Light Space Perspective Shadow Maps

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Introduction

- New shadow mapping technique
  - Based on Perspective Shadow Maps
- Problem to solve
  - PSM drawbacks
  - mainly the perspective aliasing
- Motivation
  - Any arbitrary perspective transform can be used
  - Choose a warp that affects only the shadow map plane
    - Not axis perpendicular to shadow map
- Solution
  - Perspective transform w.r.t. the coordinate axes of Light Space
steps
- Transform scene to post-perspective space of the camera (using the camera matrix)
- Transform light source using the same matrix
- Generate a standard shadow map by rendering a view from the transformed light source

results
- Decreases perspective aliasing in some cases but not all
Post-perspective light sources

- Directional lights become point lights on the *infinity* plane (inverted if behind the viewer, remain directional if parallel to image plane)
- Point lights become directional lights if the point light is on the plane through the view point which is perpendicular to the view direction
PSM best/optimal cases

- Best case for PSM is when the post-perspective light source is directional
  - Directional light parallel to image plane
  - Point light in the camera plane (miner’s lamp)
- Less optimal case is when the post-perspective light source is point light far away from the view frustum (similar to directional light) or with a large depth range
PSM drawbacks

- Worst case
  - Directional light perpendicular to image plane – results in uniform shadow map
  - Point light close to view frustum or with a small depth range
- Objects behind the viewer that can still cast shadows require moving the camera viewpoint backwards
  - Doing so however degrades towards a uniform shadow map
Shadow map aliasing

- Perspective aliasing (focus of this method and PSM)
  - Shadow map undersampling that occurs when $d$ is bigger than $d_i$ (large $d_s r_s / r_i$)

- Projection aliasing (not treated)
  - Occurs when $\cos \beta / \cos \alpha$ is large (light rays almost parallel to surface)

$$d = d_s \frac{r_s \cos \beta}{r_i \cos \alpha}$$
Applying Light Space Perspective Shadow Maps

1. Focus the shadow map on the convex body $B$ that encloses all light rays of interest (exactly as in PSMs)
2. Enclose $B$ with a perspective frustum $P$ that has a view vector parallel to the shadow map
3. Control the strength of the warping effect by choosing the distance of the projection reference point to the near plane of the frustum
4. Apply $P$ just as in standard shadow mapping
Step 1

- Focussing the shadow map
  - Focus the shadow map on the convex body B that is relevant for shadow calculation

\[ M = \text{convex hull}(l \cup V) \]

\[ H = M \cap S \cap L \]
Enclose B with a perspective frustum defined in light space

- **Light space definition**
  - Y–axis is defined by the light vector (pointing towards the light)
  - Z–axis is defined to be perpendicular to the light vector and lying in the plane containing the observer view vector and the light vector
  - X–axis perpendicular to both to form an orthogonal coordinate system
Step 2

- Perspective frustum in light space
  - The near and far planes of the perspective frustum are defined as planes parallel to the $xy$-plane and planed at the minimum and maximum $z$-coordinate among the points of $B$
  - The $x$ and $y$ coordinates of the projection reference point are chosen by taking the $x$-coordinate from the transformed viewpoint and the $y$-coordinate as the middle of the min and max $y$-coordinates of $B$
Step 3

- Choosing the free parameter $n$ for $P$ which is the distance from the projection reference point $p$ to the near plane of $P$
  - Close to near plane of $P$ $\rightarrow$ effect resembles original PSMs
  - Far away from near plane of $P$ $\rightarrow$ uniform shadow maps
Step 4

- Applying the perspective frustum
  - Combine frustum with usual projective mapping used for standard shadow maps
    - The combined mapping is used both in shadow map generation and in texture coordinate generation for rendering the shadow map
Error Analysis
Ideal Parameterization

- Logarithmic
  - Make $dp/ds = 1$ for the whole available depth range
  - For ideal case (view direction perpendicular to the light)
  - Not practical for hardware implementation
    - Graphics hardware amenable to perspective mapping
Find the SM parameterization $s$ caused by perspective transform $P$

$$\frac{dp}{ds} = \frac{(z - z_n + n)^2}{z} \cdot \frac{(z_f - z_n)}{n(n + z_f - z_n)}.$$

- $n \rightarrow \text{Infinity} = \text{Uniform Shadow Maps}$
- $n = z_n \rightarrow \text{Perspective Shadow Maps}$
LiSPSM Analysis

- LiSPSM between extremes of Uniform and PSM
- Depending on \( n \) parameter
  - Focus on optimal error distribution in whole depth range
- LiSPSM takes advantage of the extreme falloff of Uniform Shadow Maps and increases linearly like the PSM
  - Not at the same level

\[
\frac{dp}{ds} = \frac{(z - zn + n)^2}{z} \frac{(zf - zn)}{n(n + zf - zn)}.
\]
X-coordinate

- PSM in z-coordinate is error prone
  - z-coordinate projected to SM s coordinate
    - Foreshortening
- PSM is ideal
  - x-coordinate projected to SM t coordinate
    - x and t undergo same transformation
    - $dp/dt = \text{constant}$
- LiSPSM has almost same start error as z-coordinate and then the error minimizes extremely
General Case

- Deal with different light source and viewpoint angles
  - If light and view directions parallel
    - No improvement $\rightarrow$ Uniform
  - Tilt angle ($\gamma$)
    - Angle between light direction and view vector
    - View-Space $z \neq$ Light-Space $z$
    
    $n'_{opt} = n_{opt} / \sin \gamma$

  - Increasing tilt angle $\rightarrow$ decreasing perspective warping effect
Results
Advantages – Drawbacks

- LiSPSM more robust, because it decreases the worst-case perspective aliasing error
- High shadow quality
- As fast as standard shadow maps

- Projection Aliasing is not treated
- Point Lights might give some unwanted results
- Shadow Acne
  - Treated with simple offset
Future Work

- Deal with logarithmic approach
- Use of multiple shadow maps in scene, for different depth ranges
QUESTIONS?