# *VGP353 – Week 4*

- Agenda:
  - Course road-map
  - Introduce shadows
    - Importance of shadows
    - Planar projected shadows
    - Soft shadows
  - 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
- Programming assignments
  - Five weekly or bi-weekly programming assignments worth 10 points each
  - One term project of at least 3 weeks worth 50 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?

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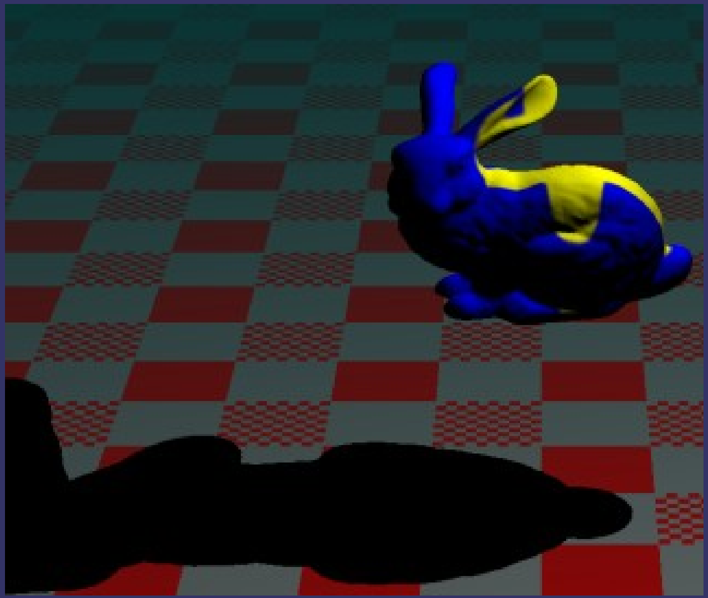
- Why are shadows important to 3D rendering?
  - Provide additional information about shadow casters
    - Relative position of casters
    - Relative position of casters and receivers
  - Provide additional information about shadow receivers
    - Show additional surface detail

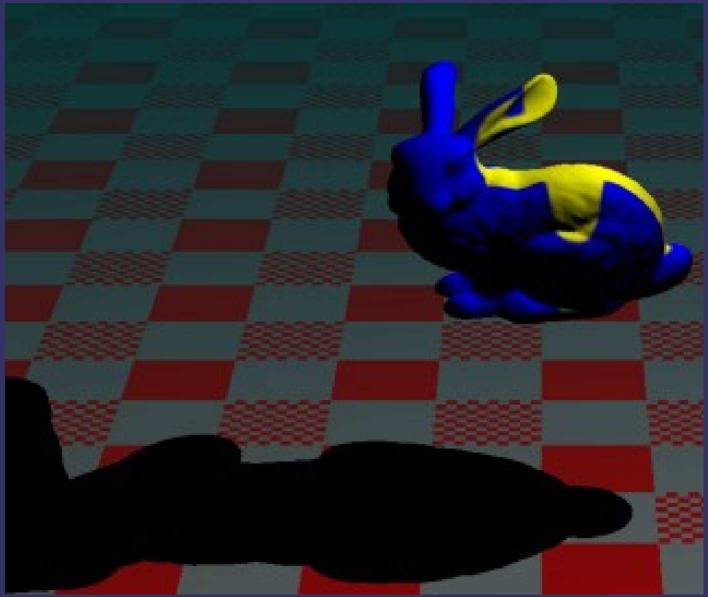
# *Planar Projected Shadows*

- 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, $P$, create a matrix that projects an arbitrary point onto that plane:

$$M_p = \begin{bmatrix} n \cdot P + d - P_x n_x & -P_x n_y & -P_x n_z & -P_x d \\ -P_y n_x & n \cdot P + d - P_y n_y & -P_y n_z & -P_y d \\ -P_z n_x & -P_z n_y & n \cdot P + d - P_z n_z & -P_z d \\ -n_x & -n_y & -n_z & n \cdot P \end{bmatrix}$$

  - 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 $P$ is the position of the light, $M_p$ will project world-space geometry onto the ground plane

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- Question: Where do we insert $M_p$ in the transformation matrix?

# Planar Projected Shadows

- If $n$ and $d$ define the ground plane and $P$ 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

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

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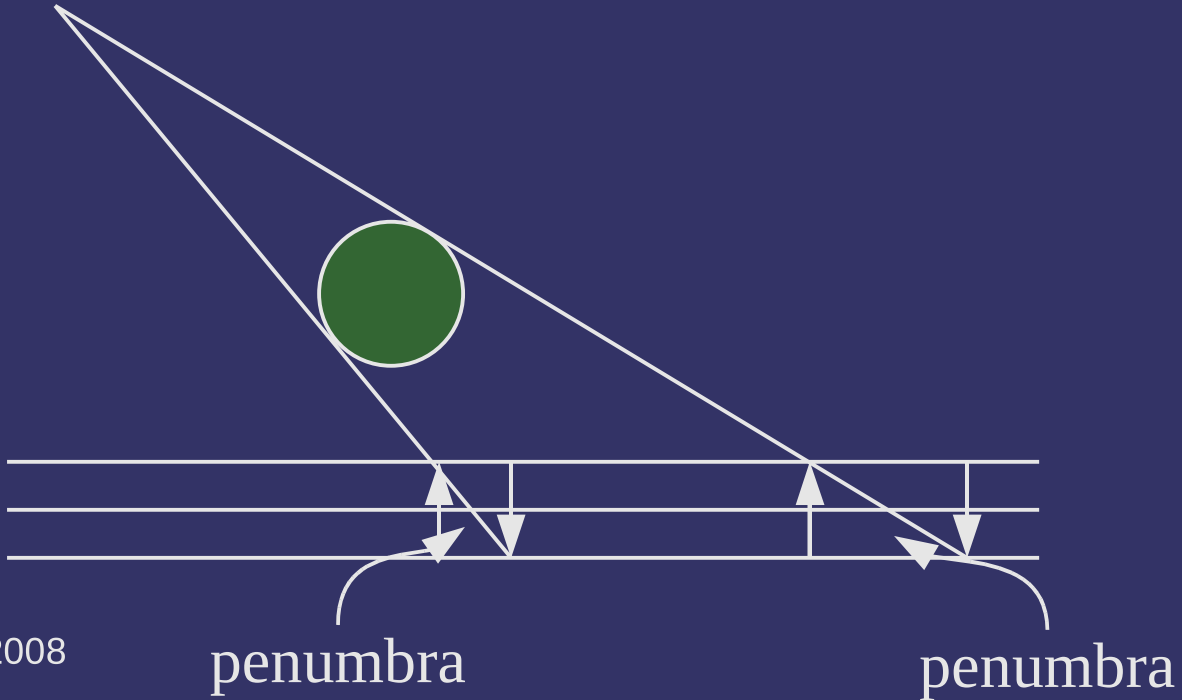
- Simulate an area light with many point lights on the area light's surface
  - If *lots* of sample points are used, this method produces *very* good results
  - If *lots* of sample points are used, this method produces *very* slow results
  - Some optimizations are possible:
    - Scale number of samples 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



# 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/

# *Next week...*

- Shadow textures
- Projective texturing
  - We talked about this in VGP351, so this *should* just be a refreher!

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