Realtime Computer Graphics on GPUs

Effects II

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Advanced Texturing

Bottlenecks of Modern Renderers

- Memory transfers between CPU (RAM) and GPU
- Communication with driver:
  - Fixed pipeline:
    - Lots of API calls to manage state
  - OpenGL 3.0+:
    - Bind operations
    - Setting shader uniforms
    - Draw calls

PROBLEM – MULTI-MATERIAL SCENE/OBJECTS

- Changing shader programs + repeated uniform setup
- Bind new textures on material switch
- Multiple draw calls

Uniform Buffer Objects I

Advantages:

- Same uniforms in multiple shader programs:

```
uniform vec4 camera_position;
uniform vec4 light_position;
uniform vec4 light_diffuse;
```

- Single buffer cointaining the data
- Larger uniform storage
- Faster switching for uniform blocks

Uniform Buffer Objects II

- Switch to uniform block in GLSL

```
uniform shader_data
{
  vec4 camera_position;
  vec4 light_position;
  vec4 light_diffuse;
};
```

- C++ counterpart:

```
struct shader_data_t
{
  float camera_position[4];
  float light_position[4];
  float light_diffuse[4];
} shader_data;
```

Uniform Buffer Objects III

- Create uniform buffer:

```
GLuint ubo = 0;
glGenBuffers(1, &ubo);
glBindBuffer(GL_UNIFORM_BUFFER, ubo);
glBufferData(GL_UNIFORM_BUFFER, sizeof(shader_data), &shader_data, ↩
      GL_DYNAMIC_DRAW);
glBindBuffer(GL_UNIFORM_BUFFER, 0);
```

- Update data:

```
glBindBuffer(GL_UNIFORM_BUFFER, gbo);
GLvoid* p = glMapBuffer(GL_UNIFORM_BUFFER, GL_WRITE_ONLY);
memcpy(p, &shader_data, sizeof(shader_data))
glUnmapBuffer(GL_UNIFORM_BUFFER);
```

- Connect UBO and GLSL program:

```
block_index = glGetUniformBlockIndex(program, "shader_data");
GLuint binding_point_index = 2;
glUniformBlockBinding(program, block_index, binding_point_index);

...

glBindBufferRange(GL_UNIFORM_BUFFER, binding_point_index,
    gbo, 0, sizeof(shader_data_t));
```

Bindless Textures

How to prevent texture binding?

- Generate integer *handle* for each texture:
  - from texture object alone
  - from texture object and sampler
  - from specific image within texture
- Texture state becomes immutable (can update contents)
- Access texture by handle from shaders
  - cannot be used until made *resident*
- Safety: errors may crash the GPU, program, OS
- Extensions: ARB_bindless_texture, NV_bindless_texture

Bindless Textures – Usage

- Creation:

```
glGetTextureHandleARB(GLuint texture);
glGetTextureSamplerHandleARB(GLuint texture, GLuint sampler);
```

- Image handle:

```
glGetImageHandleARB(GLuint texture, GLint level,
GLboolean layered, GLint layer, GLenum format);
```

- Residency:

```
glMakeTextureHandleResidentARB(GLuint64 handle);
glMakeImageHandleResidentARB(uint64 handle, enum access);
glMakeTextureHandleNonResidentARB(GLuint64 handle);
glMakeImageHandleNonResidentARB(uint64 handle);
```

Bindless Textures – GLSL Usage

- Handle must be resident
- Direct use:
  - Shader stage inputs/outputs (except FS outputs)
  - Vertex attributes (GL_UNSIGNED_INT64_ARB data type)
  - Uniforms, uniform blocks

```
layout(bindless_sampler) uniform sampler2D bindless;

uniform samplers
{
  sampler2D arr[10];
};
```

  - Local sampler variables (init form other samplers, integer cast)

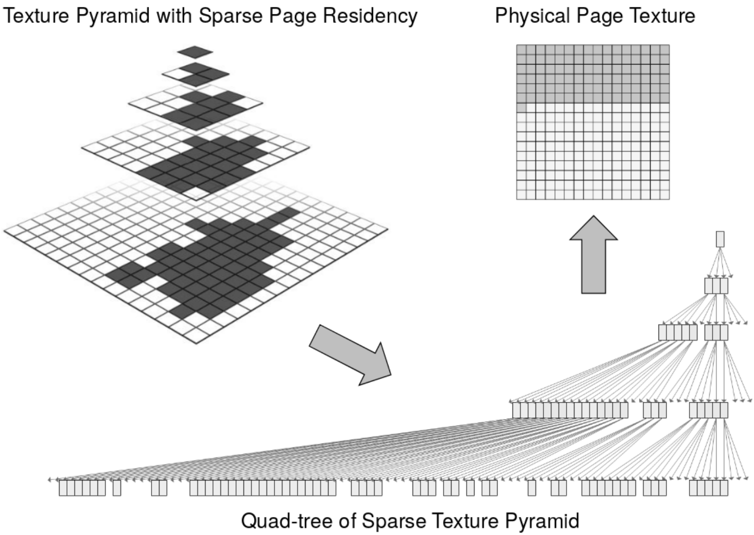
Sparse Virtual Texture

- Also known as *megatextures* (Idsoft – Rage)
- Different approach to binding prevention – one large texture for whole scene
- Texture may be larger than GPU memory (over-subscription)
  - Similar to virtual address space and physical memory
  - Pages are texture tiles
  - Page table for translation of texture coordinates
- Each object in scene uniquely textured
  - Artist less limited by technical aspects

Virtual Texturing

Virtual Texturing

Virtual Texturing



Megatextures – Page Mapping

- Access the page table with original texture coordinates (nearest neighbor)
- No special coordinate mapping
- Within-page offset:
  - Depends on mip-map level

```
page_phys_tc = texture(page_tex, vtex_tc);

within_page_tc = exp2(mip_level) * vtex_tc;
within_page_tc = fract(within_page_tc);

within_page_tc *= rescale_page_to_physical;
phys_tc = page_phys_tc + within_page_tc;

sample = texture(diffuse_tex, phys_tc);
```

Feedback Analysis

- Separate pass – render page IDs (low resolution)
  - Determine pages + mip-map levels
- Loading missing pages – delay before used (mip-map fallback)

Implementation Details

Page faults:

- Mip-map substitution
- Propagate lower mip-map levels page mapping to un-mapped upper levels

HW support:

- TexPageCommitmentARB()

Filtering:

- Bilinear filtering with/without tile borders
- Trilinear – mip-map the physical pages (larger border)
- Anisotropic – complicated

Decals, Billboards

Decals

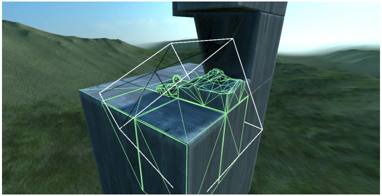
- Runtime interaction with the scene
- Additional details:
  - Bullet holes
  - Graffiti
  - Local material weathering
  - Footsteps

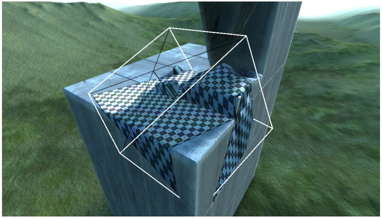
Decals – Approaches

- Megatextures:
  - Draw decals directly in the scene texture
  - Maybe permanent without increased overhead
- Special geometry rendered in front of the object
  - Z-fighting, depth offset
  - Simple scene – textured quad
  - Geometry projection in general case
  - Adding decals increases scene complexity – only few latest/important kept
- Screen space decals – deferred shading

Decals – Projecting Geometry

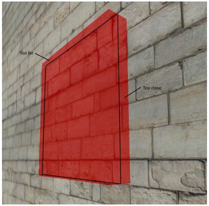
- Oriented bounding box:
  - projector along z-axis
  - x,y are mapped to u,v coordinates
- Intersection with scene geometry
  - select intersecting tringles
  - cut triangles – project to projector space, uv-mapping





Decals – Screen Space

- Deffered shading
- Render projector box
  - Reject fragments which project outside the box (use z-buffer + view direction)
  - Flattened box – projected on the geometry
- Normal mapping:
  - Normal buffer may contain modulated normals
  - Underlying geometry normal – partial derivatives in the z-buffer
- Problems:
  - Clipping the projector box
  - Projection on 90 degree corners



Billboards

- Billboard – semitransparent texture showing more complicated object/scenery
  - texture is usually mapped on a rectangle
  - often perpendicular to view direction
  - .. following the viewer – special transform matrix
  - rotation around vertical axis only (unsightly from above)
- usage
  - trees and bushes (even unoriented billboards, multi-billboards)
  - complex inscriptions, 2D graphics, HUD, lens flare..

IMPOSTORS

- Impostor – billboard created dynamically (as necessary) in a rendering engine
  - cache of complex scenery (not very dynamic)
  - complex object/scenery (geometric or color complexity)
  - for distant objects mostly
  - hierarchy, LoD, multiple instances of the (almost) same object

    ...
- trees, bushes
  - impostors might be oriented along main branches..
- technique: HW render-target textures

EXAMPLE

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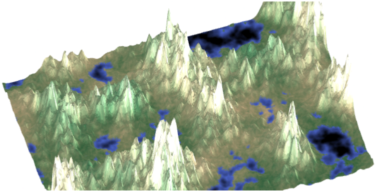
Noise Functions

Overview and Motivation

- Critical for realistic textures and models
- Simplifies creation of natural variations
- Applications: terrain, procedural texturing, simulations
- Key for realism in visual effects and games

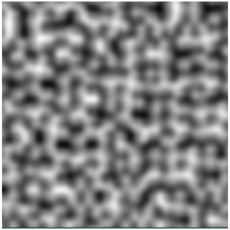


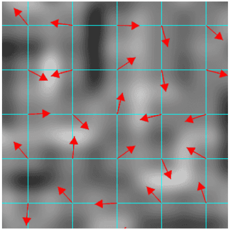
Noise Functions

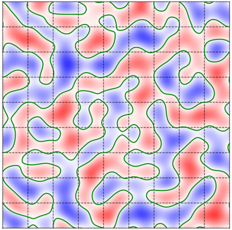
- Generate pseudo-random
- Smooth gradients – frequency limited
- Controlled randomness mimics natural forms
- Types:
  - Value
  - Gradient (Perlin, Simplex)
  - Cellular (Worley)
  - Fractal Noise

Perlin Noise

- Developed by Ken Perlin, 1983
- Algorithm:
  - Gradient vectors computed at grid points
  - Interpolated across grid to produce smooth transitions
- Properties:
  - Visually isotropic in 2D and 3D
  - Repeats over large scales, which can be controlled
- Applications: Terrain, clouds, fire textures





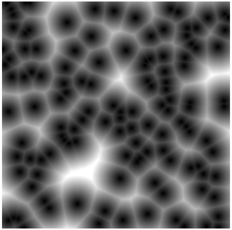


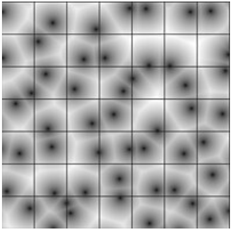
Simplex Noise

- Ken Perlin, 2001
- Algorithm:
  - Similar to Perlin but with simplex grid (triangular/hexagonal)
  - Reduces computational complexity, especially in higher dimensions
- Properties:
  - Faster computation and lower complexity than Perlin
  - Scales more efficiently to higher dimensions (4D and beyond)
- Avoids square-grid artifacts of Perlin noise

Worley Noise

- Steven Worley, 1996
- Algorithm:
  - Points randomly distributed, partitioned into cells
  - Noise generated based on proximity to nearest points
- Properties:
  - Produces a voronoi diagram-like appearance
  - Can simulate phenomena like cracked surfaces, sponge textures
- Applications: Stone, water effects, organic textures





Compositing Noise Functions

- Combines multiple noise types to increase texture complexity
- Techniques:
  - Layering different scales and amplitudes
  - Masking layers to control influence areas
- Example: Mix Perlin (base texture) + Worley (detail enhancement)
- Enhances detail and realism in procedural content

Volumetric Effects

Volumetric Effects

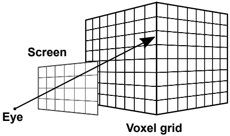
- Light usually passes through some medium (air, water, ...)
- Intensity, color (polarization) may be modulated:
  - Attenuation (fog)
  - Scattering (sunbeams, blue sky)
- Simulated by:
  - Ray traversal
  - Blending billboard slice planes

Ray Casting

- Space traversal along light ray
- Integrating properties along the ray:

$$v = \int_{ray_{start}}^{ray_{end}} f(s)ds$$

- Discrete samples:
  - Regular voxel grid
  - Procedural description
- Numerical integration:
  - Piece-wise constant
  - Interpolation (linear, polynomial)
  - …



SUNBEAMS

- Also known as crepuscular rays, god rays, ...
- Scattering on particles under direct light:
  - Sun + clouds
  - Point light source + dusty room

SUNBEAMS – IMPLEMENTATION

- Deffered shading
- Ray casting from viewer to each pixel
  - Ray sampling
  - Check if sample illuminated – shadow map test
  - Apply light scattering (physical model) to illuminated points
  - Aggregate the effect and apply to color buffer
- Heavy computation
  - Downsampled g-buffer
  - Bluring result to prevent aliasing

Other Approaches

- Create light volume geometry from shadow map and light source
  - Solve the rendering integral in intervals defined by light mesh

- Screen space approach:
  - Directional light source bluring (decreasing alpha)
  - Ligth source must be in the image