A Problem

One of the early criticisms of Computer Graphics is that it was too good, that is, everything was too perfect. Spheres were too perfectly round. And so on. Computer Graphics needed a way to add imperfections. It seemed like random numbers could be used here. But pure random numbers are rather jarring:

and that’s not what we want. What we want is randomness, but controlled randomness. In Computer Graphics, this became known as Noise.

Noise:

• Noise can be 1D, 2D, or 3D
• Noise output is a function of input value(s)
• Typically, those input values are where you are on the object, but they don’t have to be
• Noise ranges from -1.0 to +1.0, or from 0.0 to 1.0
• Noise might look random, but it really isn’t
• Noise has Coherency (i.e., if you change the input value to the noise function a little, the output value will only change a little)
• Noise has Repeatability (i.e., if you supply the same inputs, the noise function will always give you back the same output)
• Noise is Continuous (i.e., it’s smooth with no jarring jumps)

Positional Noise

Idea: Pick a random number at the whole-number input values and then fit a piecewise smooth curve through those points.

No matter what, you will get a very good plus-or-minus distribution.

Gradient Noise

Idea: Place points at the mid-line at the whole-number input values and use random numbers to pick gradients (slopes) there, and then fit a piecewise smooth curve through those points with those slopes.

Quintic (5th order) Interpolation Creates More Continuity Than Cubic

Cubic: $C^1$ continuity at the whole-number values
Quintic: $C^2$ continuity at the whole-number values
Coefficients for Cubic and Quintic Forms

\[ y(t) = C_0 N_0 + C_1 N_1 + C_2 G_2 + C_3 G_3 + C_4 N_4 + C_5 G_5 \]

**Cubic**
\[
\begin{align*}
C_{N0} &= 1 - 3t^2 + 2t^3 \\
C_{N1} &= 3t^2 - 2t^3 = 1 - C_{N0} \\
C_{G0} &= t - 2t^2 + t^3 \\
C_{G1} &= -t^2 + t^3 \\
C_{C0} &= 0 \\
C_{C1} &= 0
\end{align*}
\]

**Quintic**
\[
\begin{align*}
C_{N5} &= 1 - 10t^5 + 15t^4 - 6t^5 \\
C_{N4} &= 10t^5 - 15t^4 + 6t^5 = 1 - C_{N5} \\
C_{G3} &= t - 6t^2 + 8t^3 - 3t^4 \\
C_{G4} &= -4t^4 + 7t^5 - 3t^6 \\
C_{CS} &= \frac{1}{2}t^2 - \frac{3}{2}t^3 + \frac{3}{2}t^4 - \frac{1}{2}t^5 \\
C_{CI} &= \frac{1}{2}t^3 - t^4 + \frac{1}{2}t^5
\end{align*}
\]

**Noise Octaves**

**Idea:** Add multiple noise waves, each one twice the frequency and half the amplitude of the previous one.

**Image Representation of 2D Noise**

1 Octave

4 Octaves

**3D Surface Representation of 2D Noise**

1 Octave

4 Octaves

**3D Volume Rendering of 3D Noise**

1 Octave

Has continuity in X, Y, and Z

**Volume Isosurfaces of 3D Noise**

1 Octave

4 Octaves

S* = Mid-value

The low half of the noise values are on one side of the surface, the high half are on the other.
Examples

Deciding when to Discard for Erosion

Color Blending for Marble

Color Blending for Clouds

Turbulence

Idea: Take the absolute value of the noise about the centerline, giving the noise a “sharper” appearance and creating “creases”.

Warning: this is not the same use of the term as fluid “turbulence”.

Turbulence Example

Normal

Turbulent

Remember Noise Octaves? What if we create a lookup table of noise octaves and hide it in a texture?

A Noise Texture in Glman

The glman tool automatically creates a 3D noise texture and places it into Texture Unit 3. Your shaders can access it through the pre-created uniform variable called Noise3. You just declare it in your shader as:

uniform sampler3D Noise3;

vec4 nv = texture( Noise3, uNoiseFreq * vMCposition );

The “noise vector” texture \( nv \) is a vec4 whose components have separate meanings. The .r component is the low frequency noise. The .g component is twice the frequency and half the amplitude of the .r component, and so on for the .b and .a components. Each component is centered around the middle value of 0.5.

<table>
<thead>
<tr>
<th>Component</th>
<th>Term</th>
<th>Term Range</th>
<th>Term Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>( m_x )</td>
<td>( 0.5 \pm 0.5000 )</td>
<td>0.0000 to 0.0000</td>
</tr>
<tr>
<td>1</td>
<td>( m_g )</td>
<td>( 0.5 \pm 2.0000 )</td>
<td>0.5000 to 0.7500</td>
</tr>
<tr>
<td>2</td>
<td>( m_b )</td>
<td>( 0.5 \pm 1.2500 )</td>
<td>0.3750 to 0.6250</td>
</tr>
<tr>
<td>3</td>
<td>( m_a )</td>
<td>( 0.5 \pm 0.6250 )</td>
<td>0.4375 to 0.5625</td>
</tr>
<tr>
<td>sum</td>
<td>( 2.0 \pm 1.0 )</td>
<td>(-1.0 \pm 3.0)</td>
<td></td>
</tr>
<tr>
<td>sum – 1</td>
<td>( 1.0 \pm 1.0 )</td>
<td>(-0.0 \pm 2.0)</td>
<td></td>
</tr>
<tr>
<td>(sum – 1) / 2</td>
<td>( 0.5 \pm 0.5 )</td>
<td>(-0.0 \pm 1.0)</td>
<td></td>
</tr>
<tr>
<td>(sum – 2)</td>
<td>( 0.0 \pm 1.0 )</td>
<td>(-1.0 \pm 1.0)</td>
<td></td>
</tr>
</tbody>
</table>

So, if you would like to have a four-octave noise function that ranges from 0 to 1, then do this:

float \( n = m_x + m_g + m_b + m_a; \) // range is 1...3.

\( n = ( n - 1.0 ) / 2; \) // range is now 0...1.

If you would like to have a four-octave noise function that ranges from -1 to 1, then do this instead:

float \( n = m_x + m_g + m_b + m_a; \) // range is 1...3.

\( n = ( n - 2.0 ); \) // range is now -1...1.

By default, the glman 3D noise texture has dimensions 64 x 64 x 64. You can change this by putting a command in your GLIB file of the form

Noise3D 128

To get dimension 128 x 128 x 128, or choose whatever resolution you want (up to around 400 x 400 x 400).
A Noise Texture in Glman

The first time glman runs, it creates noise textures for you. It will take a few seconds. But glman then writes them to a local file, so that the next time this texture is needed, it is read from the file, which is a lot faster.

Getting a noise value from a 2D quantity (such as vST) works the same way as a 3D noise texture, except you get at it with:

```glsl
uniform sampler3D Noise3;
...
vec4 nv = texture( Noise3, uNoiseFreq * vec3(vST,0.) );
float n = nv.r + nv.g + nv.b + nv.a; // range is 1. -> 3.
```

Here we promote vST to be a vec3 so that it can use a 2D slice of the 3D noise texture.

Here is an example:

```c
GLuint Noise3; // a global
GLSLProgram Pattern; // a global
...
// in InitGraphics:
glGenTextures(1, &Noise3);
int nums, numt, nump;
unsigned char * texture = ReadTexture3D( "noise3d.064.tex", &nums, &numt, &nump);
If( texture == NULL ) { … }
glBindTexture(GL_TEXTURE_3D, Noise3);
glTexParameterf(GL_TEXTURE_3D, GL_TEXTURE_WRAP_S, GL_REPEAT);
glTexParameterf(GL_TEXTURE_3D, GL_TEXTURE_WRAP_T, GL_REPEAT);
glTexParameteri(GL_TEXTURE_3D, GL_TEXTURE_WRAP_R, GL_REPEAT);
glTexParameterf(GL_TEXTURE_3D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameterf(GL_TEXTURE_3D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
glTexImage3D(GL_TEXTURE_3D, 0, GL_RGBA, nums, numt, nump, 0, GL_RGBA, GL_UNSIGNED_BYTE, texture);
Pattern.Init( );
```

A 3D Noise Texture in Your C/C++ Program

The easiest way to read a noise texture into your C/C++ program is to get one of the noise textures from glman and know how to read it in. These pages will tell you how.

```c
unsigned char *
ReadTexture3D( char *filename, int *width, int *height, int *depth)
{
  FILE *fp = fopen(filename, "rb");
  if( fp == NULL ) return NULL;
  int nums, numt, nump;
  fread(&nums, 4, 1, fp);
  fread(&numt,  4, 1, fp);
  fread(&nump, 4, 1, fp);
  fprintf( stderr, "Texture size = %d x %d x %d\n", nums, numt, nump );
  *width  = nums;
  *height = numt;
  *depth  = nump;
  unsigned char * texture = new unsigned char[ 4 * nums * numt * nump ];
  fread(texture, 4 * nums * numt * nump, 1, fp);
  fclose(fp);
  return texture;
}
```

void
Display()
{
...
   glActiveTexture( GL_TEXTURE3 ); // set to use texture unit 3
   glBindTexture(GL_TEXTURE_3D, Noise3 );
   Pattern.Use();
   Pattern.SetUniformVariable( "Noise3", 3 );
   ...   << Draw something >>
   ...   Pattern.UnUse;
}

How to Use Noise

Idea: The graphics system will display “here”, using display parameters as if you were “over there”.

How much to increase the sampling rate

In the vertex shader:

```glsl
out vec3 vMCposition;

vMCposition = gl_Vertex.xyz;
```

How much to amplify the noise effect

In the fragment shader:

```glsl
uniform sampler3D Noise3;
uniform float uNoiseFreq, uNoiseAmp;

in vec3 vMCposition;

vec4 nv = texture( Noise3, uNoiseFreq * vMCposition );
float n = nv.r + nv.g + nv.b + nv.a; // range is 1. -> 3.
```

Model coordinates where this fragment is

```glsl
out vec3 vMCposition;

vMCposition = gl_Vertex.xyz;
```

Use those new “fake” input values in the original equation

```glsl
out vec3 vMCposition;

vMCposition = gl_Vertex.xyz;
```

Here we promote vST to be a vec3 so that it can use a 2D slice of the 3D noise texture.

Here is an example:

```c
GLuint Noise3; // a global
GLSLProgram Pattern; // a global
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// in InitGraphics:
glGenTextures(1, &Noise3);
int nums, numt, nump;
unsigned char * texture = ReadTexture3D( "noise3d.064.tex", &nums, &numt, &nump);
If( texture == NULL ) { … }
glBindTexture(GL_TEXTURE_3D, Noise3);
glTexParameterf(GL_TEXTURE_3D, GL_TEXTURE_WRAP_S, GL_REPEAT);
glTexParameterf(GL_TEXTURE_3D, GL_TEXTURE_WRAP_T, GL_REPEAT);
glTexParameteri(GL_TEXTURE_3D, GL_TEXTURE_WRAP_R, GL_REPEAT);
glTexParameterf(GL_TEXTURE_3D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameterf(GL_TEXTURE_3D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
glTexImage3D(GL_TEXTURE_3D, 0, GL_RGBA, nums, numt, nump, 0, GL_RGBA, GL_UNSIGNED_BYTE, texture);
Pattern.Init( );
```

A Noise Texture in Your C++ Program

How to Index Noise from 3D Model Coordinates

In the vertex shader:

```glsl
out vec3 vMCposition;

vMCposition = gl_Vertex.xyz;
```

How much to amplify the noise effect

In the fragment shader:

```glsl
uniform sampler3D Noise3;
uniform float uNoiseFreq, uNoiseAmp;

in vec3 vMCposition;

vec4 nv = texture( Noise3, uNoiseFreq * vMCPosition );
float n = nv.r + nv.g + nv.b + nv.a; // range is 1. -> 3.
```

We typically do this in Model coordinates so that the pattern sticks to the object.
How to Index Noise from 2D Texture Coordinates

In the vertex shader:

```glsl```
out vec2 vST;

vST = gl_MultiTexCoord0.st;
```

How much to amplify the noise effect

In the fragment shader:

```glsl```
uniform sampler3D Noise3;
uniform float uNoiseFreq, uNoiseAmp;
in vec2 vST;
vec4 nv = texture( Noise3, uNoiseFreq *
vec3 (vST,0.) );
float n = nv.r + nv.g + nv.b + nv.a; // range is 1. -> 3.
n = n - 2.; // range is now -1. -> 1.
n *= uNoiseAmp;
out vec2 vST;
```

We typically do this in Model coordinates so that the pattern sticks to the object.
If You Didn’t Have the Labels, Could You Tell Which of These Two Images is Displacement-Mapped and Which is Bump-Mapped?