Noise!

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.
Noise:

- Can be 1D, 2D, or 3D
- Is a function of input value(s)
- Ranges from -1. to +1. or from 0. to 1.
- Might look random, but really isn’t
- Has **Coherency** (i.e., if you change the input value to the noise function a little, the output value will only change a little)
- Has **Repeatability** (i.e., if you supply the same inputs, the noise function will always give you back the same output)
- Is **Continuous** (i.e., it’s smooth with no jarring jumps)
**Idea:** Pick a random number at the whole-number input values and then fit a piecewise smooth curve through those points.

The problem is that, due to the uncertainty of random numbers, you might get a very good plus-or-minus distribution, or a not-so-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.

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

\[ N(t) = C_{N0} N_0 + C_{N1} N_1 + C_{G0} G_0 + C_{G1} G_1 + C_{C0} C_0 + C_{C1} C_1 \]

<table>
<thead>
<tr>
<th>Noise values</th>
<th>Gradients</th>
<th>Curvatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N(t) )</td>
<td>( G(t) )</td>
<td>( C(t) )</td>
</tr>
</tbody>
</table>

### Cubic

| \( C_{N0} \) | \( 1 - 3t^2 + 2t^3 \) |
| \( C_{N1} \) | \( 3t^2 - 2t^3 = 1 - C_{N0} \) |
| \( C_{G0} \) | \( t - 2t^2 + t^3 \) |
| \( C_{G1} \) | \( -t^2 + t^3 \) |
| \( C_{C0} \) | \( 0 \) |
| \( C_{C1} \) | \( 0 \) |

### Quintic

| \( C_{N0} \) | \( 1 - 10t^3 + 15t^4 - 6t^5 \) |
| \( C_{N1} \) | \( 10t^3 - 15t^4 + 6t^5 = 1 - C_{N0} \) |
| \( C_{G0} \) | \( t - 6t^3 + 8t^4 - 3t^5 \) |
| \( C_{G1} \) | \( -4t^3 + 7t^4 - 3t^5 \) |
| \( C_{C0} \) | \( \frac{1}{2} t^2 - \frac{3}{2} t^3 + \frac{3}{2} t^4 - \frac{1}{2} t^5 \) |
| \( C_{C1} \) | \( \frac{1}{2} t^3 - t^4 + \frac{1}{2} t^5 \) |
**Noise Octaves**

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

![1 Octave](image1.png)

![4 Octaves](image2.png)
Image Representation of 2D Noise

1 Octave

4 Octaves
3D Surface Representation of 2D Noise

4 Octaves
3D Volume Rendering of 3D Noise

1 Octave

Has continuity in X, Y, and Z
Volume Isosurfaces of 3D Noise

1 Octave

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

S* = Mid-value

4 Octaves
Examples

Color Blending for Marble

Color Blending for Clouds

Deciding when to Discard for Erosion
**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?

1 Octave

4 Octaves
A Noise Texture in Glman

The *glm*n 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 .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>nv.r</td>
<td>0.5 ± .5000</td>
<td>0.0000 → 1.0000</td>
</tr>
<tr>
<td>1</td>
<td>nv.g</td>
<td>0.5 ± .2500</td>
<td>0.2500 → 0.7500</td>
</tr>
<tr>
<td>2</td>
<td>nv.b</td>
<td>0.5 ± .1250</td>
<td>0.3750 → 0.6250</td>
</tr>
<tr>
<td>3</td>
<td>nv.a</td>
<td>0.5 ± .0625</td>
<td>0.4375 → 0.5625</td>
</tr>
<tr>
<td></td>
<td>sum</td>
<td>2.0 ± ~ 1.0</td>
<td>~ 1.0 → 3.0</td>
</tr>
<tr>
<td></td>
<td>sum – 1</td>
<td>1.0 ± ~ 1.0</td>
<td>~ 0.0 → 2.0</td>
</tr>
<tr>
<td></td>
<td>(sum – 1) / 2</td>
<td>0.5 ± ~ 0.5</td>
<td>~ 0.0 → 1.0</td>
</tr>
<tr>
<td></td>
<td>(sum – 2)</td>
<td>0.0 ± ~ 1.0</td>
<td>~ -1.0 → 1.0</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:

```c
float n = nv.r + nv.g + nv.b + nv.a; // range is 1. -> 3.
n = ( n - 1. ) / 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:

```c
float n = nv.r + nv.g + nv.b + nv.a; // range is 1. -> 3.
n = ( n - 2. ); // range is now -1. -> 1.
```

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

**Noise3D 128**

to get dimension $128 \times 128 \times 128$, or choose whatever resolution you want (up to around $400 \times 400 \times 400$).
The first time \textit{glman} runs, it creates 2D and 3D noise textures for you, it will take a few seconds. But, \textit{glman} then writes them to a local file, so that the next time this 2D or 3D texture is needed, it is read from the file, which is a lot faster.

A 2D noise texture works the same way as a 3D noise texture, except you get at it with:

\begin{verbatim}
uniform sampler2D Noise2;
...
vec4 nv = texture( Noise2, uNoiseFreq * vST );
float n = nv.r + nv.g + nv.b + nv.a; // range is 1. -> 3.
n = ( n - 1. ) / 2.; // range is now 0. -> 1.
\end{verbatim}

The only difference is that a 2D noise texture is indexed by a \texttt{vec2} (such as the s-t coordinates) while the 3D noise texture is indexed by a \texttt{vec3} (such as the model x-y-z coordinates). But, both return a \texttt{vec4}. 

\textit{Oregon State University Computer Graphics}
A 2D 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.

```cpp
GLuint TexName; // a global

// in InitGraphics:

glGenTextures(1, &TexName);
int nums, numt;
unsigned char * texture = ReadTexture2D( "noise2d.064.tex", &nums, &numt );
if( texture == NULL ) { … }

glBindTexture(GL_TEXTURE_2D, TexName);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA, nums, numt, 0, GL_RGBA,
              GL_UNSIGNED_BYTE, texture);

Pattern = new GLSLProgram( );
bool valid = Pattern->Create( "pattern.vert", "pattern.frag" );
if (!valid)
    …
```

A 2D Noise Texture in Your C/C++ Program

```c
unsigned char *
ReadTexture2D( char *filename, int *width, int *height )
{
    FILE *fp = fopen(filename, "rb");
    if( fp == NULL )
        return NULL;

    int nums, numt;
    fread(&nums, 4, 1, fp);
    fread(&numt, 4, 1, fp);
    fprintf( stderr, "Texture size = %d x %d\n", nums, numt );

    *width  = nums;
    *height = numt;

    unsigned char * texture = new unsigned char[ 4 * nums * numt ];

    fread(texture, 4 * nums * numt, 1, fp);
    fclose(fp);
    return texture;
}
```
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
GLuint TexName; // a global

// in InitGraphics:

// 2D or 3D
Dimensions

glGenTextures(1, &TexName);
int nums, numt, nump;
unsigned char * texture = ReadTexture3D( "noise3d.064.tex", &nums, &numt, &nump);
If( texture == NULL ) { ... }

glBindTexture(GL_TEXTURE_3D, TexName);
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);
gTexImage3D(GL_TEXTURE_3D, 0, GL_RGBA, nums, numt, nump, 0, GL_RGBA,
            GL_UNSIGNED_BYTE, texture);

Pattern = new GLSLProgram( );
bool valid = Pattern->Create( "pattern.vert", "pattern.frag");
if (!valid)
  ...
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() {
    ...

    glEnableTexture(GL_TEXTURE_3D); // set to use texture unit 3
    glBindTexture(GL_TEXTURE_3D, TexName);

    Pattern->Use();
    Pattern->SetUniformVariable("uTexUnit", 3);
    
    << Draw something >>
    ...
    Pattern->Use(0);
}

A Noise Texture in Your C++ Program
How to Use Noise

1. Have an equation that relates some input value (x,y,z or s,t) to output values (color, height)

2. Have actual input values of where we are right now

3. Add Noise to the actual input values to produce new “fake” input values

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

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

Computer Graphics
How to Use Noise

In the vertex shader:

```glsl
out vec3 vMCposition;
...
vMCposition = gl_Vertex.xyz;
```

How much to magnify the noise effect

In the fragment shader:

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

How much to increase the sampling rate

Coordinates where this fragment is

Now add the noise value, \( n \), to the actual (s,t) location. Compute the effect at that “fake” location, but apply it at the actual location.

We typically do this in Model coordinates so that the pattern sticks to the object.
Elliptical Dots with Tolerance

\[ 1 - uTol \leq \left( \frac{s-s_c}{A_r} \right)^2 + \left( \frac{t-t_c}{B_r} \right)^2 \leq 1 + uTol \]

\[
float d = \left( \frac{s-s_c}{A_r} \right)^2 + \left( \frac{t-t_c}{B_r} \right)^2
\]

float t = smoothstep( 1.-uTol, 1.+uTol, d );
vec3 color = mix( ORANGE, WHITE, t );
Elliptical Dots with Tolerance and Noise

float n = nv.r + nv.g + nv.b + nv.a; // 1. -> 3.
   n = n - 2.; // -1. -> 1.
   n *= uNoiseAmp;

...  

float ds = st.s - sc; // wrt ellipse center
float dt = st.t - tc; // wrt ellipse center
float oldDist = sqrt( ds*ds + dt*dt );
float newDist = oldDist + n;
float scale = newDist / oldDist; // this could be < 1., = 1., or > 1.
   ds *= scale; // scale by noise factor
   ds /= Ar; // ellipse equation
   dt *= scale; // scale by noise factor
   dt /= Br; // ellipse equation
   float d = ds*ds + dt*dt;
   float t = smoothstep( 1.-uTol, 1.+uTol, d );
   vec3 theColor = mix( ORANGE, WHITE, t );

...
Elliptical Dots with Tolerance and Noise
N = NoiseMag * noise( NoiseFreq * PP );
Color Only
Displacement Only
Color and Displacement together
Surface Only

Displacement Only

Surface + Displacement

No Noise

Noise

Or

Computer Graphics
If You Didn’t Have the Labels, Could You Tell Which of These Two Images is Displacement-Mapped and Which is Bump-Mapped?