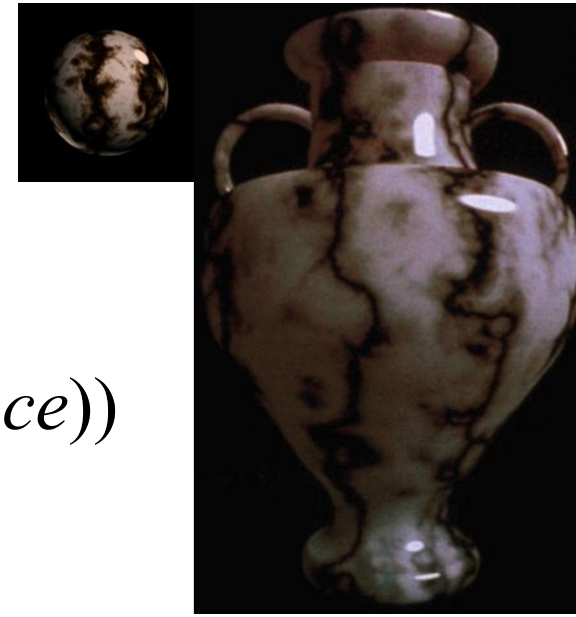


sum 1/*f*(*noise*)

sum 1/*f*(|*noise*|)

Questions?

Noise For Solid Textures



- Marble
  - recall *sin* (*x*[0] + sum 1/*f* |*noise*|)
  - *BoringMarble* = *colormap* (*sin*(*x*[0]))
  - *Marble* = *colormap* (*sin*(*x*[0]+*turbulence*))
  - http://legakis.net/justin/MarbleApplet/
- Wood
  - replace *x* (or parallel plane) by radius
  - *Wood* = *colormap* (*sin*(*r*+*turbulence*))
  - http://www.connectedpixel.com/blog/texture/wood

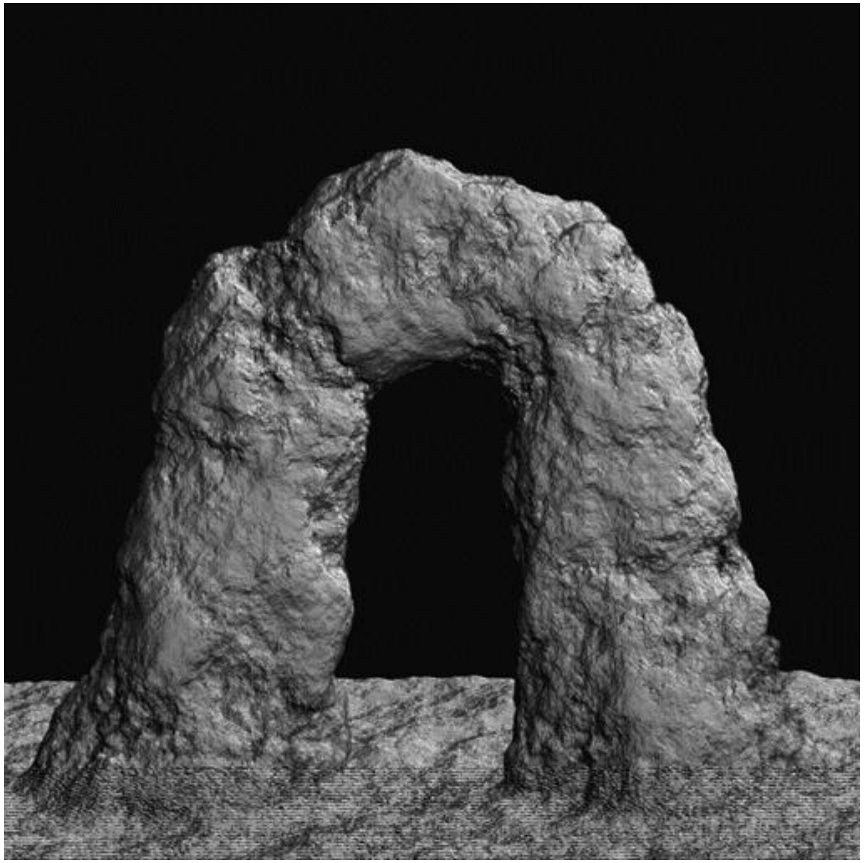
Corona

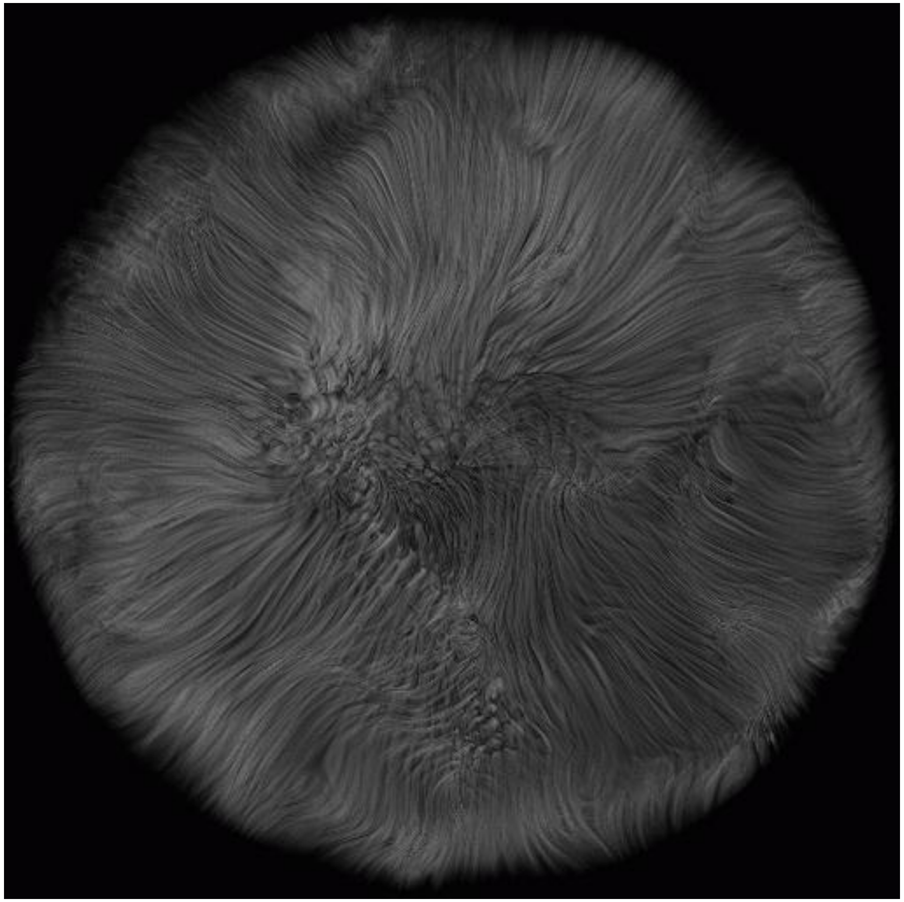
- The corona was made as follows:
  - Create a smooth gradient function the drops off radially from bright yellow to dark red.
  - Phase shift this function by adding a turbulence texture to its domain.
  - Place a black cutout disk over the image.
- Animation
  - Scale up over time
  - Use higher dim noise (for time)
  - http://www.noisemachine.com/talk1/imgs/flame500.html

Image of corona removed due to copyright restrictions.
Please see the link below for further details.

Slides by Ken Perlin

Other Cool Usage: Displacement, Fur





Questions?

Image removed due to copyright restrictions. Please the image of “blueglass.gif” from http://mrl.nyu.edu/~perlin/imgs/imgs.html.

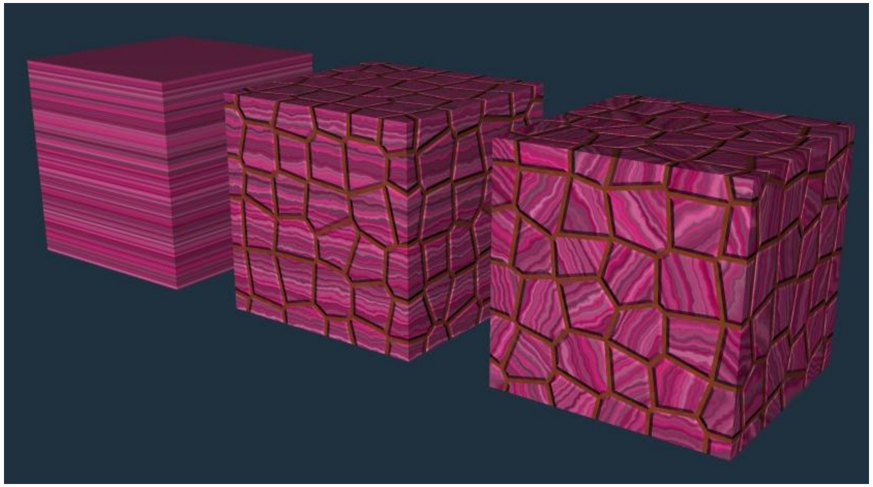
Shaders

- Noise: one ingredient of shaders
- Can also use textures
- Shaders control diffuse color, but also specular components, maybe even roughness (exponent), transparency, etc.
- Shaders can be layered (e.g. a layer of dust, peeling paint, mortar between bricks).
- Notion of shade tree
  - Pretty much algebraic tree
- Assignment 5:
  checkerboard shader based on two shaders

Bottom Line

- Programmable shader provide great flexibility
- Shaders can be extremely complex
  - 10,000 lines of code!
- Writing shaders is a black art

That’s All For Today!



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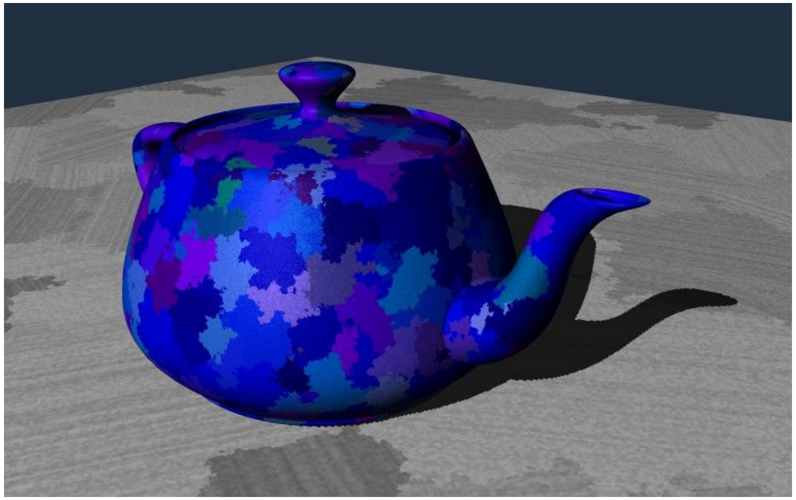

Justin Legakis

6.837 Computer Graphics
Fall 2012