Realtime Computer Graphics on GPUs

Framebuffer and Offscreen Rendering Techniques

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Introduction

Definitions and History

- Framebuffer, screen buffer, video buffer, . . .
- Memory containing bitmap driving video display
- 70s – framebuffers big enough to contain standard video image
- Atari 2600 – *Racing the beam*
- HW support for sprites, shifting the framebuffer (scrolling), . . .

Double Buffering

- Single frame buffer problems:
  - screen tearing
  - flickering
  - render artefacts
- Double buffering - also known as *page flipping*

  Front buffer – currently visible

  Back buffer – currently rendered off-screen
- Requires fast buffer swap

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Framebuffer Structure

FRAMEBUFFER

- Default framebuffer created with window creation
- Custom off-screen framebuffer:
  - Can choose resolution
  - Arbitrary attachments
  - Render to texture
  - Filtering, postprocessing
  - Interoperability with other APIs (CUDA, OpenCL, ...)

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Framebuffer Attachments

- 2D rendering target
- Almost any object containing image or image array
- For complex objects specify what part to attach:

  Cube map select face

  3D texture z-slice

  Mipmap choose a level

  ...
- Specify semantics – how it will be used in the rendering pipeline

Color Attachments

- Should match fragment shader outputs
- Color:
  - 1-4 channels
  - Integer (8-32), float
  - Special storage types: GL_R3_G3_B2, GL_RGB10_A2, . . .
- Color updated on successful pass through all fragment tests

Depth Buffer (Z-Buffer)

- Contains depth information for each pixel
- Solves visibility problem
  - Geometry can be streamed
  - Works only for opaque objects
- Precision depends on:
  - z-buffer element type
  - projection – decreasing precision with increasing distance (choose proper near/far clipping planes)

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Stencil Buffer

- Additional buffer with integer elements
- Usually shares memory with z-buffer
- Limits area for rendering – stenciling
- Often used for shadow computation
- Can be updated by results of stencil and depth test
- Behavior setup:
  glStencilFunc: what the test does
  glStencilOp: what happens on test pass/fail

Operations and Tests on Fragments

- Scissor test
- Alpha test
- Depth test
- Stencil test
- Blending
- Dithering
- Logical operations (only integer based colors)

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Depth Test

- Different conditions for different objects (e.g. outline hidden objects)
- glDepthFunc()
  - GL_NEVER, GL_ALWAYS
  - GL_LESS, GL_EQUAL, GL_LEQUAL, ...
- Z-fighting – z-buffer precision
- glPolygonOffset()
  - Modulate z-value for specified primitives
- Early depth test optimization

ALPHA TEST

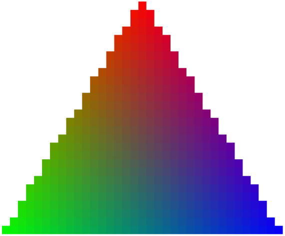
- RGBA mode – fragment accepted/rejected by the alpha test
- void glAlphaFunc(GLenum func, GLclampf ref);
- Comparison function and reference value
- By default, ref is zero, func is GL_ALWAYS
- func: GL_ALWAYS, GL_NEVER, GL_LESS, GL_EQUAL, GL_LEQUAL, GL_GEQUAL, GL_GREATER or GL_NOTEQUAL
- glEnable(GL_ALPHA_TEST);

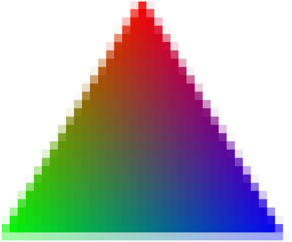
Color Blending

- How the color of the pixel is updated by fragment shader output
- Render transparent objects –
  - disable depth test, painters algorithm (order primitives)
  - order independent transparency – depth peeling
- glBlendFunc() mixing colors based on their respective alpha values.
- The source color: the color of the fragment be drawn.
- The destination color: the color already present in the color buffer.

Antialiasing

- Supersampling (SSAA)
  - Render in higher resolution
  - Show downsampled image – smoothing
- Multisampling (MSAA)
  - Multiple depth/stencil tests per pixel
  - Estimates fragment coverage – smoothing on edges





Render Buffer vs. Texture

Best buffer for framebuffer attachments?

- Render buffer object:
  - contains image, which will not be sampled (read)
  - optimized as render target
  - support MSAA
- Textures:
  - optimized for read access
  - can be used later in the rendering pipeline

Triple Buffering and V-sync

- V-Sync: new frame is rendered in sync with monitor refresh frequency (60-100 Hz)
- Double buffering + V-Sync – small interval when none of the buffers can be touched – delay, idle GPU
- Second backbuffer – no delays, highest possible framerate
- Meaningful only when refresh rate lower than maximal possible rendering framerate

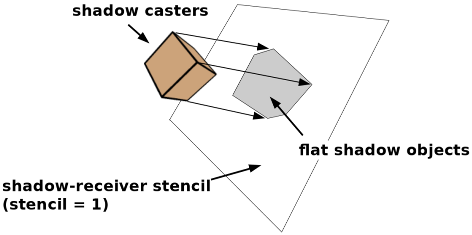
Shadows

Shadow Casting

- Static Shadows: baked light/shadow map
- Dynamic shadows:
  - single shadow-receiving plane
    - simple approach, not generally usable
  - shadow mapping
    - shadow depth-buffer, supported in HW – shadowmap sampler
  - shadow volumes
    - precise but very computationally intensive
- sharp shadows (one pass)
- soft shadows (more passes, accumulation of results)

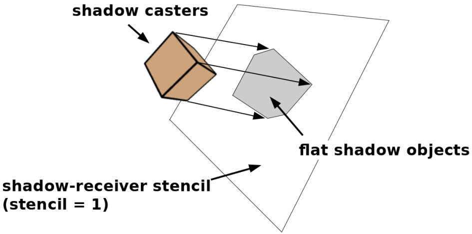
Shadow Receiving Plane

- sharp shadows – point light source
- use of stencil buffer and multiple scene passes
  - stencil prevents shadow duplication
- single shadow-receiving plane
- shadow could be opaque (destroying the original surface color) or transparent (only reducing the amount of light)



Shadow Receiving Plane – Procedure

1. the whole scene rendered using ordinary projection
   - shadow-receiver sets stencil to 1
   - other objects zero this bit
2. potential shadow-casters rendered to the shadow-receiving plane
   - depth-test is off
   - special projection matrix
   - shadows are drawn only to the (stencil==1) pixels



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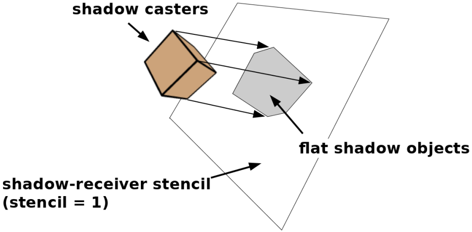
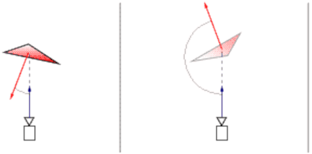


Face Culling

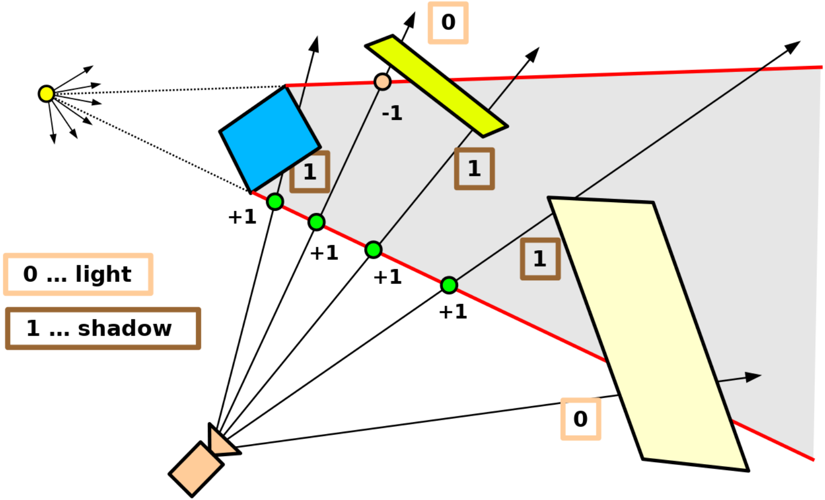
- From the point of view of camera
- GPU can filter (face cull) according to vertex order:
  - glEnable(GL_CULL_FACE);
  - glFrontFace(GL_CCW);
  - glCullFace(GL_BACK); // draw front faces only
- Speed optimization



Shadow Volume – Depth Pass

- shadow-caster – infinite shadow volume from countour (shadow solid)
- lateral faces of a shadow solid are considered, but invisible
- virtual ray from the camera is tested against these faces
- GPU can rasterize the virtual faces and ”draw” them into the stencil buffer
  - Front faces increase stencil
  - Back faces decrease stencil
- stencil buffer values define shadows in the scene
- has to be done separately for each point light source

Shadow Volume – Depth Pass



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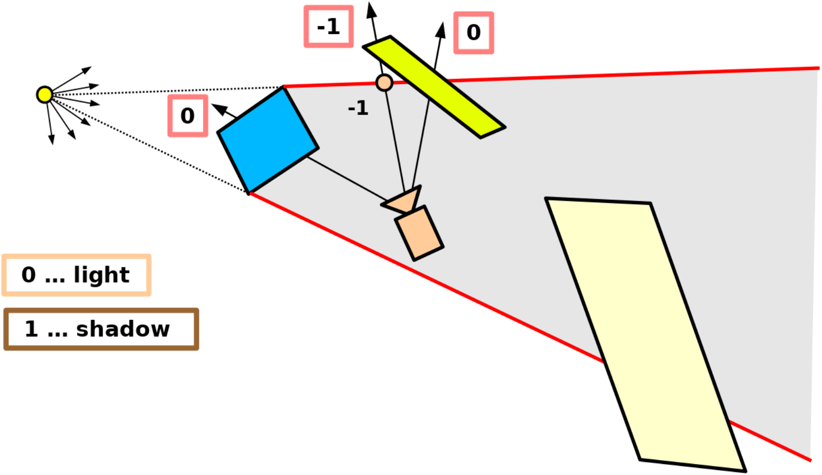
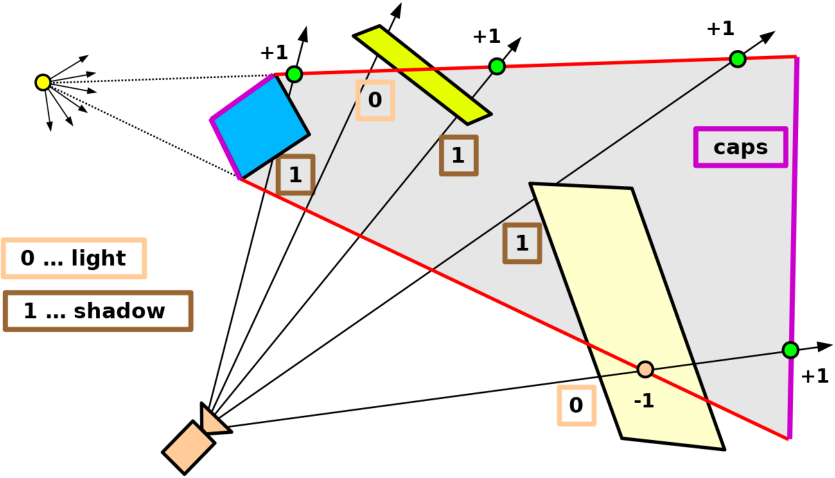


Shadow Volume – Depth Fail

- Carmack's reverse
- camera can be placed anywhere
- shadow solid sealed using ”caps”: one is illuminated part of an object, the second one in infinity
- second phase: lateral shadow faces and both ”caps”
  - Front faces – decrement on depth fail
  - Back faces – increment on depth fail
- third phase: stencil==0 means ”light”

Shadow Volume – Depth Fail



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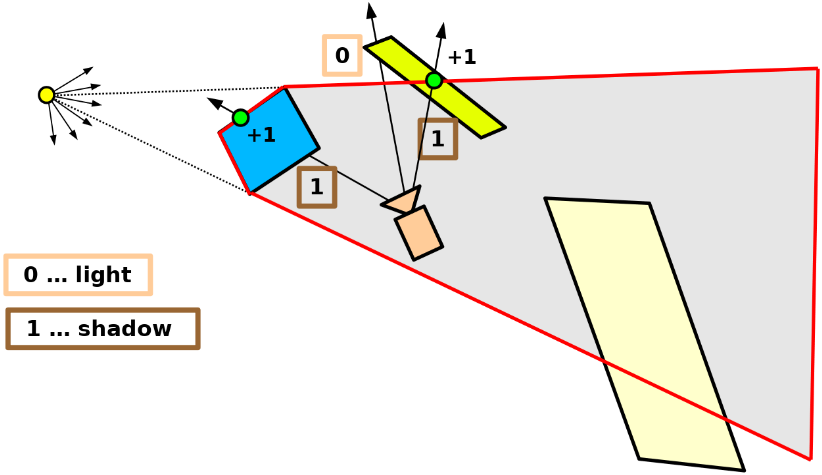
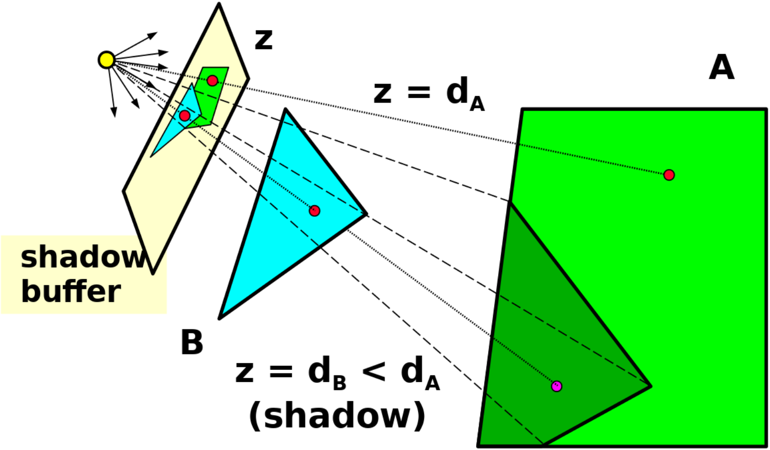


Shadow Mapping

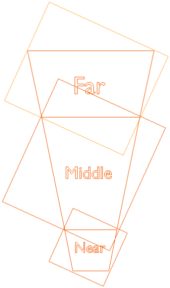
1. scene is rendered from the light-source viewpoint
   - no need to modify frame buffer, only depth-buffer has to be updated
2. depth-buffer is moved into a texture (”shadow map”)
   - regular projection according to the camera
   - use of projective texture coordinates
   - test actual distance of a fragment from the light source (in the world space) against shadow-map texture

Shadow Mapping



Shadow Mapping Problems

- Shadow acne
- Perspective aliasing
- Sharp shadows
- Hard to choose optimal size of shadow maps
  - Solution: cascaded shadow maps



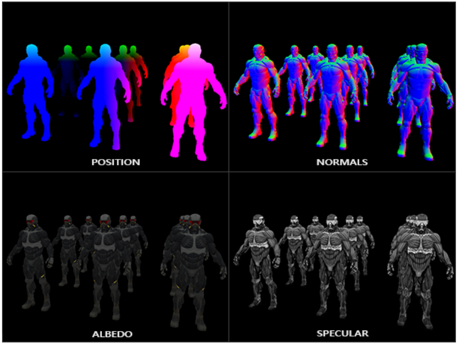
Deffered Shading

Bottlenecks in Rasterization Pipeline

- Processing lots of lights
- Complicated materials
- Lots of fragments shaded and not used

Deffered Shading

- Decouple geometry and light processing
- Two stages:
  1. Render geometry to textures – multiple render targets (G-buffer)
  2. Posprocessing – apply light computations



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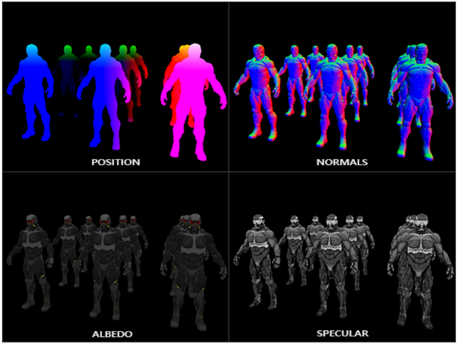

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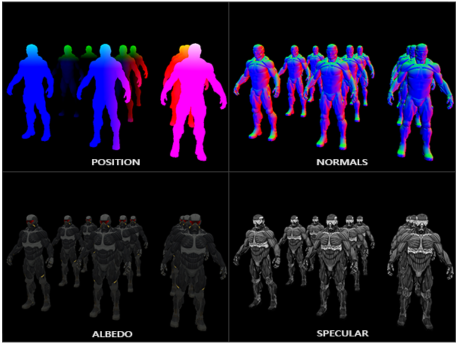

Compositing Step

- Compute shader or draw one fullscreen quad
- Apply lighting for only visible fragments
- All shading parameters come from uniforms and textures
- Modern engines do postprocessing
  - Motion blur
  - Depth of field
  - Screen space ambient occlusion
  - Screen space decals
  - Bloom
  - HDR processing

Disadvantages

- Cannot handle transparency (depth peeling)
- Complicated usage of multiple material types
- Memory intensive
- MSAA does not work:
  - Supersampling
  - Smoothing trick (small scale, rotate with linear interpolation, ...)
  - Postprocessing – edge detection and masked smoothing, morphological AA (MLAA)

Summary: OpenGL Calls

Framebuffer setup: glGenFramebuffers, glBindFramebuffer, glGenRenderbuffers, glFramebufferTexture*, glBlitFramebuffer, glRenderbufferStorageMultisample

Z-buffer and stencil buffer: glDepthFunc, glStencilMask, glStencilFunc, glStencilOp, glPolygonOffset

Other: glBlendEquation, glBlendFunc, glScissor,