Noise!

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 continuity** (i.e., if you change the input value to the noise function a little, the output value will only change a little)
- **Is repeatable** (i.e., if you supply the same inputs, the noise function will always give you back the same output)
### Positional Noise

**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 good plus-or-minus distribution, or a not-so-good distribution.

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### 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 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

**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

Image Representation of 2D Noise

1 Octave

4 Octaves

4 Octaves

1 Octave
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

S* = Mid-value

4 Octaves

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

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 as fluid “turbulence”.

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**Turbulence Example**

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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 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:

```glsl
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>
A Noise Texture in Glman

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

```cpp
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:

```cpp
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 glman runs, it creates a 3D noise texture for you, it will take a few seconds. But, glman then writes it to a local file, so that the next time this 3D texture is needed, it is read from the file, which is a lot faster.

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

```cpp
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.
```

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

// in InitGraphics:

```c
mjb – December 22, 2020
```

```c
#include <GL/.gl.h>

void InitGraphics()
{
  // 2D or 3D
  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);
  glTexParameterf(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_RGBA8, 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);

  *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;
}
```

A Noise Texture in Your C/C++ Program
void
Display( )
{
  . . .
  glActiveTexture( GL_TEXTURE3 ); // set to use texture unit 3
  glBindTexture(GL_TEXTURE_3D, TexName);
  Pattern->Use();
  Pattern->SetUniformVariable( "uTexUnit", 3 );
  . . .
  << Draw something >>
  Pattern->Use(0);
}

How to Use Noise

Have an equation that relates some input value (x,y,z or u,v) to output values (color, height)

Have actual input values of where we are right now

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

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”.
How to Use Noise

- **Noise frequency**
- **Coordinates where you are now**
- **How much to amplify the noise effect**
- **How much to increase the sampling rate**

```
float n = NoiseMag * noise( NoiseFreq * PP );
```

```
vec4 nv = texture( Noise3, uNoiseFreq * vMCposition );
float n = nv.r + nv.g + nv.b + nv.a; // range is 1. -> 3.
n = ( n - 1. ) / 2.; // range is now 0. -> 1.
n  *= uNoiseMag;
```

Now add the noise value, N, to the actual location. Compute the effect at that new location, but apply it at the actual location.

Why should PP usually be in Model coordinates instead of World coordinates?

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 );
```
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; // this could be < 1., = 1., or > 1.
    float scale = newDist / oldDist; // scale by noise factor
    ds *= scale; // ellipse equation
    dt *= scale; // ellipse equation
    float d = ds*ds + dt*dt;
    float t = smoothstep( 1.-uTol, 1.+uTol, d );
    vec3 theColor = mix( ORANGE, WHITE, t );
    ...

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

Have actual input values of where we are right now

Add Noise to the actual input values to produce near "fake" input values

Use those new "fake" input values in the original equation

uNoiseAmp = 0.

uNoiseAmp = 0.

oState
University
Computer Graphics
\[ N = \text{NoiseMag} \times \text{noise} ( \text{NoiseFreq} \times \text{PP} ); \]
Displacement Only

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

Displacement-mapped  Bump-mapped