The Road So Far...
Shadows
Shadows

- Three distinct parts of a shadow:
Shadows

- Three distinct parts of a shadow:
  - **Umbra** – full shadow
Three distinct parts of a shadow:

- **Umbra** – full shadow
- **Penumbra** – half shadow
Shadows

• Three distinct parts of a shadow:
  • **Umbra** – full shadow
  • **Penumbra** – half shadow
  • **Antumbra** – after shadow
Shadows

- Three distinct parts of a shadow:
  - **Umbra** – full shadow
  - **Penumbra** – half shadow
  - **Antumbra** – after shadow

What happens with point or directional light sources?
Global Shadows

- With path or ray tracing, shoot rays to points on the light source.
Global Shadows

- With path or ray tracing, shoot rays to points on the light source.

- If some of the rays do not hit the light source, the point is in a shadow (rays hit an occlusion).
Shadow Mapping

- Goal is the same: find an occluder between a surface point and the light source.
Shadow Mapping

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- **Render** the depth buffer **from the light source.**
Shadow Mapping

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- **Render** the depth buffer from the light source.
- For each fragment in the **main rendering** consider the depth to the light source.
● Goal is the same: find an occluder between a surface point and the light source.

● Render the depth buffer from the light source.

● For each fragment in the main rendering consider the depth to the light source.

● How to find a depth to the light source?

Will distance work?
Goal is the same: find an occluder between a surface point and the light source.

- Render the depth buffer from the light source.
- For each fragment in the main rendering consider the depth to the light source.
- How to find a depth to the light source?
- What happens if it is larger than the depth seen from the light source?

• What happens if it is larger than the depth seen from the light source?
Shadow Mapping: Directional Light
Shadow Mapping: Point Light

What problems do you see here?
Shadow Mapping

• See the example in CGLearn
Shadow Volume

- We create a volume (mesh) around the shadow of each object.
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Multiple ways to use this info:
- Depth pass – counts from front
  Shadow volume faces between the object and the camera
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- Depth fail – counts from back (Carmack's reverse)
  Shadow volume faces after the object to infinity
Shadow Volume

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- When rendering, we count the number of times, we enter a volume, minus the number of times we exit a volume, to get to a fragment.
- Multiple ways to use this info:
  - Depth pass – counts from front
    Shadow volume faces between the object and the camera
  - Depth fail – counts from back (Carmack's reverse)
    Shadow volume faces after the object to infinity
- When count is 0, object is lit.
1. Shadow Volume

- Find the silhouette of the object.
1. Shadow Volume

- Find the silhouette of the object.
- How to find those edges?
2. Shadow Volume

- Copy the vertices and extrude the copy to infinity from the light source.
2. Shadow Volume

- Copy the vertices and extrude the copy to infinity from the light source.

- Assigning 0 as the fourth coordinate, results in a point projected to infinity.

Works like a laser...
3. Shadow Volume

- Create **caps and sides** of the shadow volume.
3. Shadow Volume

- Create **caps and sides** of the shadow volume.
- In order for the far plane not to clip the volume, send the *far plane to infinity*.

\[
\lim_{{\text{far} \to \infty}} P = \begin{pmatrix}
\frac{1}{ar \cdot \tan(\alpha)} & 0 & 0 & 0 \\
0 & \frac{1}{\tan(\alpha)} & 0 & 0 \\
0 & 0 & -1 & -2 \cdot \text{near} \\
0 & 0 & -1 & 0
\end{pmatrix}
\]
4. Shadow Volume

- **Depth-pass** – number of front facing shadow planes minus the back facing shadow planes in front of an object.
4. Shadow Volume

- **Depth-fail** – number of front facing shadow planes minus the back facing shadow planes in back of an object.
Conclusion

- Coordinate Systems
  - Left / Right Handed
- Triangles
  - Planar
- Polygons
  - Convex / Concave
  - Simple
Conclusion

- Convex Combination
- Barycentric Coordinates
- Points and Vectors
Conclusion

- Standard Graphics Pipeline
- Application code
- GPU steps
Conclusion

- Linear Transformations
  - Rotation
  - Scale
  - Shear
- Affine Transformations
  - Translation
- Homogeneous Coordinates

\[
\begin{pmatrix}
\cos(\alpha) & -\sin(\alpha) \\
\sin(\alpha) & \cos(\alpha)
\end{pmatrix}
\]

\[
\begin{pmatrix}
a_x & 0 \\
0 & a_y
\end{pmatrix}
\]

\[
\begin{pmatrix}
1 & 0 \\
\tan(\varphi) & 1 \\
1 & \tan(\varphi)
\end{pmatrix}
\]

\[
(\mathbf{x}, \mathbf{y}, \mathbf{z}, \mathbf{w}) = \left(\frac{x}{w}, \frac{y}{w}, \frac{z}{w}\right)
\]

\[
\left(\begin{array}{ccc}
1 & 0 & x_t \\
0 & 1 & y_t \\
0 & 0 & 1
\end{array}\right)
\]
Conclusion

- Augmented Transformation Matrix

\[
\left(\begin{array}{cccccc}
  a & b & c & x_t \\
  d & e & f & y_t \\
  g & h & i & z_t \\
  0 & 0 & 0 & 1 \\
\end{array}\right)
\cdot
\left(\begin{array}{c}
x \\
y \\
z \\
1 \\
\end{array}\right) =
\left(\begin{array}{c}
ax + by + cz + x_t \\
dx + ey + fz + y_t \\
gx + hy + iz + z_t \\
1 \\
\end{array}\right)
\]

Used for perspective projection...
Conclusion

- Projection
  - Orthographic
  - Oblique
  - Perspective
Conclusion

- Frames of Reference
  - Object Space
  - World Space
  - View Space
  - Clip Space
  - Normalized Device Space
  - Screen Space
Conclusion

- Shading Models
  - Flat
  - Gouraud
  - Phong

- Lighting Models
  - Single color
  - Lambert
  - Phong
  - Blinn-Phong

- sRGB Color Space and Gamma
Conclusion

- Textures
  - UV Mapping
  - Mipmap
  - Interpolation
    - Upscale
    - Downscale
- Anisotropy
Conclusion

• Blending
  • Alpha
    – Conventional
    – Premultiplied
  • General Blending Function
    – Alpha Blending
    – Additive
    – Multiplicative

blend\left( src , dst \right) = (src \cdot srcFactor) function(dst \cdot dstFactor)

Multiplicative blending example in World Remade by Jaanus Jaggo
Conclusion

- Asset Pipeline
- Code vs Design vs Art
- Vertical Slice
- Game Engine
  - Runtime
  - Tools
  - Layered Architecture
- Drivers, OS, Resource Manager, Middleware, SDK

Image by Ats Kurvet and Timo Kallaste
Conclusion

- Curves
  - Interpolating vs Approximating
  - Smoothness $C^n$ and $G^n$
  - Construction with constraints
- Hermite
- Catmull-Rom
- Bezier
Conclusion

- Procedural Generation
  - Noise
    - Value noise
    - Perlin noise
  - Lindenmayer Systems
  - Particle Systems
    - Boids
Conclusion

- Ray Casting
  - Ray-Triangle Intersection
- Ray Tracing
  - Ray Trace Rendering
- Data Structures
  - Octree
  - K-D Tree
  - Binary Space Partitioning
  - Bounding Volume Hierarchy
Conclusion

- Global Illumination
  - Path Tracing
  - Photon Mapping
  - Radiosity

- The Rendering Equation

$$L_{\text{emit}}(x, \omega_o) + \int_\Omega f_{\text{brdf}}(x, \omega_i, \omega_o) \cdot L_i(x, \omega_i) \cdot (\omega_i \cdot n) \, d\omega_i$$
Conclusion

- Shadows
  - Global Illumination Shadows
  - Shadow Mapping
  - Shadow Volume
- Umbra, penumbra, antumbra
Conclusion

- Conclusion
  - Coordinate System Handedness
- Polygons
  - Convex and Concave
  - Simple
- Triangles
  - Planar
- Barycentric coordinates
- ...

...
Computer Graphics

Thanks for the ride!

The End...
What knowledge did you gain today?

What more would you like to know?

Next time: **Open mic lecture!**

Shalva Avanashvili – Object Pooling

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