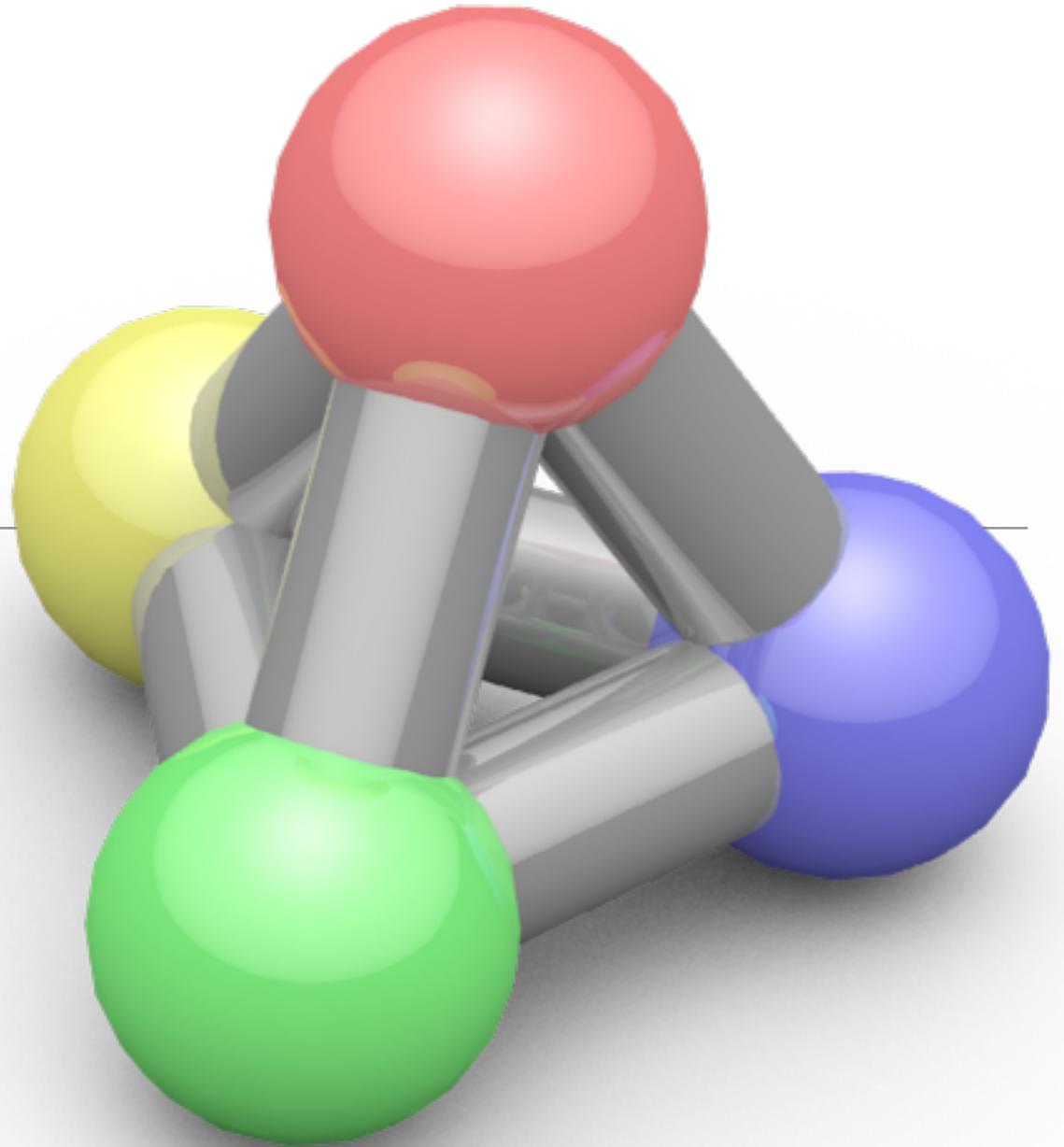


Texture Mapping

CPSC 453 – Fall 2016

Sonny Chan



Outline for Today & Wednesday

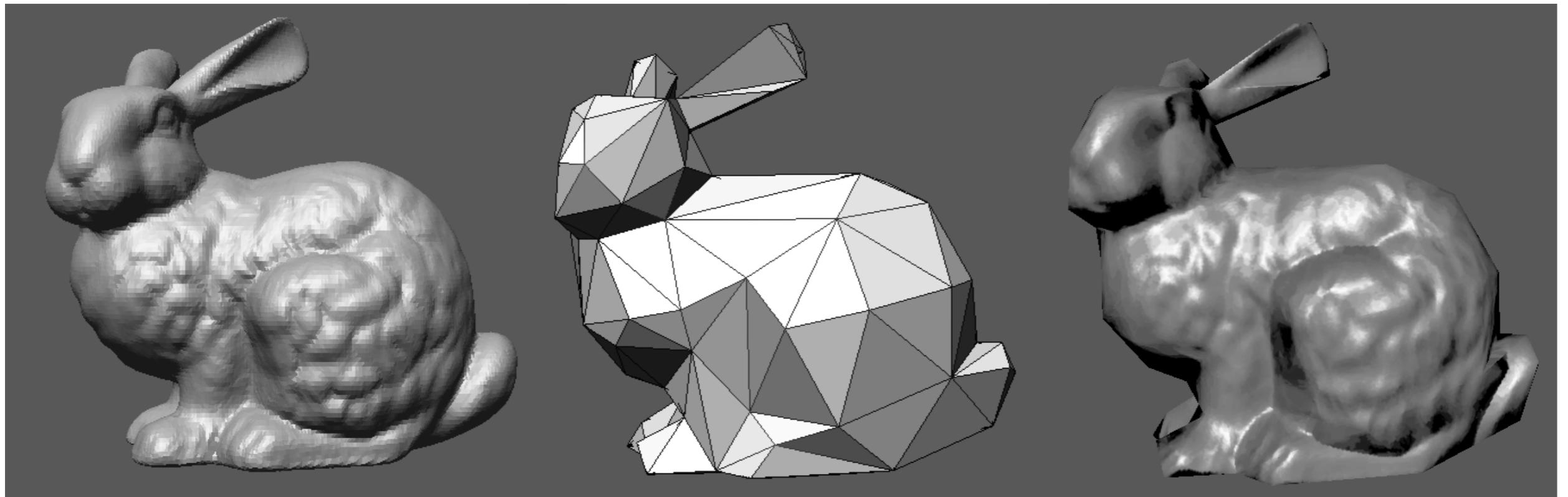
- Motivation
- Texture mapping function
- Texture sampling
- Surface properties

Motivation





Triangle Geometry?



69400 triangles

251 triangles

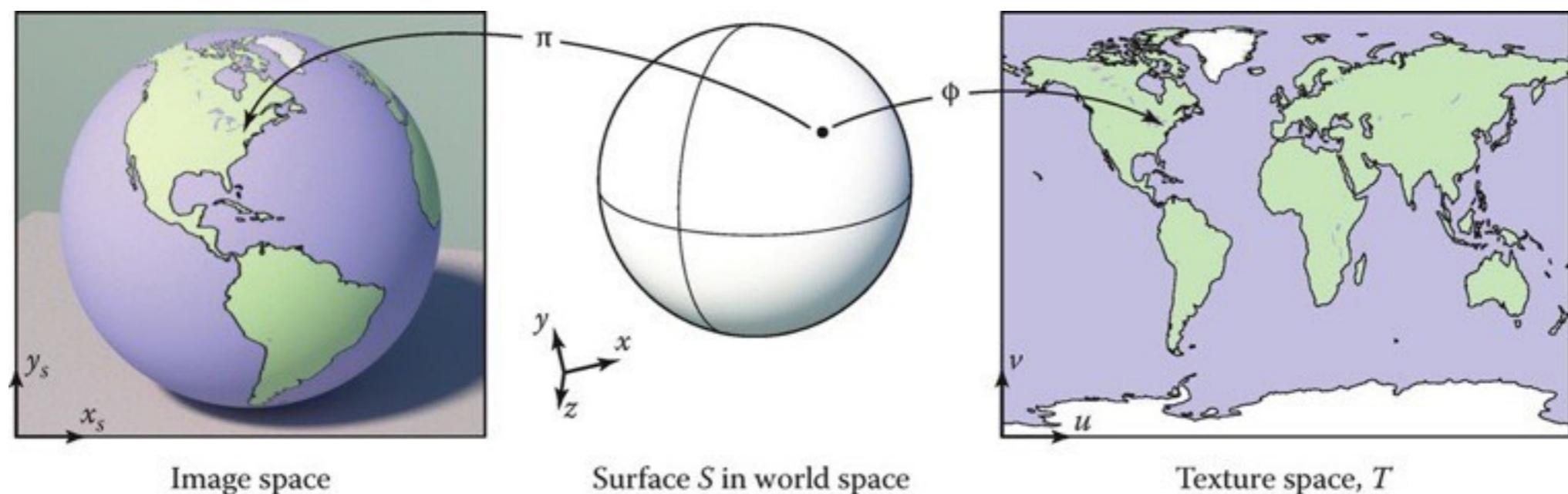
texture mapped

[from M. Tarini et al., *Computer Graphics Forum* 19(3), 2000]

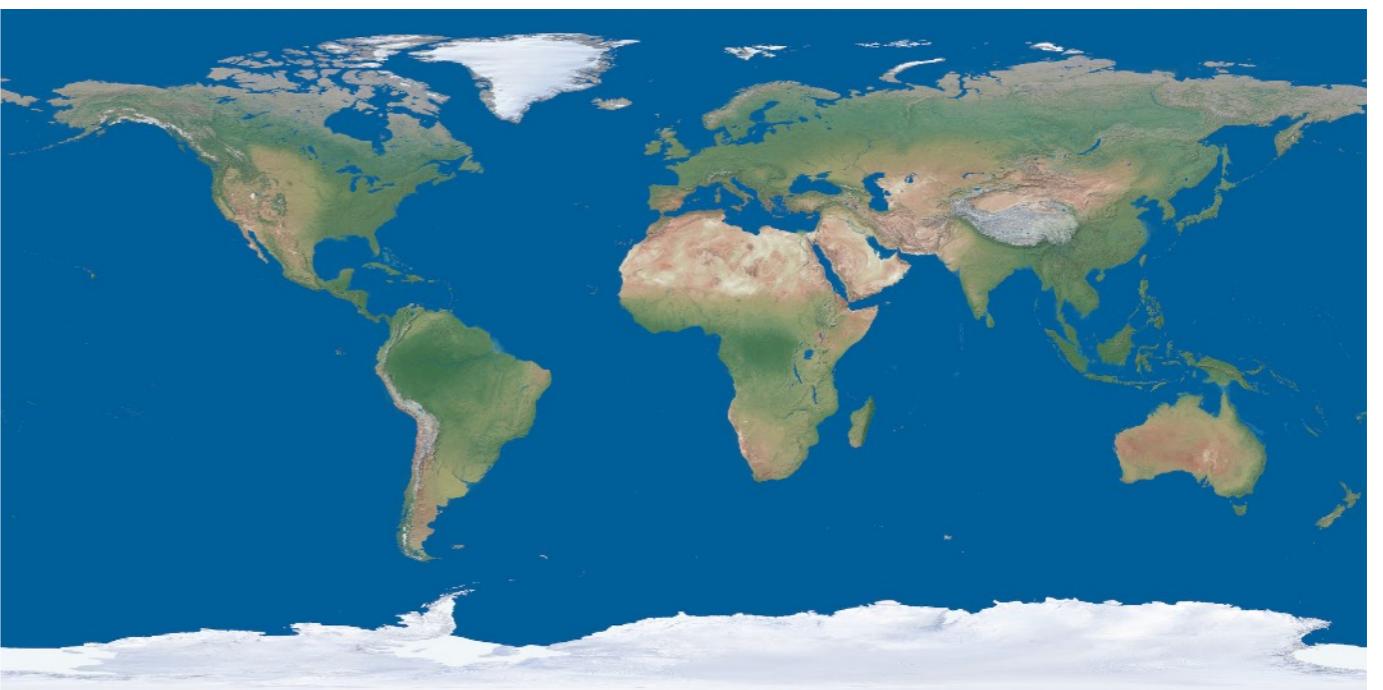
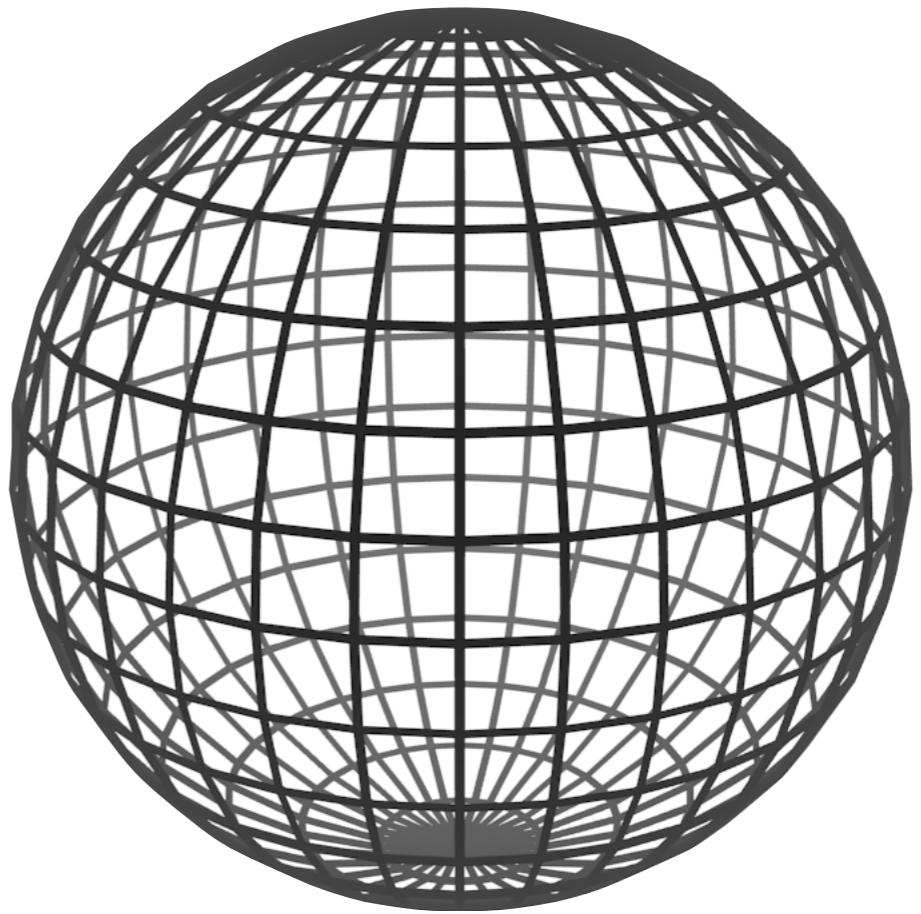
Texture mapping is the use of an image to store and render spatially varying surface properties.

Three Sub-Problems

- Defining the texture **mapping** function
- Looking up the image values: **sampling**
- Modifying surface **properties**



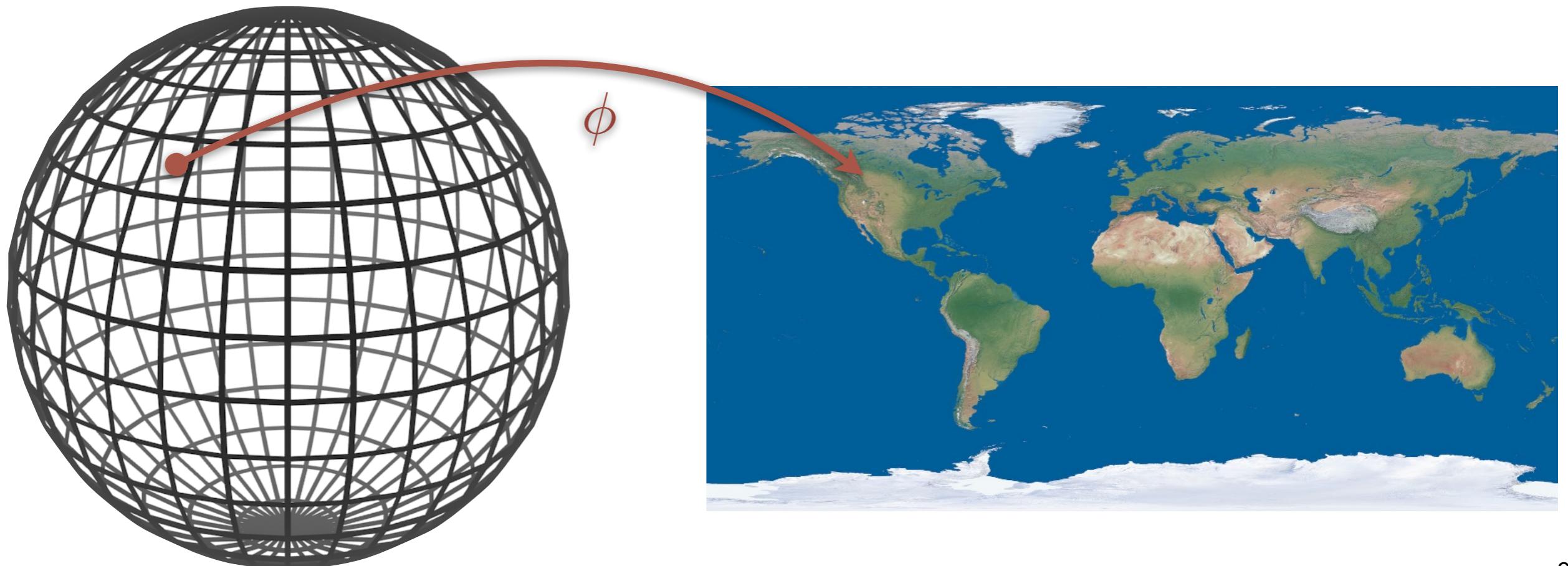
The Mapping Function



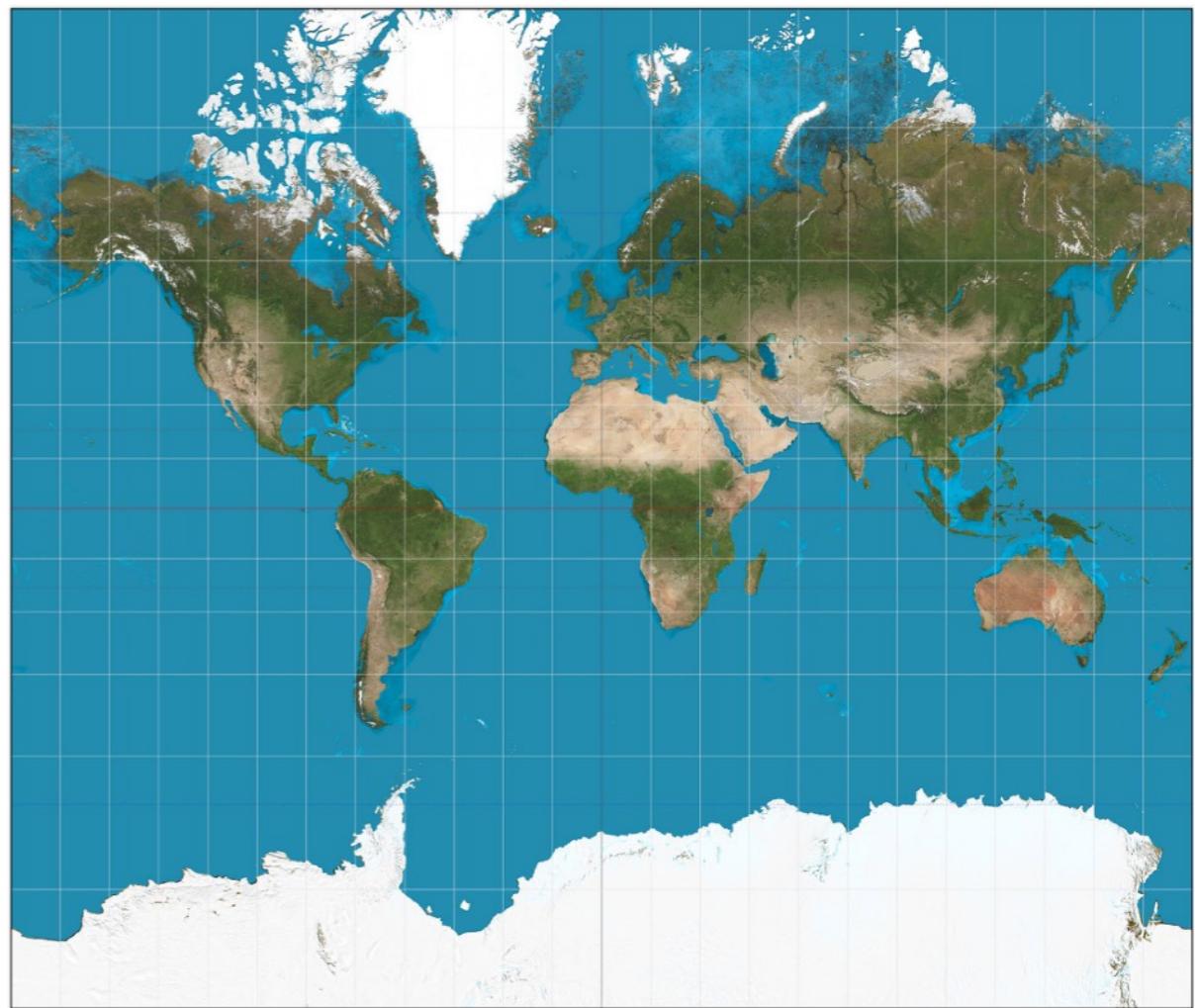
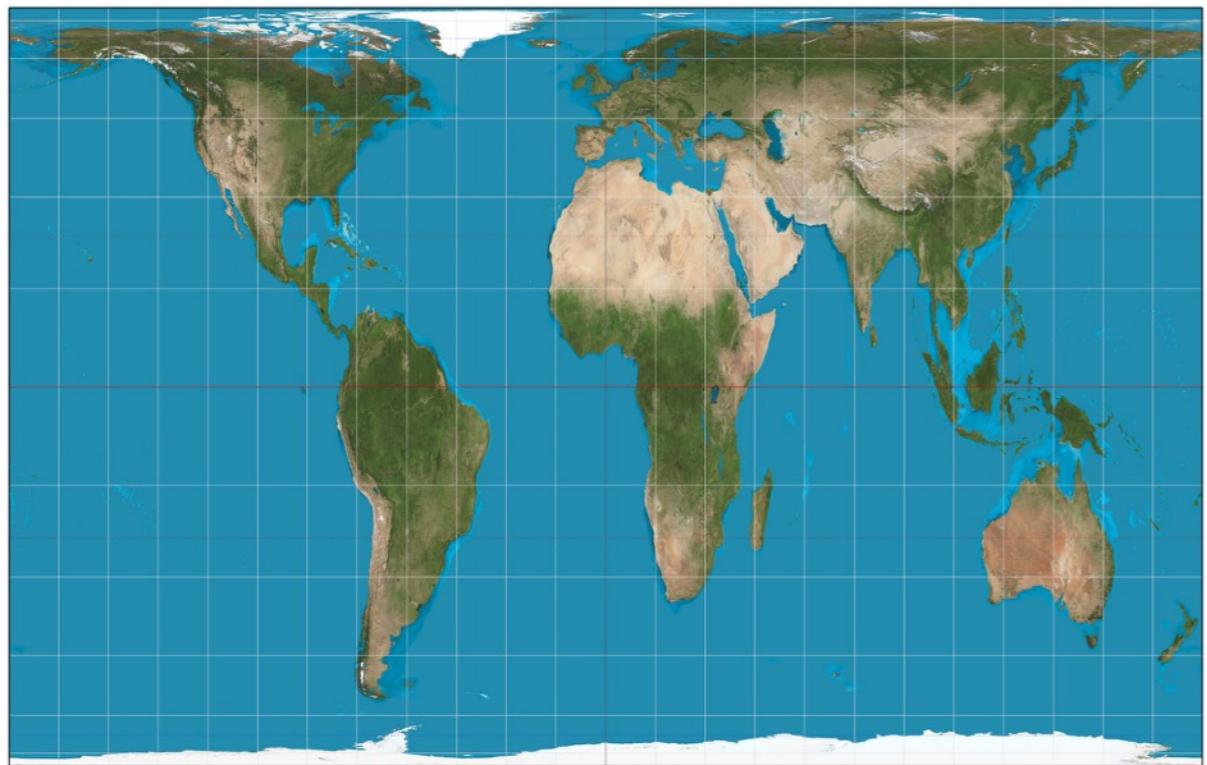
The Mapping Function

- Defined from object space to texture space:

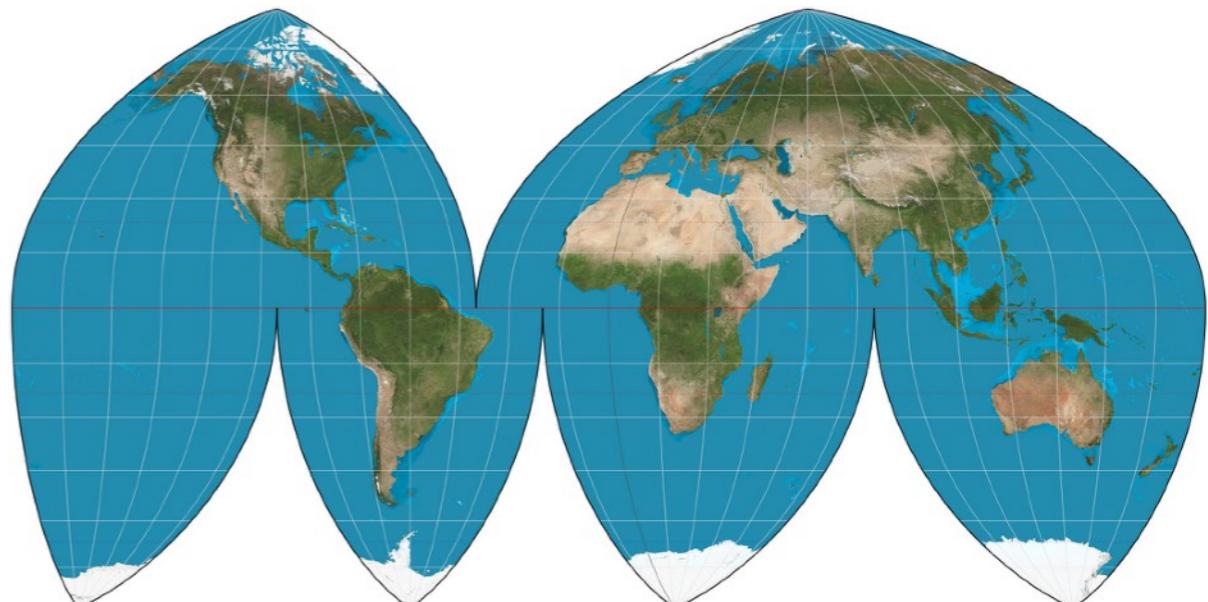
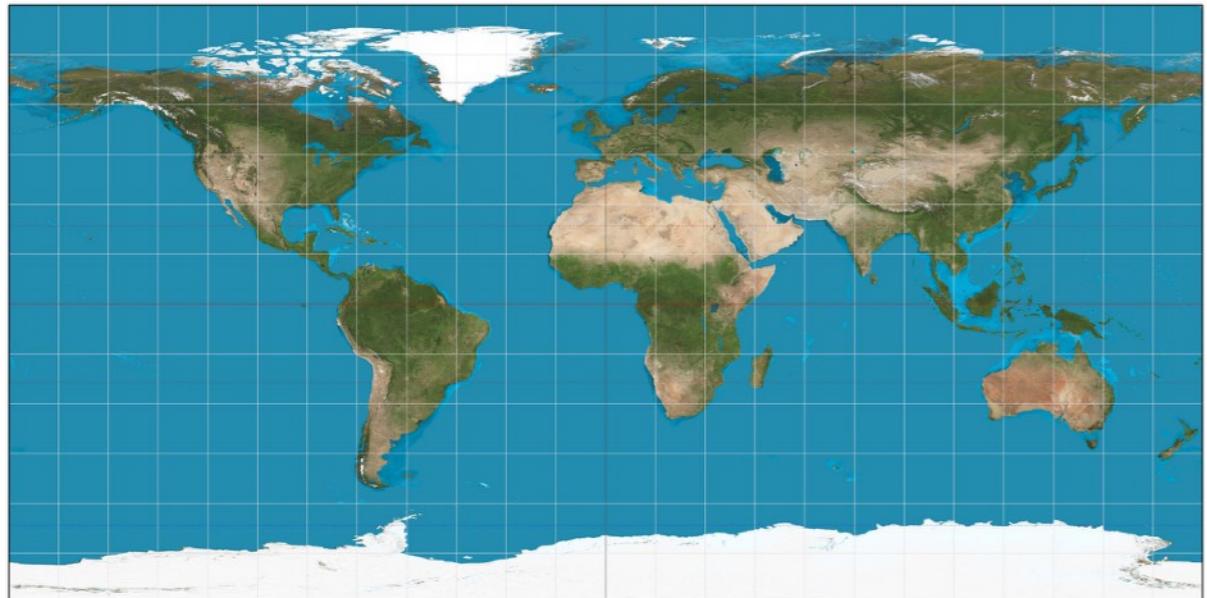
$$\begin{aligned}\phi : S &\mapsto T \\ &: (x, y, z) \mapsto (u, v)\end{aligned}$$



What are the most desirable function
characteristics?



Which one is best?



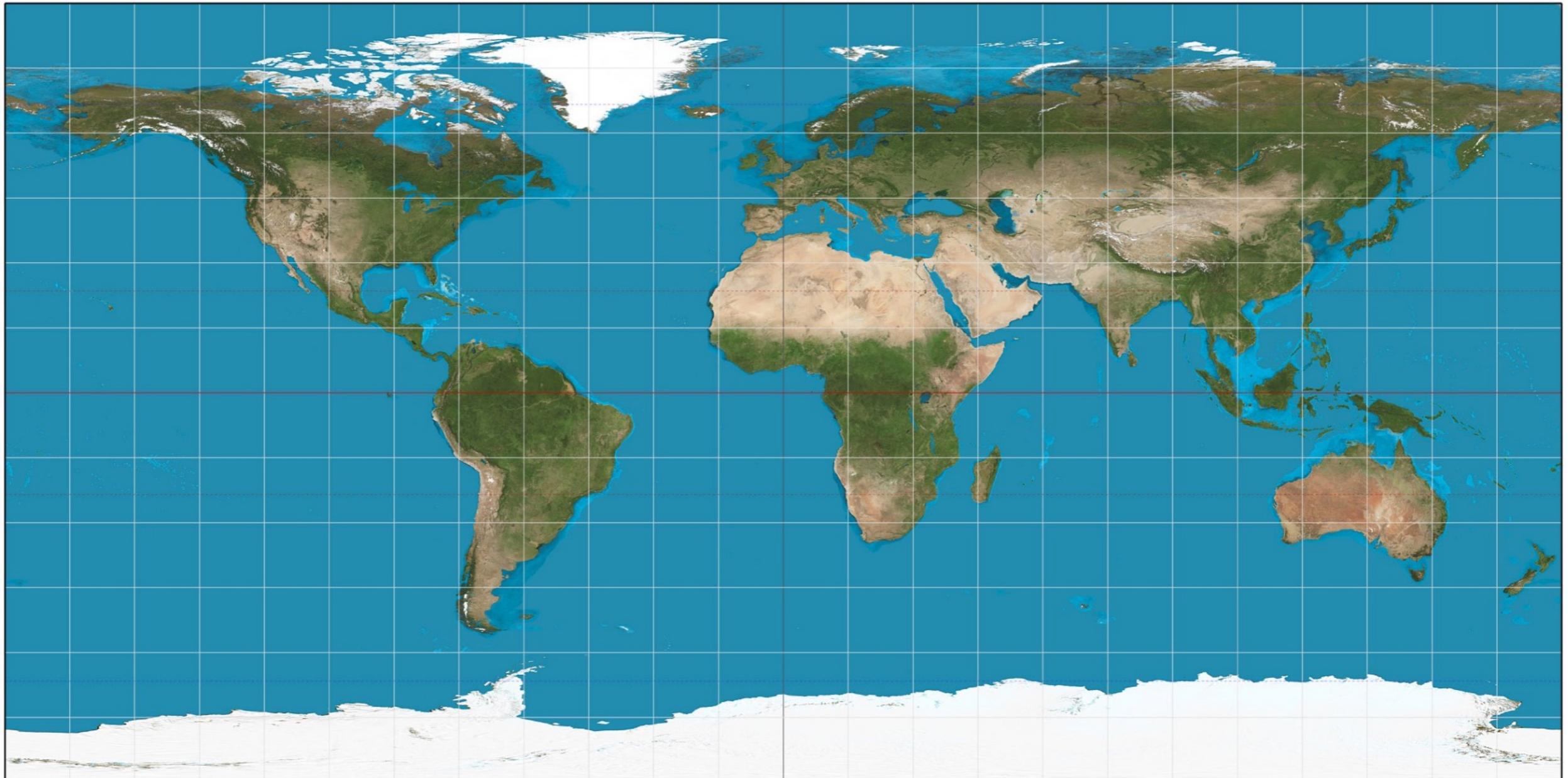
Desirable Characteristics of the Mapping Function

- **Bijectivity**: mapping function has inverse
- **Minimal distortion**: little stretching or warping
- **Continuity**: adjacent positions map to adjacent texels

Bijectivity

- Recall our mapping function:
$$\begin{aligned}\phi : S &\mapsto T \\ : (x, y, z) &\mapsto (u, v)\end{aligned}$$
- One-to-many: not possible because it's a function
- Many-to-one: one texture value has influence on properties of many surface points
- **One-to-one:** ideal for optimal control
 - every surface point maps to a *different* texture image position

Size Distortion

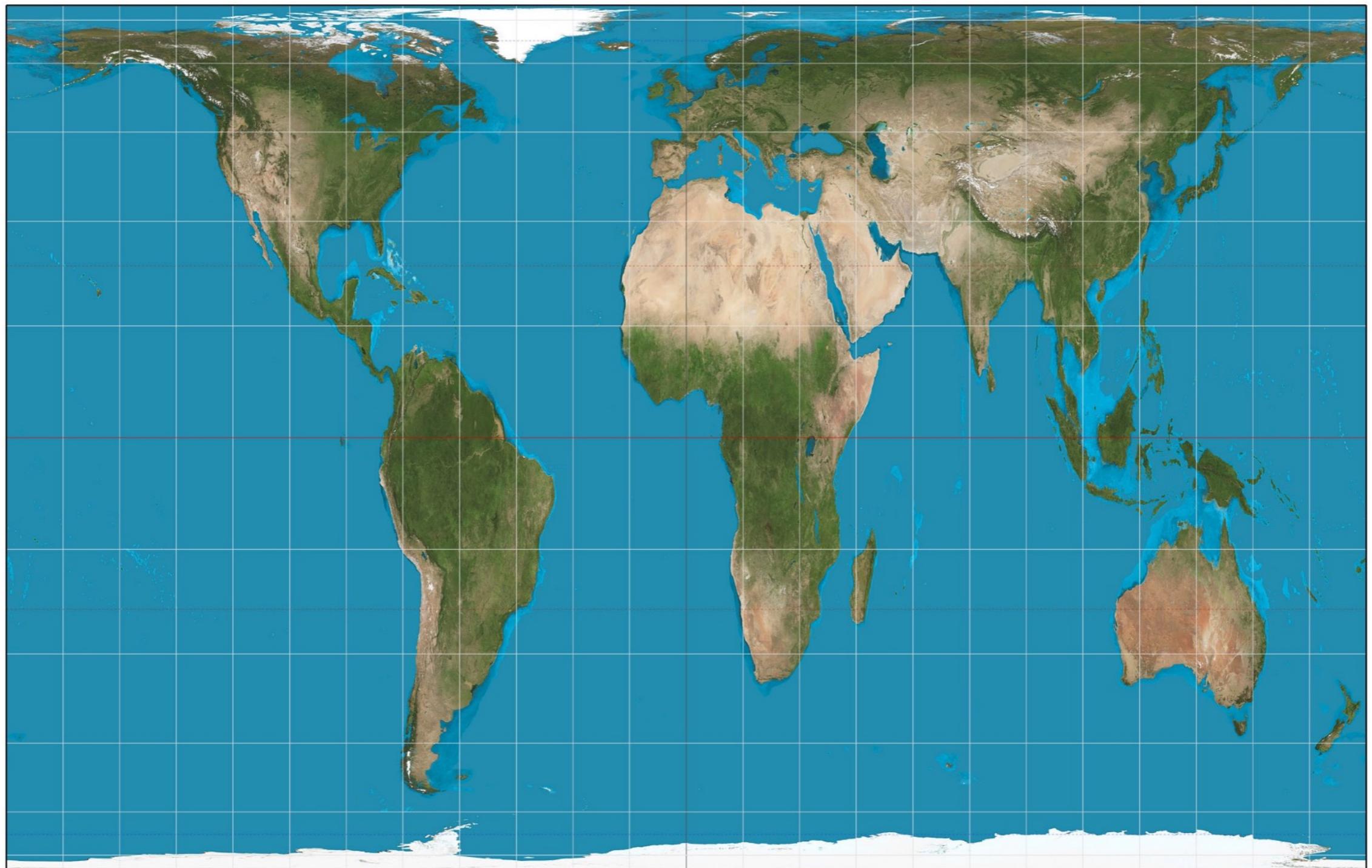


Which is bigger, Australia or Greenland?

Size Distortion

- Ideally want the scale of the texture to be roughly constant across the surface
 - Derivatives of ϕ should not vary much
- Level of detail consistent over the object
- More intuitive to create and interpret the texture
- Can you think of an instance where you may deliberately want to have size distortion?

Shape Distortion



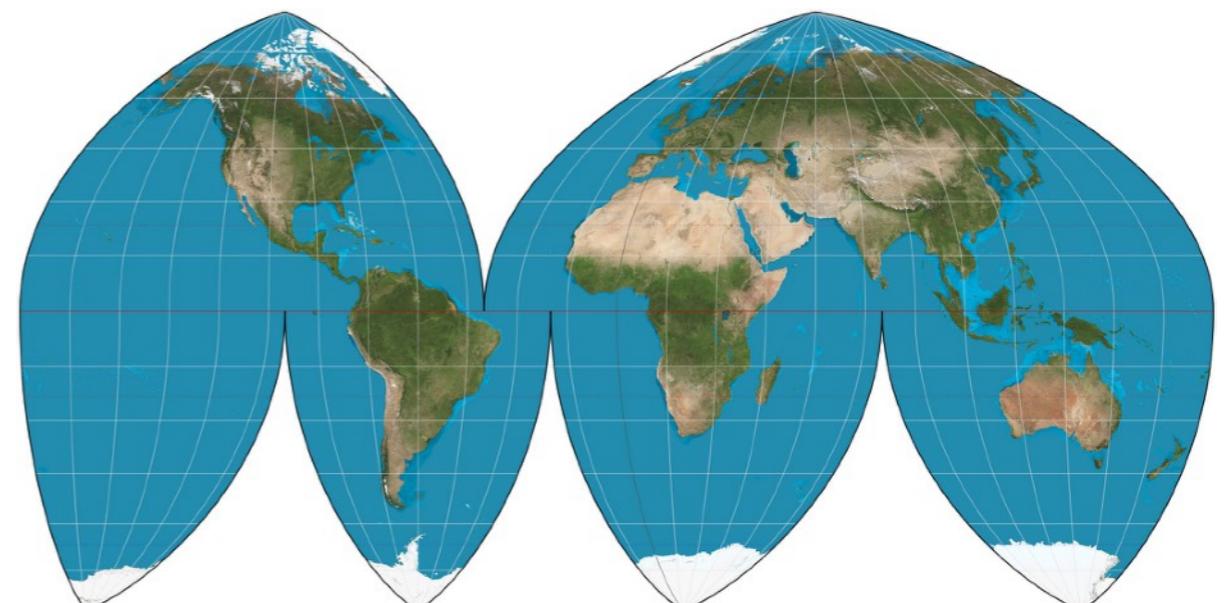
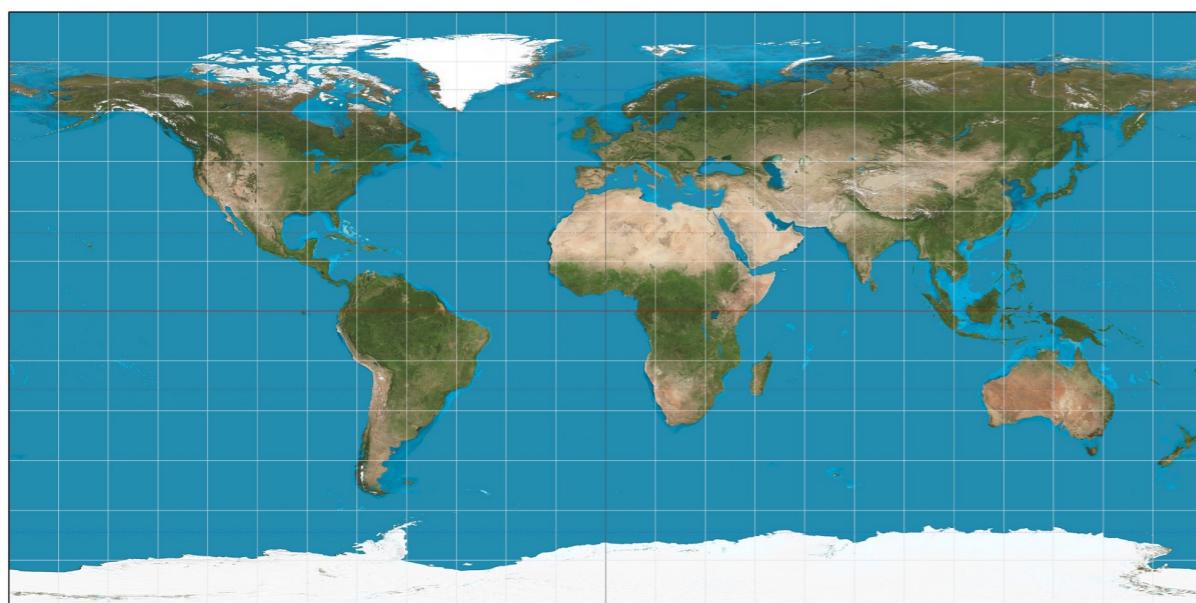
Shape Distortion

- A shape (e.g. a circle) drawn on the object surface would ideally map to the same shape in the texture
- Derivatives of ϕ should be similar in all directions
- More intuitive to create and interpret the texture

Is it ever possible to have
perfect continuity?

Continuity

- Goal is to have a few seams as possible
- Put seams in inconspicuous places on the model
- Often a trade-off between other characteristics



Texture Mapping Functions

- Parametric surfaces
- Geometrically determined mappings
 - Planar projection
 - Spherical or cylindrical mapping
- Manually determined mappings
- Mapping a single triangle

What mapping function might suit a
parametric surface?

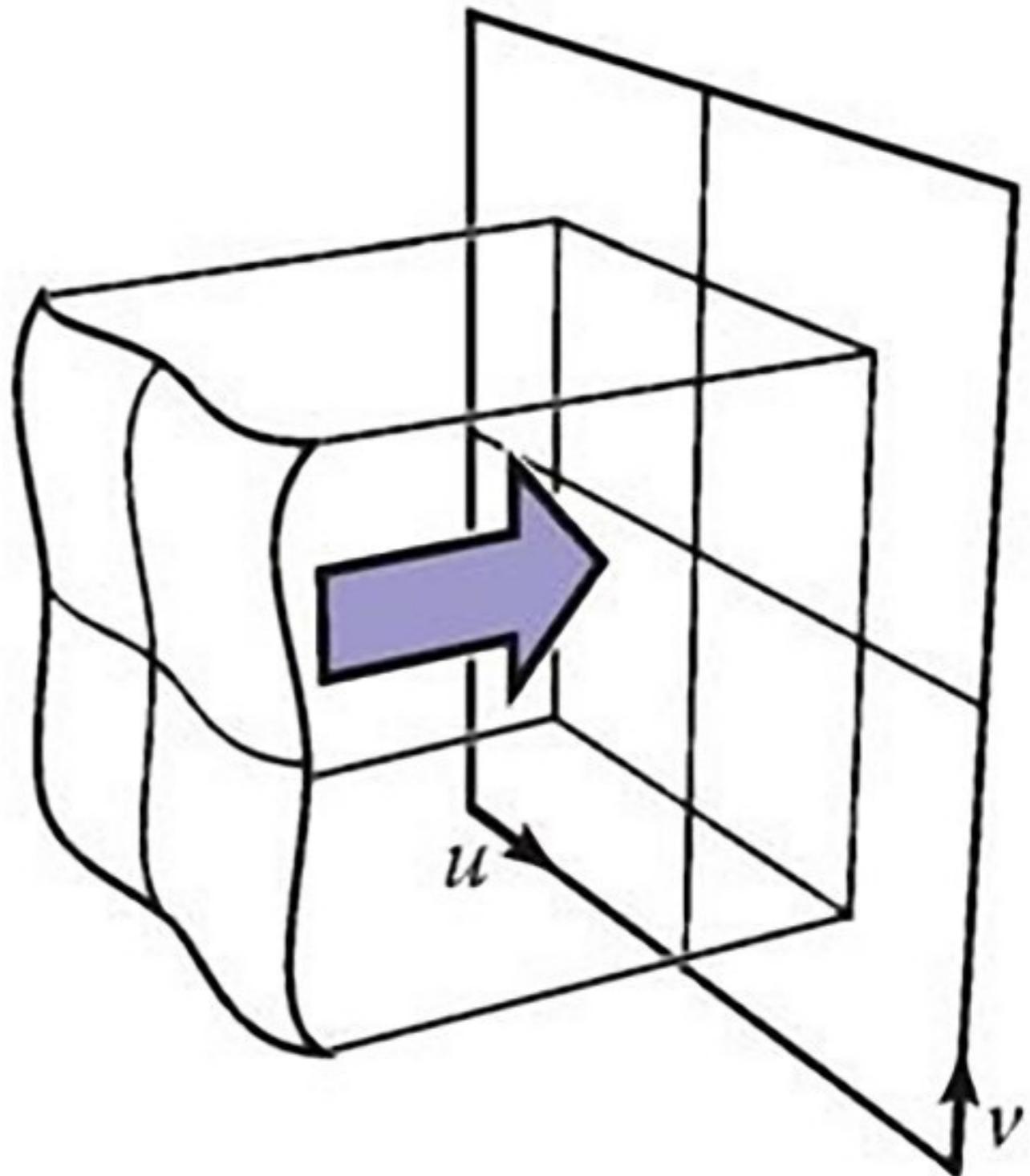
Planar Projection

$$\phi(x, y, z) = (x, y)$$

or

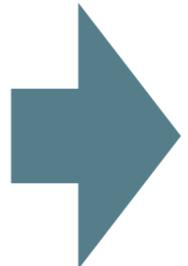
$$u = x$$

$$v = y$$



Characteristics of Planar Projection

09	19	29	39	49	59	69	79	89	99
08	18	28	38	48	58	68	78	88	98
07	17	27	37	47	57	67	77	87	97
06	16	26	36	46	56	66	76	86	96
05	15	25	35	45	55	65	75	85	95
04	14	24	34	44	54	64	74	84	94
03	13	23	33	43	53	63	73	83	93
02	12	22	32	42	52	62	72	82	92
01	11	21	31	41	51	61	71	81	91
00	10	20	30	40	50	60	70	80	90



Spherical Coordinates

Works well for “sphere-ish” objects

$$\phi(x, y, z) = \begin{bmatrix} \frac{\pi + \tan^{-1}\left(\frac{y}{x}\right)}{2\pi} \\ \frac{\pi - \cos^{-1}\left(\frac{z}{\|x\|}\right)}{\pi} \end{bmatrix}$$



Non-spherical objects?

09	19	29	39	49	59	69	79	89	99
08	18	28	38	48	58	68	78	88	98
07	17	27	37	47	57	67	77	87	97
06	16	26	36	46	56	66	76	86	96
05	15	25	35	45	55	65	75	85	95
04	14	24	34	44	54	64	74	84	94
03	13	23	33	43	53	63	73	83	93
02	12	22	32	42	52	62	72	82	92
01	11	21	31	41	51	61	71	81	91
00	10	20	30	40	50	60	70	80	90



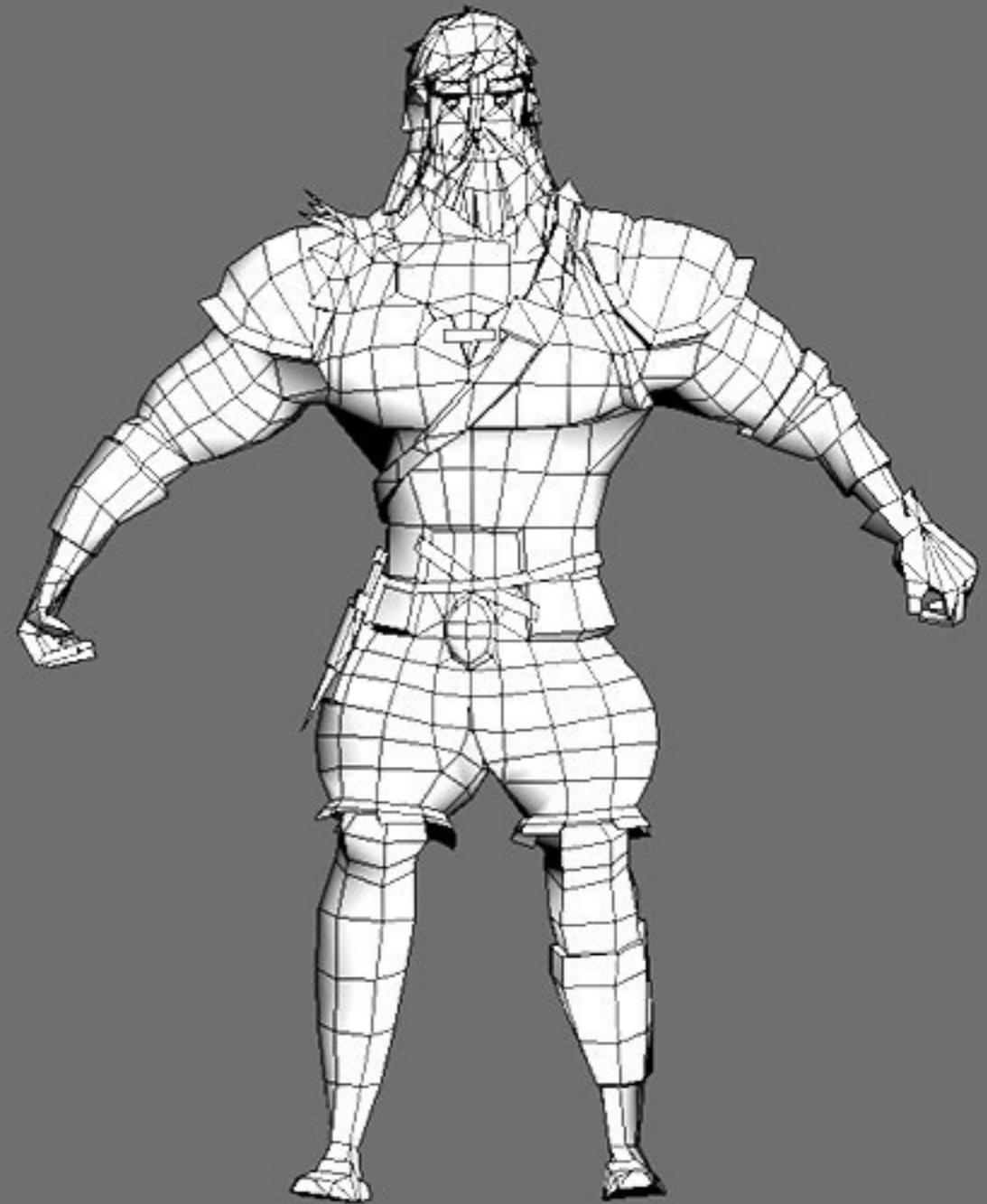
Cylindrical Coordinates

$$\phi(x, y, z) = \left[\begin{array}{c} \frac{\pi + \tan^{-1}\left(\frac{y}{x}\right)}{2\pi} \\ \frac{1+z}{2} \end{array} \right]$$

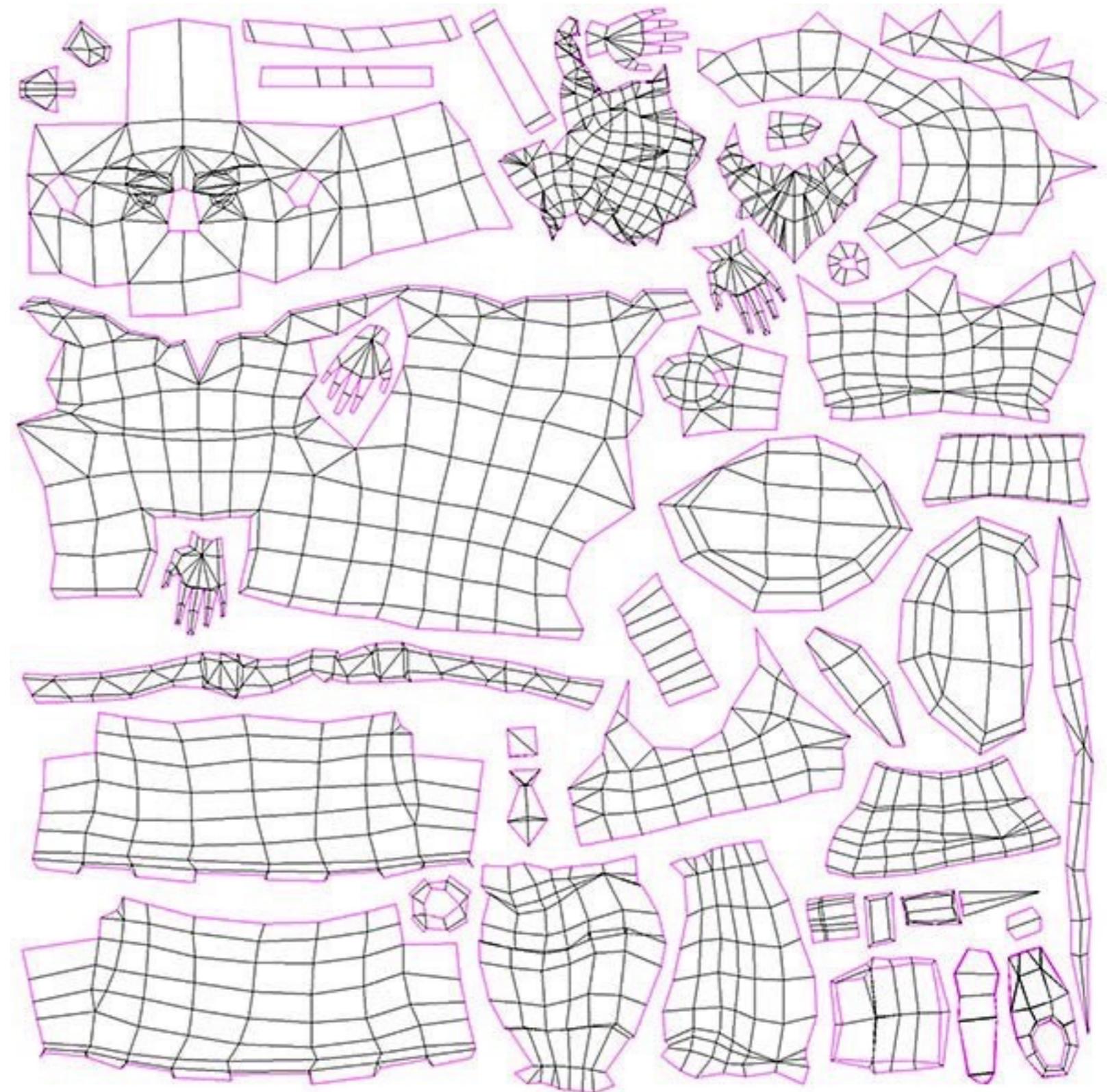
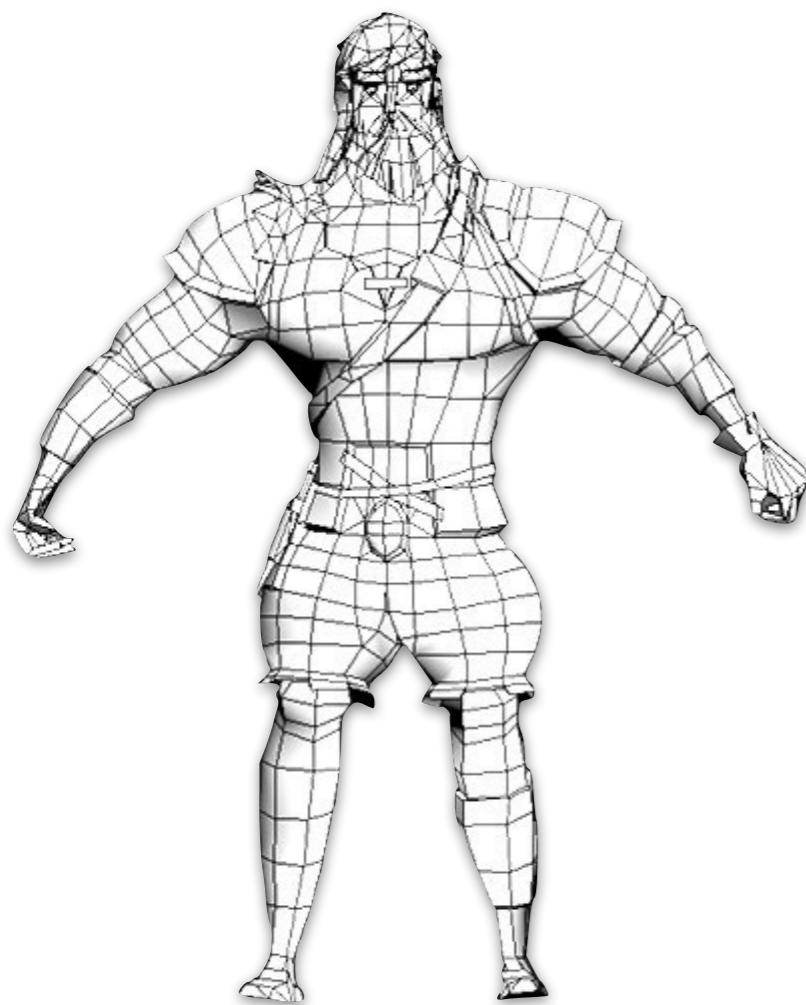


Complex Shapes

What mapping function would we use for an object such as this?



Hand-Crafted



[from crossofthedutchman.com] 28

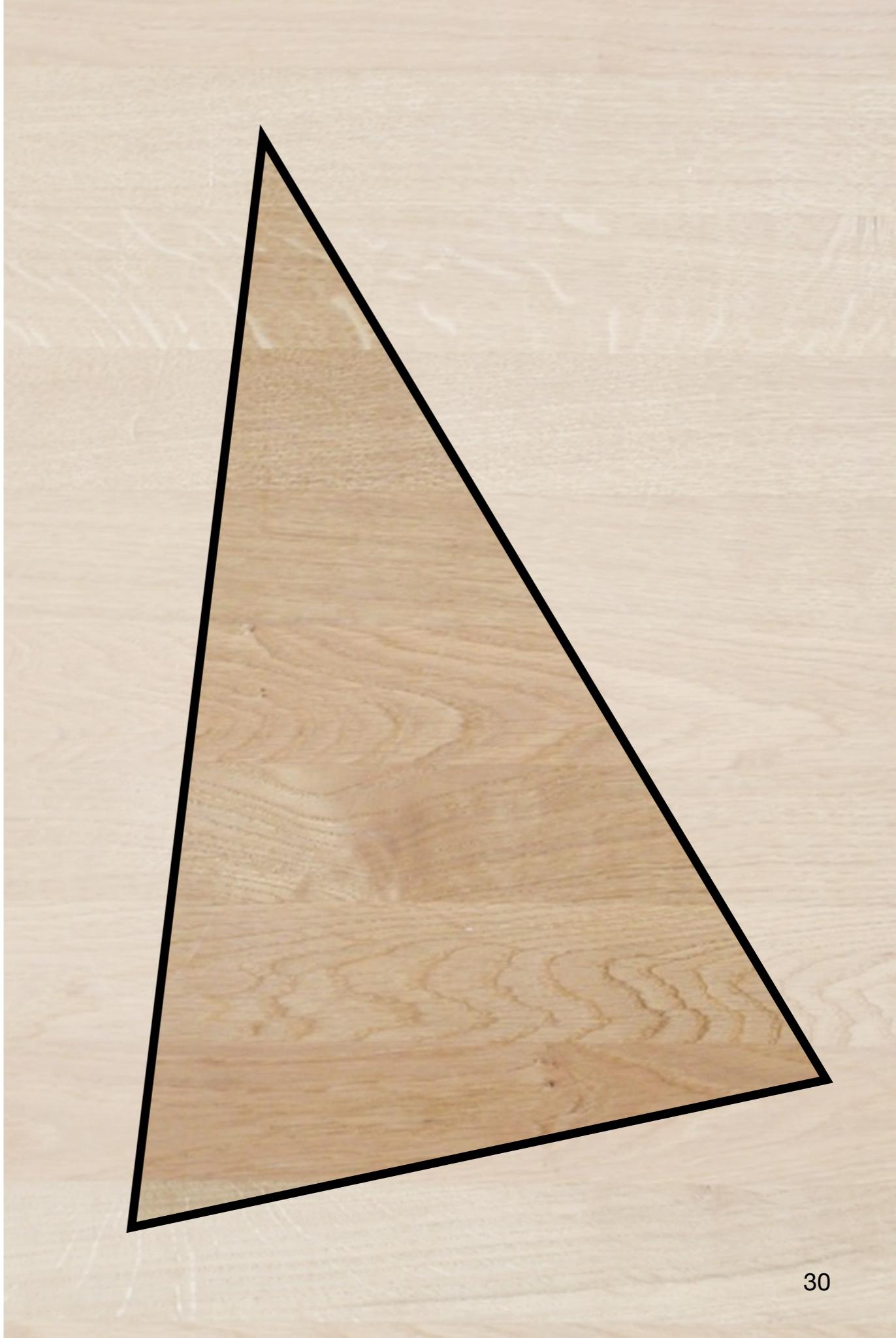


The Final Mapping

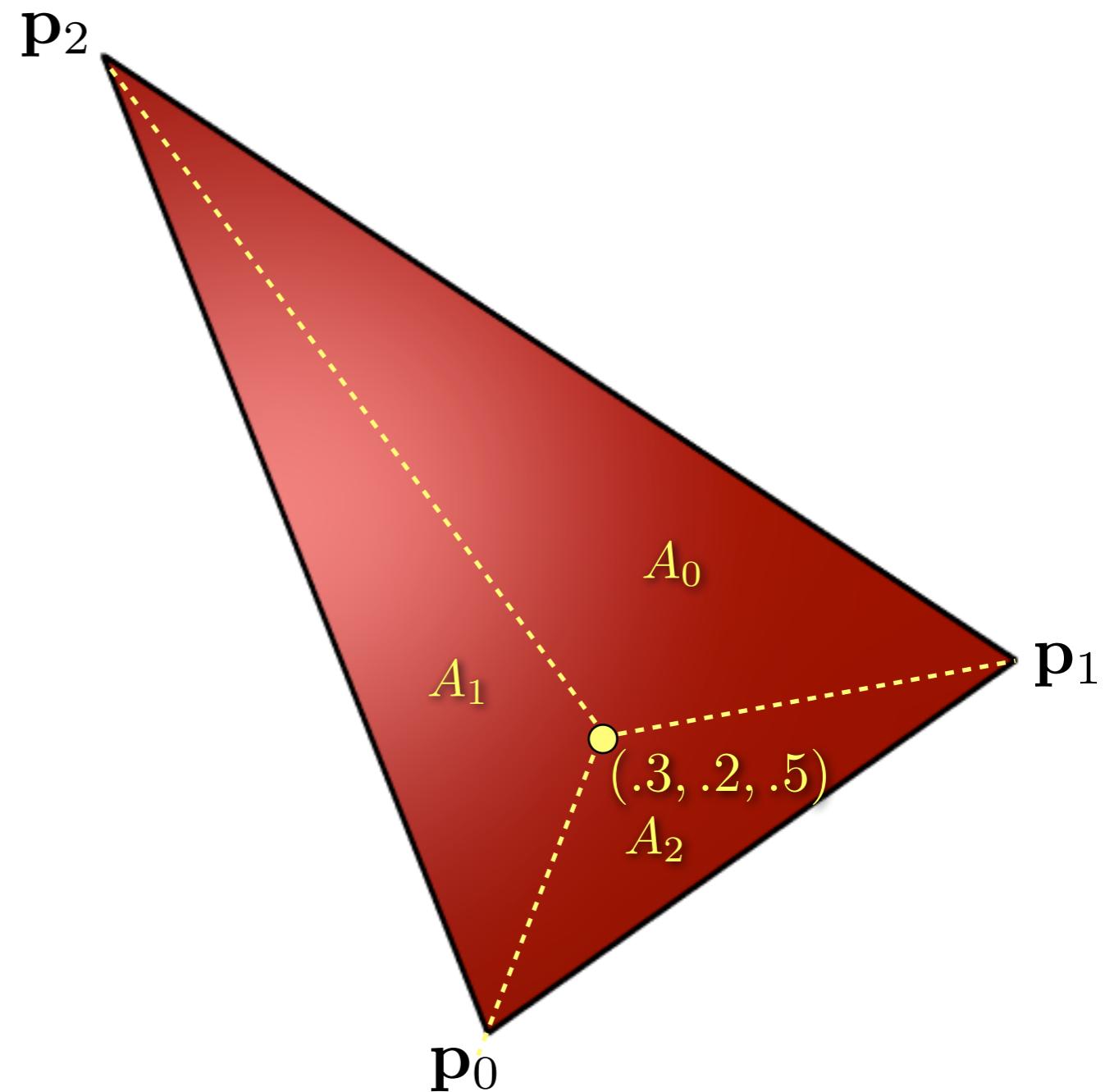
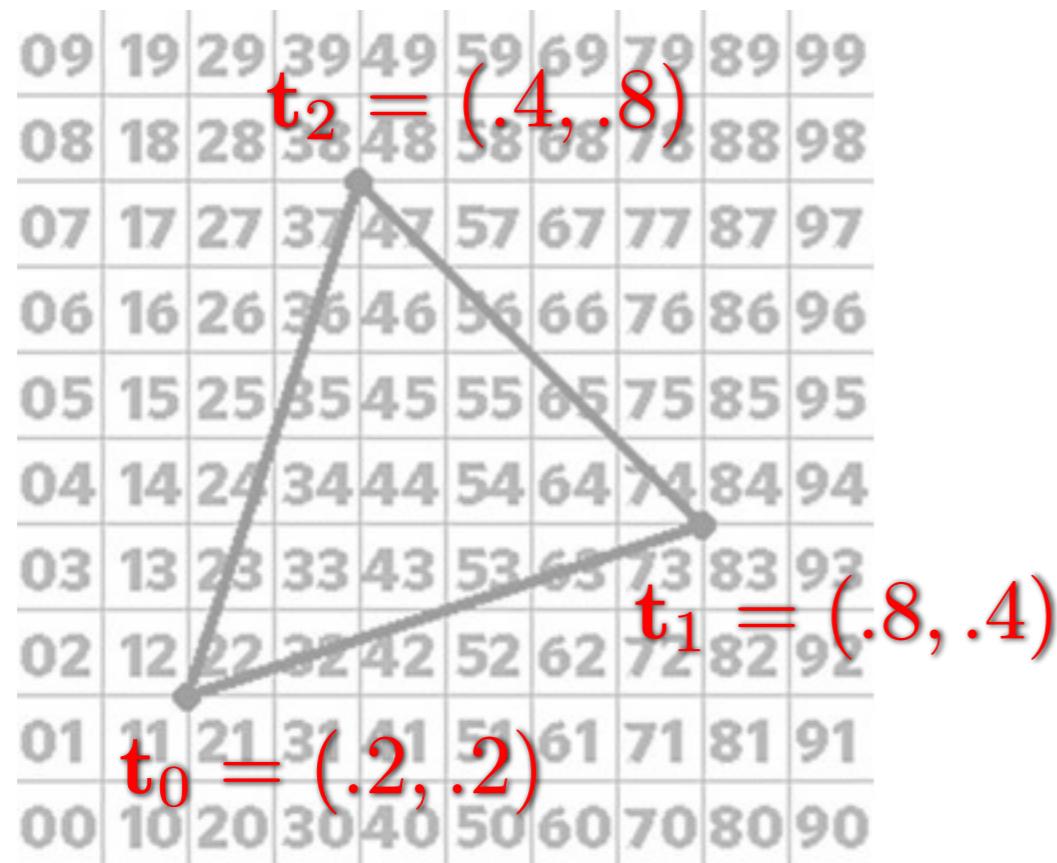
Can you spot the seams?

Texturing a Triangle

What mapping function do we use?



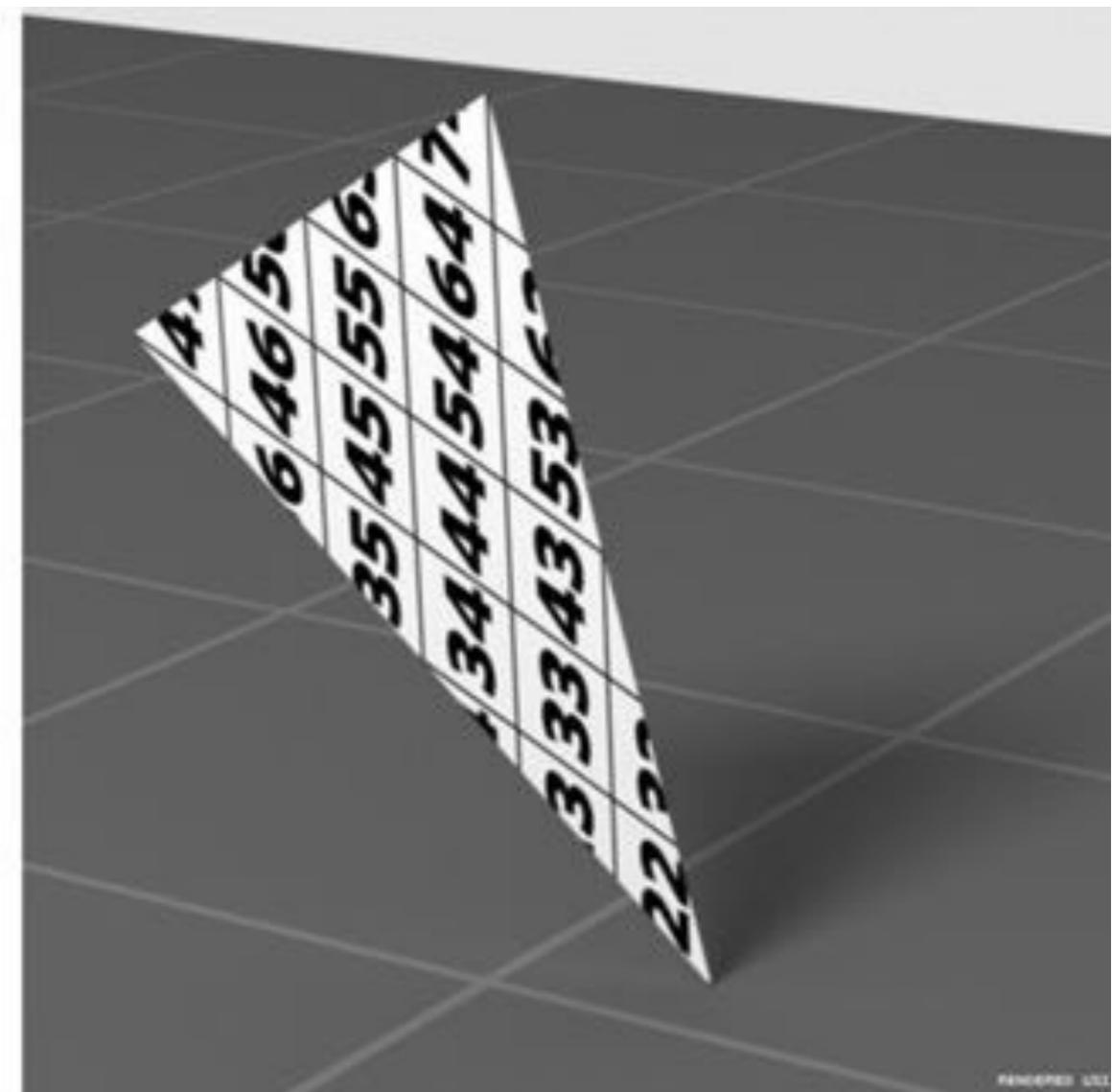
Barycentric Mapping



$$(u, v) = 0.5 \mathbf{t}_0 + 0.3 \mathbf{t}_1 + 0.2 \mathbf{t}_2$$

Texture-Mapped Triangle

09	19	29	39	49	59	69	79	89	99
08	18	28	38	48	58	68	78	88	98
07	17	27	37	47	57	67	77	87	97
06	16	26	36	46	56	66	76	86	96
05	15	25	35	45	55	65	75	85	95
04	14	24	34	44	54	64	74	84	94
03	13	23	33	43	53	63	73	83	93
02	12	22	32	42	52	62	72	82	92
01	11	21	31	41	51	61	71	81	91
00	10	20	30	40	50	60	70	80	90



Mapping Function Summary

- Goal is to define a function from the object to the image
 - ideally continuous, bijective, and minimizes distortion
- Standard mapping functions sometimes work well
 - planar projection, spherical mapping, cylindrical mapping
- Complex objects often require hand-crafted functions
- Barycentric coordinates are used to interpolate texture values across individual triangles



Texture Sampling

reading our values...

What is that setting,
anisotropic filtering?

MAIN MENU / OPTIONS / VIDEO

FRAMERATE

Unlimited

ANISOTROPIC FILTERING

16x

BULLET DECALS

FOLIAGE DISTANCE

TEXTURE QUALITY

GAME DETAIL

AMBIENT OCCLUSION

DEPTH OF FIELD

FXAA

VIEW DISTANCE

PHYSX EFFECTS

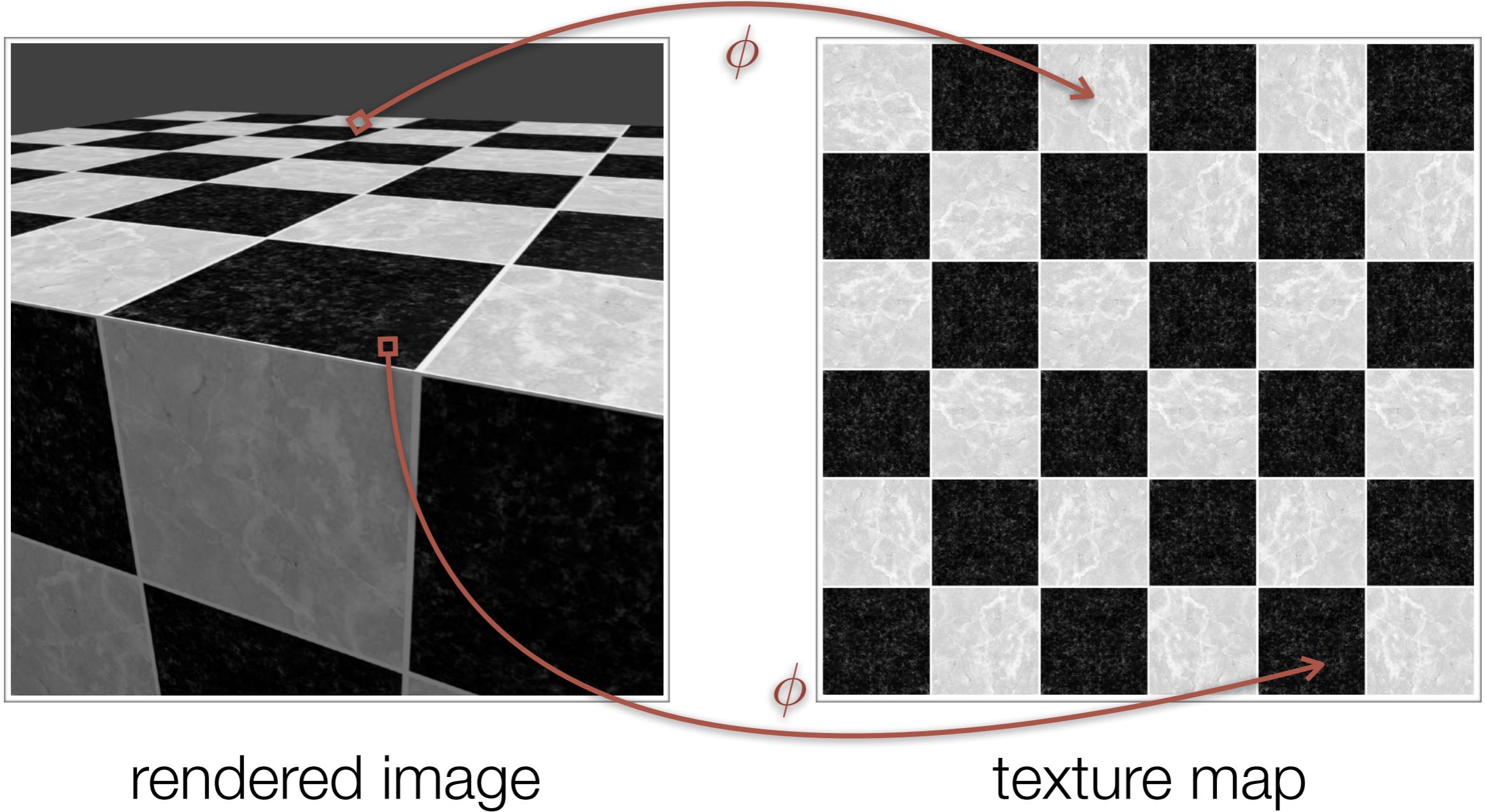
Expand field of view to see more of the game world.



What does this setting do?

(Borderlands 2, 2K Games)

Texture Footprint: Texel to Pixel Ratio



Are the texels larger or smaller than the pixels?

Texture Magnification

one texel → many pixels

What is our main challenge?

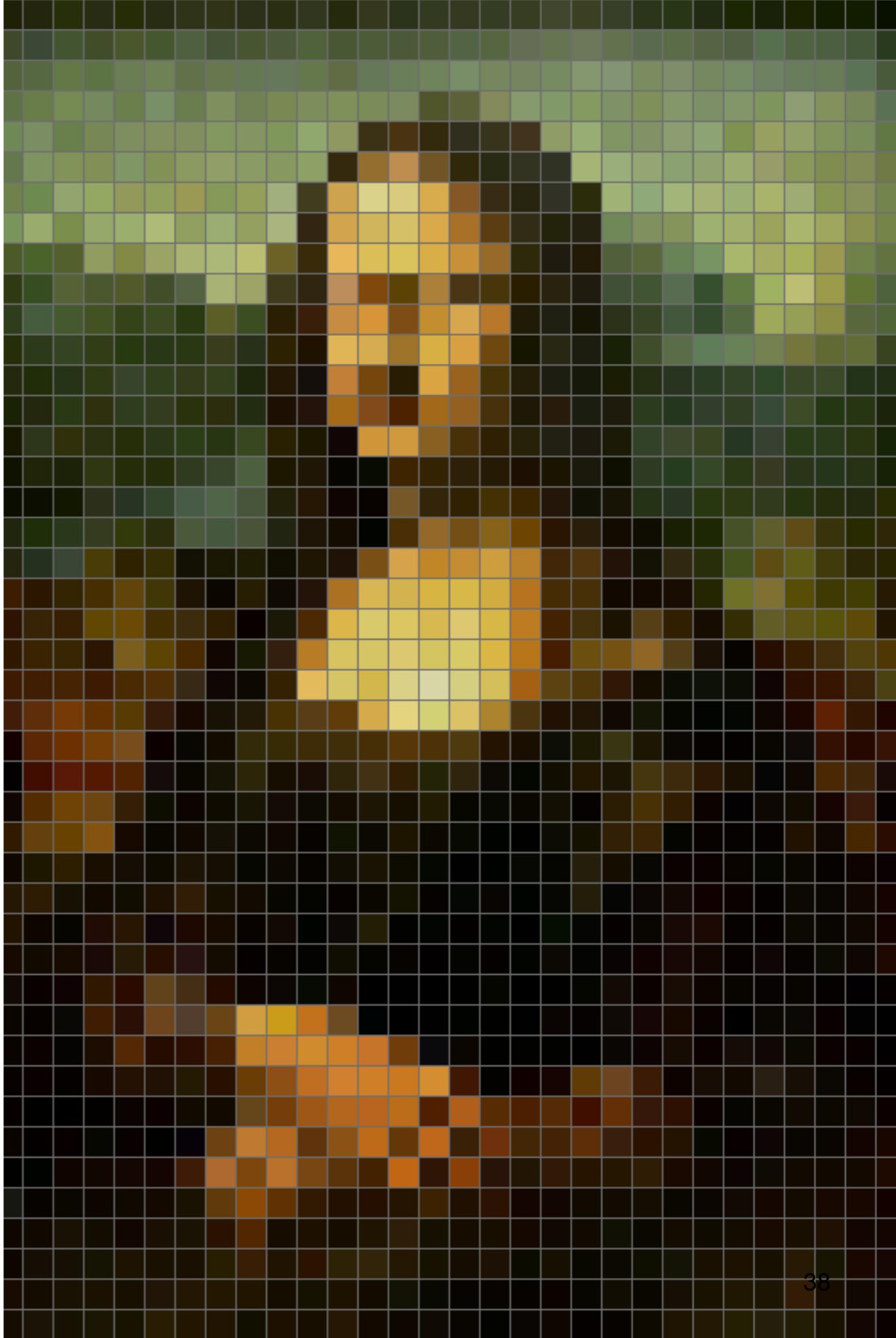


Image Reconstruction: An Interpolation Problem



nearest



linear

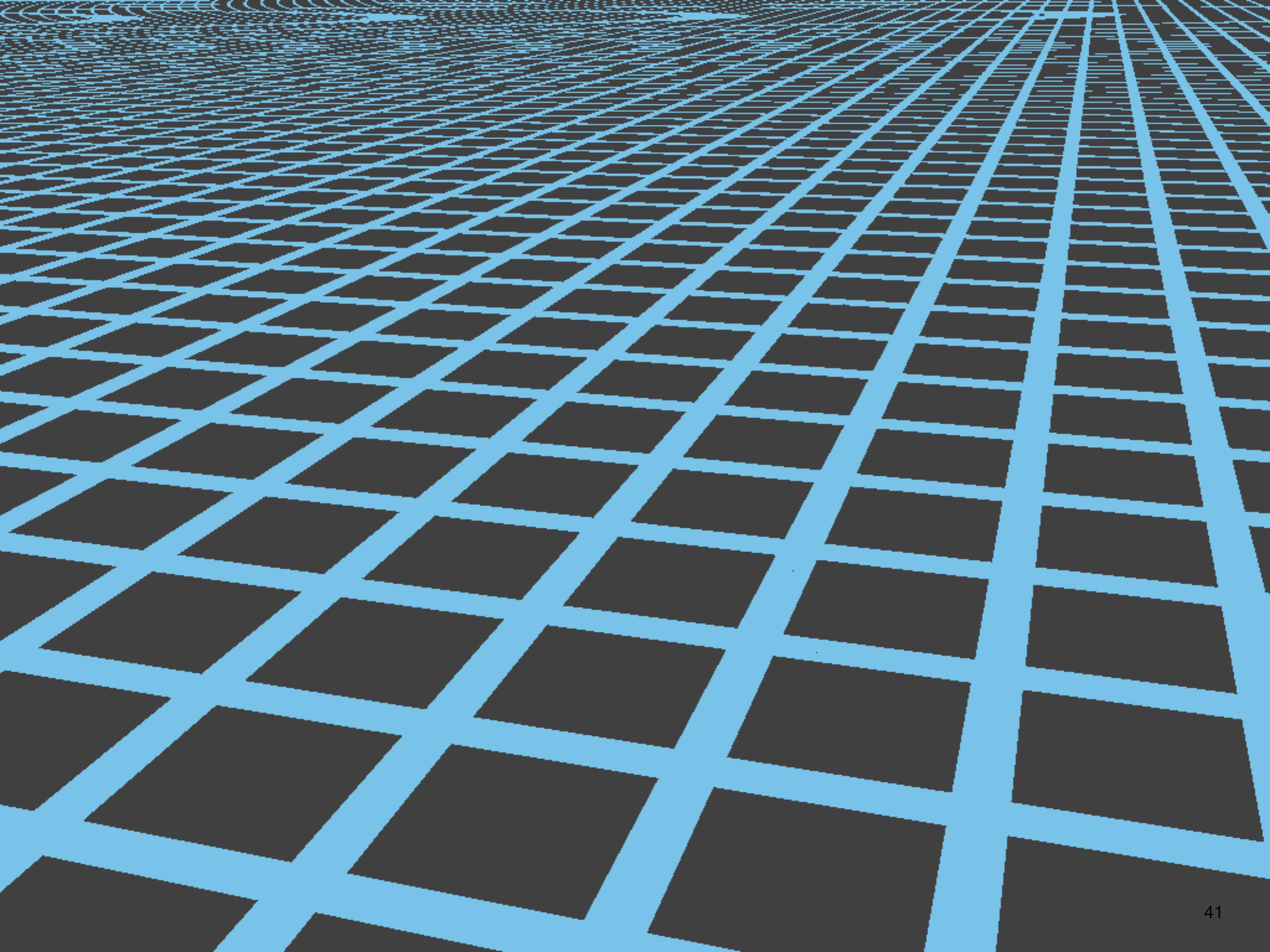


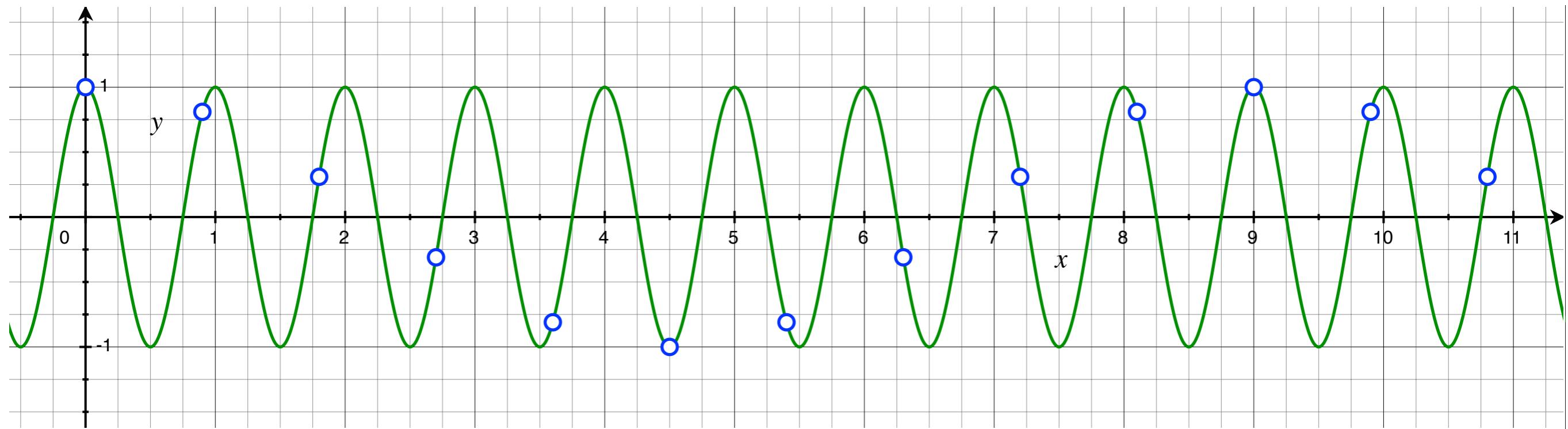
sinc

Texture Minification

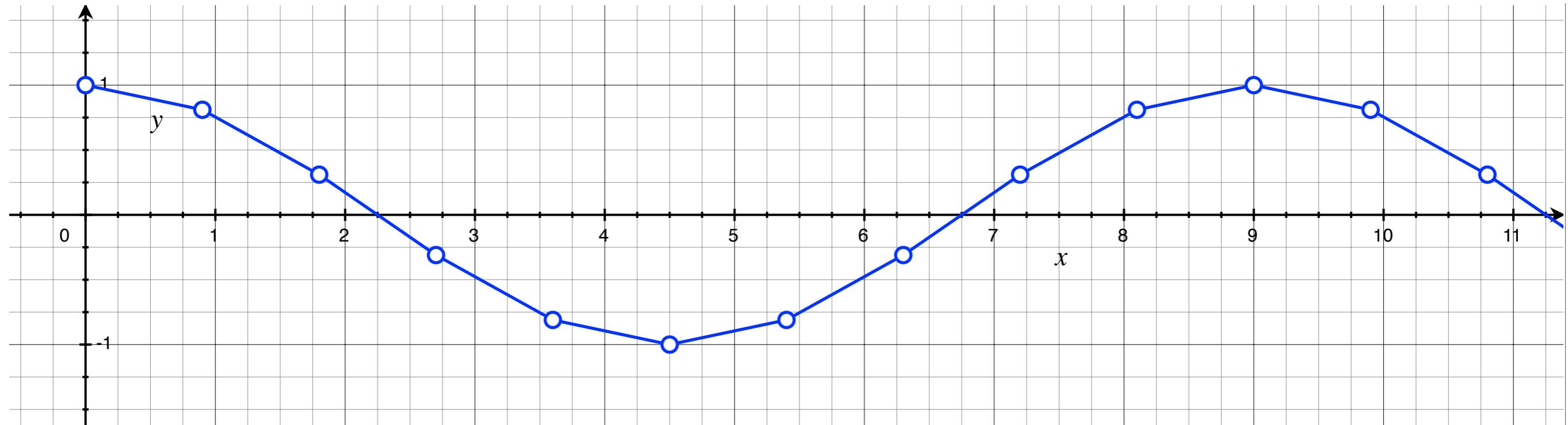
many texels → one pixel

What is our main challenge?





Aliasing!!!



Anti-Aliasing Textures

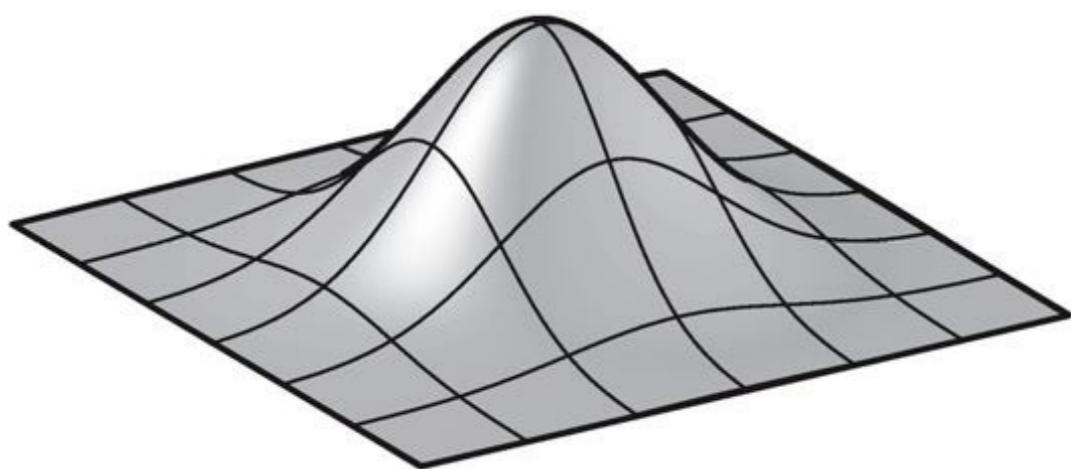
How do we do it?



No jaggies!

Anti-Aliasing Textures

How do we do it?

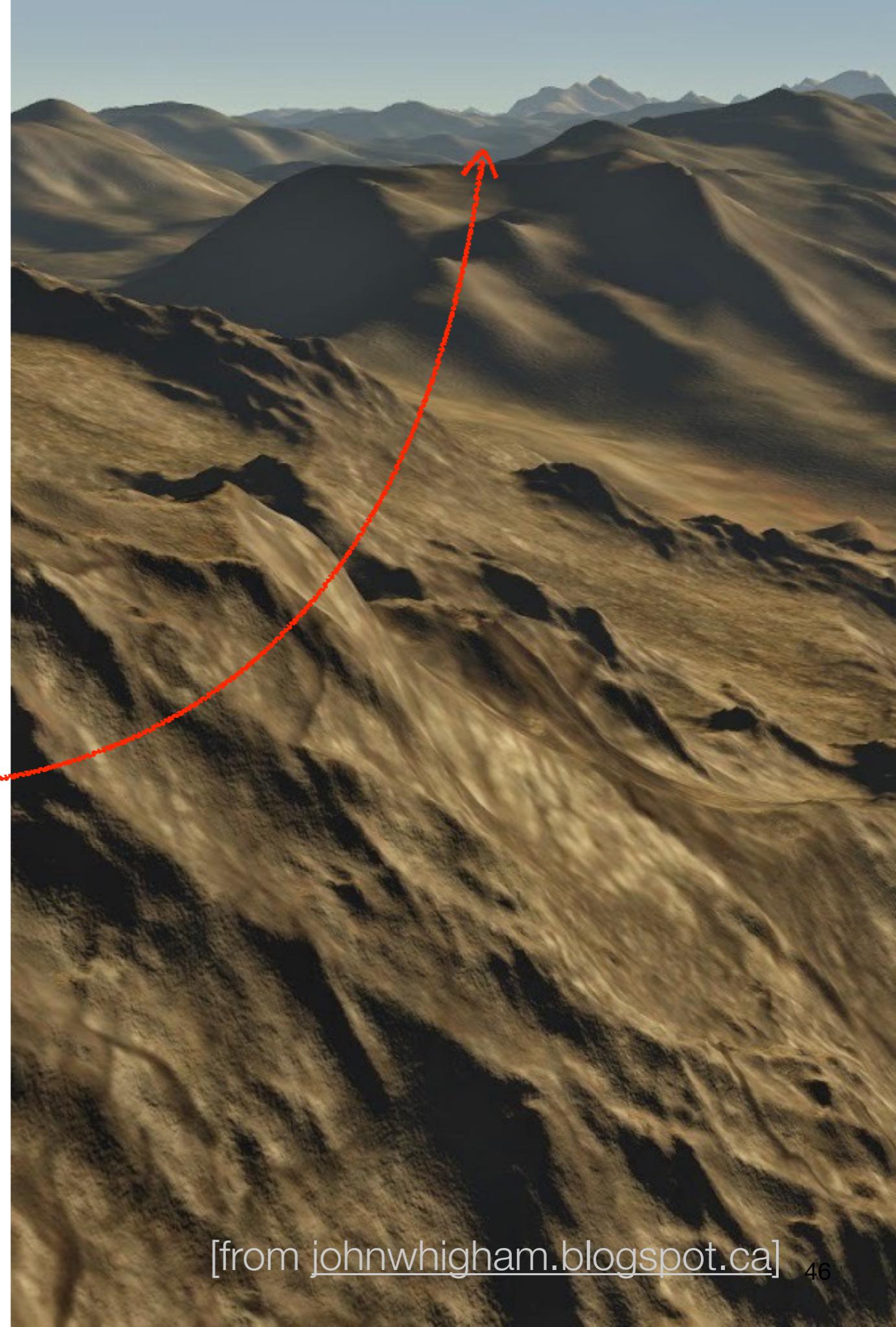


No jaggies!

How much do we blur?

Texture Filtering

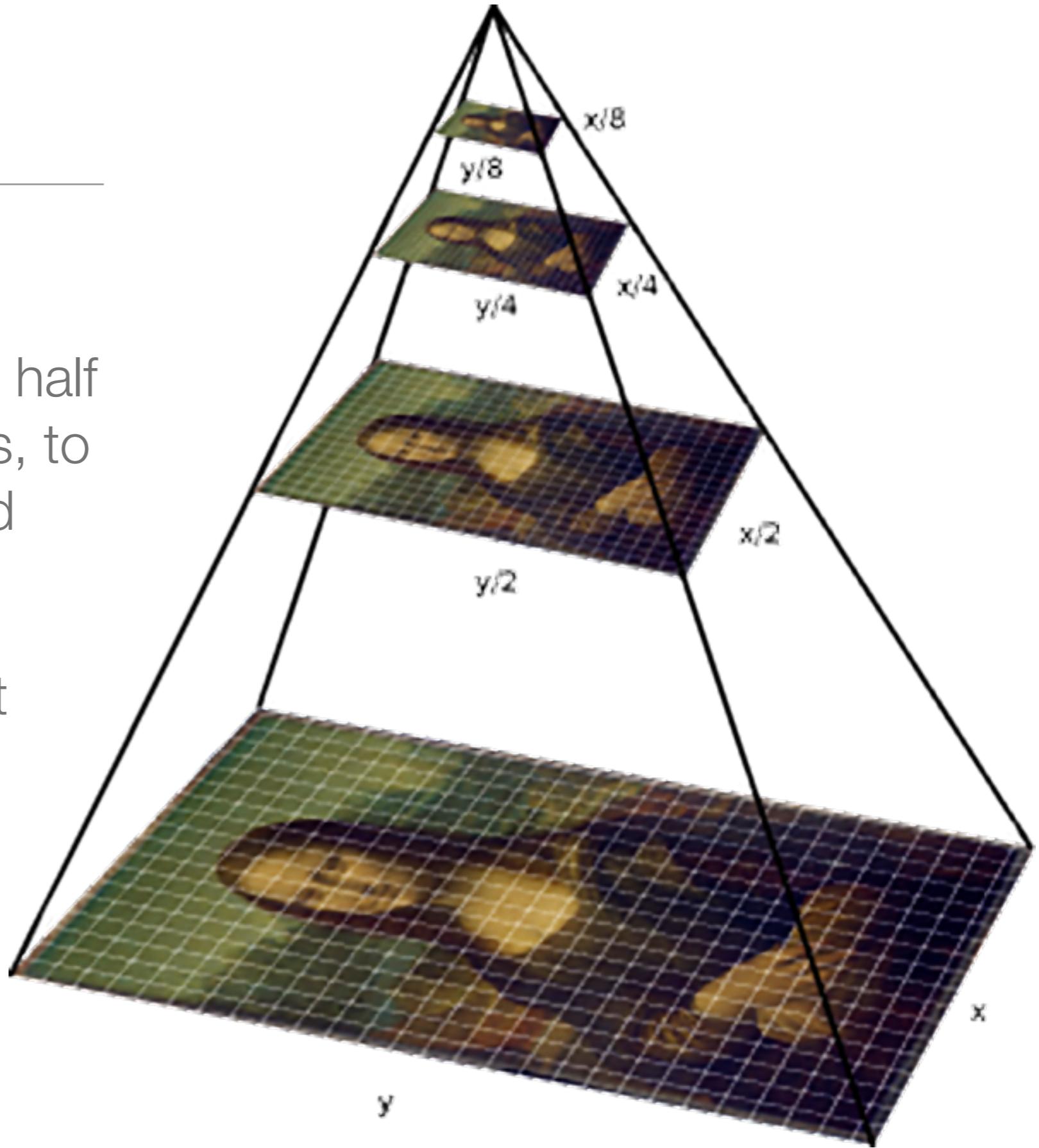
How many texture image pixels
does this screen pixel cover?



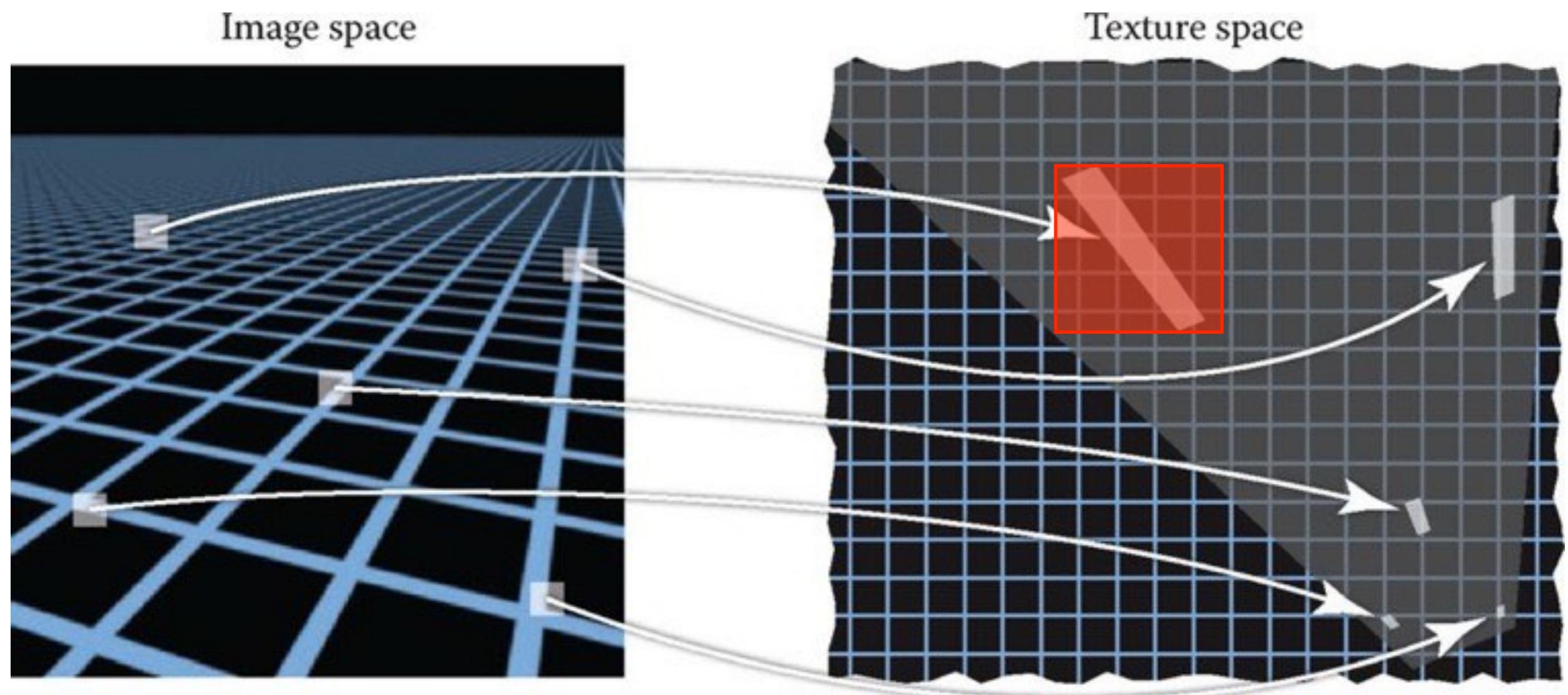
[from johnwhigham.blogspot.ca]

Mipmaps

- *multum in parvo*
- Construct layers, each half the size of the previous, to form an image pyramid
- Choose pyramid level depending on footprint
- What is the highest frequency content of each level?

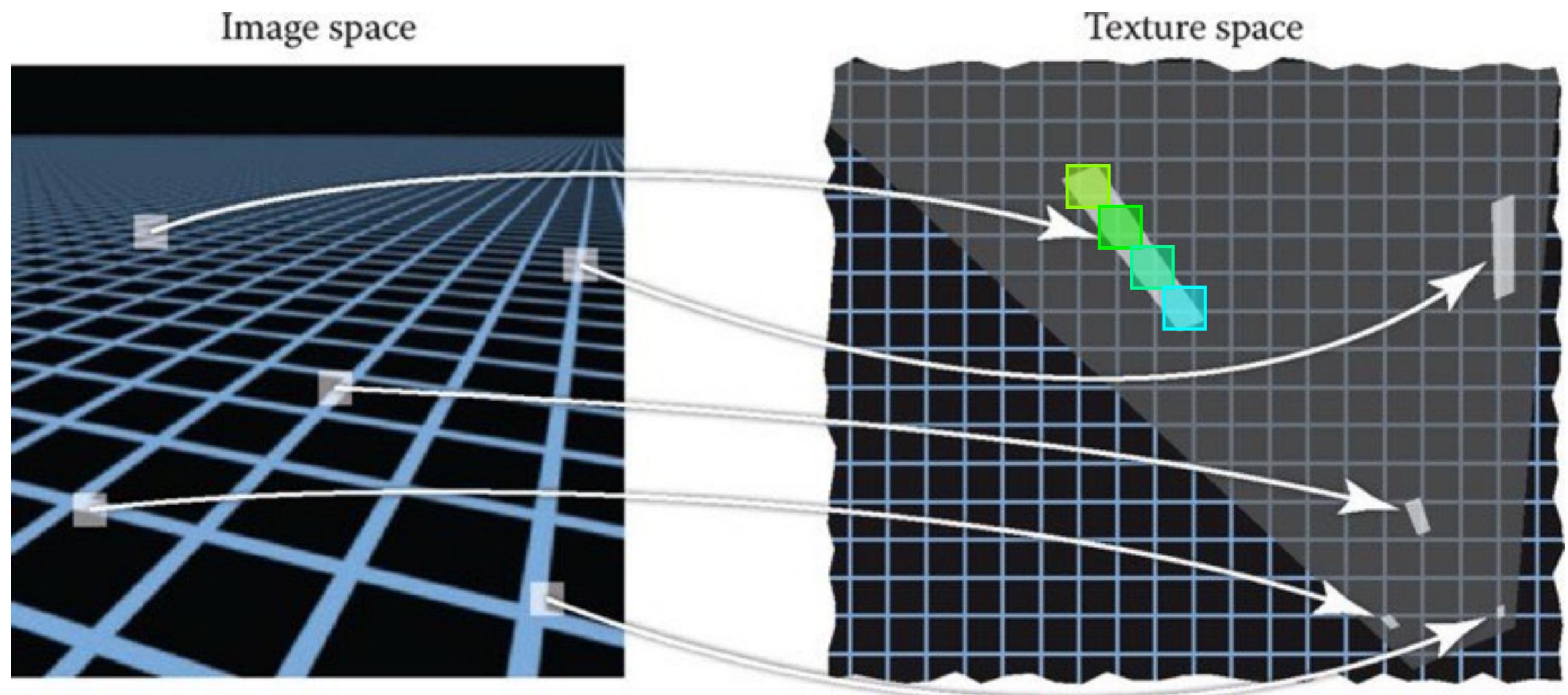


Revisiting the Texture Footprint



mipmap sampling

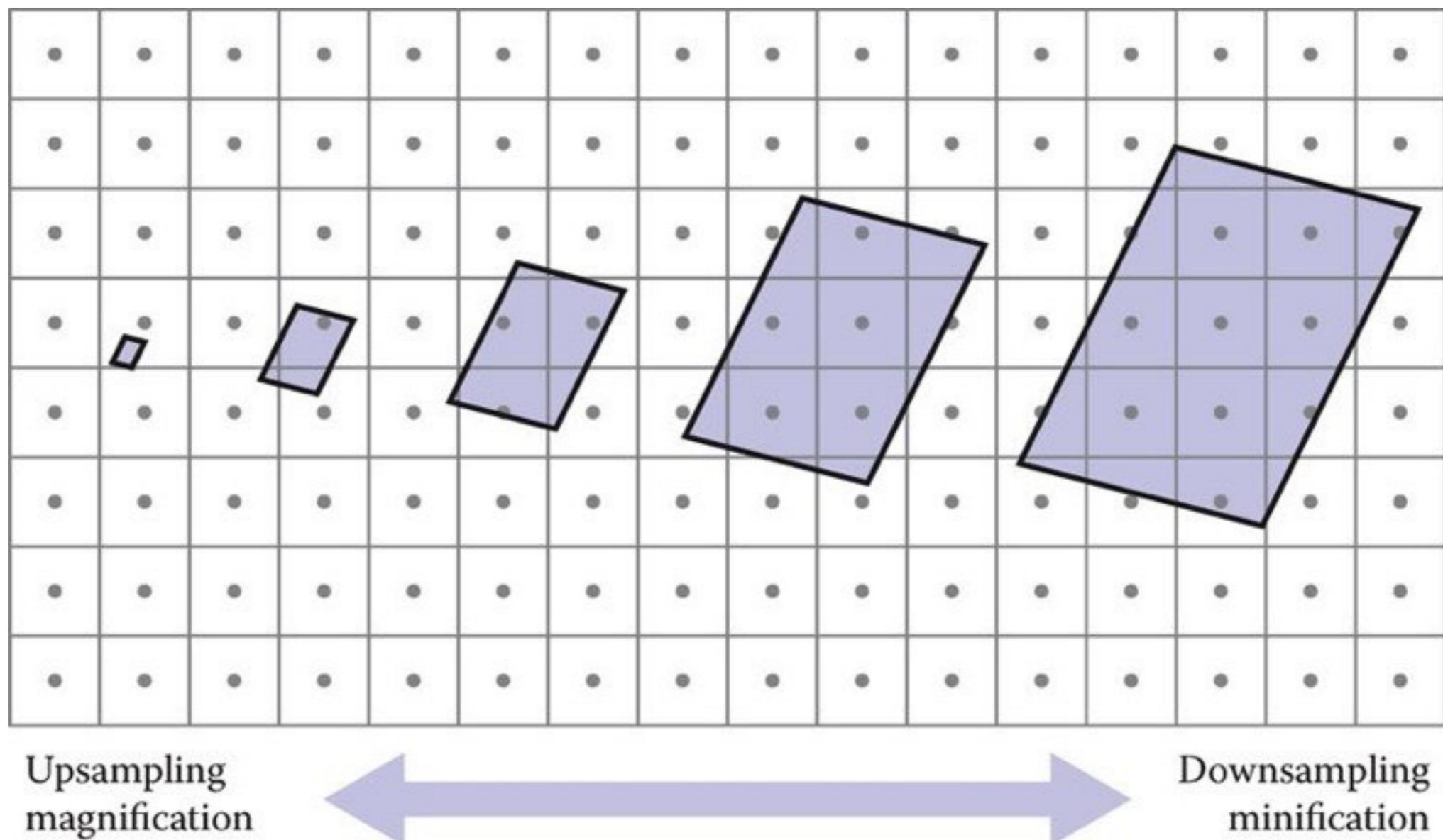
Anisotropic Filtering



4x anisotropic filtering

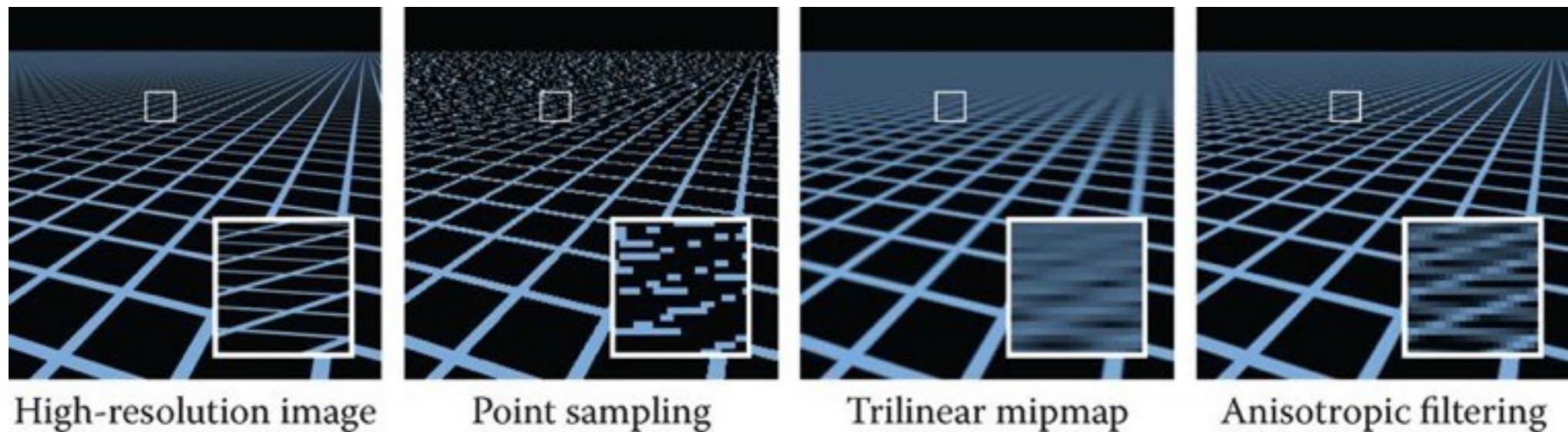
Texture Sampling/Filtering Summary

- Must choose the right strategy depending on the pixel!



Texture Sampling/Filtering Summary

- Must choose the right strategy depending on the pixel!
- Magnification is an interpolation problem
- Magnification is an anti-aliasing problem



Surface Properties

What can we texture map?



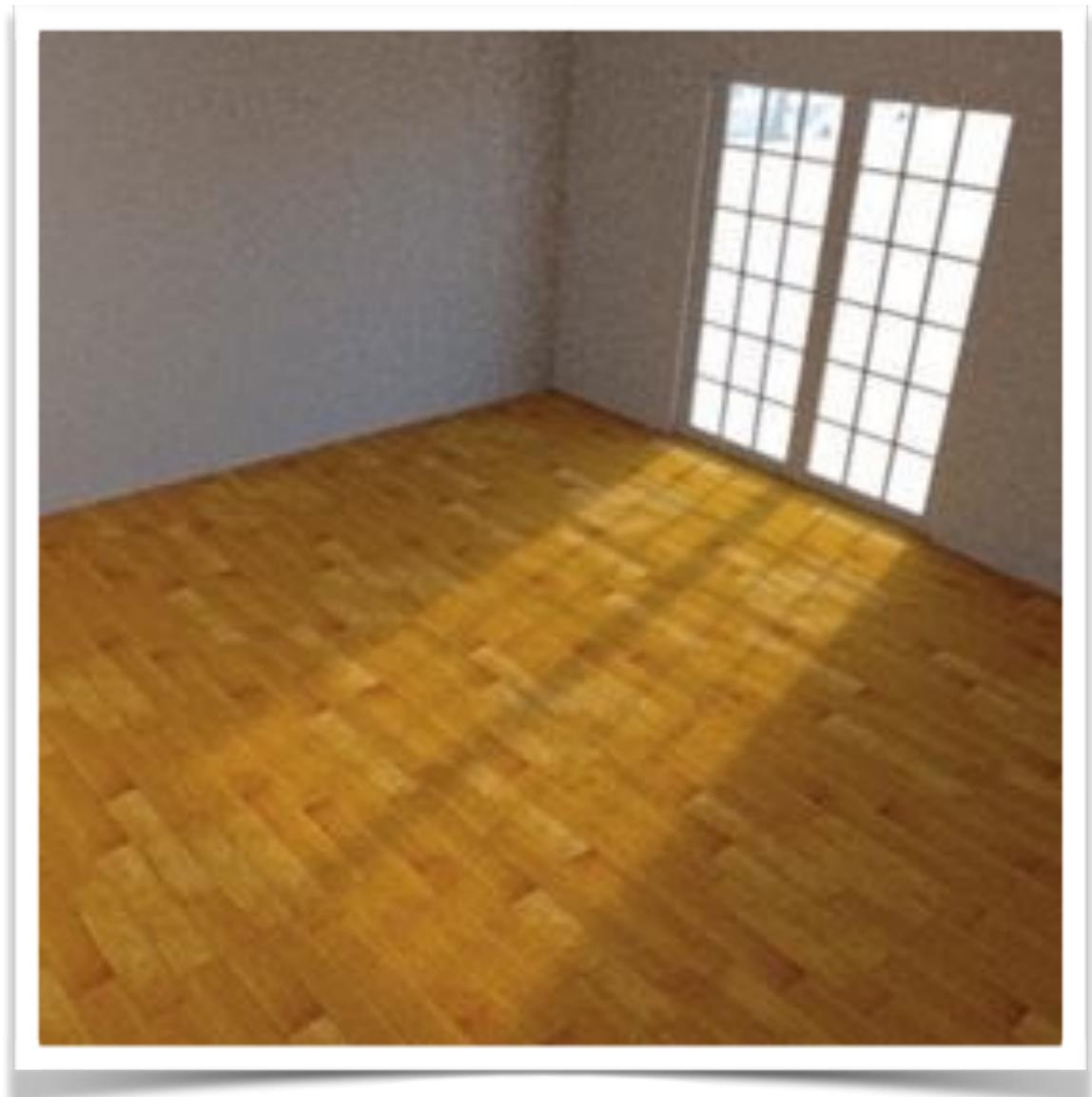
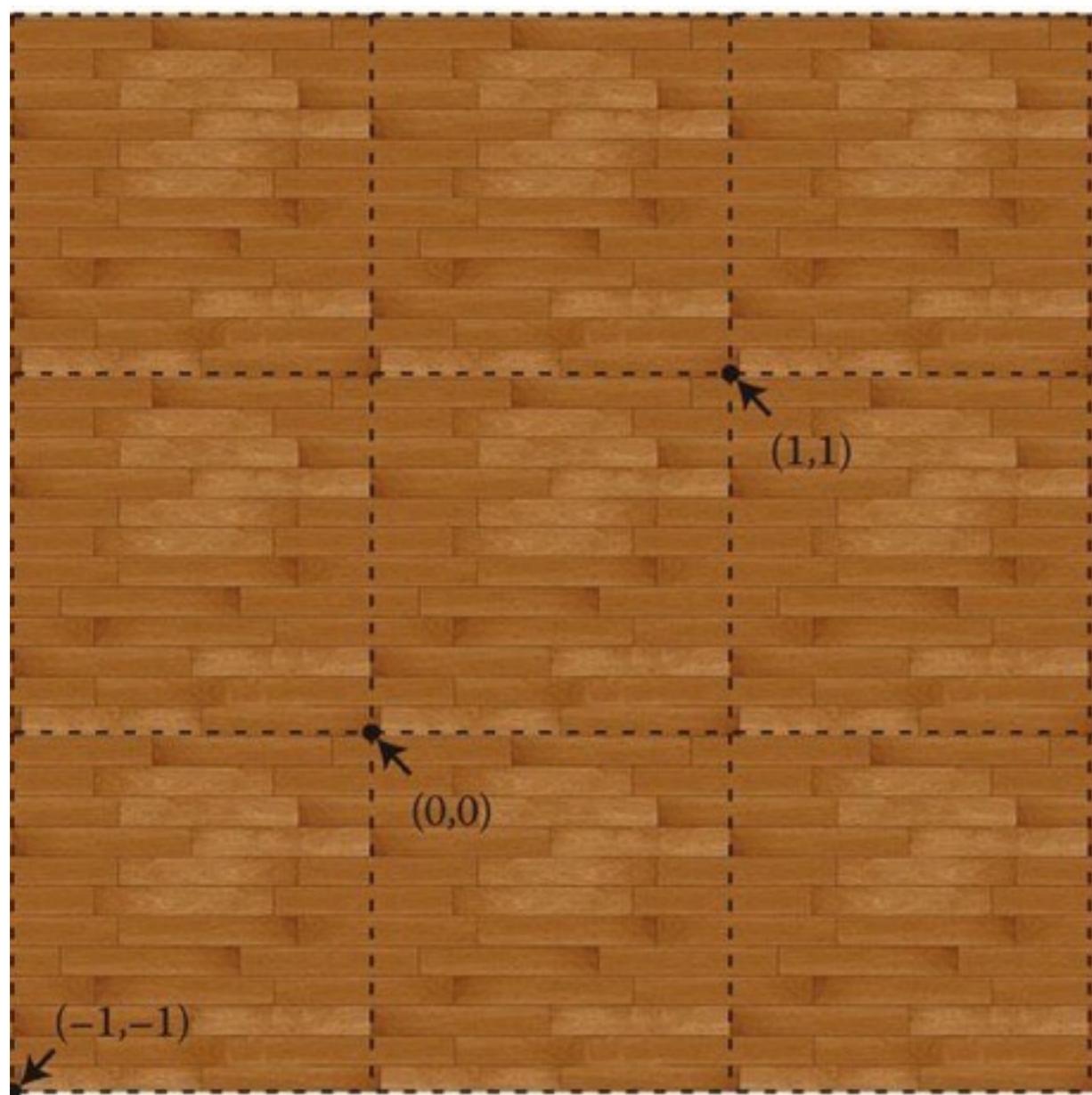
Our heuristic shading equation from last week...

- with ambient, diffuse, and specular terms:

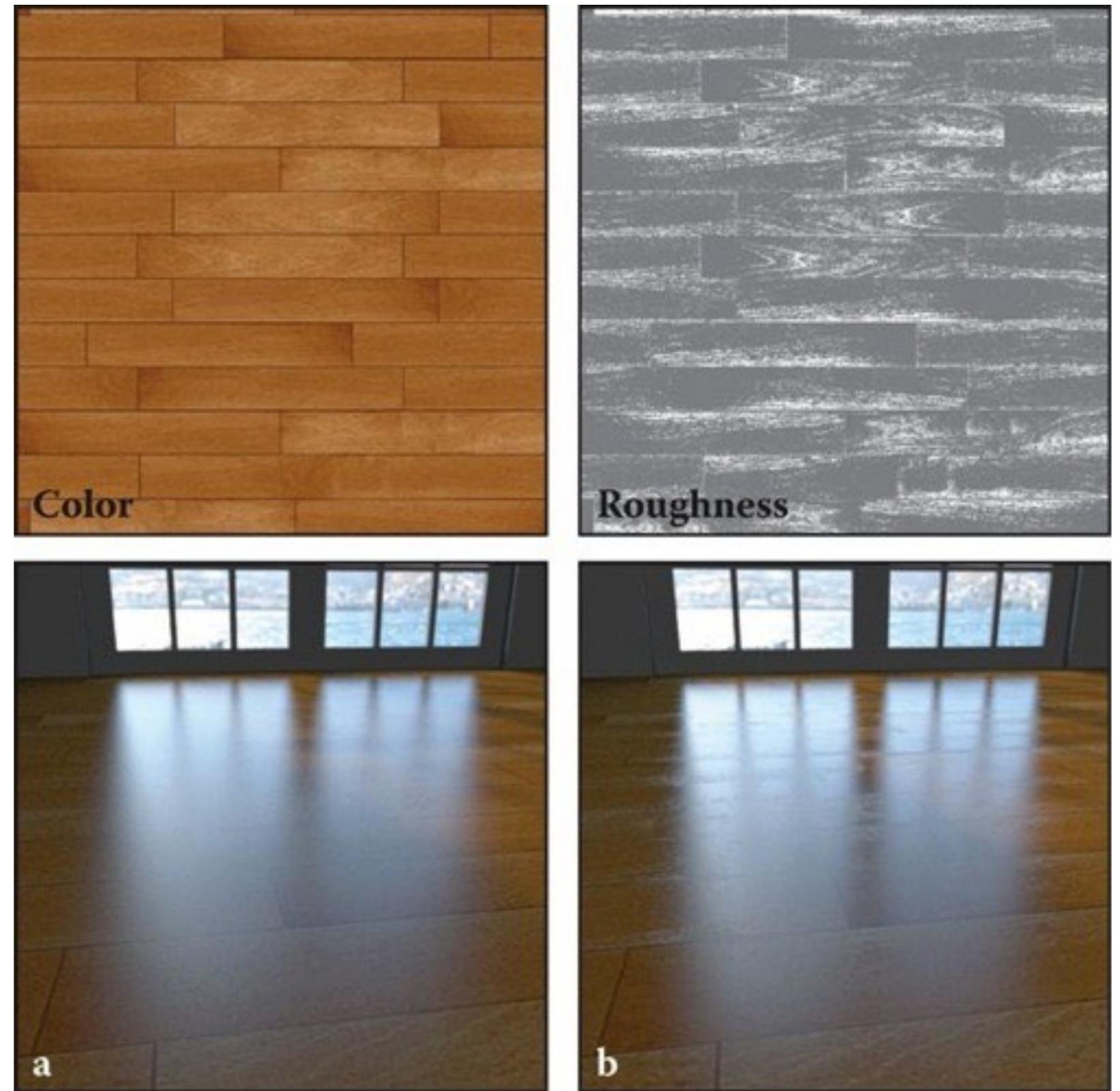
$$c = c_r \left(c_a + c_l \max(0, \hat{\mathbf{n}} \cdot \hat{\mathbf{l}}) \right) + c_l c_p \left(\hat{\mathbf{h}} \cdot \hat{\mathbf{n}} \right)^p$$

- c_r is reflectance (diffuse) colour of material
- c_p is specular colour of material
- p is Phong exponent, or shininess of material
- c_l is light source intensity (colour)
- c_a is ambient light intensity (colour)

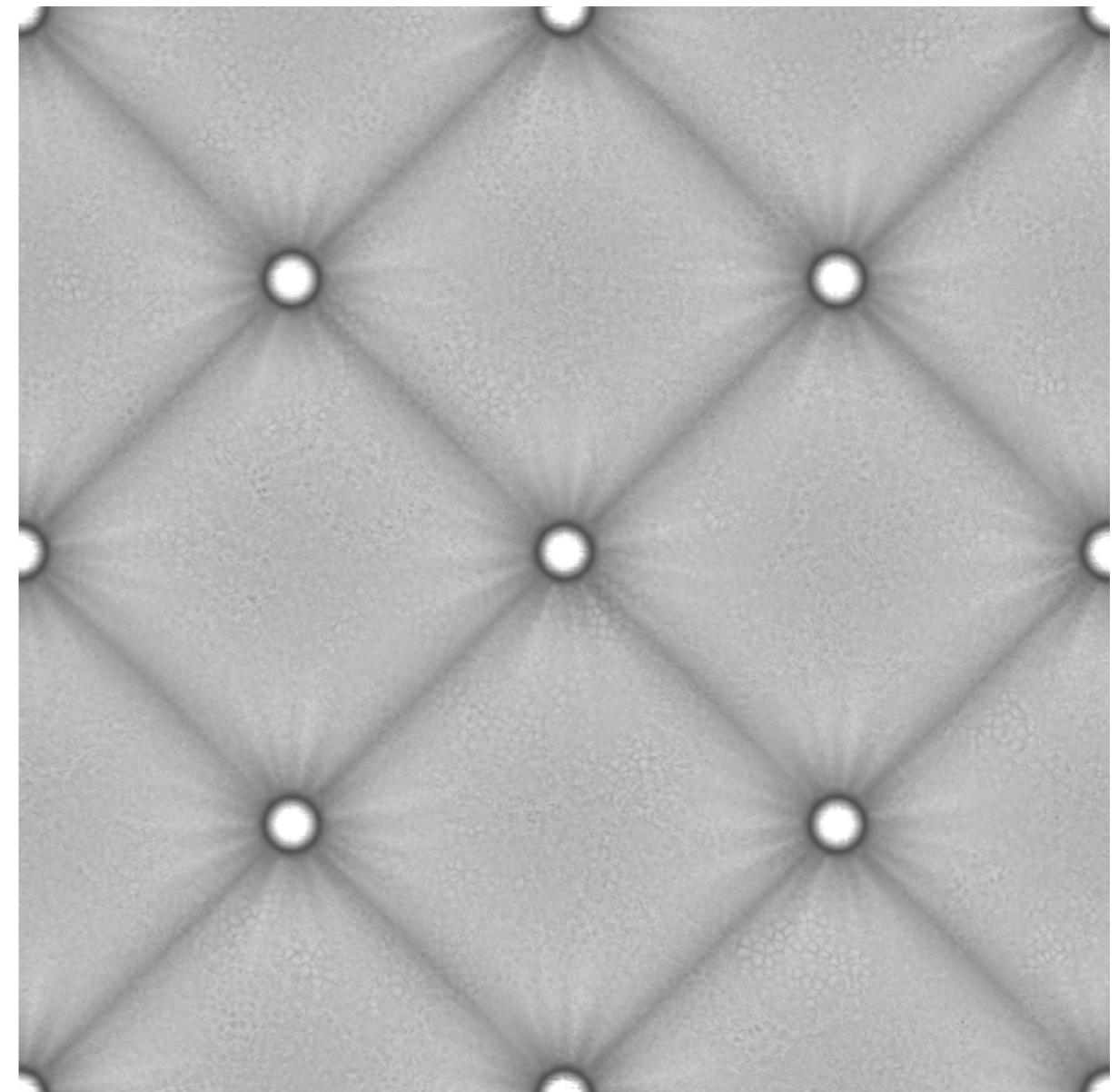
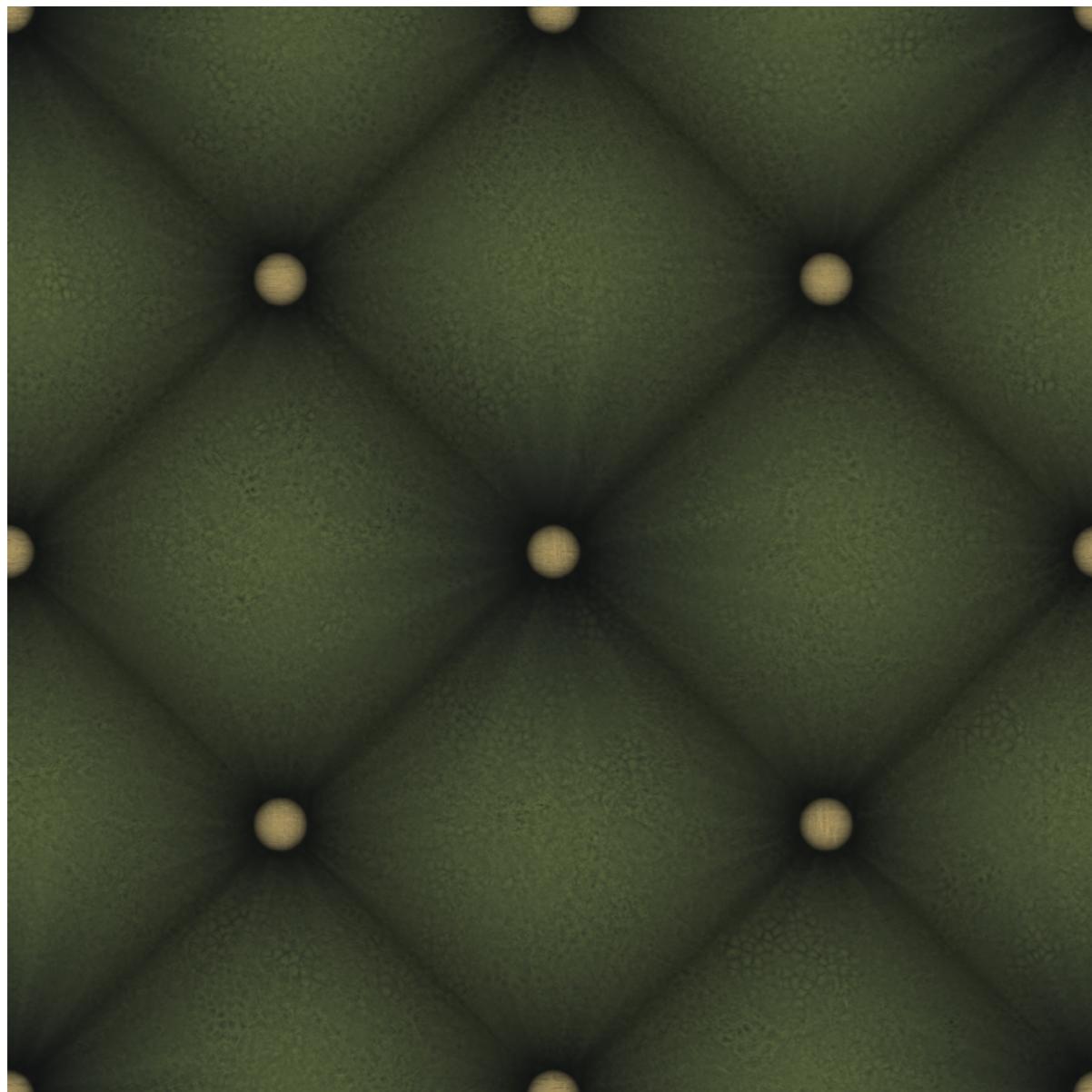
Colour or Diffuse Maps



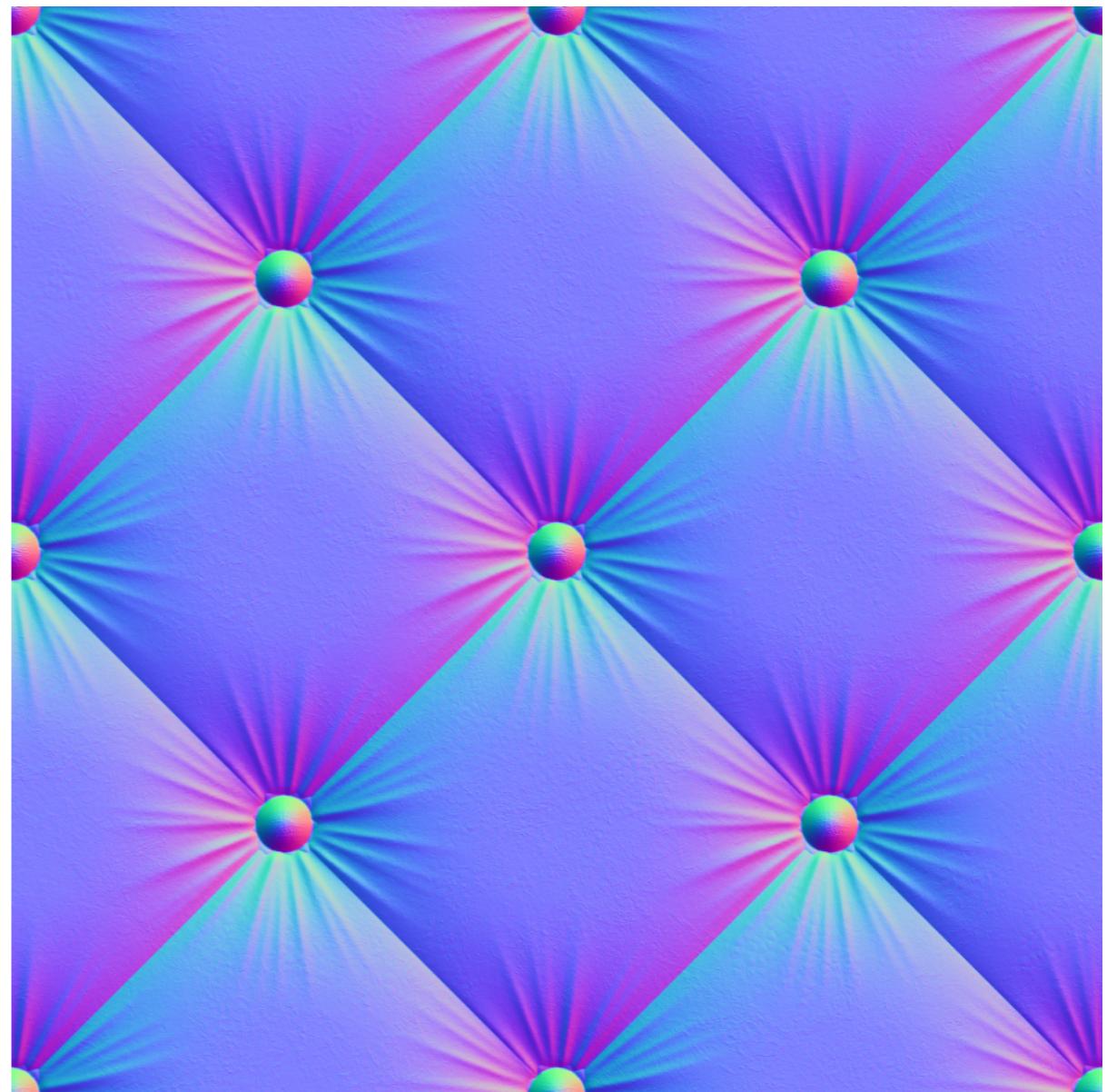
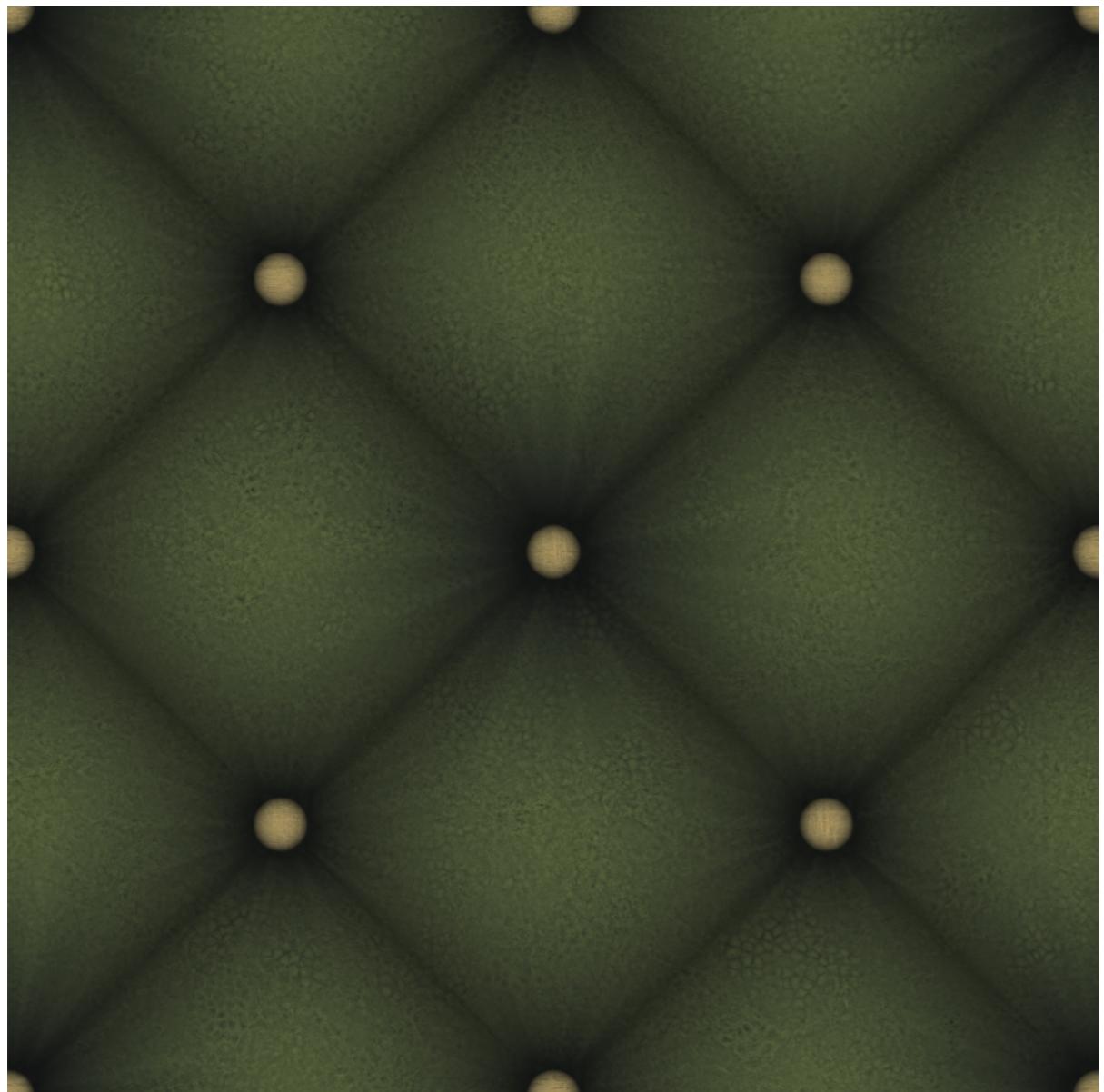
Specular Maps



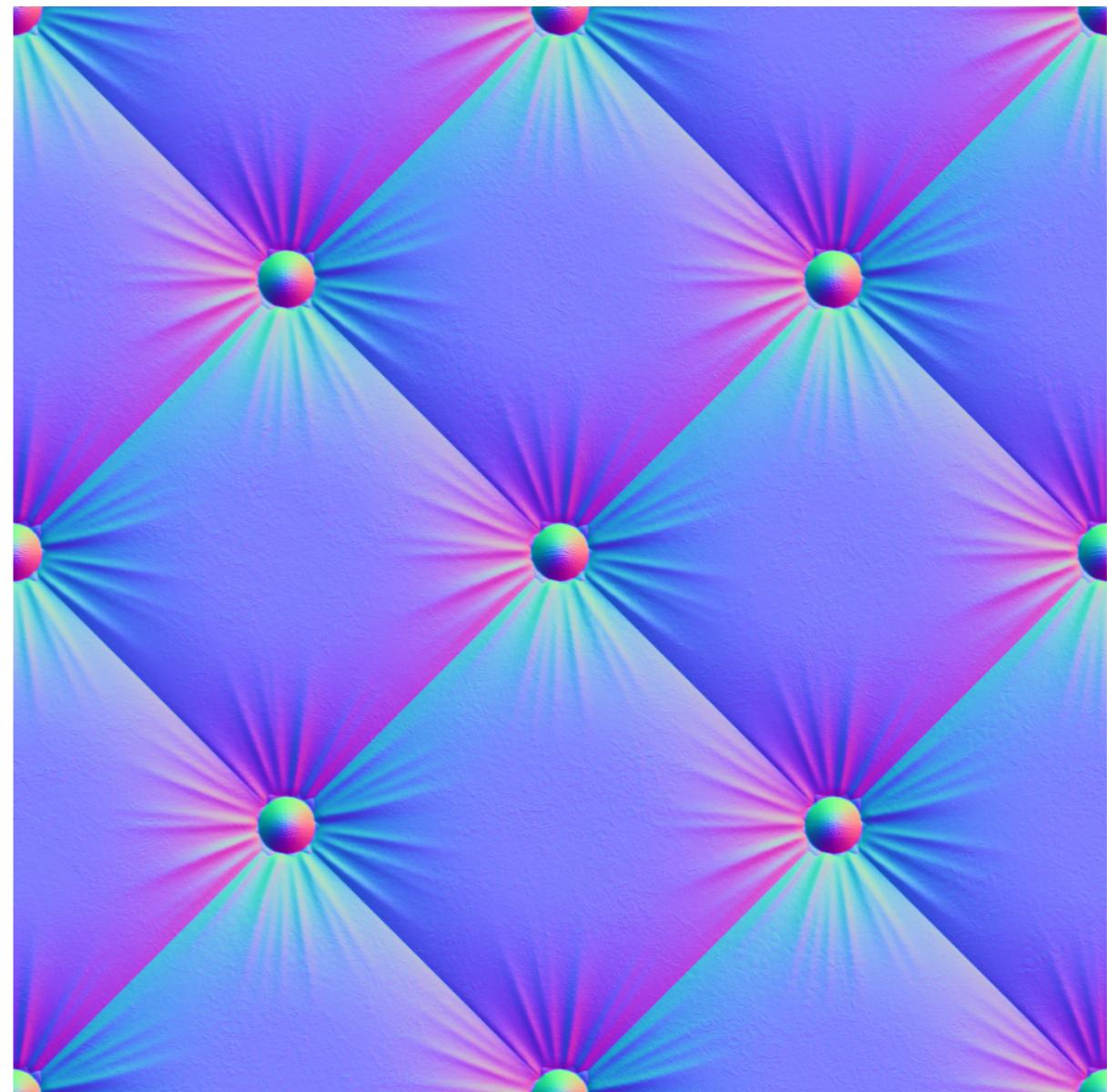
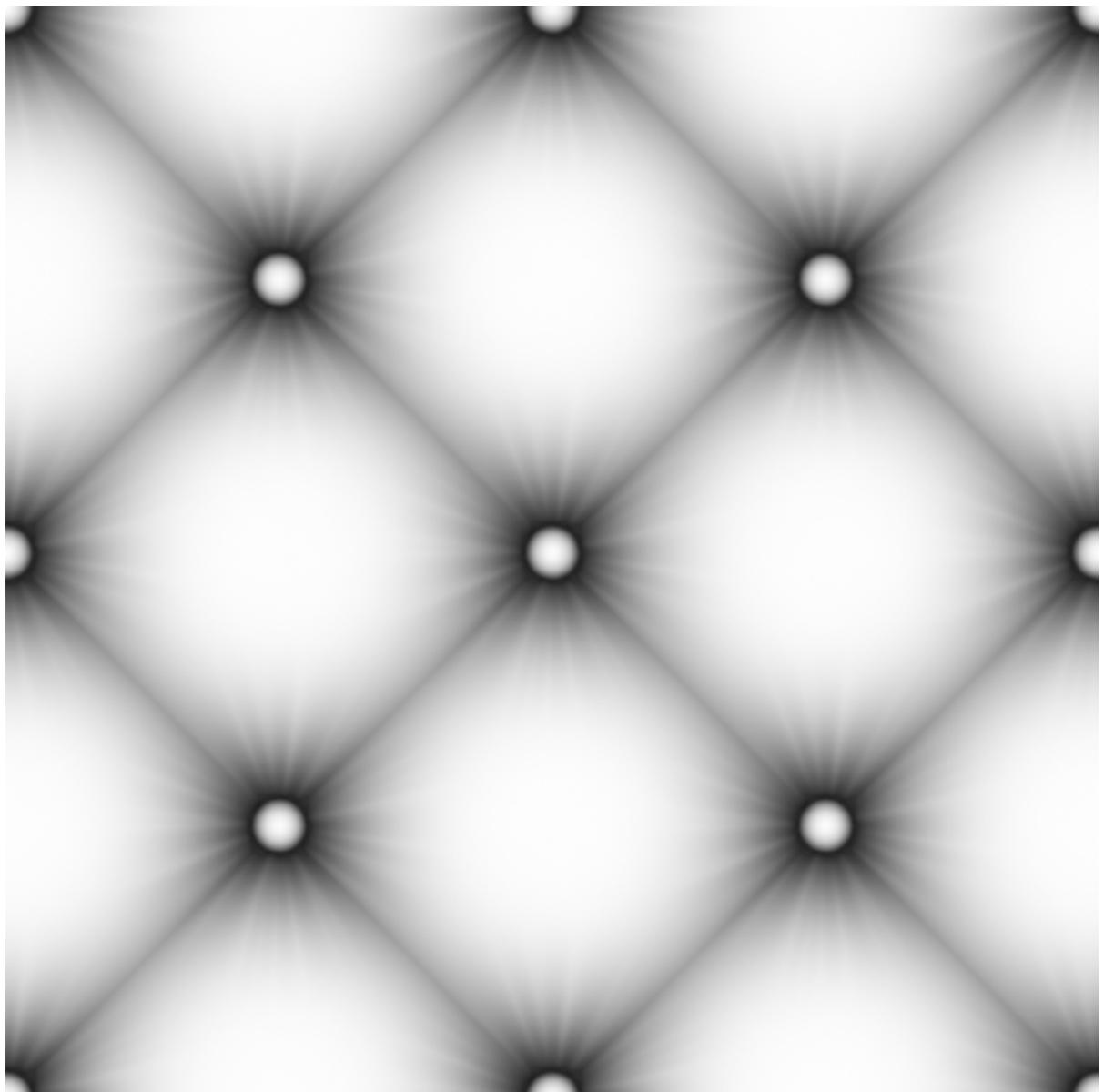
Specular Maps



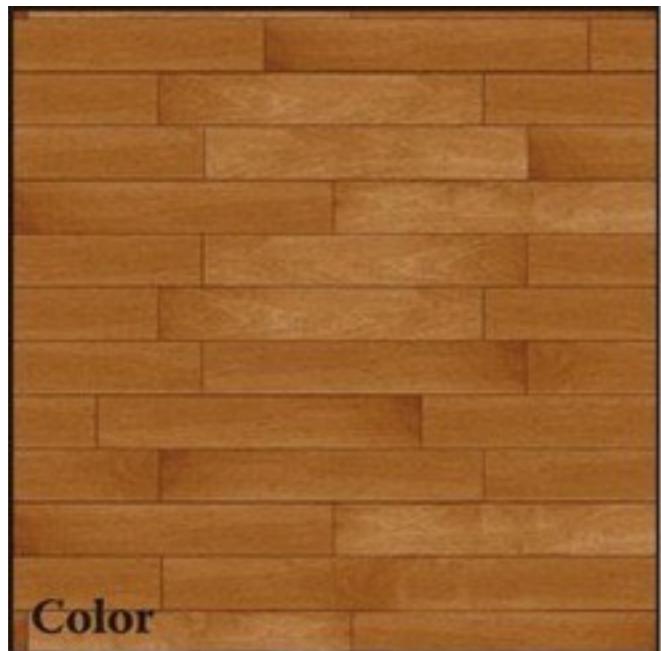
Normal Maps



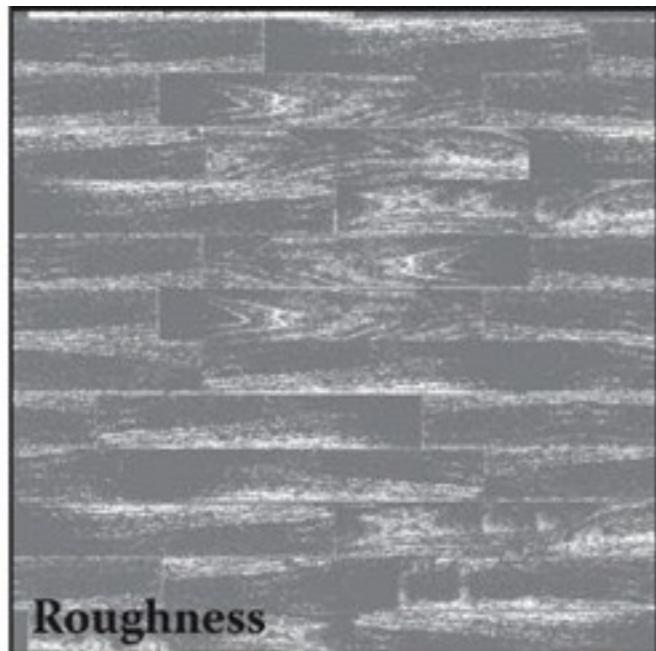
Bump Maps



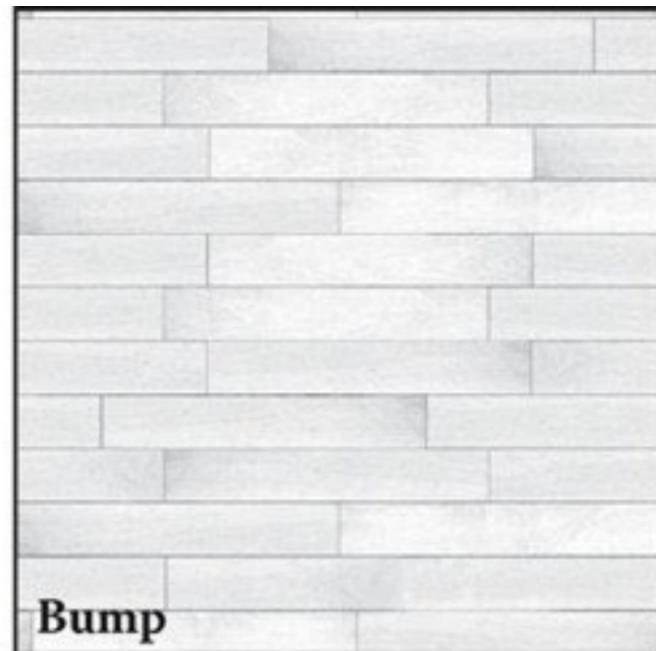
Bump Maps



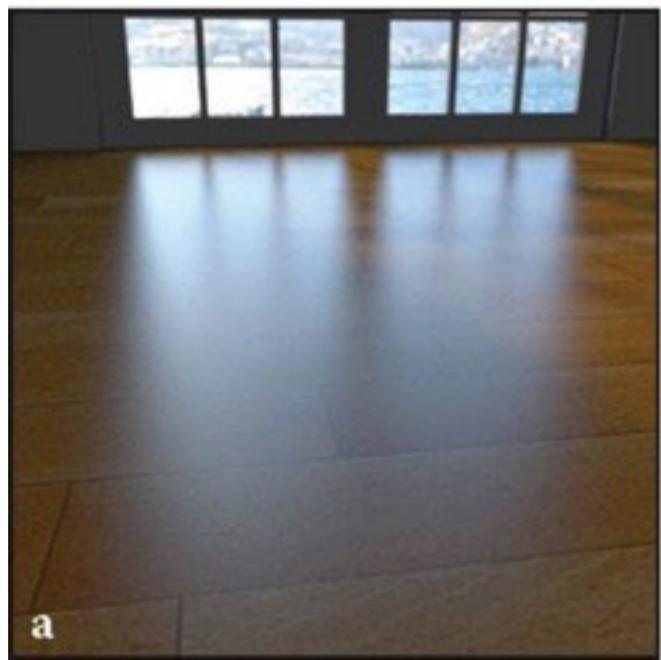
Color



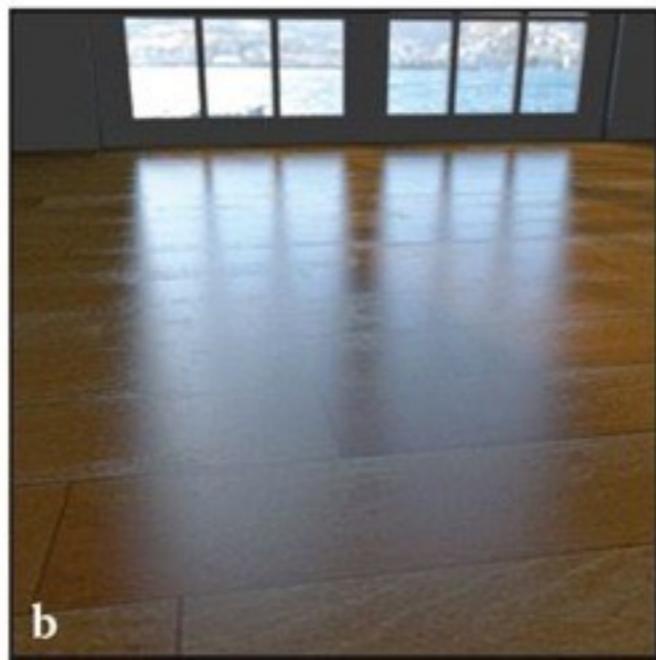
Roughness



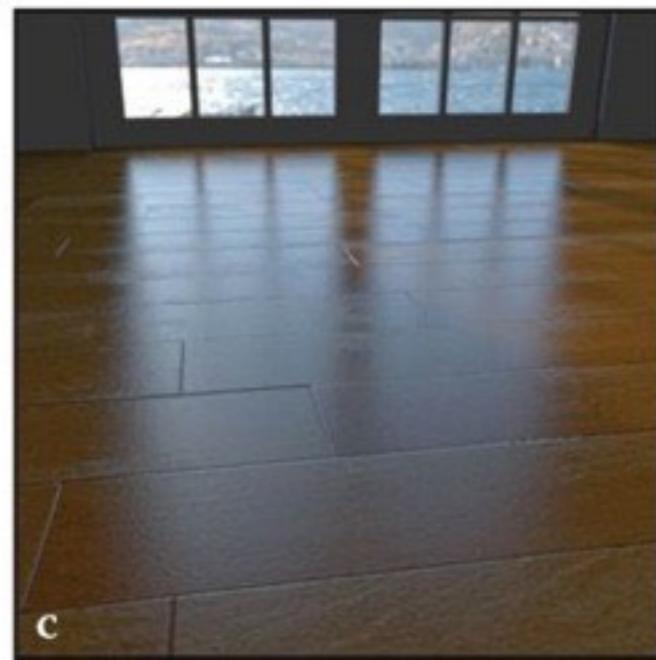
Bump



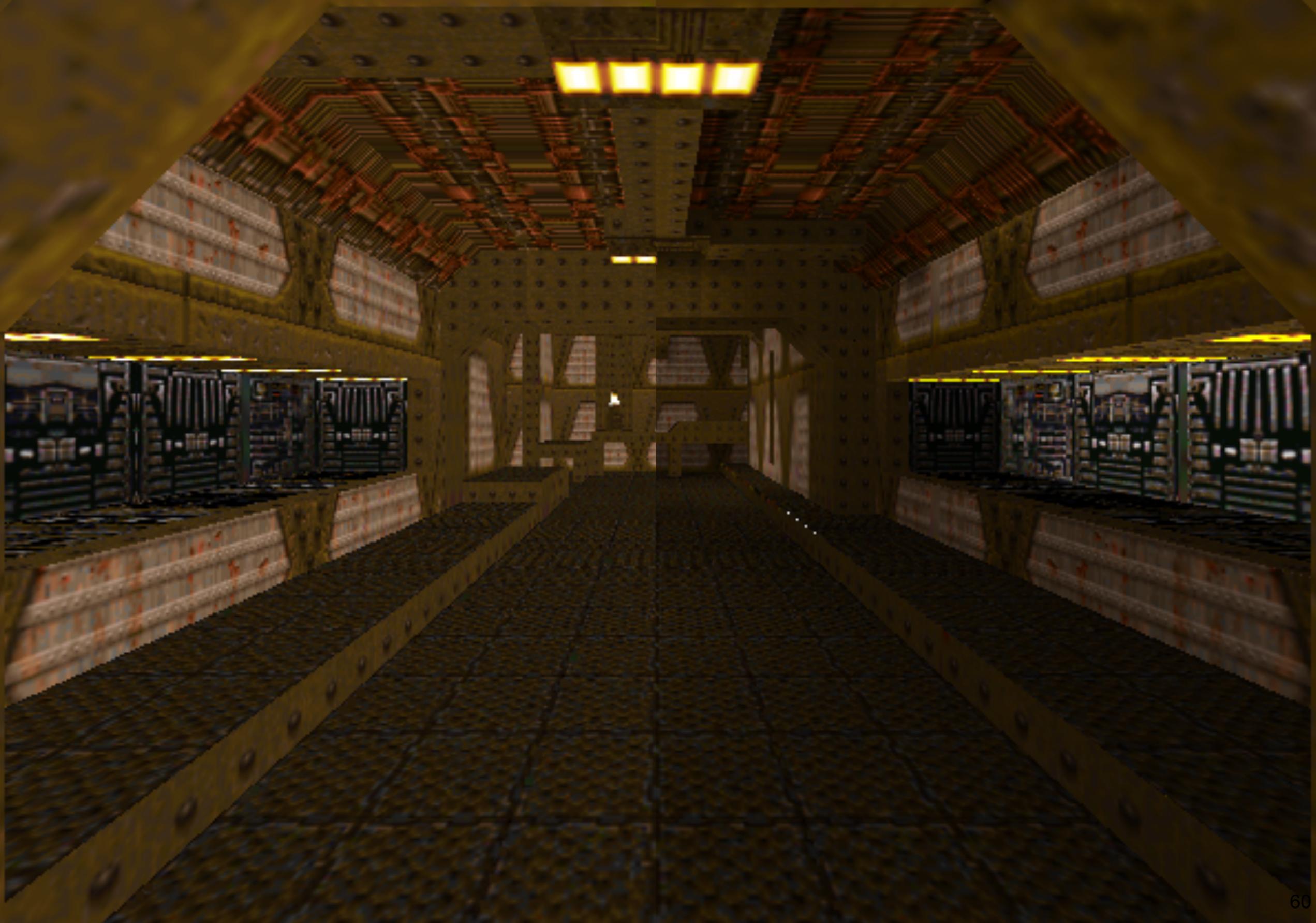
a



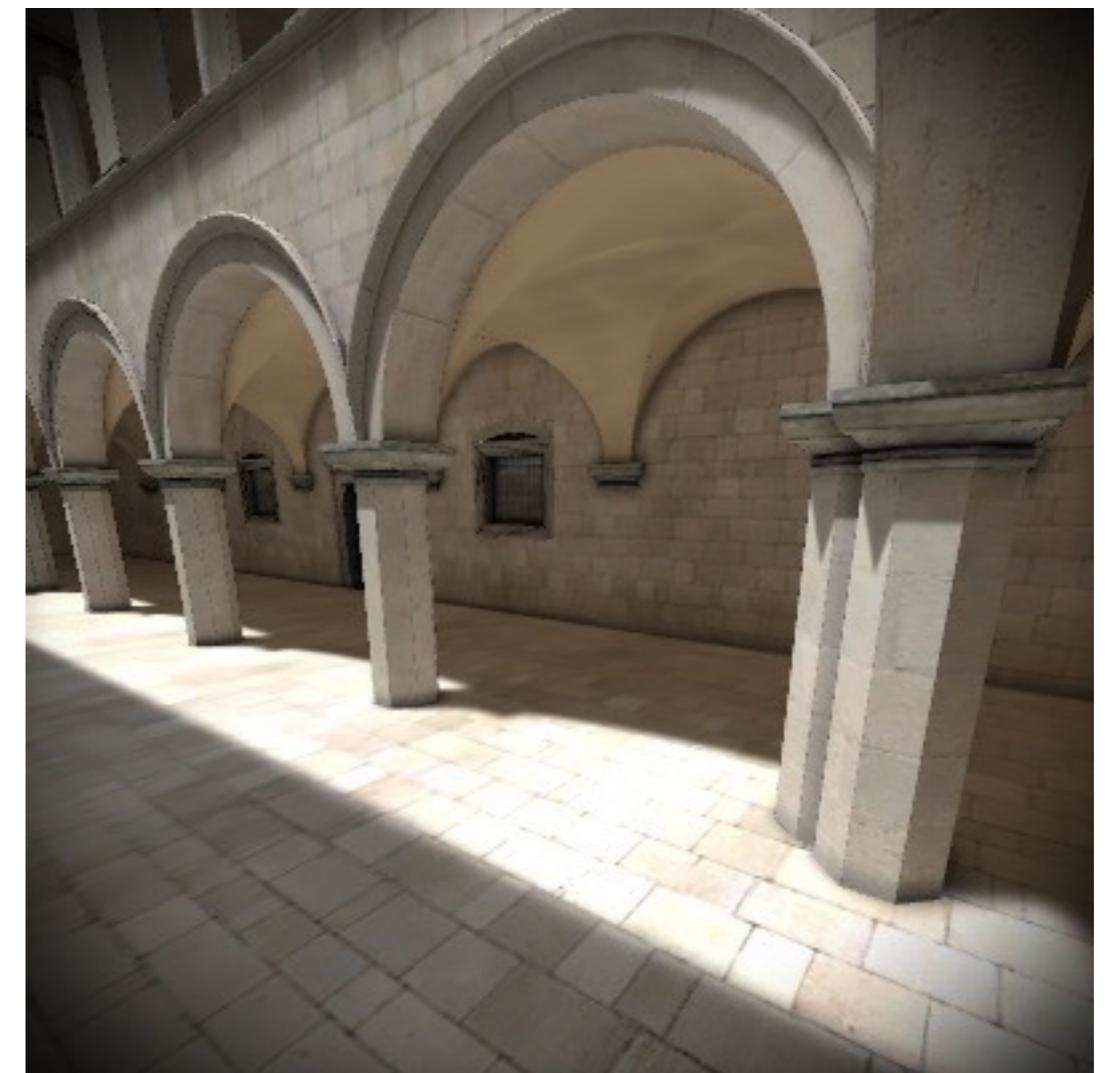
b

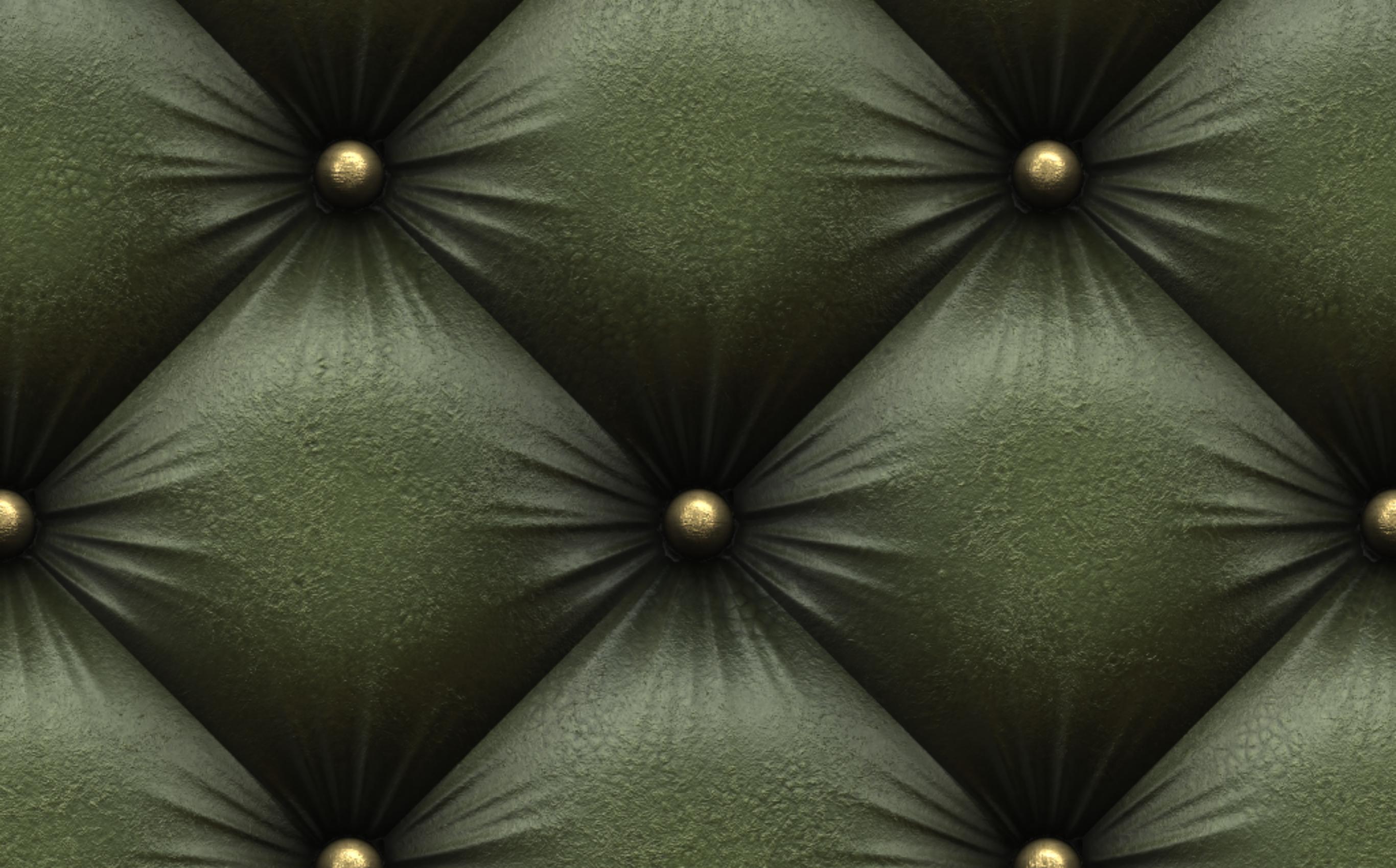


c

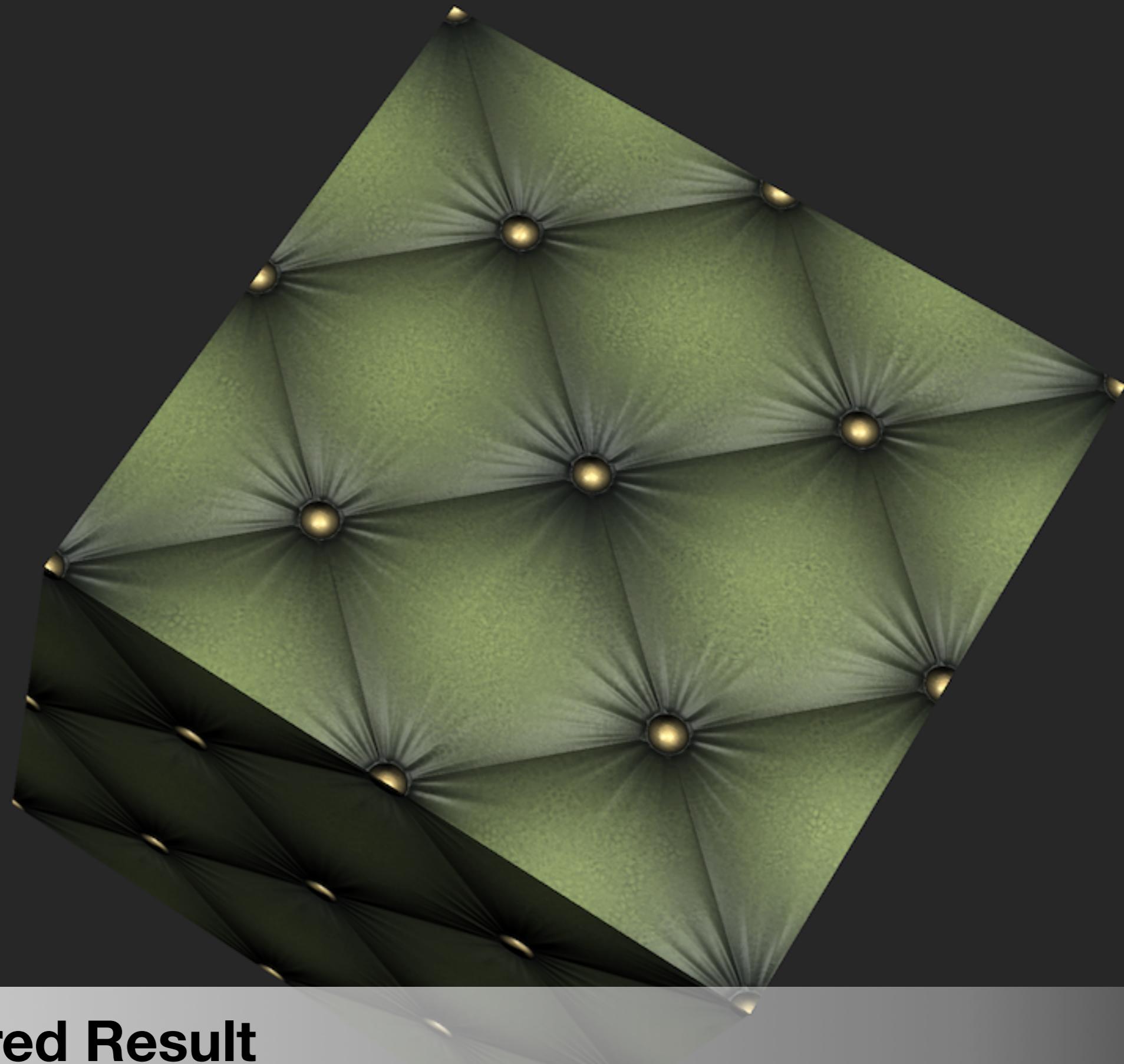


Light Maps





Rendered Result
Putting all the maps together...



Rendered Result
Oops, did we break the illusion?

Things to Remember

- Texture mapping involves defining a mapping function, sampling the image, and applying the texture values
- Mapping functions balance bijectivity, continuity, and minimizing distortion
- Interpolation and anti-aliasing play an important role in high-quality texture sampling
- Texture mapping can be used to modify any surface property that appears in our lighting equation!