Dynamic Texturing

Mark Harris

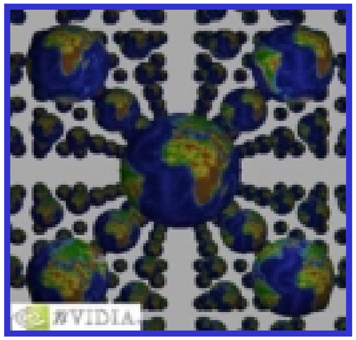
NVIDIA Corporation

What is Dynamic Texturing?

- The creation of texture maps “on the fly” for use in real time.
- A simplified view:
  - Loop:
    - Render an image.
    - Create a texture from that image.
    - Use the texture as you would a static texture.

Applications of Dynamic Texturing

- Impostors
- Feedback Effects
- Dynamic Cube / Environment map generation
- Dynamic Normal map generation
- Dynamic Volumetric Fog
- Procedural Texturing
- Dynamic Image Processing
- Physical (PDE) Simulation



Overview

- Copying Texture Data
- Off-Screen Rendering with Pixel Buffers
- Rendering Directly To Textures
- Procedural Texturing

The Basics: Copying Texture Data

- **How do we get a rendered image into a texture?**
  - **glReadPixels() → glTexImage*() ?**
    - **SLOW!**
  - **glCopyTexImage*()**
    - **Better.**
  - **glCopyTexSubImage*()**
    - **Best (currently).**
  - **Render to Texture**
    - **Coming Soon!**

glCopyTexSubImage

- Not just for sub-images anymore!
- Performance is better than glCopyTexImage
  - Doesn't require allocation of texture memory.
  - Optimized in NVIDIA's Release10 driver.

What About Mipmaps?

- **Sometimes we want mipmaps for our dynamic textures.**
- **How do we generate them?**
  - **The obvious way: generate them yourself.**
  - **GluBuild2DMipmaps().**
  - **Automatic mipmap generation.**

Automatic Mipmap Generation!

- SGIS_generate_mipmap extension
  - New token GL_GENERATE_MIPMAP_SGIS for glTexParameter*()
  - Set to GL_TRUE, causes mipmap levels to be updated anytime base level image changes
  - Faster than gluBuild2DMipmaps

```
glBindTexture( GL_TEXTURE2D, tid );
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER,
                 GL_LINEAR_MIPMAP_NEAREST );
glTexParameteri( GL_TEXTURE_2D, GL_GENERATE_MIPMAP_SGIS, GL_TRUE );
glCopyTexSubImage2D( GL_TEXTURE_2D, … );
```

Automatic Mipmap Generation: On NVIDIA GPUs

- **Works with glTex[Sub]Image, glCopyTex[Sub]Image.**
- **Extension supported for ALL texture formats for ENTIRE GeForce family.**
- **Only HW-Accelerated when used with glCopyTex[Sub]Image2D and the following formats:**
  - **GL_RGB8**
  - **GL_RGBA8**
  - **GL_RGB5**
- **Copies w/ auto-mipmap enabled will copy at 50% the speed of just updating the base level texture.**
  - **Copies 5x faster with release 10 driver**

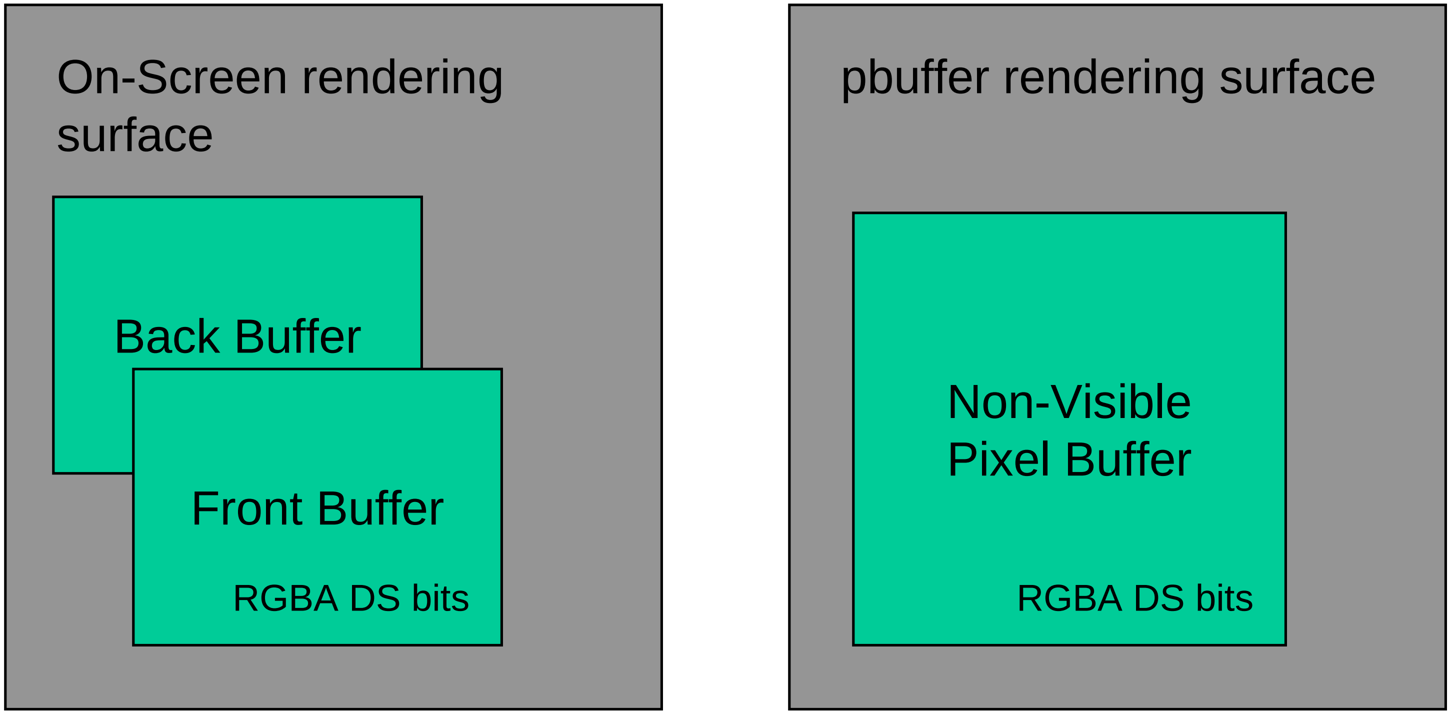
Off-Screen Rendering with Pixel Buffers

- We don't always want to use the frame buffer to render our dynamic textures.

- Why not?
  - Resolution is limited to the window resolution.
  - Might need a different pixel format.
  - Can require a lot of OpenGL state juggling.
  - Overlapping windows can mess up copies.
  - Can't be used to render to texture (more later).

- Use a pbuffer instead!

What is a Pbuffer?



For On-Screen rendering surface: buffer dimensions and bit properties are constrained by the current display mode.

For pbuffer rendering surface: dimensions and bit properties are independent of the current display mode.

Using Pbuffers

- Windows
  - WGL_ARB_pixel_format extension
  - WGL_ARB_pbuffer extension
- Linux
  - Supported in GLX 1.3
- MAC
  - Future extension(s)

Using Pbuffers

- **Setting up pbuffers can be tedious**
  - **Requires windowing system specific calls**
  - **Can be "abstracted" away**
    - **Implement once and reuse!**
    - **Something like glutInitWindowSize() and glutInitDisplayString() / glutInitDisplayMode()**

- **Three Key Components – same as for a window**
  - **Creating a pbuffer**
  - **Binding a pbuffer**
  - **Destroying a pbuffer**

Pbuffer Creation (In Windows)

- **Quick Overview**

1. **Get a valid device context**

   HDC hdc = wglGetCurrentDC();

2. **Choose a pixel format**

   Specify a set of minimum attributes

   - **Color, Depth, Stencil bits, etc.**
   - **Can specify single- or double-buffered, just like a window.**
   - **Will usually need only single buffer (save RAM!).**

   Then call wglChoosePixelFormat()

   - **Returns a list of formats which meet minimum requirements.**
   - **fid = pick any format in the list.**

Pbuffer Creation (In Windows)

- **Quick Overview (cont.)**

3. **Create the pbuffer**

   ```
   HPBUFFER hbuf = wglCreatePbufferARB( hdc, fid, w, h, attr );
   ```

   "attr" is a list of other properties for your pbuffer.

4. **Get the device context for the pbuffer**

   ```
   hdc = wglGetPbufferDCARB( hbuf );
   ```

5. **Get a rendering context for the pbuffer:**
   - **Either create a new one (pbuffer gets its own GL state!):**

     ```
     hglrc = wglCreateContext( hdc );
     ```

   - **Or use the current context:**

     ```
     hglrc = wglGetCurrentContext();
     ```

Binding a Pbuffer (In Windows)

- **Easy!**

  wglMakeCurrent(hdc, hglrc);

  - **Makes the pbuffer device context the current rendering target for the rendering context.**
  - **Subsequent OpenGL primitives rendered to the off-screen buffer.**

Destroying a Pbuffer (In Windows)

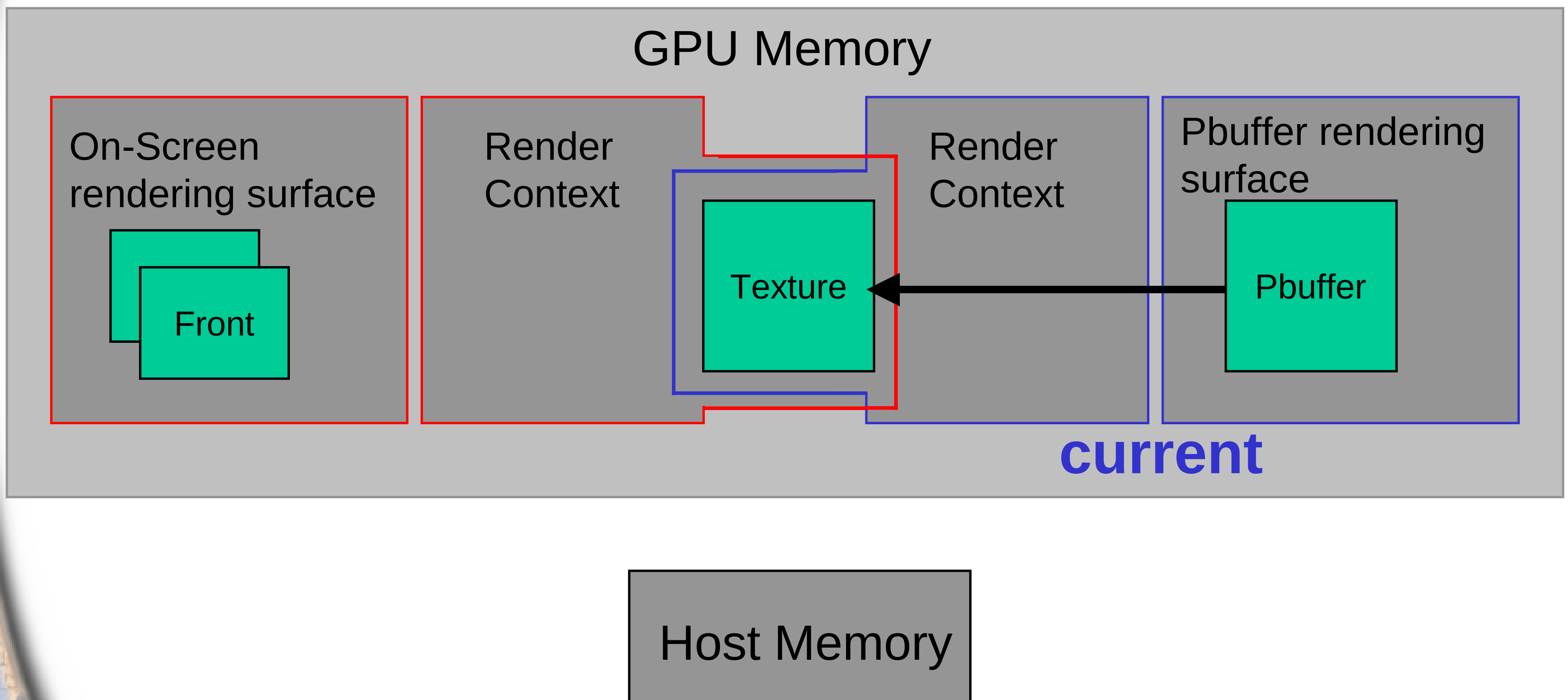
- **3 Step Process**

1. **Delete the rendering context**
2. **Release the pbuffer's device context**
3. **Destroy the pbuffer**

```
wglDeleteContext( hpbufglrc );
wglReleasePbufferDCARB( hbuf, hbufdc );
wglDestroyPbufferARB( hbuf );
```

Retrieving Data from a Pbuffer

- **Copy-to-Texture via "shared textures"**



Retrieving Data from a Pbuffer

- **Copy-to-Texture via "shared textures"**
  - **Use wglShareLists(hVisibleGLRC, hPbufferGLRC)**
    - **Allows sharing of ALL display list and texture objects between rendering contexts.**
    - **Call just once immediately after creating the Pbuffer.**
    - **Don't need if pbuffer uses same GLRC as app window.**
  - **Bind to pbuffer**
  - **Render to pbuffer**
  - **glCopyTexSubImage2D();**
  - **Bind to on-screen rendering surface**
  - **Render frame**

Pbuffers: On NVIDIA GPUs

- Windows
  - Hardware accelerated for TNT, TNT2, and the ENTIRE GeForce family of GPUs.
  - Release 10 driver and beyond
- Linux and MAC support coming…

Things to Keep in Mind…

- **Pbuffers consume Video Memory**
  - **Frame Buffer, Textures, Display Lists, and pbuffers all in video memory.**
  - **Large/Lots of pbuffers on low-end may limit performance**
    - **One single-buffered pbuffer is often enough.**
    - **Don’t request depth if you don’t need it.**
    - **Error check the creation routines.**
- **Keep track of your state!**
  - **Don’t get confused about which context is current when setting GL state.**

Example uses for pbuffers

- Shadow Map Creation.
- Rendering dynamic text to a texture.
- "Pre-baked" terrain texturing:
  - Each terrain vertex has a set of weights for blending basis textures:
    - w_0 * grass + w_1 * rocks + w_2 * dirt + w_3 * water… + ….
  - Pre-blend textures using reg. Combiners and / or multipass into a single texture for each terrain region.
  - Copy to texture using auto-mipmap generation.
  - Use to texture terrain.

Rendering Directly to Textures

- Our most requested OpenGL feature.
- We're finally going to have it! (in windows)
  - Will be available in an upcoming driver release.
- Implementation of WGL_ARB_render_texture extension.
  - Allows a pbuffer to be bound as a texture.
  - Defines three new functions:
    - wglBindTexImageARB ()
    - wglReleaseTexImageARB ()
    - wglSetPbufferAttribARB ()

Using WGL_ARB_render_texture

1. **Create a pbuffer with appropriate pixel format.**
   - **In wglChoosePixelFormat():**
     - **Specify WGL_DRAW_TO_PBUFFER and either WGL_BIND_TO_TEXTURE_RGB_ARB or WGL_BIND_TO_TEXTURE_RGBA_ARB as TRUE.**
   - **In wglCreatePbufferARB():**
     - **Set WGL_TEXTURE_FORMAT_ARB:**
       - **WGL_TEXTURE_RGB_ARB or WGL_TEXTURE_RGBA_ARB**
     - **Set WGL_TEXTURE_TARGET_ARB:**
       - **WGL_TEXTURE_CUBE_MAP_ARB, WGL_TEXTURE_1D_ARB, or WGL_TEXTURE_2D_ARB**
     - **Use WGL_MIPMAP_TEXTURE_ARB to request space for mipmaps.**
       - **If non-zero and the texture format is WGL_TEXTURE_RGB[A]_ARB, then storage for mipmaps will be allocated.**
     - **Set pbuffer width and height to size of the level zero mipmap image.**

Using WGL_ARB_render_texture

2. **Create a context for the pbuffer.**
   - **Make the context current to the pbuffer and initialize the context's attributes.**

3. **Render to the pbuffer.**

4. **Make the context current to the window**
   - **Bind a texture object to the appropriate texture target and set desired texture parameters.**

Using WGL_ARB_render_texture

5. **Call wglBindTexImageARB to bind the pbuffer drawable to the texture.**
   - **Set <iBuffer> to WGL_FRONT or WGL_BACK depending upon which color buffer was used for rendering the texture.**

```
BOOL wglBindTexImageARB (HPBUFFERARB hPbuffer,
                         int iBuffer)
```

Using WGL_ARB_render_texture

6. **Render to the window using the texture.**
7. **Call wglReleaseTexImageARB to release the color buffer of the pbuffer. Goto step 3 to generate more frames.**

BOOL wglReleaseTexImageARB (HPBUFFERARB hPbuffer,
int iBuffer)

***** NOTE: you *must* release the pbuffer from the texture before you can render to it again. *****

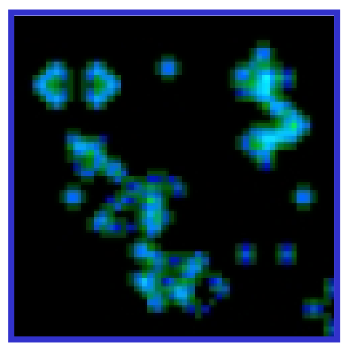
Rendering Cube Maps and Mipmaps

- **Can use wglSetPbufferAttribARB() to choose which cube map face or mipmap level to render.**

```
BOOL wglSetPbufferAttribARB (HPBUFFERARB hPbuffer,
                             const int *piAttribList)
```

Procedural Texturing

- **Combine dynamic texture creation and programmable shading for endless possibilities!**
  - **Dynamic bump and normal maps**
  - **Feedback Effects:**
    - **Fire, blur, etc.**
  - **Computation:**
    - **Cellular Automata**
    - **Physics**



Procedural Texturing Concepts

- **Rendering to texture (already discussed).**
- **Sampling a Texel's Neighbors.**
  - **Use vertex programs and register combiners.**
- **Use of texture shaders:**
  - **Dependent texture reads, dot products, and other operations.**
- **Use of Register Combiners:**
  - **Weighted texture sampling.**

Sampling a Texel's Neighbors

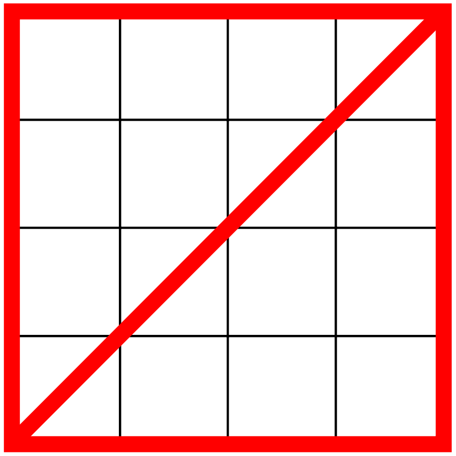
- **Very powerful and important technique!**
  - **The key to using texture ops for SIMD computation.**
  - **Can think of it as communication between processor elements.**
- **Offset texture coordinates by a multiple of the texel dimensions.**
  - **Ideal candidate for a vertex program.**
- **Initialize offsets based on dimensions of texture:**
  - **float texelWidth = 1.0f / (float)textureWidth;**
    float texelHeight = 1.0f / (float)textureHeight;

Sampling a Texel's Neighbors

- **Example: sampling 4 nearest neighbors.**
- **Load the offsets into VP constant memory:**

```
glProgramParameter4fNV(GL_VERTEX_PROGRAM_NV, 40, -texelWidth, 0, 0, 0);  // left
glProgramParameter4fNV(GL_VERTEX_PROGRAM_NV, 41, texelWidth, 0, 0, 0);   // right
glProgramParameter4fNV(GL_VERTEX_PROGRAM_NV, 42, 0, texelHeight, 0, 0);  // top
glProgramParameter4fNV(GL_VERTEX_PROGRAM_NV, 43, 0, -texelHeight, 0, 0); // bottom
```

- **Render a quad which exactly covers the render buffer with texture coordinates from (0,0) to (1,1)**

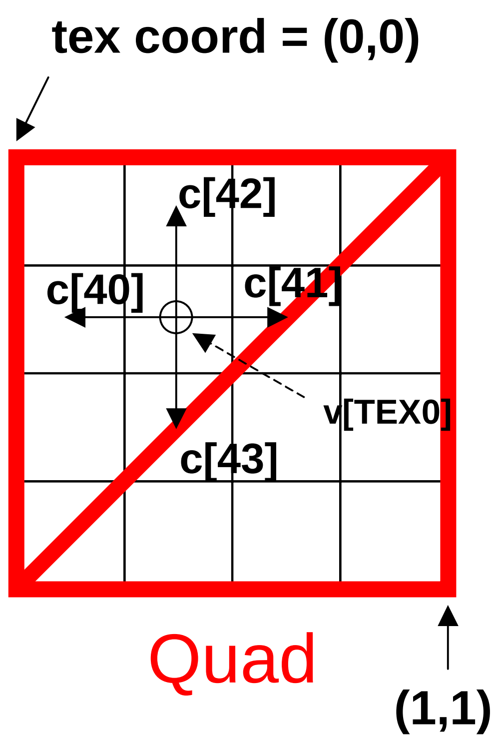


Quad

Sampling a Texel's Neighbors

- Vertex Shader writes different texture coordinates to each texture stage
- Each of the four coordinates is offset by vector in constant memory: c[40], c[41], c[42], or c[43].
- In a vertex program, add offsets to input texture coordinates, creating 4 sets of independent texture coordinates:

```
ADD o[TEX0], c[40], v[TEX0];
ADD o[TEX1], c[41], v[TEX0];
ADD o[TEX2], c[42], v[TEX0];
ADD o[TEX3], c[43], v[TEX0];
```



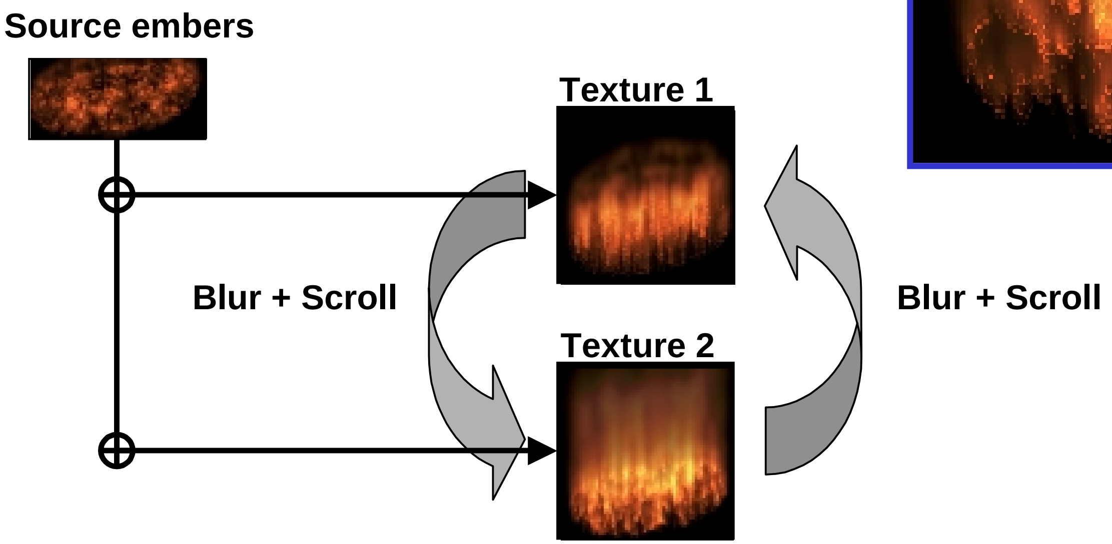
Sampling a Texel's Neighbors

- **Use register combiners to combine the samples.**
- **Bind same texture to all four inputs.**
- **Example nvparse RC1.0 script to average four samples:**

```
const0 = (0.25, 0.25, 0.25, 0.25);
{
   rgb
   {
        discard = tex0 * const0;
        discard = tex1 * const0;
        spare0 = sum();
   }
}
{
   rgb
   {
        discard = tex2 * const0;
        discard = tex3 * const0;
        spare1 = sum();
   }
}
out.rgb = spare0 + spare1;
out.a = spare1.a;
```

Procedural Texturing Example

- **Fire effect using feedback:**
  - **Blur and scroll upward**
    - **by sampling and averaging neighbors with downward offset.**
  - **Drive flames with a "seed" texture of bright embers.**

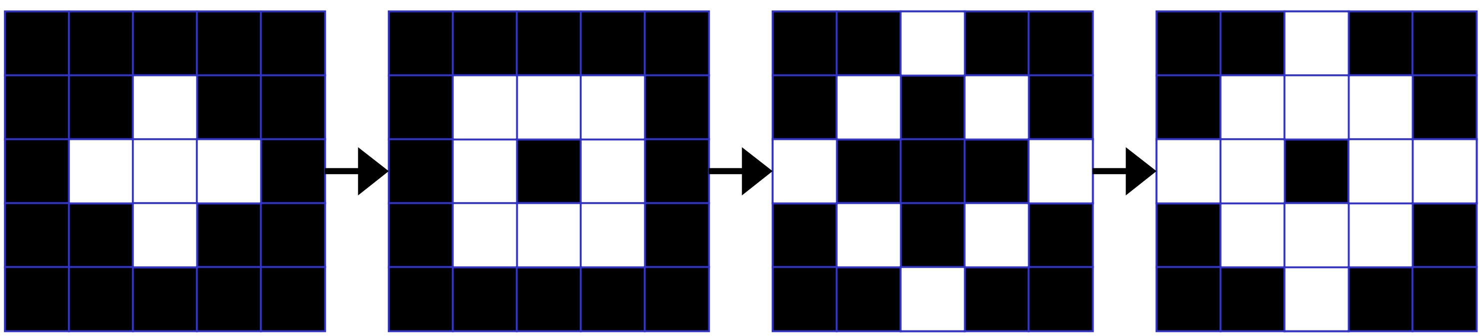


Detailed Example: Game Of Life

- **Cellular Automata**
  - **Useful for generating noise and other animated patterns to use in blending.**
  - **The Game Of Life is used as the “embers” texture in the fire demo!**
- **Game Of Life demo:**
  - **Uses three rendering passes per generation.**
  - **Dependent texture address texture shader.**
  - **Register combiners / vertex program to sample all 8 neighbors of a texel.**

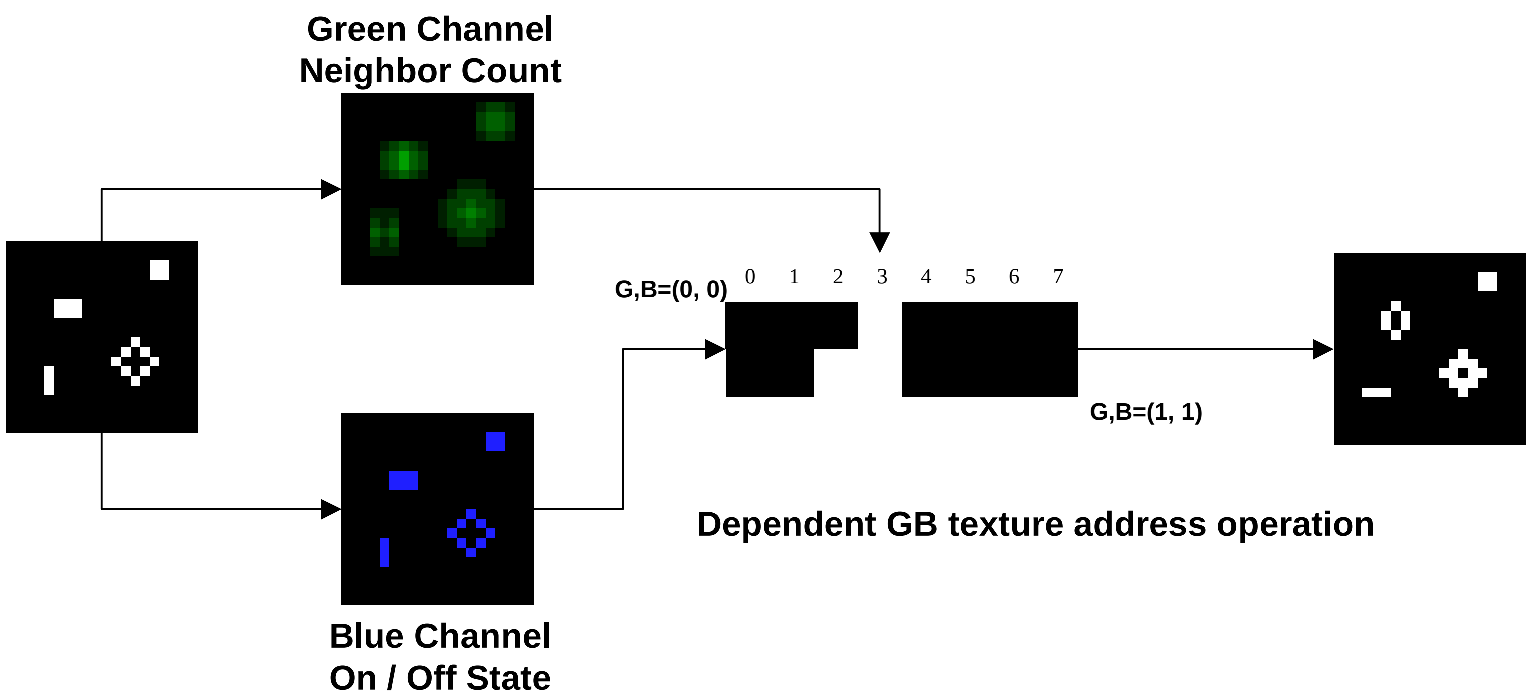
Rules of the Game of Life

- **A cell will be "alive" in the next generation if:**
  - **The cell is alive in the current generation and has two or three living neighbors, or**
  - **The cell is not alive in the current generation and has exactly three neighbors.**



The Game Of Life

- **How the Game of Life demo operates:**

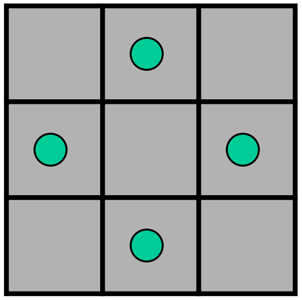


The Game Of Life

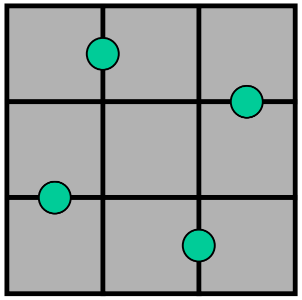
- **Pass One: discard all but blue.**
  - **Also bias a little to ensure correct addressing.**
- **Pass Two: count neighbors of each texel.**
  - **add count to green channel.**
- **Pass Three: Determine next generation:**
  - **use sum of passes one and two as input for dependent GB address lookup into rules texture.**

The Game Of Life

- **How do we count the neighbors of a texel?**
  - **Use the neighbor sampling from before, slightly modified.**
  - **Instead of sampling like this:**

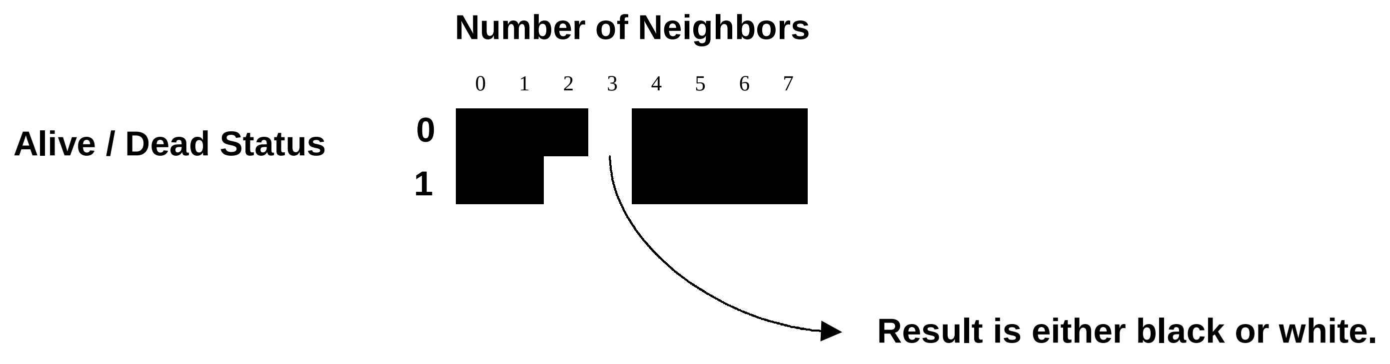


  - **Change offsets to sample all 8 neighbors:**
    - **Must enable linear texture filtering.**



The Game Of Life

- **Use results of first two passes to do a dependent lookup into the "rules texture".**
- **Value in blue channel acts as t-coordinate.**
  - **Encodes "cell is alive in current generation".**
- **Value in green channel acts as s-coordinate.**
  - **Encodes number of living neighbors of each cell.**



More complex Procedural Shading

- Game of Life is just a simple example.
  - Possibilities are endless!
- Can use texture operations to do physical simulation!
  - Dynamic bump-mapped waves.
  - Neighbor sampling allows finite-difference integration of simple PDEs!
  - Demo maintains 3 textures:
    - Force, velocity, and height.
    - Neighbor sampling determines force.
    - Force applied to velocity.
    - Velocity applied to height.

For More Information…

- Questions to: jspitzer@nvidia.com
- NVIDIA Developer Website
  - http://www.nvidia.com/developer
  - Pbuffer and auto mipmap gen presentations.
  - Performance presentation.
  - Texture shader and Vertex program presentations.
  - Demos, demos, demos.
    - GL Game Of Life demo.
    - Several D3D Demos using procedural textures.
    - More always coming.