CSE 168
Texturing

Wojciech Jarosz
May 6, 2008

Class Update

- Assignment 2 is due Thursday night.
  - Questions?
- Assignment 0 & 1 graded
- Assignment 3 will be posted shortly.

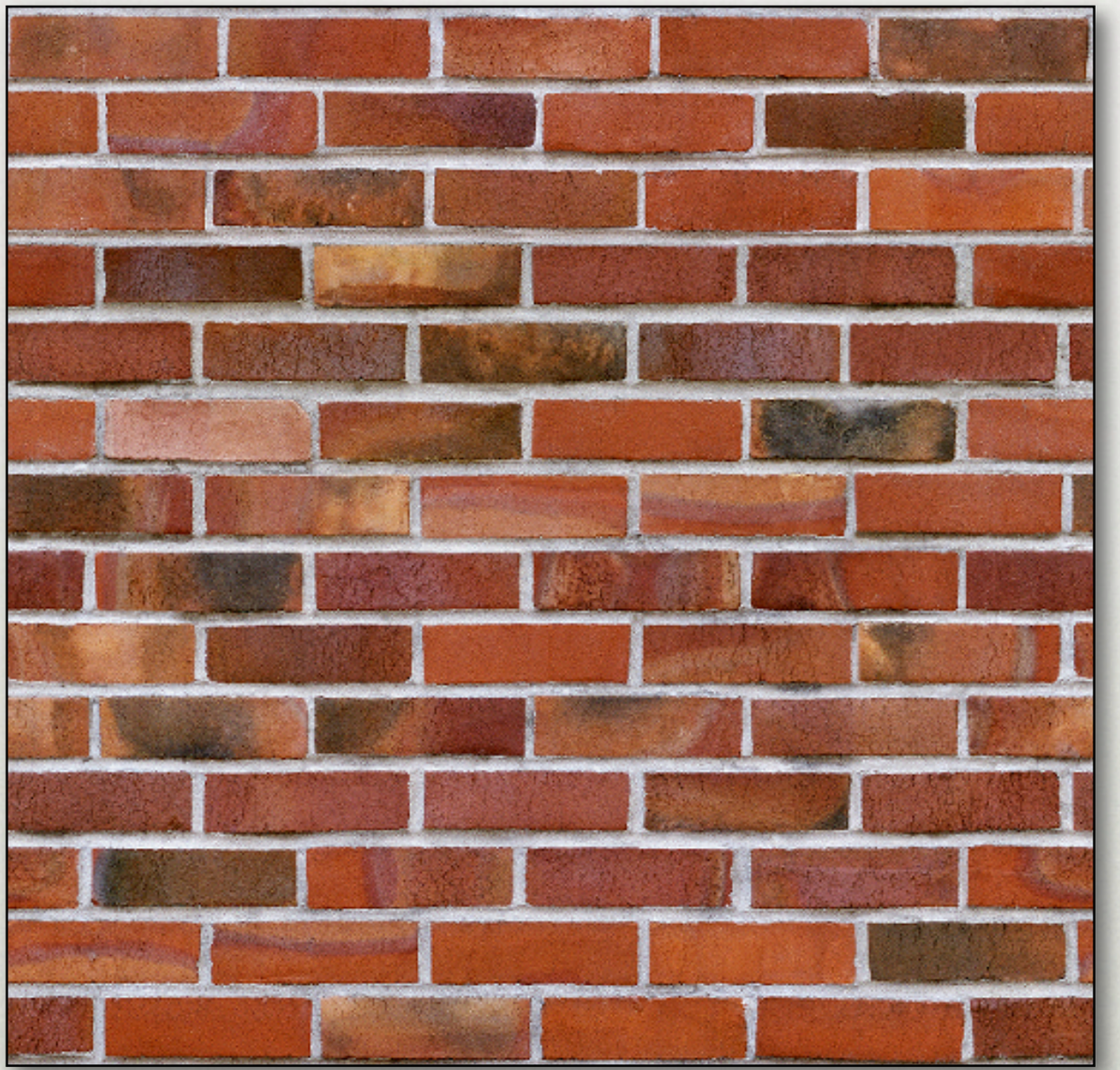
Today's Menu

- 2D texturing
- Environment mapping
- Procedural texturing

2D Texturing Mapping

Take a 2D texture and wrap it around an object

A Wall

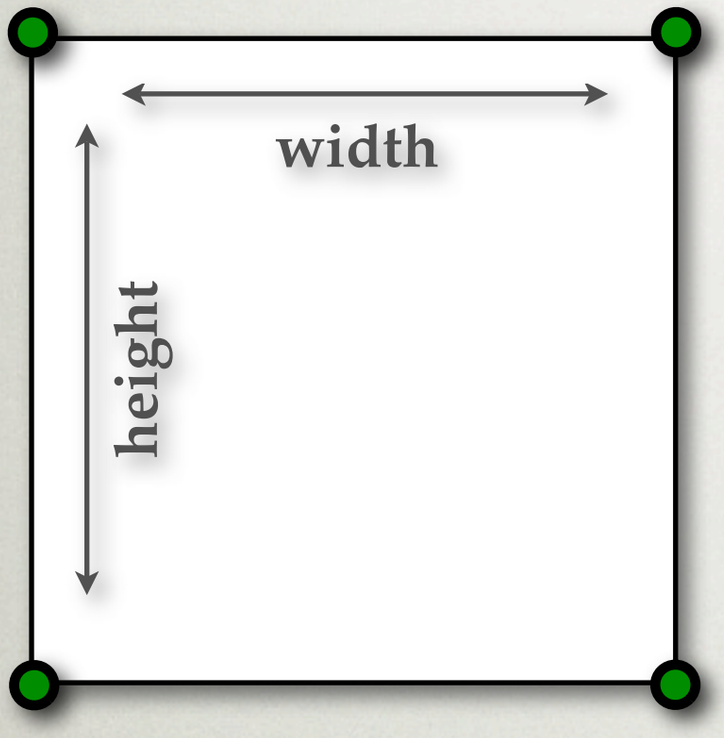


A Difficult Wall

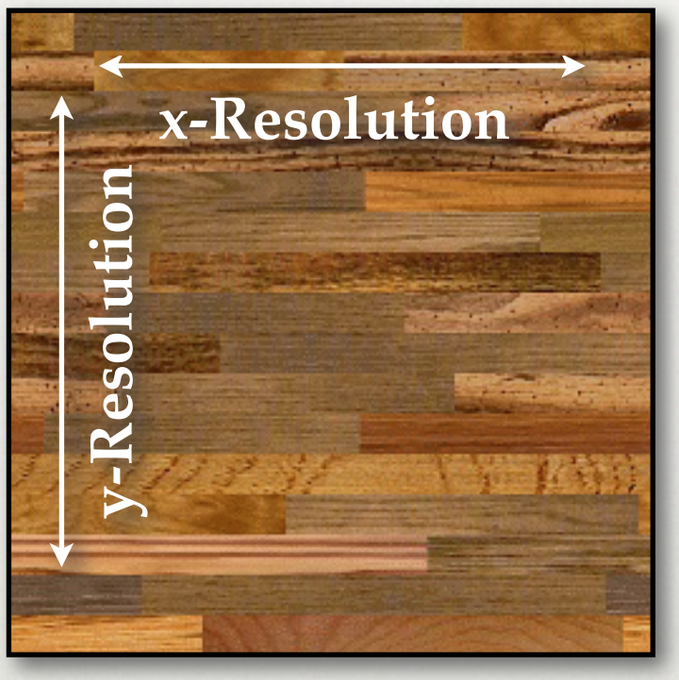
A Square

$$T(u,v) = I(x,y)$$

Texturing A Square



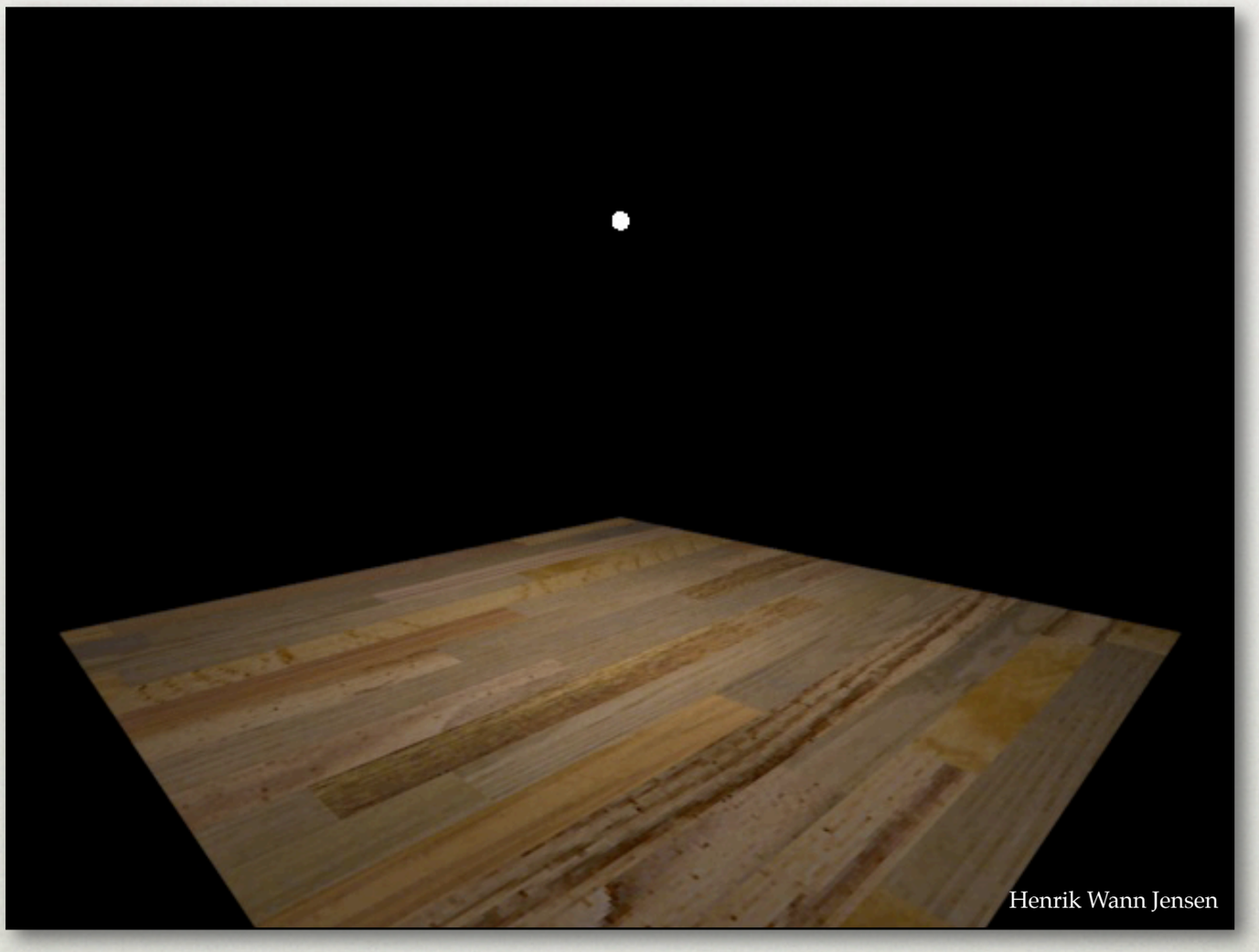
Object Space



Raster Space

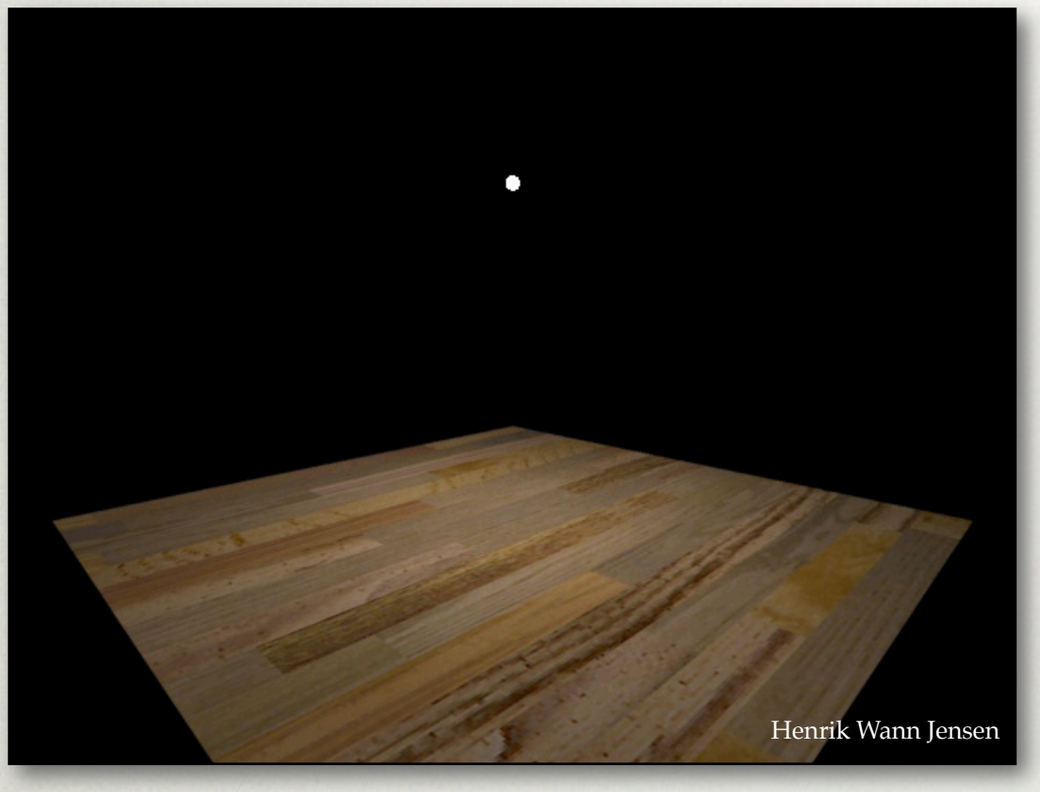
Object Space

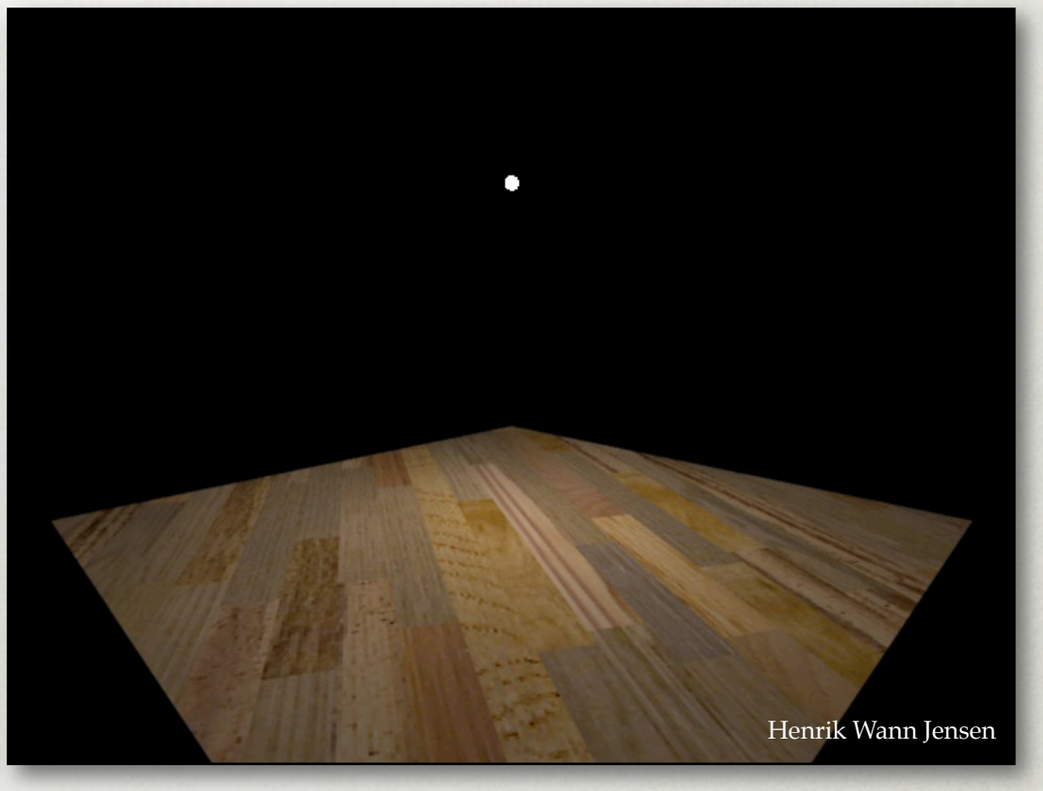
A Square



$$R_d = T(u,v)$$

Transformations



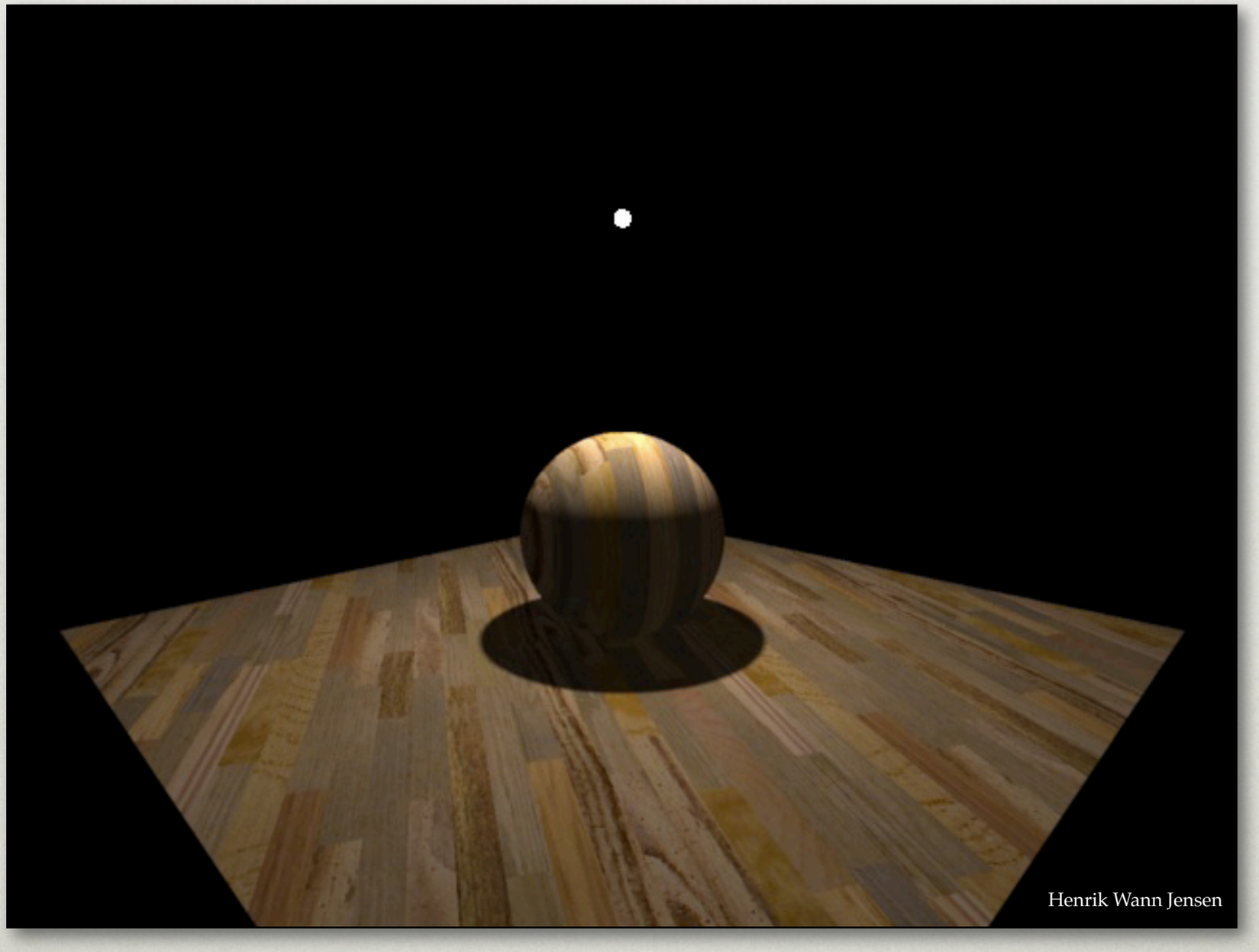


$$R_d = T(\text{transform}(u,v))$$

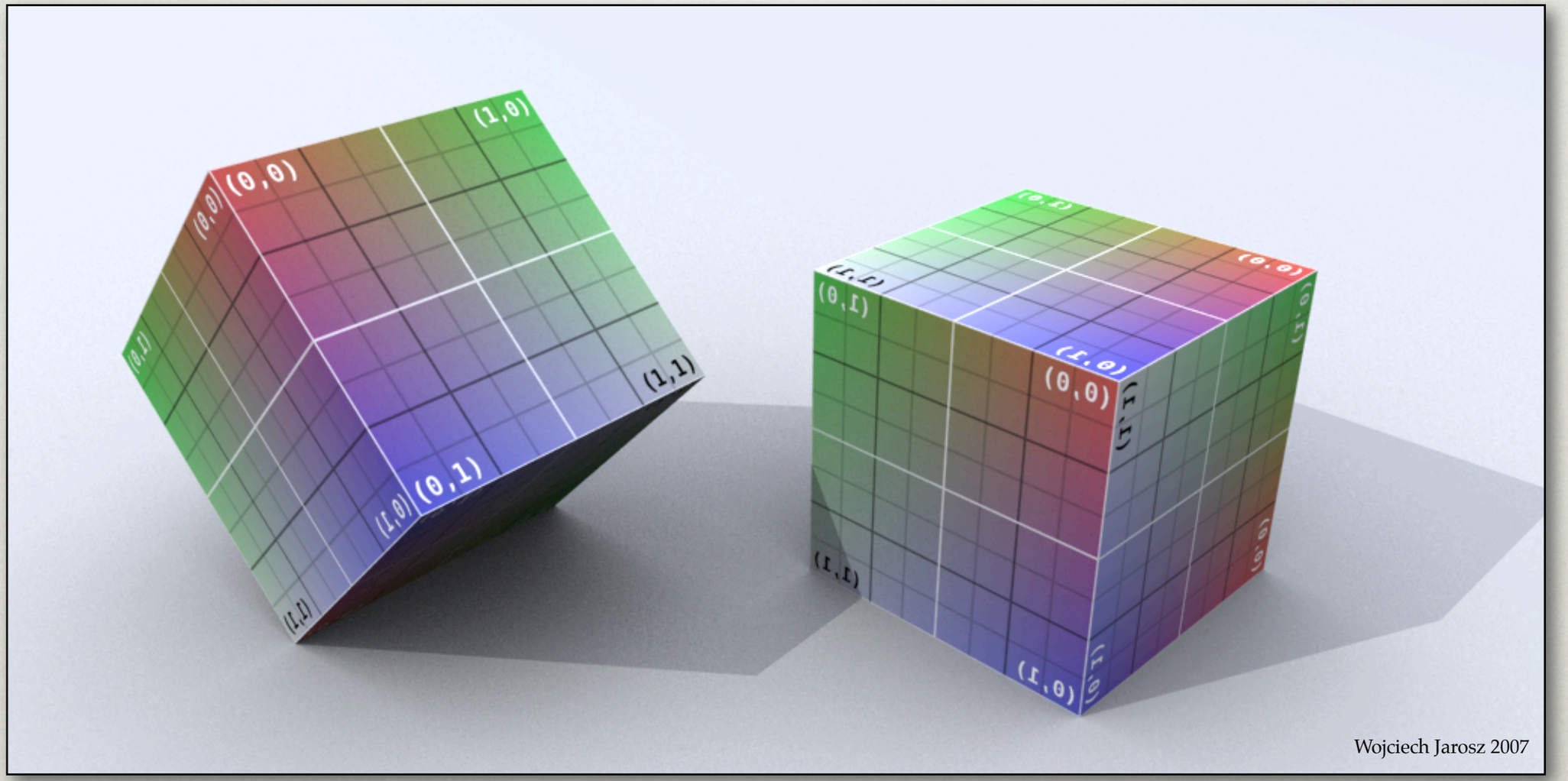
Mapping

- What if the object is not a square?
  - Need to determine mapping from 3D coordinates to 2D pixel coordinates.
    - Projection mapping
    - Parametric surfaces
    - Assigned UVs

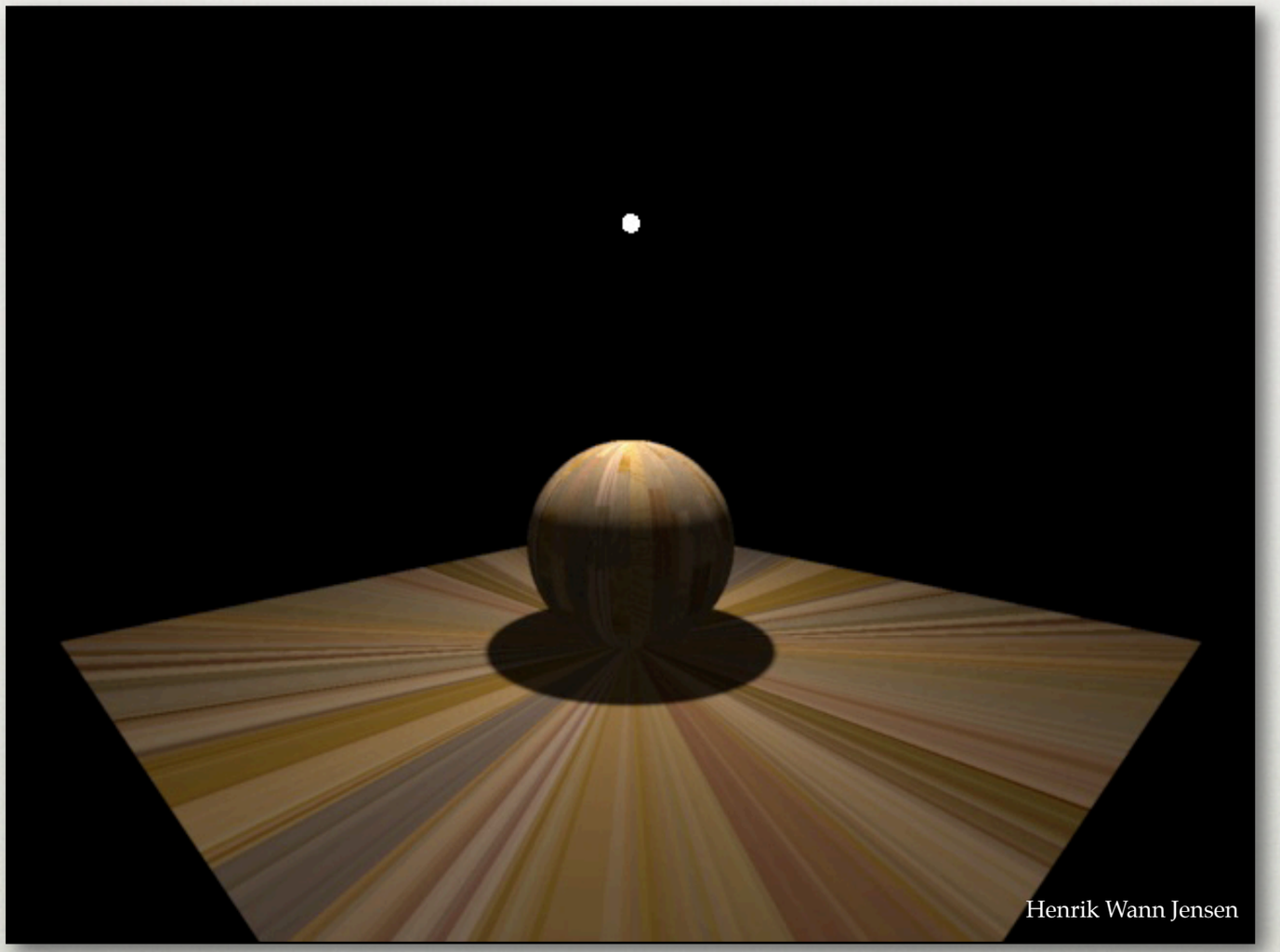
Planar Projection



Cubic Projection



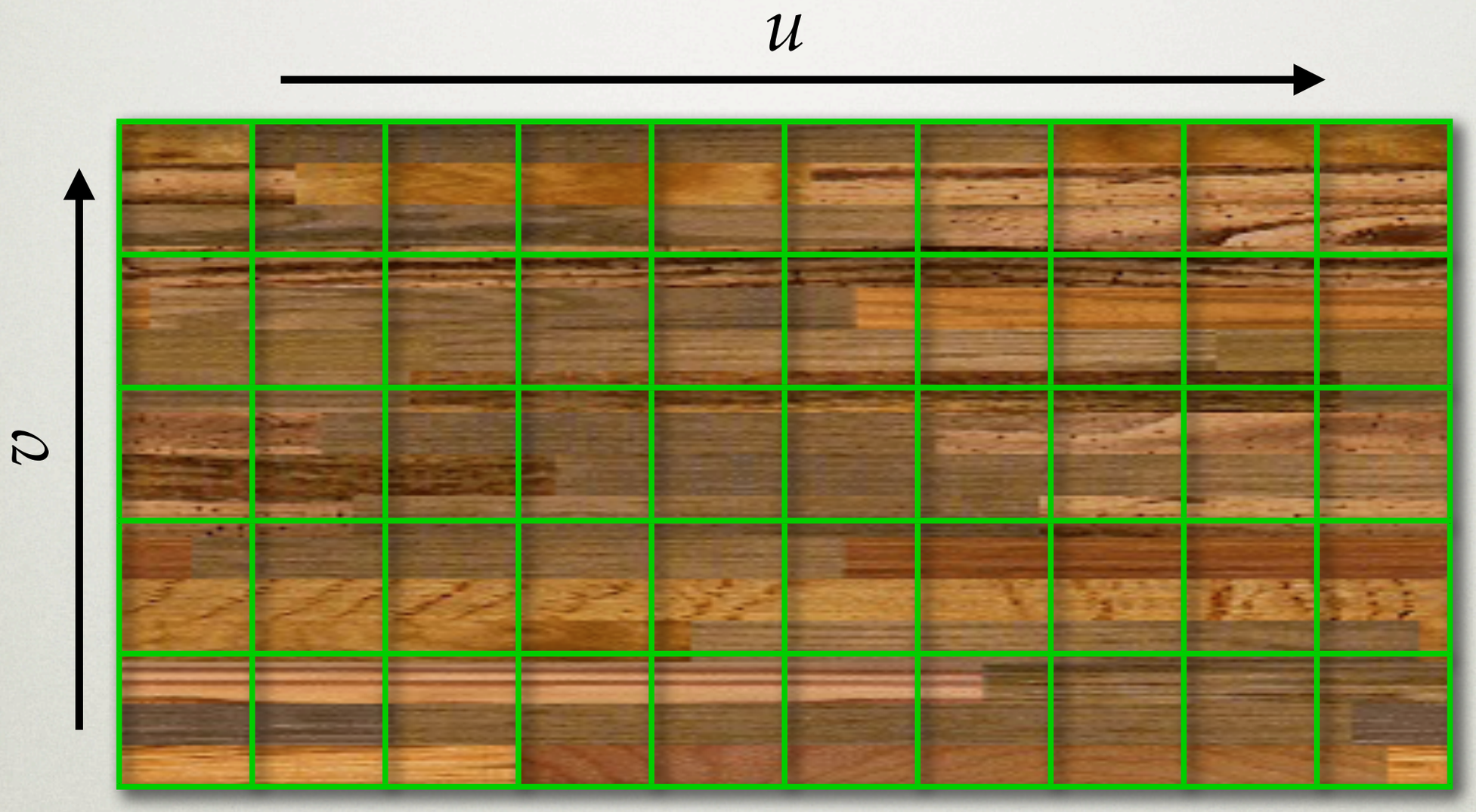
Spherical Projection



$$u = \mathrm{atan2}(y,x)/(2\pi)$$
$$v = \mathrm{acos}(z/\mathrm{sqrt}(x^2+y^2+z^2))/\pi$$

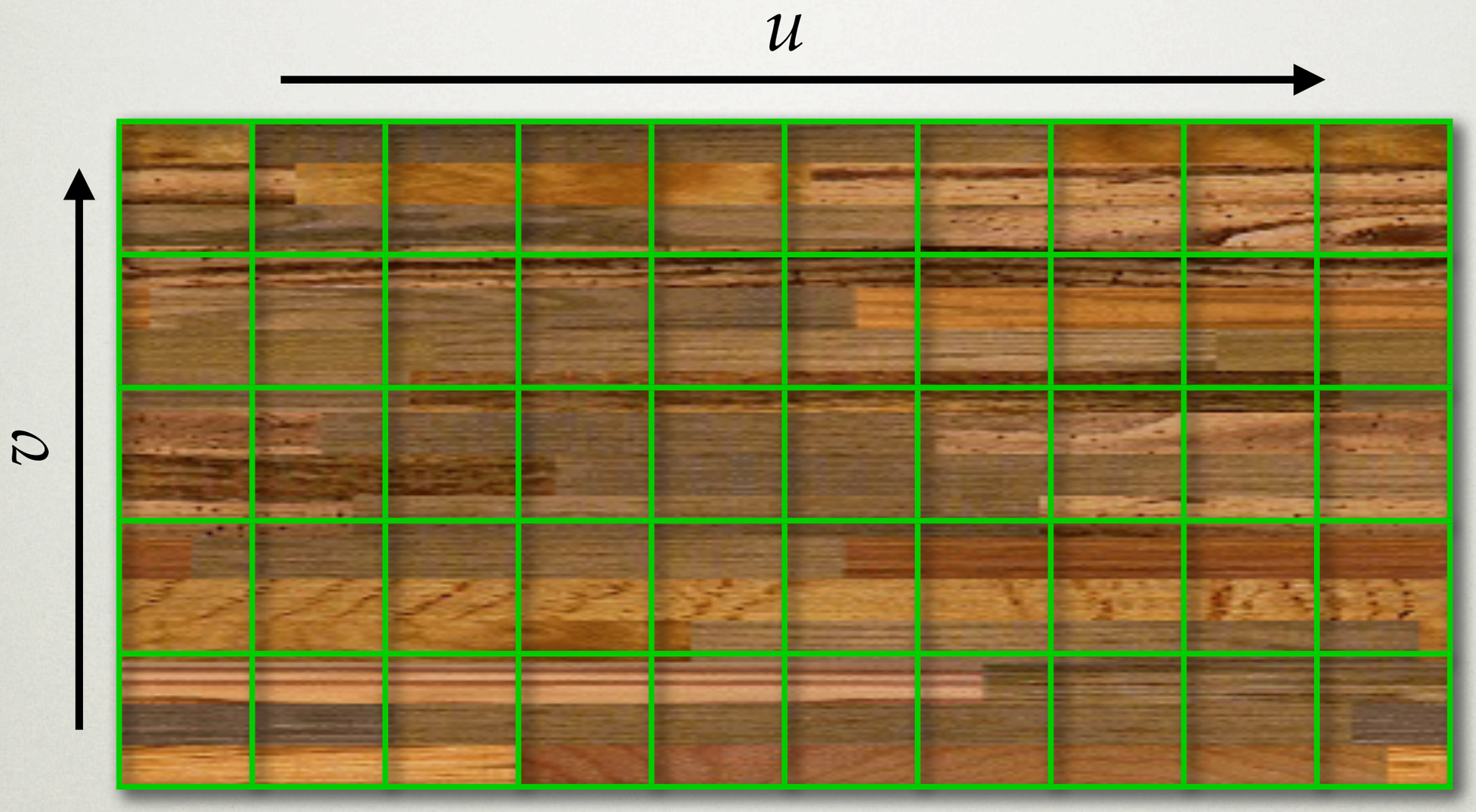
Spherical Projection

Spherical Projection



$$u = \text{atan2}(y, x) / (2\,\pi)$$
$$v = \text{acos}(z / \text{sqrt}(x^2+y^2+z^2)) / \pi$$

Cylindrical Projection

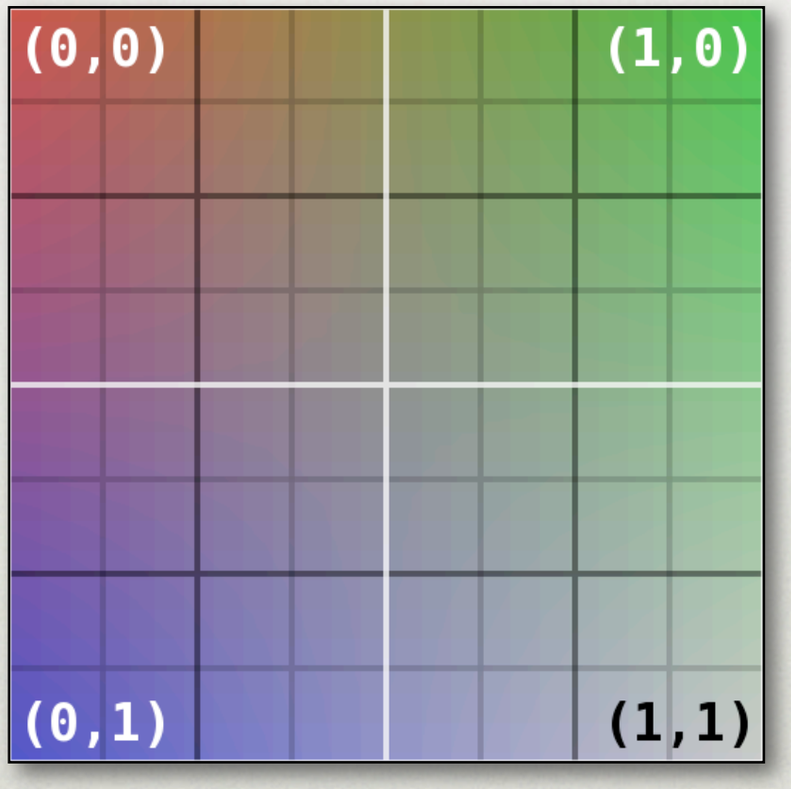


$$u = \text{atan2}(y, x) / (2\,\pi)$$

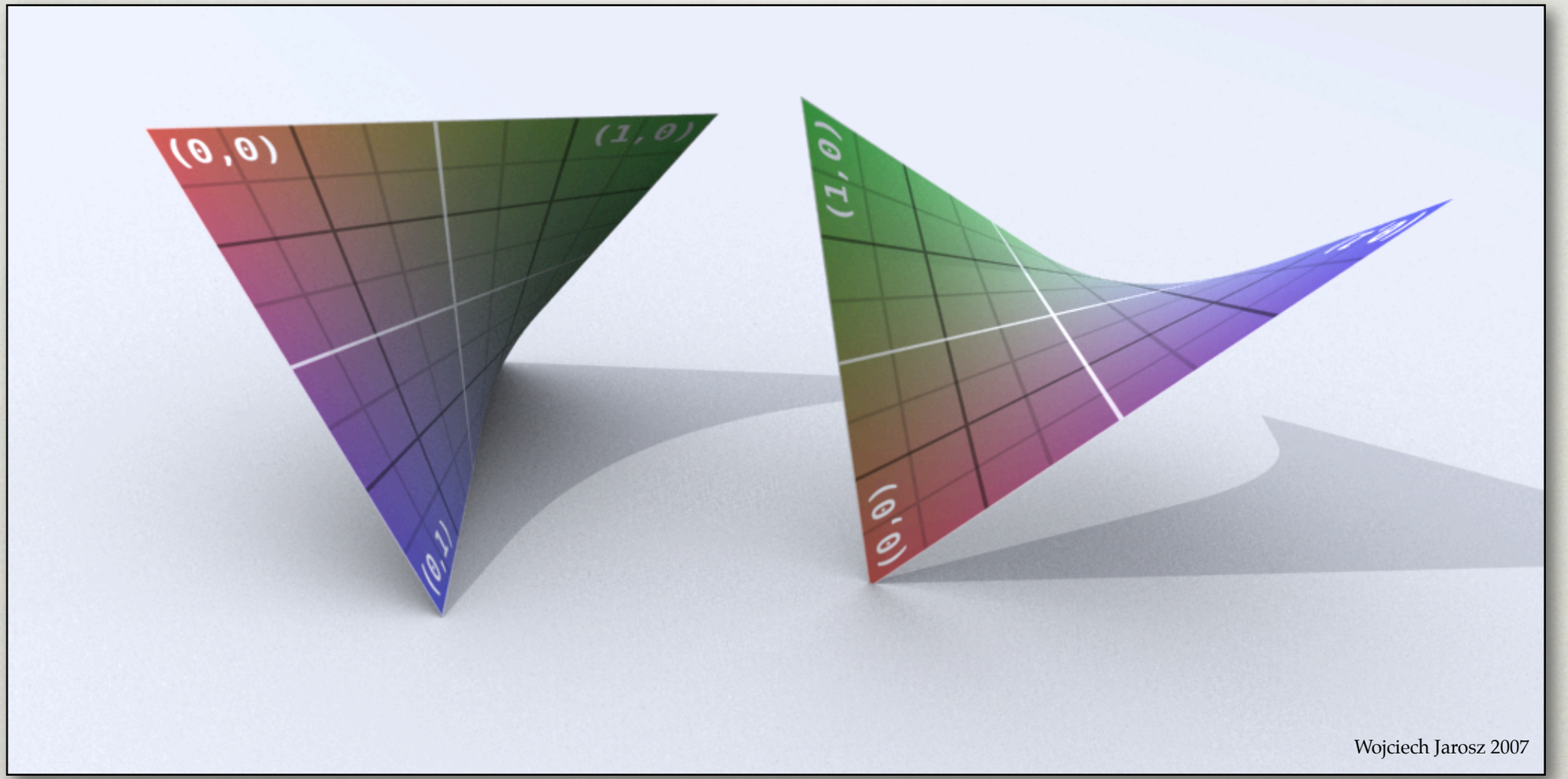
$$v = z$$

Parametric Surfaces

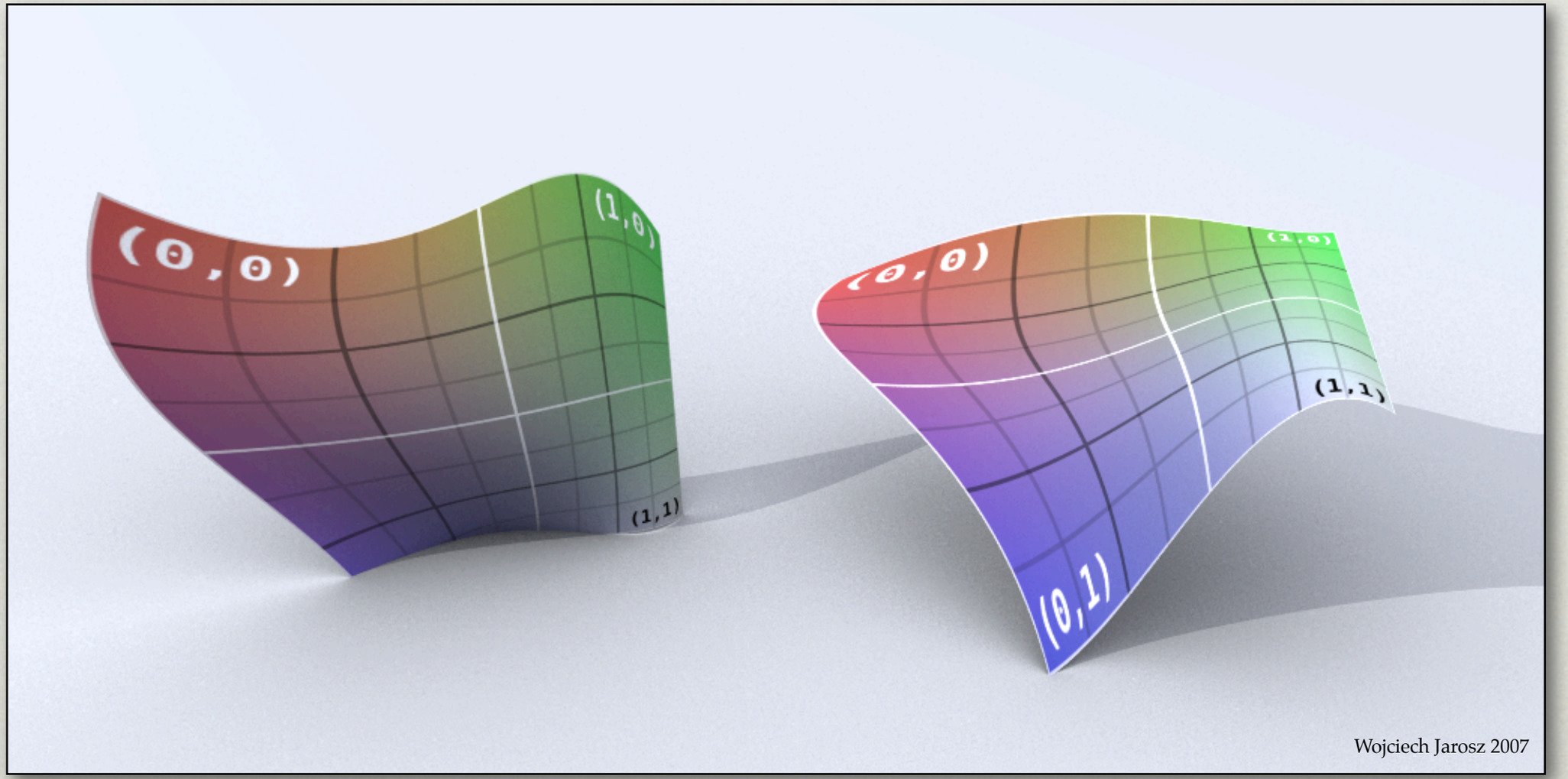
- Parametric surfaces have a natural 2D coordinate system.



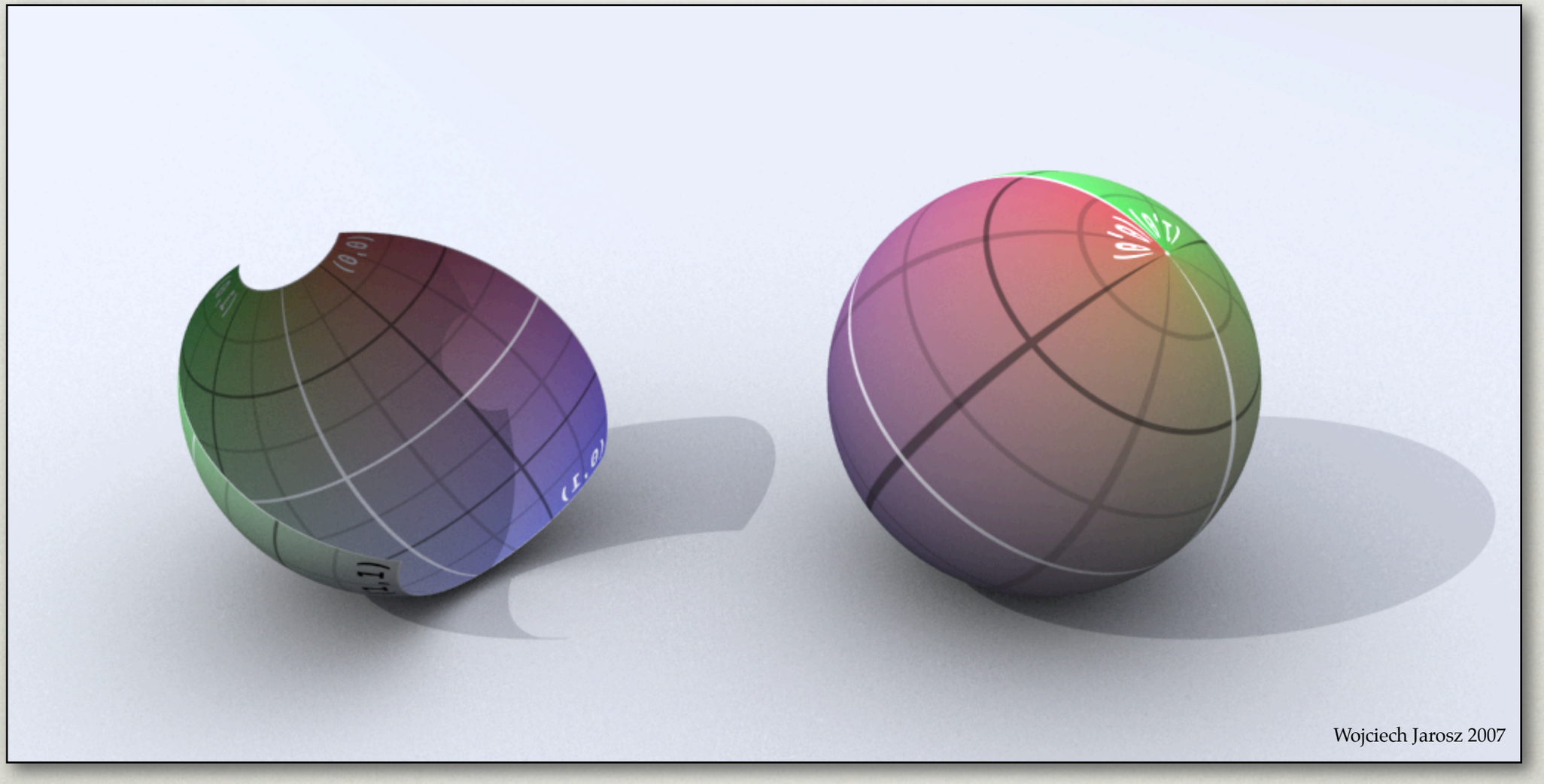
Bilinear patches



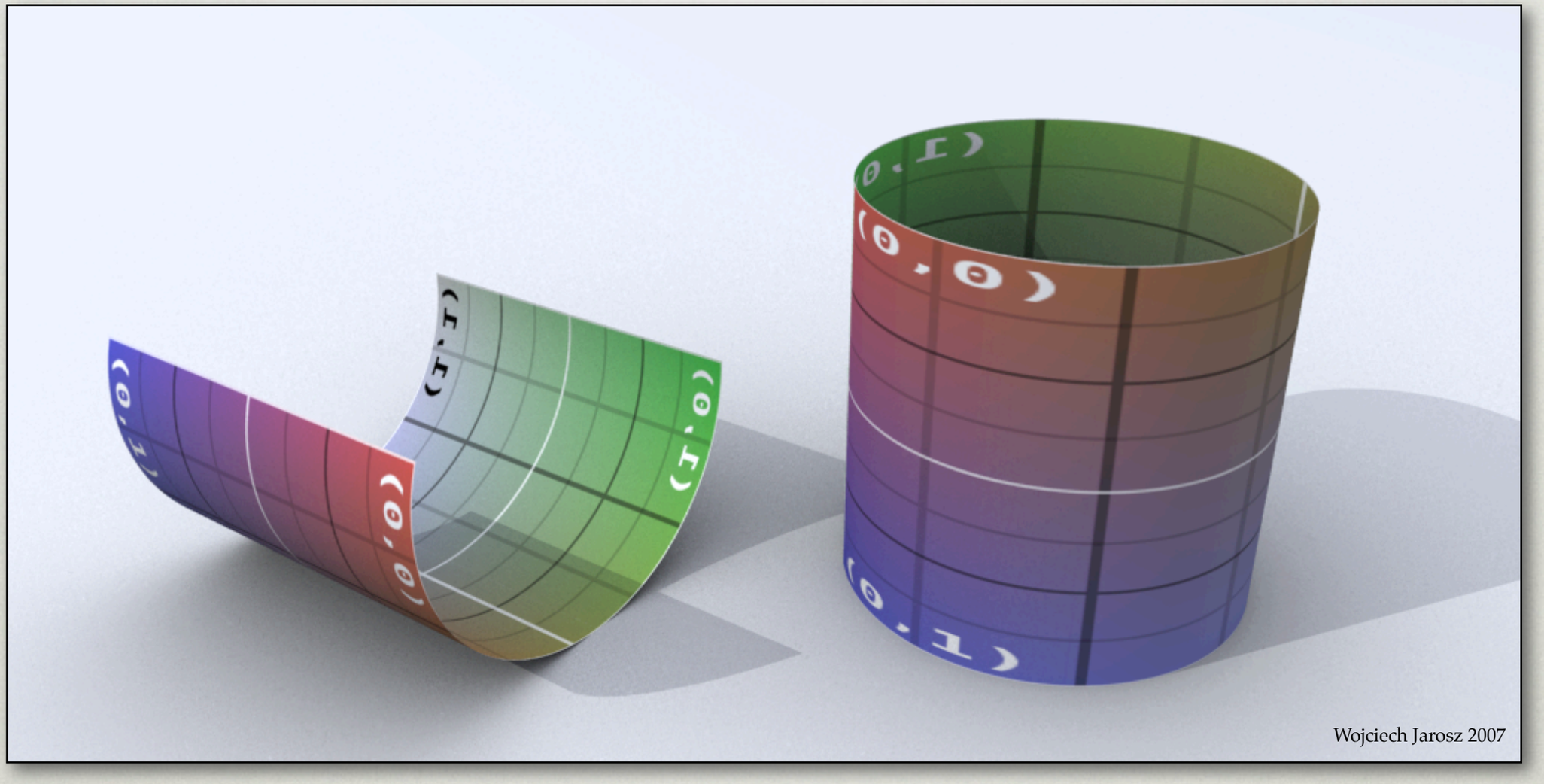
Bicubic patches



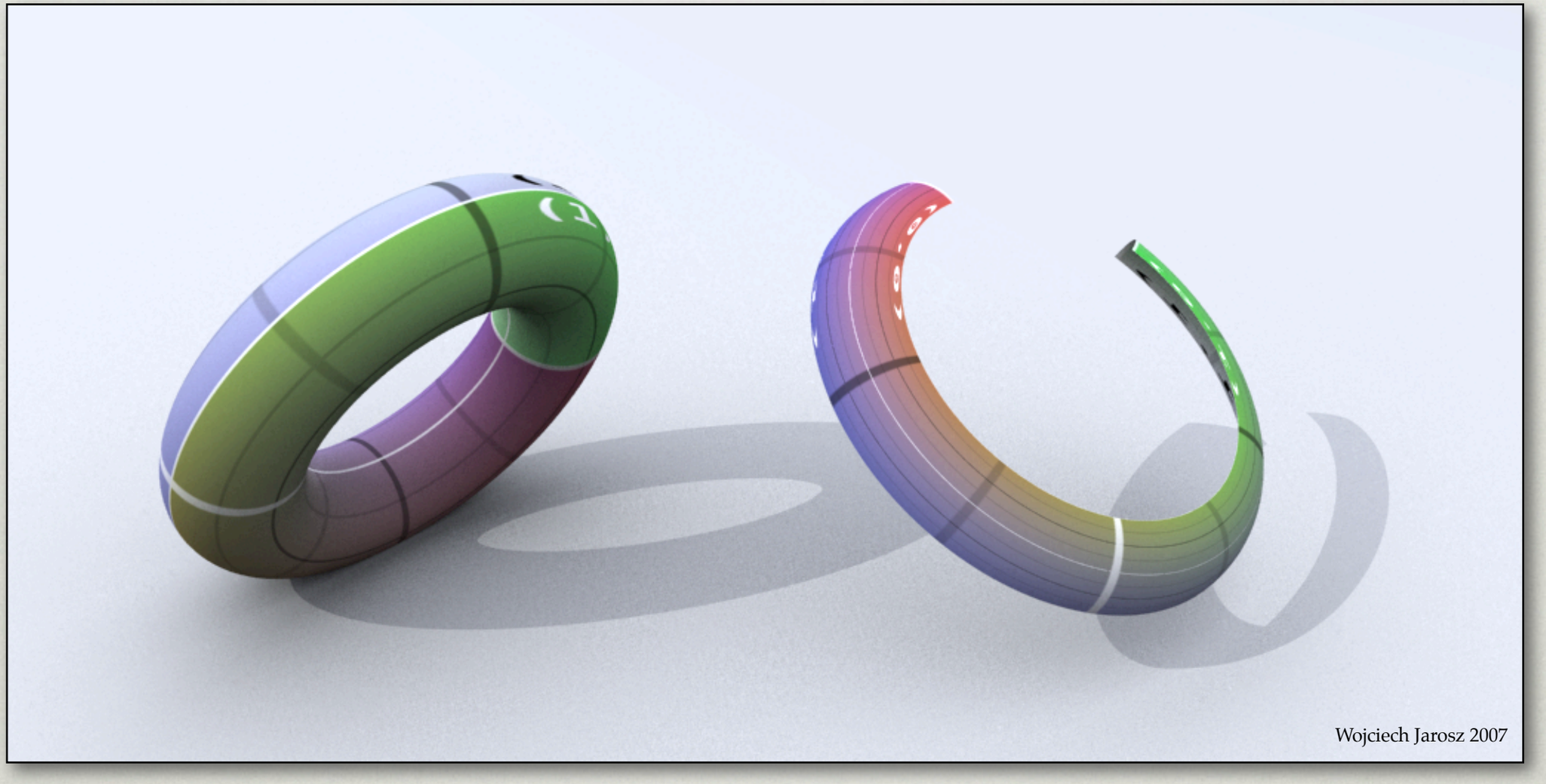
Spheres



Cylinders



Toruses



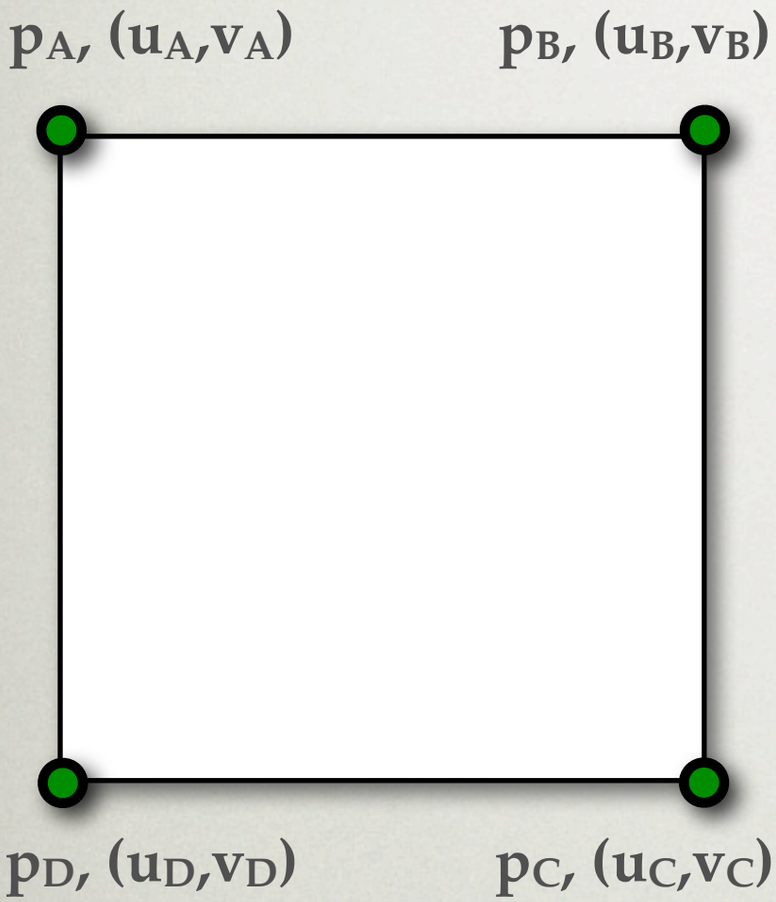
UV Texturing

- Assign UV coordinates at vertices.
- Interpolate using bilinear or barycentric interpolation.

$$(u,v) = lerp(lerp((u_A,v_A), (u_B,v_B), s), lerp((u_C,v_C), (u_D,v_D), s), t)$$

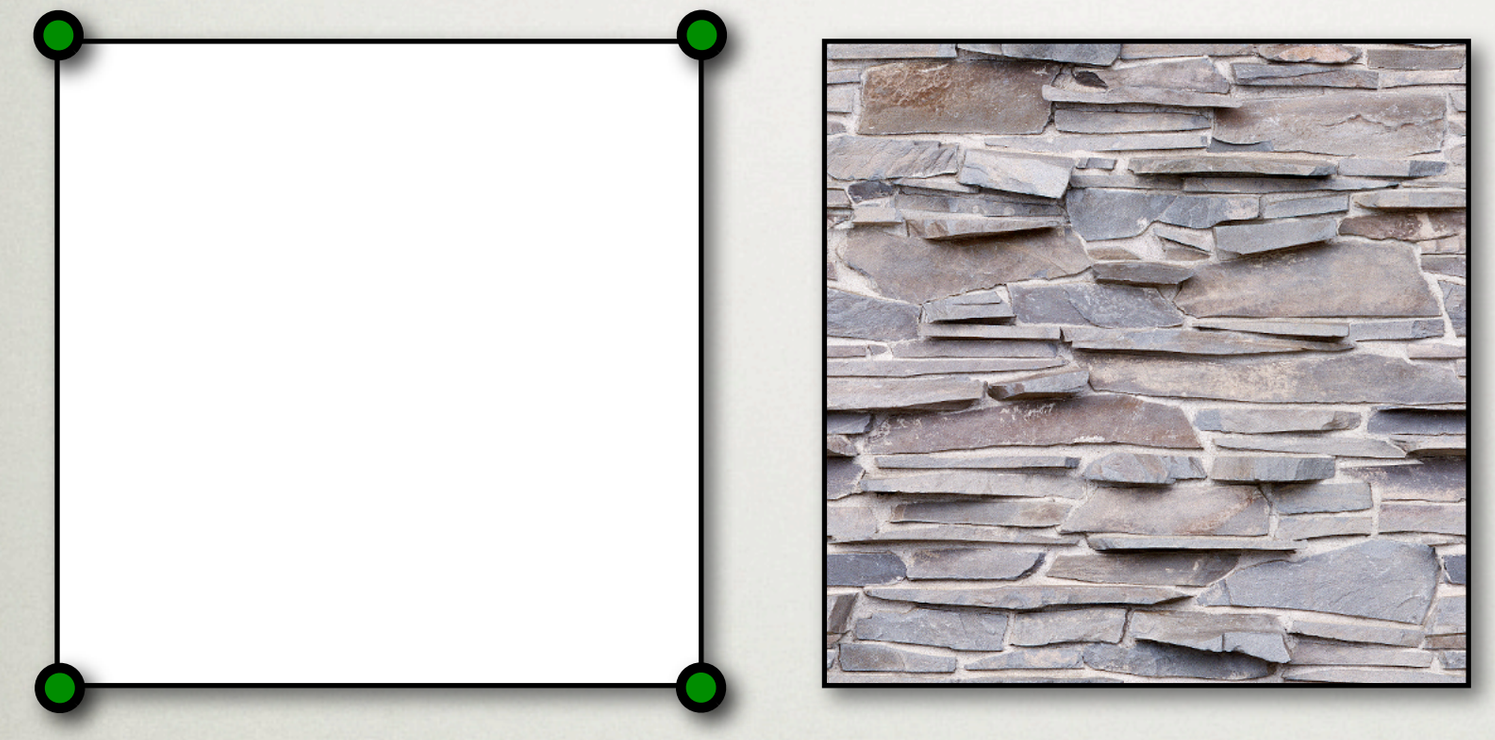
$$(u,v) = \alpha(u_A,v_A) + \beta(u_B,v_B) + \gamma(u_C,v_C)$$

Texture Coordinates



Object Space

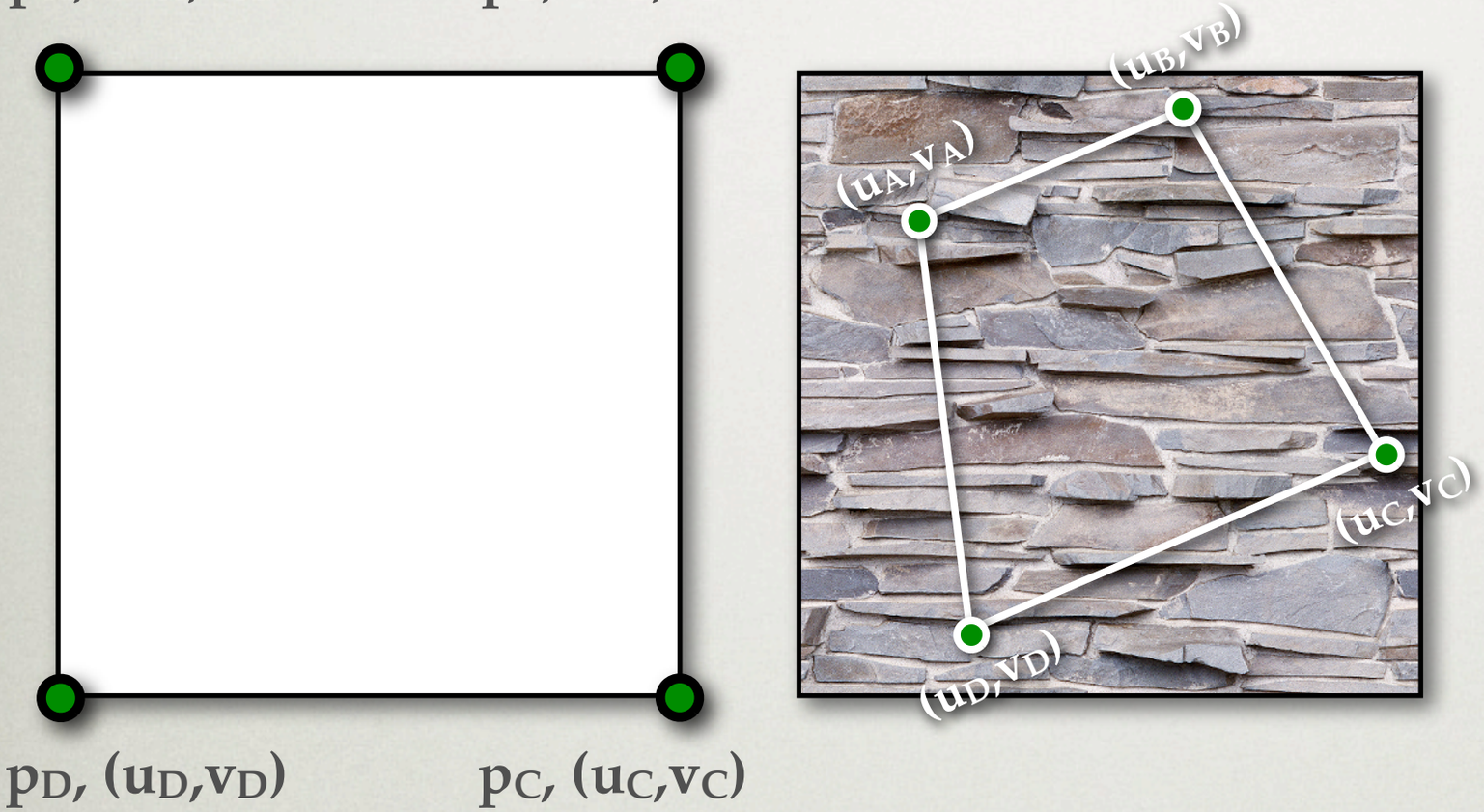
Texture Coordinates



Object Space

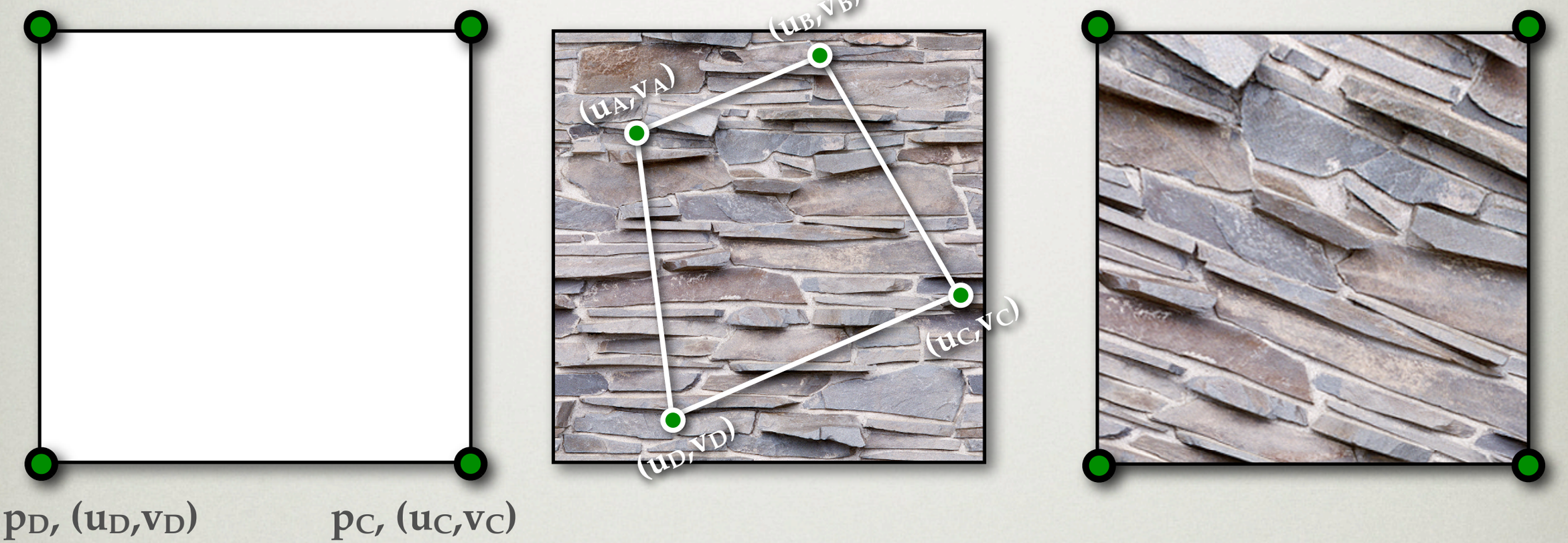
Texture Space

Texture Coordinates



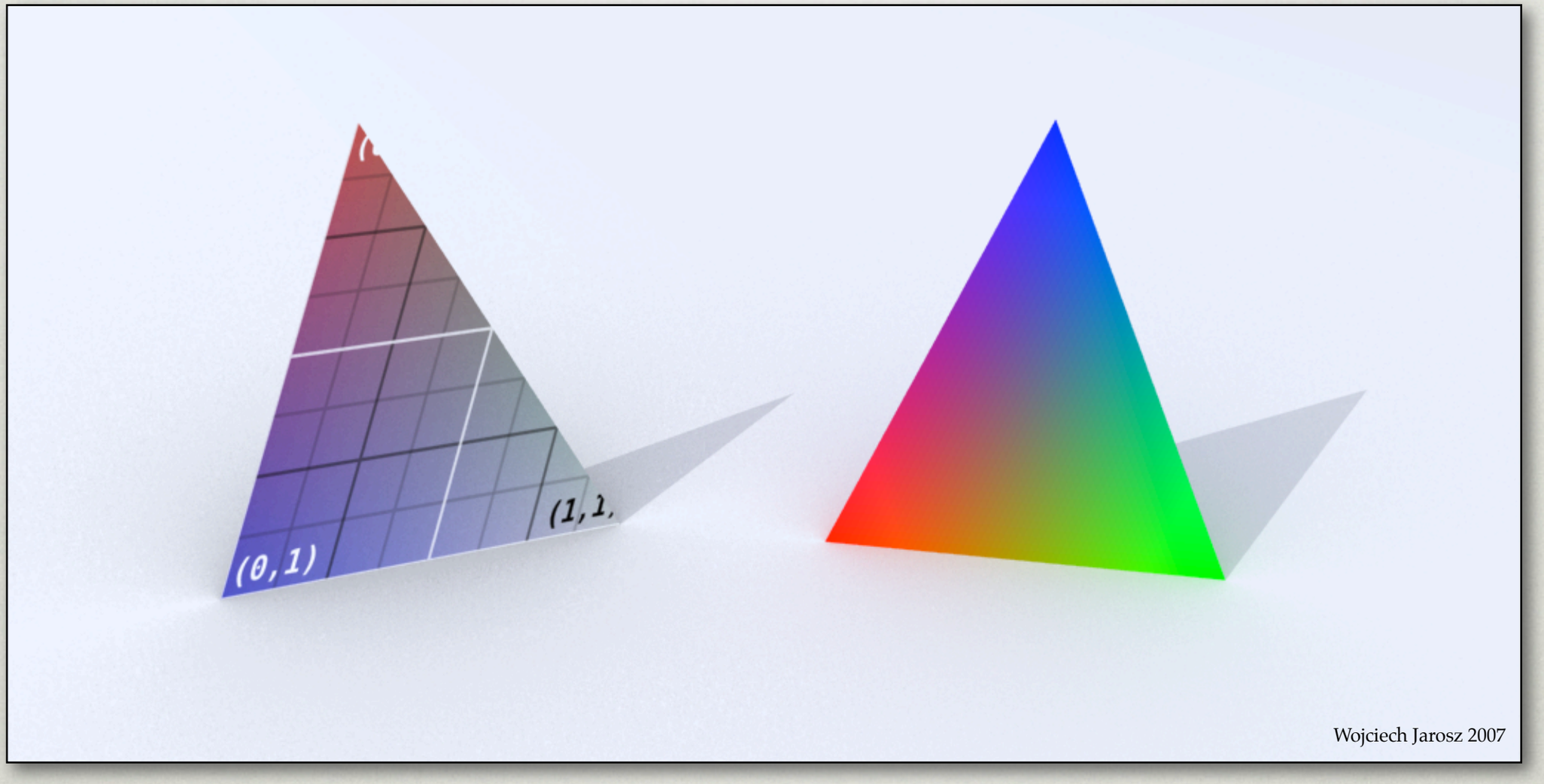
Object Space Texture Space

Texture Coordinates



Object Space Texture Space Object Space

UV Texturing



Texture Filtering

- Magnification: Texel size larger than pixel size
- Minification: Text size smaller than pixel size (potential aliasing)

Texture Filtering

Magnification

Nearest Neighbor

Texture Filtering

Magnification

Nearest Neighbor

Bilinear

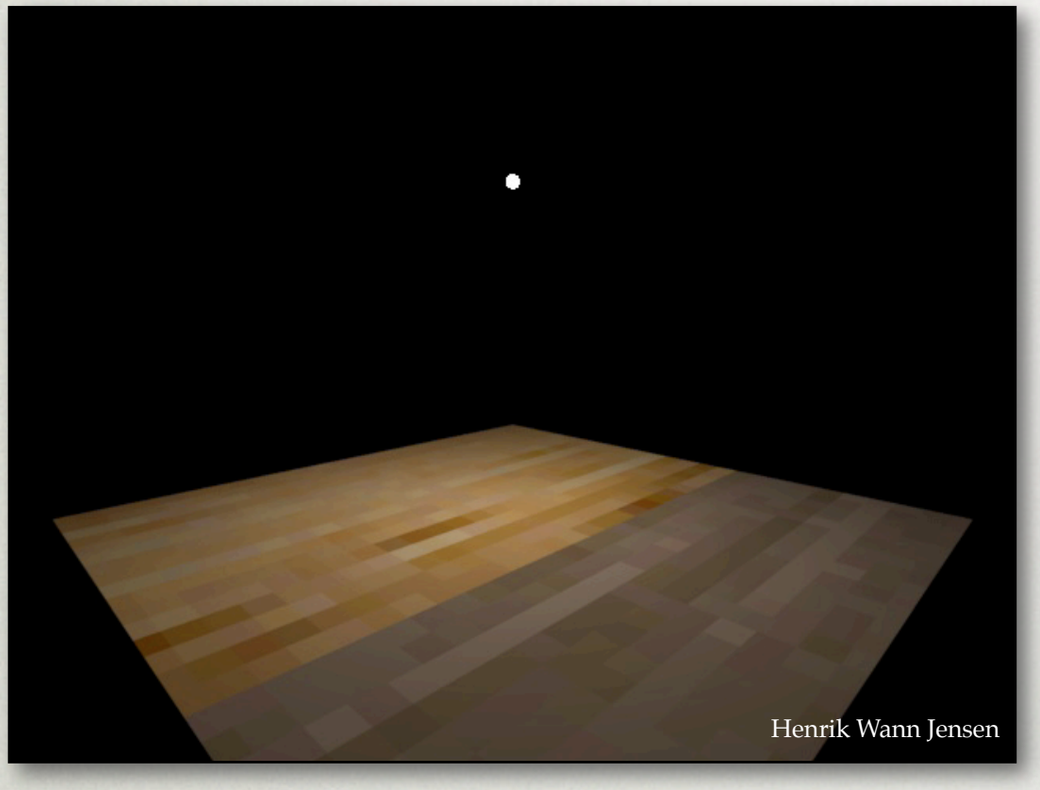
Texture Filtering

Magnification

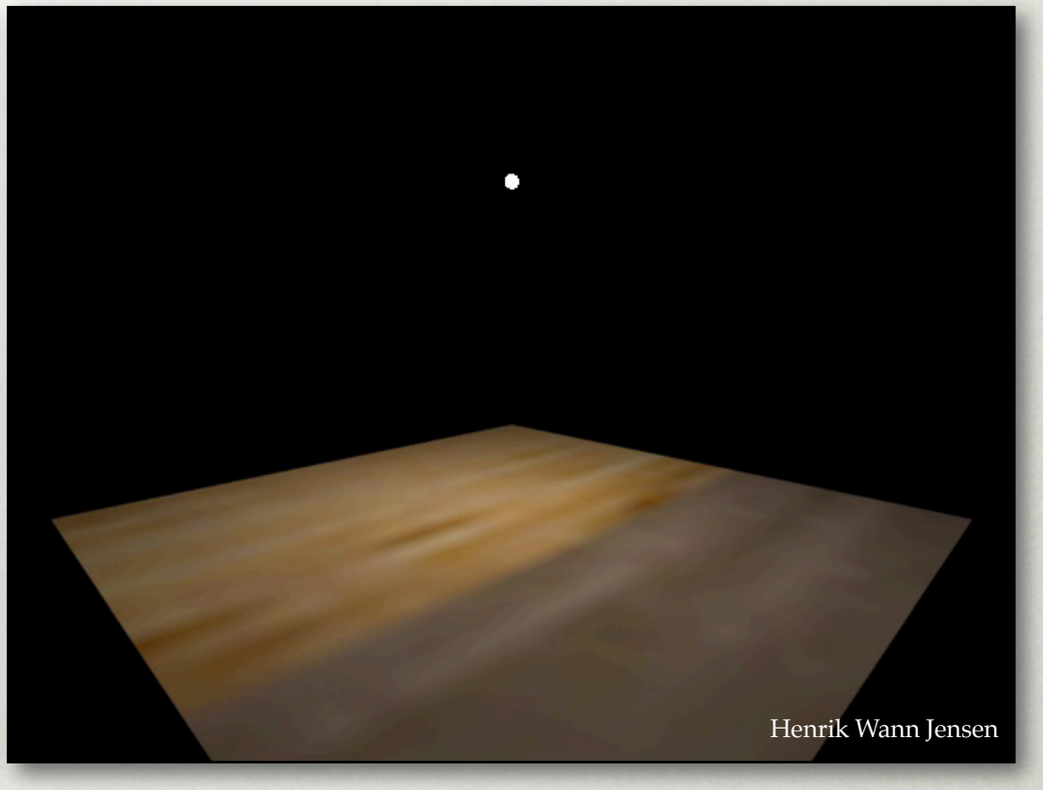
Nearest Neighbor Bilinear Bicubic

Texture Filtering

Magnification

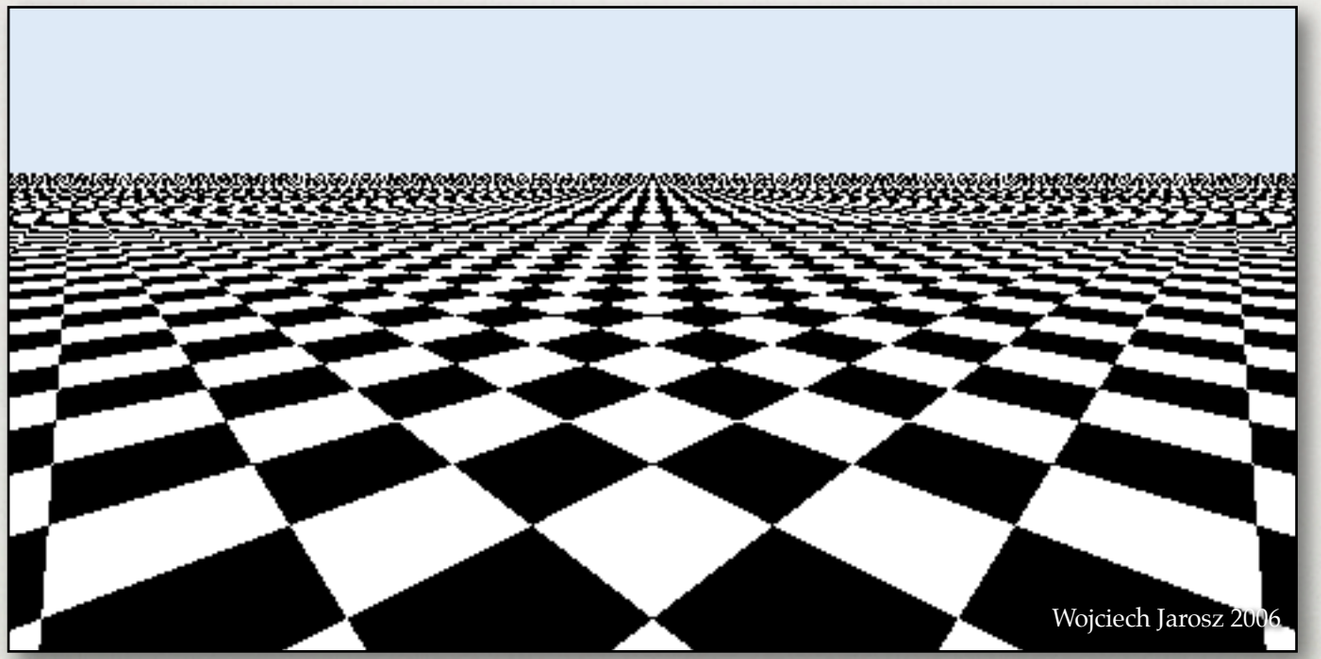


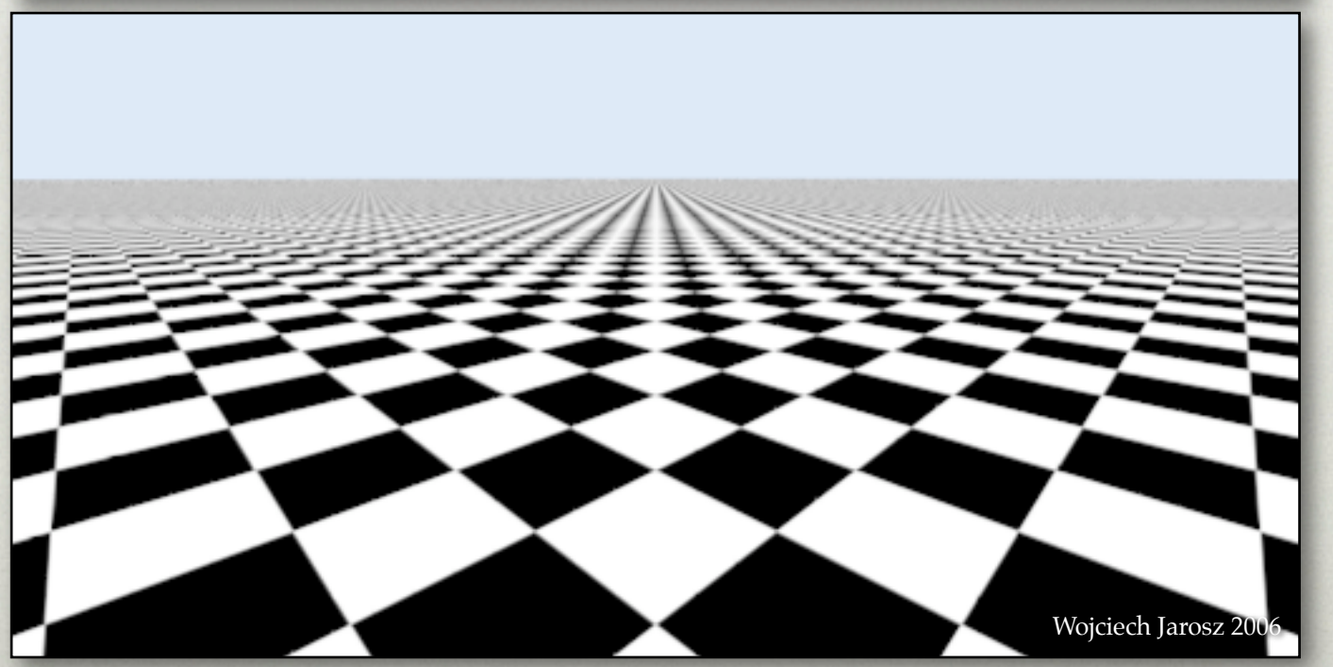
Nearest Neighbor



Bilinear

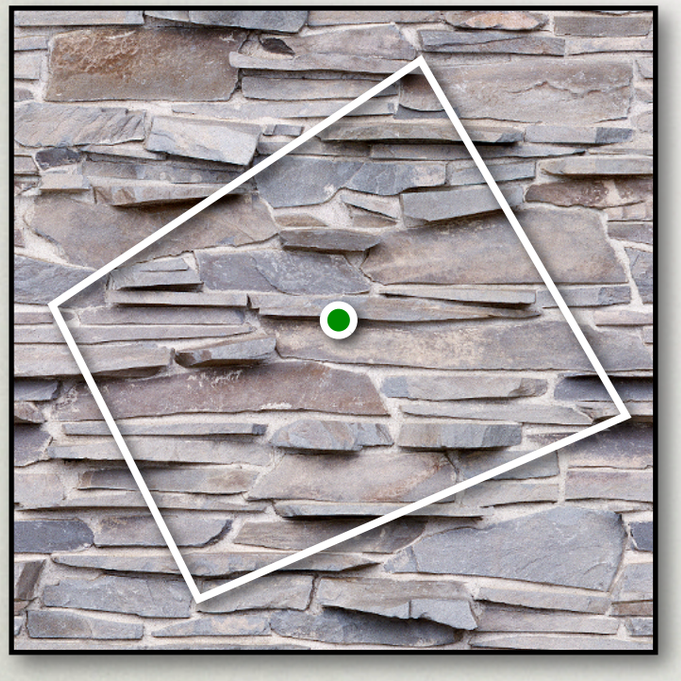
Aliasing





Texture Filtering

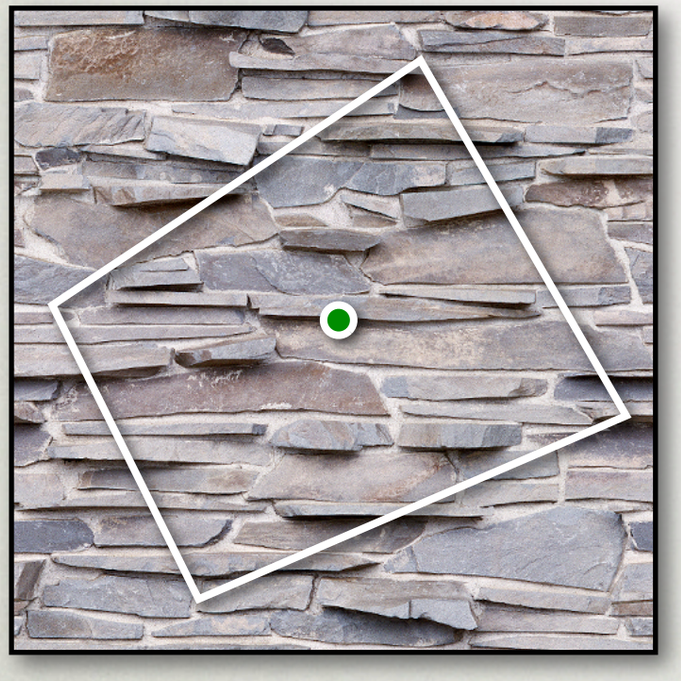
Minification



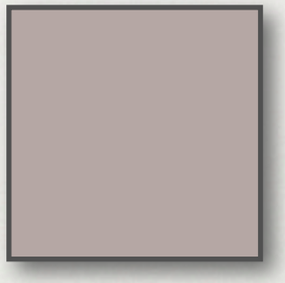
Point Sample

Texture Filtering

Minification



Point Sample



Area Average

Texture Filtering

- Averaging over large texture areas at every texture lookup is costly.
- How can we make this more efficient?

MipMap

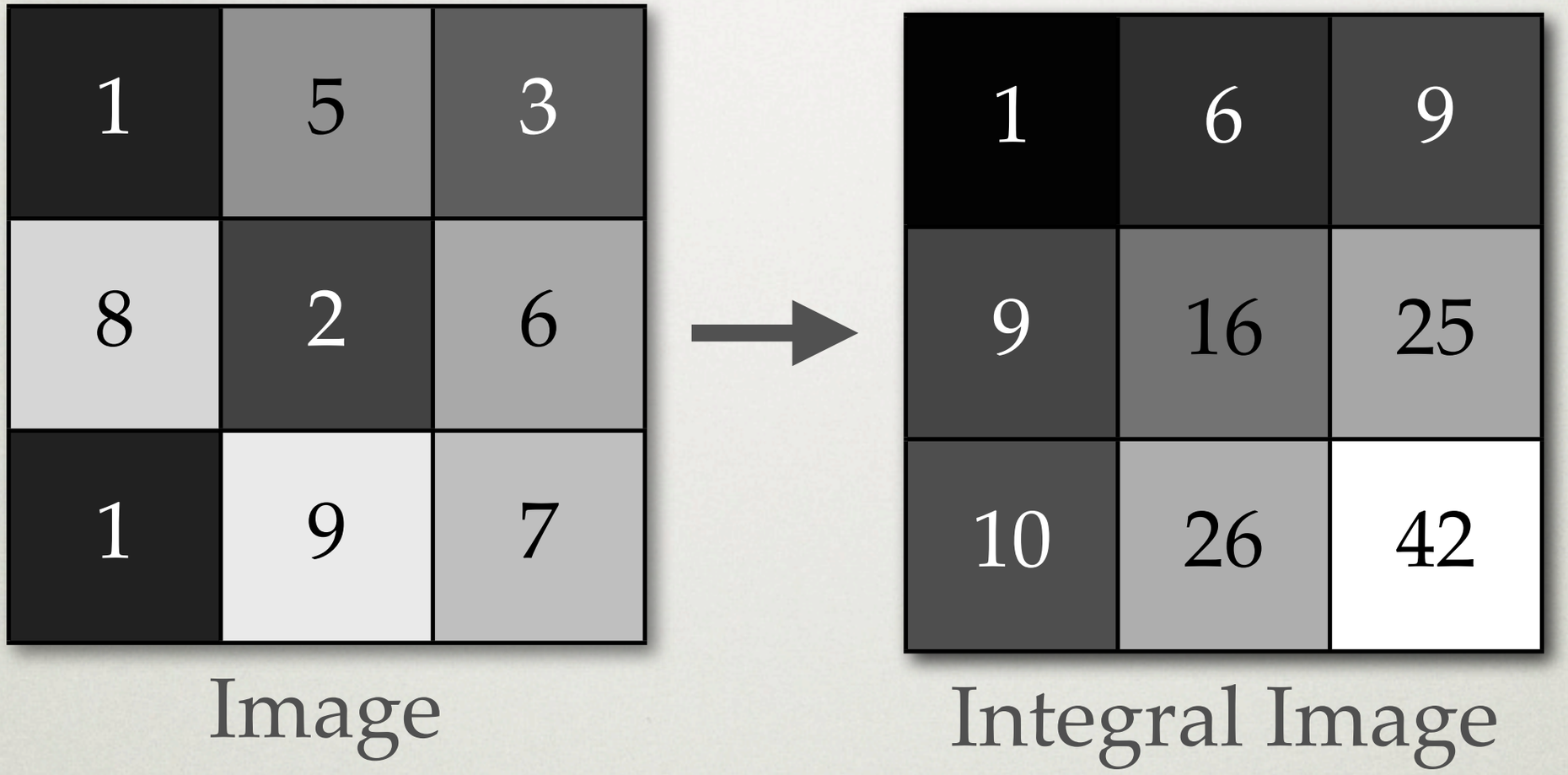
RipMap

Summed Area Table

1	5	3
8	2	6
1	9	7

Image

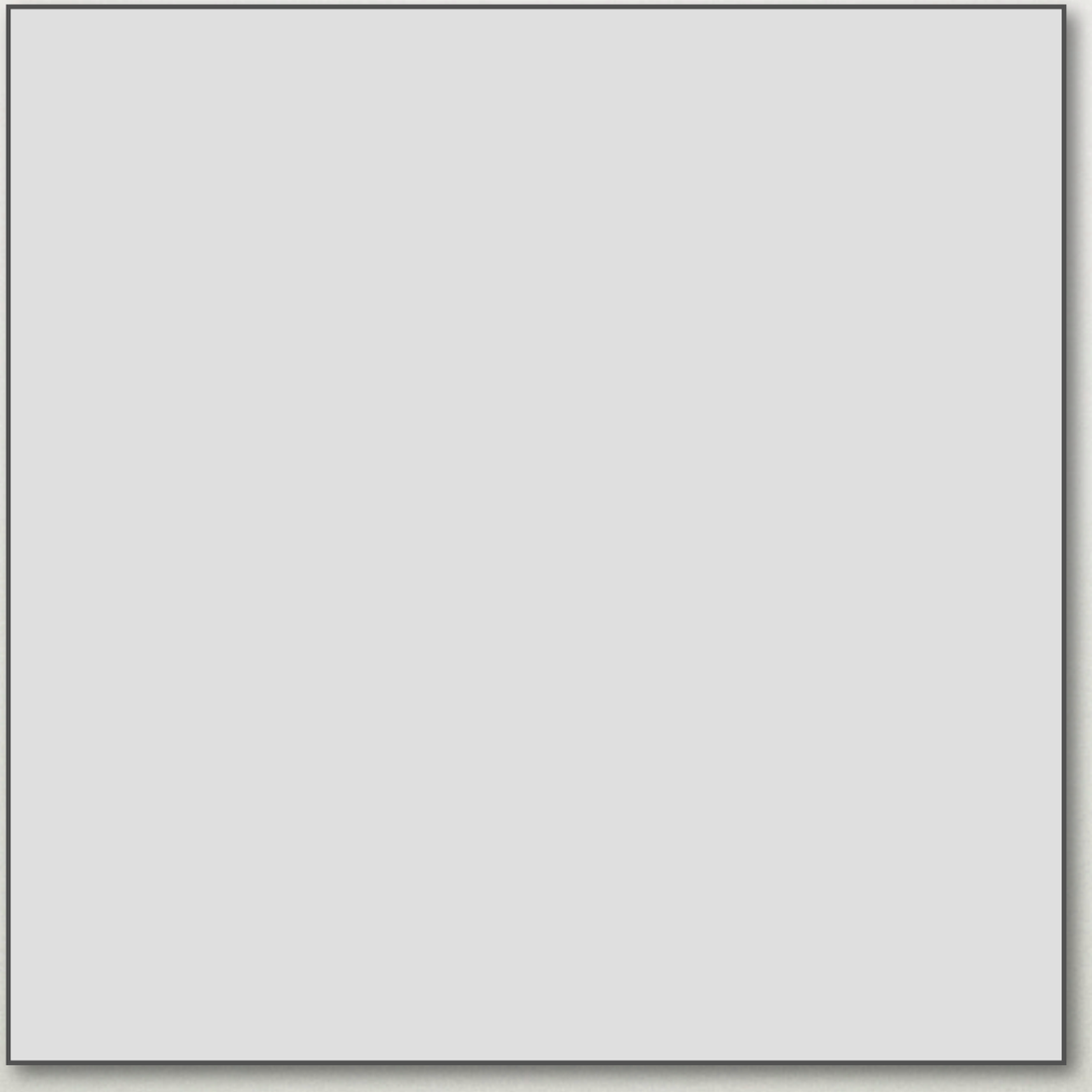
Summed Area Table



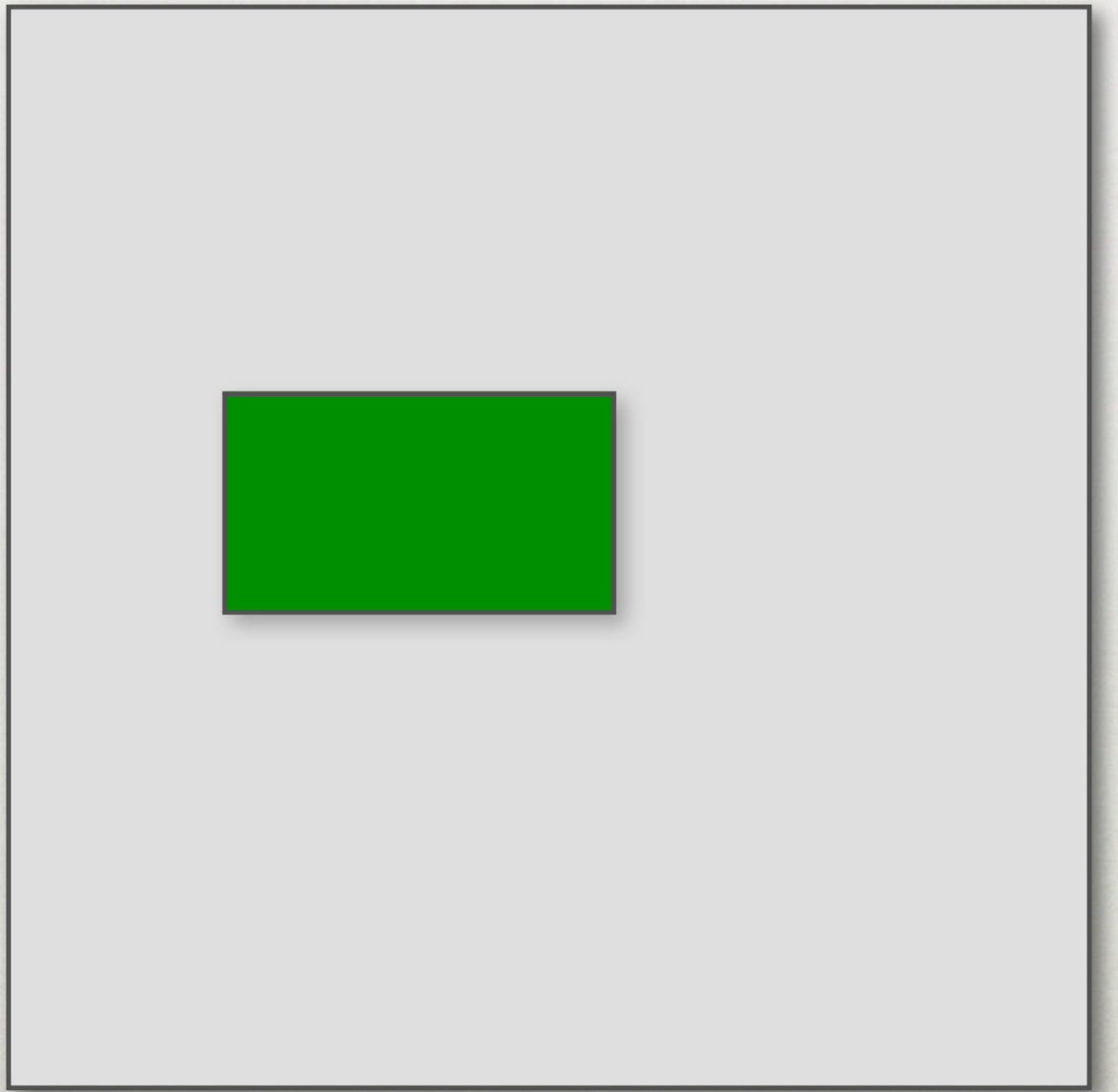
Image

Integral Image

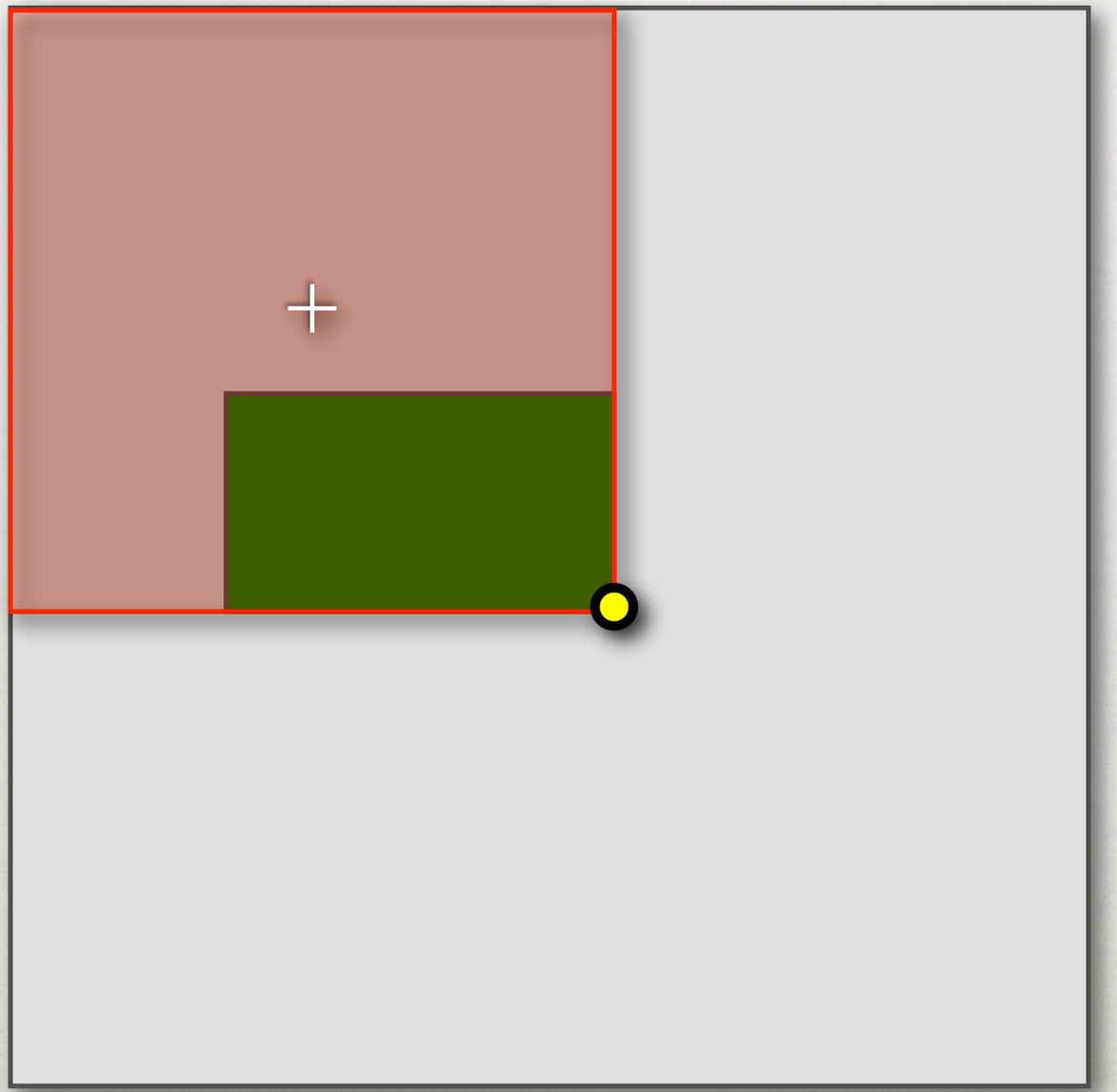
Summed Area Table



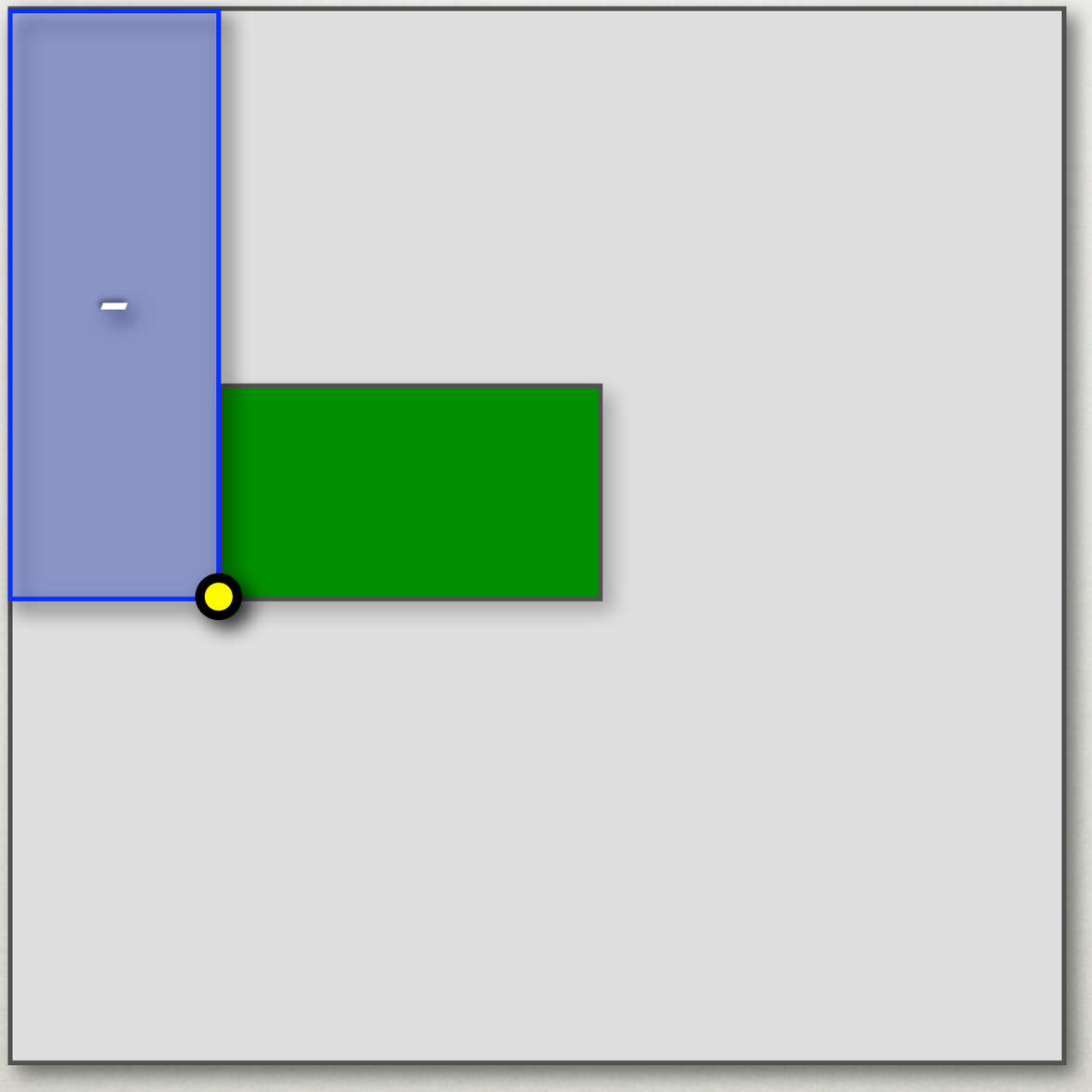
Summed Area Table



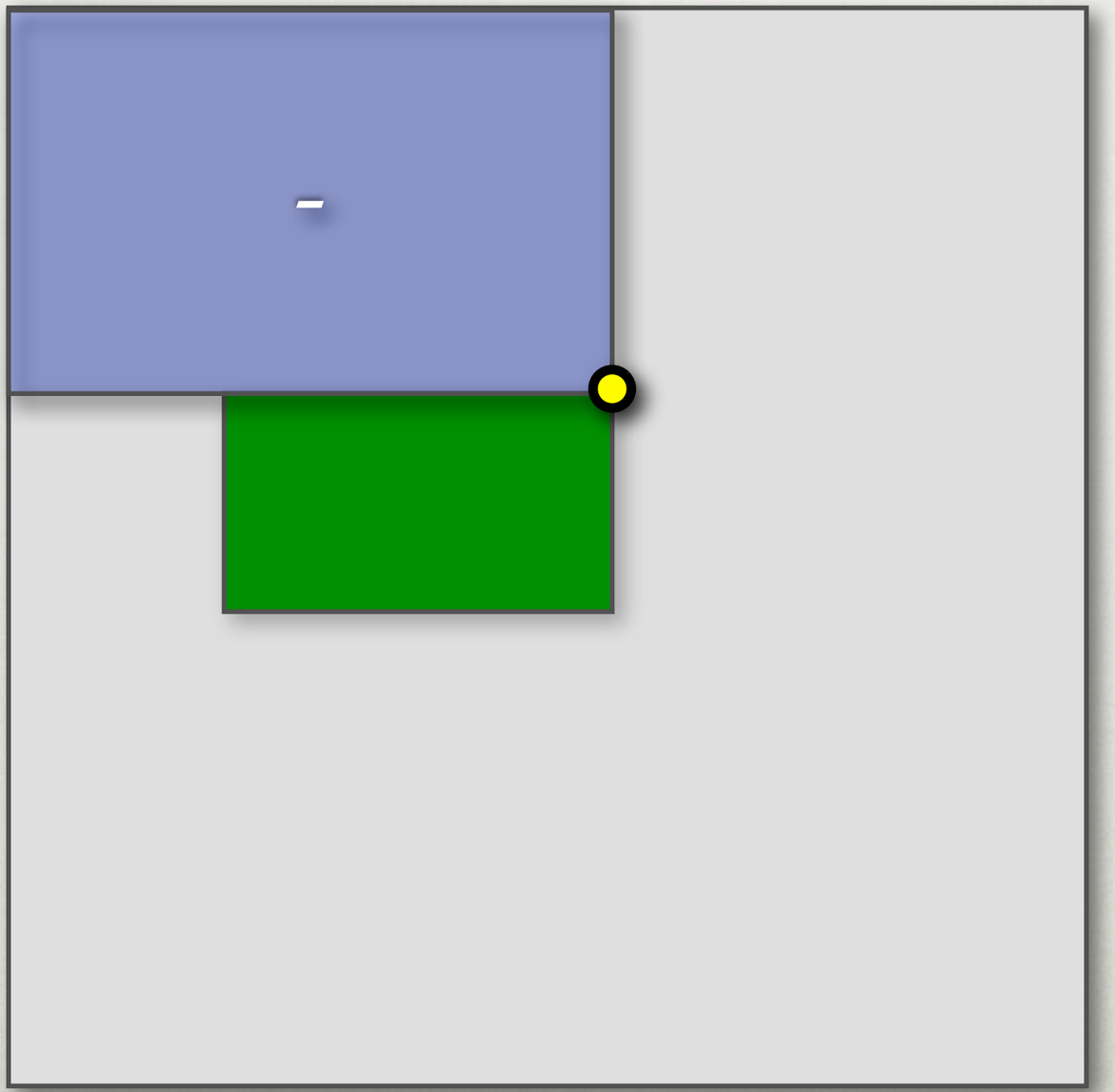
Summed Area Table



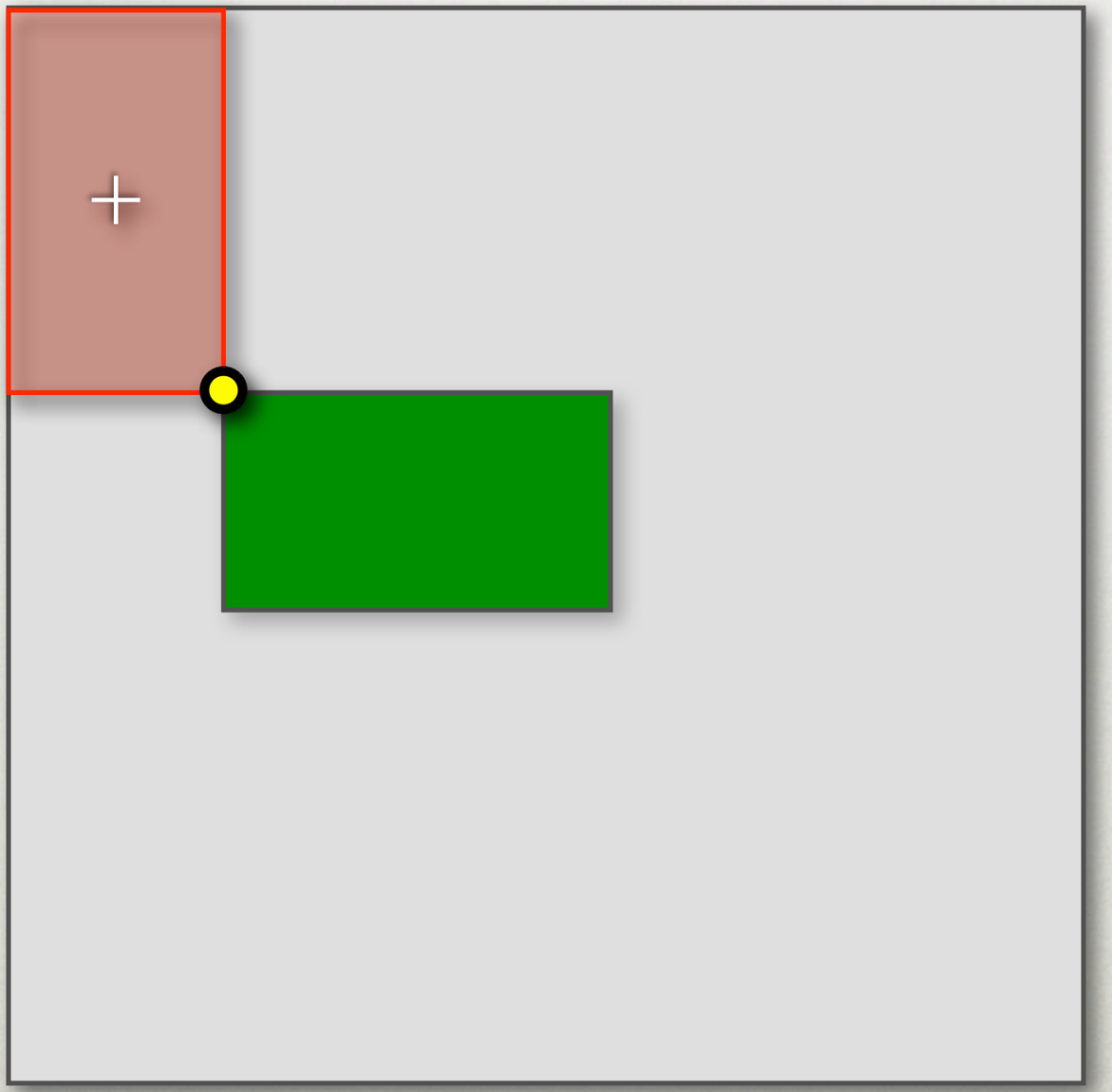
Summed Area Table



Summed Area Table



Summed Area Table



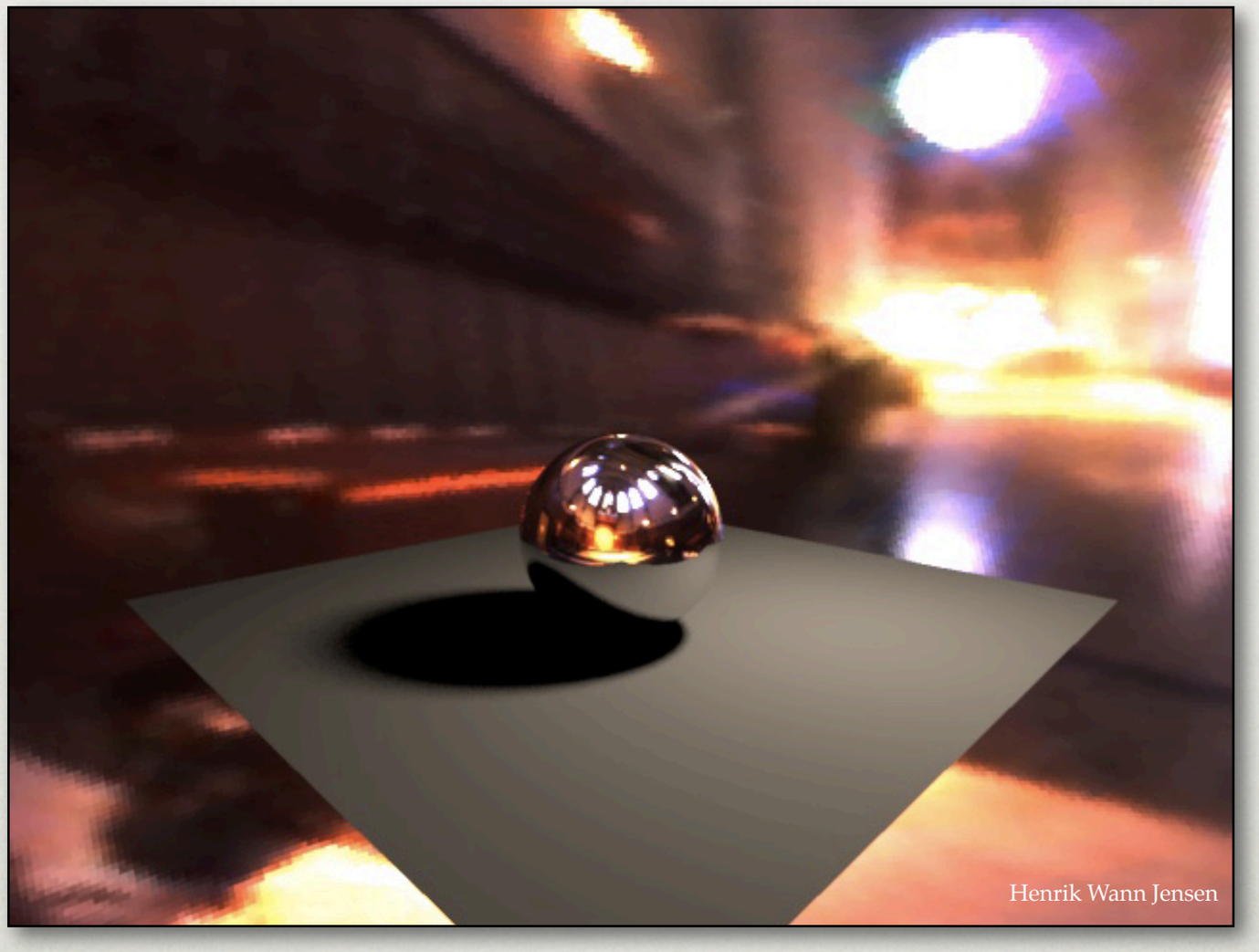
Environment Mapping

- Use a texture to represent the surrounding scene.

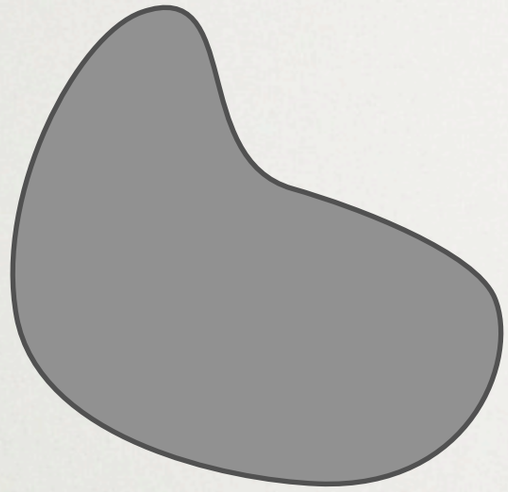
Environment Mapping

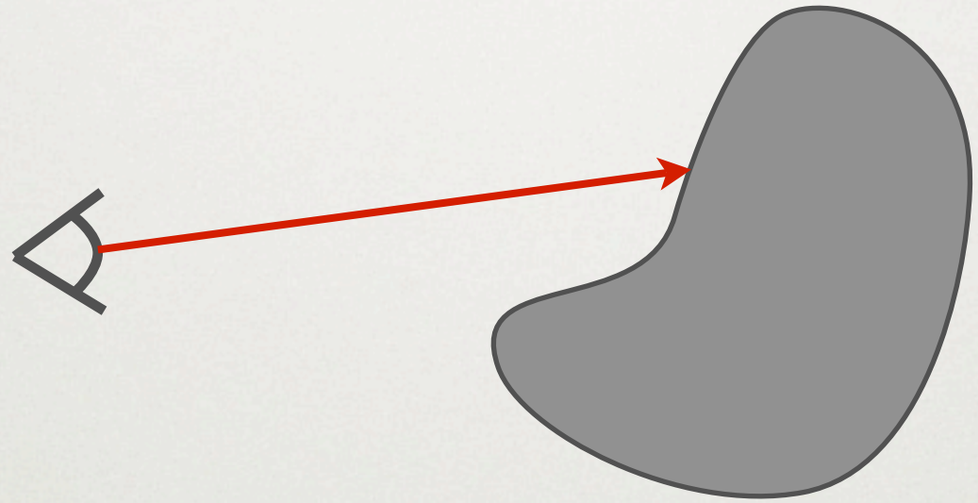
Grace cathedral environment map

Environment Mapping



Environment Mapping

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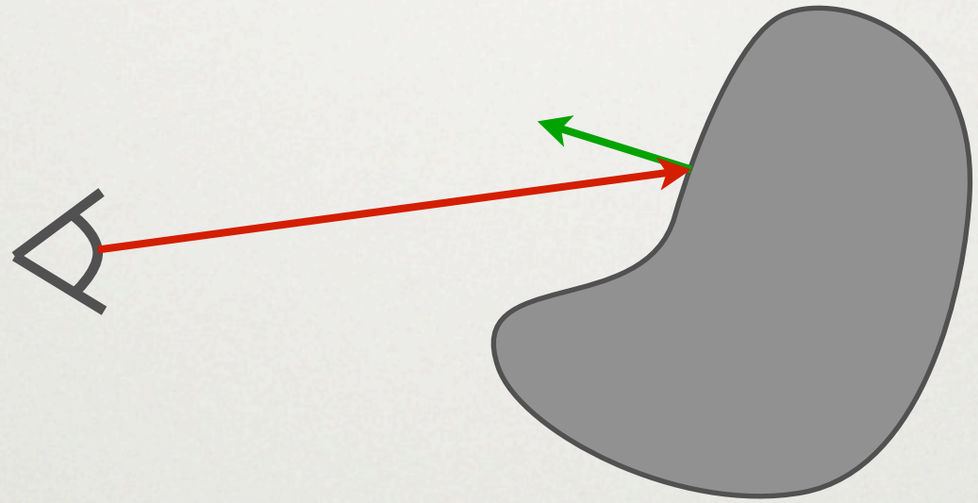
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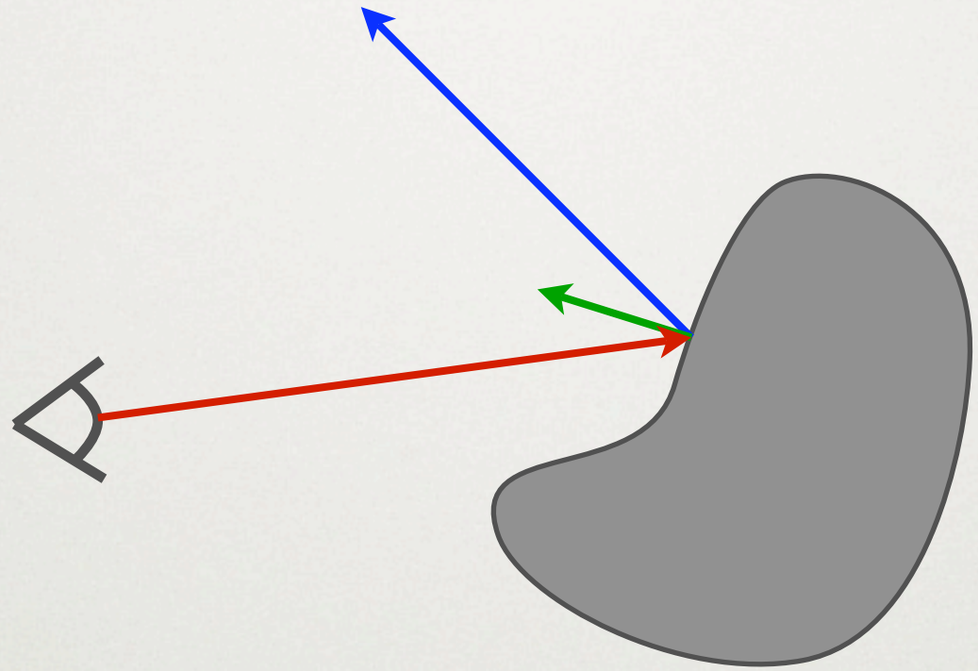
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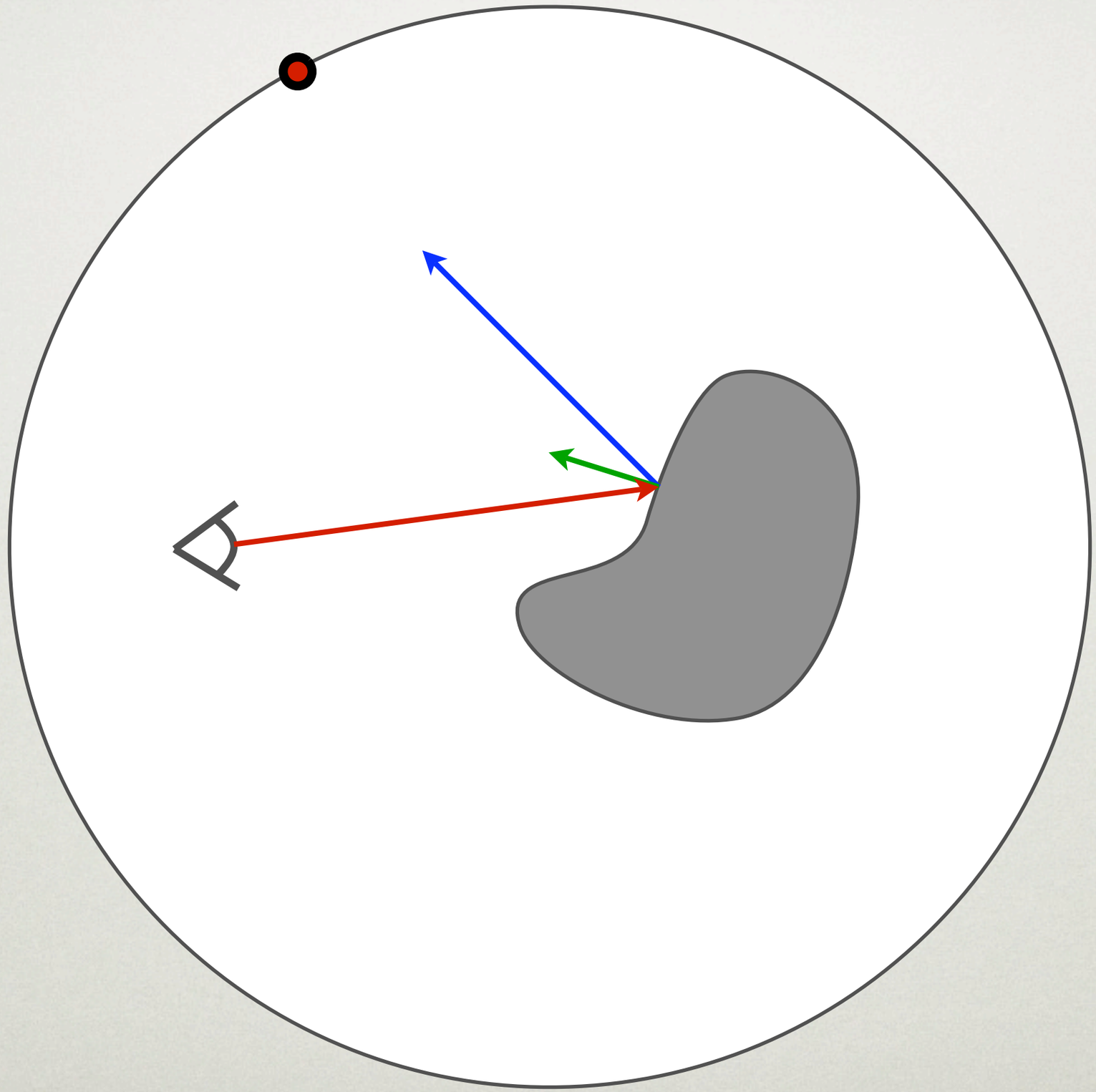
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Implementation Hints

- If a ray doesn't hit any objects, in Scene::raytraceImage, use environment mapping.
- To compute environment map pixel, use only the ray's direction component

Cubemap Projection

- Easy to produce with renderer
- Possible to produce with camera

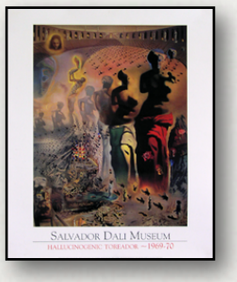
Capturing Environment Maps

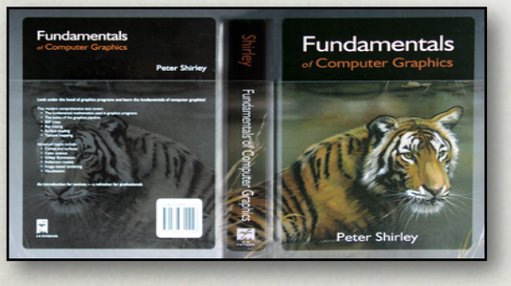
Mirror Sphere

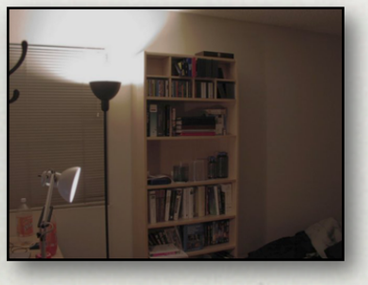
Angular Map

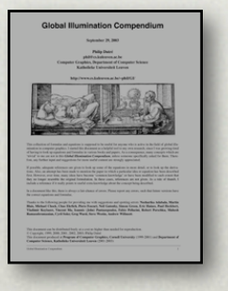
Latitude/Longitude

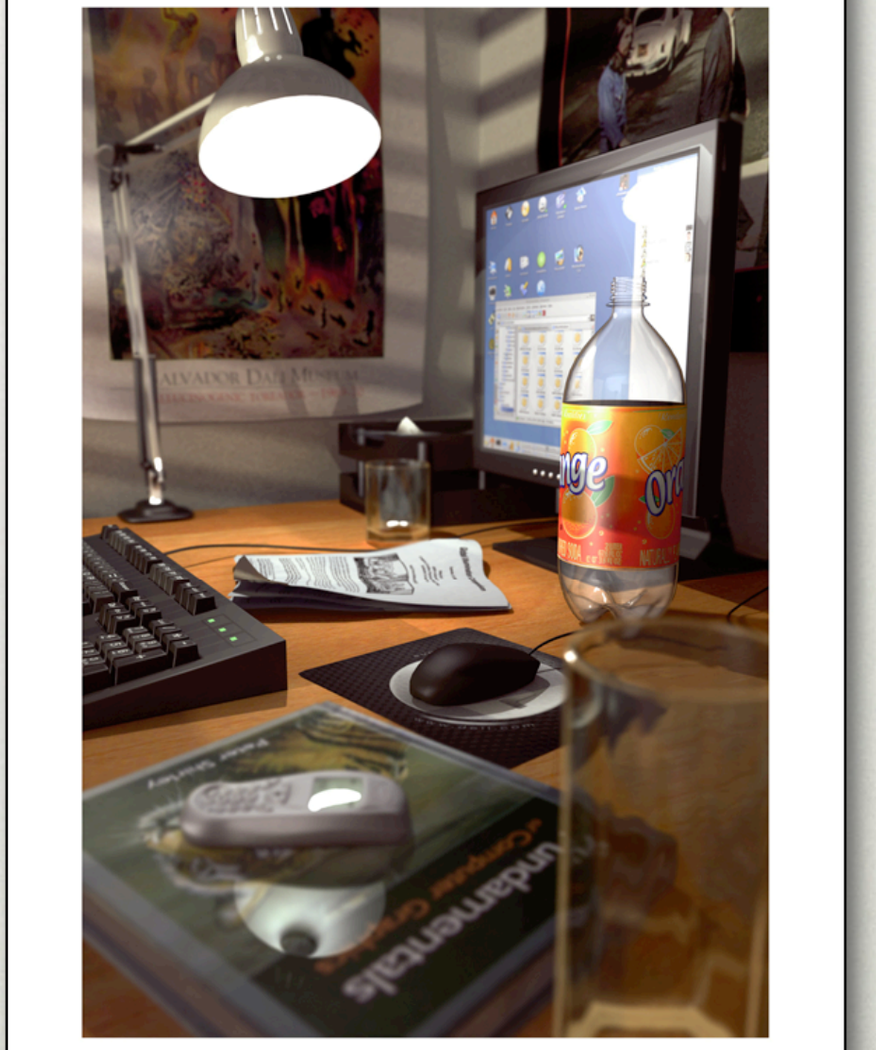
Exploit Texturing!











Cluttered Desk

Wojciech Jarosz 2004

Questions?

Procedural Texturing

- Instead of using image data, define texture procedurally.
  - Simple example:
    - color = 0.5*sin(x) + 0.5
- Often called “solid texturing” because texture can vary in all 3 dimensions.

Procedurals vs Images

- Pixar almost exclusively uses procedural textures.
- Why?

Procedural Synthesis

created using Terragen

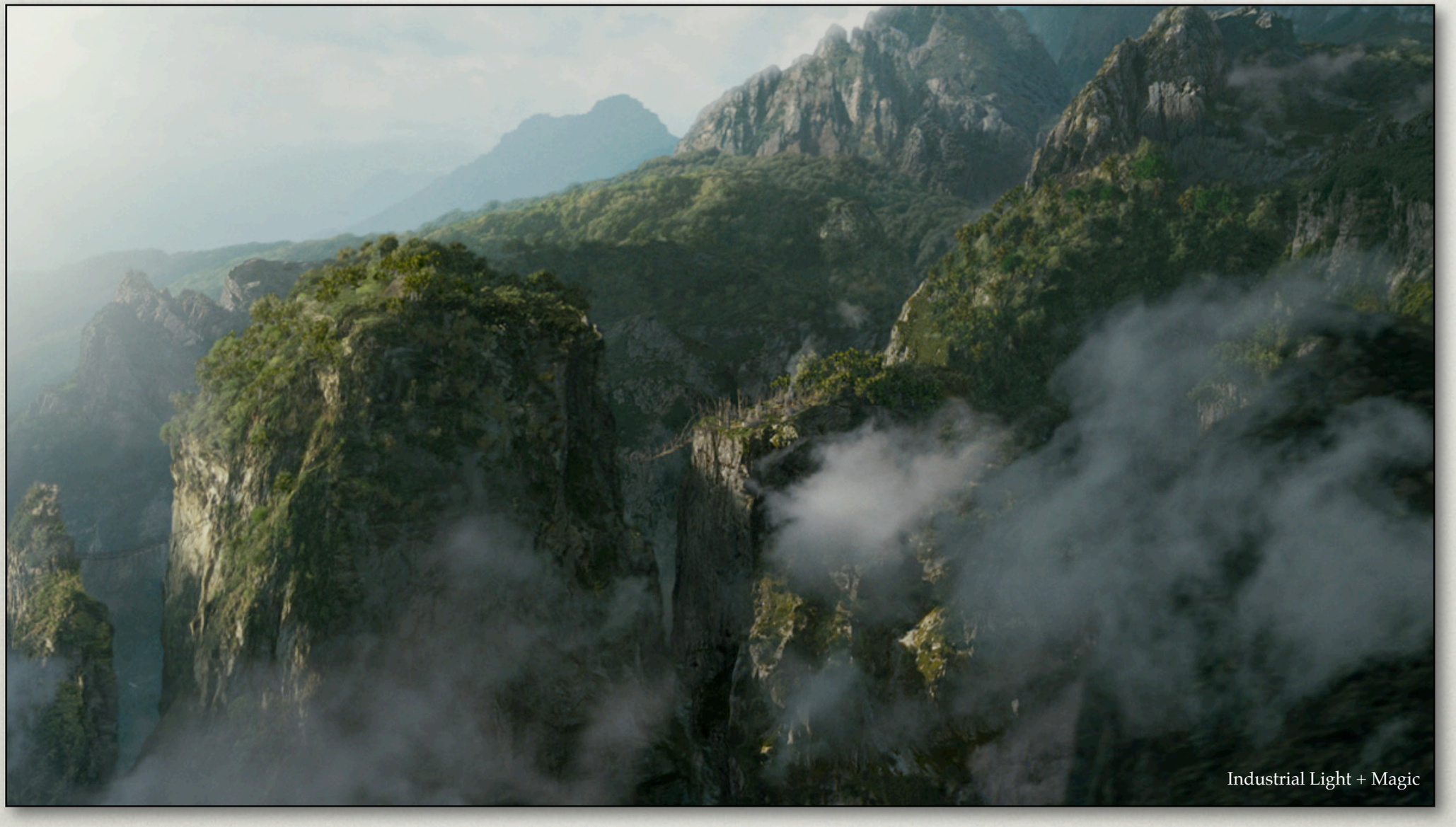
Procedural Synthesis

created using Terragen

Procedural Synthesis

created using MojoWorld

Procedural Synthesis



Digital matte painting for Pirates of the Caribbean 2
created using Vue Infinite

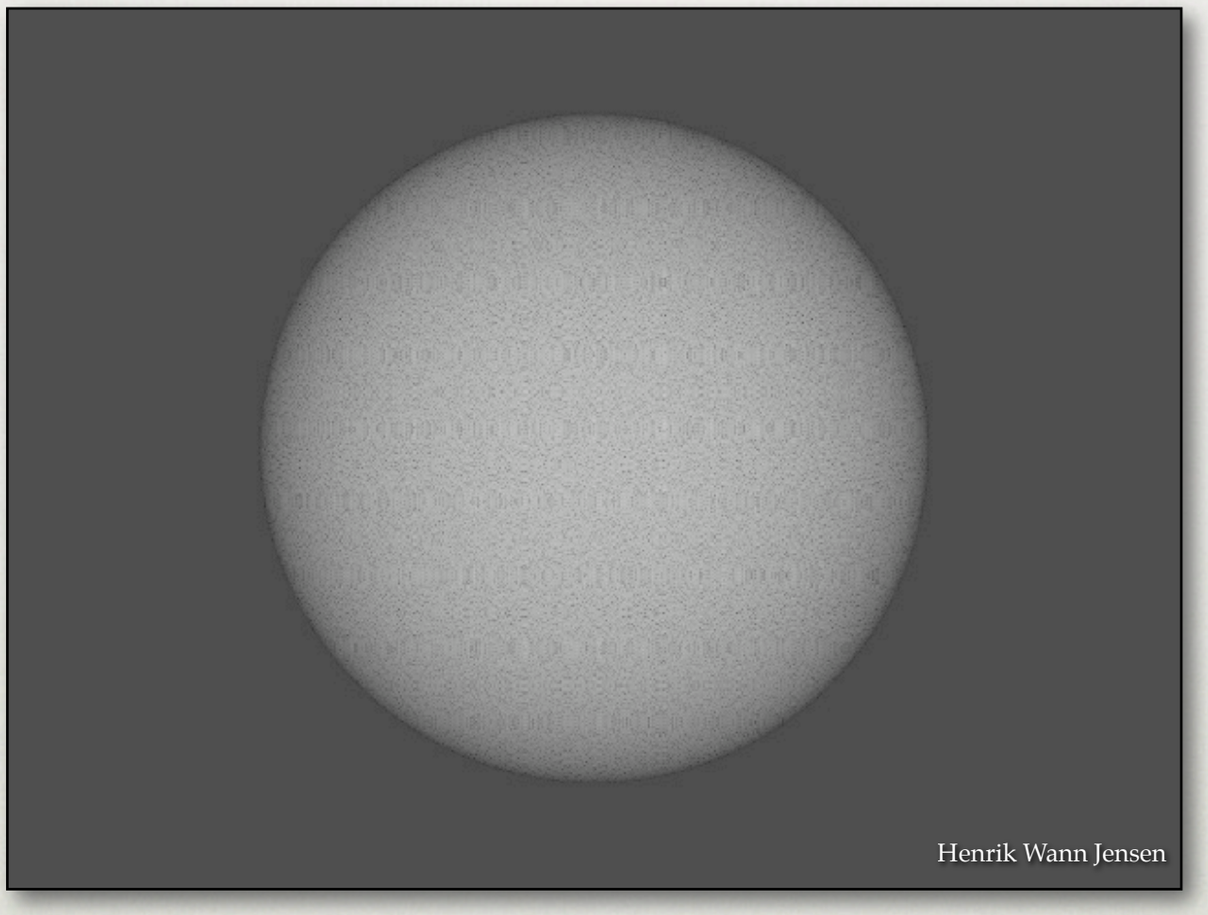
Procedural Synthesis

created using Vue Infinite

Procedural Textures

- Often want to add controlled variation to a texture.
- Just calling rand() is not that useful.

Random Noise



- R_d = rand()/RAND_MAX;
- Not band-limited, white noise.

Noise Functions

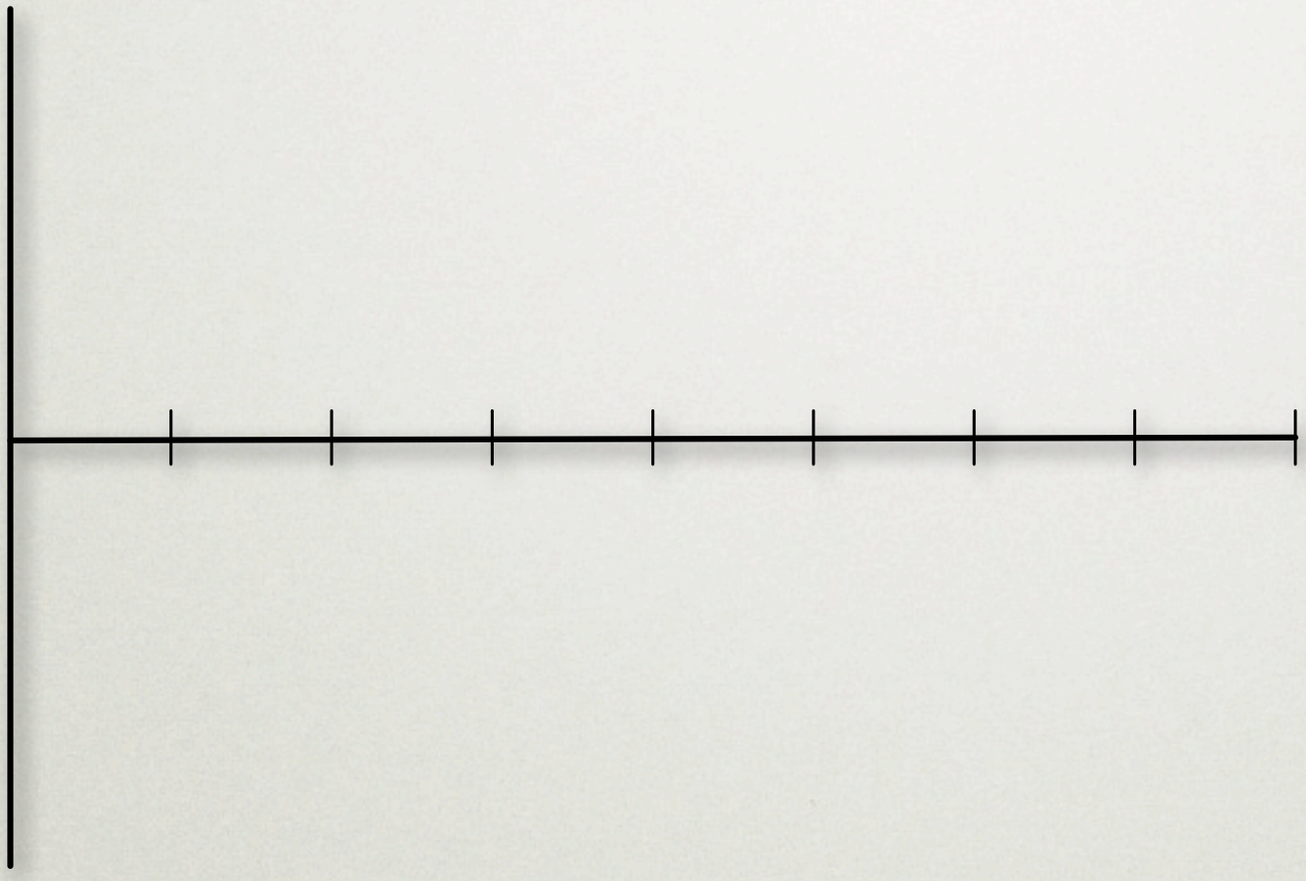
- Function: $R^n \rightarrow [-1,1]$, where n = 1,2,3,...
- Desirable properties:
  - Band-limited
  - No obvious repetition
- Fundamental building block of most procedural textures.

Value Noise

Implementation

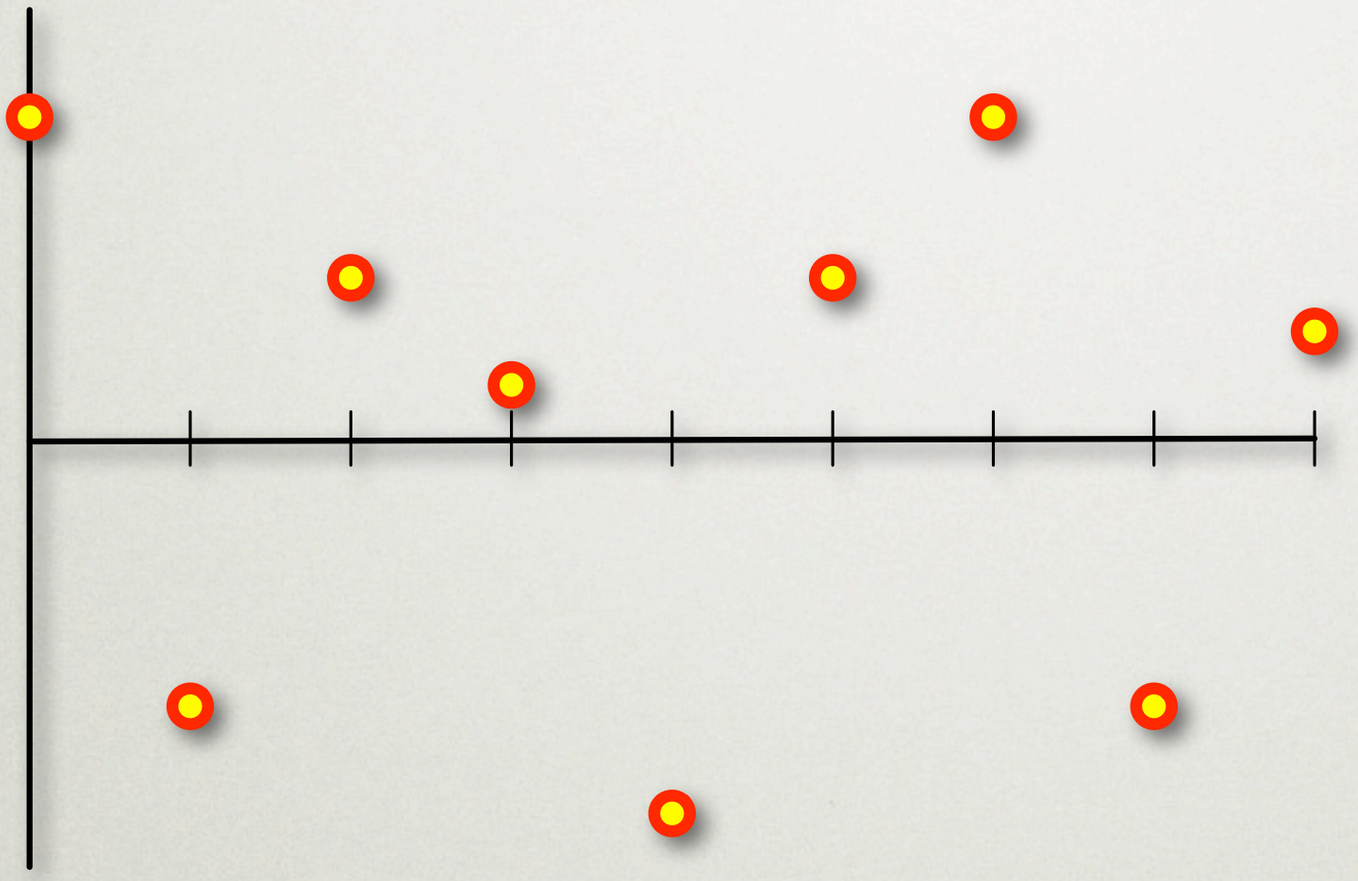
- Values associated with integer lattice locations.
- Given arbitrary position, interpolate value from neighboring lattice points.

Value Noise Example



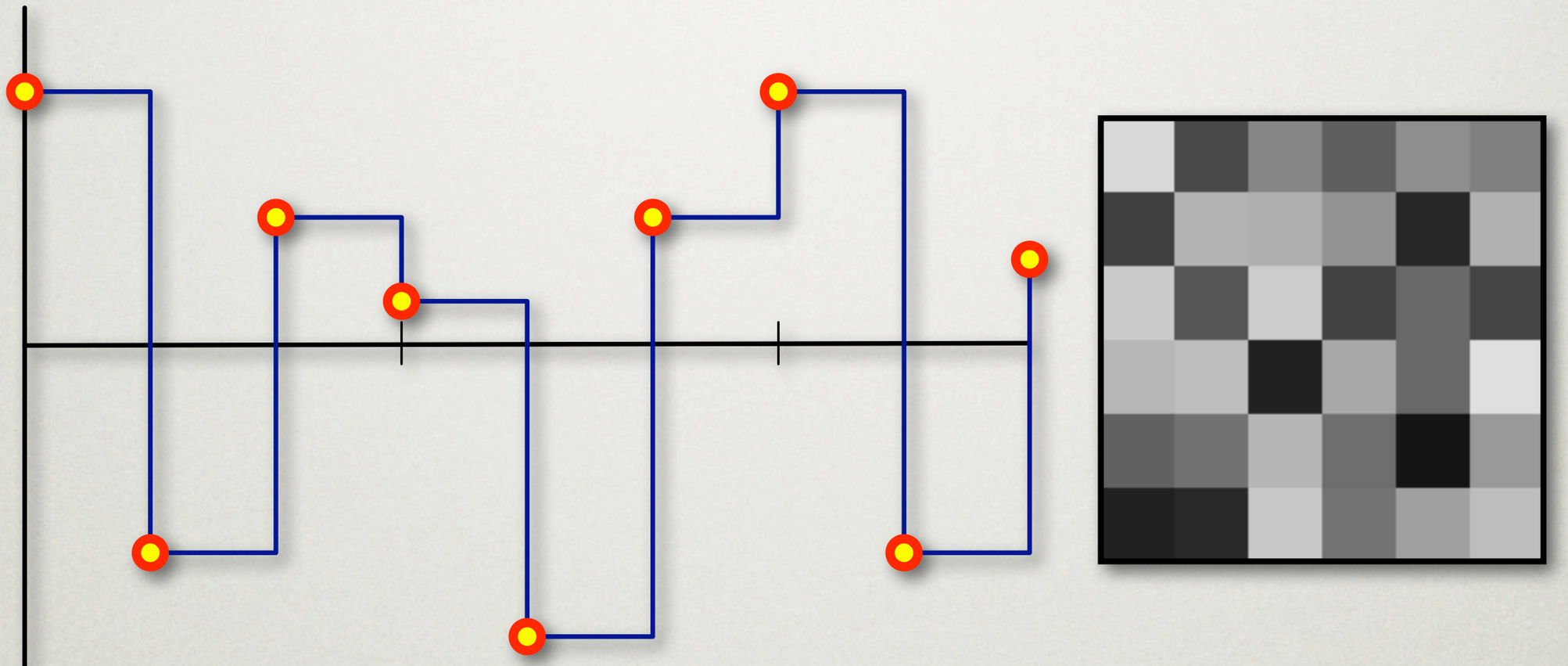
Value Noise Example

Random Values on Grid



Value Noise Example

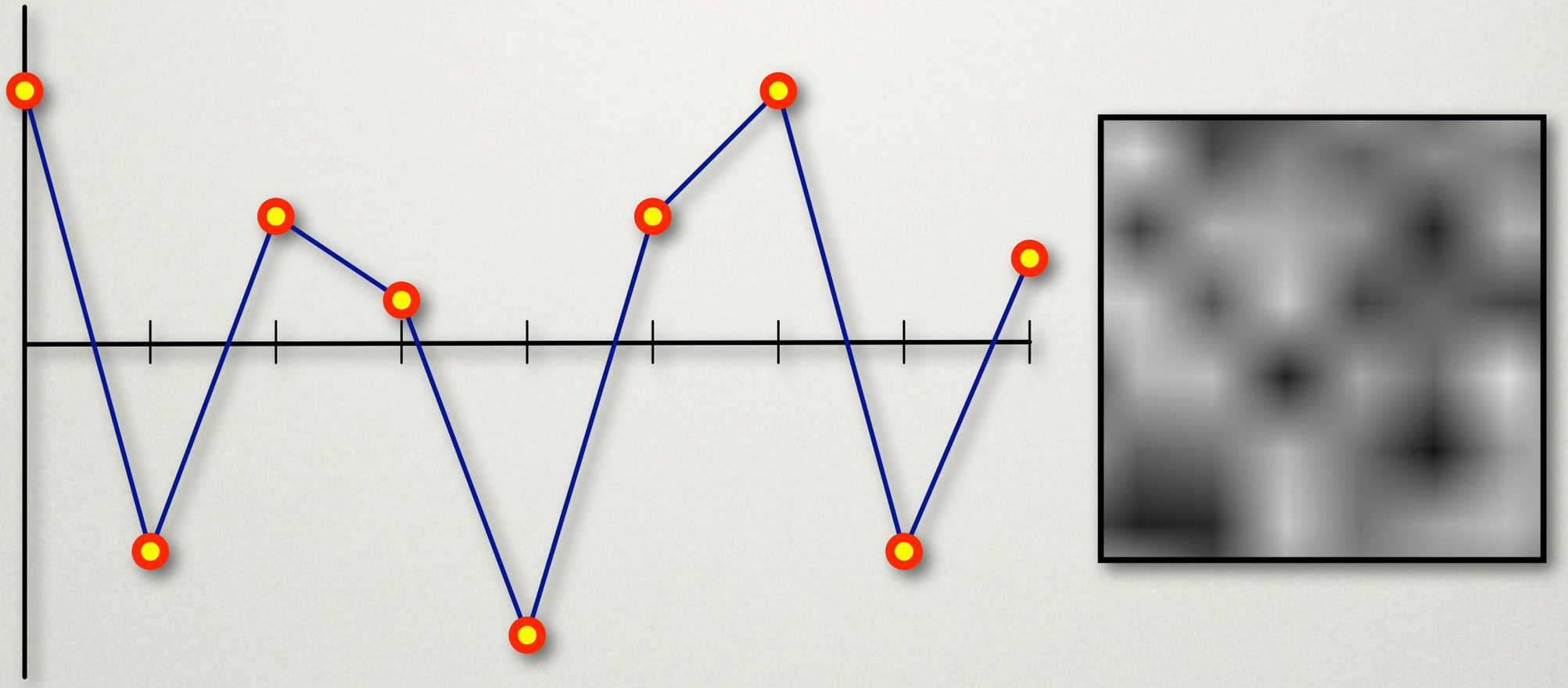
Random Values on Grid



- Also called cell noise
  - Not to be confused with cellular noise

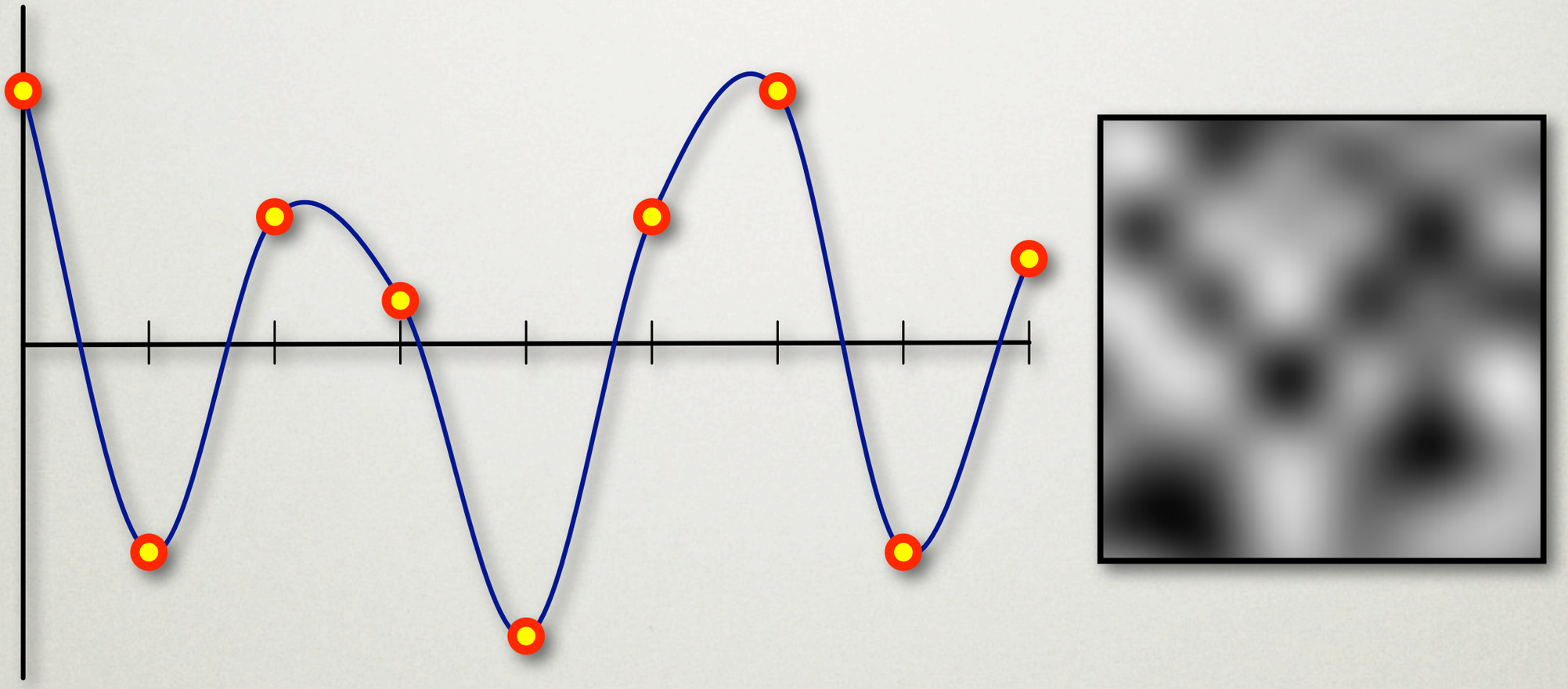
Value Noise Example

Linearly Interpolated Values



Value Noise Example

Cubic Interpolation



Value Noise

Implementation Issues

- Not feasible to store values at all integer locations
- Hash function can be used to map lattice locations to a pre-computed set of pseudo-random values

Value Noise

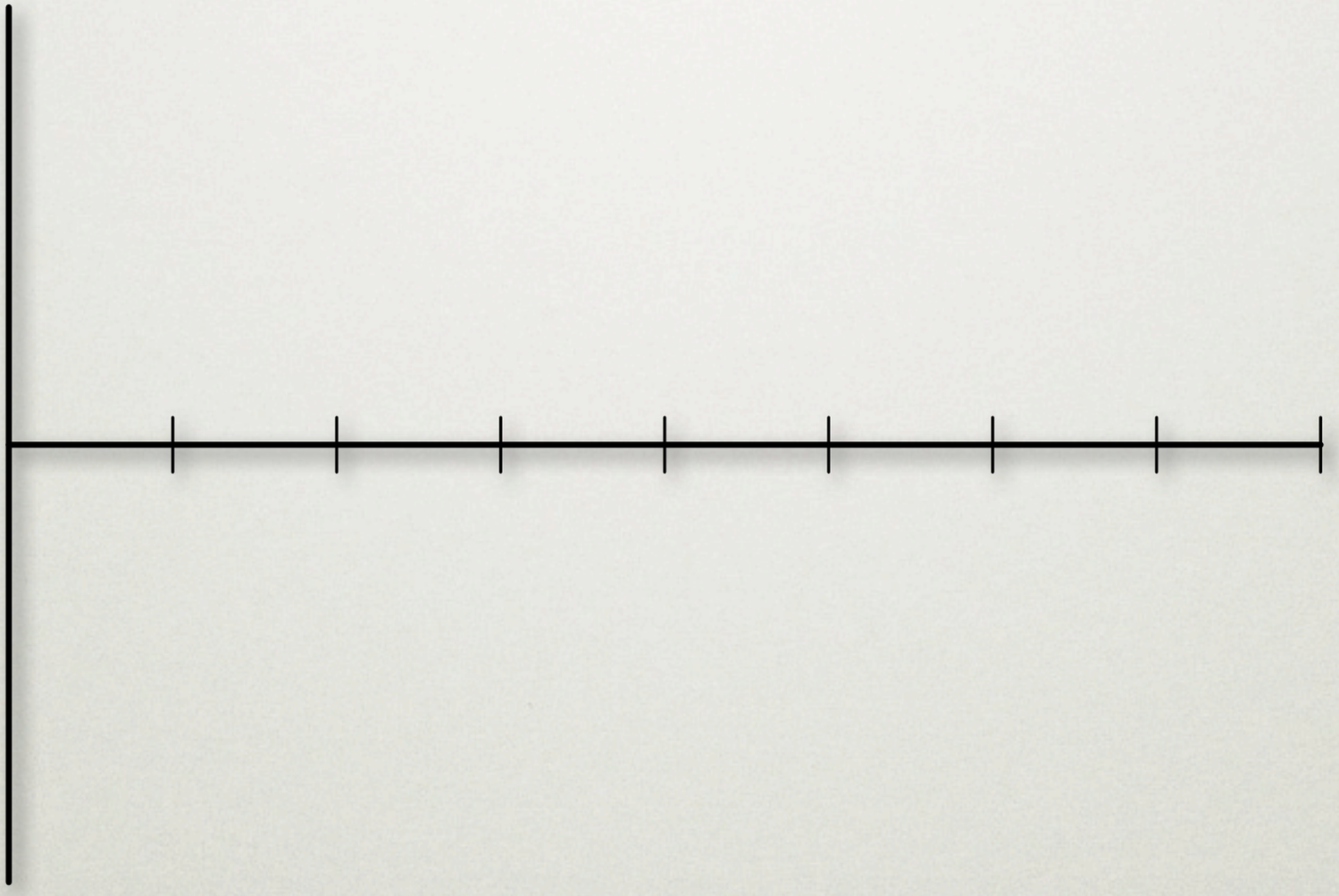
Implementation Details

```
// randomly permuted array of 0...255, duplicated
const unsigned char values[256*2] = [1, 234, ...];

float noise1D(float x)
{
   int xi = int(floor(x)) & 255;
   return lerp(values[xi], values[xi+1], x-xi)/128.0-1;
}

// 2D hashing:
// values[xi + values[yi]];
// 3D hashing:
// values[xi + values[yi + values[zi]]];
// etc.
```

Perlin Noise

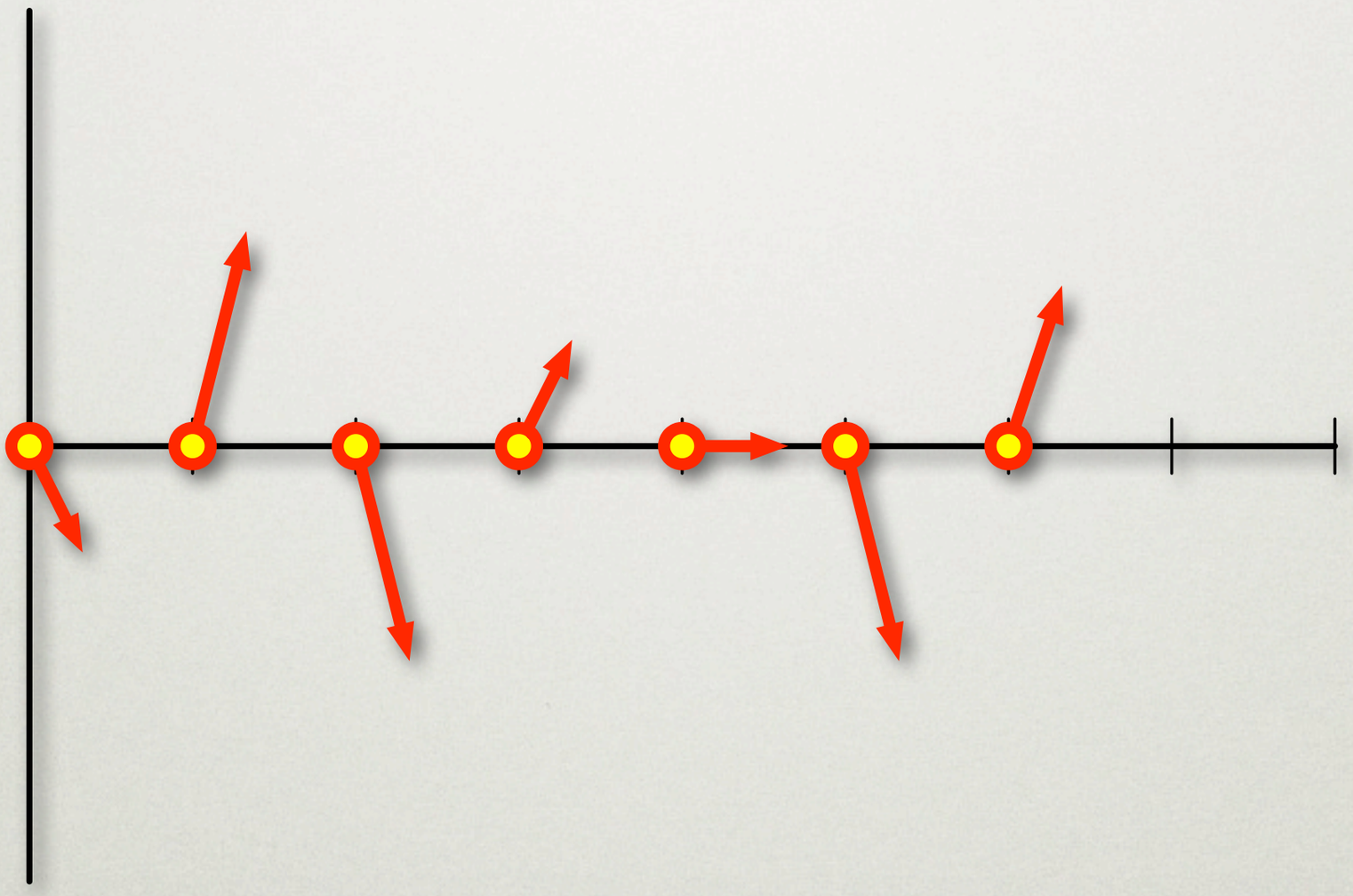
- Perlin Noise, invented by Ken Perlin in 1984.
- Generate random vectors at lattice locations.
- Use Hermite interpolation to compute noise value.
- Also called gradient noise.

Classic Perlin Noise



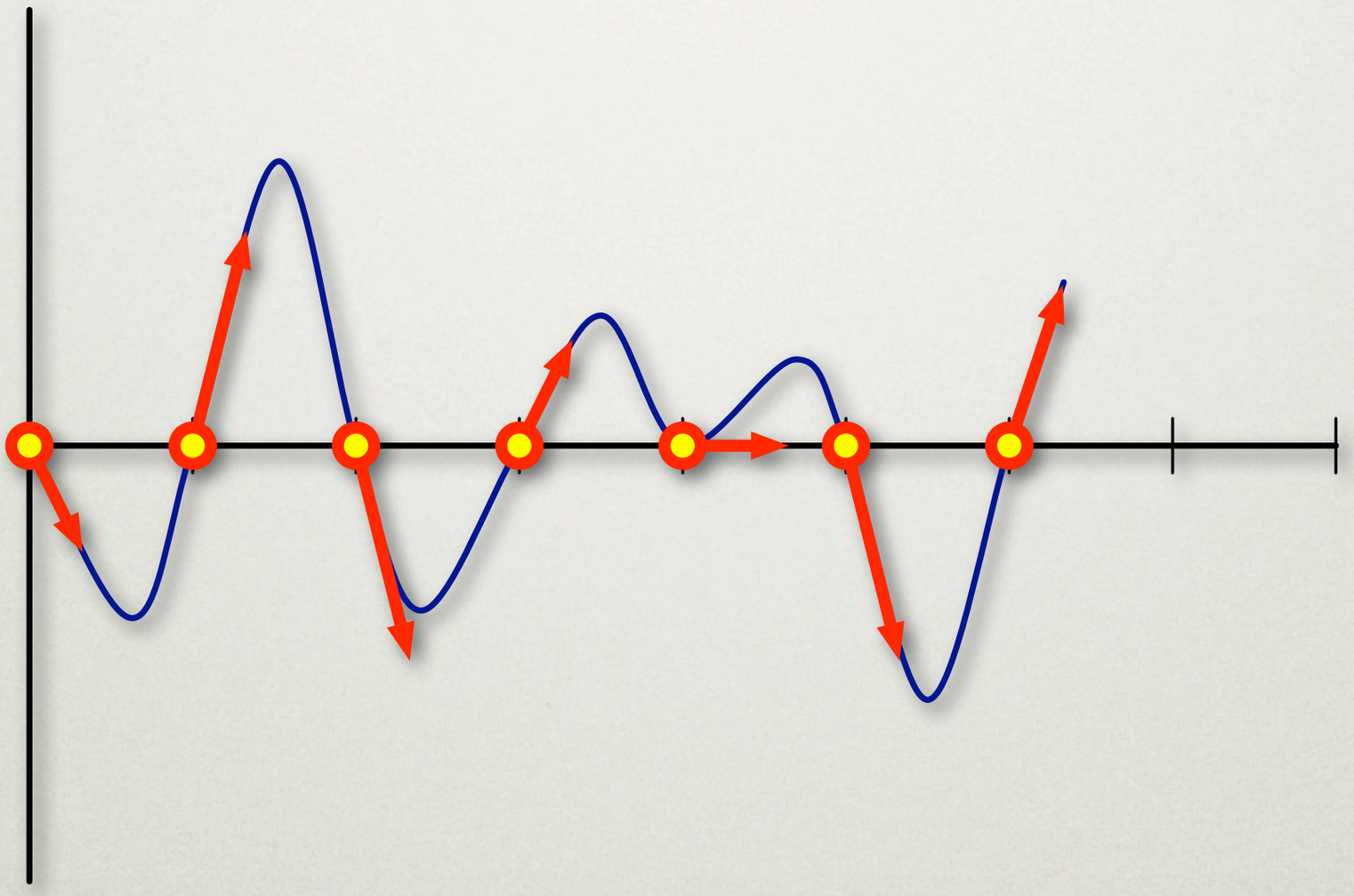
Classic Perlin Noise

Random Gradients on Grid

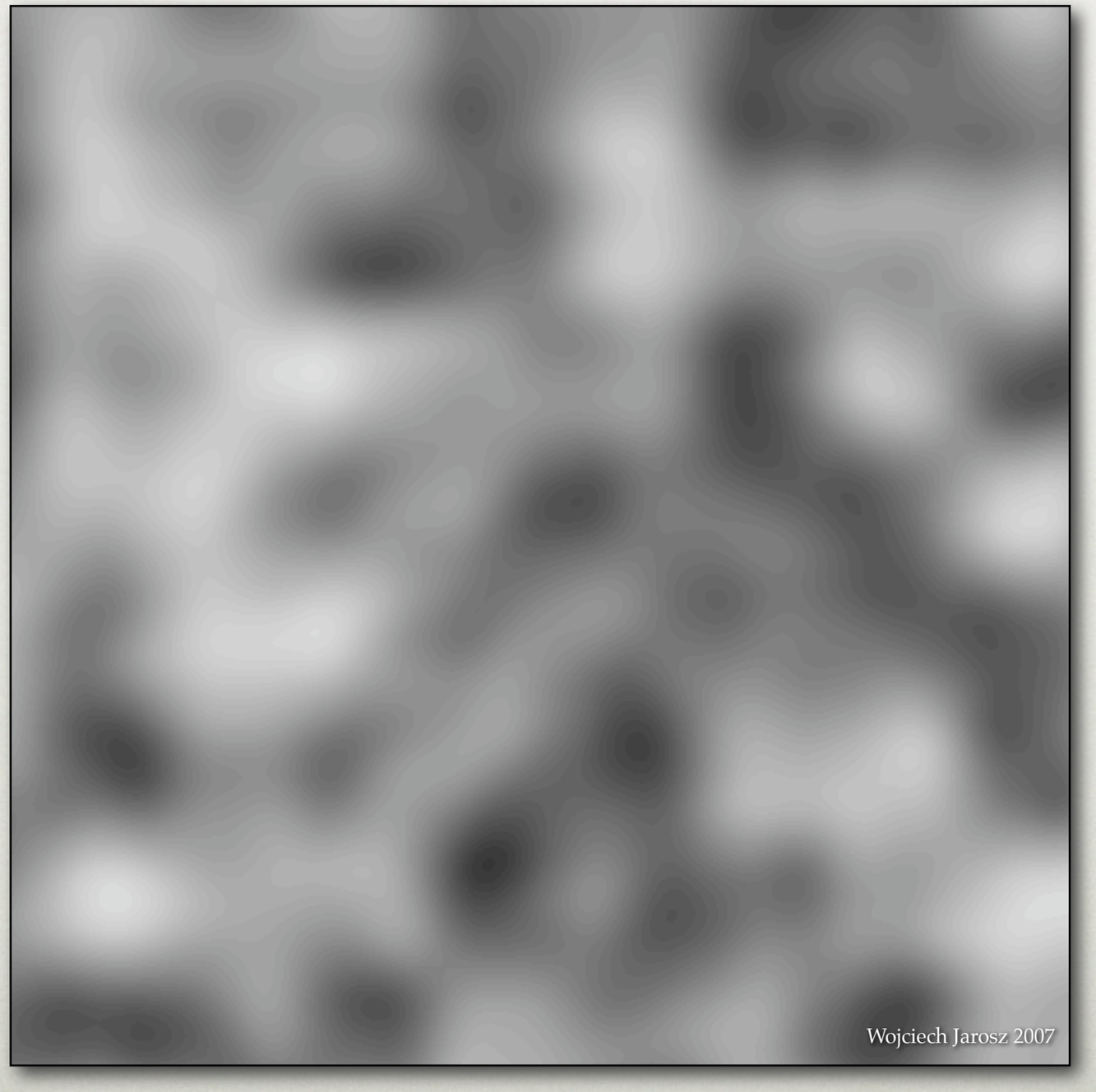


Classic Perlin Noise

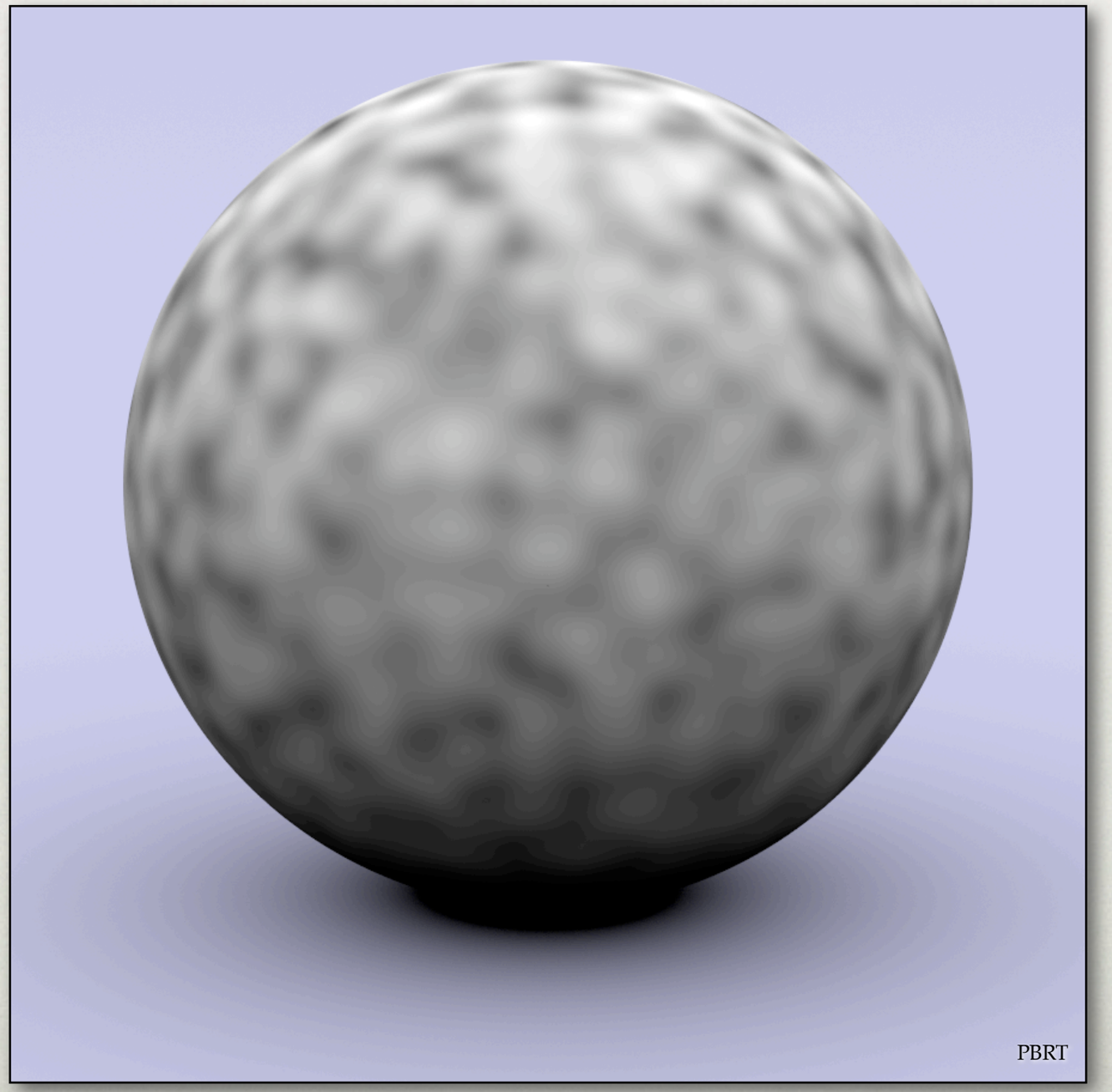
hermite-interpolated values



2D Perlin Noise



3D Perlin Noise



Perlin Noise

- Change amplitude: 10*noise(x)
- Change frequency: noise(10*x)

Spectral Synthesis

- Representing a complex function $f_s(s)$ by a sum of weighted contributions from another function f(x):

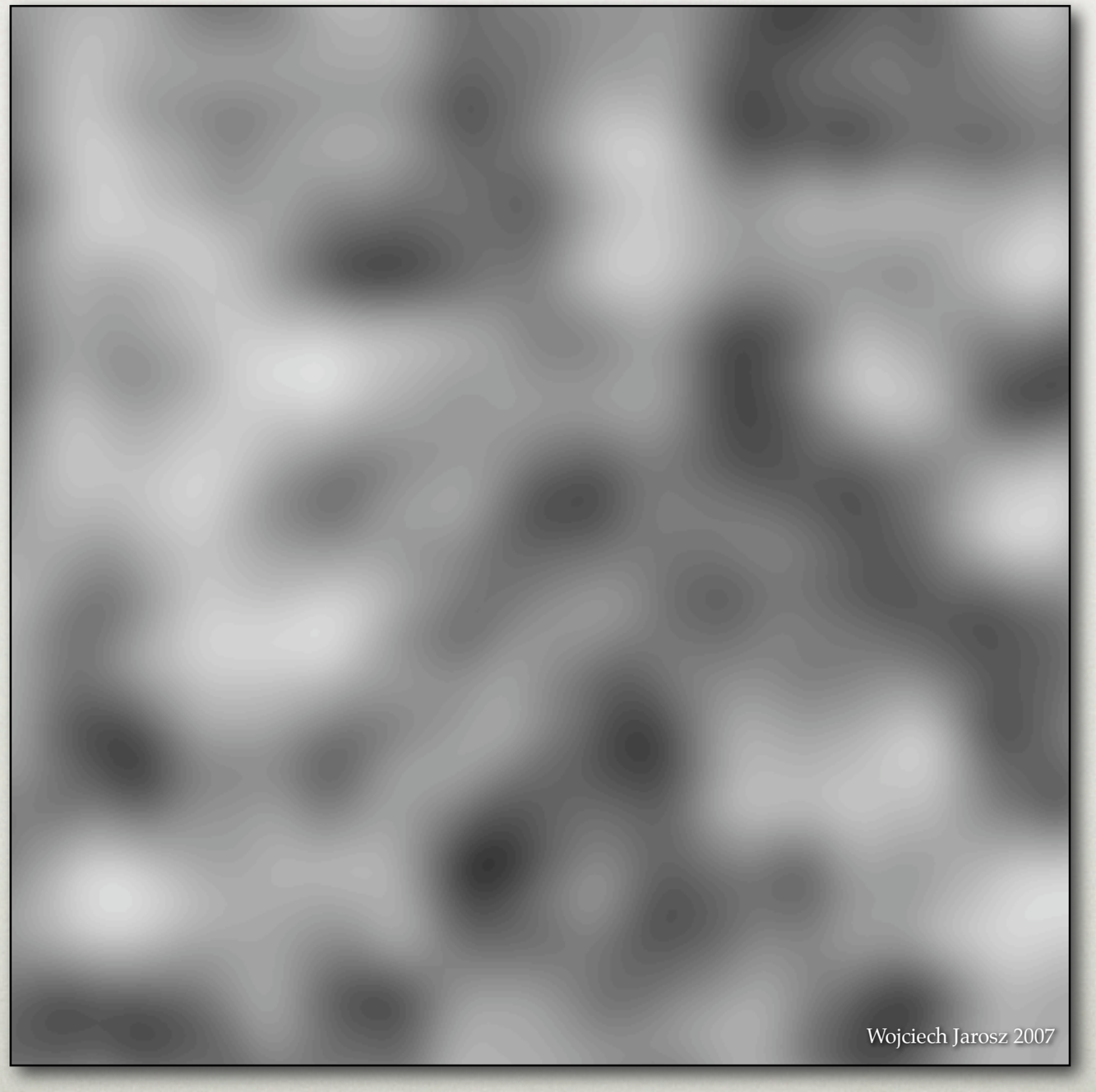
$$f_s(x) = \sum_i \mathrm{w}_i f(s_i x)$$

- Each term in the summation is called an octave.

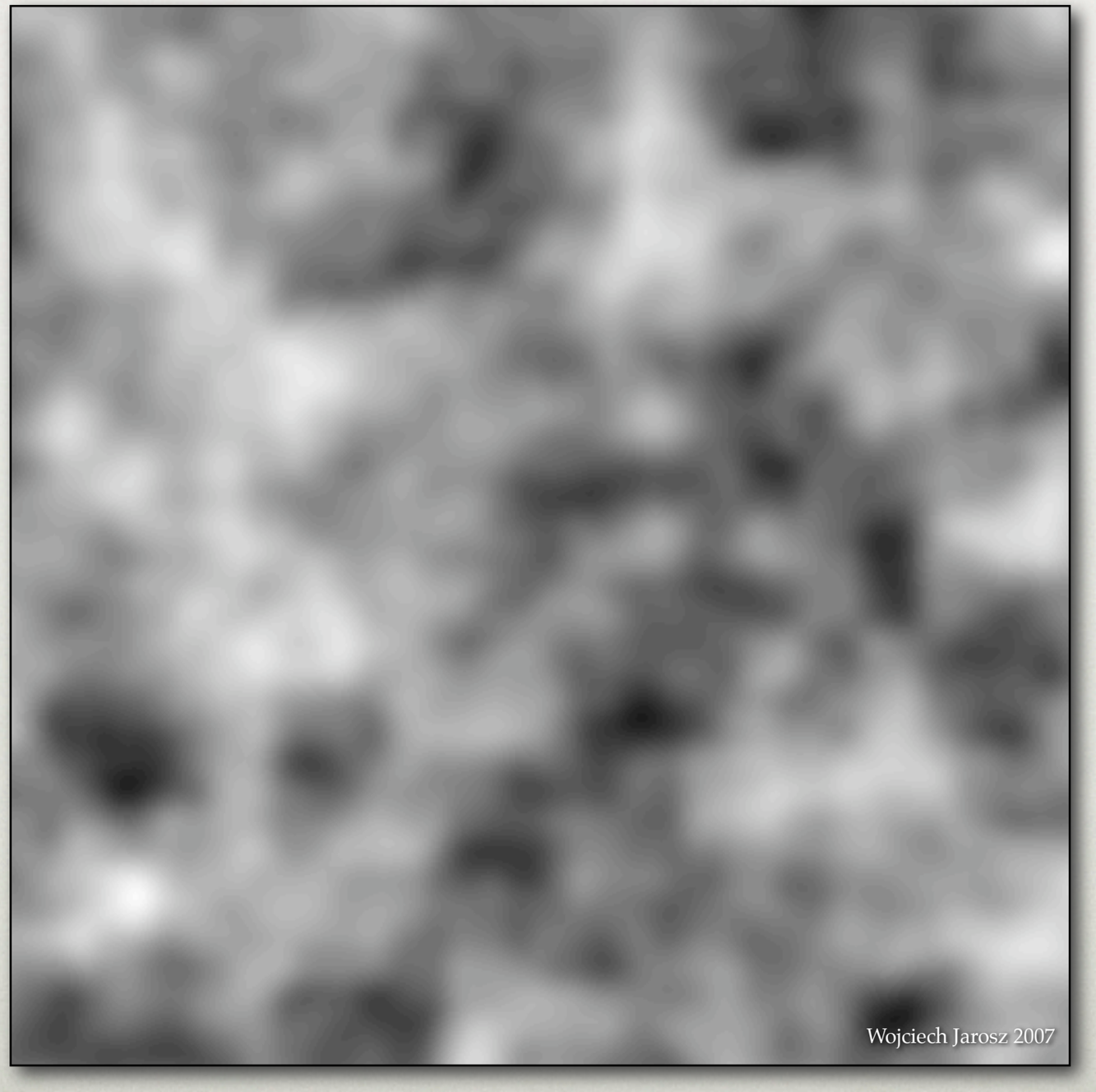
FBm

- Fractional Brownian motion: Spectral synthesis of Perlin noise function.
  - Progressively smaller frequency
  - Progressively smaller amplitude

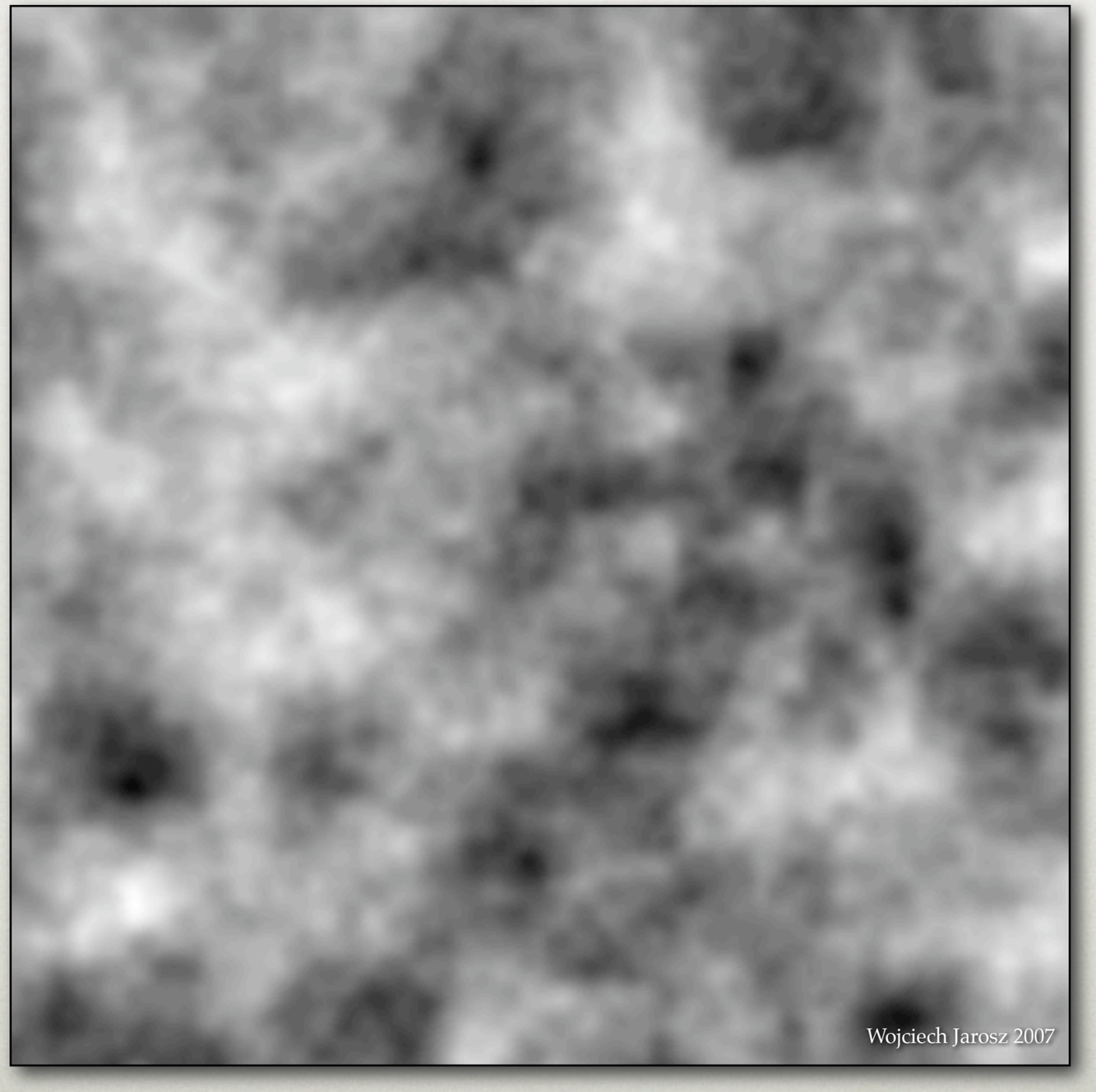
FBm - 1 Octave



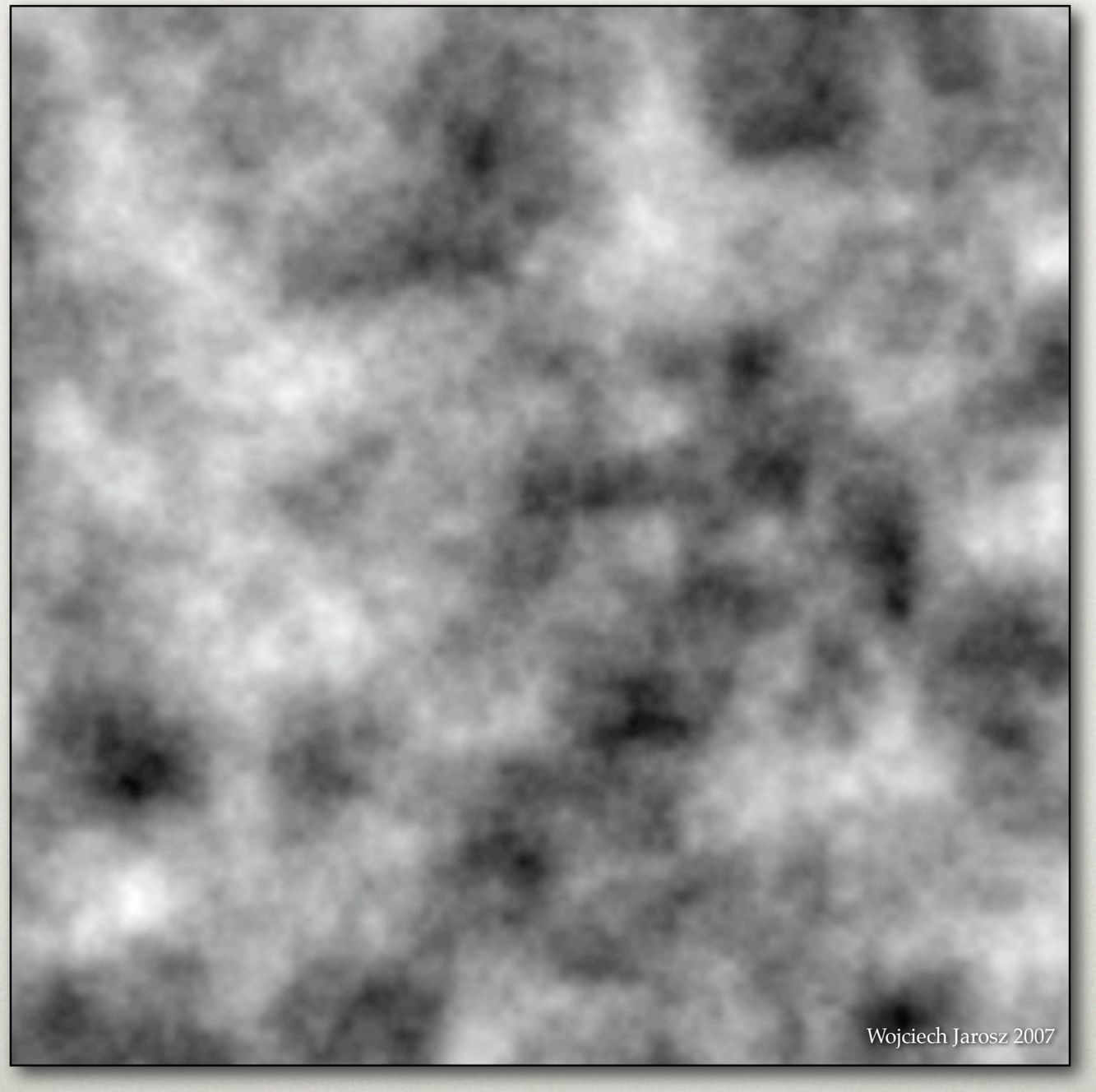
FBm - 2 Octaves



FBm - 3 Octaves



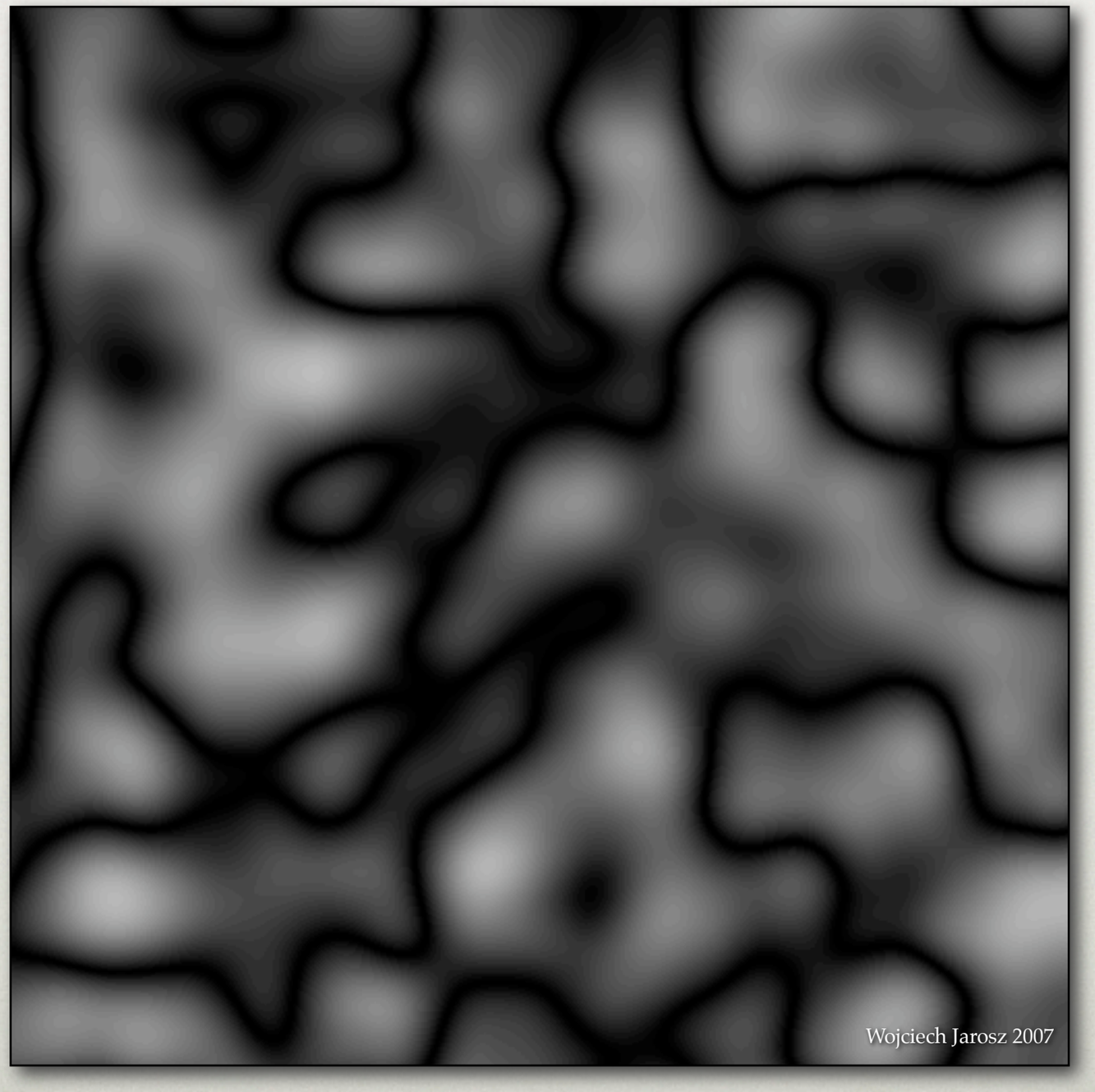
FBm - 4 Octaves



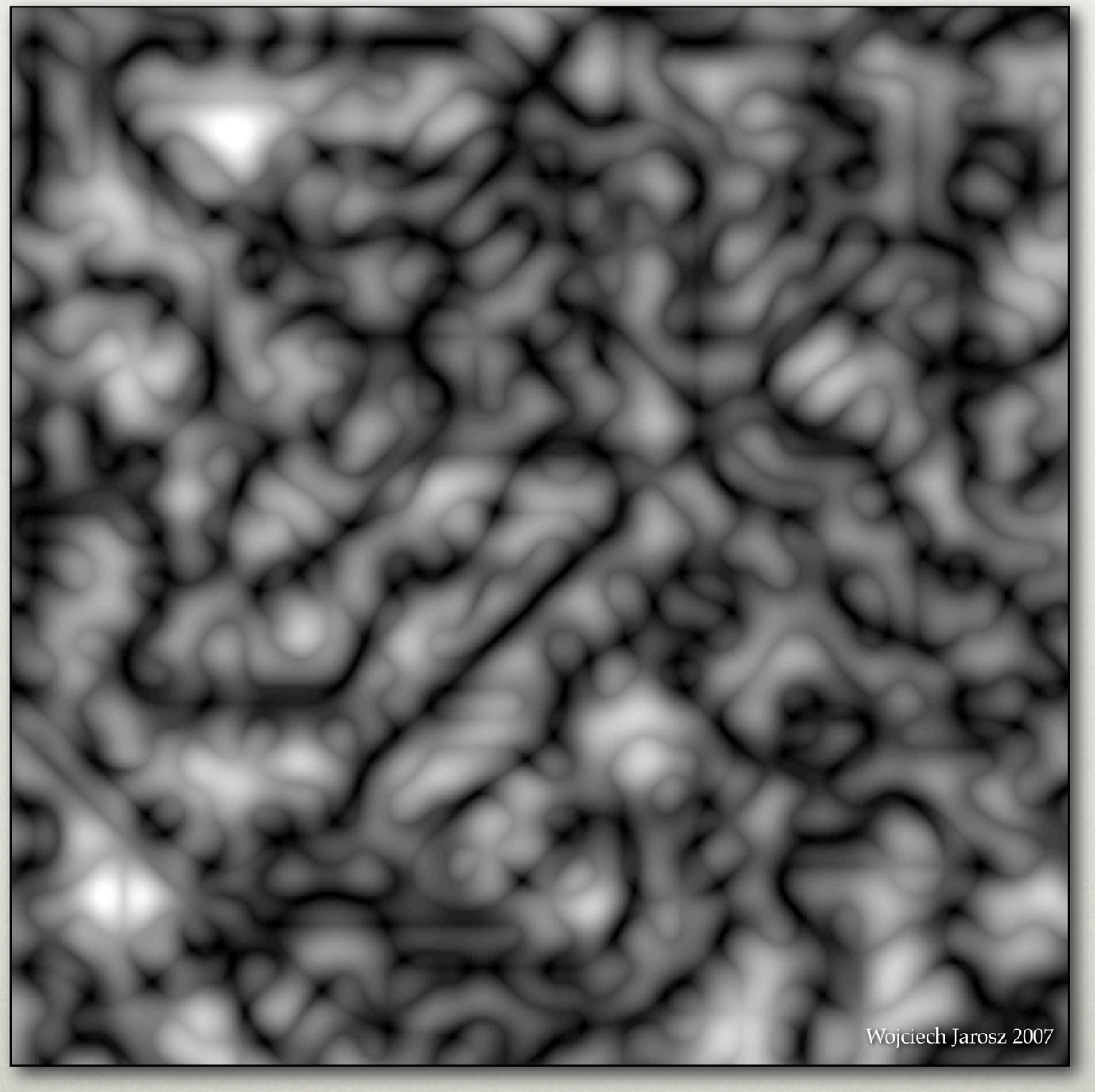
Turbulence

- Same as FBm, but sum absolute value of noise function.

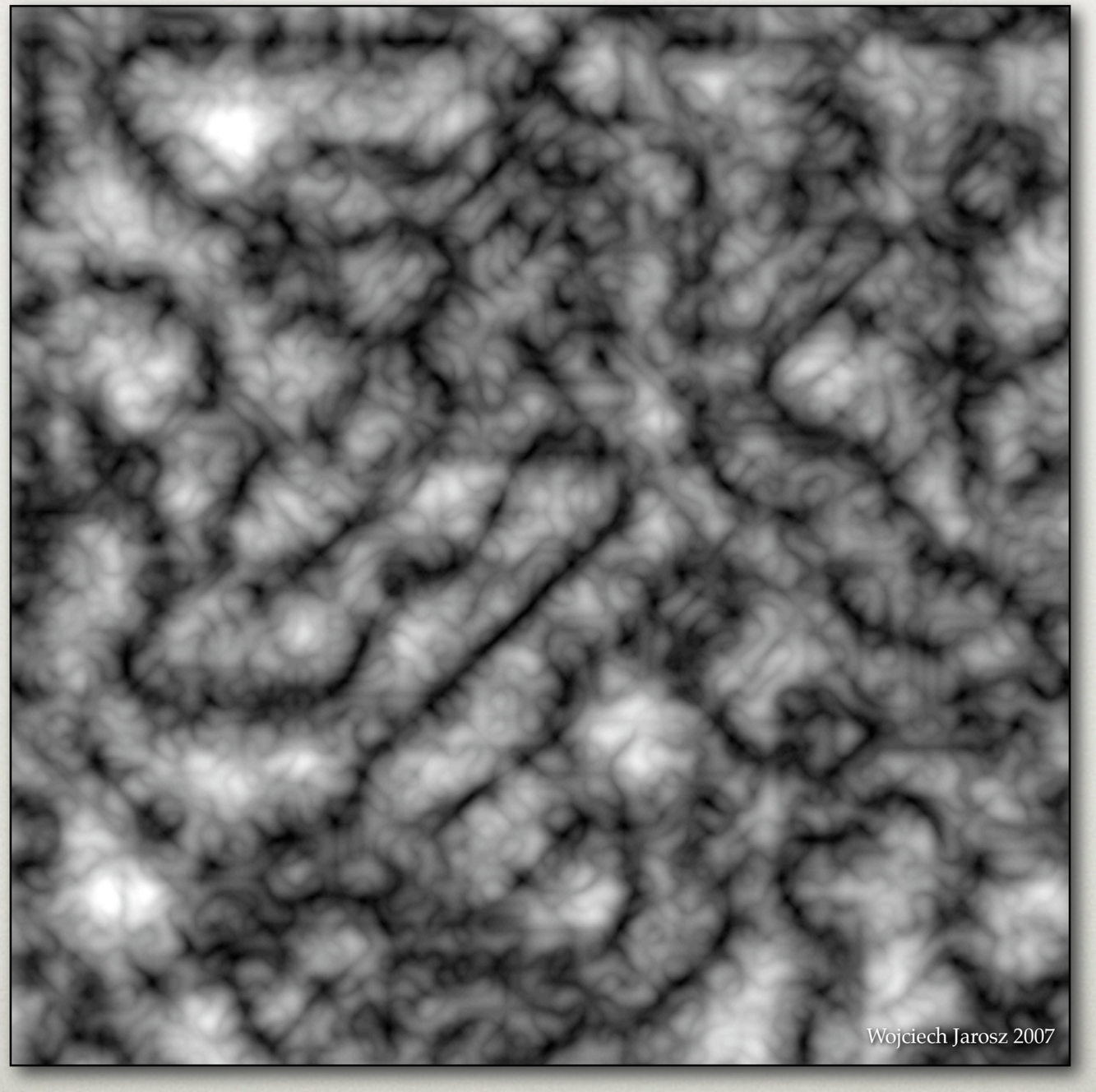
Turbulence - 1 Octave



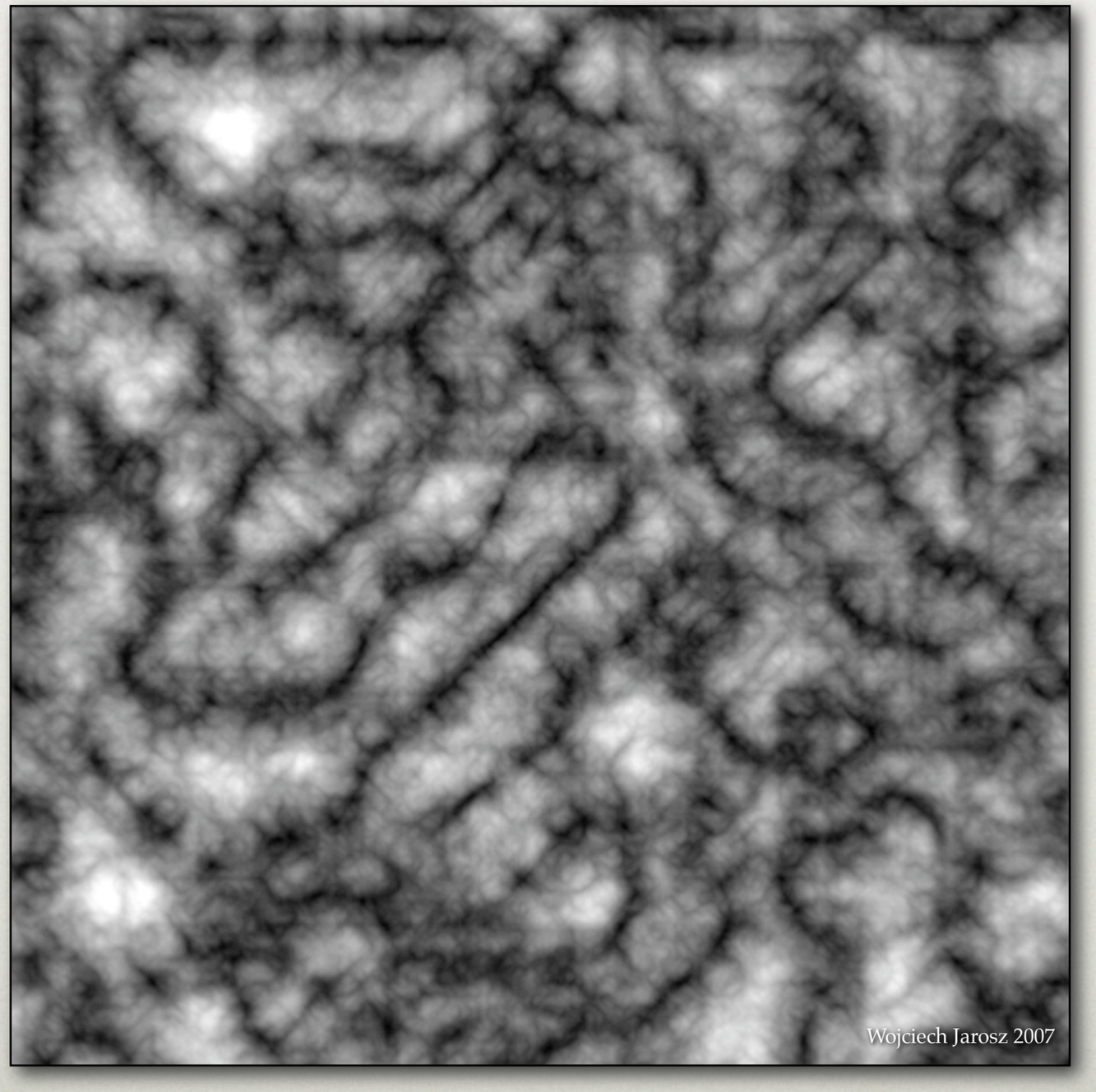
Turbulence - 2 Octaves



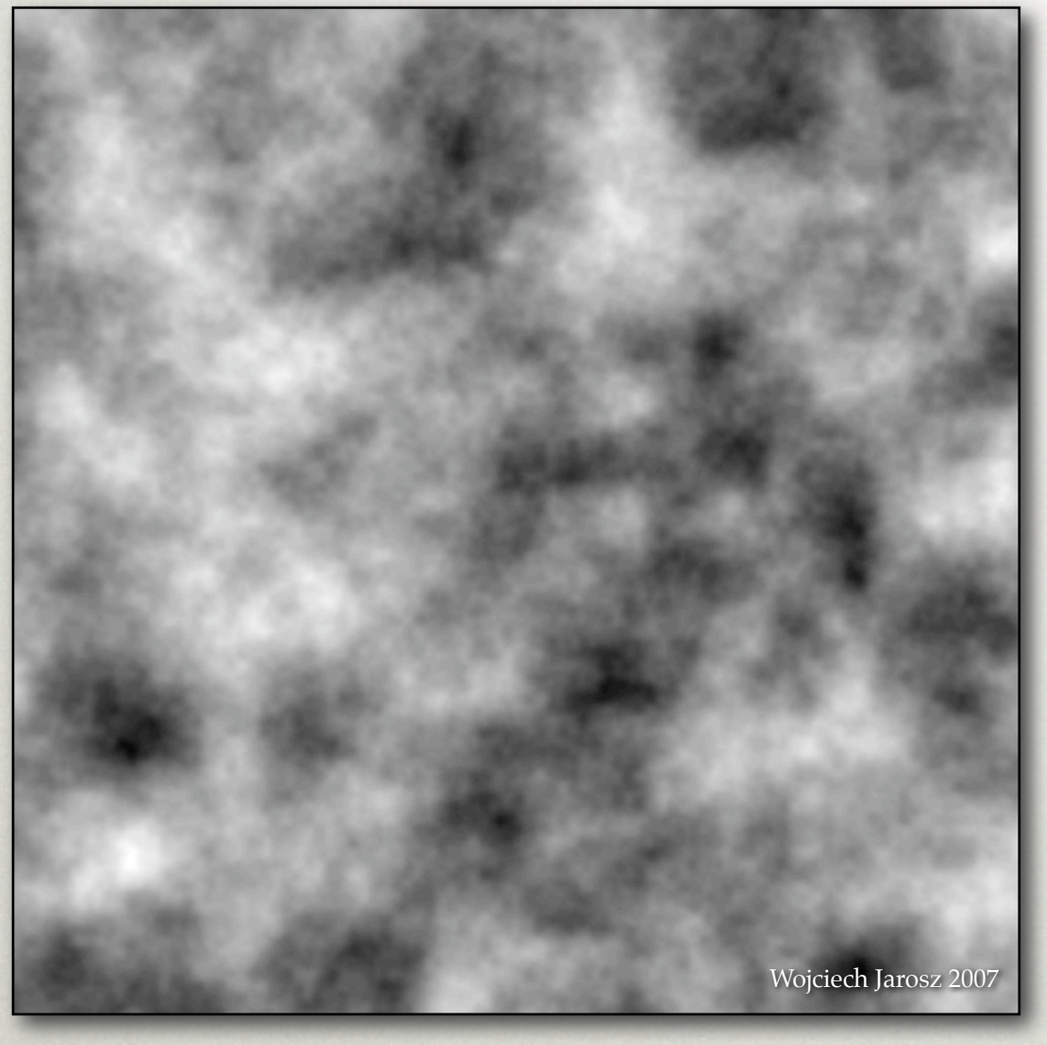
Turbulence - 3 Octaves

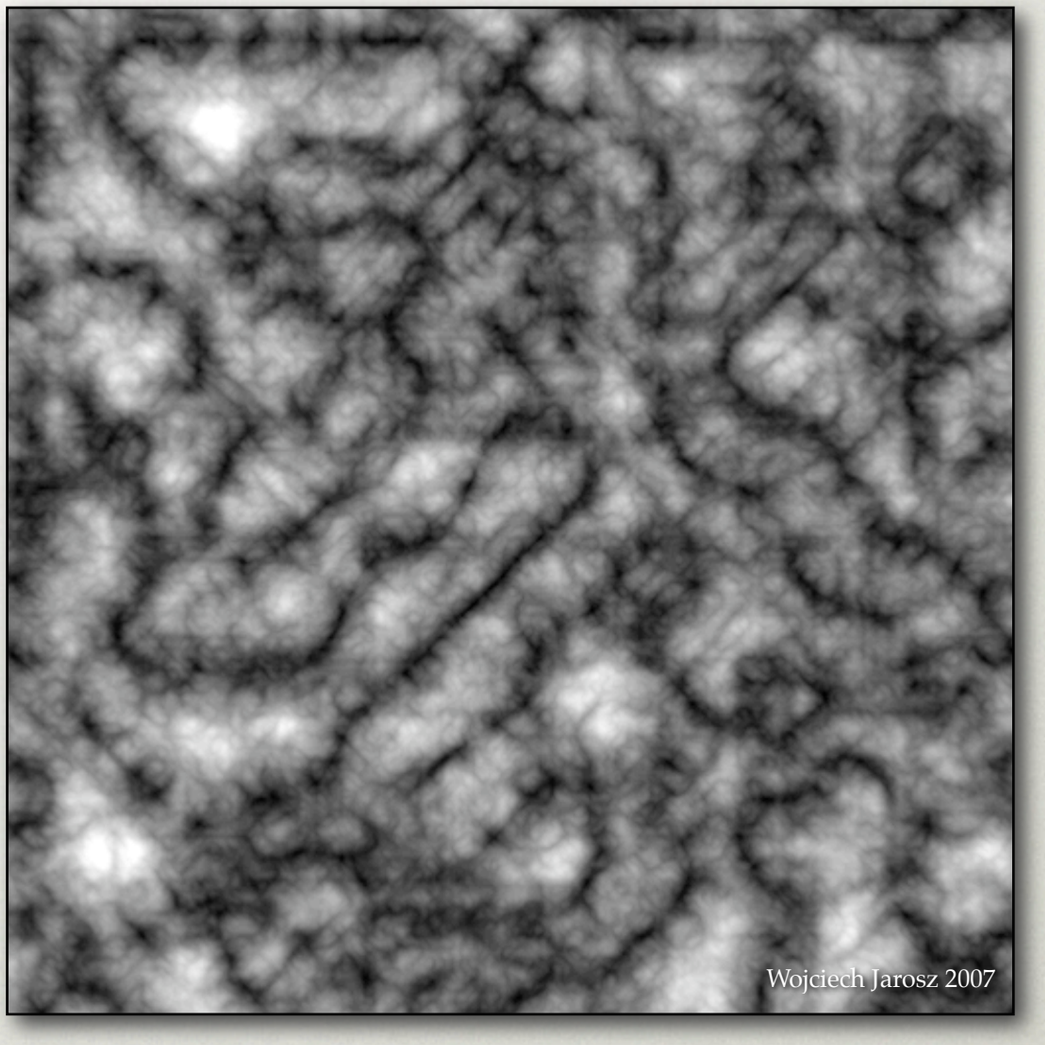


Turbulence - 4 Octaves

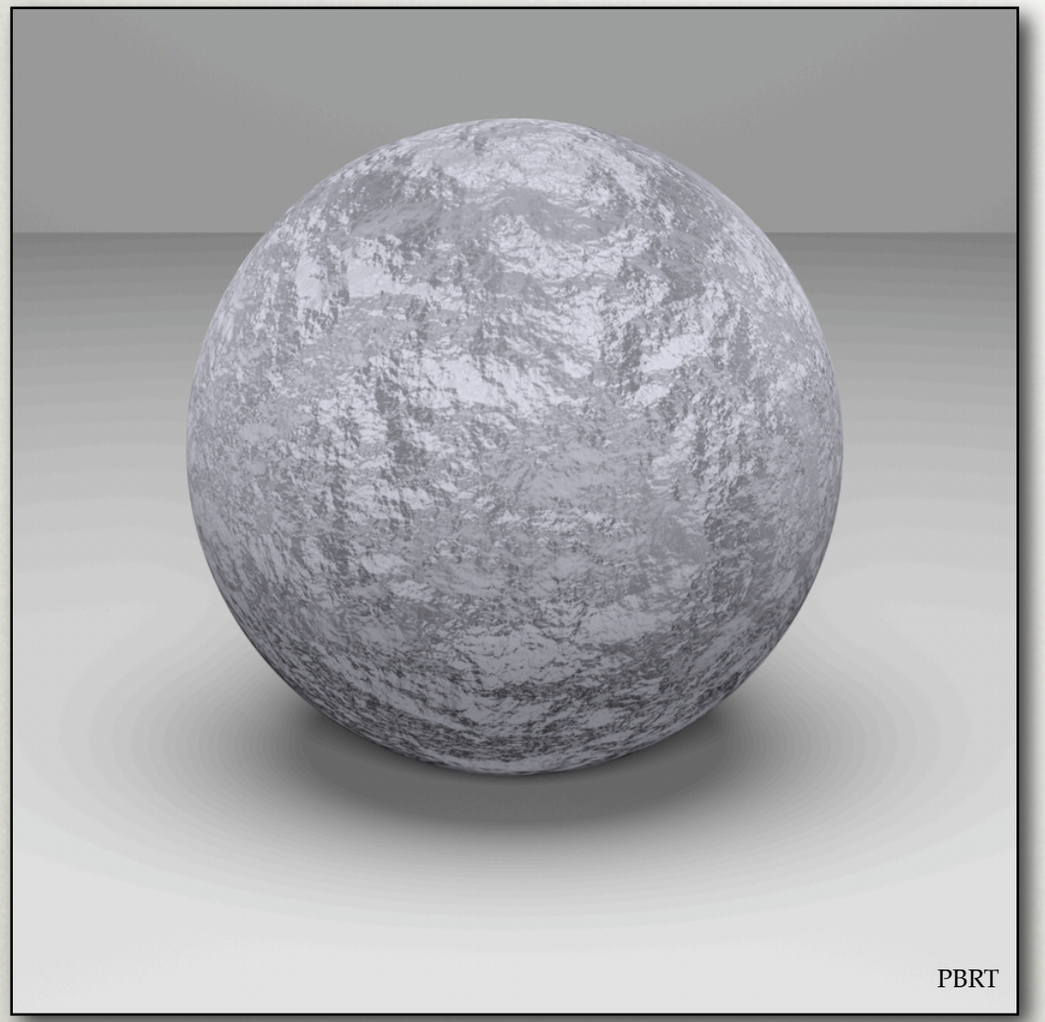


FBm vs Turbulence

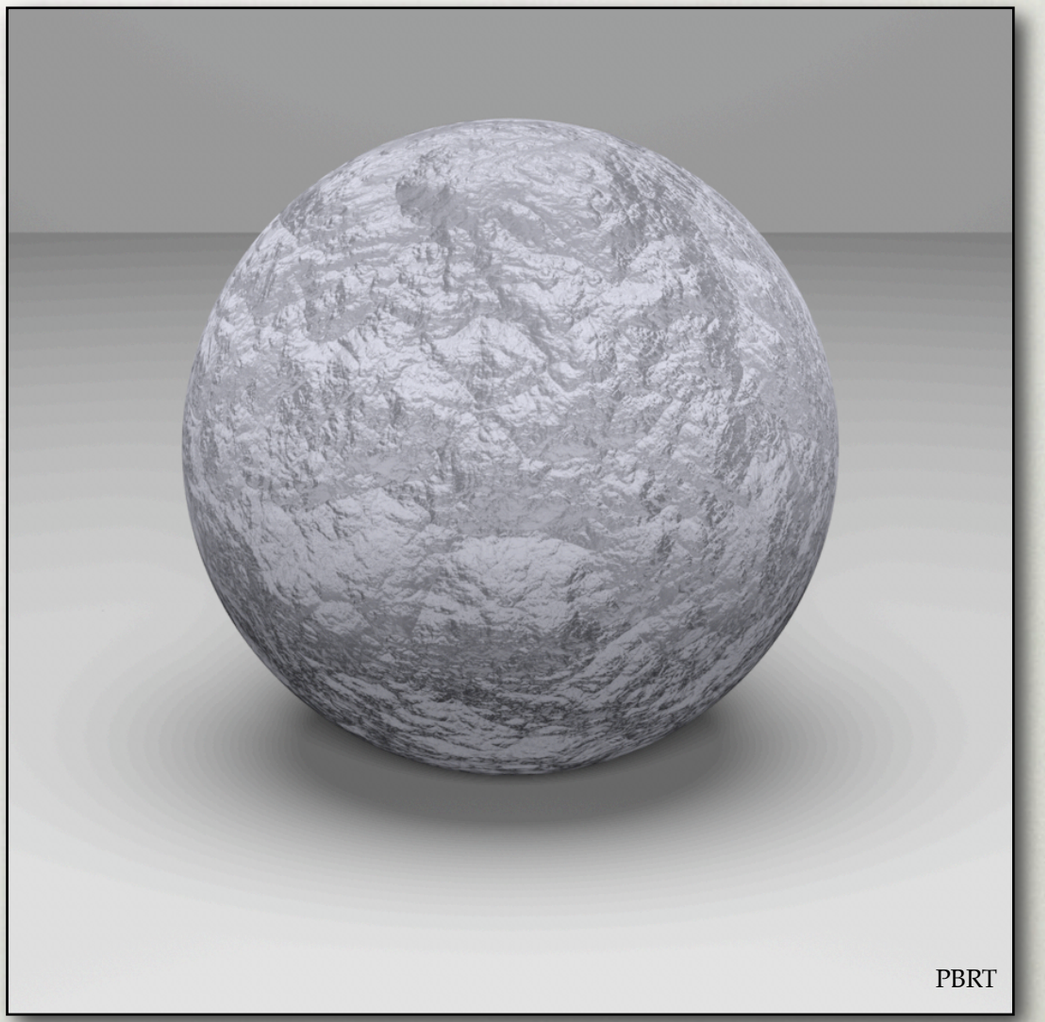




Bump Mapping



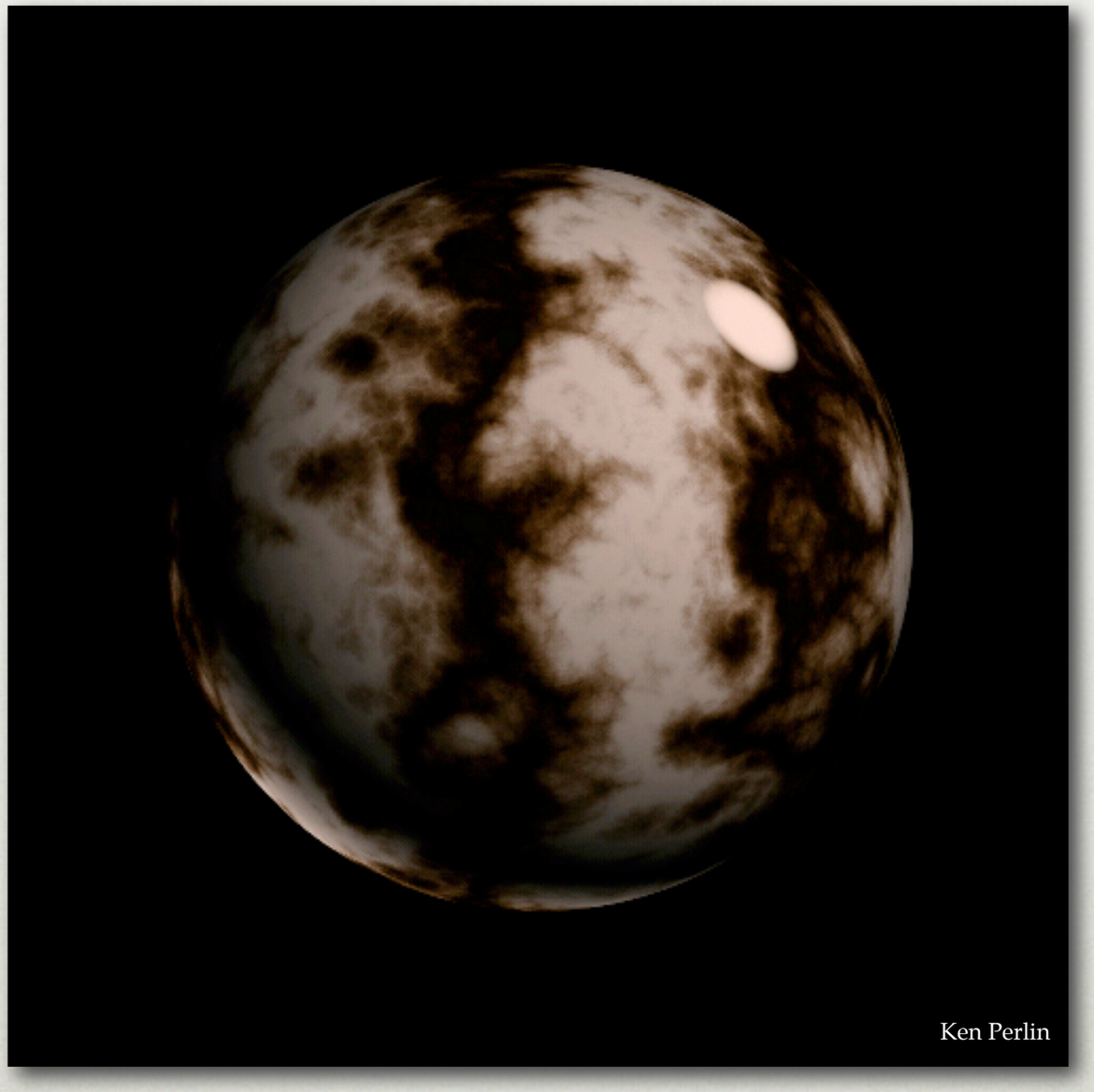
FBm



Turbulence

Noise Demo

Marble



$color = sin(x + \text{turbulence}(x,y,z))$

Wood

$$color = sin(sqrt(x*x+y*y) + \mathrm{FBm}(x,y,z))$$

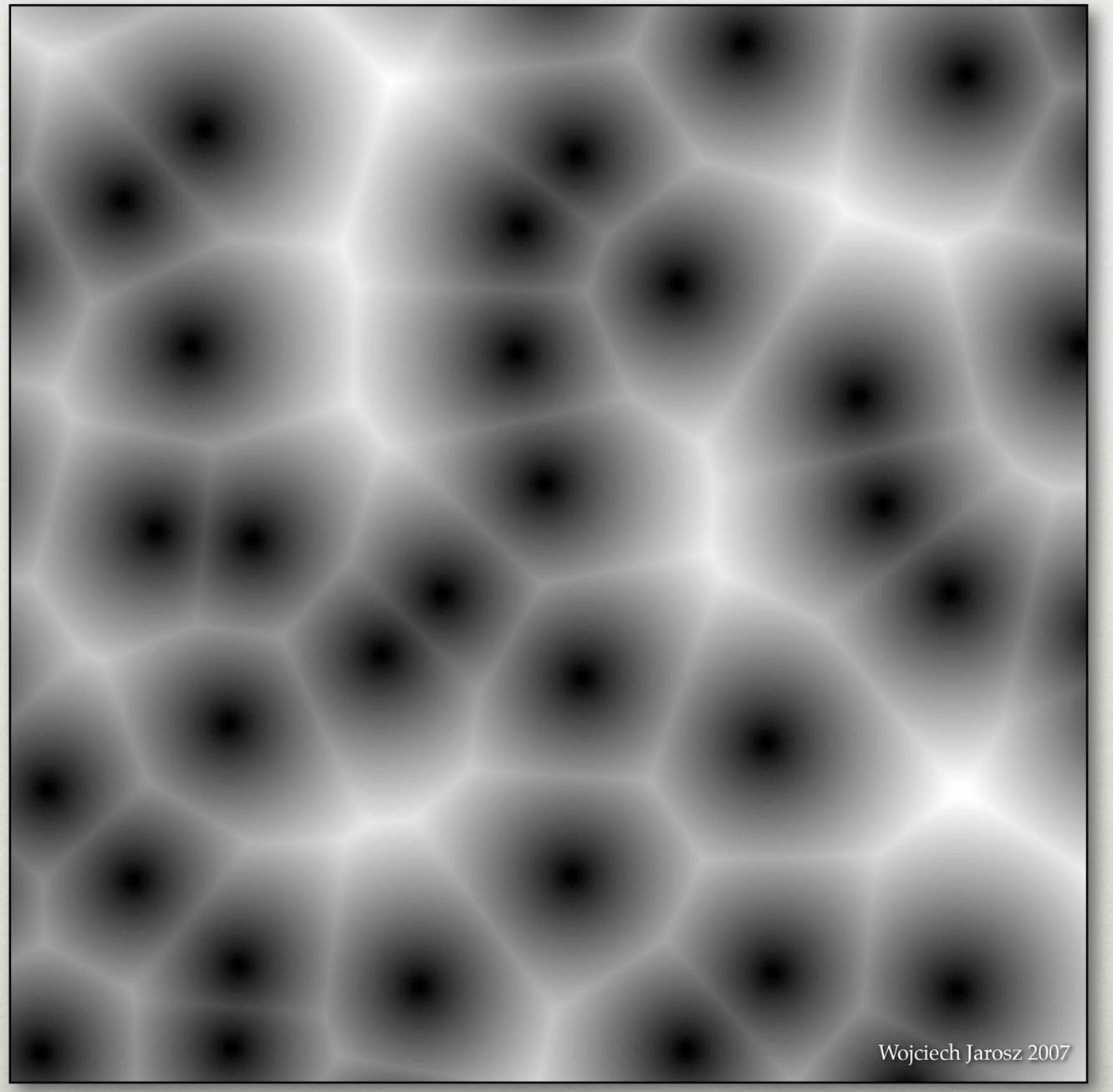
and More...

and More...

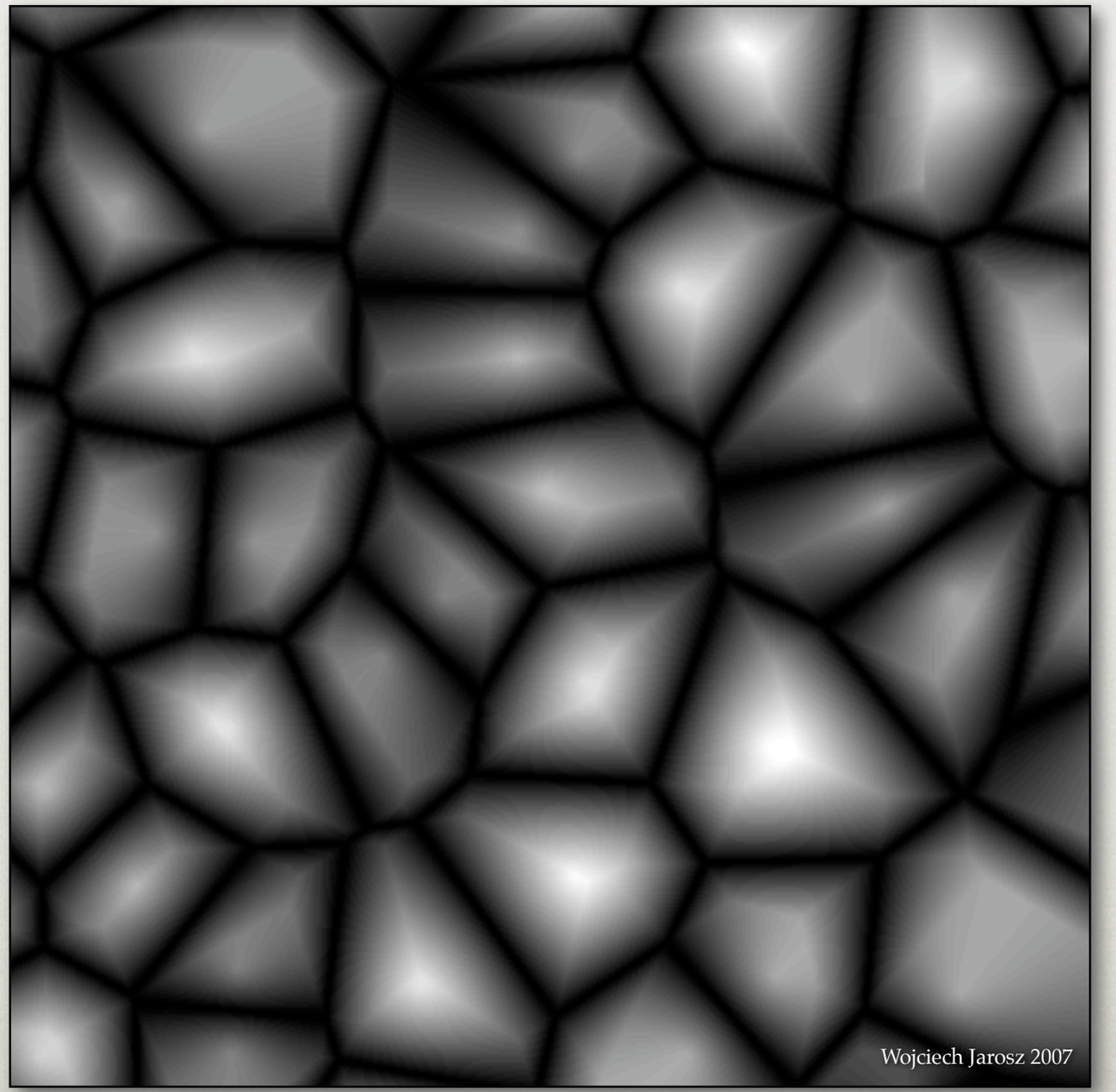
Worley Noise

- In 1996, Steve Worley introduced a cellular texture based function.
  - Randomly distribute “feature points” in space.
  - $F_n(x)$ = distance to n^{th} closest point to x.

2D Worley Noise: F1

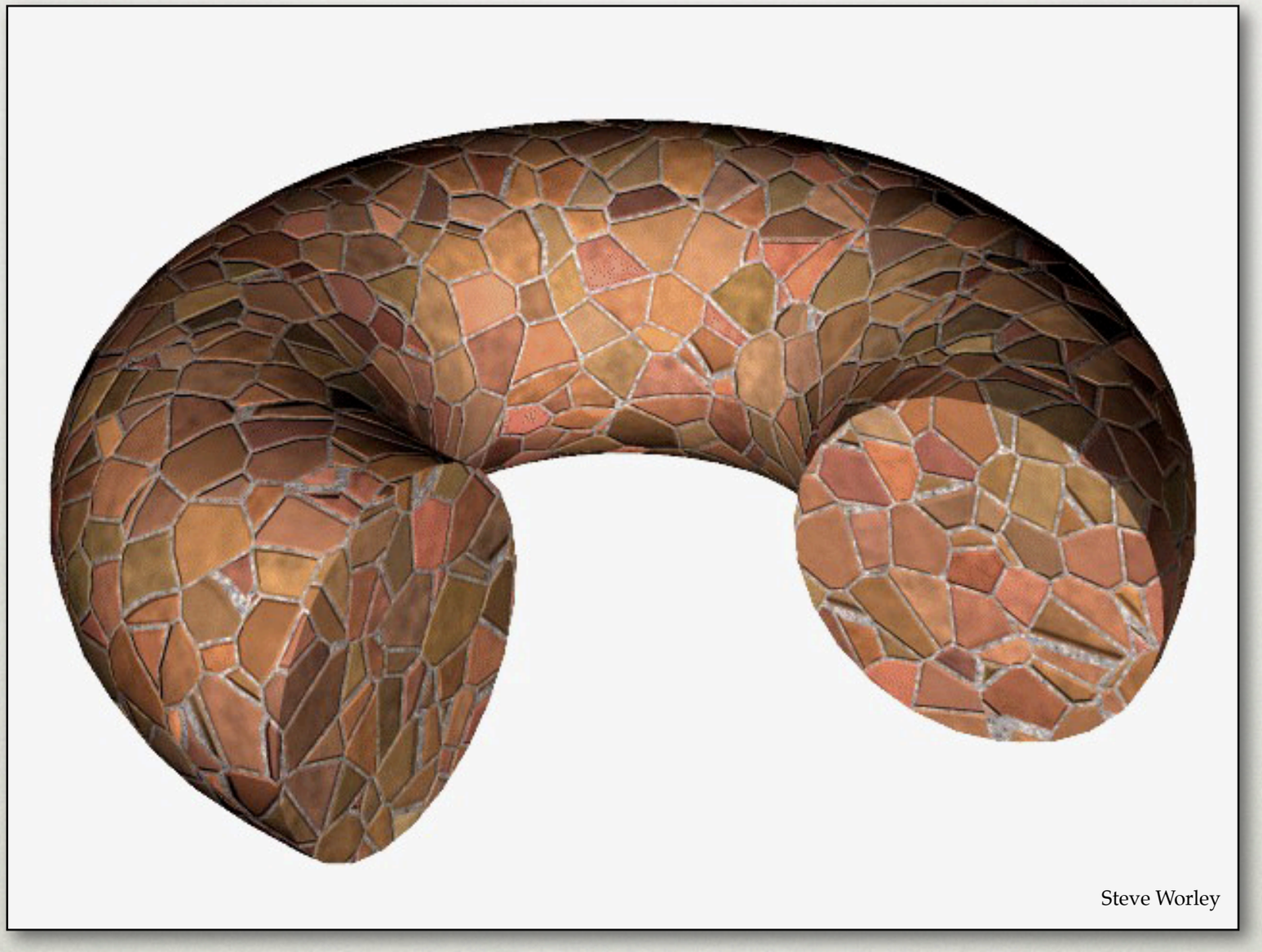


2D Worley Noise: F2-F1



Noise Demo

3D Worley Noise



F2-F1

Worley Noise

Fractal F1-F4 combinations

Worley Noise

Fractal F1, color and bump map

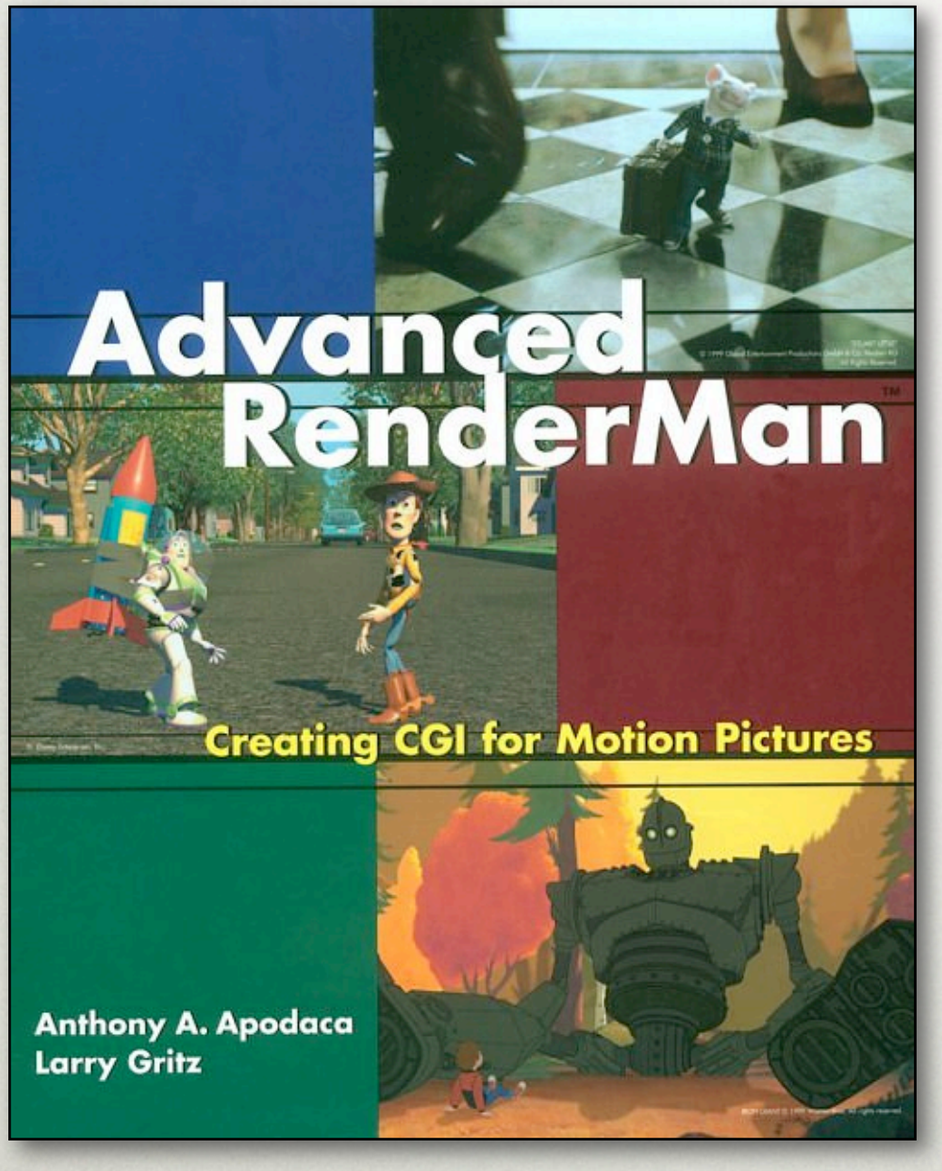
Worley Noise

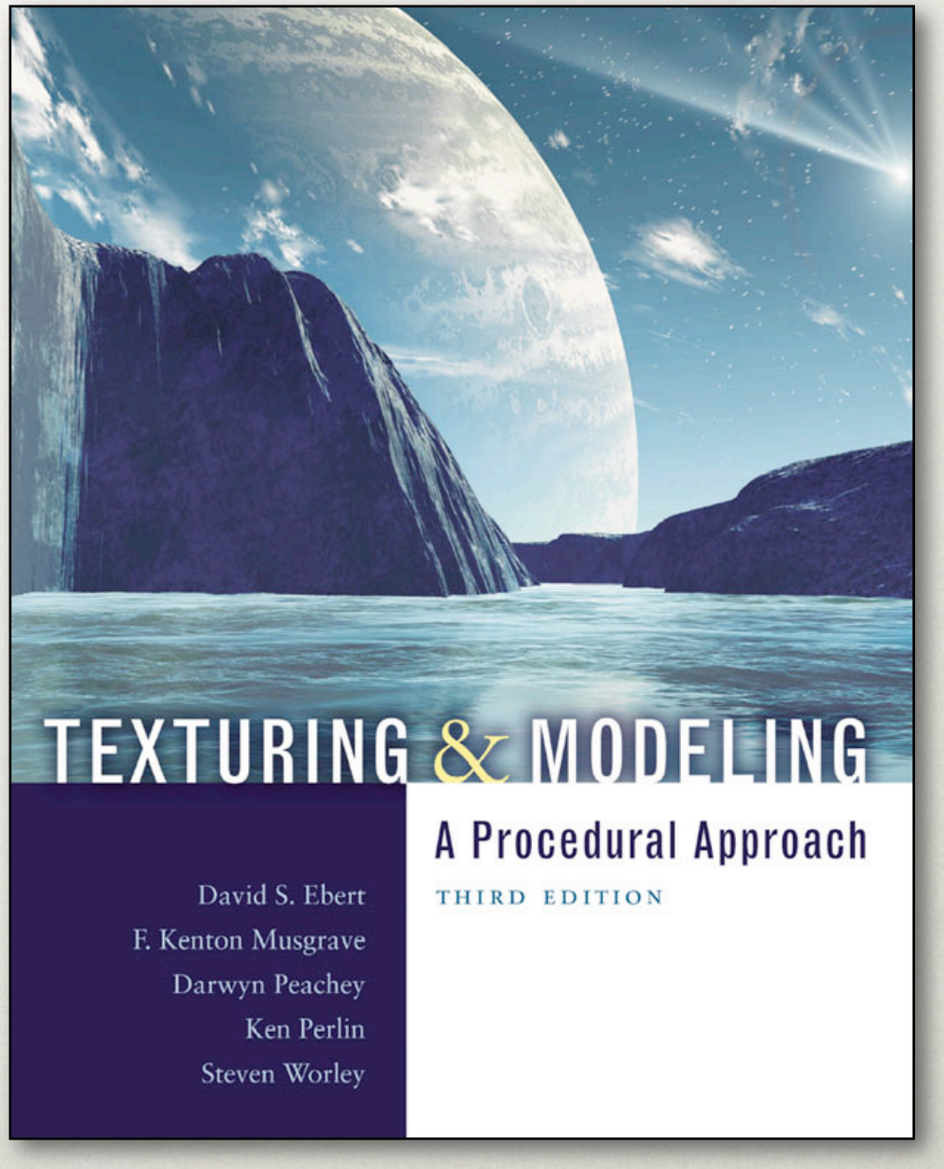
Fractal F1, bump map

Worley Noise

Fractal F1, bump map

Other Resources





Assignment 3

- Shading and Texturing
  - Reflections / refractions
  - HDR environment mapping
  - Procedural textures
  - Global illumination
  - and more!

Questions?