Procedural Bump Mapping and Noise

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

Bump Mapping - Computing N'

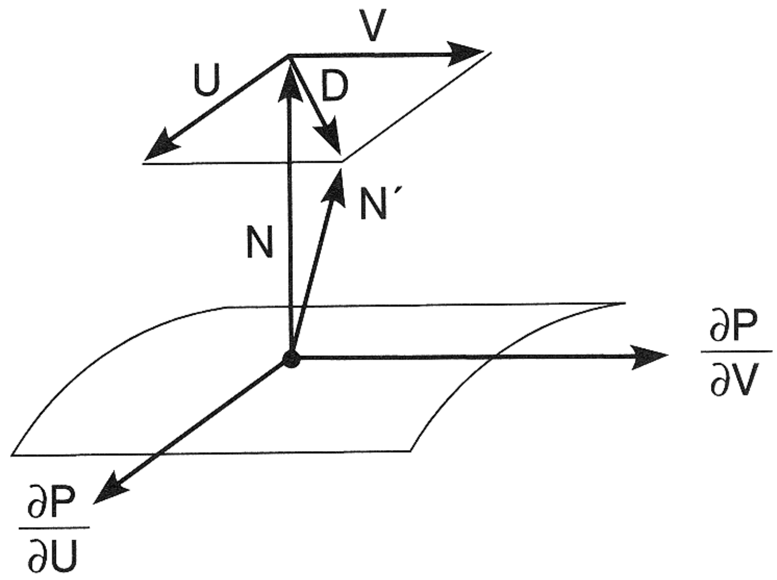


Figure 17. The geometry of bump mapping.

F(u,v) =

bump height function

P(u,v) =

surface position

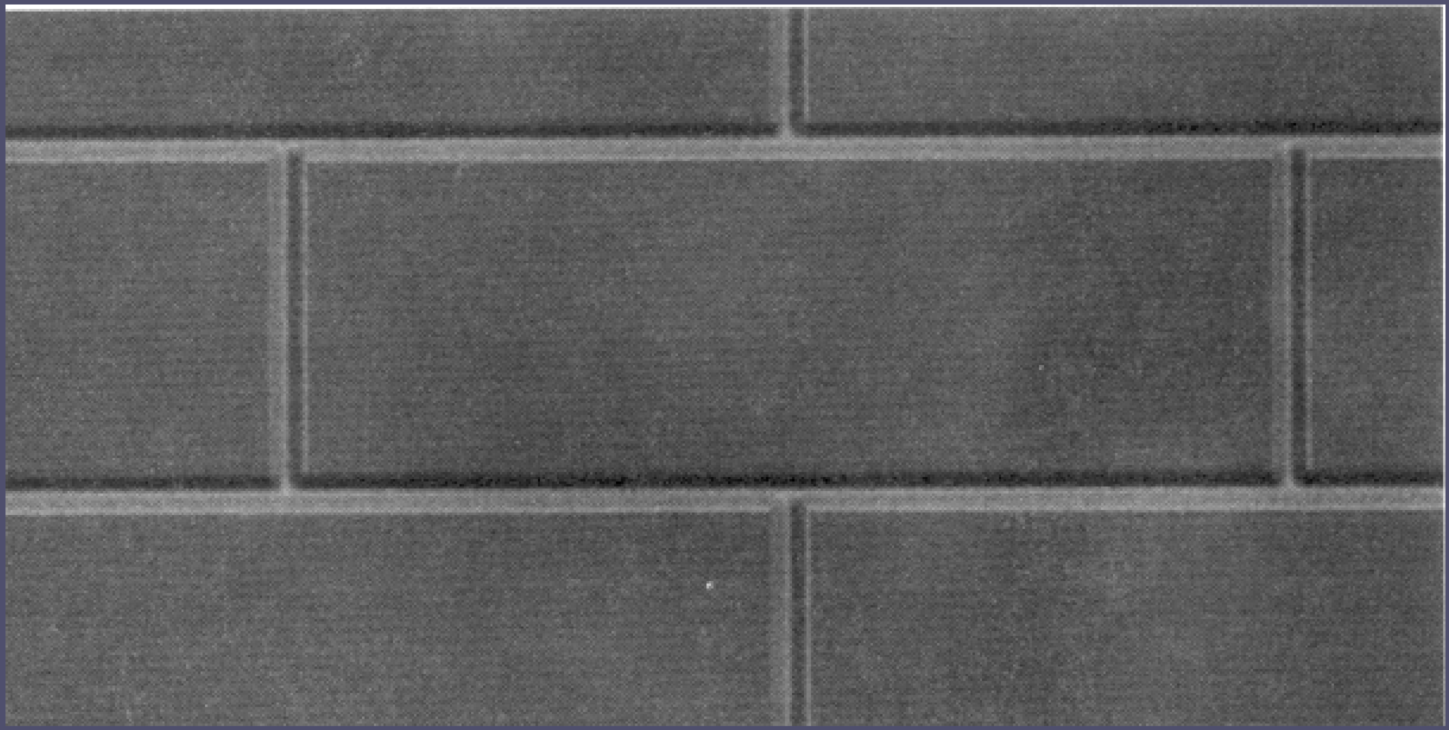
$U = \partial f/\partial u \, (N \times \partial P/\partial v)$

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

$D = U + V$

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

Bump-Mapped Brick



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

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

Bevelling Effects

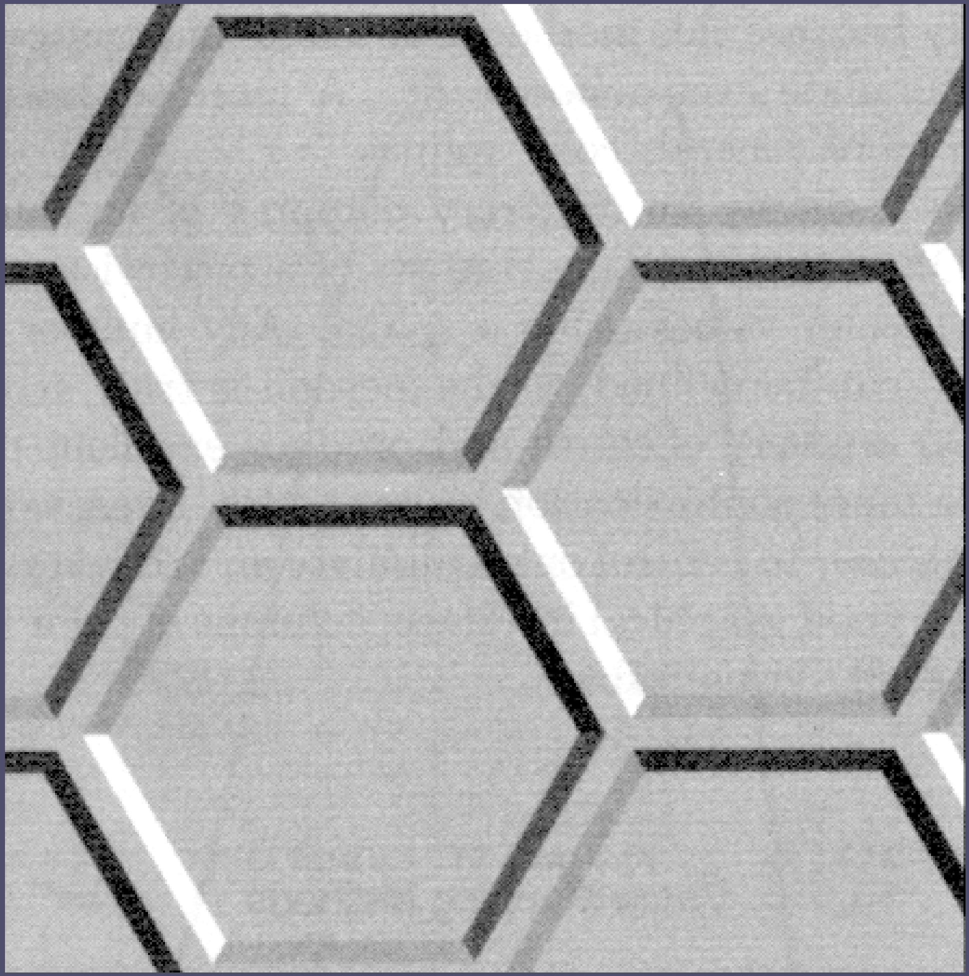
Nice ridges along edges of geometric figures

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

Bevelling



Noise Functions

Break up regularity

Enable modelling of irregular phenomena

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

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

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

Generating a Lattice

- Generate a fixed-size table of random numbers
- Hashing function indexes into the table to get value at any lattice point

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]

Value Noise

- Create additional table of random values (in range [-1,1])
- Index table according to permuation-based INDEX function just presented

(see sample code handout)

Interpolation Schemes

Linear interpolation -

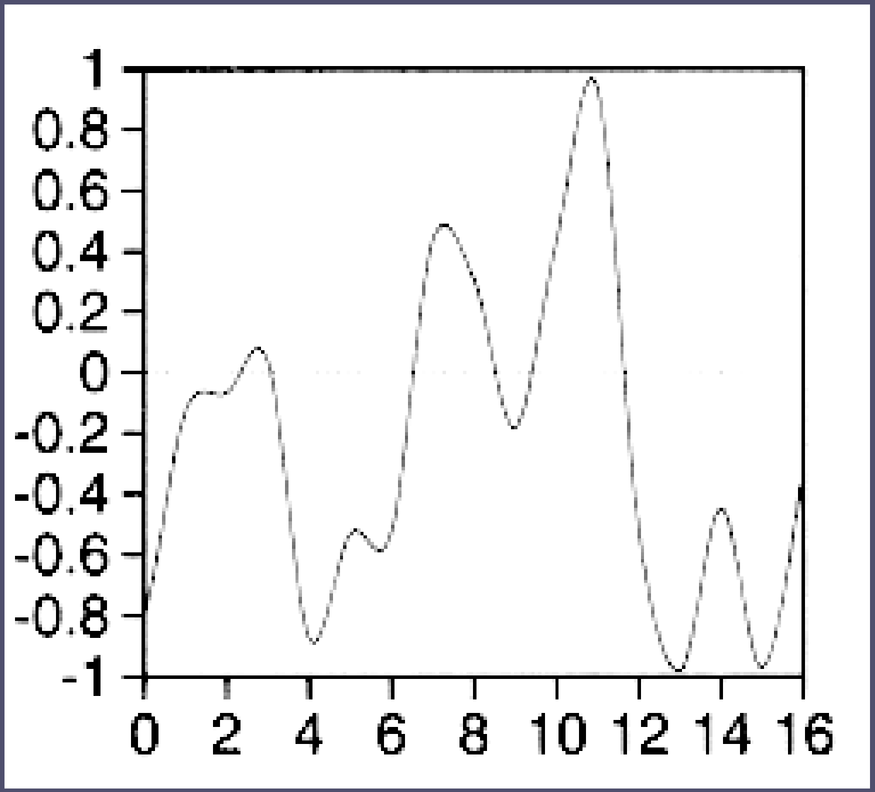
- not really smooth enough

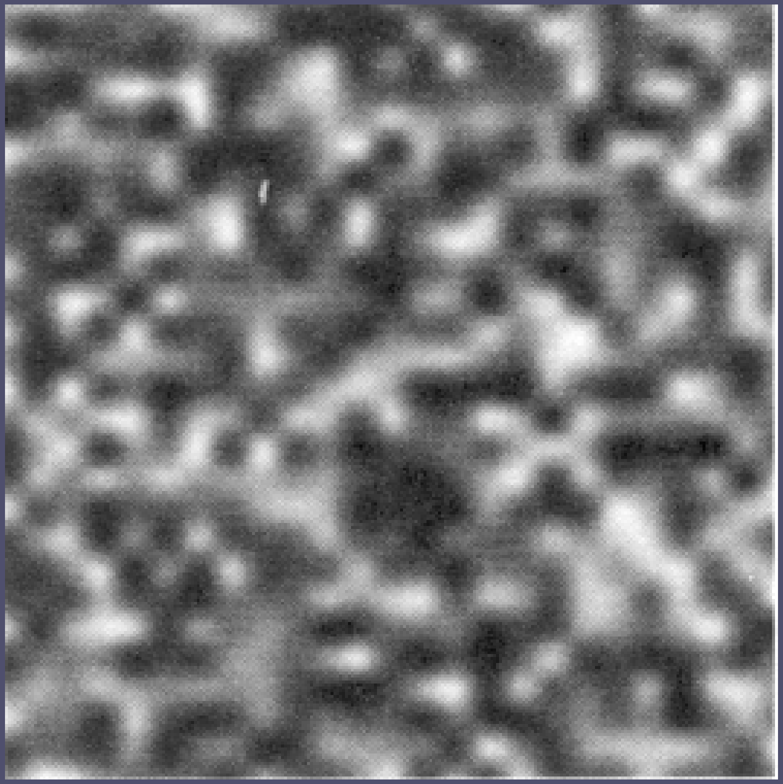
Quadratic or cubic spline interpolation

- may still have some artifacts resulting from grid layout

Convolution with radially symmetric filter kernel

1D and 2D Value Noise





Gradient Noise

Store direction vector at each lattice point

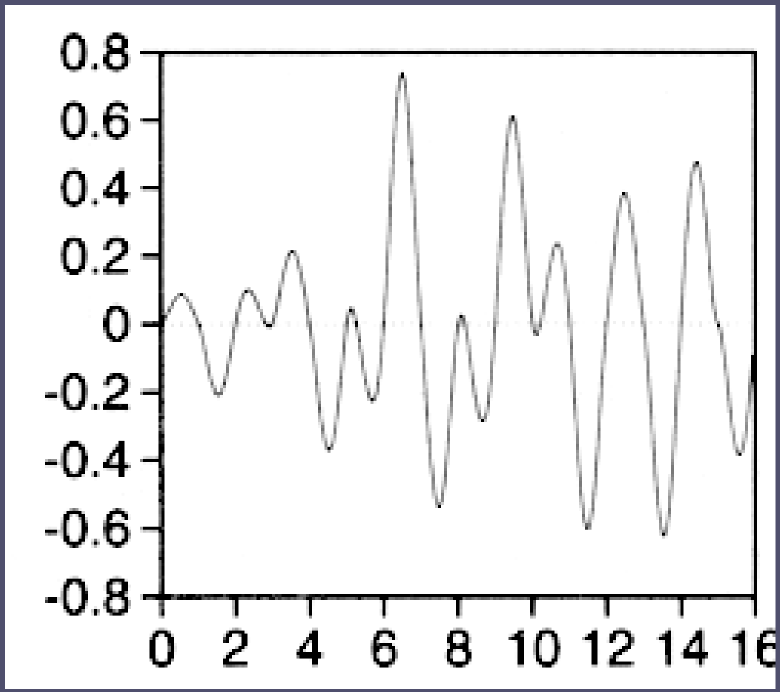
Noise values at lattice point is zero

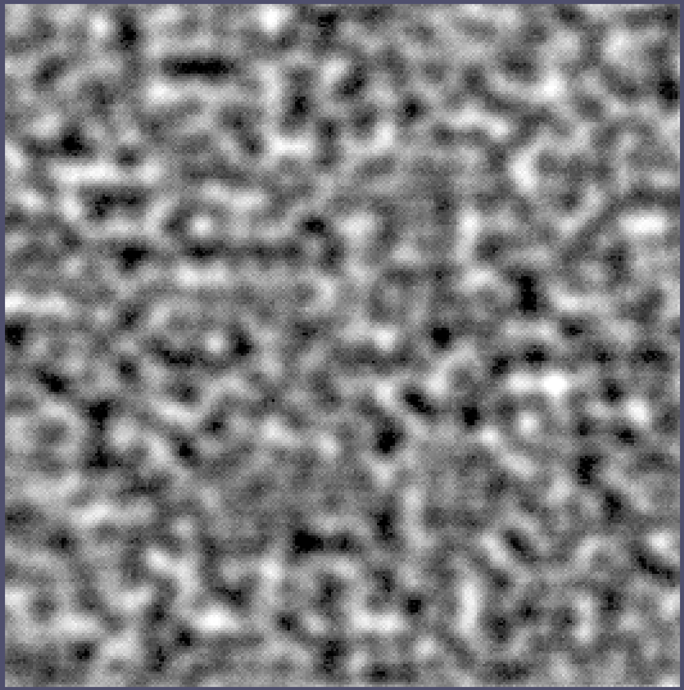
Computing intermediate values:

- For each neighboring lattice point
  - compute displacement along direction
- Linearly interpolate between resulting 8 values to get final value

(see sample code handout)

1D and 2D Gradient Noise





Value vs. Gradient Noise

Both noises have limited frequencies

Value noise slightly simpler to compute

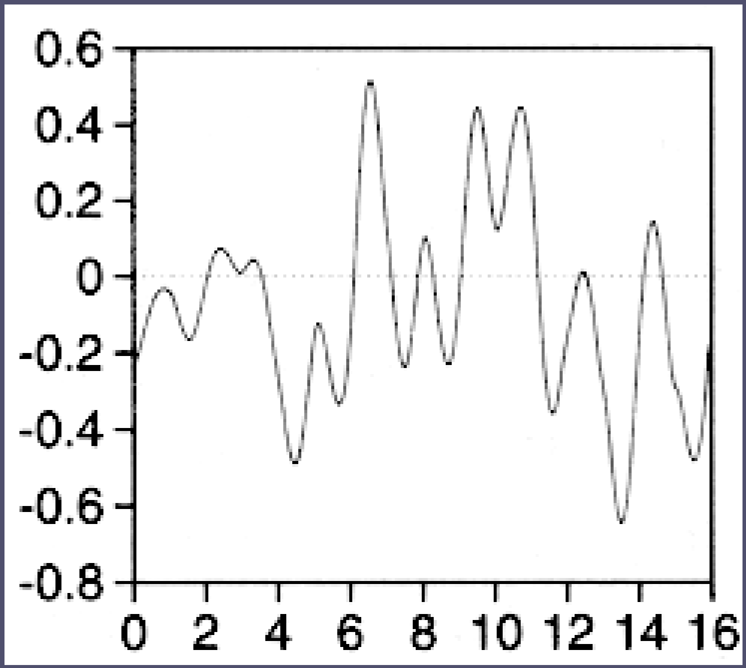
Gradient noise has most of the energy in the higher frequencies

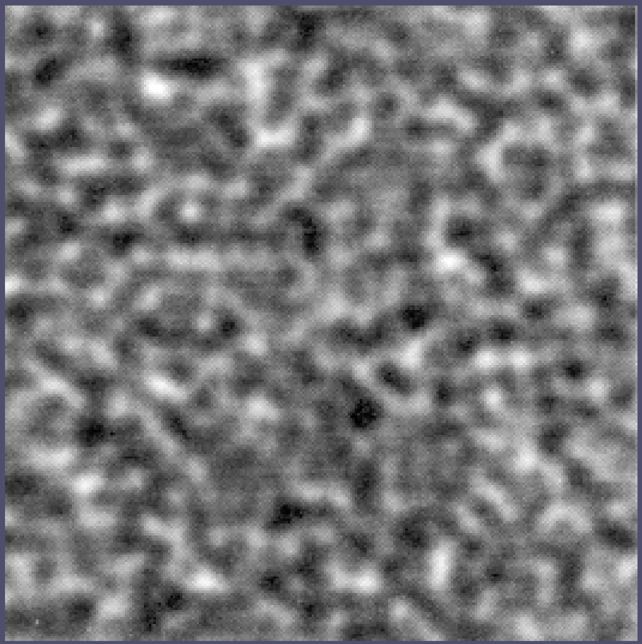
- forced zero crossings

Gradient noise has regularity because of zero crossings

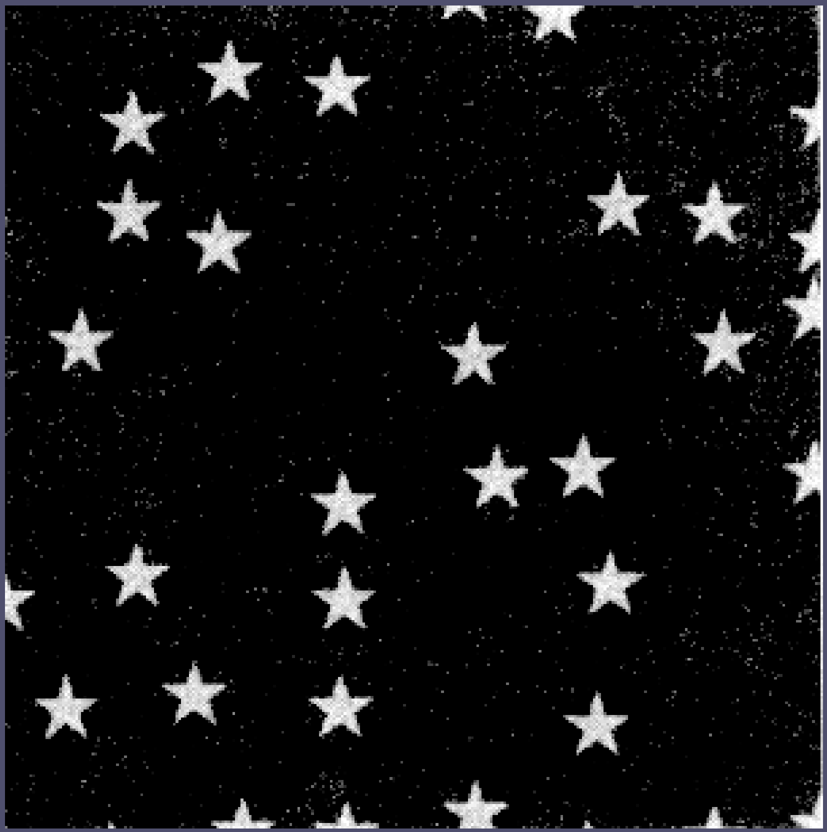
Value Gradient Noise

Weighted sum of value and gradient noises





Example - Star Wallpaper



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)

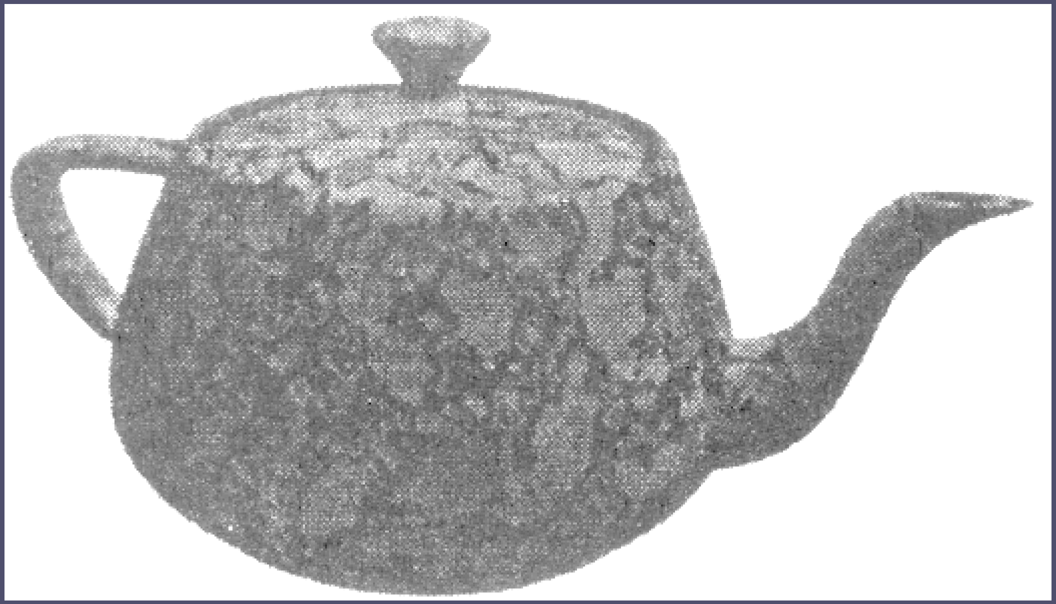
Example - Perturbed Texture

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)

Example - Blue Marble



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

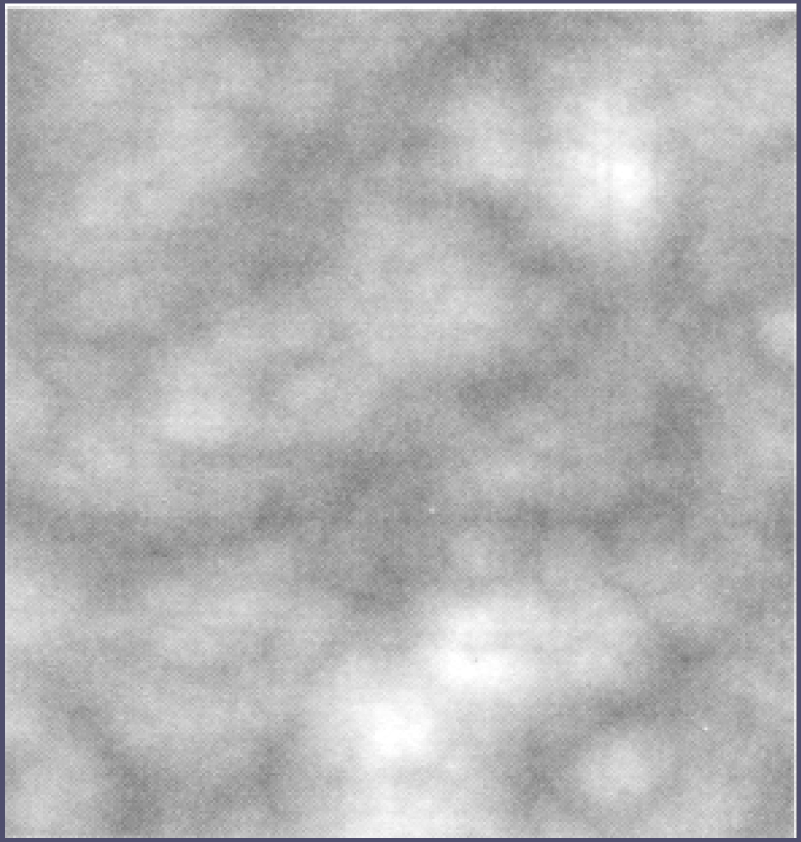
Example - Blue Marble

- 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

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.

Turbulence



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)

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;
}
```

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

Steaming Tea Cup

More Turbulence Uses

Add variation to color of surface textures

Use as bump mapping function to add variety to normals