VGP353 – Week 1

- Agenda:
  - Course road-map
  - Introduce shadows
    - Importance of shadows
    - Planar projected shadows
    - Soft shadows
    - Shadow textures
  - Projective texturing review
  - First programming assignment

What should you already know?

- All of the prerequisites of VGP351 & VGP352:
  - C++ and object-oriented programming
  - Basic graphics terminology and concepts
  - Some knowledge of linear algebra and vector math
  - Using OpenGL extensions
  - OpenGL Shading Language

What will you learn?

- Algorithms and supporting data-structures for implementing shadows
  - Planar projected shadows
  - Shadow textures
  - Shadow maps
  - Shadow volumes

Grading

- Tests and quizzes
  - Bi-weekly quizzes worth 5 points each
  - Final exam worth 50 points
- Four programming assignments
  - Two will be smallish and worth 10 ponts
  - Two will be largeish and worth 20 points
- One in-class presentation worth 10 points

Grading – Programming Assignments

- Does the program produce the correct output?
- Are the required algorithms / data-structures used?
- Is the code readable and clear?
  - This includes both C++ code *and* shader code!

Grading – In-class Presentation

- Select one paper assigned during the term
- Present a summary of the paper to the class
  - What is the problem being solved?
  - How does the paper solve the problem?
    - What is the overall algorithm?
    - What simplifying assumptions are made?
    - What class of hardware does it target?
  - What is novel about the presented solution?
    - What is the paper's contribution?
  - What questions are left unanswered?
    - What areas remain for further research?

Shadow Terms

- Receiver – object that is shadowed
- Caster – object that blocks light from the receiver
  - May also be called *occluder* because it occludes the light from the receiver
- Umbra – Region on receiver that is completely shadowed
- Penumbra – Transition region between umbra and non-shadowed area

Shadows

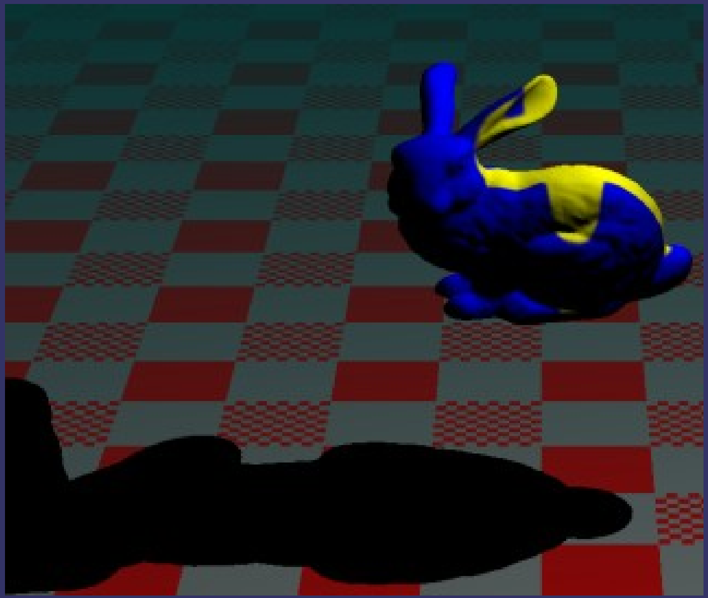
- Why are shadows important to 3D rendering?

Shadows

- Why are shadows important to 3D rendering?
  - Provide additional information about shadow casters
    - Relative position of casters
    - Relative position of casters and receivers
  - Provide additional information about shadow receivers
    - Show additional surface detail

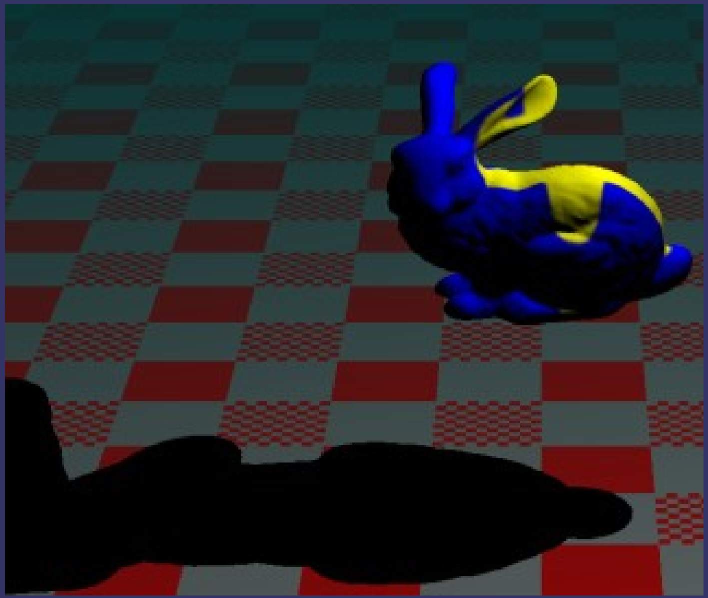
Planar Projected Shadows

- Simplest shadow algorithm: project object geometry directly onto a flat plane



Planar Projected Shadows

- Simplest shadow algorithm: project object geometry directly onto a flat plane
  - As the description implies, this is accomplished using a projection matrix



Planar Projected Shadows

- Given a point on a plane, p, and the normal of that plane, n, the plane equation is:

$$d = -(n \cdot p)$$

$$n \cdot p_i + d = 0$$

  - Every p_i where this equation is 0, is “on” the plane

Planar Projected Shadows

- Given a plane, defined by n and d, and a projection point, L, create a matrix that projects an arbitrary point onto that plane:

$$M_p = \begin{bmatrix} n \cdot L + d - L_x n_x & -L_x n_y & -L_x n_z & -L_x d \\ -L_y n_x & n \cdot L + d - L_y n_y & -L_y n_z & -L_y d \\ -L_z n_x & -L_z n_y & n \cdot L + d - L_z n_z & -L_z d \\ -n_x & -n_y & -n_z & n \cdot L \end{bmatrix}$$

  – This matrix is similar to the matrix used to project onto the view plane from the eye point

Planar Projected Shadows

- If n and d define the ground plane and L is the position of the light, M_p will project world-space geometry onto the ground plane

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Planar Projected Shadows

- If n and d define the ground plane and L is the position of the light, M_p will project world-space geometry onto the ground plane
- Question: Where do we insert M_p in the transformation matrix?
  - Answer: After the object-to-world space transformations, but before the world-to-eye space transformation

$$M = M_{eye} M_p M_{world}$$

Planar Projected Shadows

- Can be drawn several different ways

Planar Projected Shadows

- Can be drawn several different ways
  - Disable depth buffer writes

```
glDepthMask(GL_FALSE);
```

  - Draw shadow to alpha component

```
glColorMask(GL_FALSE, GL_FALSE, GL_FALSE, GL_TRUE);
```

  - Re-enable depth buffer writes

```
glDepthMask(GL_TRUE);
```

  - Draw object normally
  - Draw ground plane and modulate with destination alpha

```
glEnable(GL_BLEND);
glBlendFunc(GL_ONE_MINUS_DST_ALPHA, GL_ONE);
```

Hard Shadows vs. Soft Shadows

- Hard shadows are better than nothing, but still not very realistic
  - Perfectly hard shadows are only cast by infinitesimal light sources...the super bright LED in a dark room
  - Or if the light is *very* far away from the shadow caster relative to the size of the light source
  - If the light has any area, it will cast soft shadows

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Really talking about the solid angle of the light from the PoV of the occluder

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  - If the light has any area, it will cast soft shadows
- Can this technique be extended to create soft shadows?

Heckbert and Herf's Method

- Simulate an area light with many point lights on the area light's surface
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Heckbert and Herf's Method

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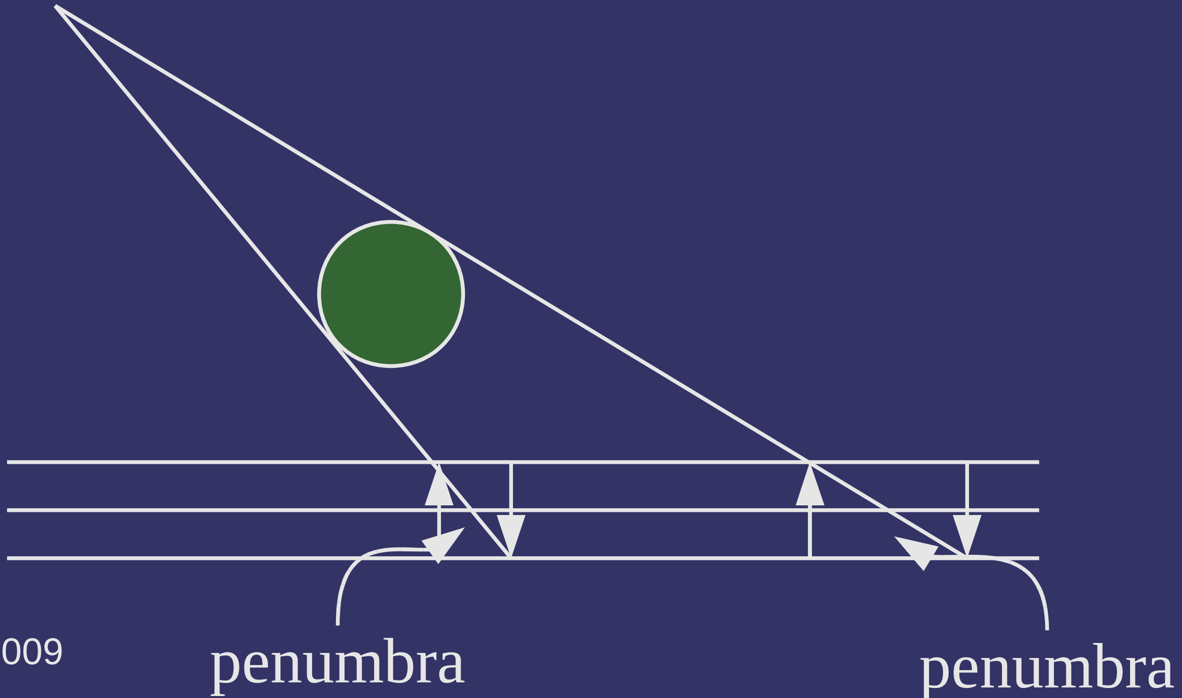
  - If *lots* of sample points are used, this method produces *very* good results
  - If *lots* of sample points are used, this method produces *very* slow results
  - Some optimizations are possible:
    - Scale number of samples with size of light
    - Scale number of samples with distance between light and shadow caster

Gooch's Method

- By moving the receiving plane towards and away from the light, the penumbra can be simulated
  - Accomplished by biasing d in the plane equation
  - After the projecting onto the offset plane, move the projected (flattened) object back
  - The simulated penumbra is always too big



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References

Gooch, B., Sloan, P. J., Gooch, A., Shirley, P., and Riesenfeld, R. 1999. Interactive technical illustration. In *Proceedings of the 1999 Symposium on Interactive 3D Graphics* (Atlanta, Georgia, United States, April 26 - 29, 1999). I3D '99. ACM, New York, NY, 31-38. http://www.cs.utah.edu/~bgooch/ITI/

Paul Heckbert and Michael Herf, *Simulating Soft Shadows with Graphics Hardware.* CMU-CS-97-104, CS Dept, Carnegie Mellon U., Jan. 1997. http://www.stereopsis.com/shadow/

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Planar Projected Shadows

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  - No self-shadowing
  - Can only cast shadows on the ground plane
  - Can only cast shadows on a ***flat*** ground plane
- Shadow textures fix *most* of these problems

Shadow Textures

- Algorithm outline:
  - Render shadow caster to a texture from the point of view of the light
    - Texture background is the color of the light
    - Object is rendered in black
  - Using *projective texturing* cast the shadow texture onto each shadow receiver
  - Use the sampled texture color as the light color

Shadow Textures

- Advantages?

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Shadow Textures

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  - Can cast shadows on non-flat surfaces
  - Can cast shadows on multiple objects

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  - Can cast shadows on non-flat surfaces
  - Can cast shadows on multiple objects
- Disadvantages?

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Shadow Textures

- Advantages?
  - Can cast shadows on non-flat surfaces
  - Can cast shadows on multiple objects
- Disadvantages?
  - No self-shadowing
    - Shadow *maps* will solve this problem...next week
  - Requires render-to-texture pass for *each* shadow caster for each light
  - Shadow receiver must sample multiple shadow textures

Shadow Texture Creation

- Setup model-view-projection matrix to render from the light looking at the object
  - The light position becomes the eye-point
  - Set the FoV to just enclose the object
    - The object's bounding box is helpful here
- Render object as shadow
  - Clear the color buffer to the light's color
  - Render the object as solid black
    - Can “fake” soft shadows by using distance from light (eye) to determine color: closer to the light is darker, farther is lighter

Determining Receiver / Caster

- For each shadow texture, determine which objects are potential receivers
  - If the object is *completely* on the opposite side of the near plane from the light, it is a candidate

Projective Texturing

- Does what it says: projects a texture onto an object
- This is a *perspective* projection, so what is needed to make it “work”?

Projective Texturing

- Does what it says: projects a texture onto an object
- This is a *perspective* projection, so what is needed to make it “work”?
  - Divide by Z...just like perspective viewing projections
    - Uses the q texture coordinate

Projective Texturing

- Algorithm outline:
  - Use object-space vertex positions as initial texture coordinates
  - Transform object-space texture coordinate to projector-space
  - Apply perspective transformation
    - Same MVP matrix as is used to render to the texture
  - Scale and bias coordinates from [-1, 1] to [0, 1]
    - Unless one of the mirroring wrap modes is being used

Projective Texturing

- Uses different sampling functions in GLSL:
  - `texture[123]DProj` vs `texture[123]D`
  - Use these functions instead of doing the perspective divide by hand
  - Cubic textures are not supported. Why?

Projective Texturing

- Uses different sampling functions in GLSL:
  - `texture[123]DProj` vs `texture[123]D`
  - Use these functions instead of doing the perspective divide by hand
  - Cubic textures are not supported. Why?
    - The q component is already used as part of the texture lookup!

Projective Texturing

- What happens if the point is *behind* the projection point?

  Hint: What happens if an object is behind the eye?

Projective Texturing

- What happens if the point is *behind* the projection point?

  Hint: What happens if an object is behind the eye?

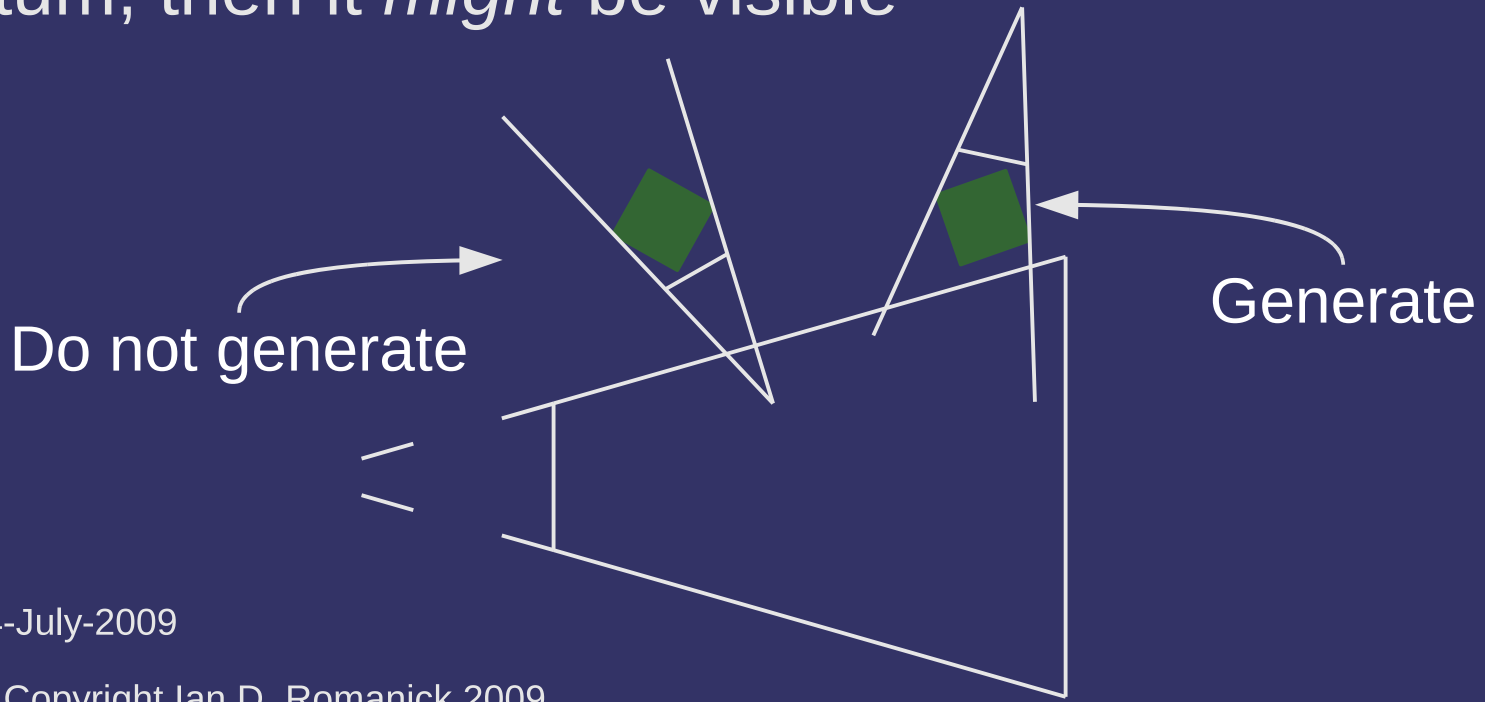
  - It gets a *negative* Z (or q) value
  - The projection then “flips” the position
    - Because it divides by a negative number

Optimizations

- Performance problems with shadow textures:
  - Lots of textures need to be generated *per frame*
  - Shadow receivers need to read lots of textures
- General speed-up techniques:
  - Regenerate a texture only if light or caster moved
  - Generate textures for shadows that might intersect view volume
  - Apply texture only to objects that might be shadowed
  - Composite multiple shadow textures together

Optimizations

- Generate textures for shadows that might intersect view volume
  - Each shadow texture has an associated frustum
    - “View” frustum used to render the shadow texture
  - If the shadow's frustum intersects the view (eye) frustum, then it *might* be visible



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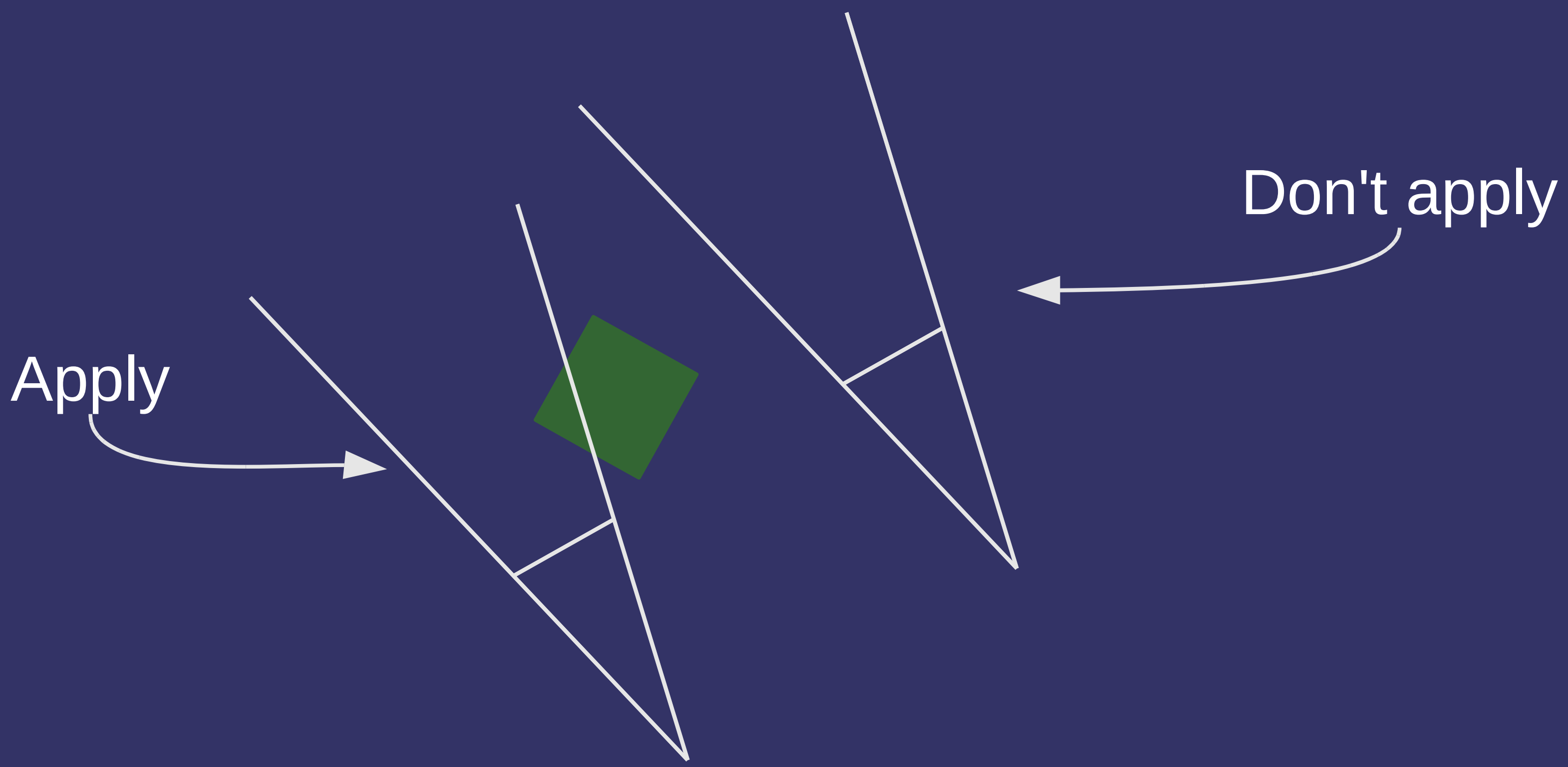
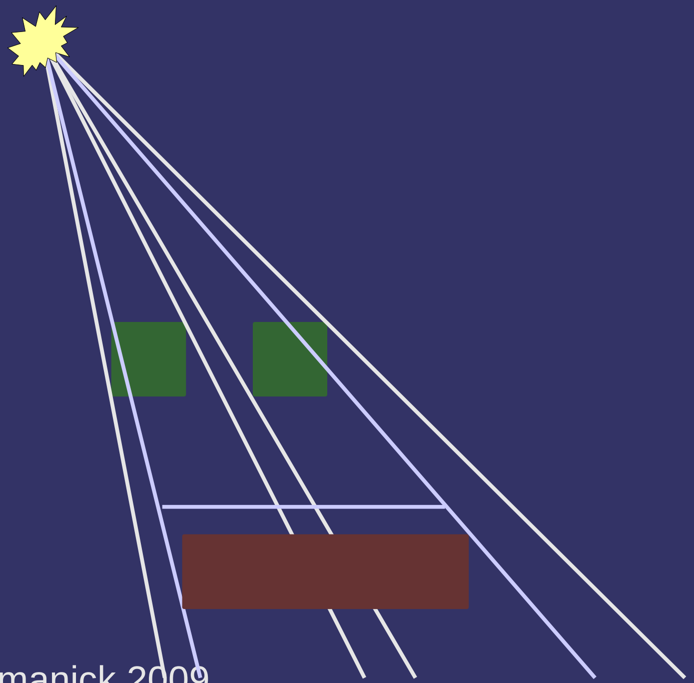
Optimizations

- Apply texture only to objects that might be shadowed
  - Any object that does not intersect the shadow's frustum is not a receiver



Optimizations

- Composite multiple shadow textures together
  - Many casters can affect all members of a group of receivers
  - Create a new shadow texture by compositing all potential casters shadow textures together
  - Project each shadow texture onto the near-plane



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Bloom, Charles. *Projective Shadow Mapping* [article on-line]. June 30, 2000, accessed April 4, 2008; available from http://www.cbloom.com/3d/techdocs/shadowmap.txt; Internet.

Bloom, Charles, and Teschner, Phil. *Advanced Techniques in Shadow Mapping* [article on-line]. June 3, 2001, accessed April 4, 2008; available from http://www.cbloom.com/3d/techdocs/shadowmap_advanced.txt; Internet.

Next week...

- Shadow maps, part 1
  - Read:

Eric Haines, "Soft Planar Shadows Using Plateaus." journal of graphics tools , vol. 6 , no. 1 , pages 19-27. 2001. http://www.acm.org/tog/editors/erich/plateaus.pdf

Everitt, Cass; Rege, Ashu; and Cebnoyan, Cem, *Hardware Shadow Mapping*. NVIDIA. Decemeber 2001. http://developer.nvidia.com/object/hwshadowmap_paper.html

  - Start assignment #1... due *next week*

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