Shadows

Real-time Shadowing Techniques

Programming – Computer Graphics

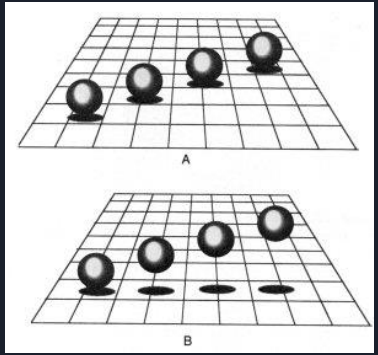
SPECIALIST EDUCATORS IN
GAMES, ANIMATION & FILM VFX

Contents

- Drop Shadows
- Stencil Shadows
- Shadow Mapping

Introduction

- Shadows are important in games for several reasons:
  - Depth perception
    - They make it easier for players to judge the relative depth of objects
      - This is particularly useful in platform games
    - Without shadows some items appear to be “floating”
      - Shadows help ground items
  - Realism
    - Shadows make scenes feel much more realistic
      - The more sophisticated the shadows, the more realistic the scene looks
  - Game Play
    - Shadows can be used for game play elements
      - For example, sneaking in a stealth game



Blob Shadows

- Shadows can be simple alpha "blobs" drawn under the character
  - Ray trace down from the centre of the character
  - Note the first solid object the ray hits
  - Calculate the intersection point
  - Draw a quad, textured with the shadow, at the intersection point

- Such shadows don't add much to realism but help a lot with depth perception

Advantages and Disadvantages

- Advantages:
  - Fast to implement and calculate at runtime
- Disadvantages:
  - Shadow shape doesn’t match the object
  - Shadow doesn’t map to object it’s cast onto
- Improvements:
  - Decrease the shadow size the further the character is from the ground
  - Use the surface normal at the point of intersection and orientate the shadow to the surface
  - Project the texture onto the surface rather than render a separate quad
  - Flatten the objects mesh and render dark so to make a shadow that more closely represents the object casting the shadow

Stencil Shadow Volumes

- Shadow Volumes are areas occluded from light by an object
  - The shadow then appears on the surface of a receiver, but the area between the occluder and receiver is the volume in shadow
- Commonly implemented using Stencil Buffers that identify areas where the shadow volume intersects receiving geometry

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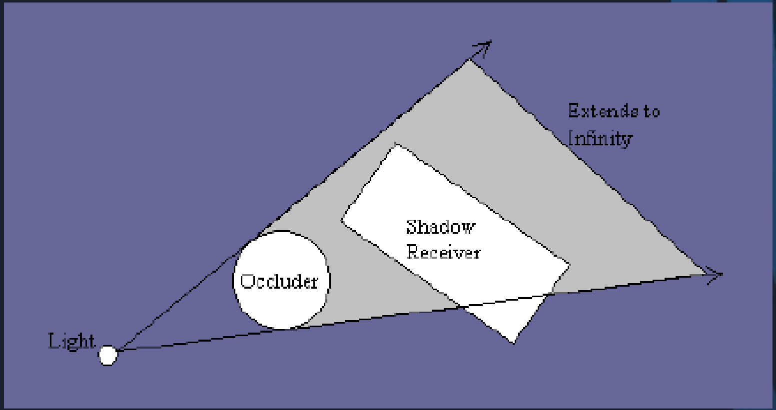
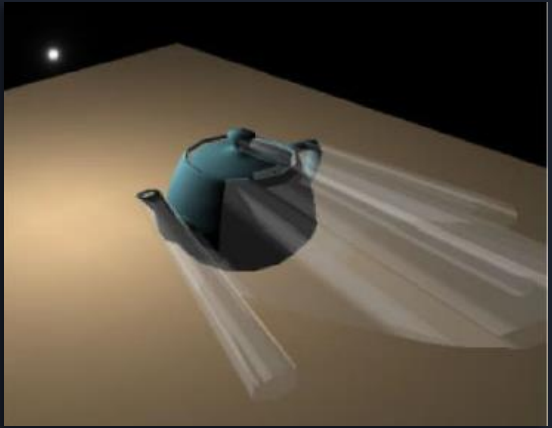
Shadow Volume Theory

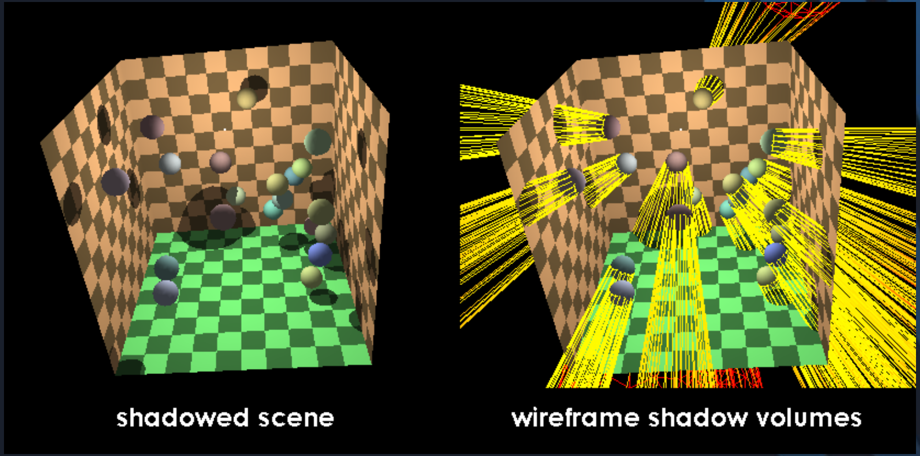
- Any object that casts a shadow is called an Occluder
- Any object that receives a shadow is called a Receiver
- To determine what areas are in shadow we need to determine the silhouette of the occluders, extruded and projected onto the shadow receivers
  - This is the Shadow Volume





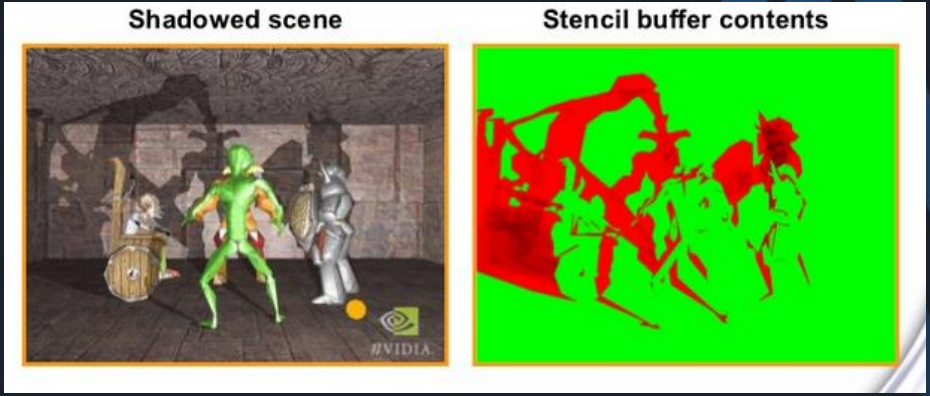
Shadow Volume Theory

- Creating the Shadow Volume can be difficult
- Determining the silhouette involves
  1. Determine if a triangle is lit
  2. If triangle is lit, check the triangles that share its edges
  3. If a triangle with a shared edge is lit and its neighbour isn't then that edge is part of the silhouette



Shadow Volume Theory

- Once we have created a Shadow Volume we need to create a Stencil Buffer



- A stencil buffer is a type of render target
  - Acts as a "mask" rather than colour
- In its simplest form a stencil buffer is used to specify areas that are in shadow or aren't in shadow
  - 0 if it is not in shadow
  - 1+ if it is in shadow

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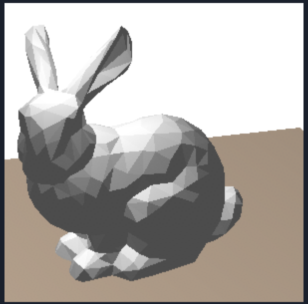
Shadow Volume Process

- First we need a depth buffer containing the receivers
  - i.e. Render all receivers so that we have a depth buffer
- Next we render the front faces of the shadow volumes to the stencil buffer, disabling writing to the depth buffer
  - Any faces NOT culled by the depth buffer add a 1 to the stencil buffer at that pixel
- Next we render the back faces of the shadow volumes to the stencil buffer, still disabling writing to the depth buffer
  - Any faces NOT culled by the depth buffer subtract 1 from the stencil buffer at that pixel
- What remains is a stencil buffer with 0's written where there are no shadows



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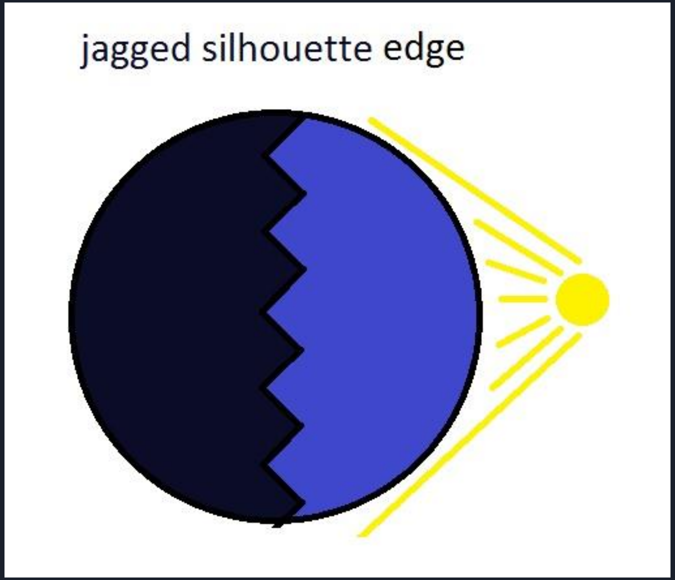
Advantages and Disadvantages

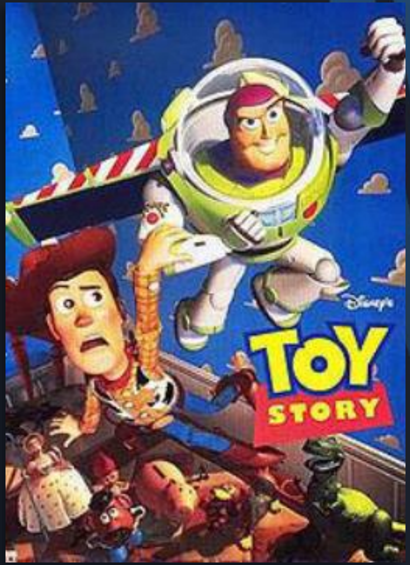
- Advantages:
  - Automatic self shadowing
  - Broadly supported in most hardware
- Disadvantages:
  - Requires a high fill-rate
  - Silhouette determination can be costly
  - Artefacts can appear near object edges
  - Shadows have sharp edges

Shadow Volume Disadvantages



Shadow Mapping

- Introduced by Lance Williams (1978)
  - *"Casting Curved Shadows on Curved Surfaces"*
  - Technique used by Pixar's RenderMan
  - Used in Toy Story
  - Common in games
    - Many variations!



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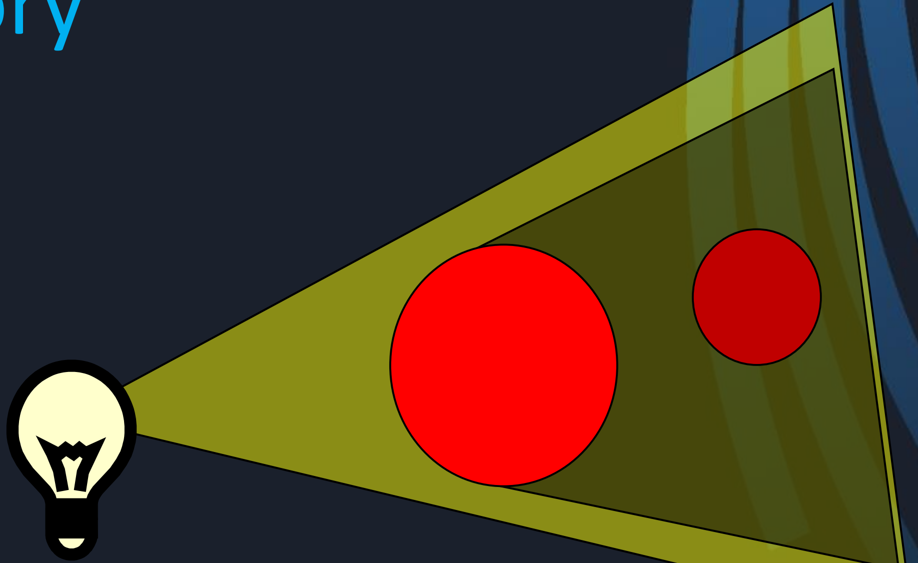
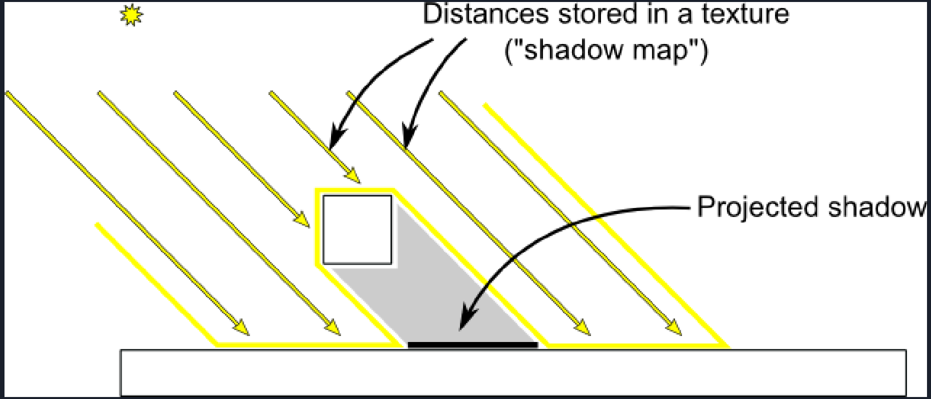
Shadow Mapping Theory

- *Any area that can not be seen by the point of view of the light is in shadow*
- If we were to render the scene from the point of view of the light to a render target, then we could determine which surfaces the light does and does not see
  - This render target is commonly called a Shadow Map



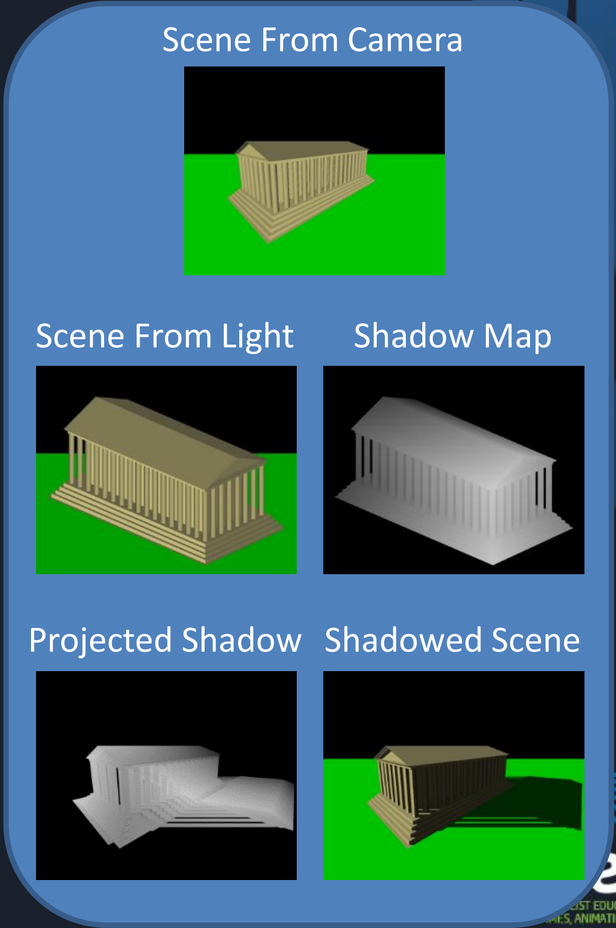
Shadow Mapping Theory

- However, if we rendered into a frame buffer from the light's perspective it wouldn't be much use
  - How can we tell which surface is visible just based on a pixel colour?
- What we could render instead is the distance of the surface to the light
  - This way we can test every pixel visible to the camera to see how far it is away from the light
  - We compare that against the distances the light can see
  - If our pixel is further away than what the light saw then it is in shadow!



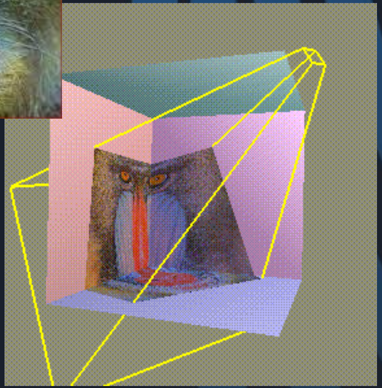
Shadow Mapping Theory

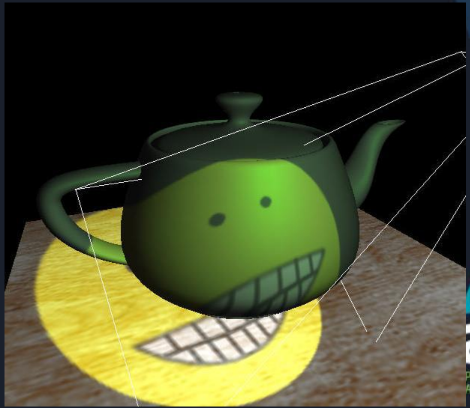
- First we render all the shadow casting objects from the perspective of the light into our shadow map
  - Storing distance to the light rather than colour
  - It is best to give our shadow a maximum distance and scale the distance to fit within the range [0.0 and 1.0]
- Next we render the scene as usual from the perspective of the camera, and all shadow receiving pixels test their pixels against their corresponding pixel in the shadow map
  - If the current pixel is further from the light than the pixel the light can see, then it is shadowed
- We can determine which pixel in the shadow map matches the current pixel by projecting the shadow map onto the scene
  - This technique is called Projected Texture Mapping



Projected Texture Mapping

- A technique which maps a texture across a surface by generating texture coordinates based off a projection matrix
  - It appears as if the texture is cast over the surface from a projector
- When we render a scene we project it onto the screen using a camera's View and Projection matrices
  - These matrices flatten our 3D scene onto a 2D plane, within a [-1,1] range
- We can use a similar technique to generate texture coordinates
  - Create a View and Projection matrix at the location and facing that our texture is projecting from
  - Transform the scene vertices against the camera as usual, but also project onto the new View and Projection matrix separately to create texture coordinates in the range [-1,1]
  - Convert the result of the transform from [-1,1] to [0,1]
  - Use this new result as texture coordinates!





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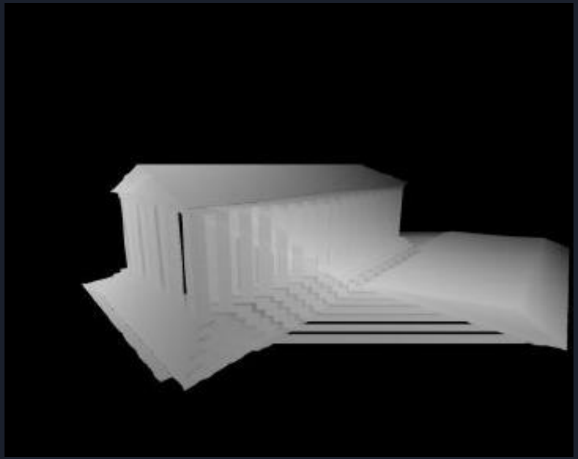
Projected Texture Mapping

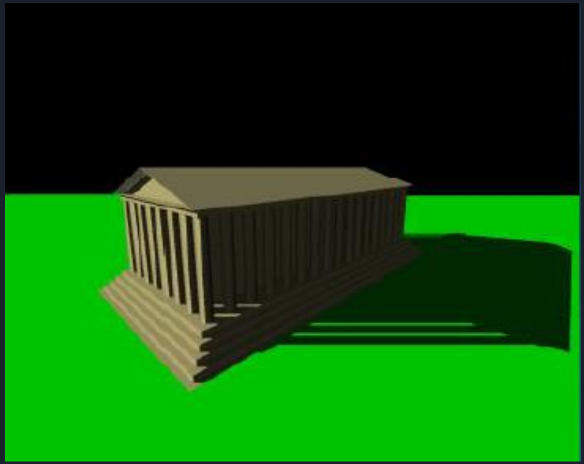
- Projected textures have many uses
  - Stained Glass
  - Spell Effects
  - Decals

- For Shadow Mapping we project the shadow across the scene using the same View and Projection as we used for rendering from the perspective of the light

Shadow Mapped Scene



The Depth Texture from the
Light projected across the scene



The final scene drawn only lighting pixels
that were closer to the light source

Shadow Mapping Summary

- Advantages:
  - Shadow Mapping is an image-space technique that can work for any objects rendered on the GPU
  - Avoids high fill-rate
  - Handles curved surfaces

- Disadvantages:
  - Shadow quality is usually dependant on the resolution of the shadow map
  - The scene geometry must be rendered again for each light source
  - GPU usage increases exponentially as more lights and objects are added to the scene
  - Distance Lights require large textures to contain the world, or only shadow small areas
  - Point Lights require the use of Cube Maps and rendering to 6 Shadow Maps

Alternative Shadow Mapping Techniques

- New advances in how shadow maps are calculated have resulted in many new and improved methods for shadow mapping
  - Cascaded Shadow Maps
  - Variance Shadow Maps
  - Percentage Closer Filtering
  - And many more…

- The quality of the shadow map is also controlled by the size and format of the render target used, and how much area the shadow map covers
  - A large map could be used for an entire scene, or a small map used for the player character's shadow

Soft Shadow Tweaks

- Both Shadow Volumes and Shadow Mapping create shadows with hard edges
  - Real shadows have soft edges called the penumbra

Soft Shadow Tweaks

- Soft shadows can be simulated by either
  - Jittering the light source and averaging all the frames
  - Blurring the shadow texture in the case of Shadow Mapping
- Both take additional GPU power but are common in modern engines

Summary

- Shadows can enhance a scene in many ways, creating a more realistic environment, or just making the character seem like they are actually standing on a solid surface!
- Stencil Shadow Volumes are used less than Shadow Mapping now
- Each technique can be expensive to calculate the more lights there are
- Advanced implementations of Shadow Maps create extremely pleasing results

Further Reading

- Wolff, D, 2013, *OpenGL 4 Shading Language Cookbook*, 2nd Edition, PACKT Publishing
- Haemel, N, Sellers, G & Wright, R, 2014, *OpenGL SuperBible*, 6th Edition, Addison Wesley
- Akenine-Möller, T, Haines, E, 2008, *Real-Time Rendering*, 3rd Edition, A.K. Peters

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