



## Procedural Bump Mapping and Noise

Code and images from Ebert, David S., editor, *Texturing and Modeling: a Procedural Approach*, 1994

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## Bump Mapping - Computing N'

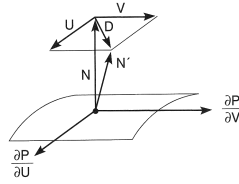


Figure 17. The geometry of bump mapping.

$F(u,v) =$   
bump height function

$P(u,v) =$   
surface position

$U = \partial f / \partial u (N \times \partial P / \partial v)$

$V = -\partial f / \partial v (N \times \partial P / \partial u)$

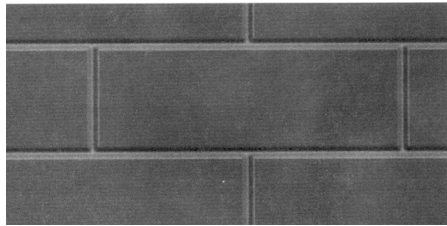
$D = U + V$

$N' = (N + D) / |N + D|$

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## Bump-Mapped Brick



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## Example - Bumped Brick

Describe height function in terms of texture coordinates

Using built-in RenderMan functions:

- displace point along normal according to height
- find partial derivatives of new surface with respect to texture coordinates
- cross the partials to get vector normal to new surface

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## Without Special Assistance

Compute  $\partial P / \partial u$  and  $\partial P / \partial v$  analytically according to surface geometry (e.g. sphere)

OR

- Evaluate  $P$  at 4 nearby points by varying  $u$  and  $v$  slightly, then approximate partial using differences

Compute  $\partial f / \partial u$  and  $\partial f / \partial v$  analytically according to height function

Apply preceding formulas

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## Bevelling Effects

Nice ridges along edges of geometric figures

Parameters:

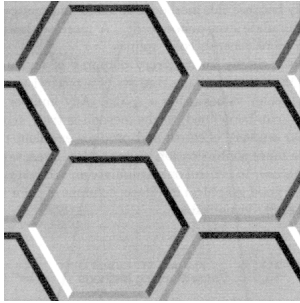
- Total ridge and plateau widths
- slope at top and bottom of ridge

Use perpendicular direction to closest edge as  $D$  (to add to normal), and scale according to ridge function

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## Bevelling



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## Noise Functions

**Break up regularity**

**Enable modelling of irregular phenomena**

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## White Noise

**Sequence of random numbers**

**Uniformly distributed**

**Totally uncorrelated**

- no correlation between successive values

**Not desirable for texture generation**

- Too sensitive to sampling problems
- Arbitrarily high frequency content

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## Ideal Noise for Texture Generation

**Repeatable pseudorandom function of inputs**

**Known range [-1, 1]**

**Band-limited (maximum freq. about 1)**

**No obvious periodicities**

**Stationary and isotropic**

- statistical properties invariant under translation and rotation

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## Lattice Noise

**Low pass filtered version of white noise**

- Random values associated with integer positions in noise space
- Intermediate values generated by some form of interpolation
- Frequency content limited by spacing of lattice

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## Generating a Lattice

**Generate a fixed-size table of random numbers**

**Hashing function indexes into the table to get value at any lattice point**

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## Example Lattice Indexing

```
#define TABSIZE      256
#define TABMASK     ( TABSIZE - 1 )
#define PERM(x)     perm[ (x) & TABMASK ]
#define INDEX(ix,iy,iz) \
    PERM((ix)+PERM((iy)+PERM(iz)))
```

perm contains random permutation of integers in  
[0, TABSIZE - 1]

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## Value Noise

Create additional table of random values  
(in range [-1,1])

Index table according to permutation-based  
INDEX function just presented

(see sample code handout)

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## Interpolation Schemes

### Linear interpolation -

- not really smooth enough

### Quadratic or cubic spline interpolation

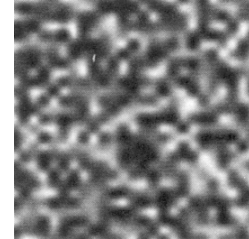
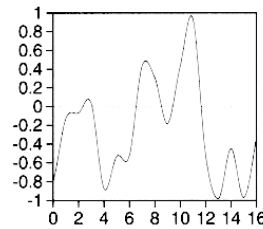
- may still have some artifacts resulting from grid layout

### Convolution with radially symmetric filter kernel

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## 1D and 2D Value Noise



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## Gradient Noise

Store direction vector at each lattice point

Noise values at lattice point is zero

Computing intermediate values:

For each neighboring lattice point

compute displacement along direction

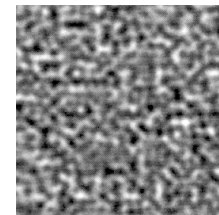
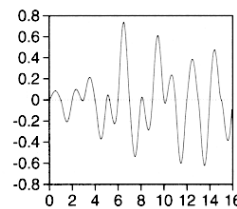
Linearly interpolate between resulting 8 values  
to get final value

(see sample code handout)

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## 1D and 2D Gradient Noise



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## Value vs. Gradient Noise

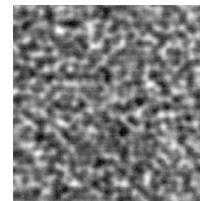
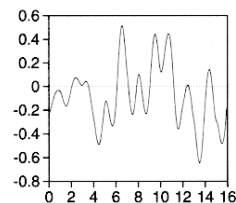
- Both noises have limited frequencies
- Value noise slightly simpler to compute
- Gradient noise has most of the energy in the higher frequencies
  - forced zero crossings
- Gradient noise has regularity because of zero crossings

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## Value Gradient Noise

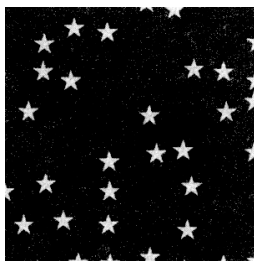
### Weighted sum of value and gradient noises



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## Example - Star Wallpaper



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## Example - Star Wallpaper

- Divide 2D texture space into uniform grid
  - Decide whether or not to place a star in each cell
  - Perturb position of star within each cell
  - To render a point on surface, check nearby cells for stars which may cover point
- (see code handout)

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## Example - Perturbed Texture



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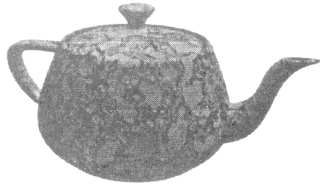
## Example - Perturbed Texture

- Use noise function to apply perturbation to texture coordinates
  - Look up image texture (or generate procedural texture) using modified coordinates
- (see code handout)

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## Example - Blue Marble



Marble vase (right) from Foley, van Dam, Feiner, and Hughes. *Computer Graphics: Principles and Practice*.

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## Example - Blue Marble

Use 3D position to compute 3D texture coordinates

Accumulate noise functions at several frequencies

- one type of spectral synthesis

Use sum of noise to determine marble color

- using spline interpolation between colors

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## Modelling Gases

Represent 3D gas as density volume

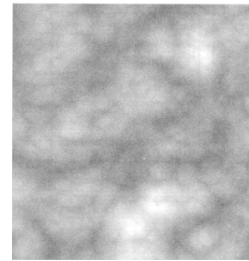
Use turbulence function as basic gas description

Adjust turbulence by raising it to a power, taking the sine, etc.

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## Turbulence



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## Turbulence

```
float turbulence(point Q)
{
  float value = 0;
  for (f= MINFREQ; f < MAXFREQ; f += 2)
    value += abs(noise(Q*f))/f;
  return value;
}
```

(in practice, don't use a round number like 2)

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## Basic gas

```
float gas(point P, float max_density,
float exponent)
{
  float turb, density;
  turb = turbulence(pt);
  /* or turb = (1 + sin(turbulence(pt)*PI))/2 */
  density =
    pow(turb*max_density, exponent);
  return density;
}
```

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## Placing and Shaping Gas

**Place some primitive shape to contain density volume**

**Attenuate density to account for dissipation**

**Steaming teacup example**

- **attenuate according to distance from center of tea surface**
- **attenuate according to height above tea surface**

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## Steaming Tea Cup



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## More Turbulence Uses

**Add variation to color of surface textures**

**Use as bump mapping function to add variety to normals**

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