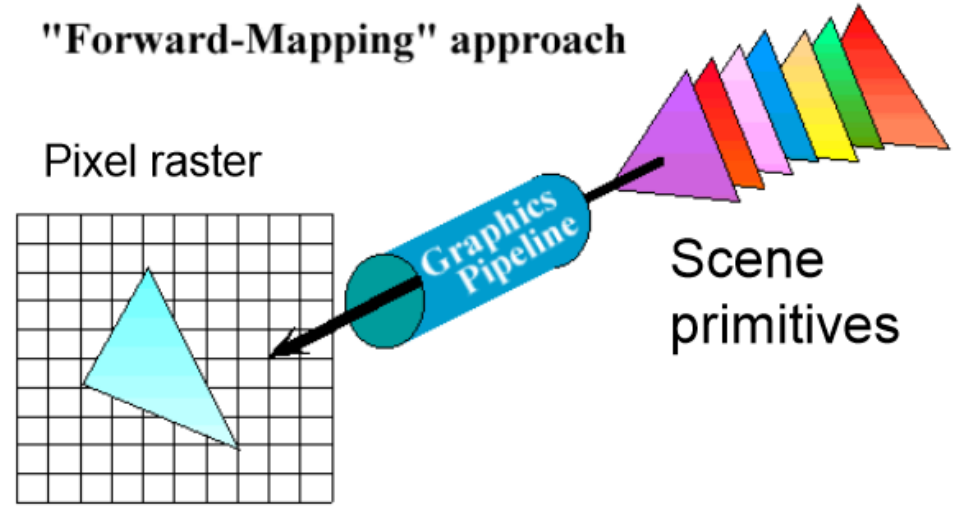
Advanced image synthesis

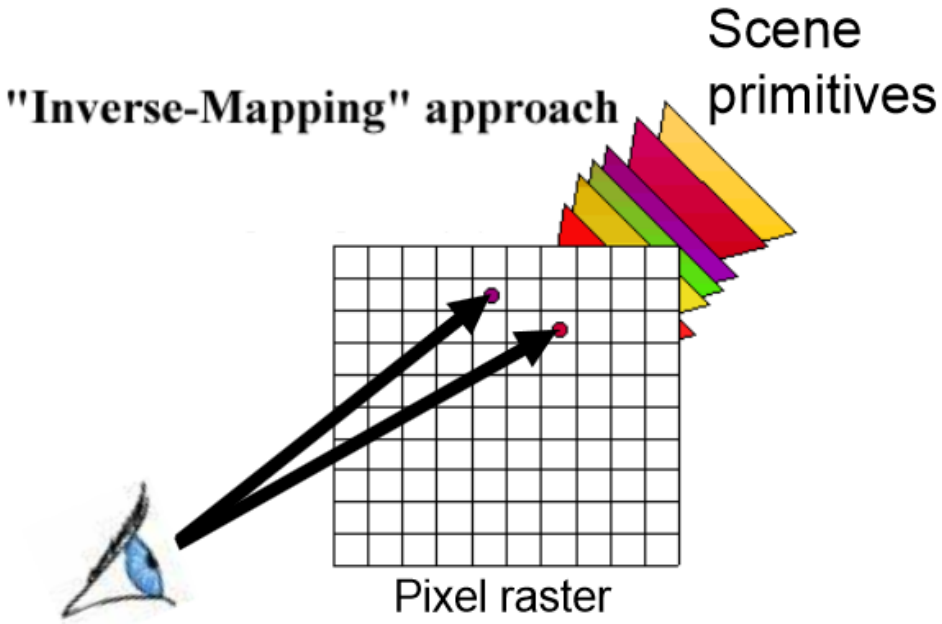
Romain Vergne – 2014/2015

Rasterization VS ray-casting

- For each triangle
  - Project triangle to image plane
  - For each pixel
    - Check pixel in triangle
    - Resolve visibility with z-buffer

- For each pixel
  - Compute pixel ray
  - For each triangle
    - Check ray-triangle intersection
    - Get closest intersection

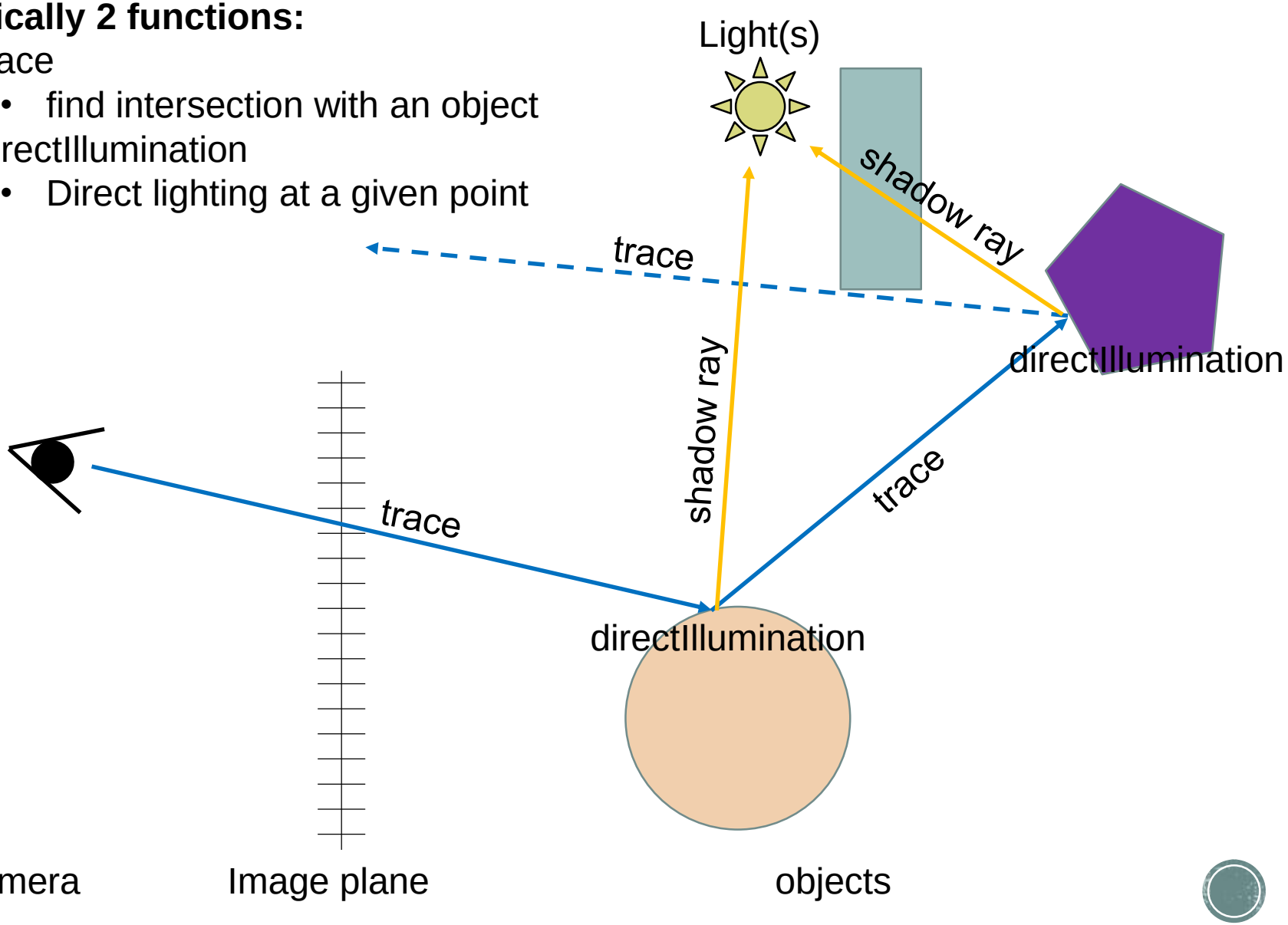




Ray tracing

Basically 2 functions:

- trace
  - find intersection with an object
- directIllumination
  - Direct lighting at a given point



Ray tracing

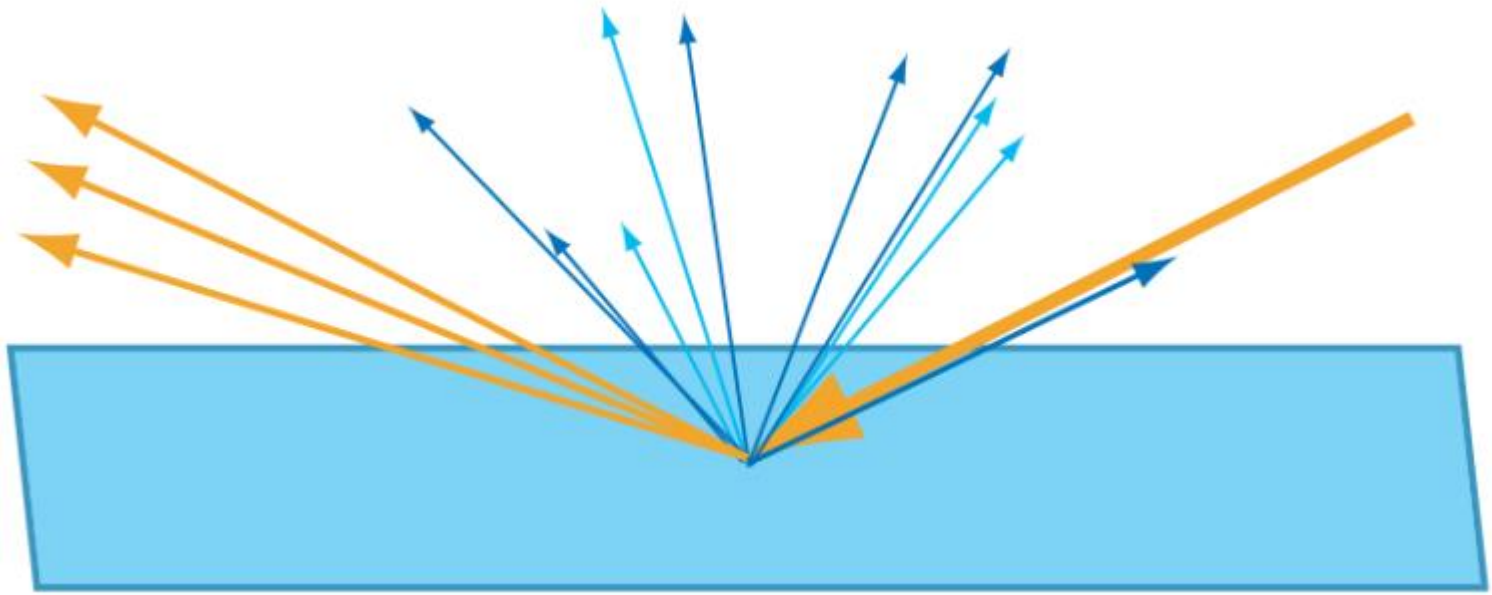
- color trace(ray) {
  - hit = intersectScene(ray)
  - if(hit) {
    - color = directIllumination(hit)
    - if hit is reflective
      - color += c_refl * trace(reflected ray)
    - if hit is transmissive
      - color += c_trans * trace(refracted ray)
  - } else
    - color = background_color
  - return color
- }

Ray tracing

- color directIllumination(hit) {
  - color = (0,0,0)
  - for each light L {
    - T = cast shadow ray to L
    - if hit is not shadowed by L
      - color += Ambient+diffuse+specular terms(L,hit)
  - }
  - return color
- }

Physics → Maths

- Radiance
  - radiometric quantity used mesure the amount of light along a single ray
  - Spectral quantity (RGB in practice), Watt per steradian per square meter
- If shading can be handled locally, light response depends on
  - Light direction
  - View direction



Physics → Maths

- **B**idirectionnal
- **R**eflectance
- **D**istribution
- **F**unction

$$f(\mathbf{l}, \mathbf{v})$$

$$L_o(\mathbf{v}) = \int_\Omega f(\mathbf{l}, \mathbf{v}) \otimes L_i(\mathbf{l})(\mathbf{n} \cdot \mathbf{l}) d\omega_i$$

Outgoing radiance

BRDF

Ingoing radiance

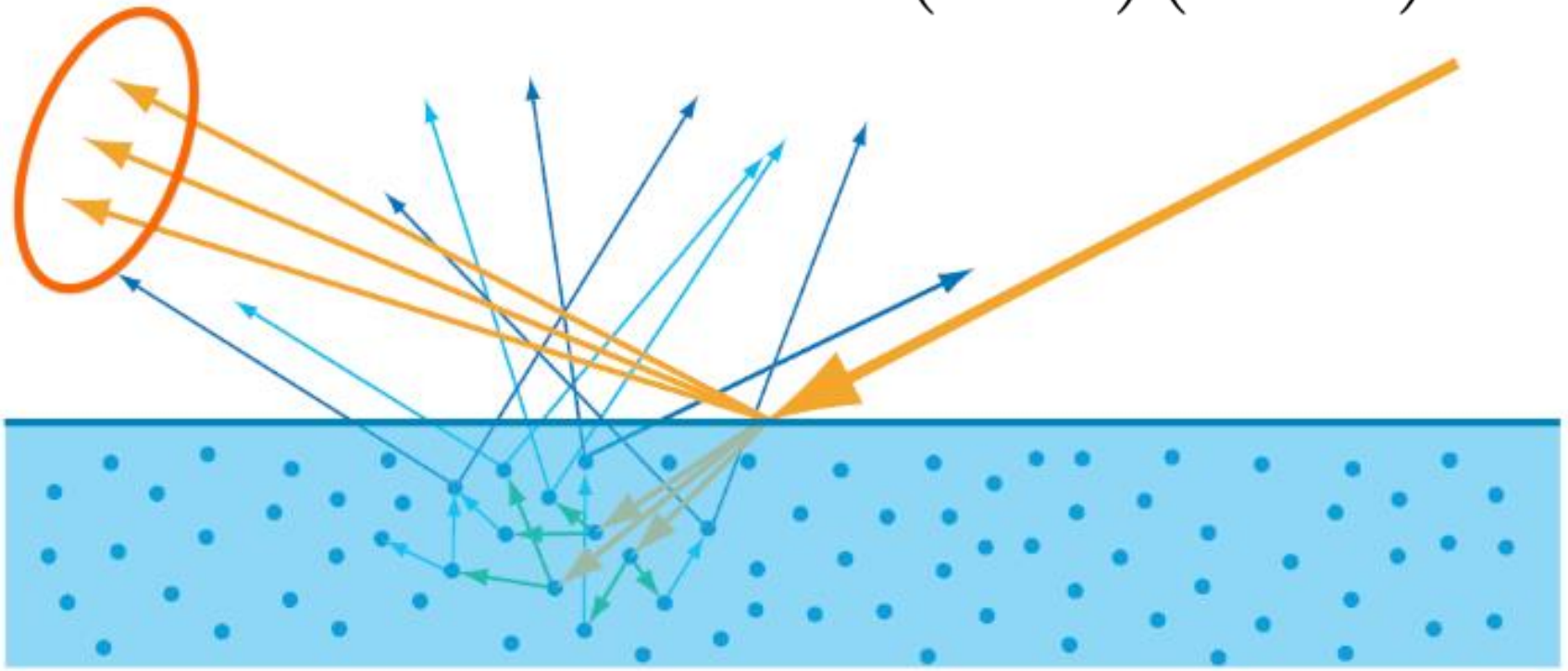
Surface orientation

Reflectance equation

Microfacet theory

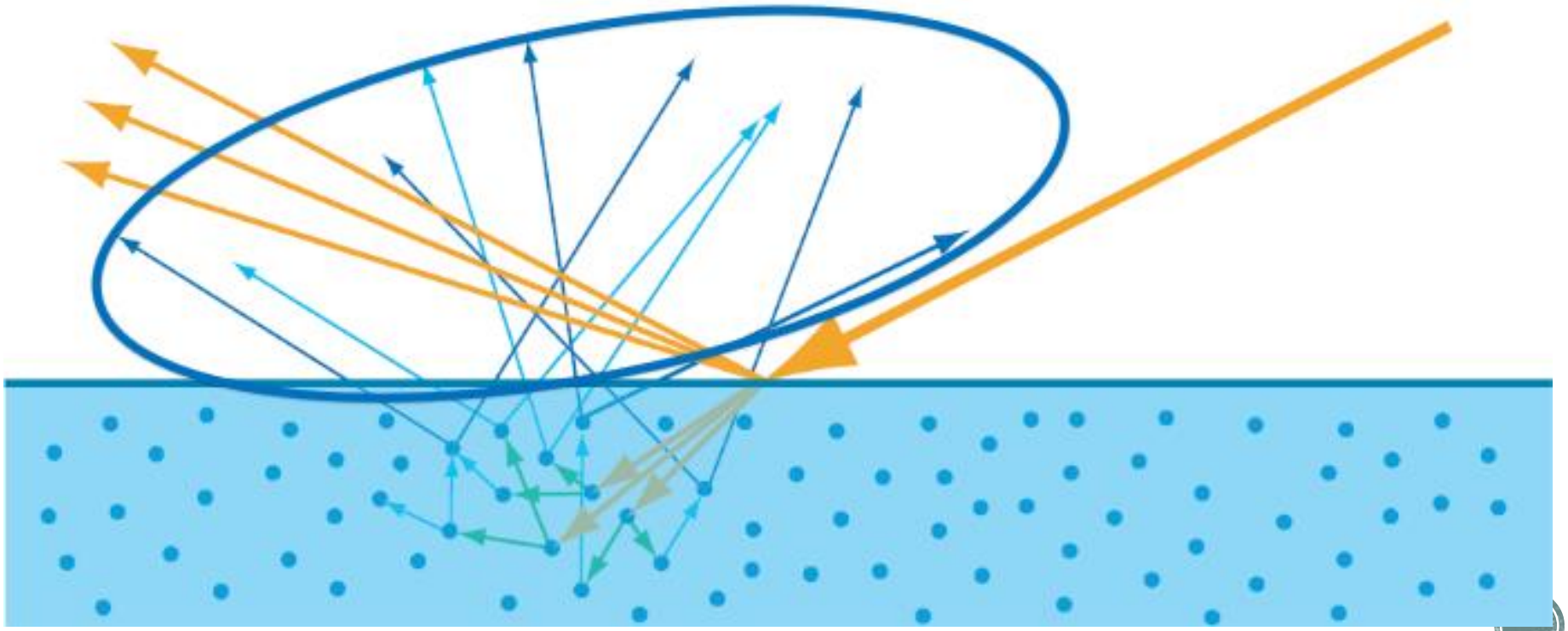
- Surface reflection (specular term)

$$f(\mathbf{l},\mathbf{v}) = \frac{F(\mathbf{l},\mathbf{h})G(\mathbf{l},\mathbf{v},\mathbf{h})D(\mathbf{h})}{4(\mathbf{n}\cdot\mathbf{l})(\mathbf{n}\cdot\mathbf{v})}$$



Microfacet theory

- Subsurface reflection (diffuse term)
  - Constant: $f_{\text{Lambert}}(\mathbf{l}, \mathbf{v}) = \frac{\mathbf{c}_{\text{diff}}}{\pi}$



Spatial variation

- All materials seen so far are the same everywhere…

Spatial variation

- All materials seen so far are the same everywhere…
  - No real reason to make this assumption



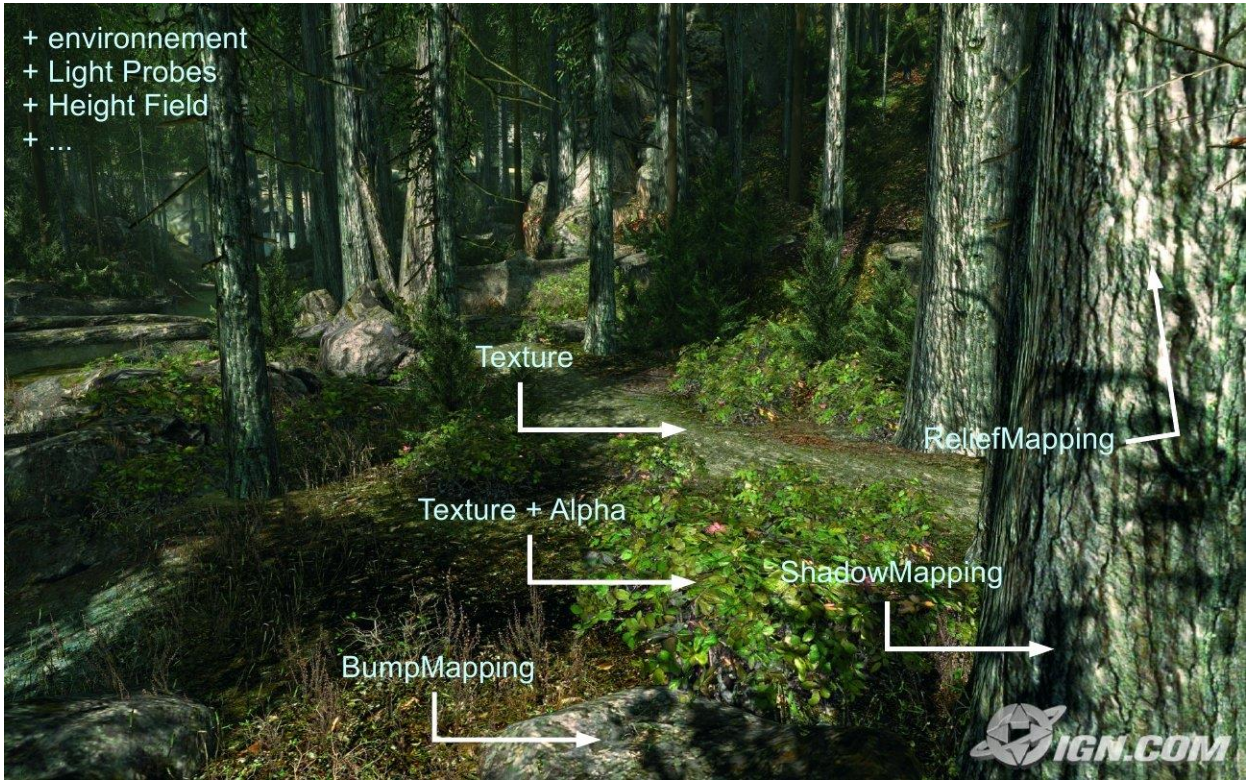



Spatial variation

- Allow BRDF parameters to vary over space
  - Diffuse / specular colors, roughness, normal

Spatial variation

- Textures are used for representing all elements
  - Material (BRDFs, BTFs)
  - Geometry (normal / bump / displacement maps)
  - Lighting (light / environment maps)

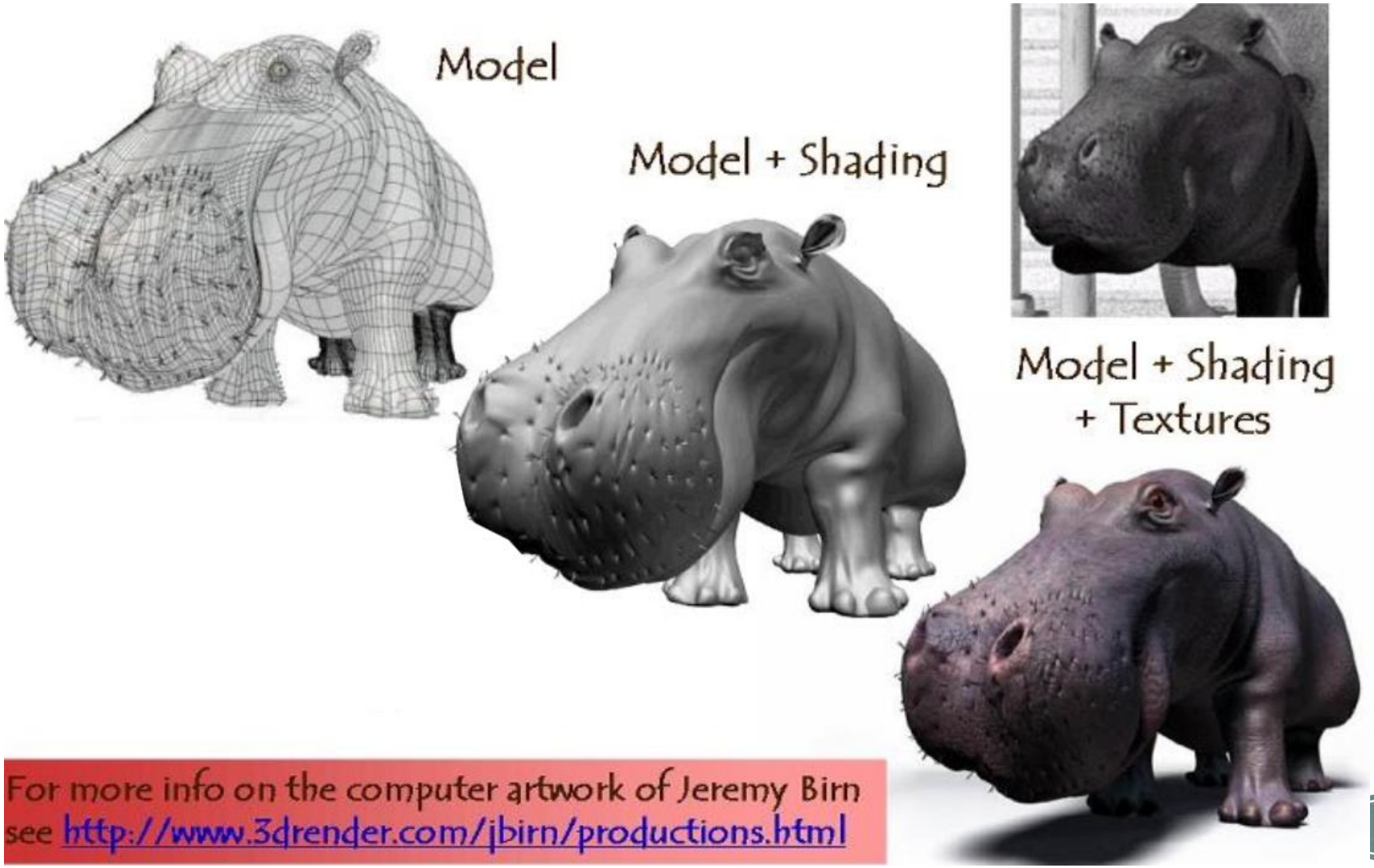


The bad idea

- Store BRDF properties on each vertex
  - Refine / tesselate if necessary
- On a given point, interpolate properties (barycentric coords)
- But:
  - Details mean (much) more geometry/memory
  - Only works on meshes

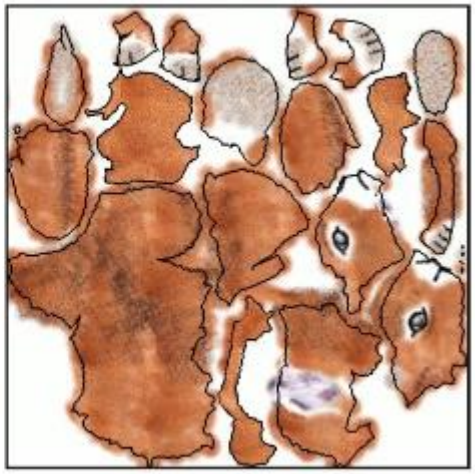
The good idea

- Use textures



2 approaches

- From data
  - Colors, coefs, normals stored in 2D images



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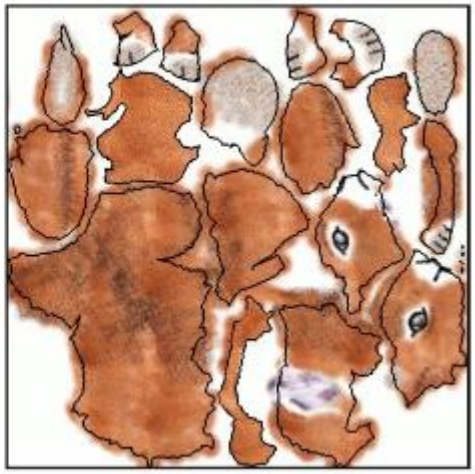
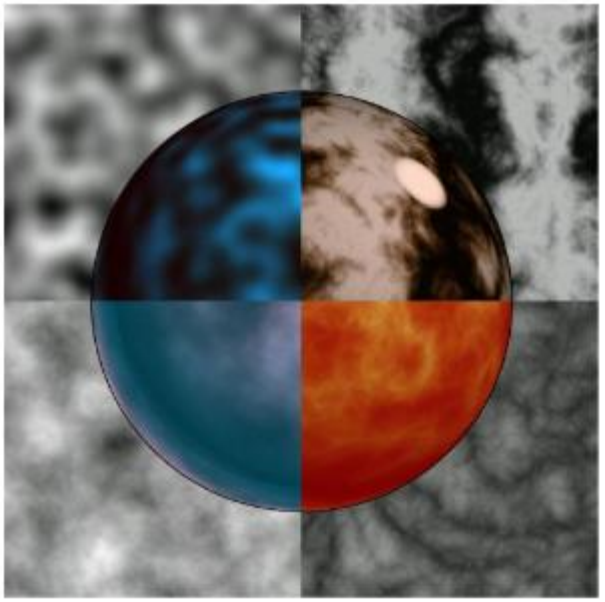
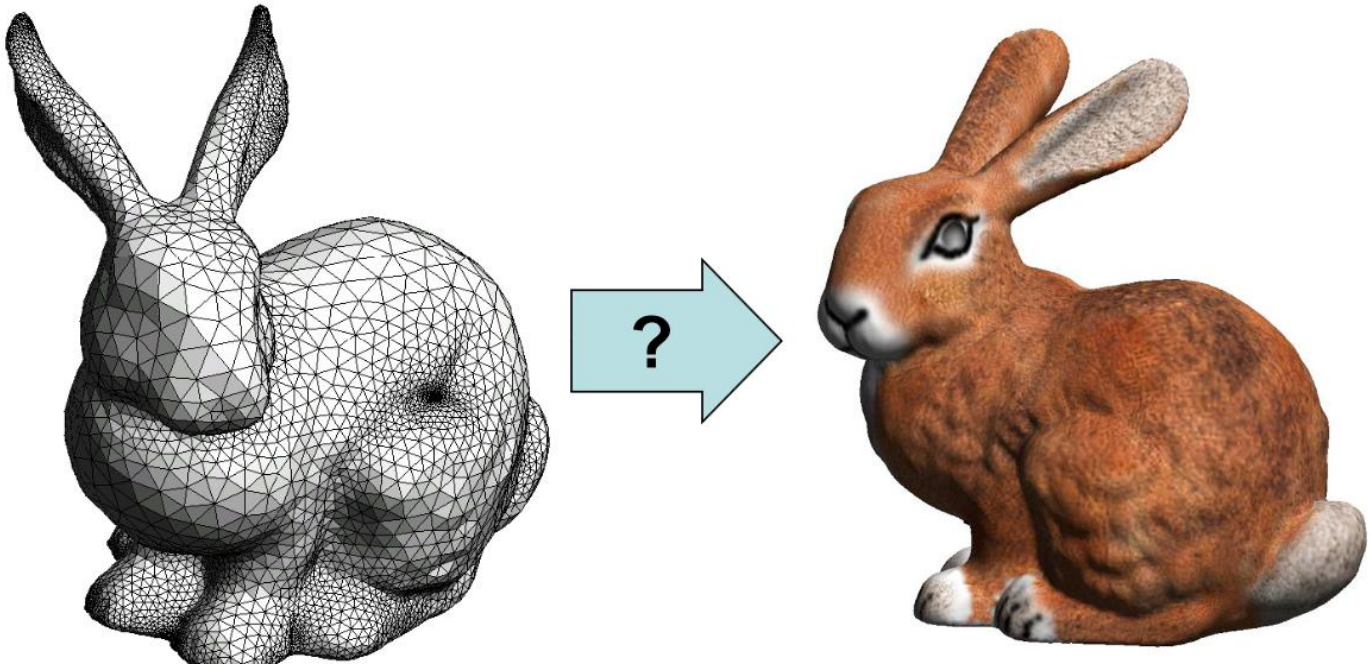


- Procedural shader
  - Little program that compute info at a given position



Texture mapping



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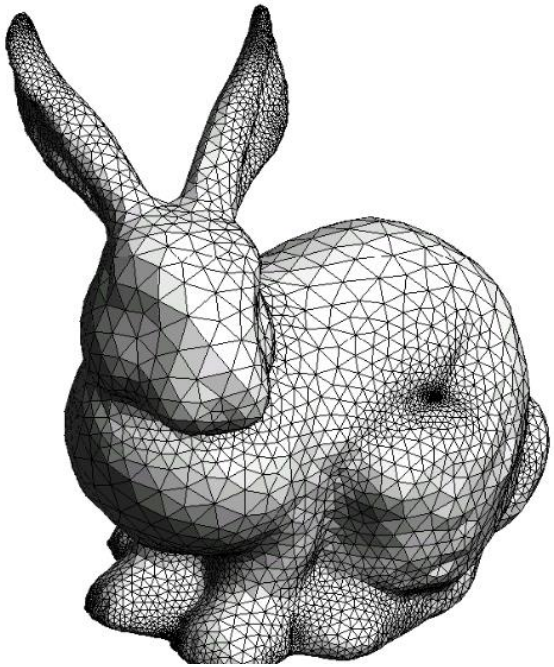
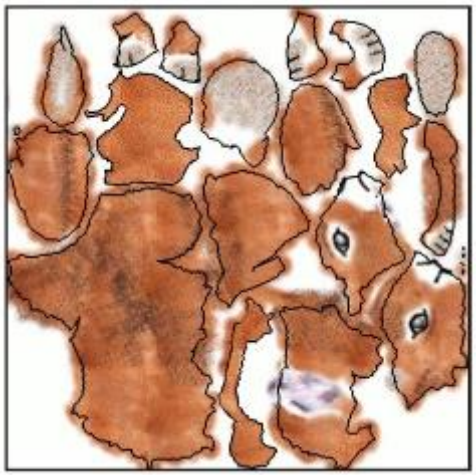


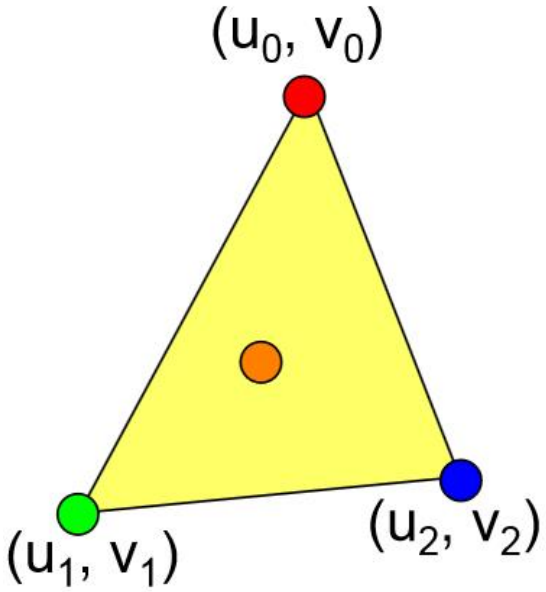
?

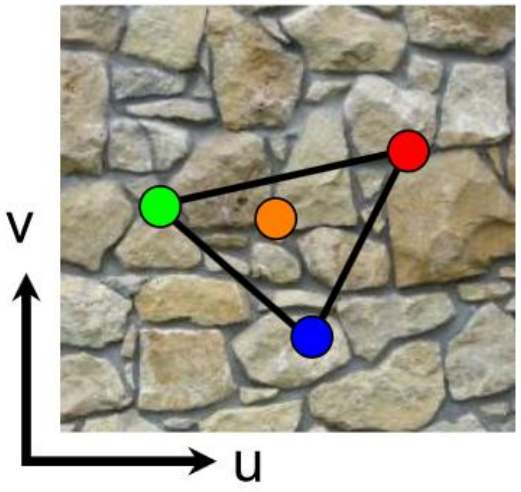
R3→R2



UV coordinates

- Store uv coords on each vertex of the input mesh
- Interpolate using barycentric coordinates





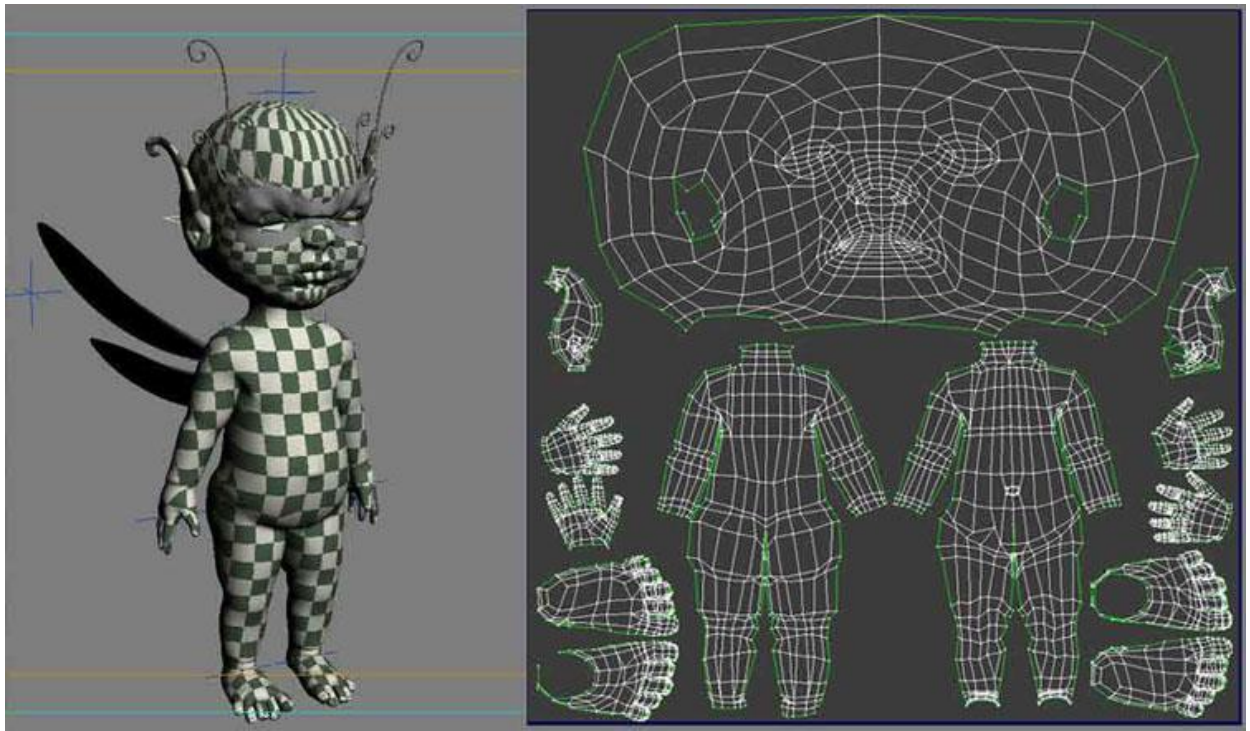
UV coordinates

- Store uv coords on each vertex of the input mesh
- Interpolate using barycentric coordinates

- How to generate coordinates?
  - Manually (time consumming, difficult)
  - Automatically (parametrization optimization)
  - Mathematical mapping (ivertex independent)

Parametrization optimization

- Flatten 3D object onto 2D UV coordinates
- Minimize distortion for each vertex:
  - Distances in UV correspond to distances on mesh
  - Angles in UV plane correspond to angles on 3D mesh
  - Usually requires cuts



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SIGGRAPH course:
http://www.inf.usi.ch/hormann/parameterization/

Rendering a 3D mesh

- Per vertex attributes:
  - Position
  - Normal
  - Tangent
  - UV coordinates
  - BRDF (const)
  - …
- + textures

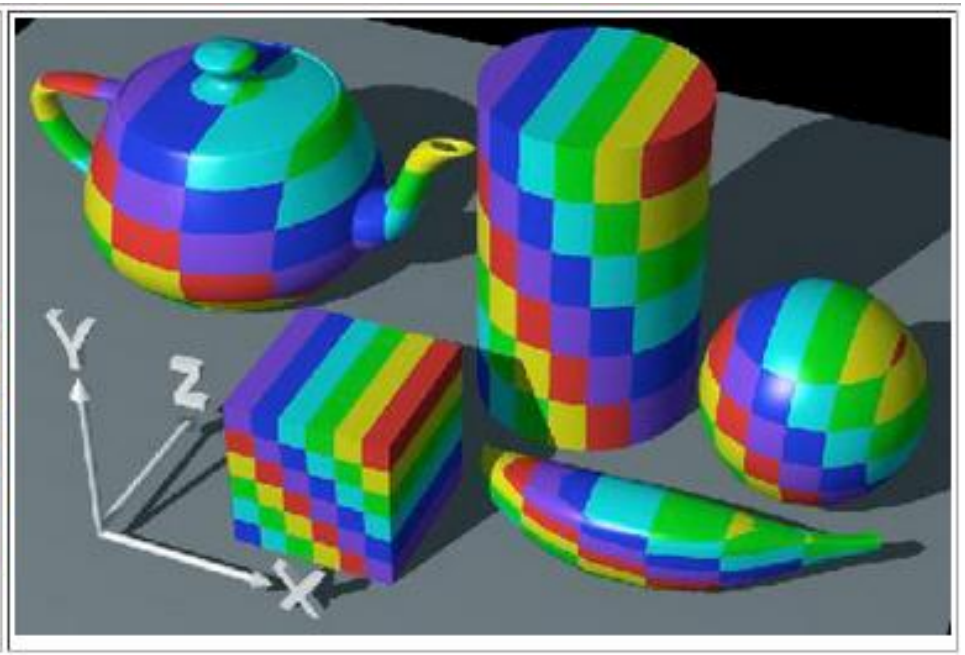
Mathematical mapping

- What if non-triangular geometry?
  - No vertices…

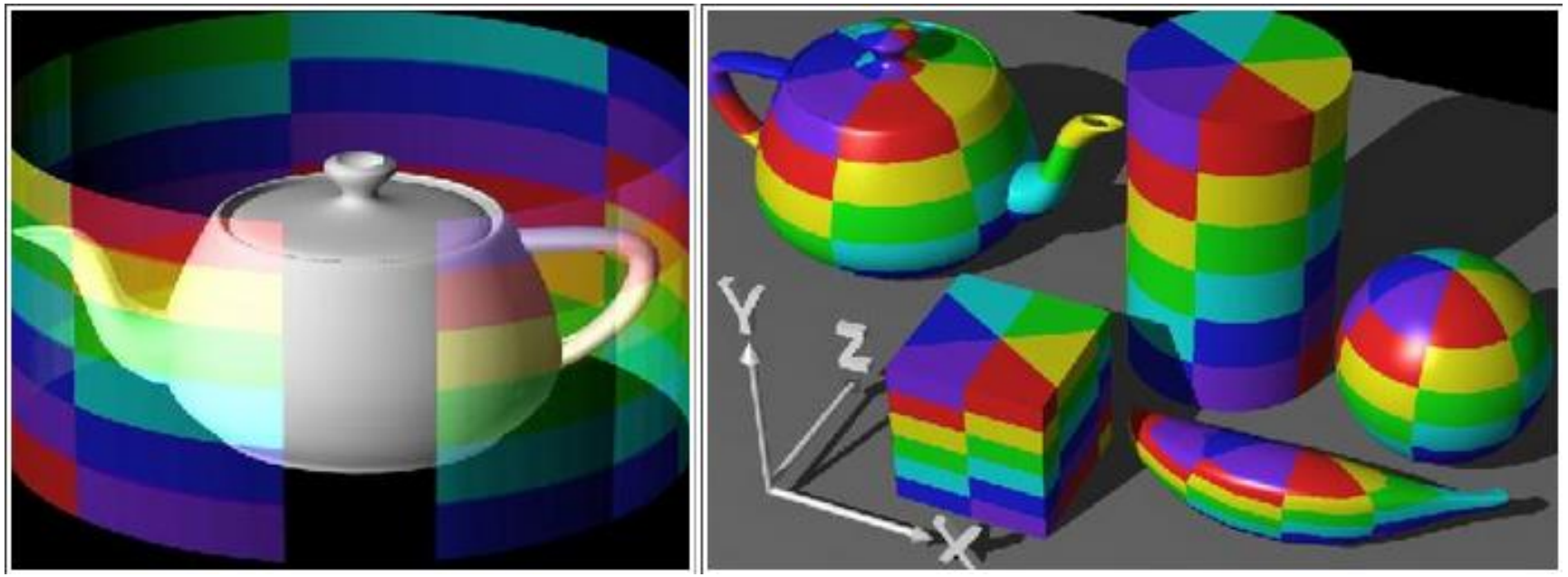
Mathematical mapping

- What if non-triangular geometry?
  - No vertices…
- Use parametric texturing:
  - Deduce (u,v) from (x,y,z)
  - Various possible mappings:

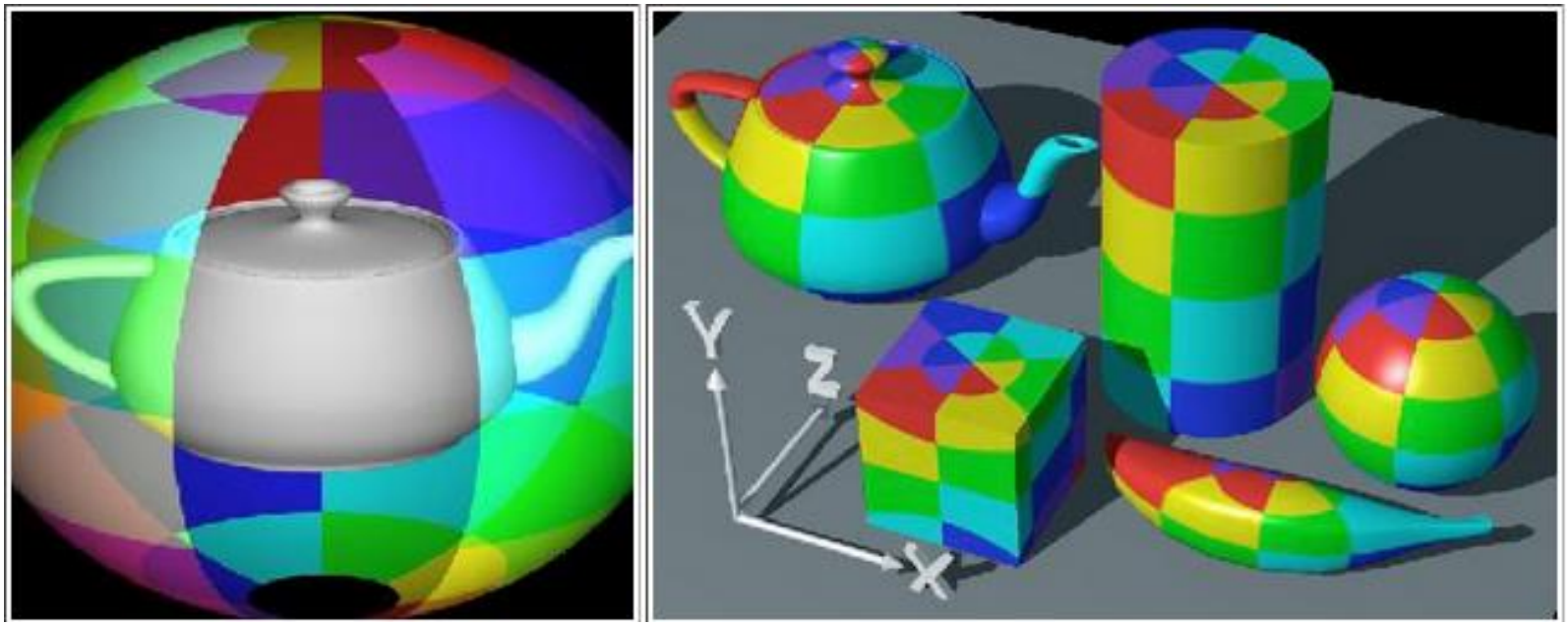
Planar mapping



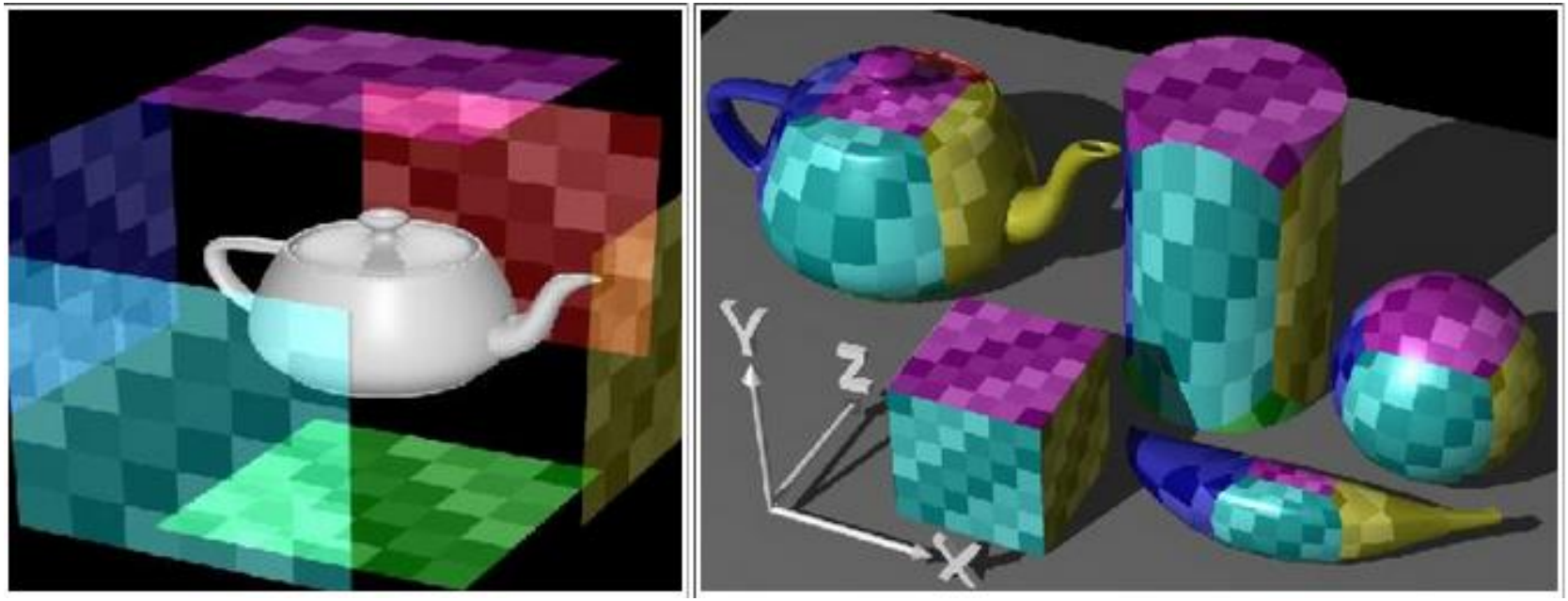
Cylindrical mapping



Spherical mapping



Cube mapping



Projective mapping

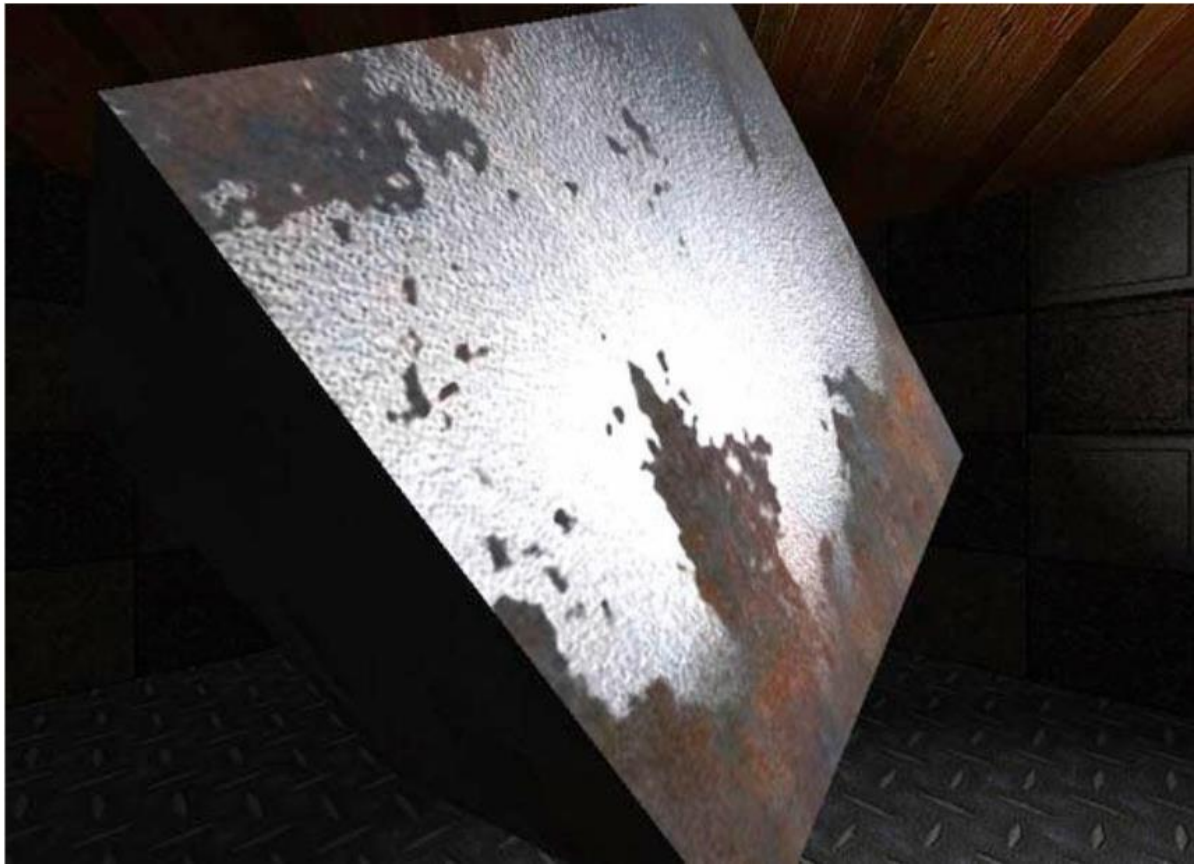
- Slide projector
  - Analogous to a camera
  - No need to specify texture coords explicitely

Projective mapping

- Slide projector https://www.youtube.com/watch?v=RPhGEiM_6lM
  - Analogous to a camera
  - No need to specify texture coords explicitely
- For a given 3D point:
  - Project onto 2D space
  - Use result as texture coordinate

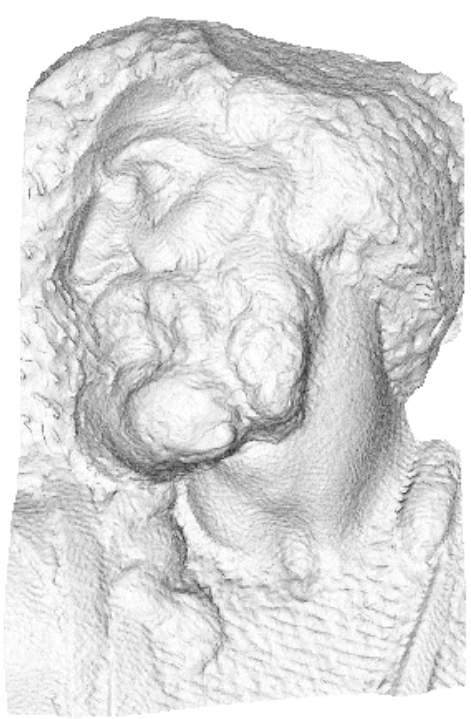
Textures for what?

- BRDF variations

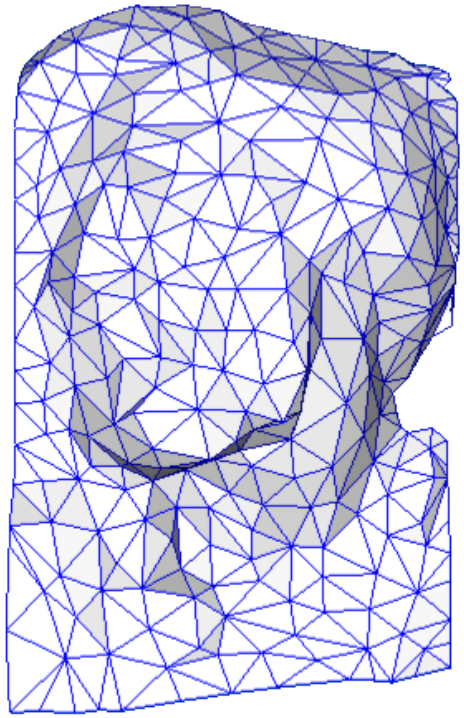


Textures for what?

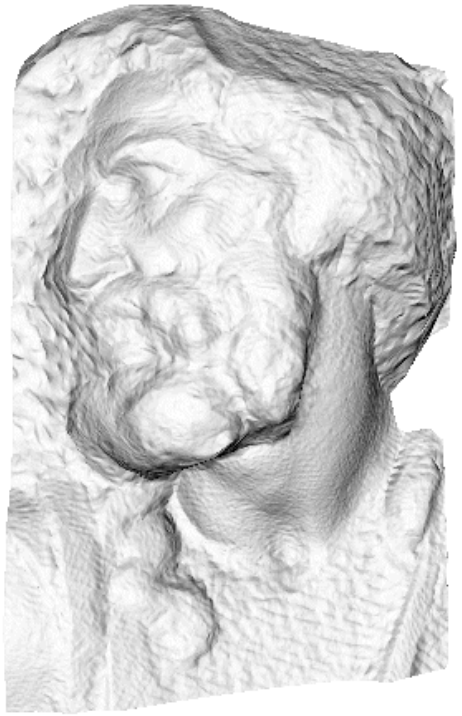
- Geometry variations



original mesh
4M triangles



simplified mesh
500 triangles



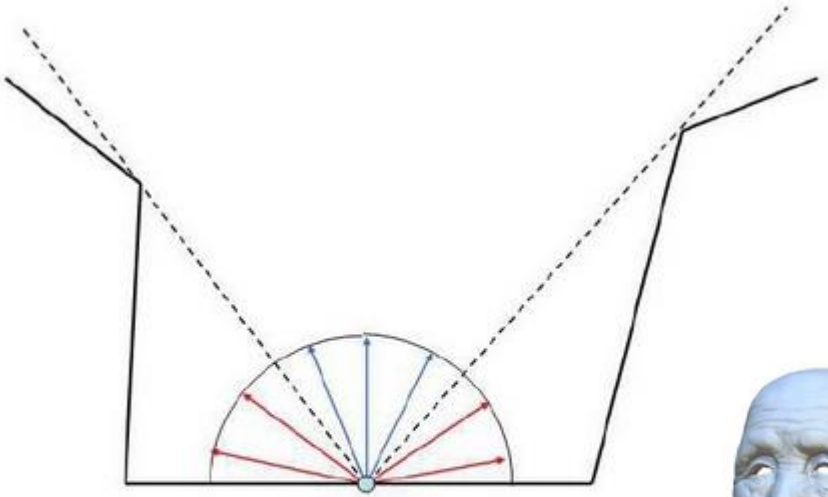
simplified mesh
and normal mapping
500 triangles

Textures for what?

- Geometry variations

Textures for what?

- Visibility (ambient occlusion)



Coarse shadows approximation

$$A = \frac{1}{\pi} \int V(\omega)(\mathbf{n} \cdot \omega) d\omega$$

Original model

With ambient occlusion

Extracted ambient occlusion map

Textures for what?

- Lighting environments

Textures for what?

- Lighting environments

Extreme case

- Image based rendering
  - Produce an image from other images!

Extreme case

- Image based rendering
  - Produce an image from other images!

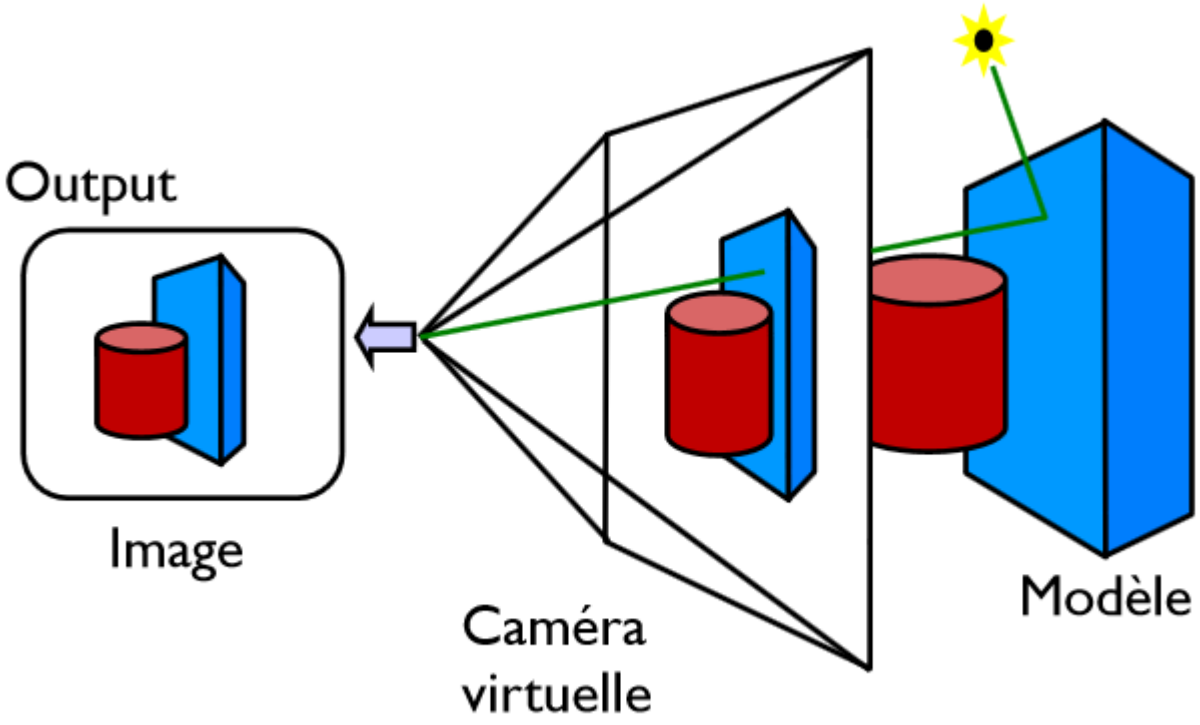
synthesis

- Easy to create new worlds
- Easy to manipulate
  - Viewpoints
  - Objects
- Difficult to make it realistic!

photography

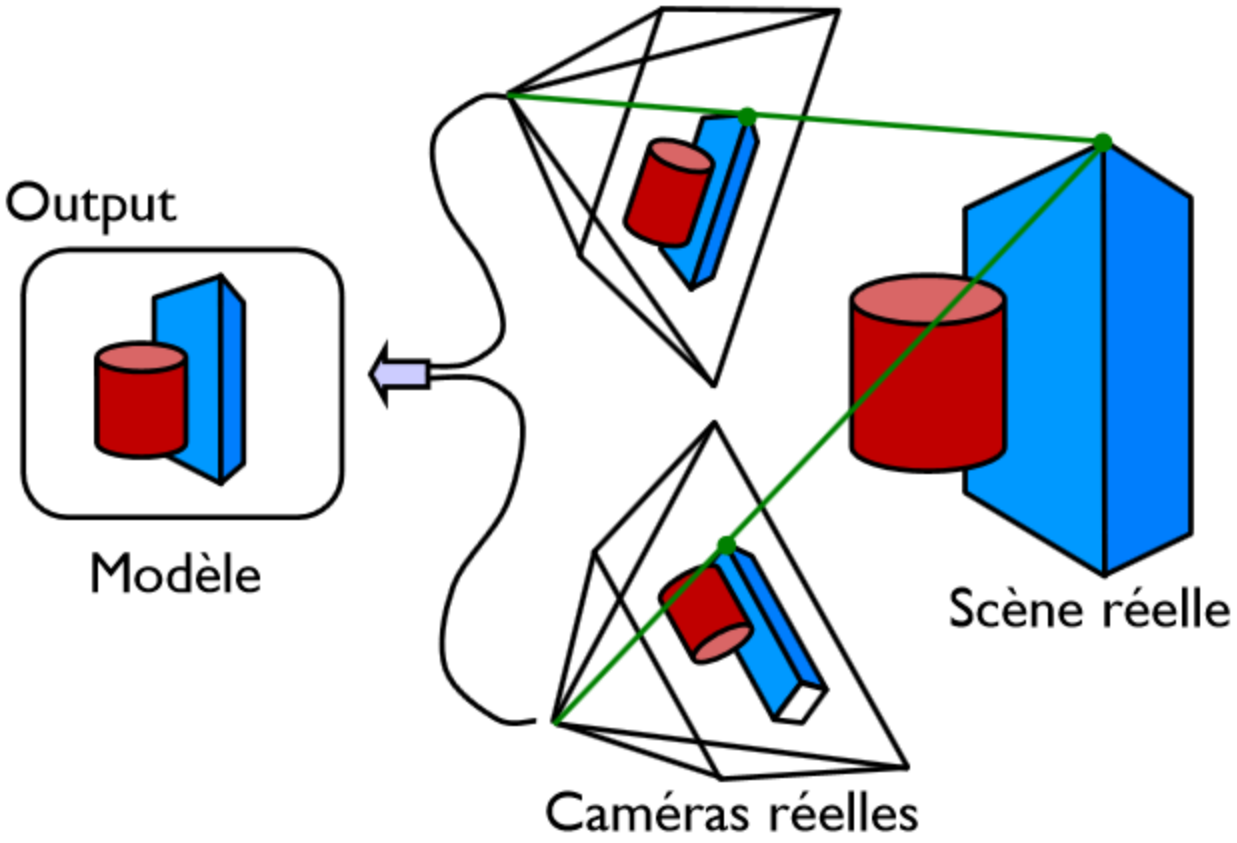
- Realistic…
- Simple aquisition (clic)
- Difficult to manipulate
  - Viewpoints
  - objects

Image synthesis



From Pierre Benard lecture on IBR

Vision



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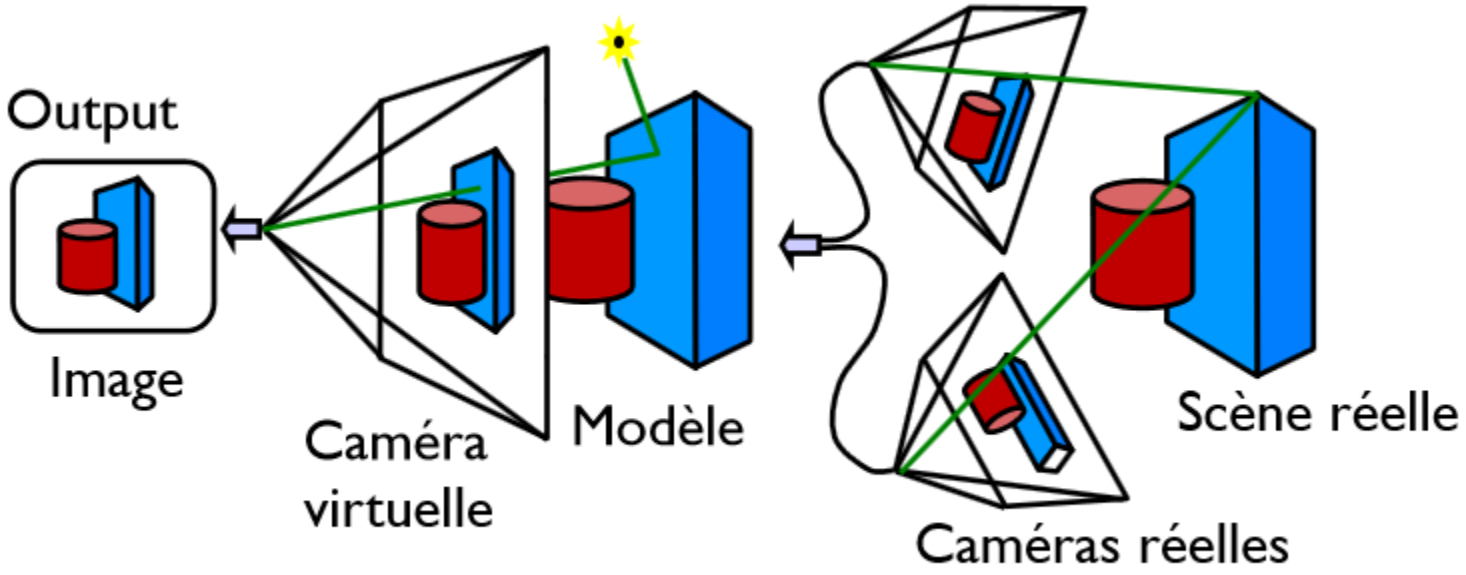
Combine both



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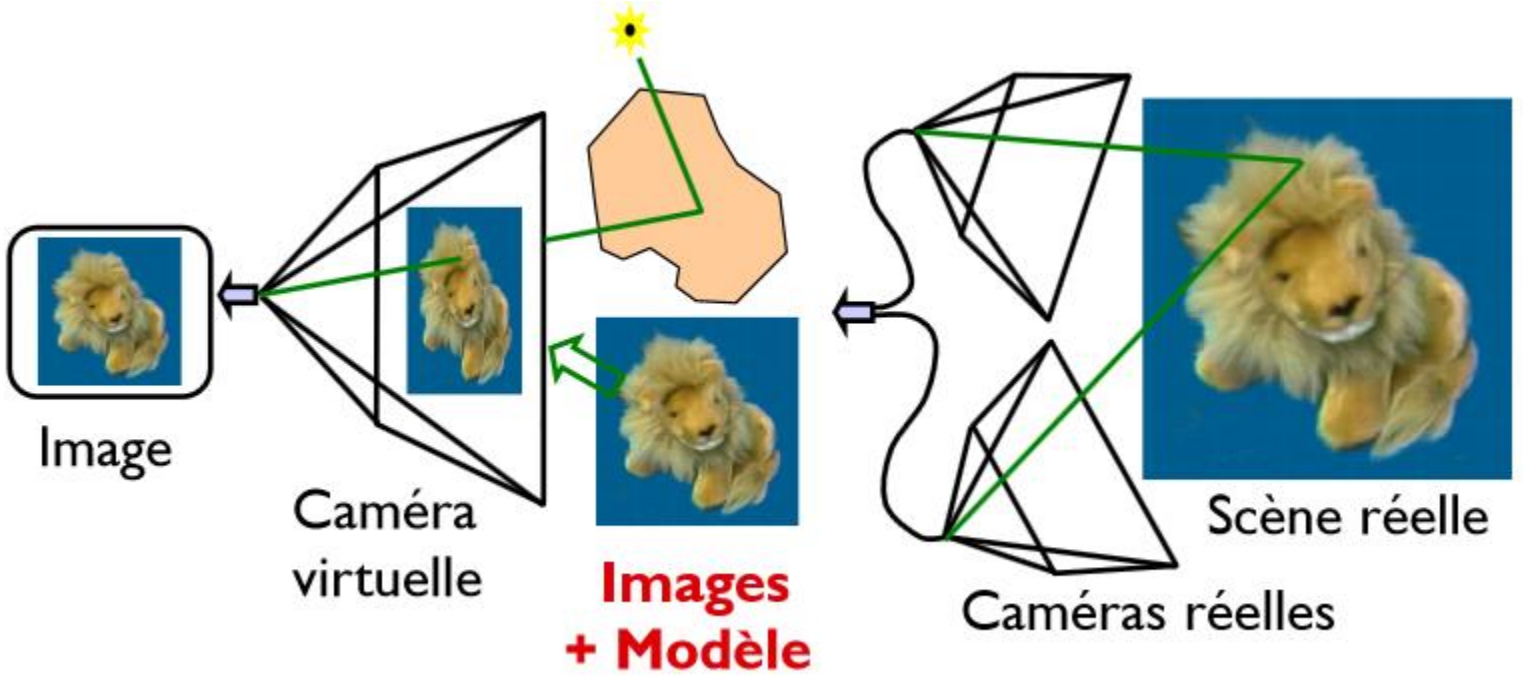
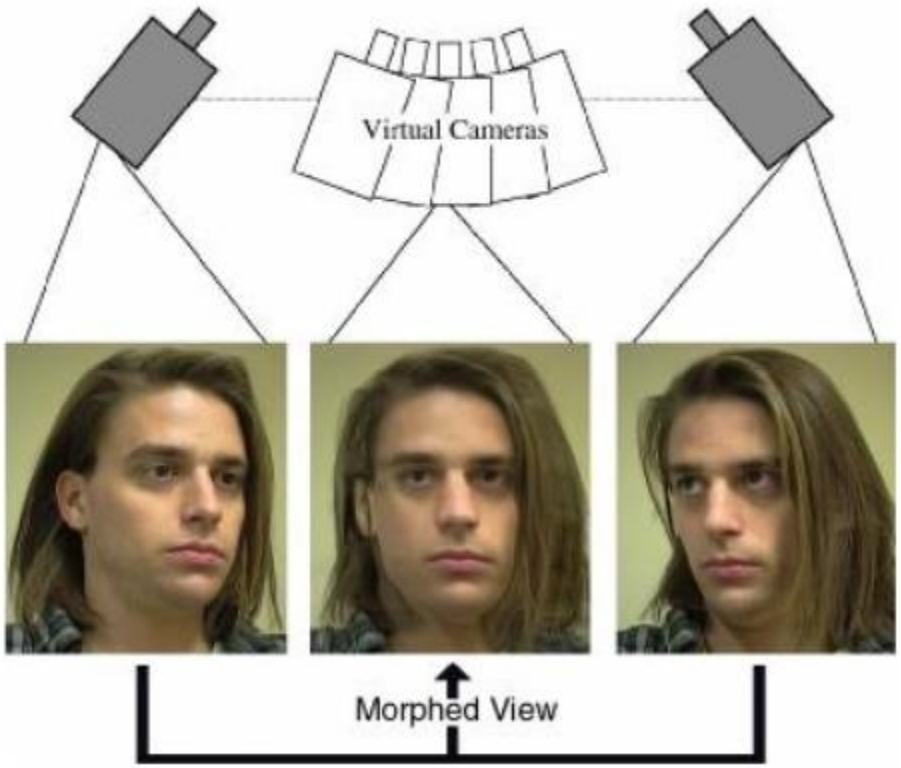


From Pierre Benard lecture on IBR

Interpolate viewpoints

[Beier and Neely '92, Chen and Williams '93, Seitz and Dyer '96]



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Morphing

https://www.youtube.com/watch?v=nUDIoN-_Hxs

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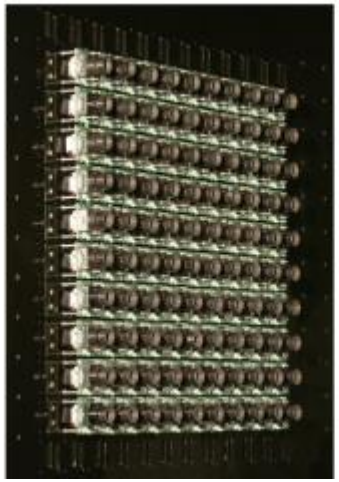
Plenoptic function

$$P(\theta, \phi, \lambda, t, V_x, V_y, V_z)$$

- Capture all possible images around u
- IBR = reconstruct P from samples

From Pierre Benard lecture on IBR

Standford cameras



- Array of cameras
  - 640X480 pixels X 30 FPS X 128 cameras
  - X 30 FPS

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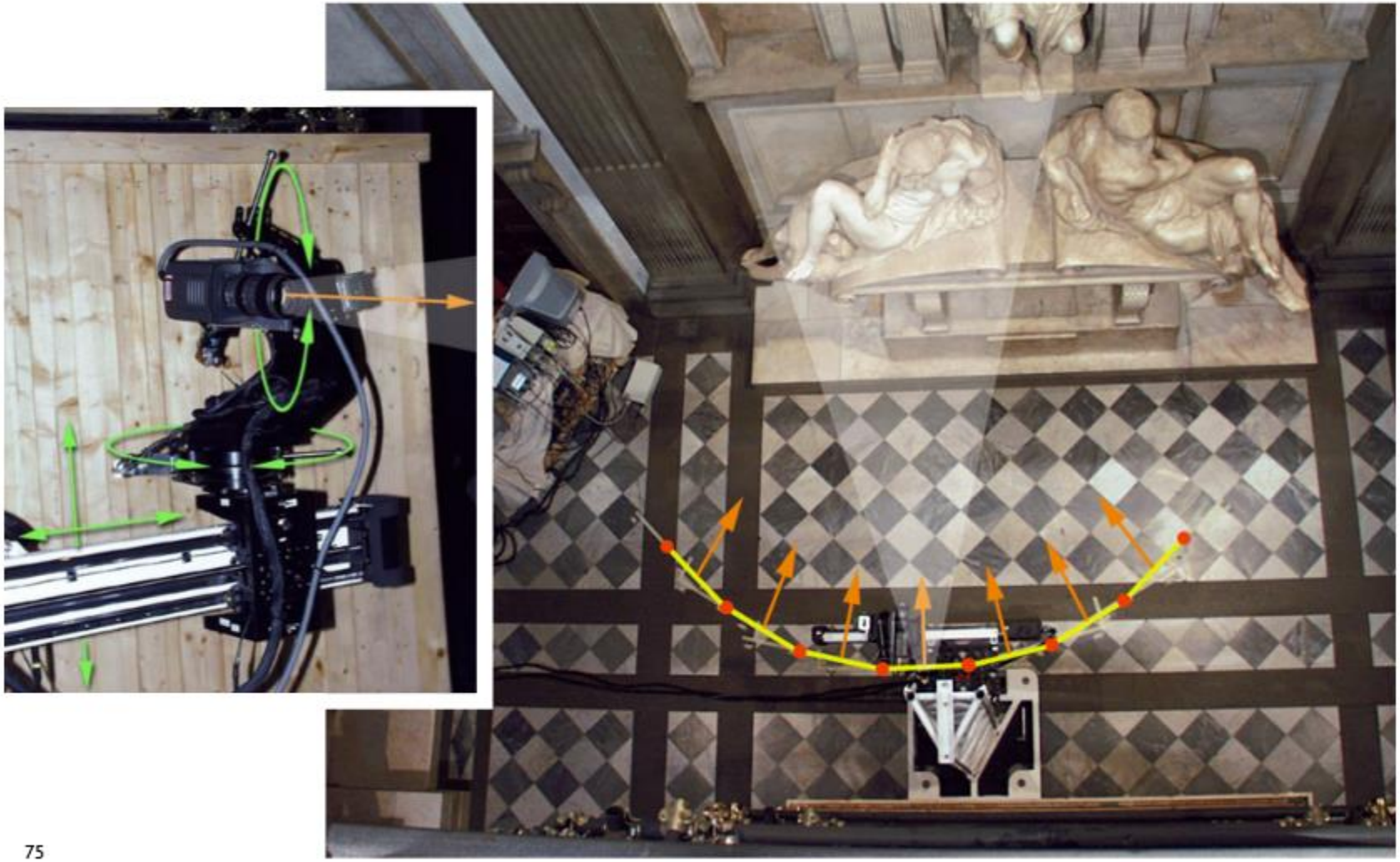
Digital Michelangleo project



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Light field viewer

http://lightfield.stanford.edu/lfs.html

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Time splice

http://www.timesplice.com.au/camera-array.html

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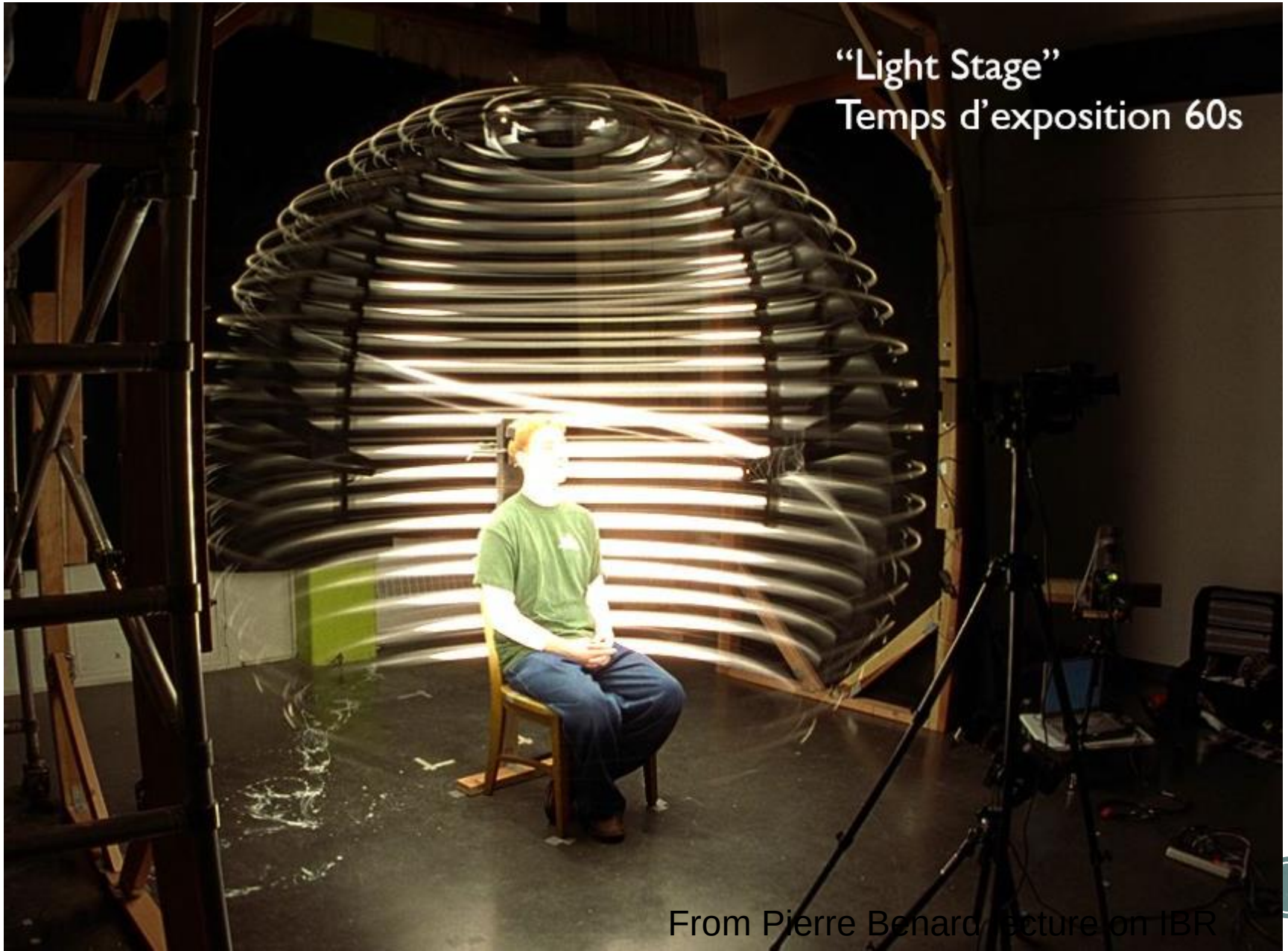
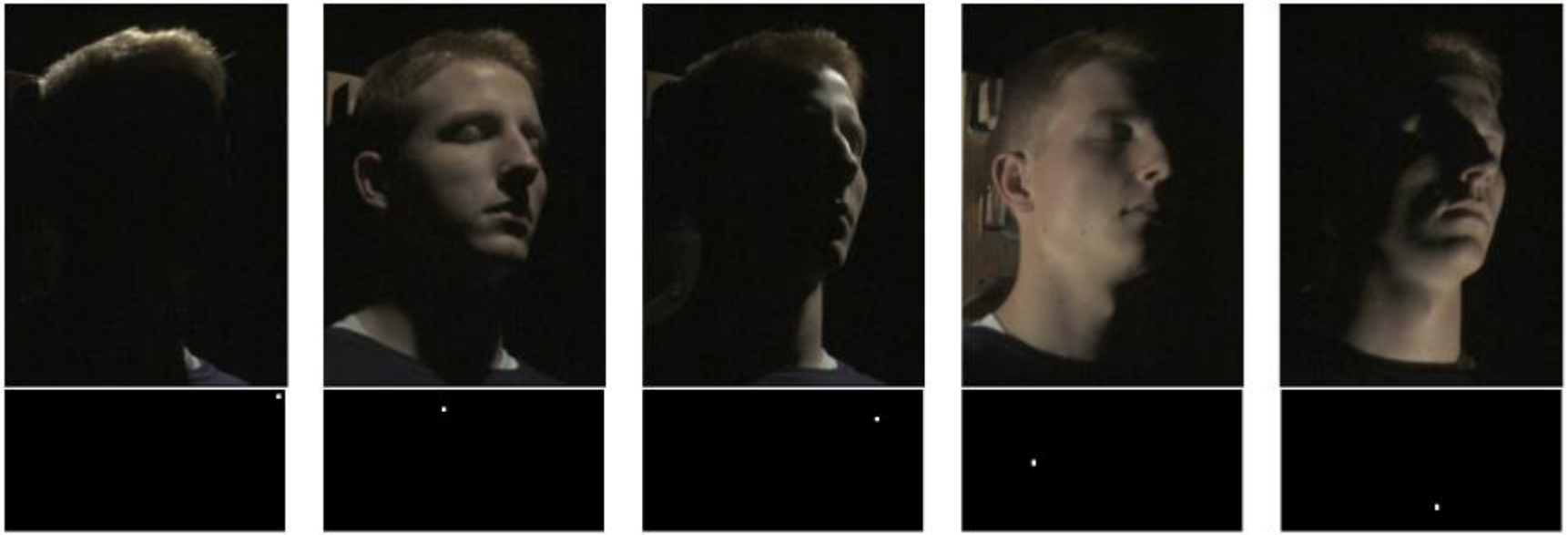
Relighting



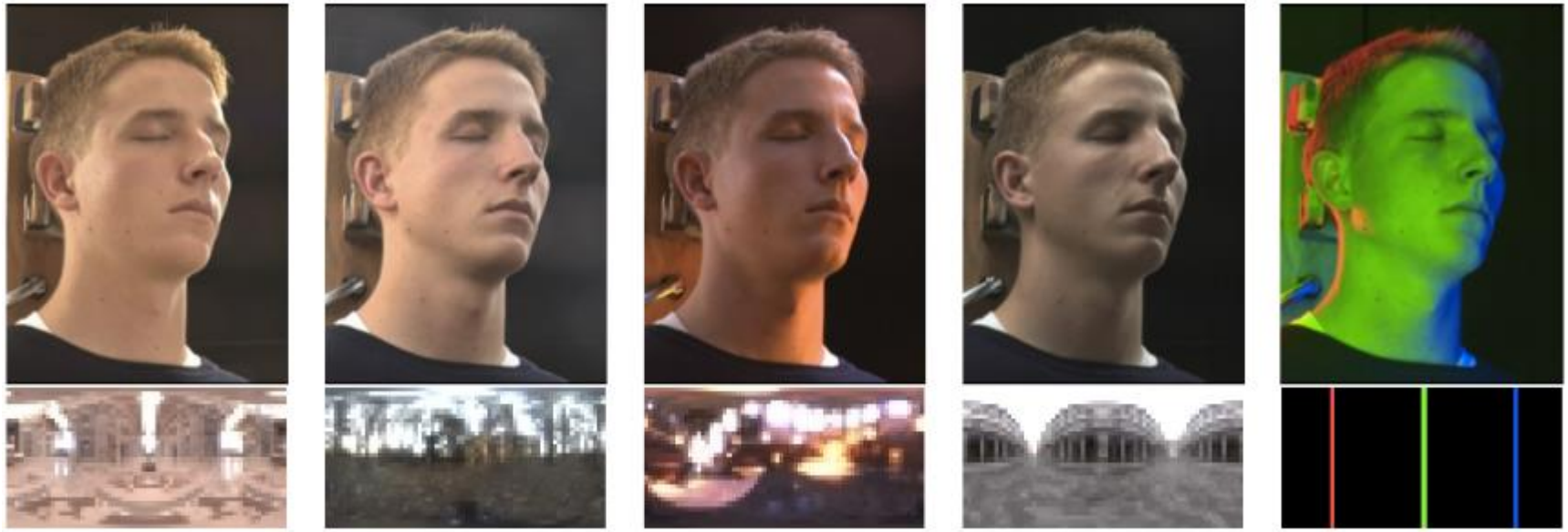
From Pierre Benard : cture on IBR

Relighting



From Pierre Benard lecture on IBR

Relighting

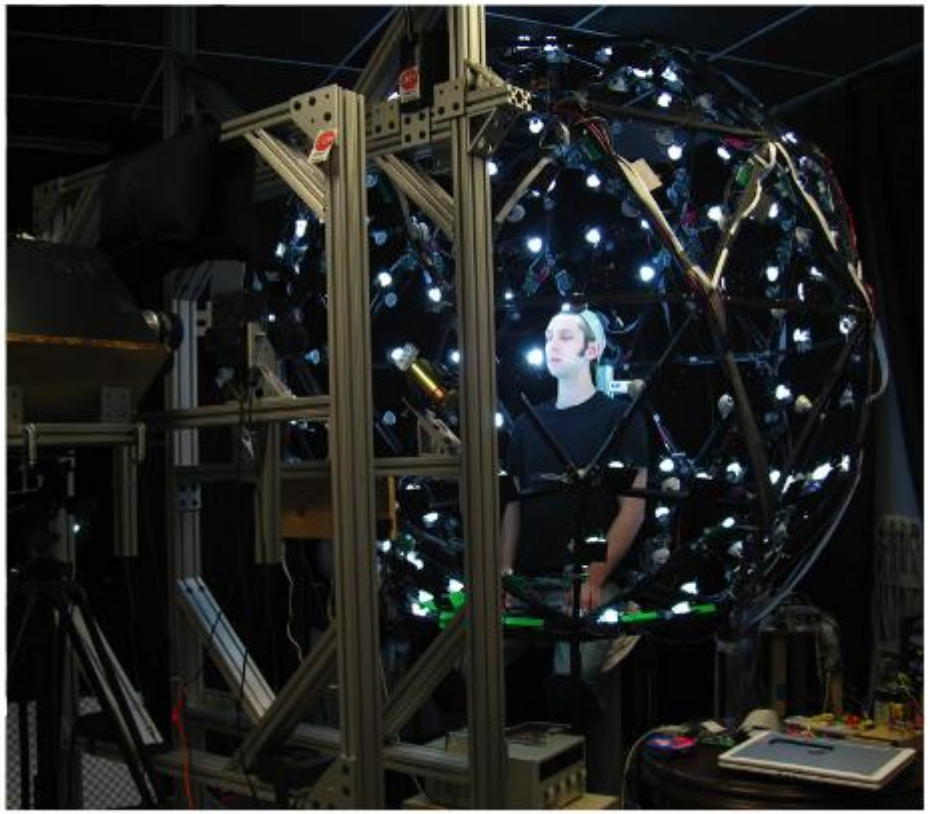


From Pierre Benard lecture on IBR

Relighting

The Curious Case of Benjamin Button

Avatar



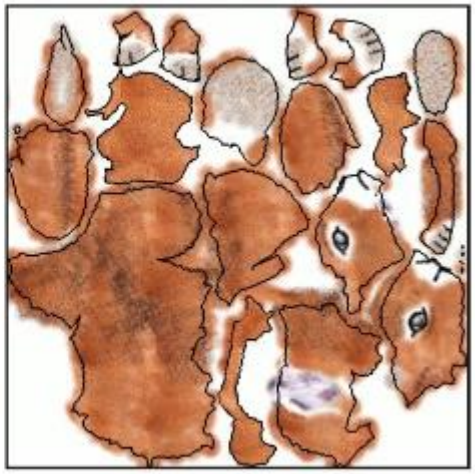
https://www.youtube.com/watch?v=piJ4Zke7EUw

Digital Emily project

From Pierre Benard lecture on IBR

Lets go back to our textures!

- From data
  - Colors, coefs, normals stored in 2D images



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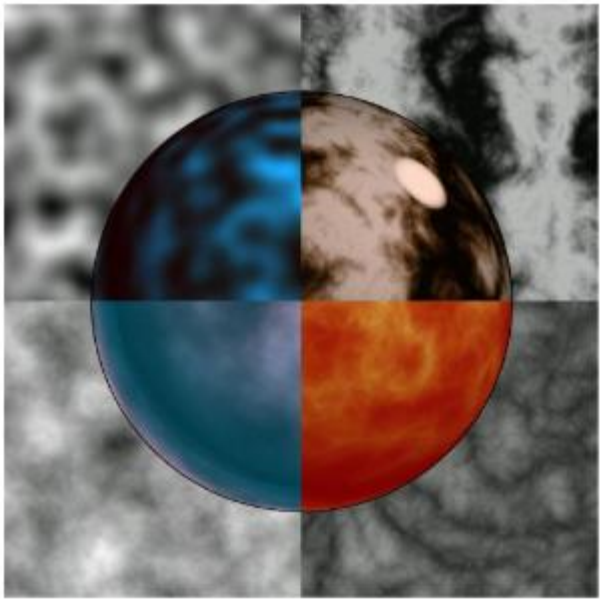
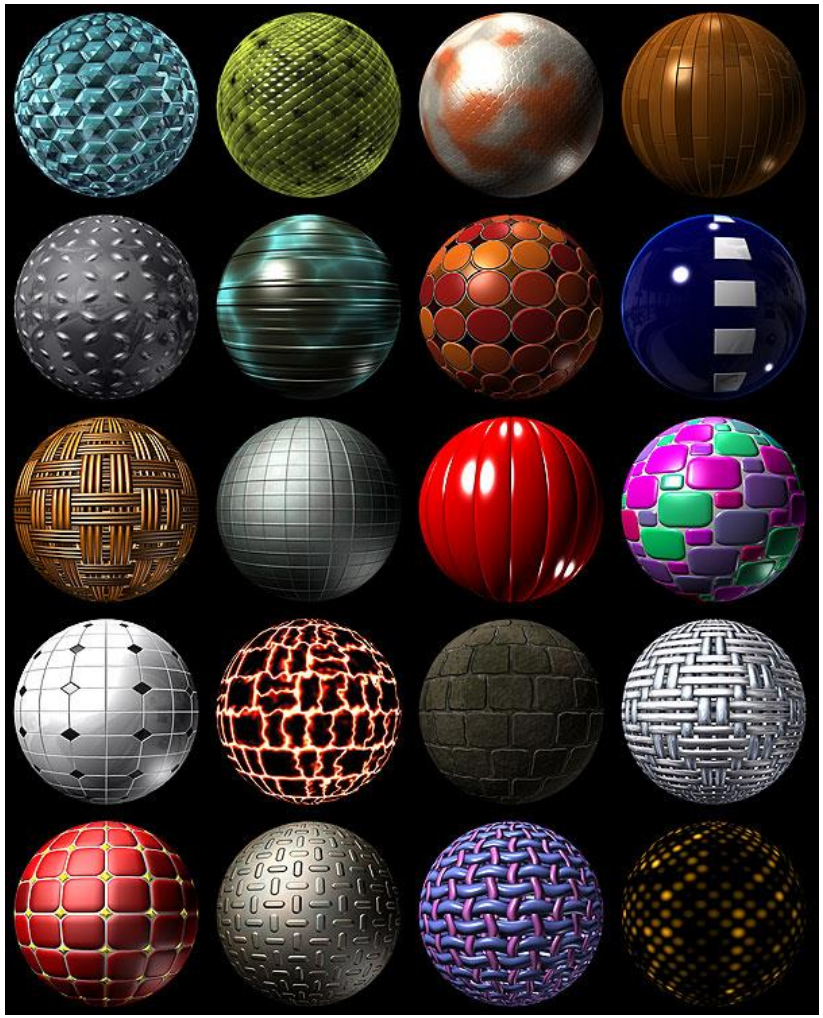


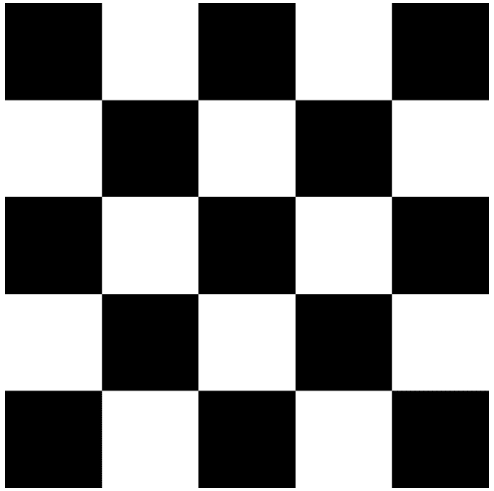
Procedural textures

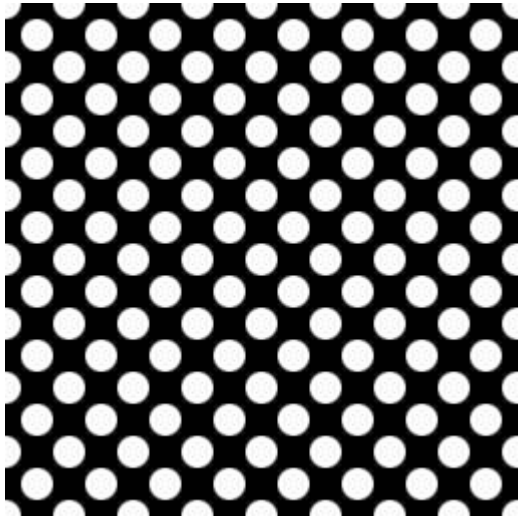
- pros
  - Easy to implement (ray tracing)
  - Compact
  - Infinite resolution
- Cons
  - Non-intuitive
  - Difficult to match existing textures

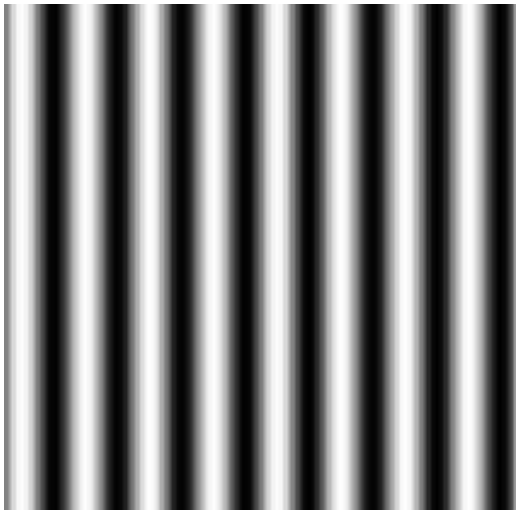


Simple math functions

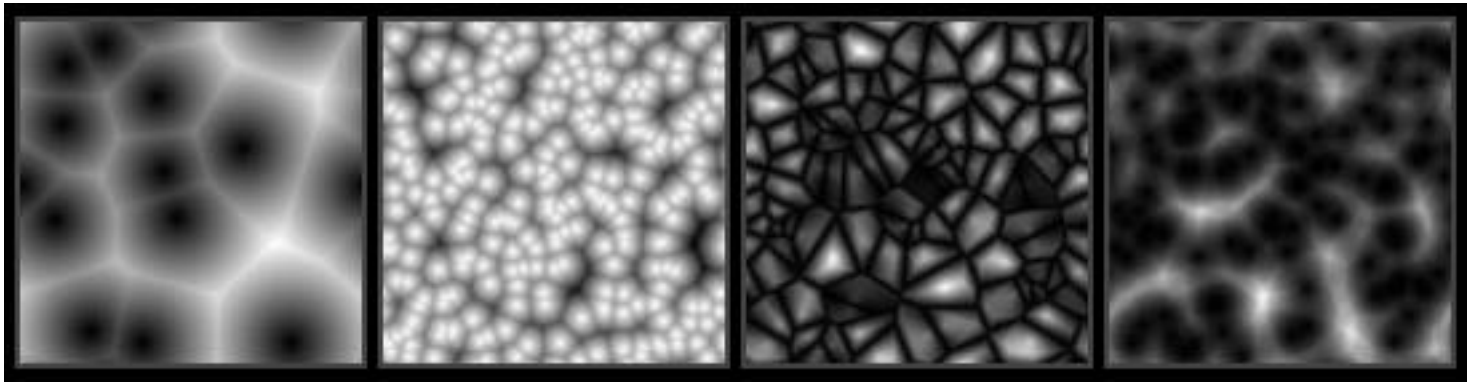
- Combination of simple functions
  - Mod
  - Clamp
  - Mix
  - Sin / cos / tan
  - Pow
  - Exp
  - Etc…







Cellular textures

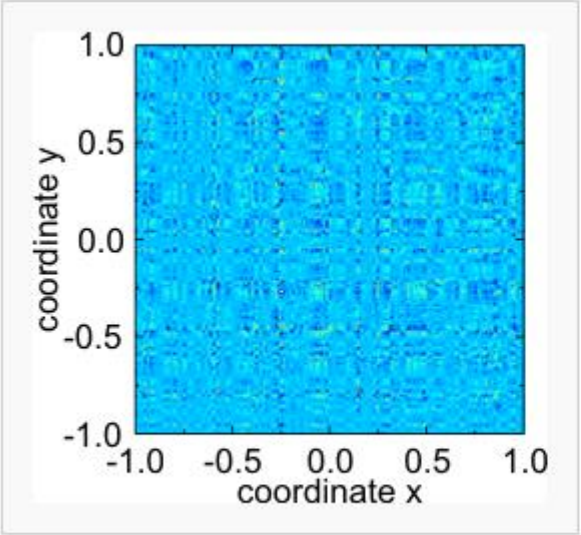


- Generate a bunch of random points
- For each pixel
  - Find the nearest distance to the nearest couple points
  - Use these values to determine a color
- Voronoi-like

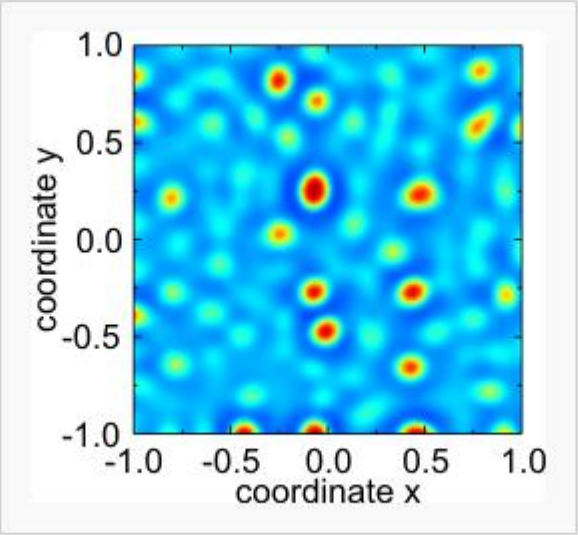
https://www.google.fr/search?q=cellular+texture&tbm=isch&tbo=u&source=univ&sa=X&ei=FADJVKG8McXwUpfRg6AK&ved=0CCIQsAQ&biw=1920&bih=969

Minimizing functions

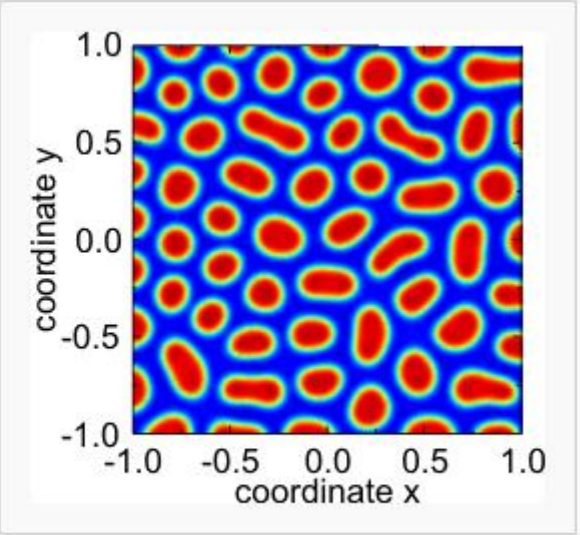
- Genetic algorithms
- Reaction-diffusion
- …



Noisy initial conditions at $t = 0$.



State of the system at $t = 10$.



Almost converged state at $t = 100$.

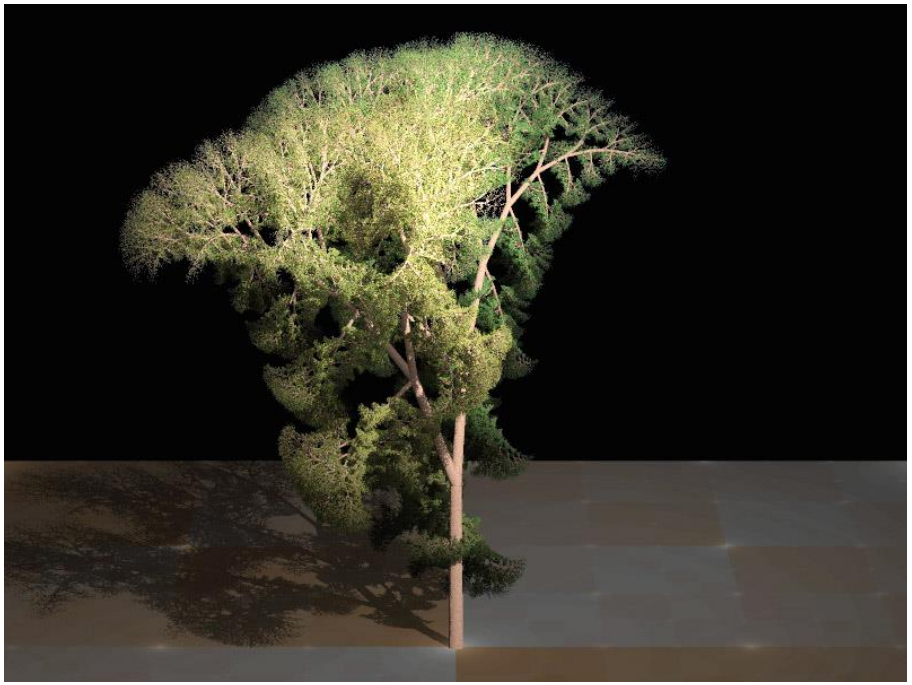
L-systems

- Formal grammar

  - Alphabet : V = {A, B}
  - Constantes : S = {}
  - Axiome de départ : w = A
  - Règles : (A → AB) ∧ (B → A)

Notation :

```
Algue
{
Axiom A
A=AB
B=A
}
```



L-systems

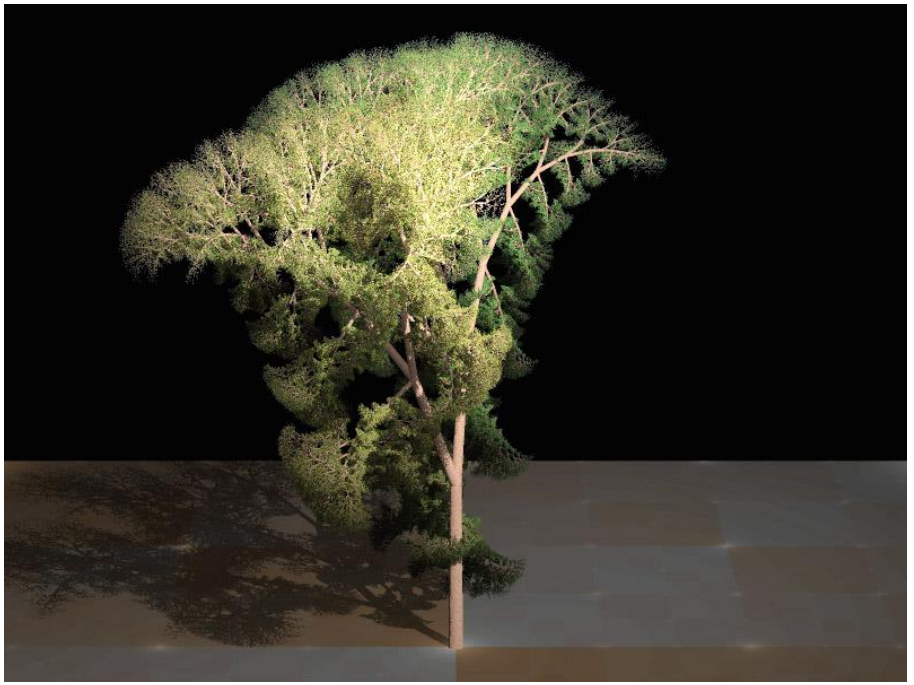
- Formal grammar

  - Alphabet : V = {A, B}
  - Constantes : S = {}
  - Axiome de départ : w = A
  - Règles : (A → AB) ∧ (B → A)

Notation :

```
Algue
{
Axiom A
A=AB
B=A
}
```

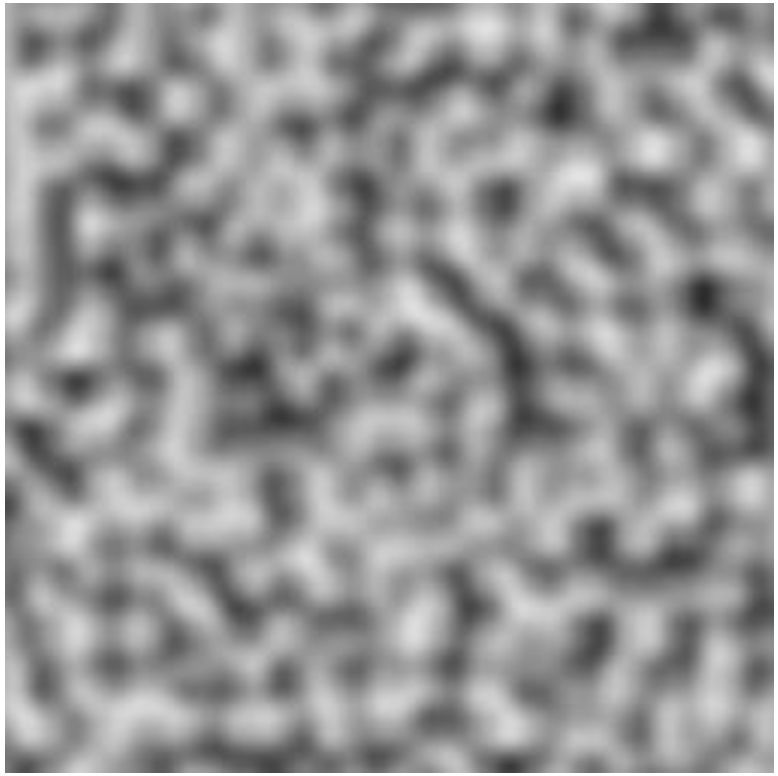
- n=0, A
- n=1, AB
- n=2, AB A
- n=3, AB A AB
- n=4, AB A AB AB A
- n=5, AB A AB AB A AB A AB
- n=6, AB A AB AB A AB A AB AB A AB AB A



http://www.kevs3d.co.uk/dev/lsystems/

Perlin-like textures

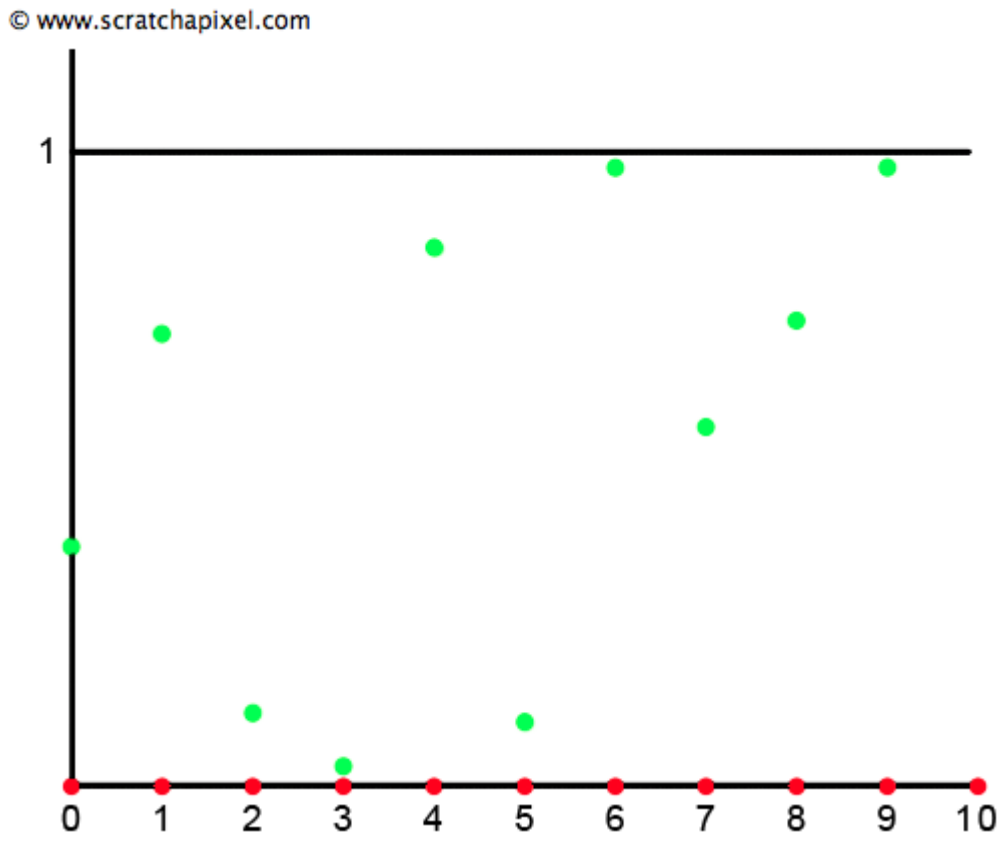
- Requirements
  - Pseudo random
  - Arbitrary dimension
  - Smooth
  - Band pass (one scale)
  - Little memory usage
  - Implicit evaluation



Perlin-like textures

Value noise 1D case

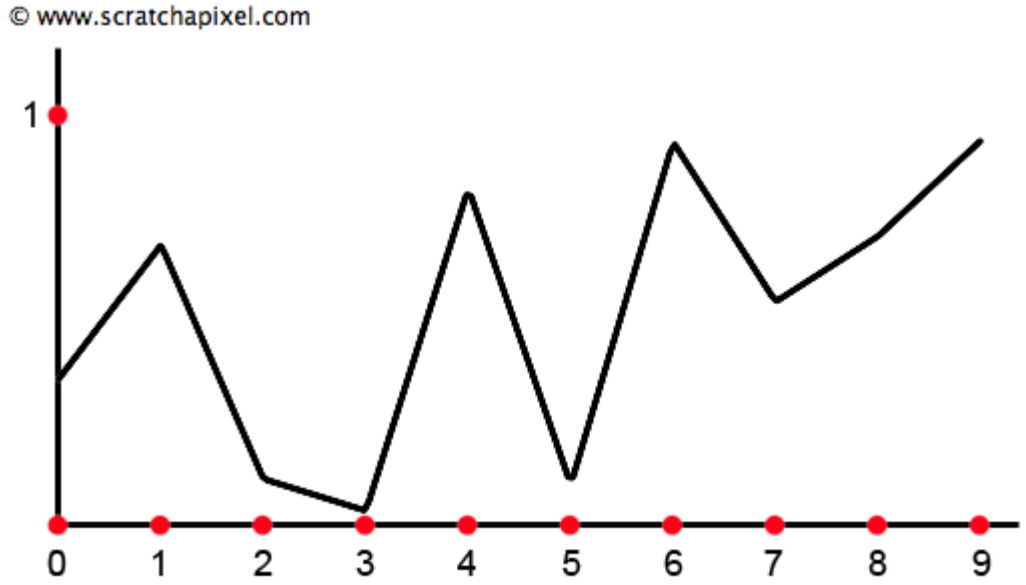
- Distribute random values at particular locations (a grid)…



Perlin-like textures

Value noise 1D case

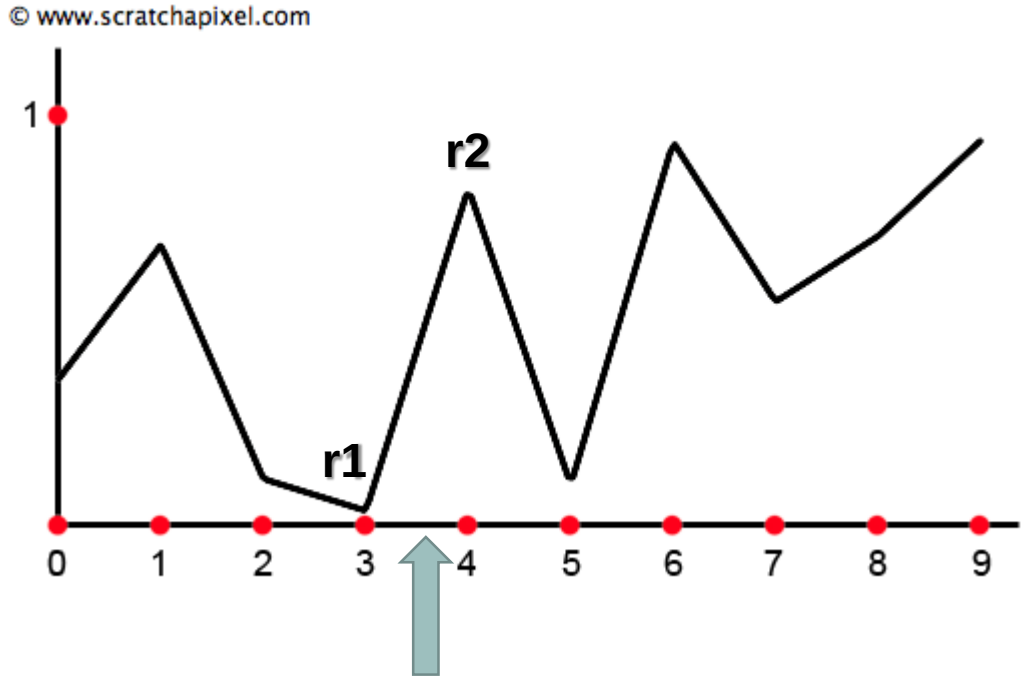
- Distribute random values at particular locations (a grid)…
- … and interpolate



Perlin-like textures

Value noise 1D case

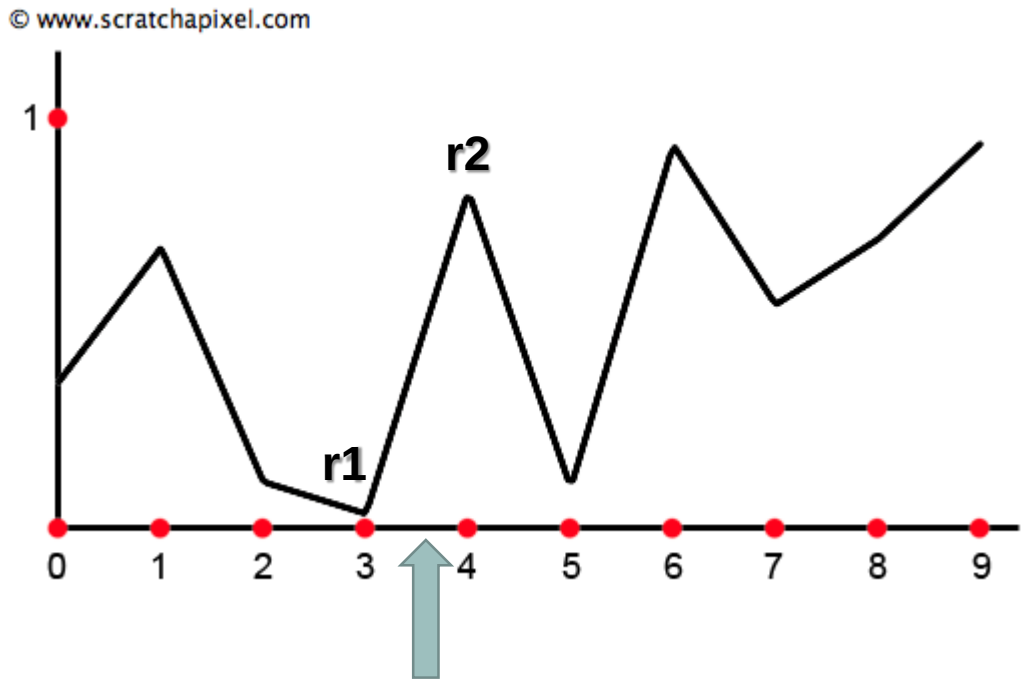
- Evaluation algorithm for a given point x



Perlin-like textures

Value noise 1D case

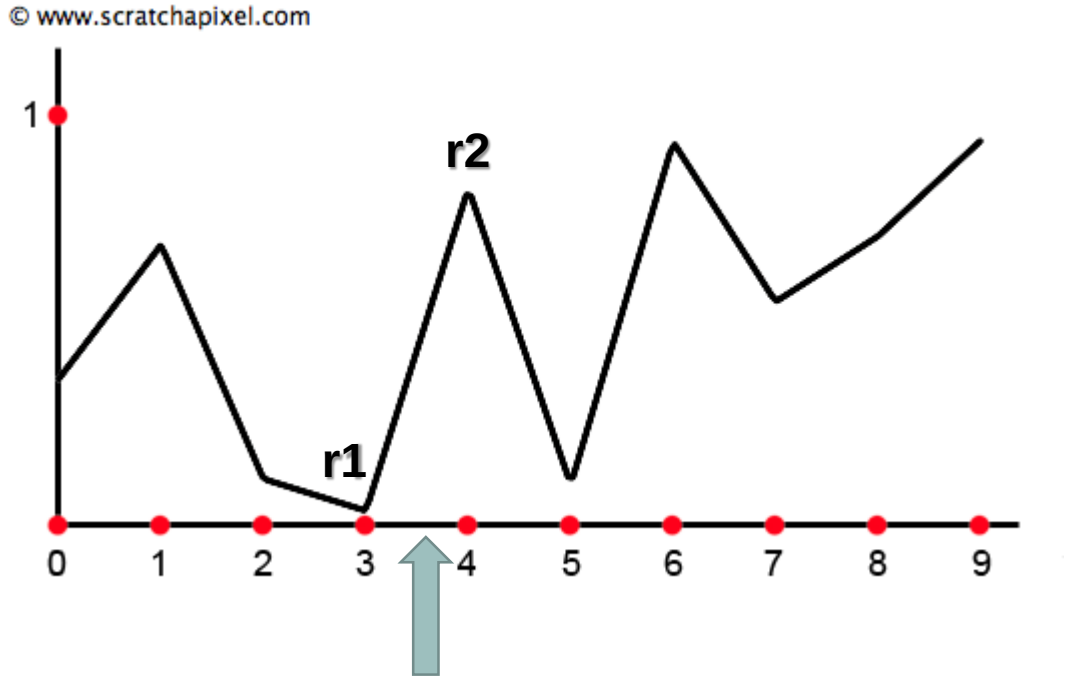
- Evaluation algorithm for a given point x
- Get the associated 2 random values?



Perlin-like textures

Value noise 1D case

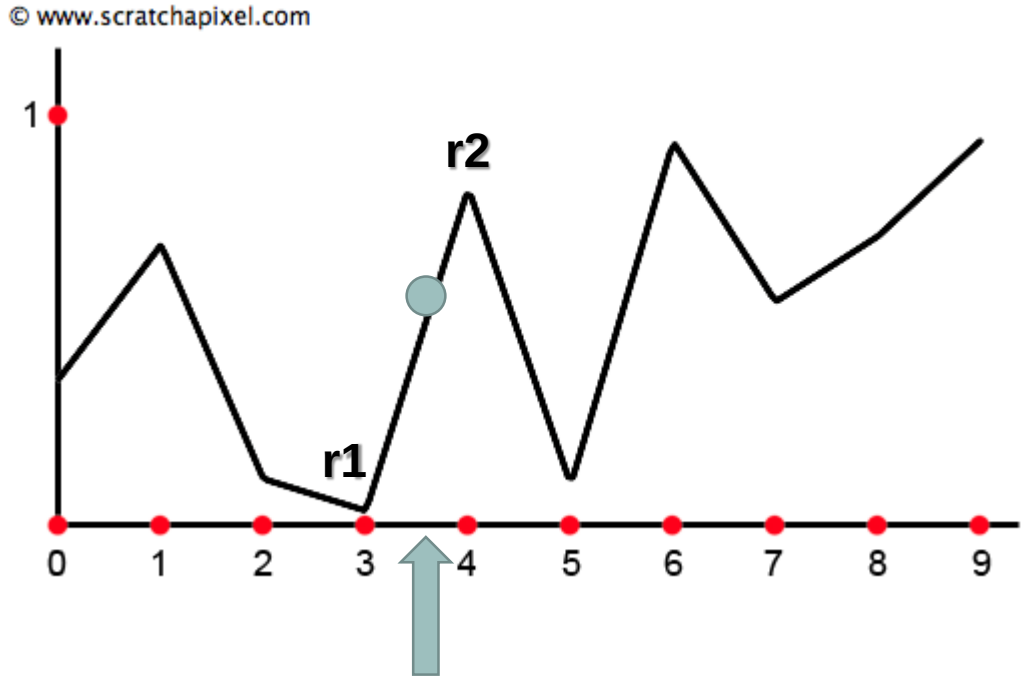
- Evaluation algorithm for a given point x
- Get the associated 2 random values?
  - Pseudo random function
  - Precomputed in an array



Perlin-like textures

Value noise 1D case

- Evaluation algorithm for a given point x
- Get the associated 2 random values?
  - Pseudo random function
  - Precomputed in an array
- Get relative position of x (between 0 and 1)
- Mix



Perlin-like textures

Value noise 1D case

- Evaluation algorithm for a given point x
- Get the associated 2 random values?
  - Pseudo random function
  - Precomputed in an array
- Get relative position of x (between 0 and 1)
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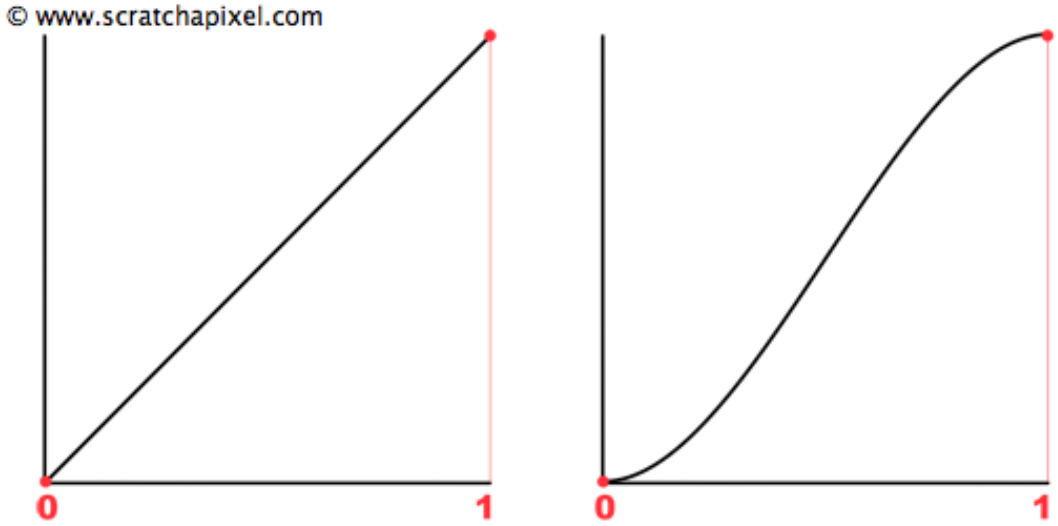
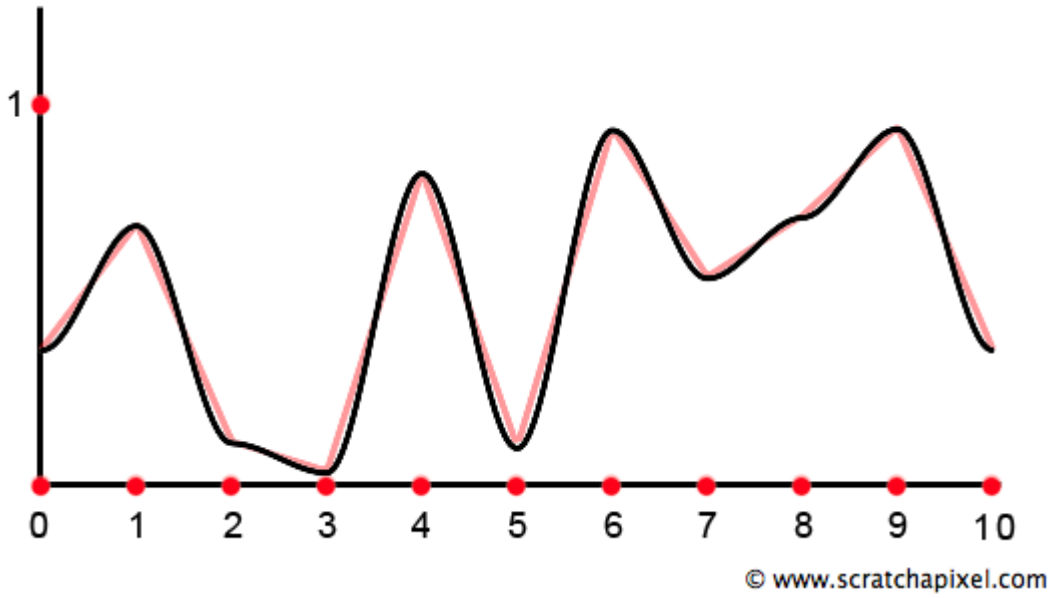


S-shaped function $t = t^2(3 - 2t)$

Perlin-like textures

Value noise 1D case

- Evaluation algorithm for a given point x
- Get the associated 2 random values?
  - Pseudo random function
  - Precomputed in an array
- Get relative position of x (between 0 and 1)
- Mix



Perlin-like textures

Value noise 1D case

- Evaluation algorithm for a given point x
- Get the associated 2 random values?
  - Pseudo random function
  - Precomputed in an array

Pros/cons?

- Get relative position of x (between 0 and 1)
- Mix

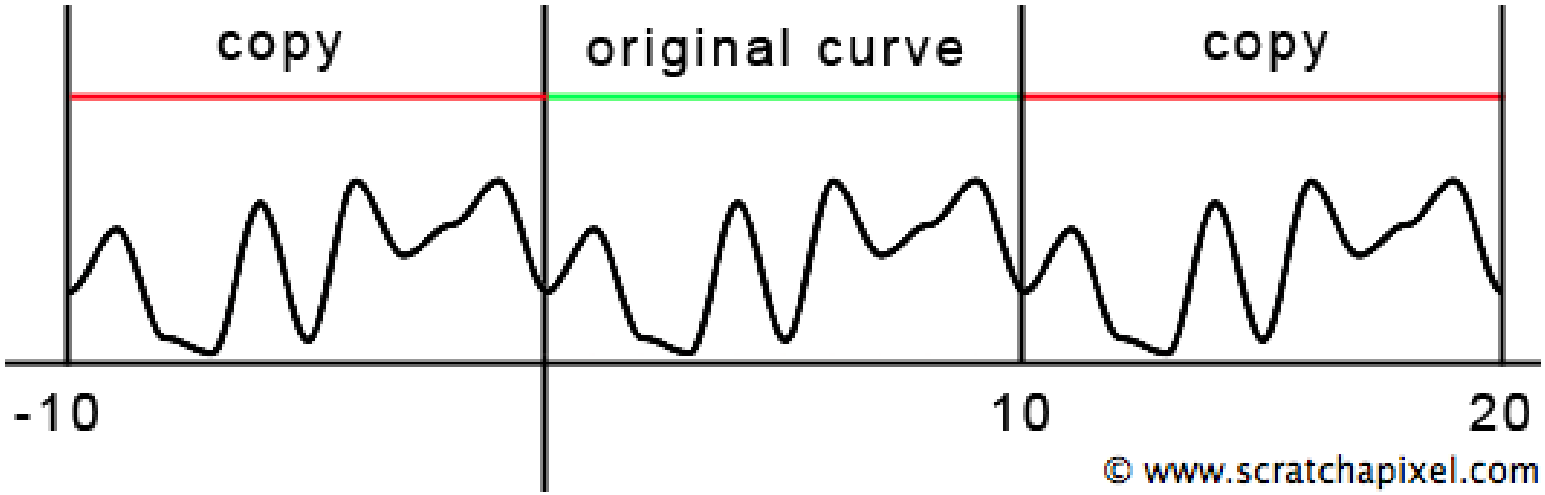
Perlin-like textures

Value noise 1D case

- Evaluation algorithm for a given point x
- Get the associated 2 random values?
  - Pseudo random function
  - Precomputed in an array

Pros/cons?

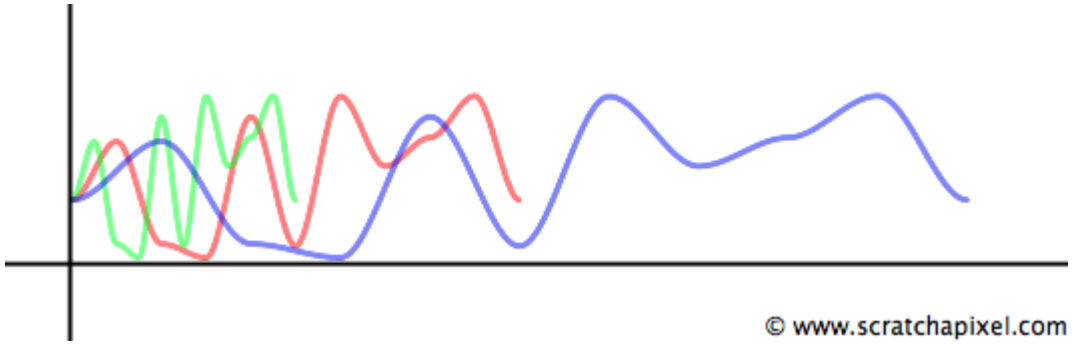
- Get relative position of x (between 0 and 1)
- Mix



Perlin-like textures

Value noise 1D case

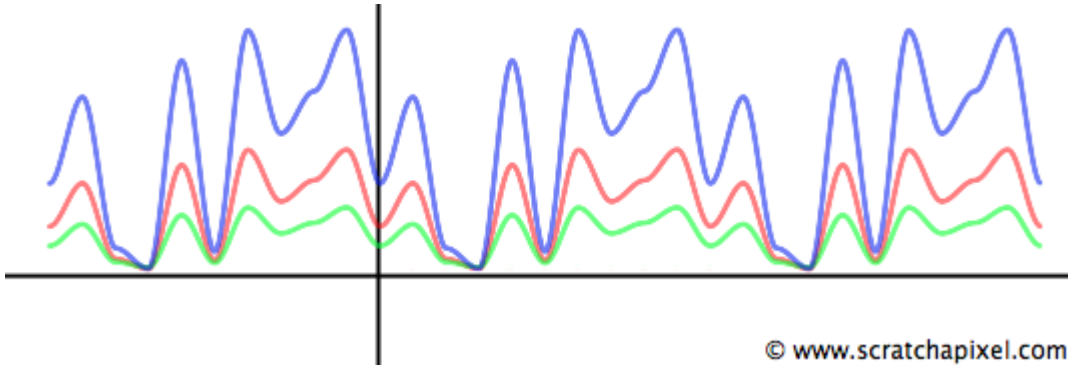
- Controls
  - Frequency: evalNoise(x * freq)



Perlin-like textures

Value noise 1D case

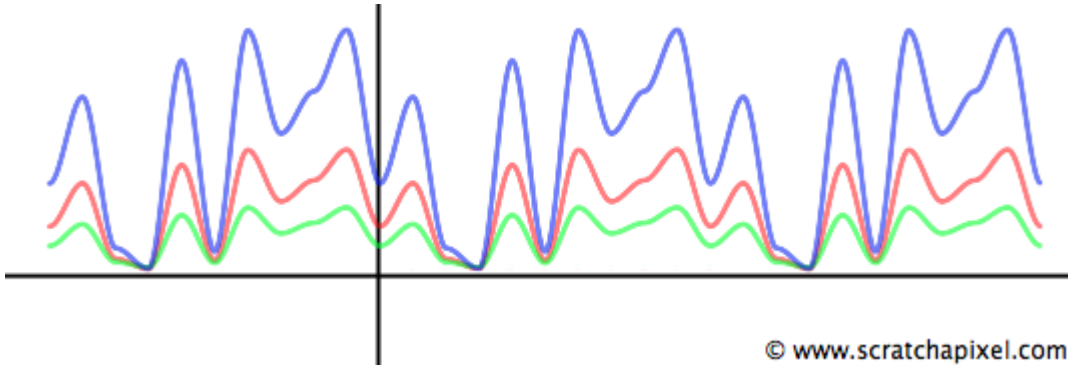
- Controls
  - Frequency: evalNoise(x * freq)
  - Amplitude: evalNoise(x) * amplitude



Perlin-like textures

Value noise 1D case

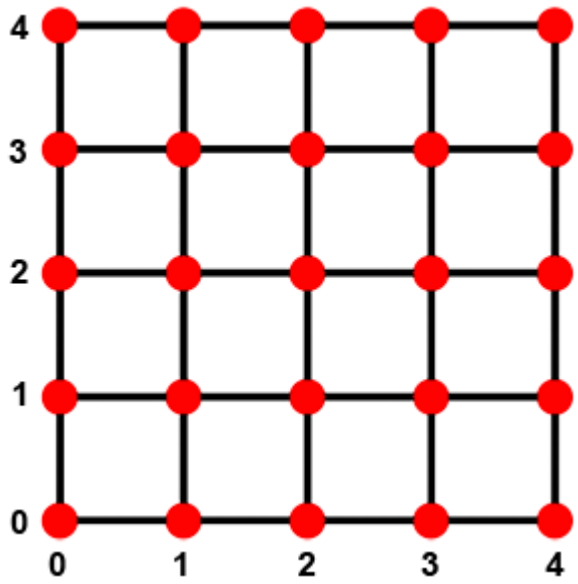
- Controls
  - Frequency: evalNoise(x * freq)
  - Amplitude: evalNoise(x) * amplitude
  - Offsetting: evalNoise(x + offset)



Perlin-like textures

Value noise 2D case

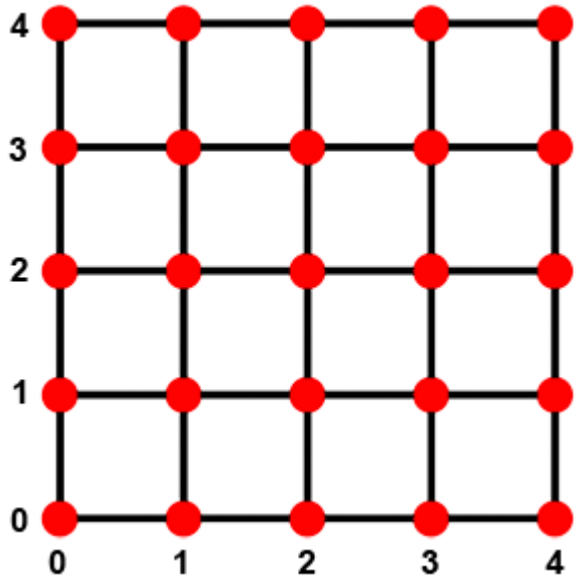
- Same principle, using a 2D grid

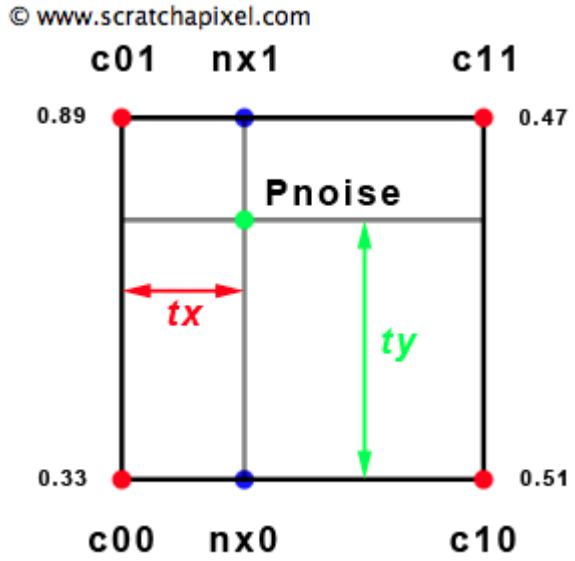


Perlin-like textures

Value noise 2D case

- Same principle, using a 2D grid
- Need 3 interpolations instead of 1



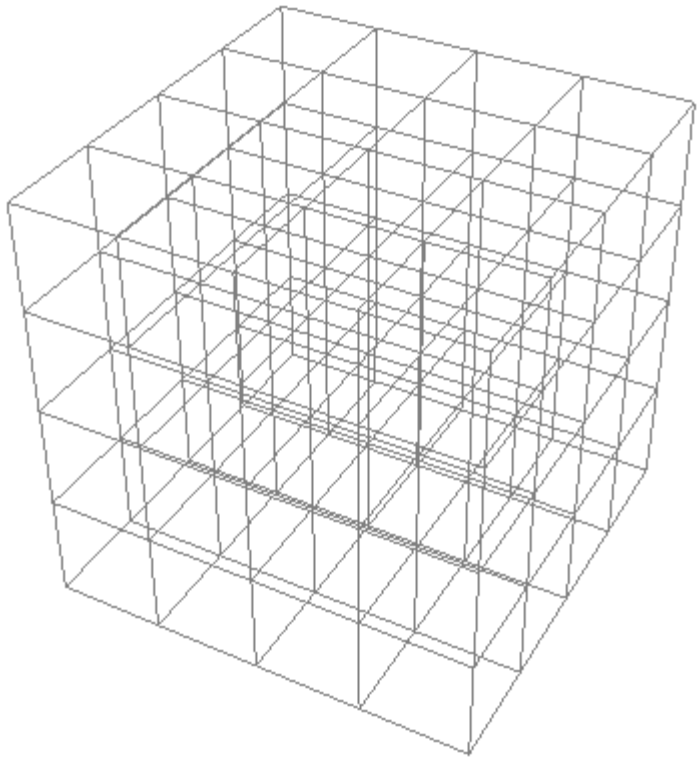


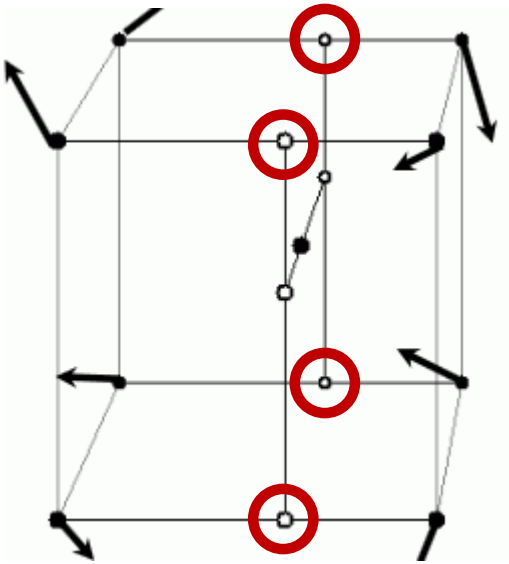
https://www.shadertoy.com/view/lsf3WH

Perlin-like textures

Value noise 3D case

- Same principle, using a 3D grid
- Need 7 interpolations

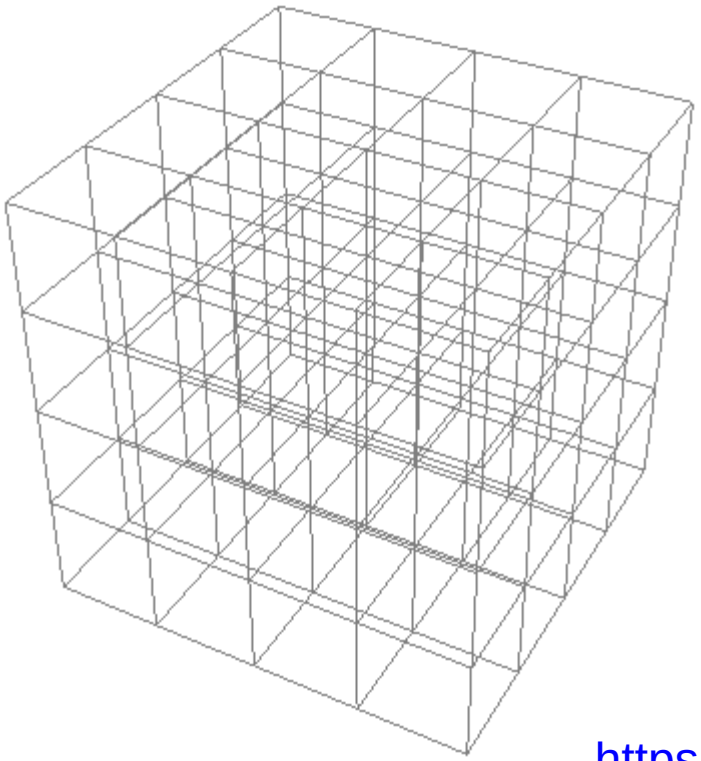


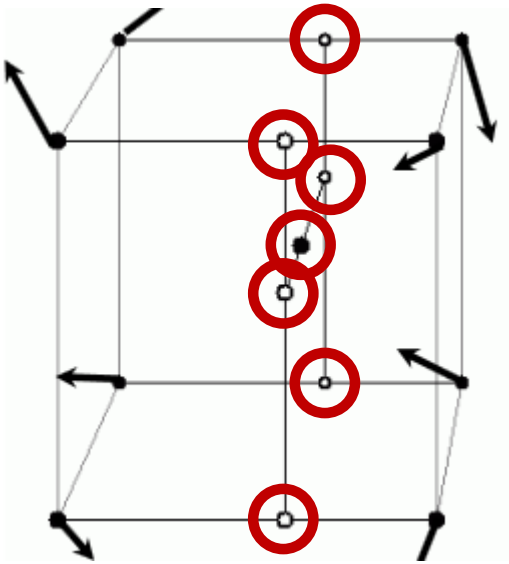


Perlin-like textures

Value noise 3D case

- Same principle, using a 3D grid
- Need 7 interpolations



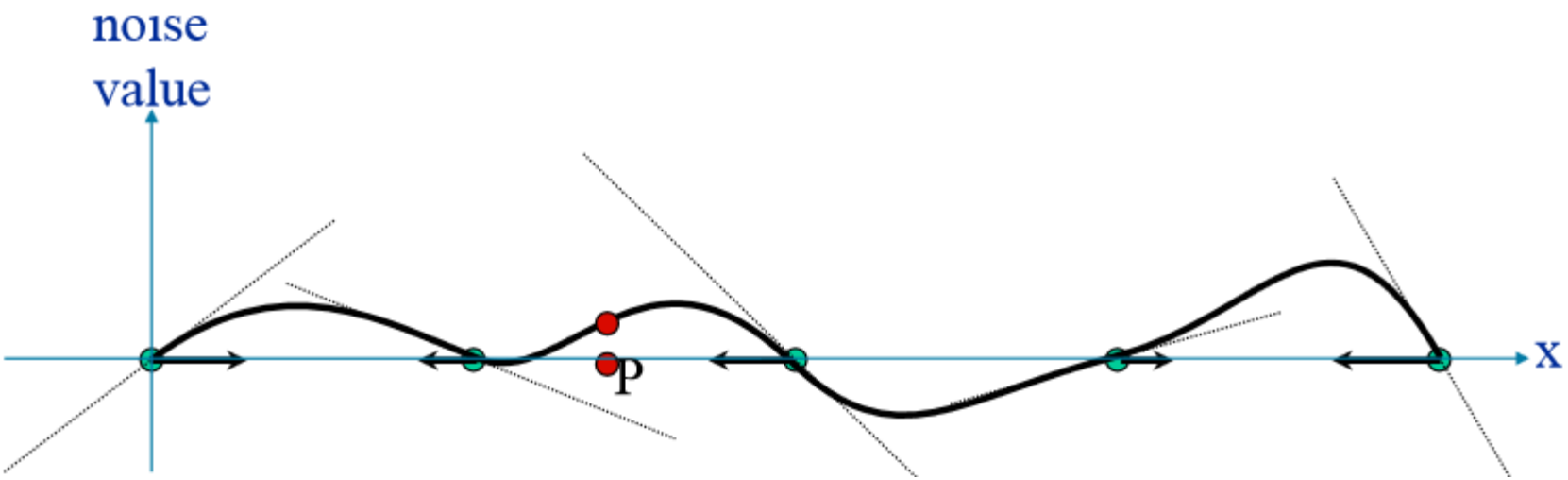


https://www.shadertoy.com/view/4sfGzS

Perlin-like textures

Gradient noise (1D case)

- Instead of distributing random positions:
  - Consider positions at 0
  - Distribute random gradients
  - Interpolate

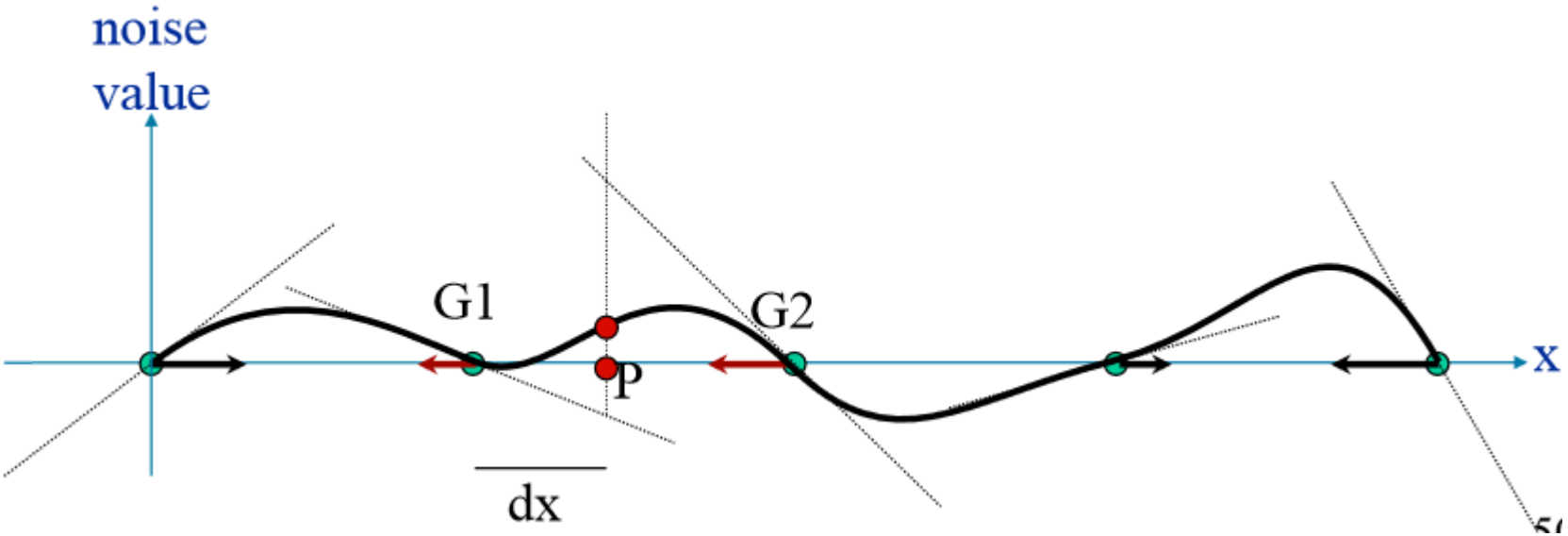


Perlin-like textures

Gradient noise (1D case)

- Instead of distributing random positions:
  - Consider positions at 0
  - Distribute random gradients
  - Interpolate

Available: G1, G2 and dx

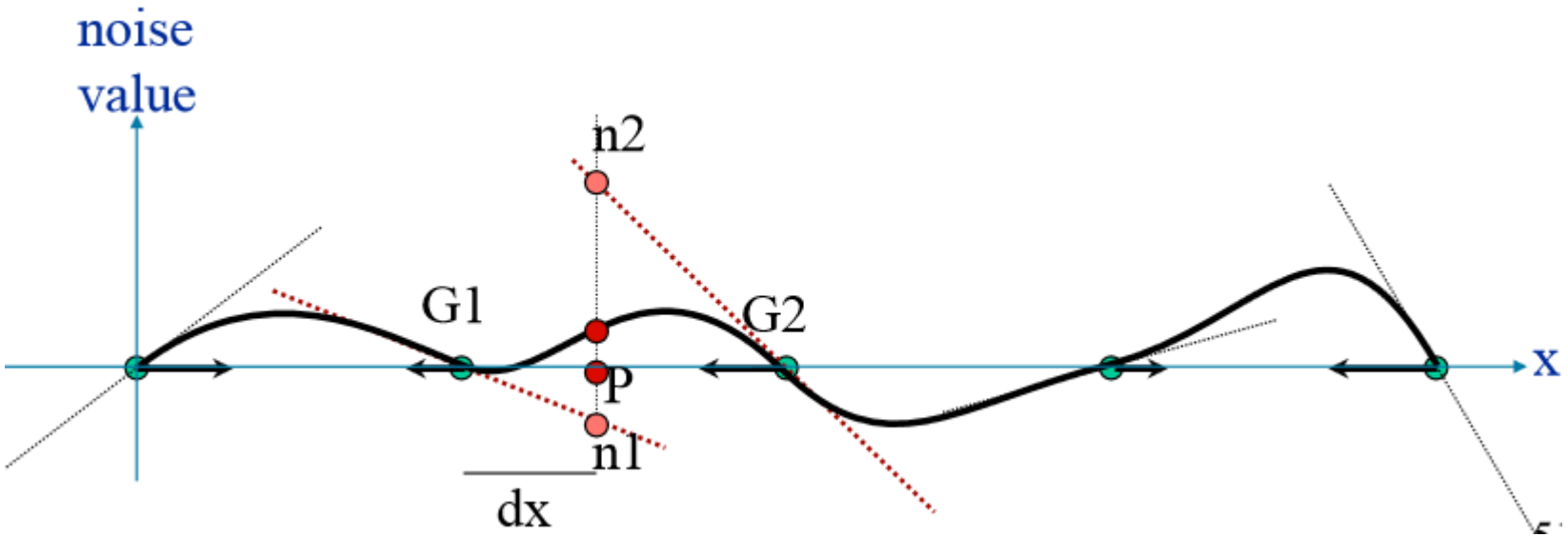


Perlin-like textures

Gradient noise (1D case)

- Instead of distributing random positions:
  - Consider positions at 0
  - Distribute random gradients
  - Interpolate

Available: G1, G2 and dx
n1 = dx*G1
n2 = (dx-1)*G2



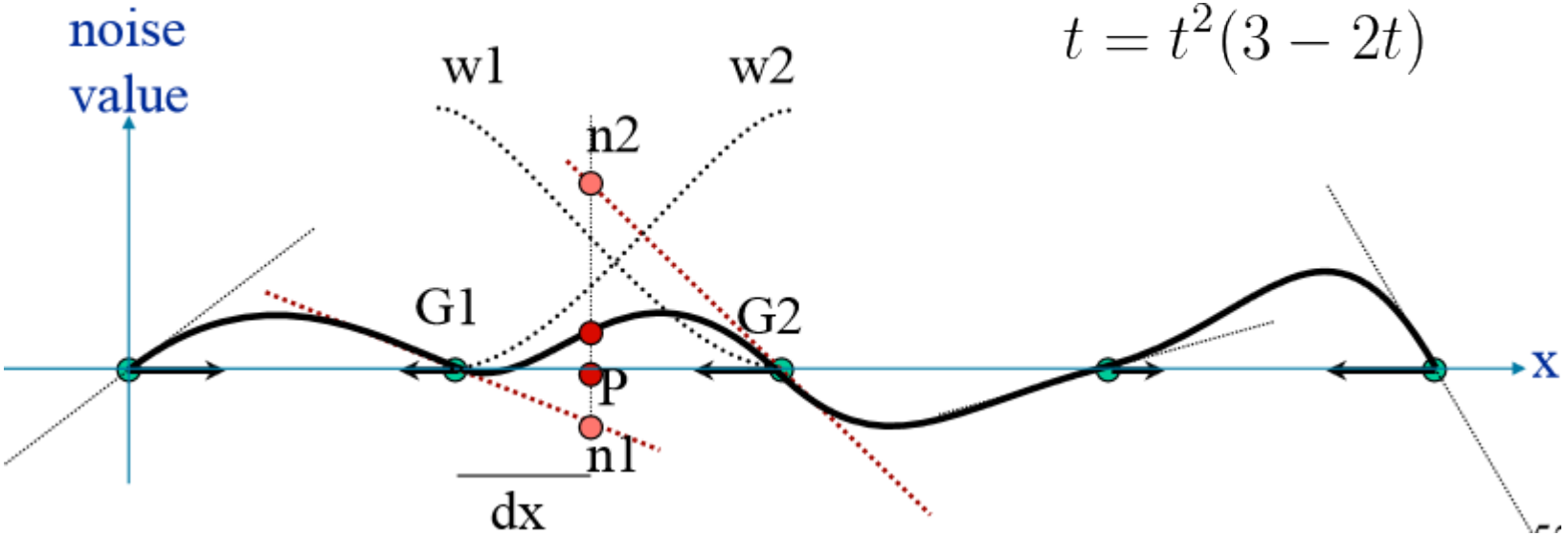
Perlin-like textures

Gradient noise (1D case)

- Instead of distributing random positions:
  - Consider positions at 0
  - Distribute random gradients
  - Interpolate

Available: G1, G2 and dx
n1 = dx*G1
n2 = (dx-1)*G2

P = w1.G1.dx + w2.G2.(dx-1)



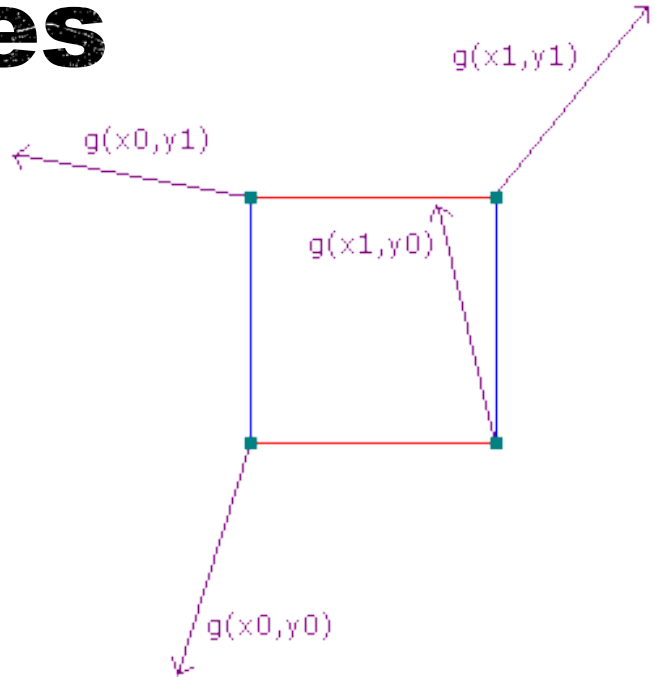
$$t = t^2(3 - 2t)$$

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

Perlin-like textures

Gradient noise (2D case)

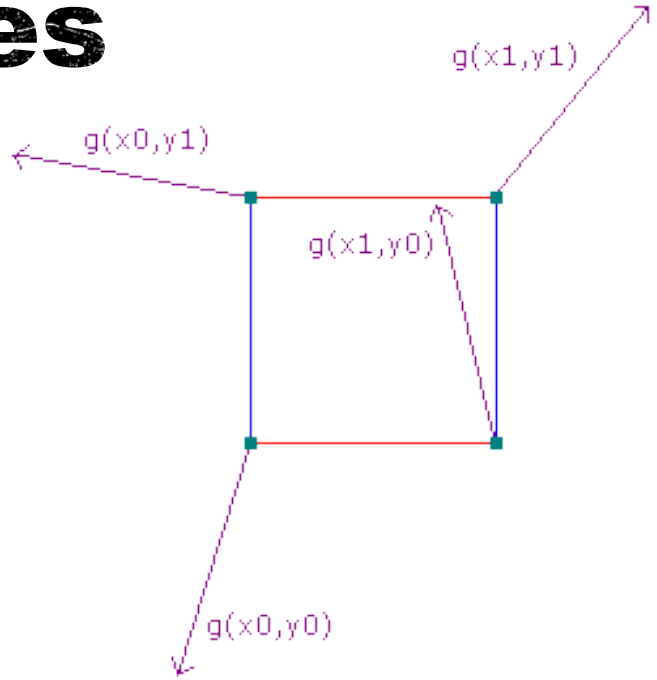
- Same principle
  - 2D gradients on each point

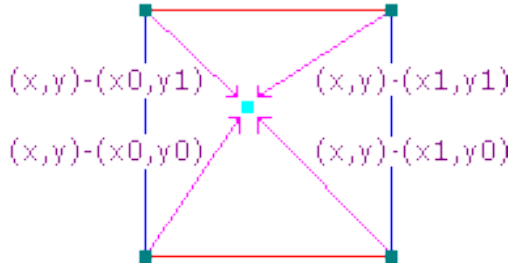


Perlin-like textures

Gradient noise (2D case)

- Same principle
  - 2D gradients on each point
  - Compute positional differences



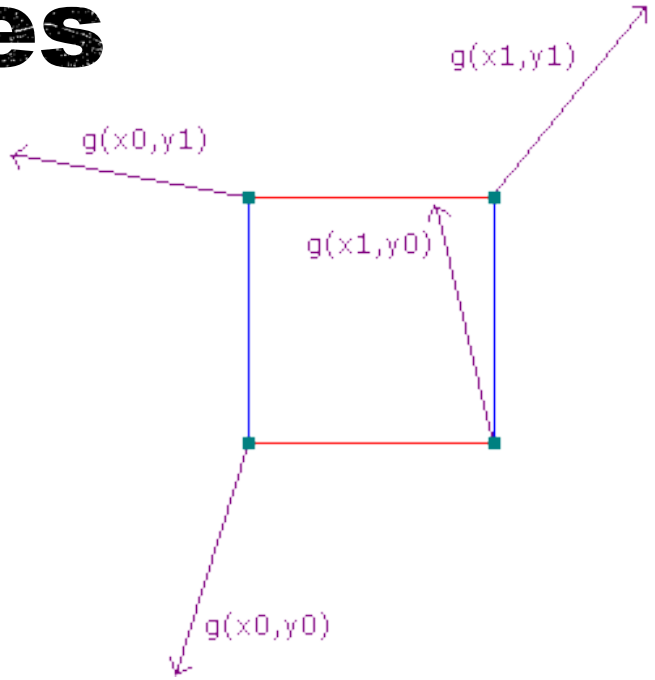


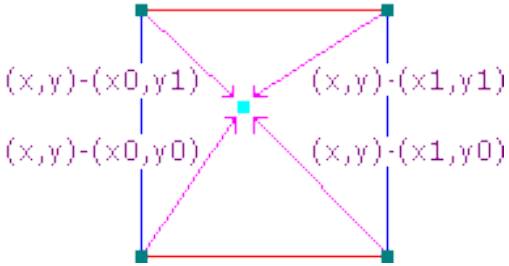
Perlin-like textures

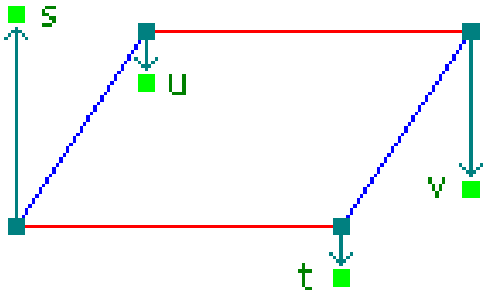
Gradient noise (2D case)

- Same principle
  - 2D gradients on each point
  - Compute positional differences
  - Compute corner values

$$s = g(x_0, y_0) \cdot ((x, y) - (x_0, y_0)),$$
$$t = g(x_1, y_0) \cdot ((x, y) - (x_1, y_0)),$$
$$u = g(x_0, y_1) \cdot ((x, y) - (x_0, y_1)),$$
$$v = g(x_1, y_1) \cdot ((x, y) - (x_1, y_1)).$$







Perlin-like textures

Gradient noise (2D case)

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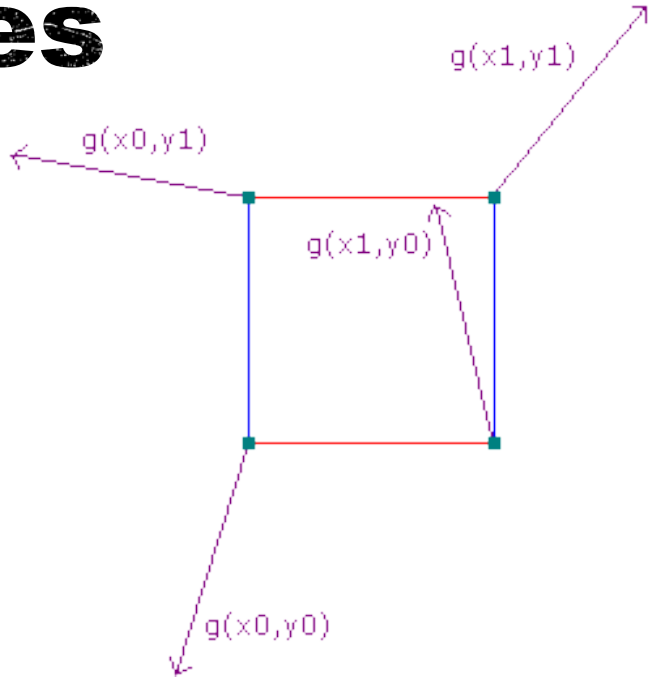
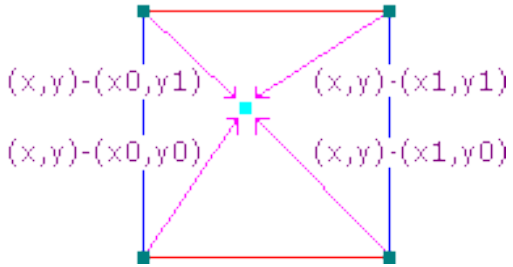
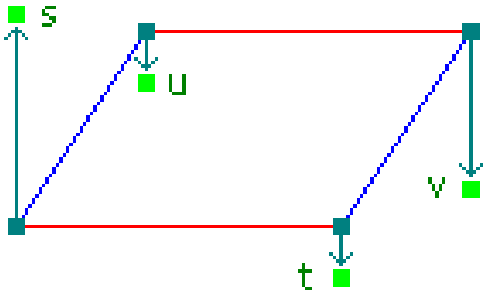
  - Compute positional differences
  - Compute corner values

$$s = g(x_0, y_0) \cdot ((x, y) - (x_0, y_0)),$$
$$t = g(x_1, y_0) \cdot ((x, y) - (x_1, y_0)),$$
$$u = g(x_0, y_1) \cdot ((x, y) - (x_0, y_1)),$$
$$v = g(x_1, y_1) \cdot ((x, y) - (x_1, y_1)).$$





- And interpolate, as before

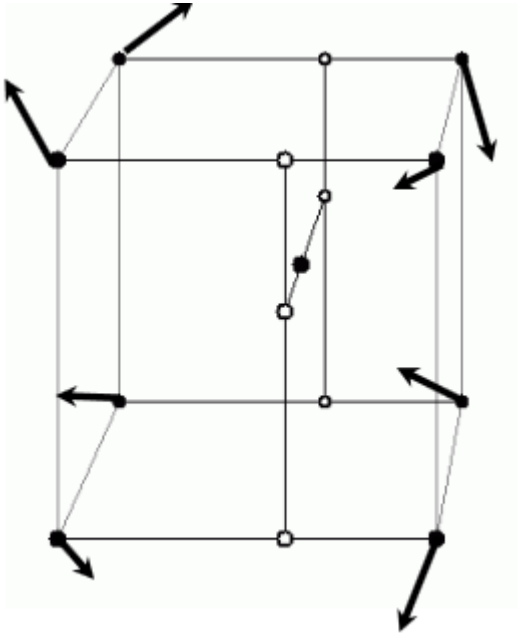


https://www.shadertoy.com/view/XdXGW8

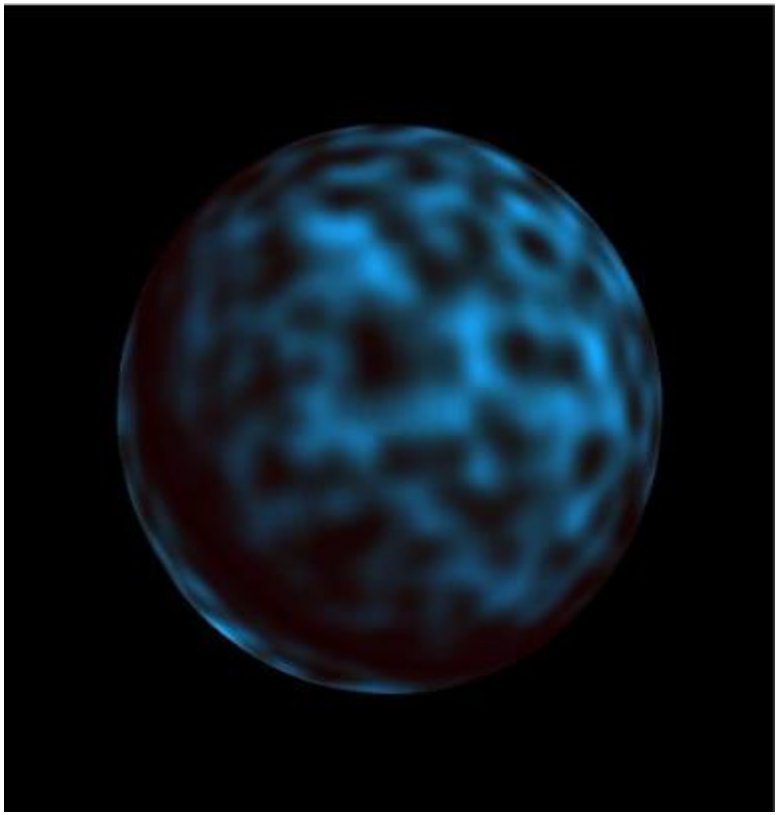
Perlin-like textures

Gradient noise (3D case)

- Same principle… again
  - 3D gradients on each point
  - Compute positional differences
  - Compute corner values
  - And interpolate, as before



Perlin-like textures



Gradient noise (3D case)

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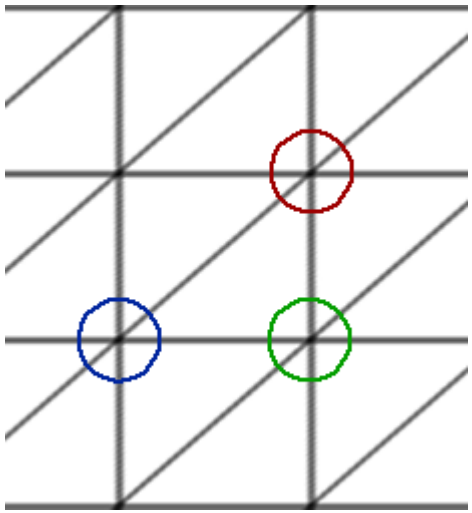
  - Compute positional differences
  - Compute corner values
  - And interpolate, as before

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

Perlin-like textures

Gradient noise (3D case)

- Simplex noise
  - Use triangles instead of quads
  - Sum contributions instead of interpolating



http://webstaff.itn.liu.se/~stegu/simplexnoise/simplexnoise.pdf

Perlin-like textures

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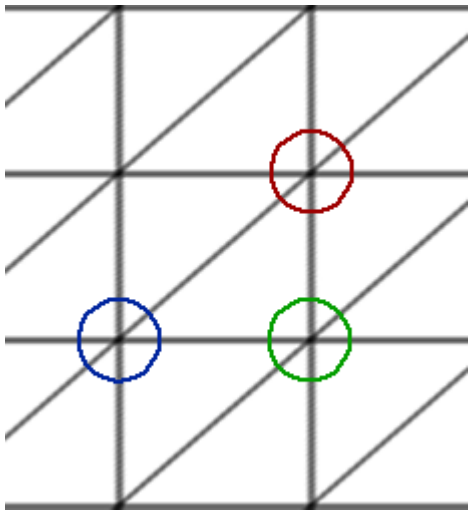
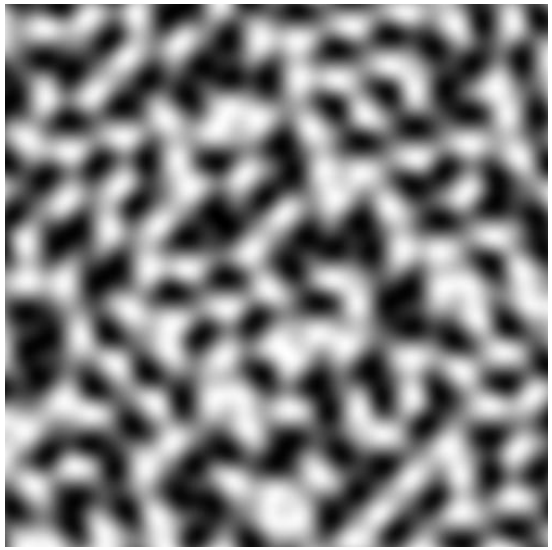
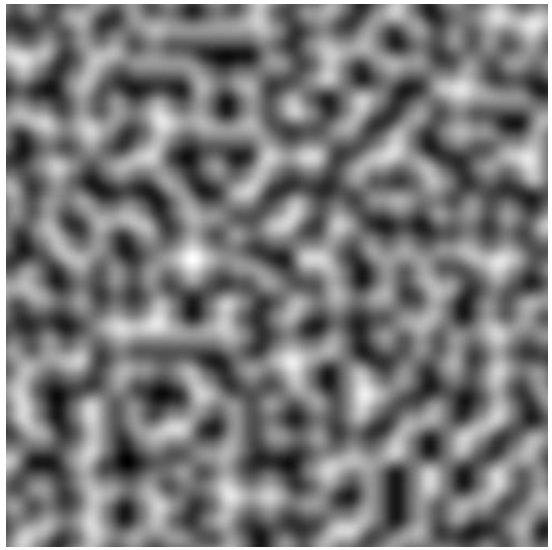


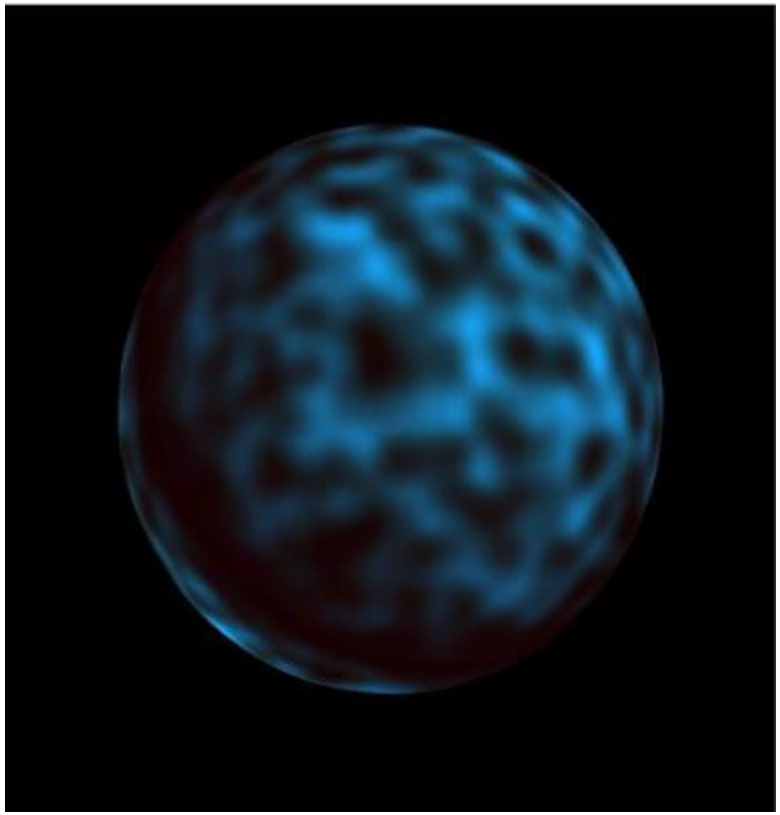




http://webstaff.itn.liu.se/~stegu/simplexnoise/simplexnoise.pdf

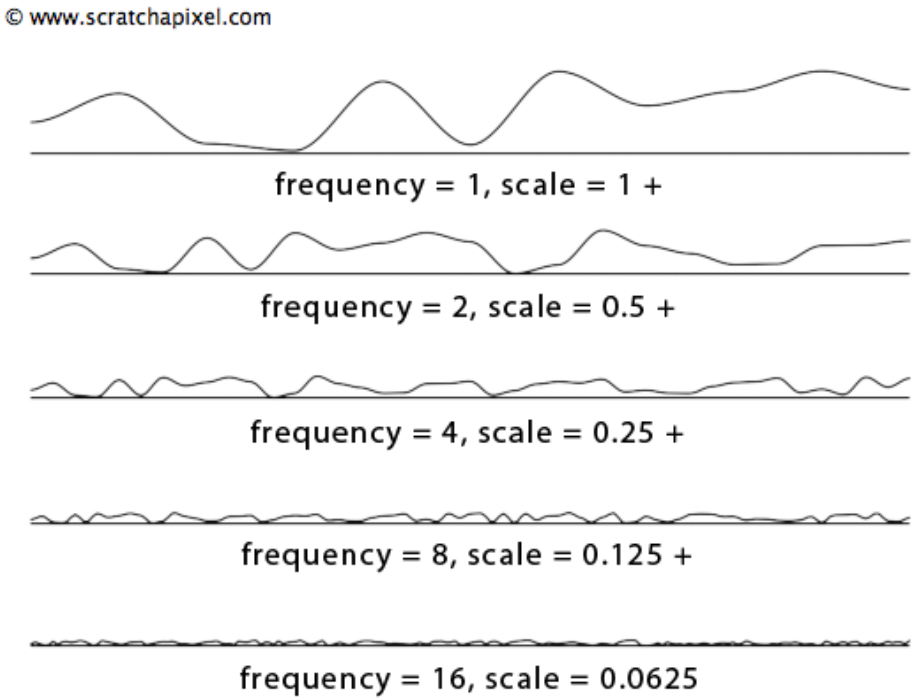
Fractal textures

- Noise at one scale = 1 octave



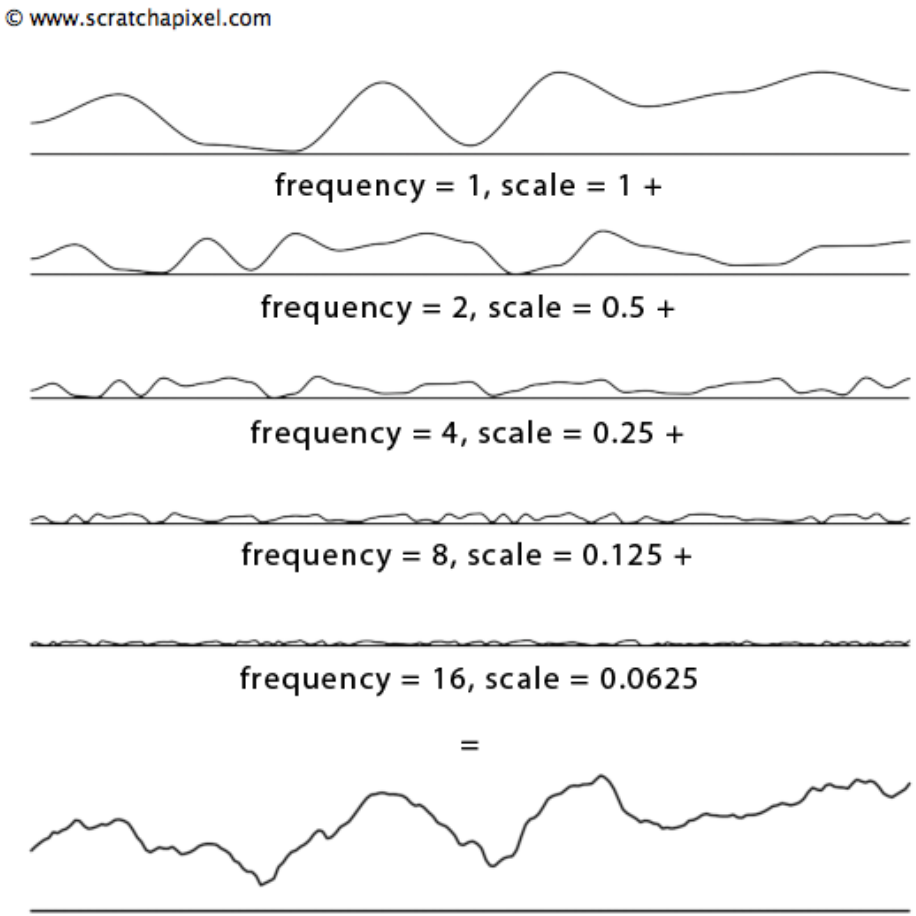
Fractal textures

- Noise at one scale = 1 octave
- Multiple octave usually used
  - Frequency multiplied by 2 each time
  - Hence the name octave
  - Different amplitudes too



Fractal textures

- Noise at one scale = 1 octave
- Multiple octave usually used
  - Frequency multiplied by 2 each time
  - Hence the name octave
  - Different amplitudes too
- Sum of all noises =
  - Fractal noise



Fractal textures

- Computing the ith noise texture:

$$frequency = 2^i$$
$$amplitude = persistence^i$$

Fractal textures

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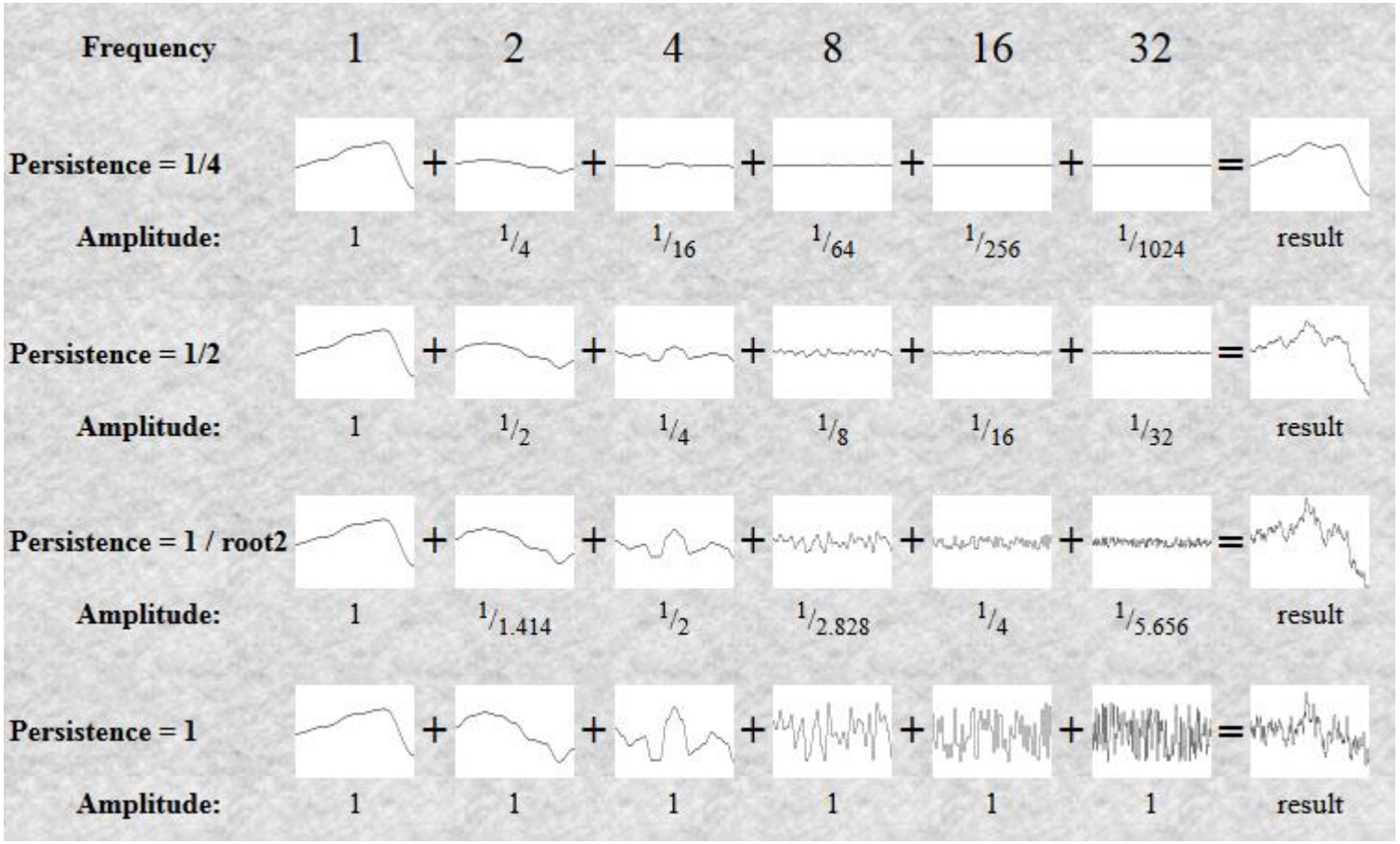

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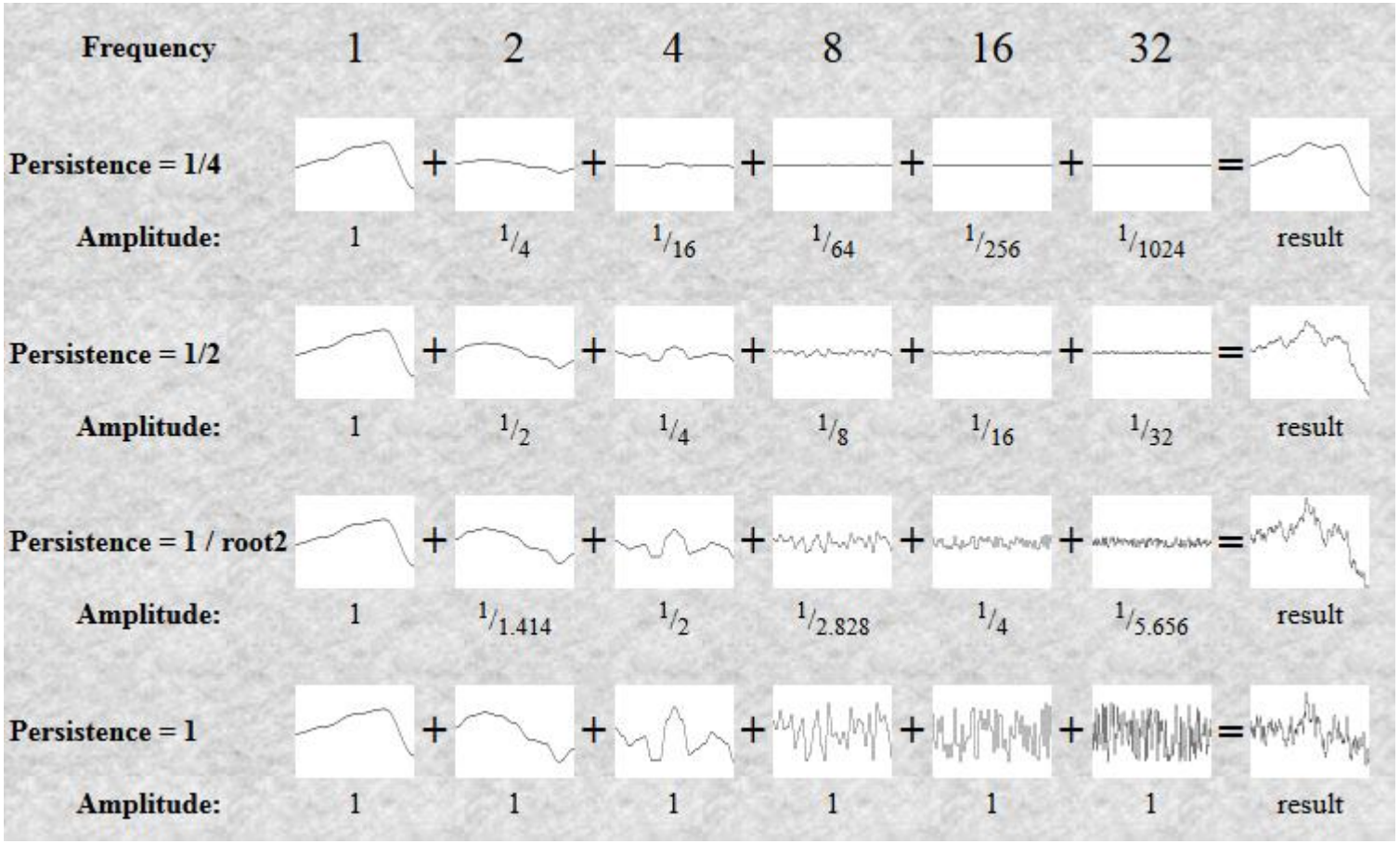
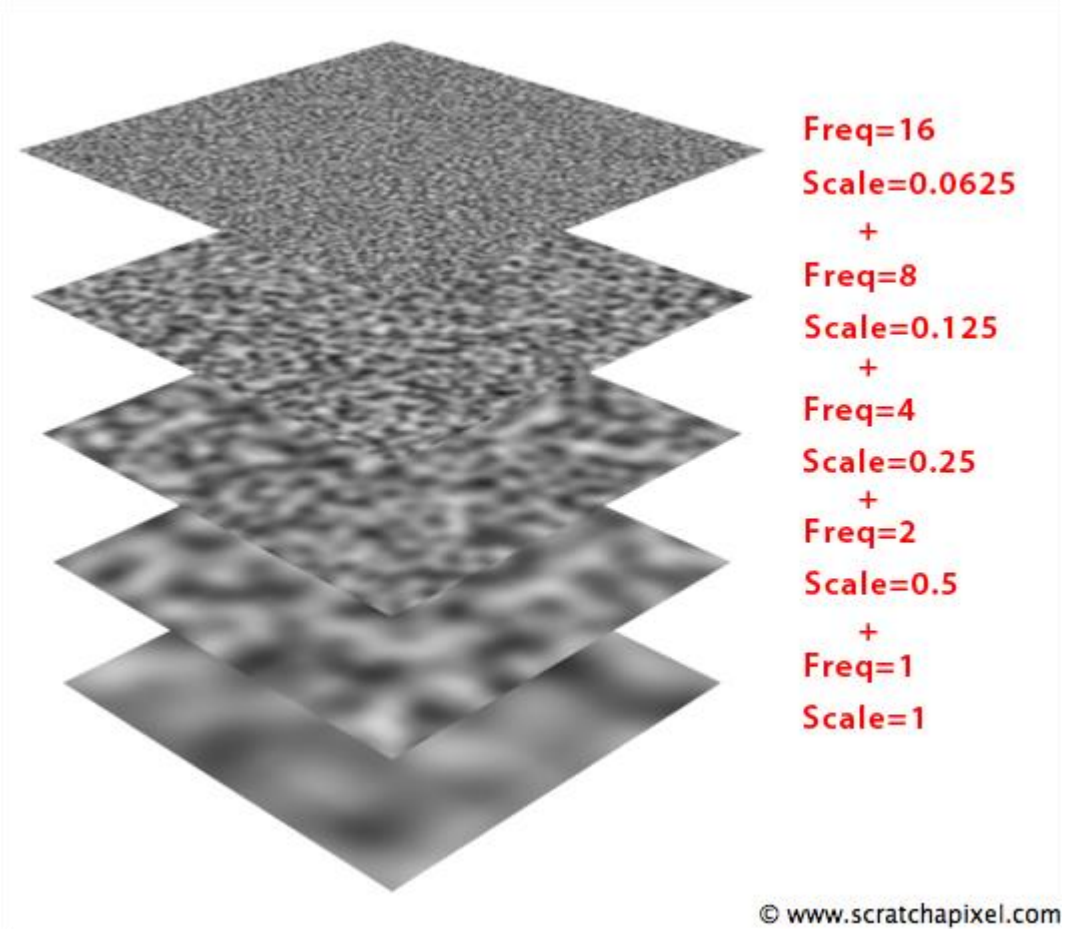


Fractal textures

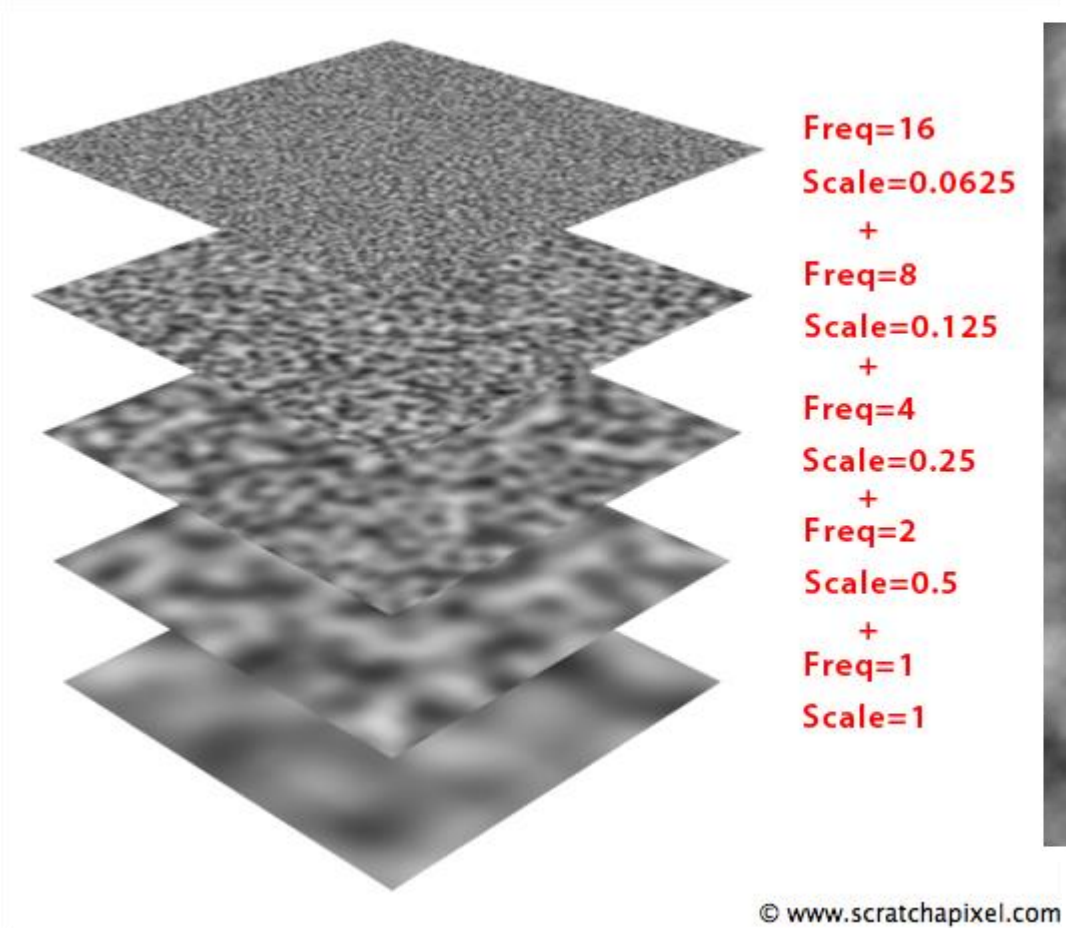
- 2D example

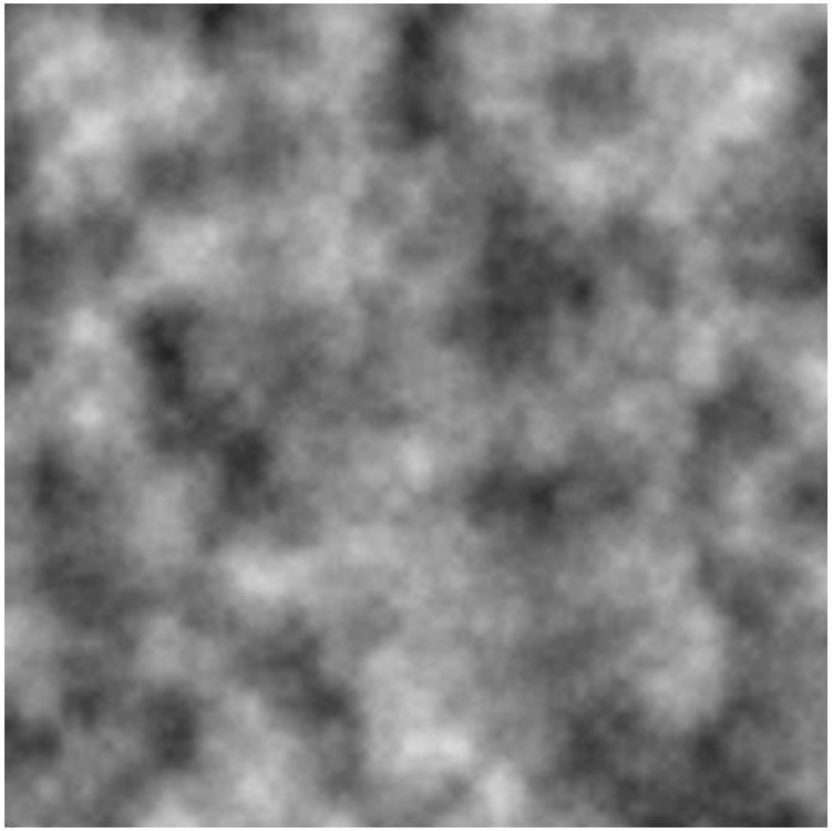


Fractal textures

- 2D example

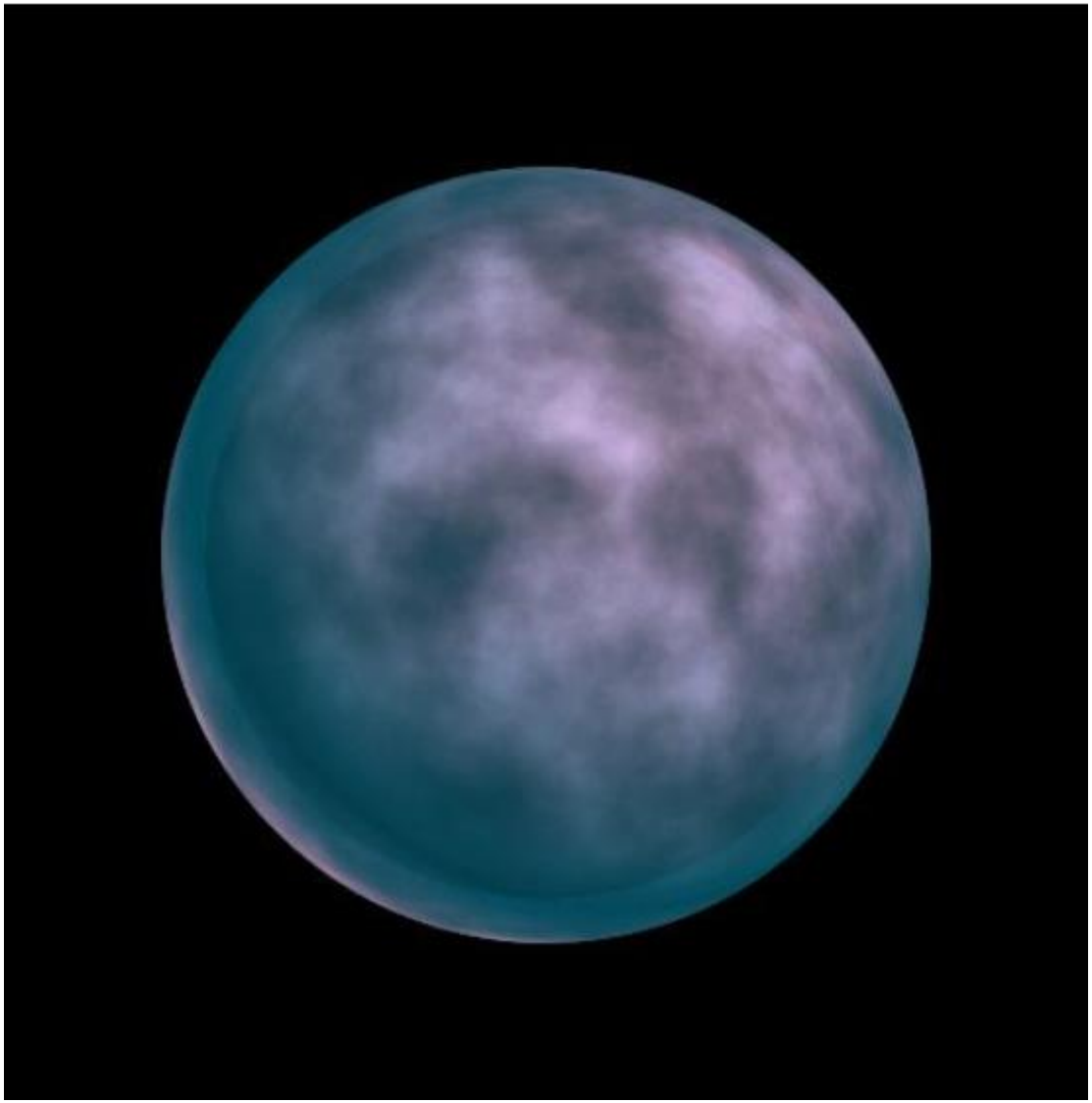
Each octave f has weight 1/f





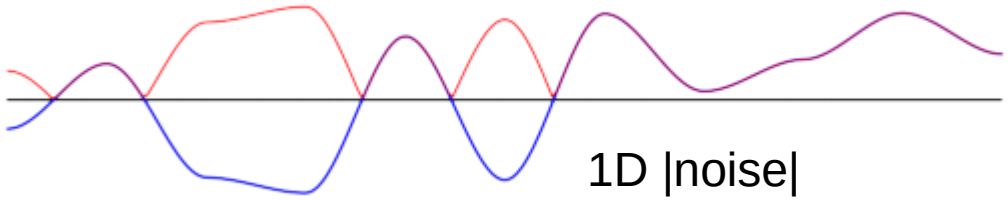
Fractal textures

- 3D example Sum 1/f(noise)



Fractal textures

- Taking the absolute value of the noise Sum 1/f(|noise|)



1D |noise|

Creates C0 discontinuities

Fractal textures

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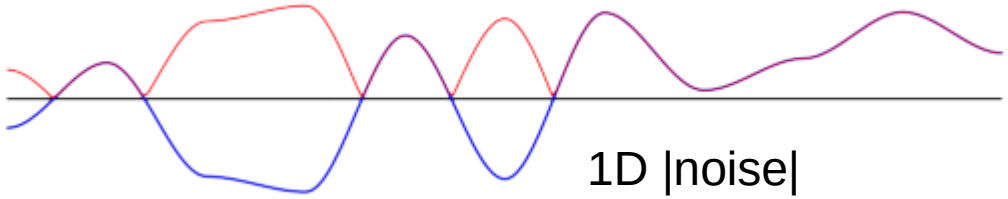

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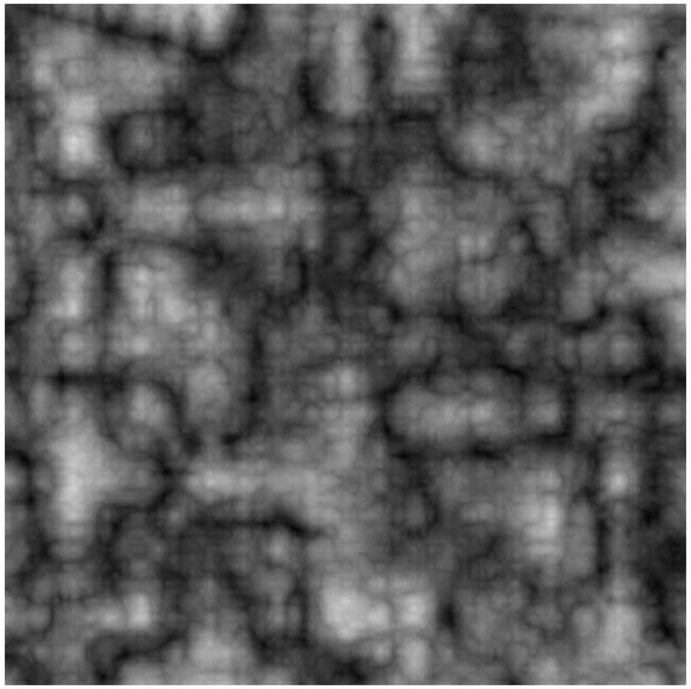
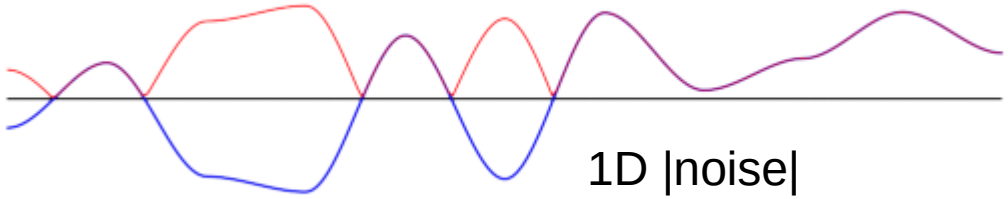


2D |noise|

Fractal textures

- Taking the absolute value of the noise Sum 1/f(|noise|)



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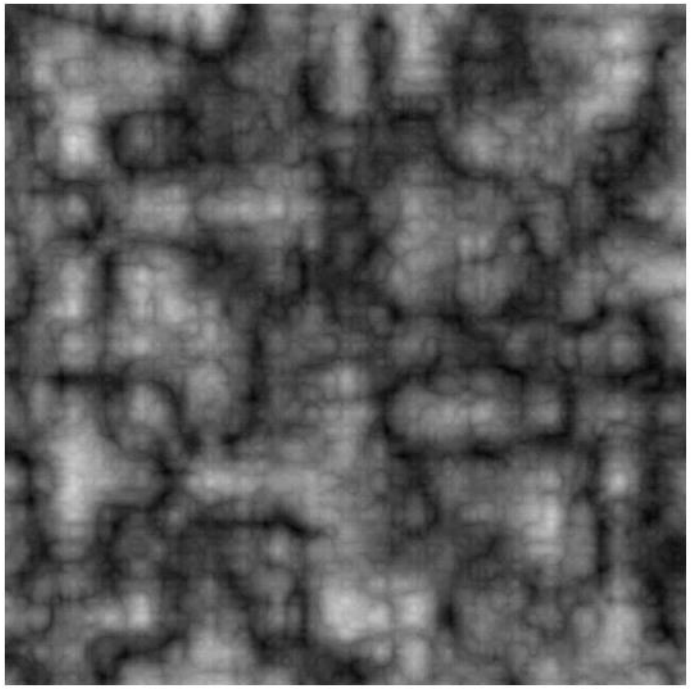
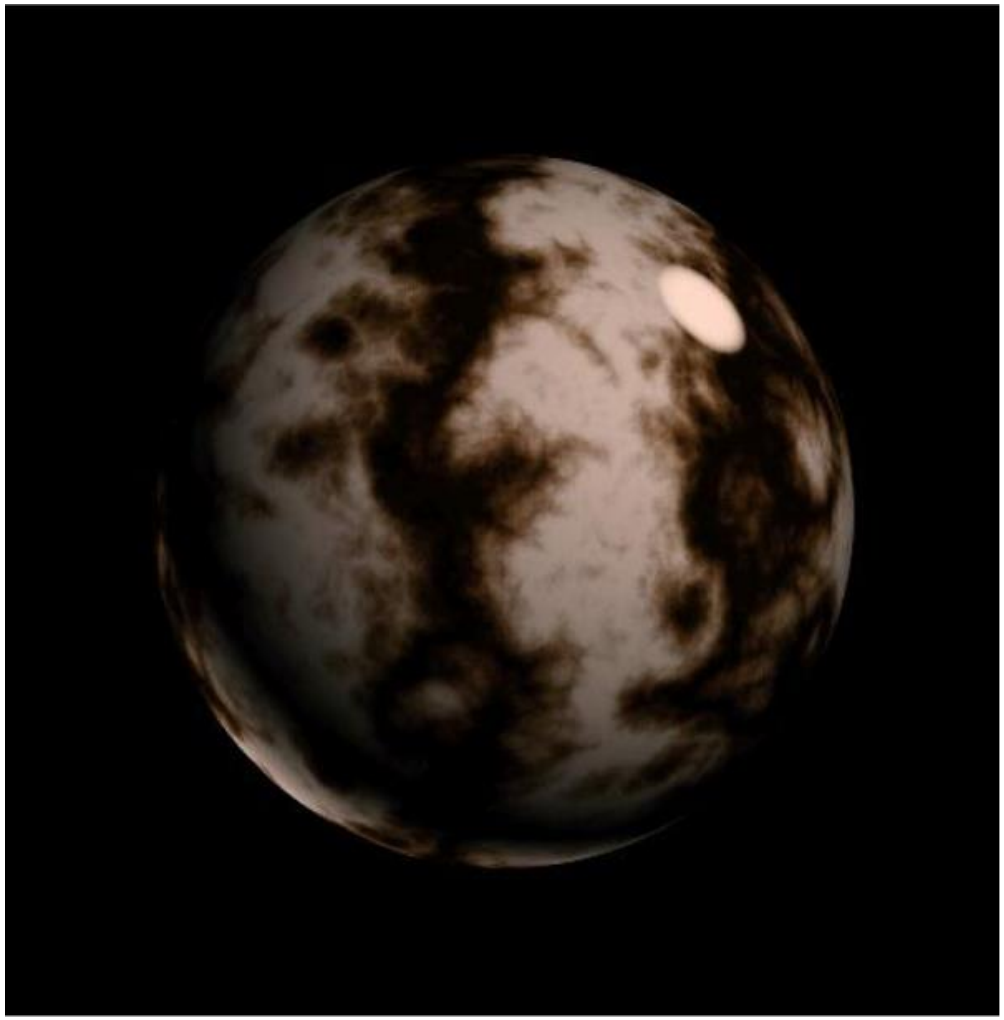


2D |noise|

3D |noise|

Fractal textures

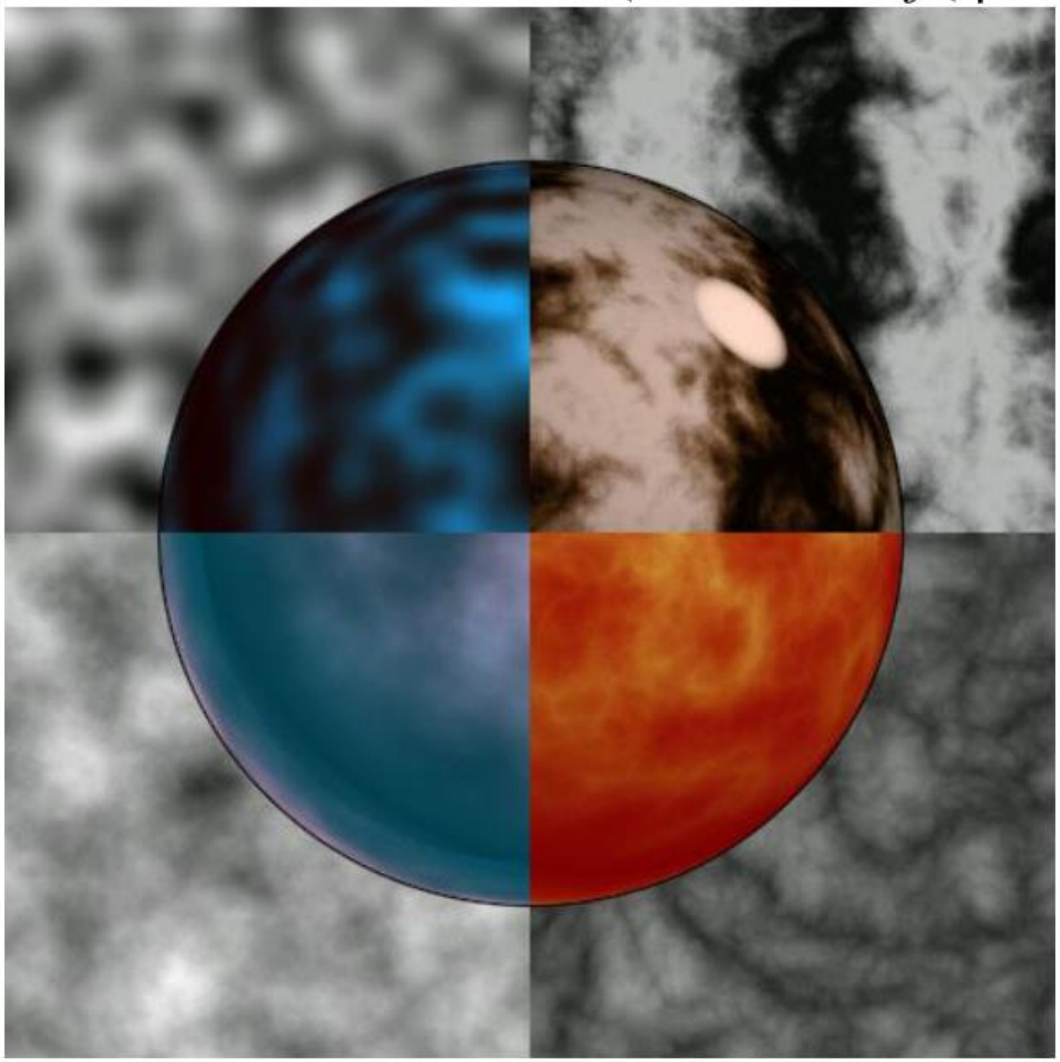
- Even better: Sin (x + Sum 1/f(noise))



Fractal textures

- *noise*

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



sum 1/*f*(*noise*)

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

Fractal textures

- Marble

Sin (x + Sum 1/f(noise))
=
Colormap(Sin (x + turbulence))

- Wood

Colormap(Sin (radius + turbulence))

Fractal textures

- Texture
- Terrain
- Clouds
- Fire

- But also,
- Density for distributing elements
  - Forest
  - Plants
  - Etc

References

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