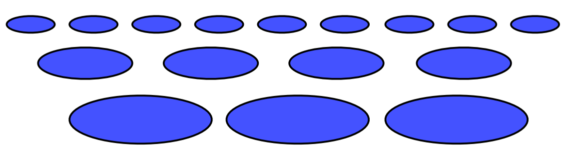
Procedural shading and texturing

Local shading is complex

- Assume we know diffuse, specular, transmitted, ambient components
- Must apply
  - texture
    - from map
    - procedural
    - volume
  - bump
  - displacement
  - opacity
  - etc
- Shaders
  - device for managing this complexity

Texturing

- Makes materials look more interesting
  - Color - e.g. decals
  - Opacity - e.g. swiss cheese, wire
  - Wear & tear - e.g. dirt, rust
- Provides additional depth cue to human visual system



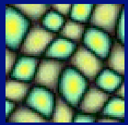
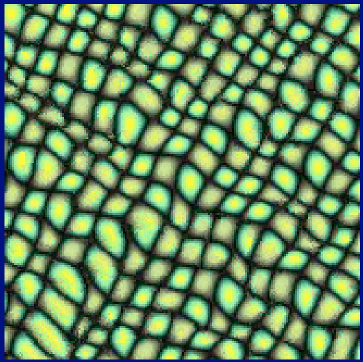
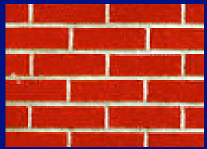
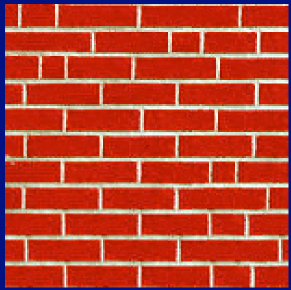
Texture Mapping

- Maps image onto surface
- Depends on a surface parameterization (s,t)
  - Difficult for surfaces with many features
  - May include distortion
  - Not necessarily 1:1

Kettle, by Mike Miller

Texture synthesis

- Use image as a source of probability model
- Choose pixel values by matching neighbourhood, then filling in
- Matching process
  - look at pixel differences
  - count only synthesized pixels

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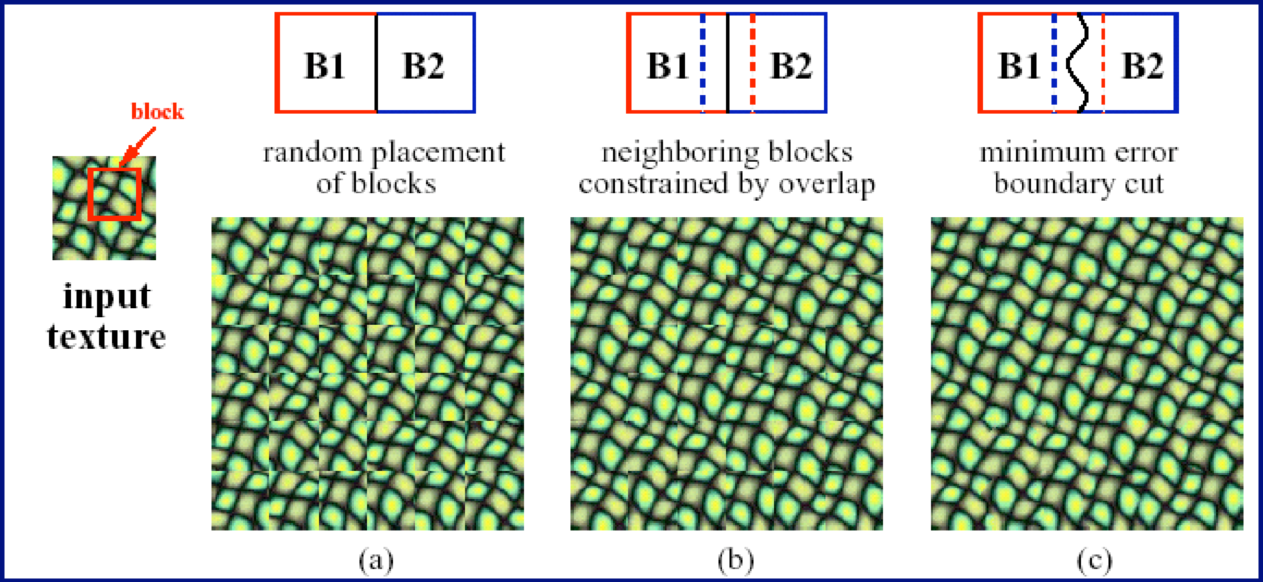
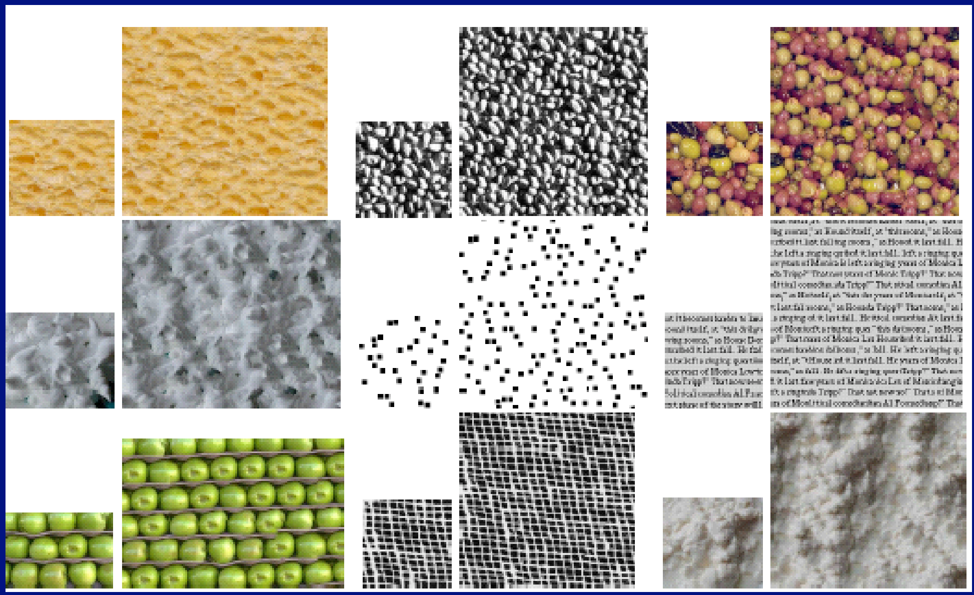


From “Image quilting for texture synthesis and transfer”, Efros and Freeman, SIGGRAPH 2001



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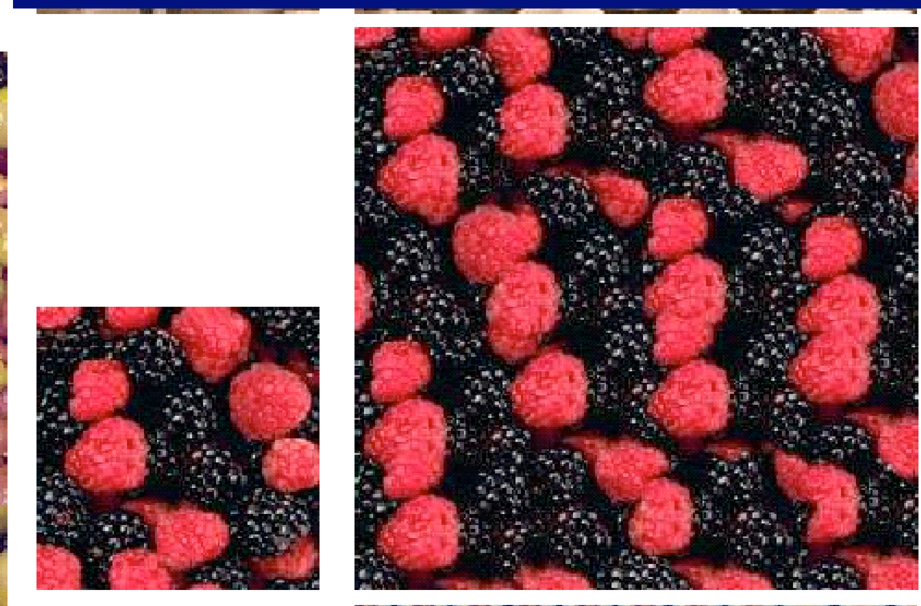

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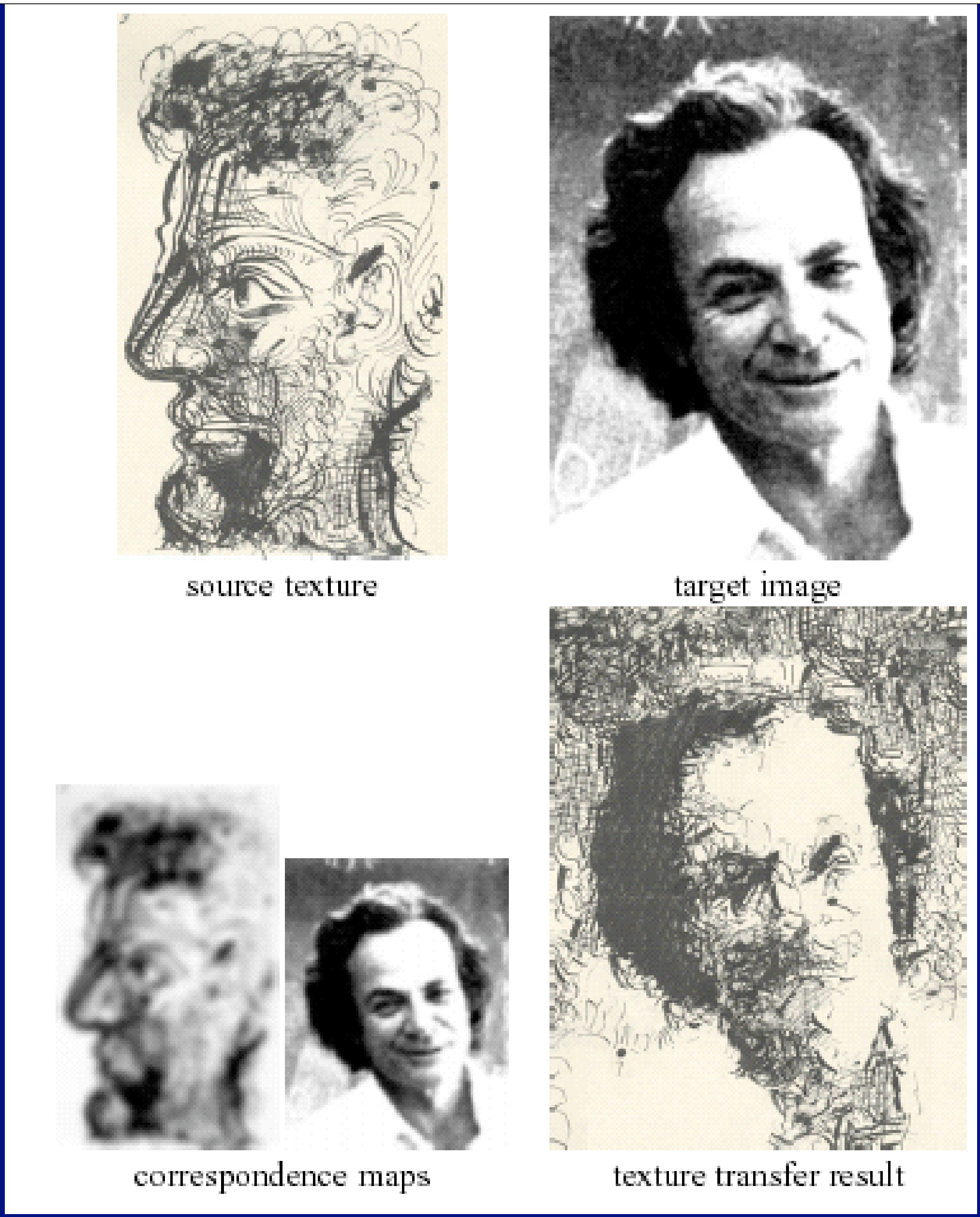

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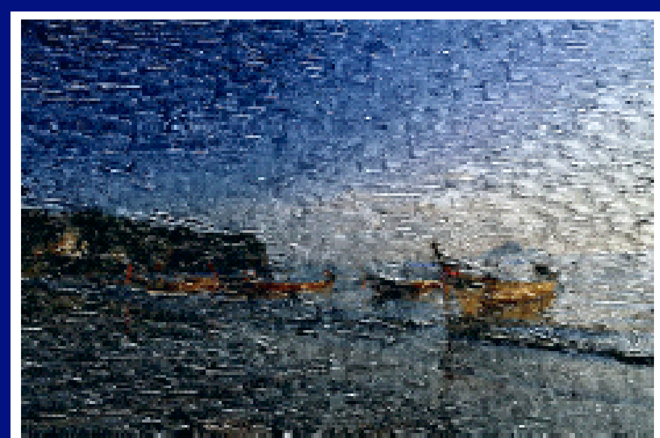
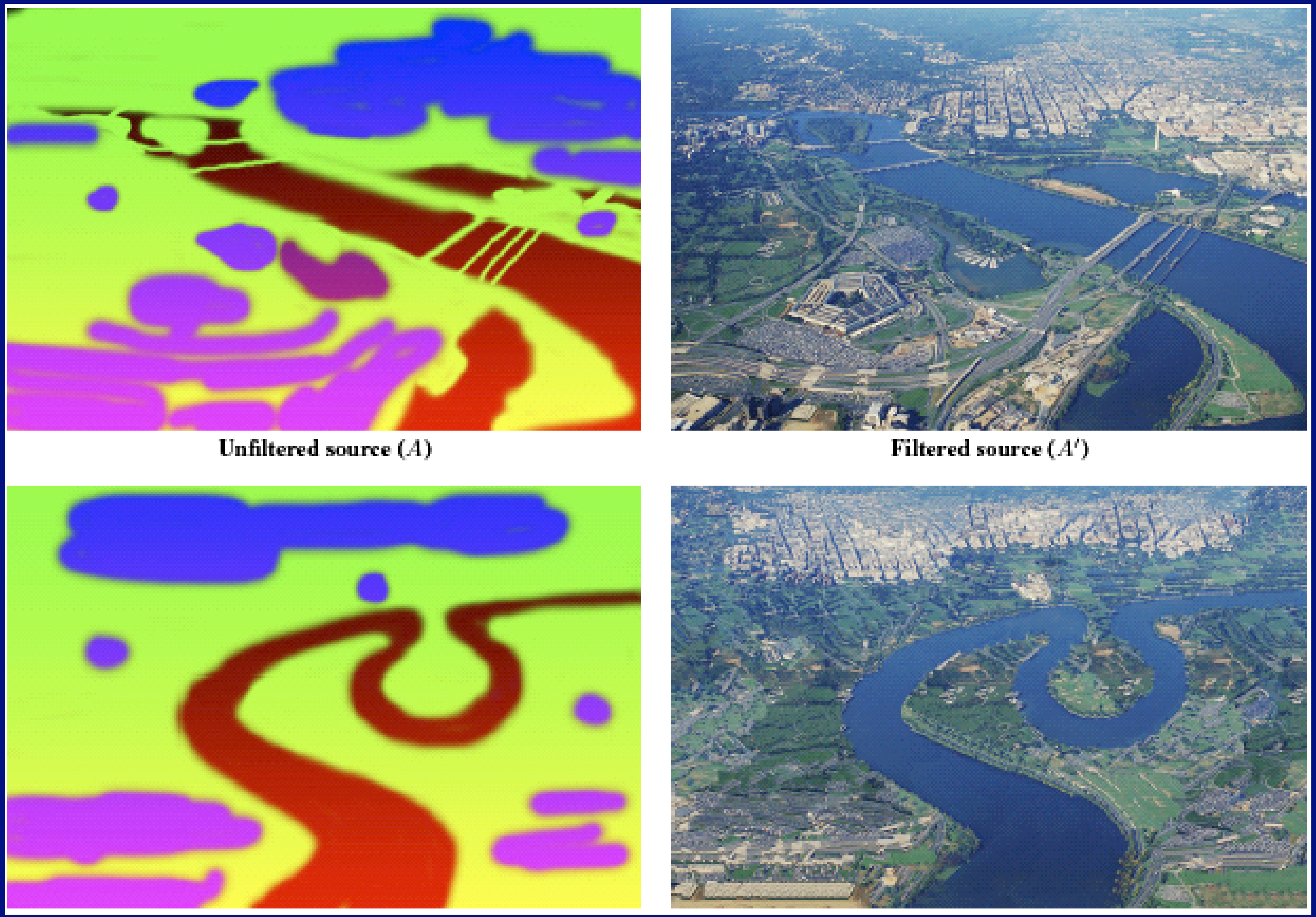


From “Image analogies”, Herzmann et al, SIGGRAPH 2001



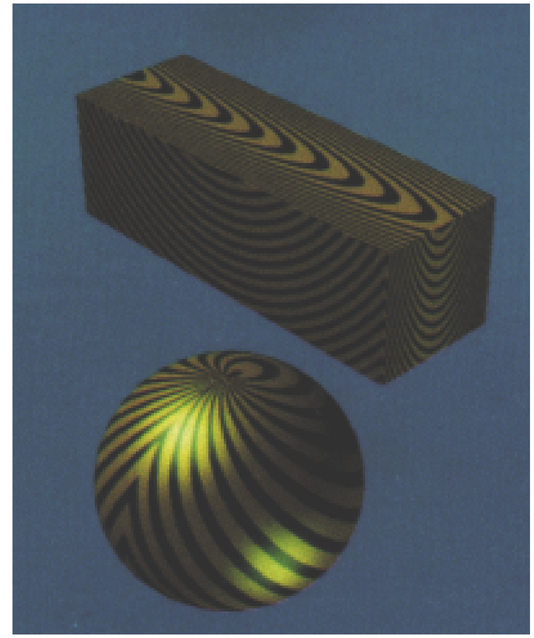
From “Image analogies”, Herzmann et al, SIGGRAPH 2001

Solid Texturing

- Uses 3-D texture coordinates (s,t,r)
- Can let $s = x$, $t = y$ and $r = z$
- No need to parameterize surface
- No worries about distortion
- Objects appear sculpted out of solid substance

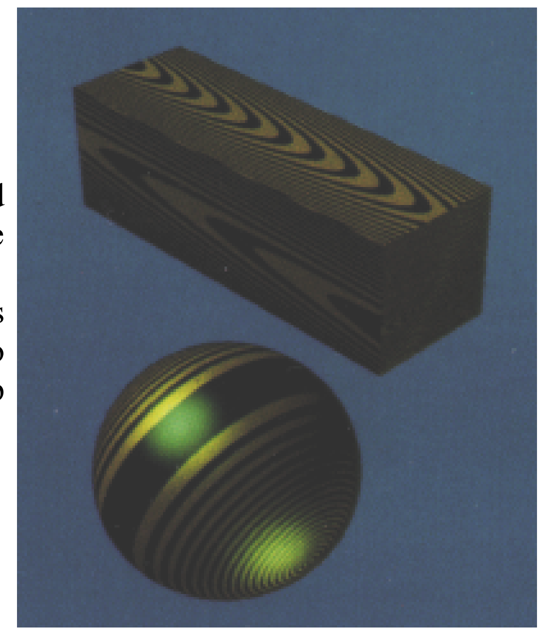
Surface Texture

features don't line up



Solid Texture

features do line up



Darwyn Peachey, 1985

Solid Texture Problems

- How can we deform an object without making it swim through texture?
- How can we efficiently store a procedural texture?

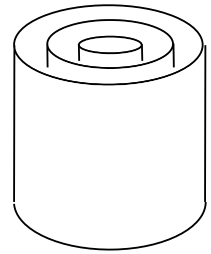
Procedural Texturing

- Texture map is a function
- Write a procedure to perform the function
  - input: texture coordinates - s,t,r
  - output: color, opacity, shading
- Example: Wood
  - Classification of texture space into cylindrical shells

$$f(s,t,r) = s^2 + t^2$$

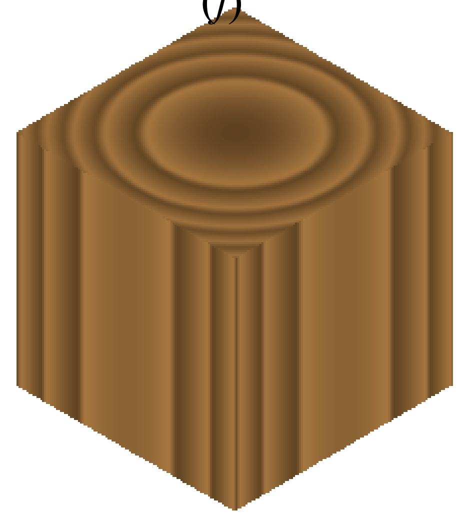
  - Outer rings closer together, which simulates the growth rate of real trees
  - Wood colored color table
    - Woodmap(0) = brown “earlywood”
    - Woodmap(1) = tan “latewood”

$$\text{Wood}(s,t,r) = \text{Woodmap}(f(s,t,r) \bmod 1)$$



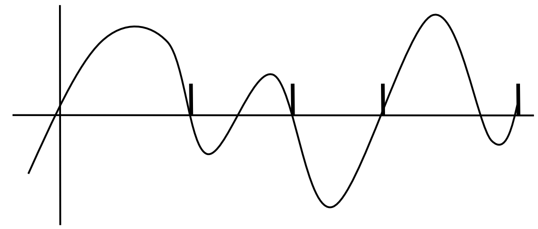
$f(s,t,r) = s^2 + t^2$

Woodmap (f)



Wood(s,t,r)

Noise Functions

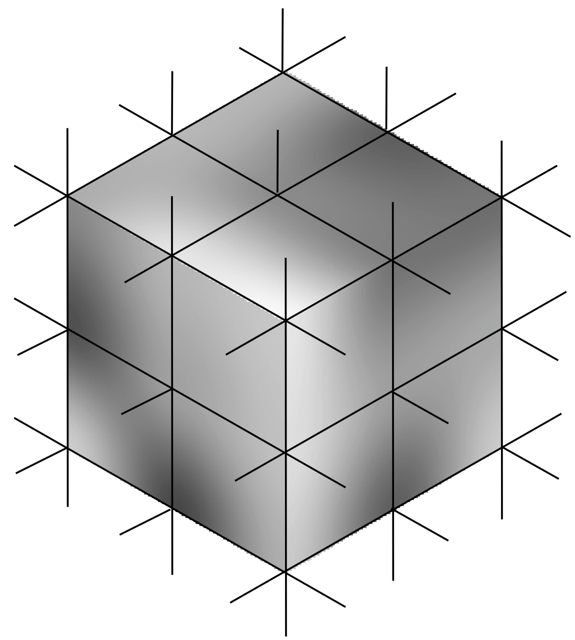


- Add “noise” to make textures interesting
- Perlin noise function $N(x,y,z)$
  – Smooth
  – Correlated
  – Bandlimited
- $N(x,y,z)$ returns a single random number in [-1,1]
- Gradient noise
  – Like a random sine wave

$$N(x,y,z)=0 \text{ for int } x,y,z$$

- Value noise
  – Also like a random sine wave

$$N(x,y,z)=\text{random for int } x,y,z$$



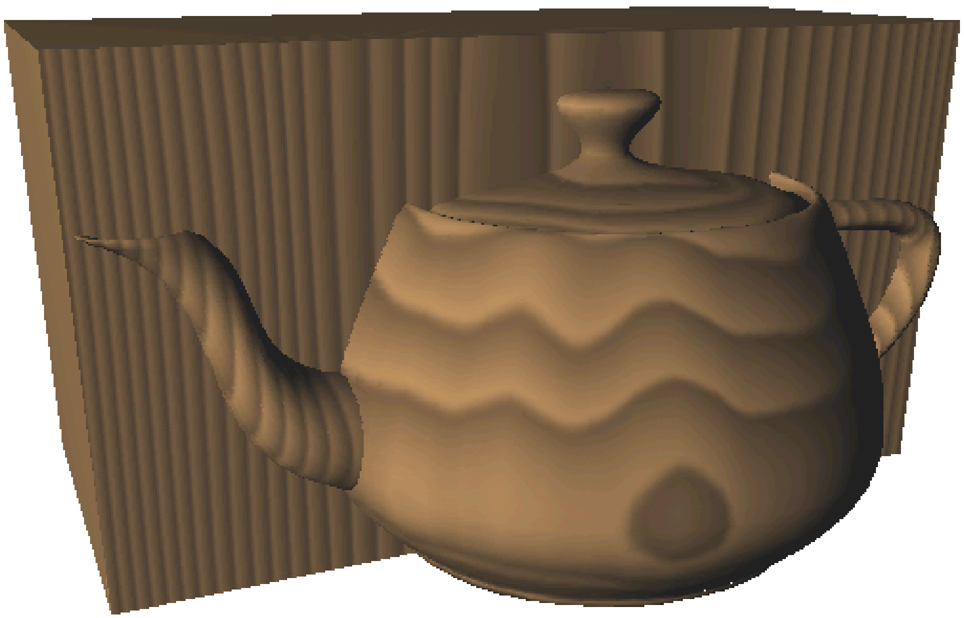
Using Noise

- Add noise to cylinders to warp wood
  - Wood($s^2 + t^2 + N(s,t,r)$)
- Controls
  - Amplitude: power of noise effect

    $$a\,N(s,\ t,\ r)$$
  - Frequency: coarse v. fine detail

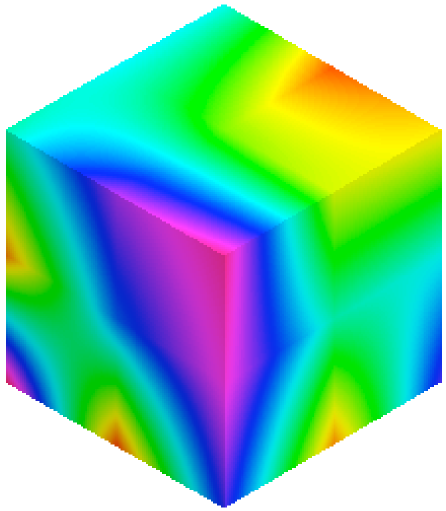
    $$N(f_s\,s, f_t\,t, f_r\,r)$$
  - Phase: location of noise peaks

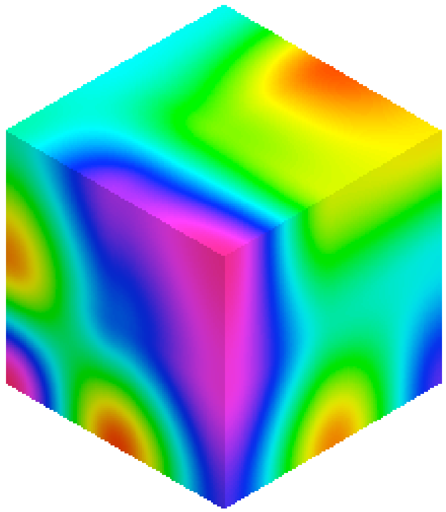
    $$N(s + \phi_s,\ t + \phi_t,\ r + \phi_r)$$



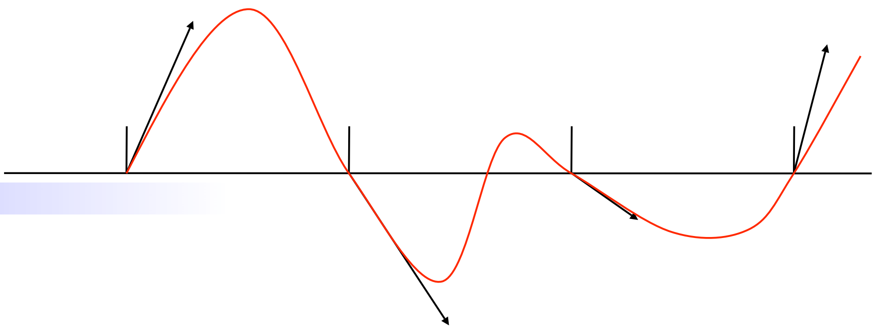
Making Noise

- Good:
  - Create 3-D array of random values
  - Trilinearly interpolate
- Better
  - Create 3-D array of random 3-vectors
  - Hermite interpolate

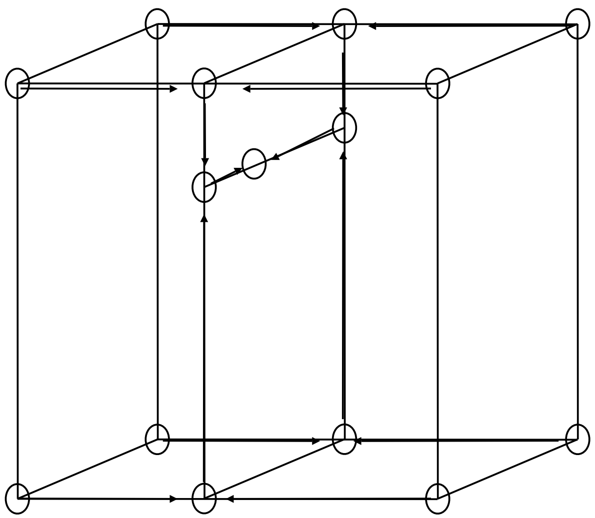




Hermite Interpolation

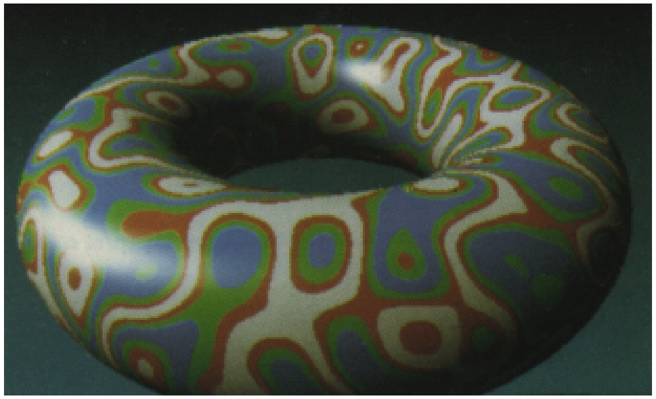


- Some cubic $h(t) = at^3 + bt^2 + ct + d$ s.t.
  - $h(0) = 0$ $(d = 0)$
  - $h(1) = 0$ $(a + b + c = 0)$
  - $h'(0) = r_0$ $(c = r_0)$
  - $h'(1) = r_1$ $(3a + 2b + r_0 = r_1)$
- Answer:
  - $h(t) = (r_0 + r_1)\, t^3 - (2r_0 + r_1)\, t^2 + r_0 t$
- Tricubic interpolation
  - Interpolate corners along edges
  - Interpolate edges into faces
  - Interpolate faces into interior



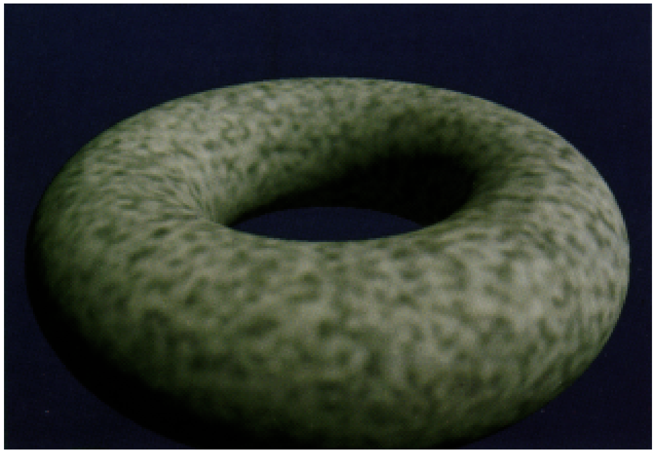
Colormap Donuts

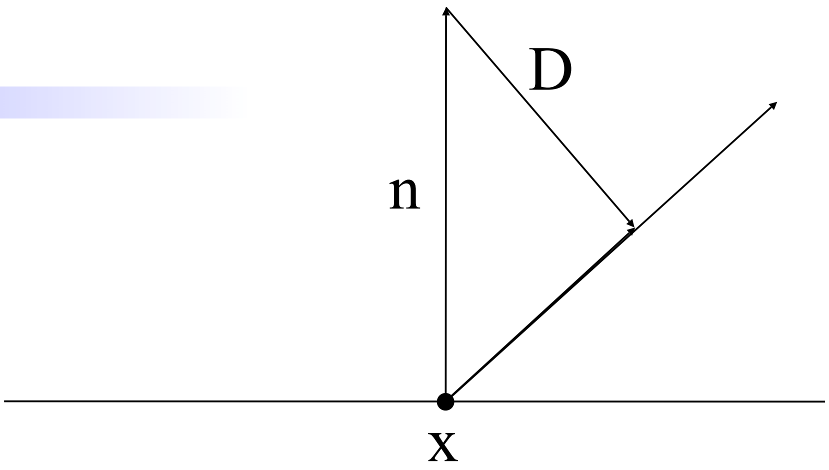
- Spotted donut
  - Gray(N(40*x,40*y,40*z))
  - Gray() - ramp colormap
  - Single 40Hz frequency



- Bozo donut
  - Bozo(N(4*x,4*y,4*z))
  - Bozo() - banded colormap
  - Cubic interpolation means contours are smooth

Bump Mapped Donuts





n += DNoise(x,y,z); normalize(n);

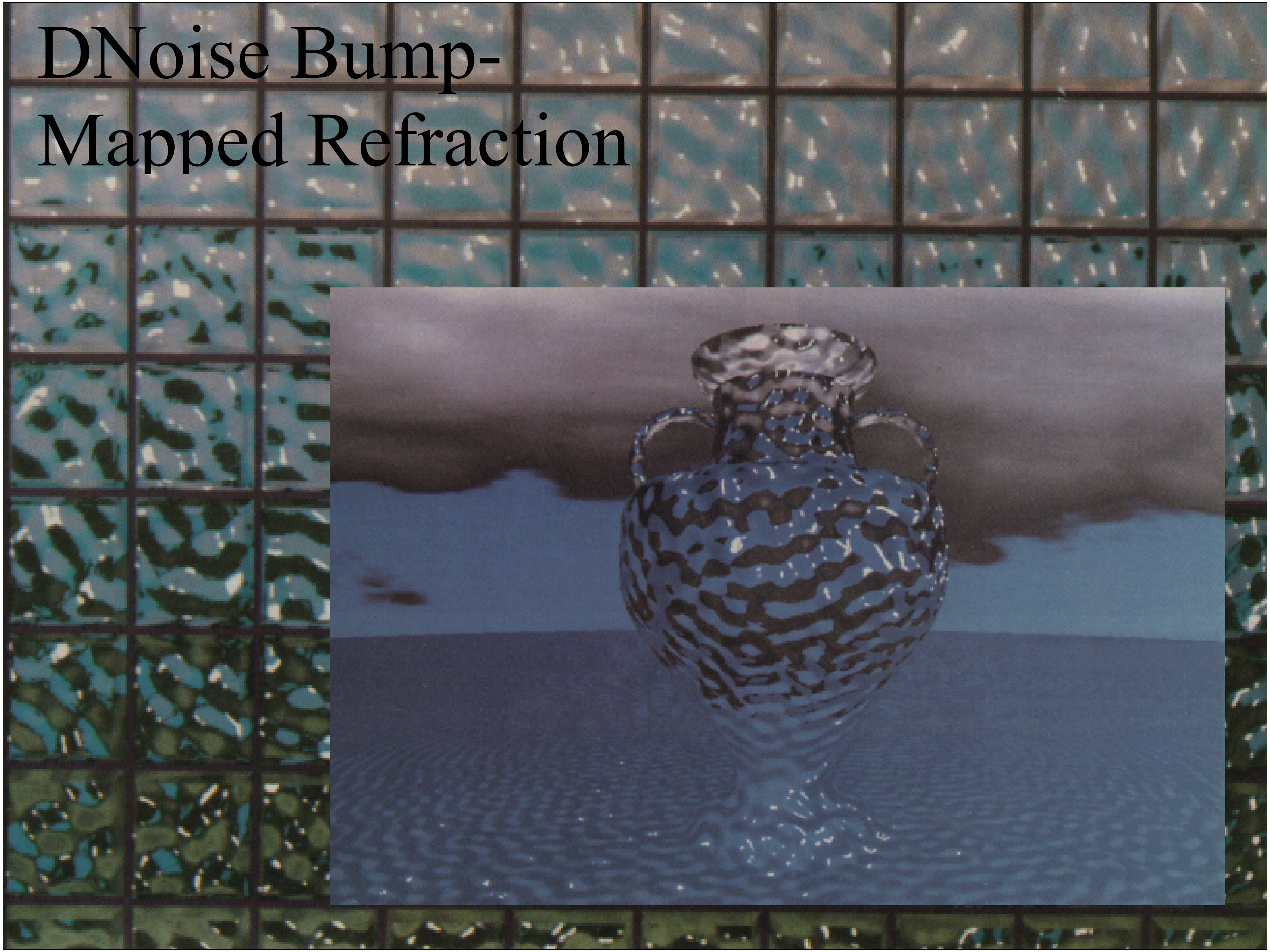
- DNoise(s,t,r) = ∇Noise(s,t,r)
- Bumpy donut
  - Same procedural texture as spotted donut
  - Noise replaced with DNoise

Composite Donuts

- Stucco donut
  - Noise(x,y,z)*DNoise(x,y,z)
  - Noisy direction
  - noisy amplitude

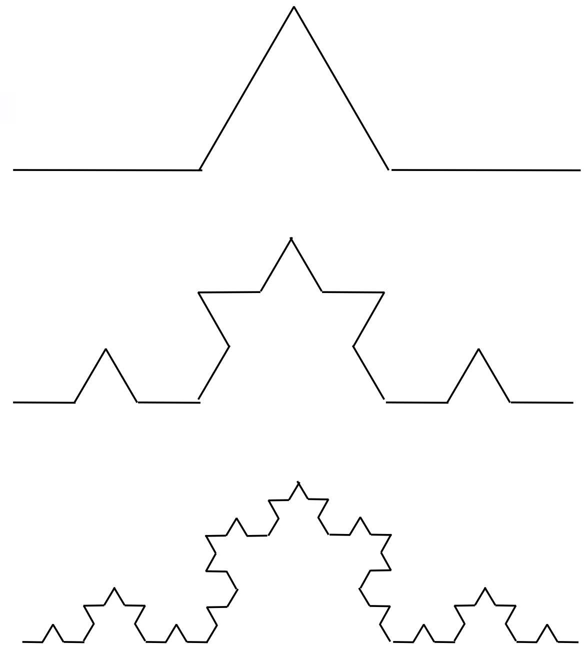
- Fleshy donut
  - Same texture
  - Different colormap

DNoise Bump-Mapped Refraction



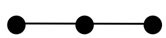
Fractals

- Fractional dimension - not
- Fractal dimension exceeds topological dimension
- Self-similar
- Detail at all levels of magnification
- 1/*f* frequency distribution

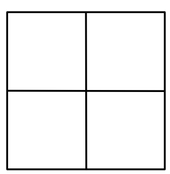


How Can Dimension be Fractional?

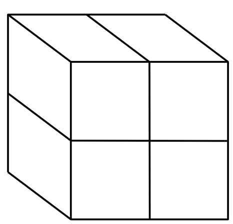
Point: D = 0, N=1, s=1/2



Line: D = 1, N=2, s=1/2



Square: D = 2, N=4, s=1/2



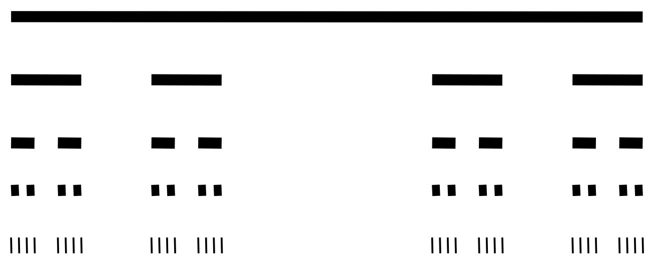
Cube: D = 3, N=8, s=1/2

$N = (1/s)^D$

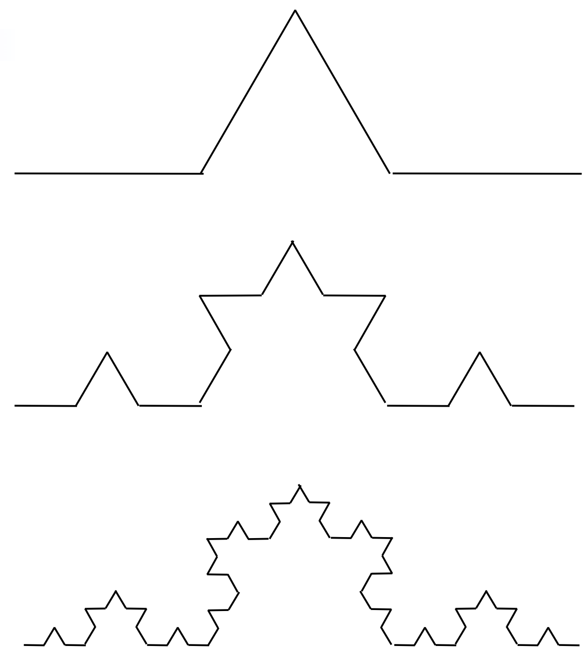
$\log N = D \log (1/s)$

$$\boxed{D = \log(N)/\log(1/s)}$$

Examples

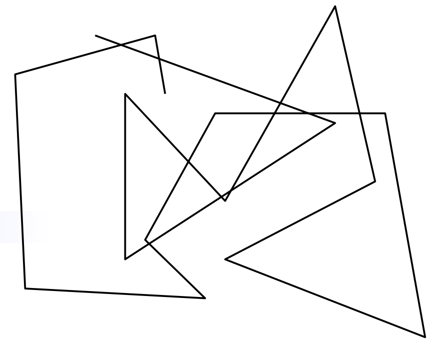


N=2
s=1/3
D = log 2/log 3
D = .6...

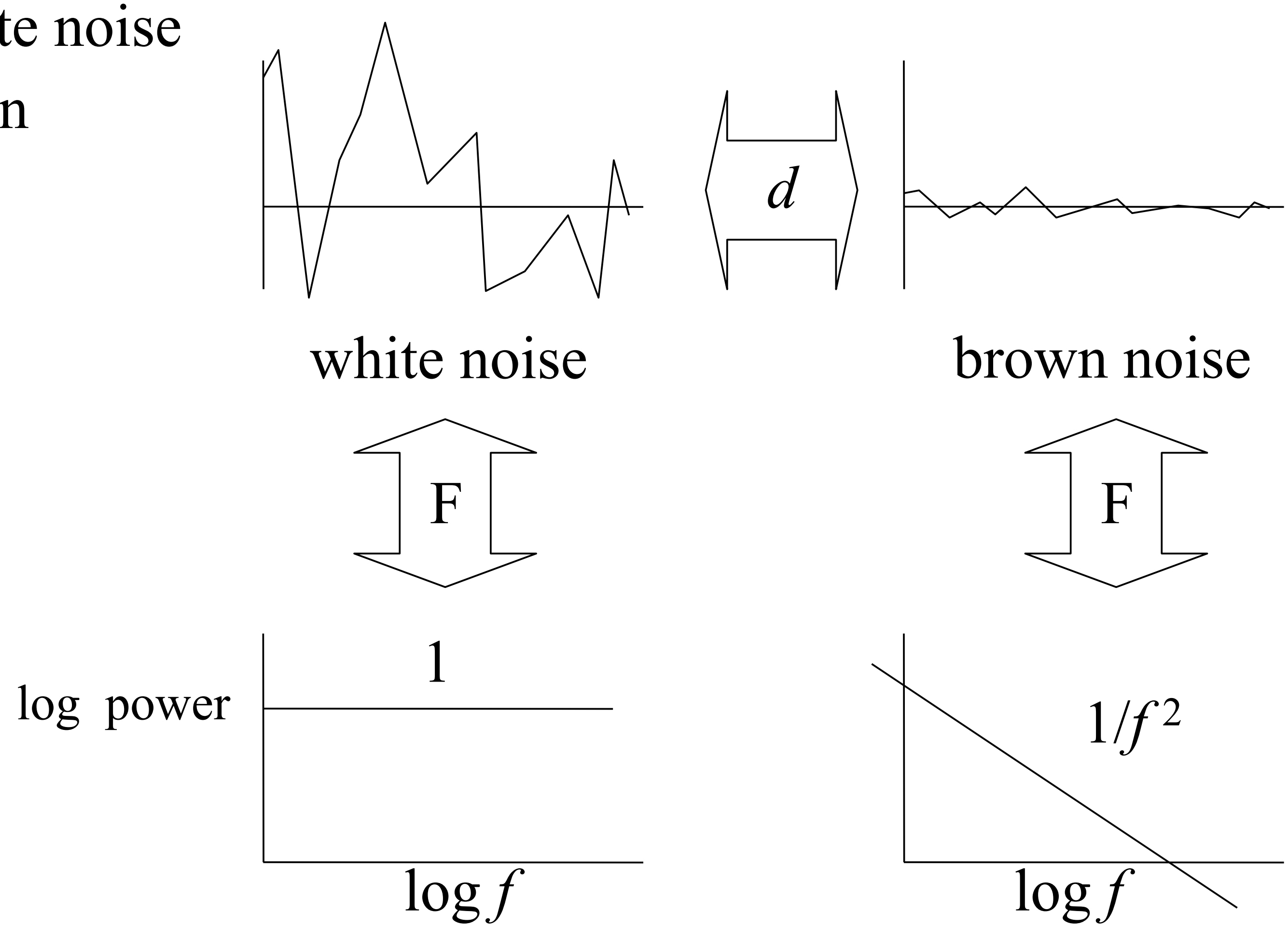


N=4
s=1/3
D = log 4/log 3
D = 1.3...

Brownian Motion



- random paths
- Integral of white noise
- $1/f^2$ distribution

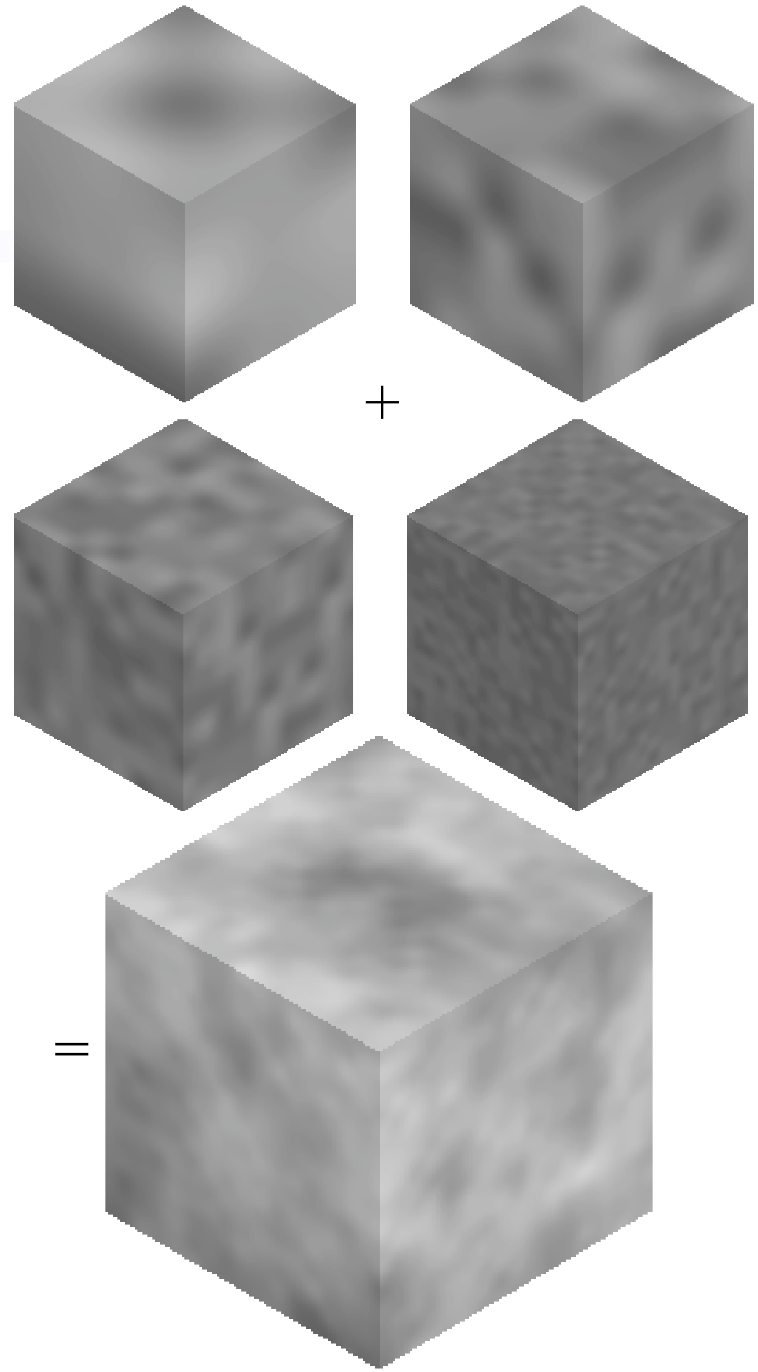


Fractional Brownian Motion

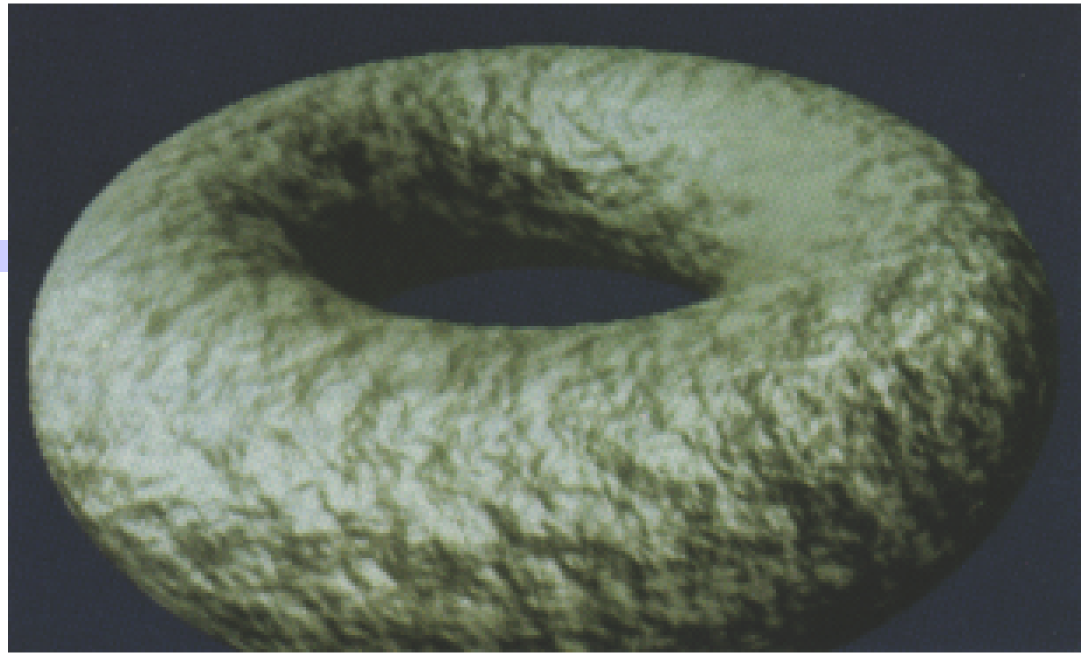
- $1/f^{\beta}$ distribution
- Roughness parameter β
  - Ranges from 1 to 3
  - β = 3 - smooth, not flat, still random
  - β = 1 - rough, not space filling, but thick
- Construct using spectral synthesis

$$f(\mathbf{s}) = \sum_{i=1}^{4} 2^{-i\beta} n(2^{i}\mathbf{s})$$

  - Add several octaves of noise function
  - Scale amplitude appropriately



Fractal Bump-Mapped Donut

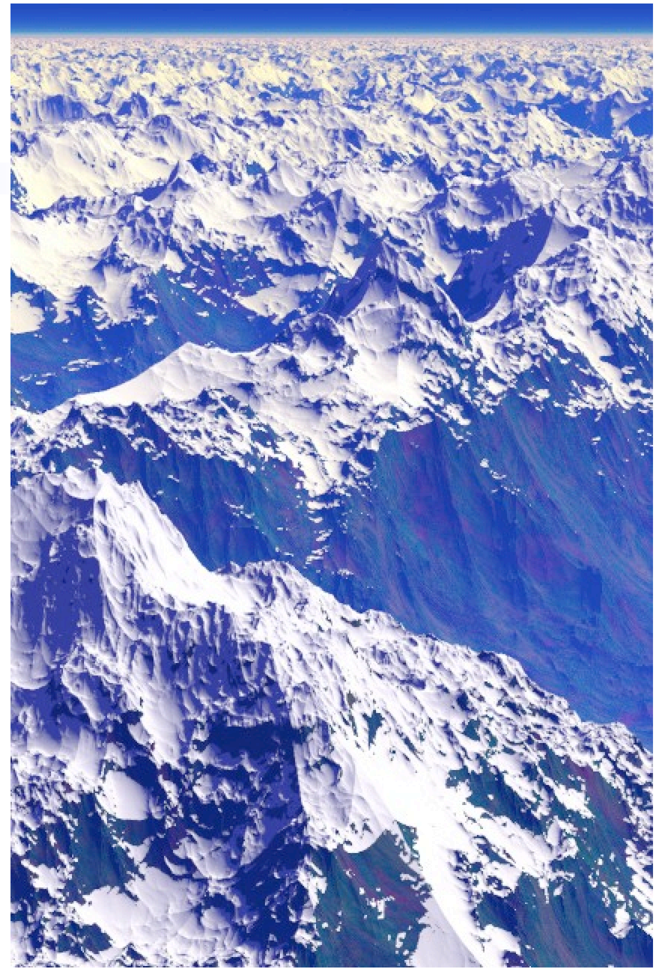


```
fbm(beta) {
    val = 0; vec = (0,0,0);
    for (i = 0; i < octaves; i++) {
        val += Noise(2^i*x, 2^i *y, 2^i *z)/pow(2,i*beta);
        vec += DNoise(2^i*x, 2^i *y, 2^i *z)/pow(2,i*beta);
    }
    return vec or val;
}
```

Fractal Mountains

- Displacement map of meshed plane
- Can also be formed using midpoint displacement

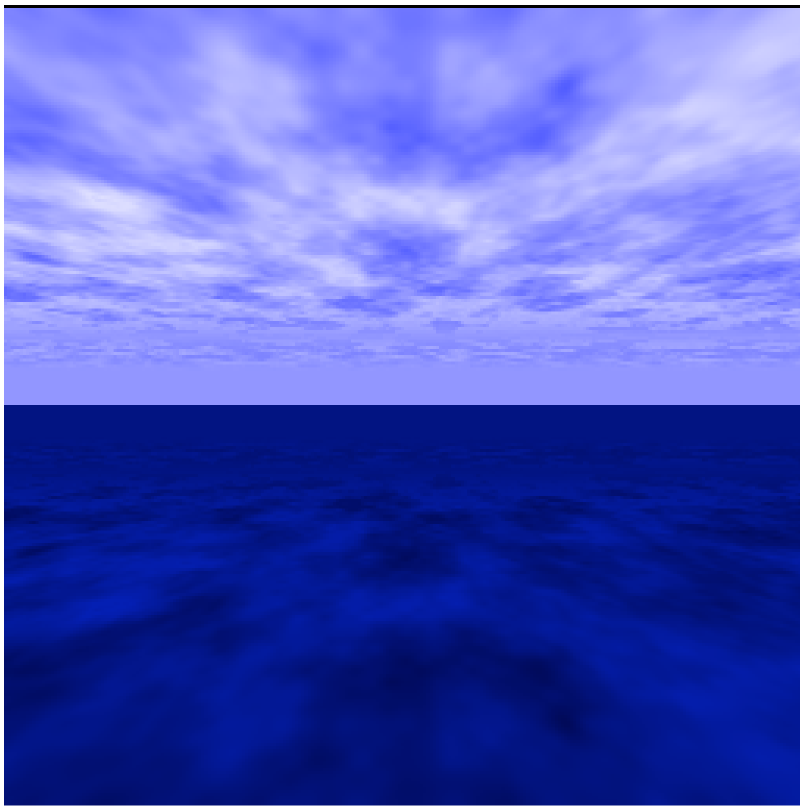
Gunther Berkus via Mojoworld



Ken Musgrave

Clouds
Water

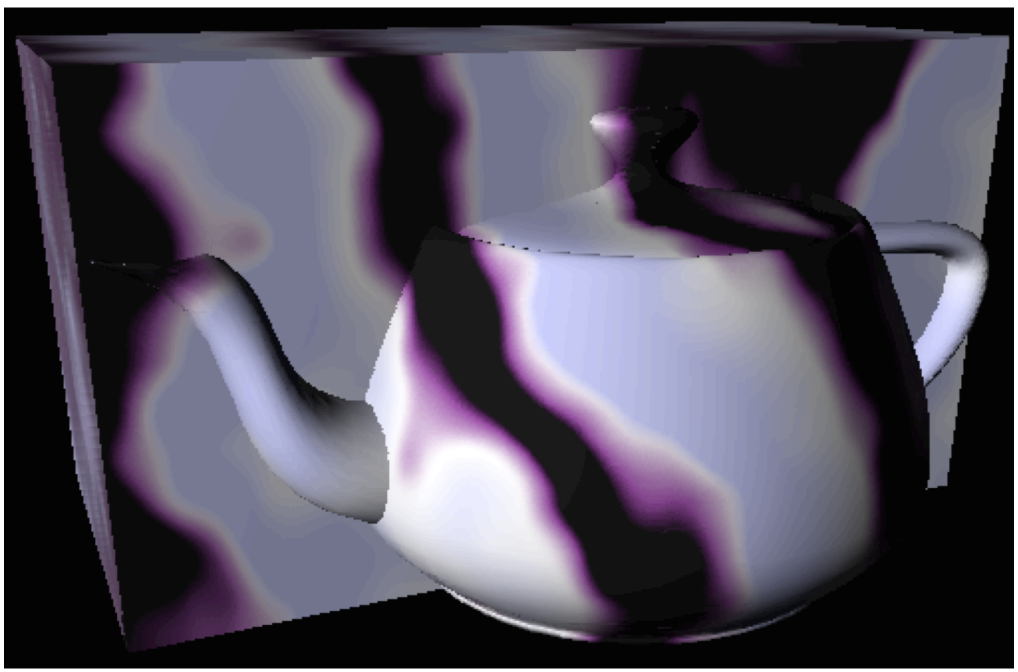
$$f(\mathbf{s}) = \sum_{i=1}^{4} 2^{-i} n(2^i \mathbf{s})$$



Gunther Berkus via Mojoworld

Marble

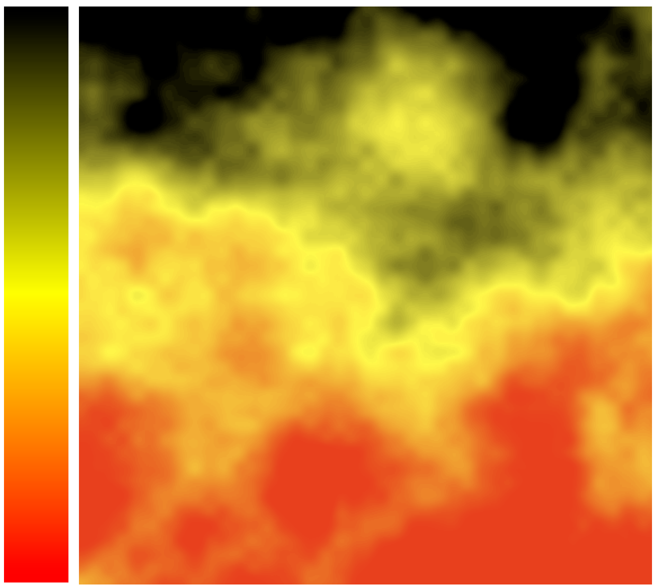
$$f(s,t,r) = r + \sum_{i=1}^{4} 2^{-i} n(2^i s, 2^i t, 2^i r))$$



Ken Perlin, 1985

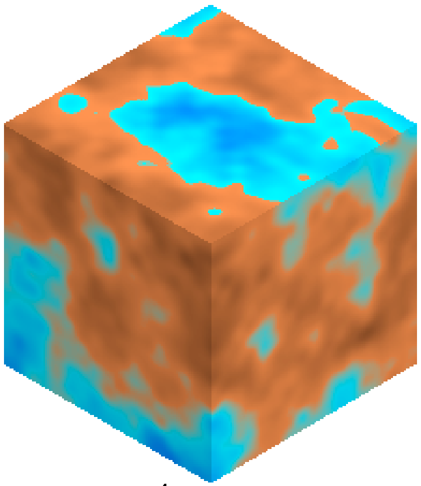
Fire

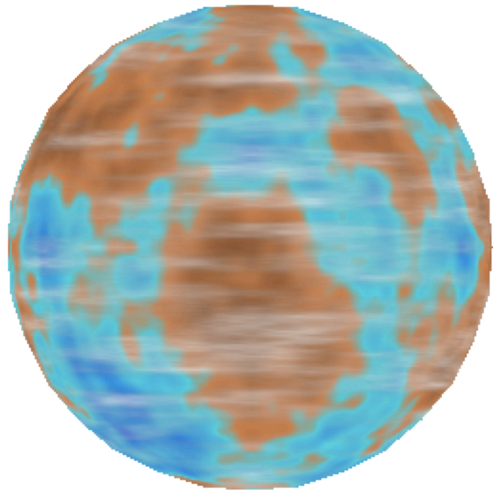
$$f(s,t,r) = r + \sum_{i=1}^{4} 2^{-i} n(2^i s, 0, 2^i r + \phi)).$$



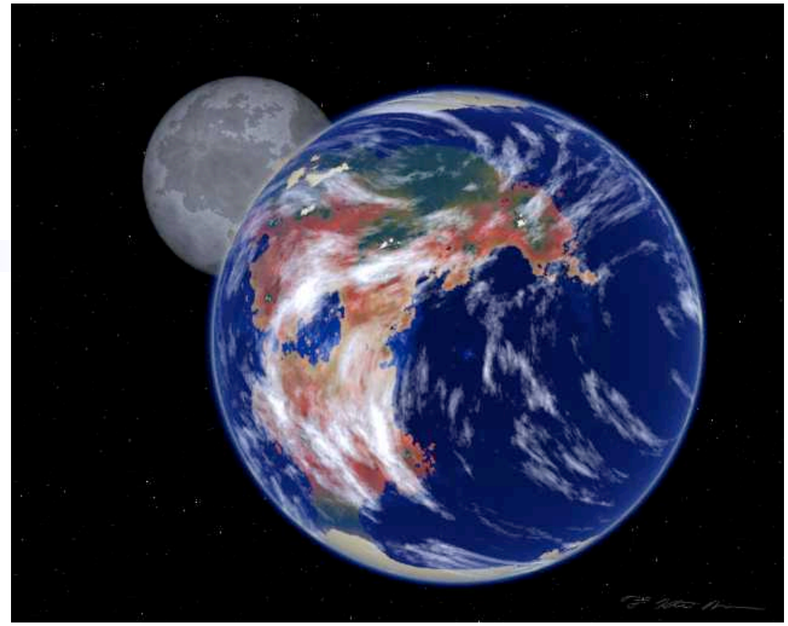
Ken Musgrave

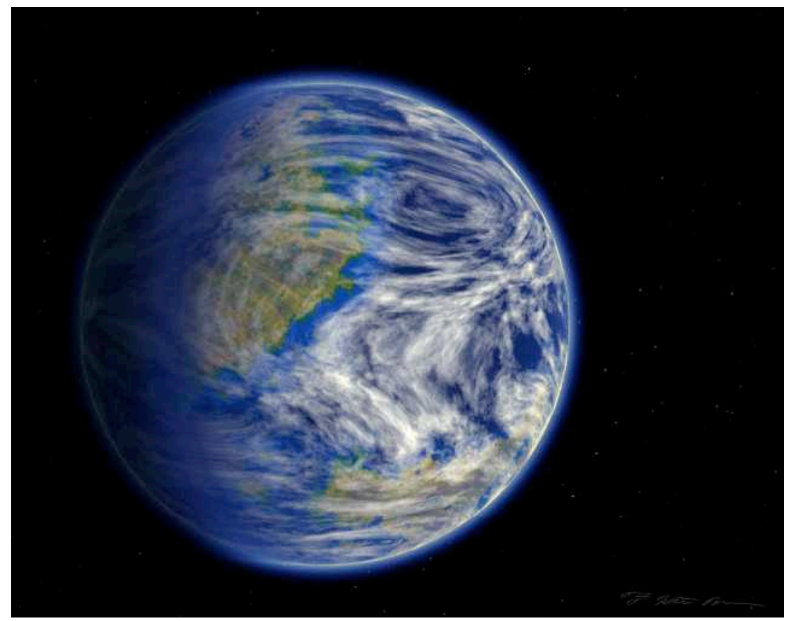
Planets





$$f(\mathbf{s}) = \sum_{i=1}^{4} 2^{-i} n(2^{i}\mathbf{s})$$





Ken Musgrave

Moonrise

Ken Musgrave