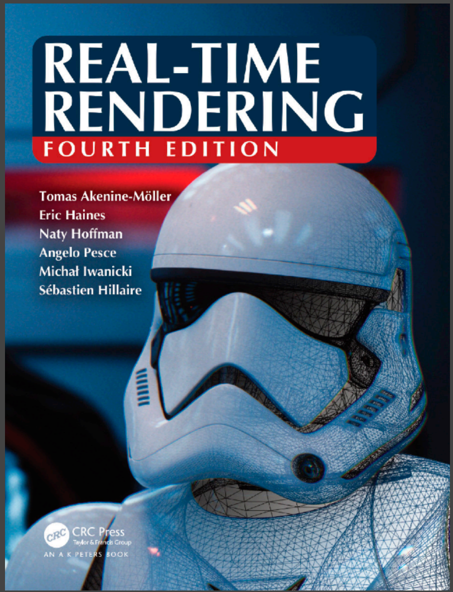
Real-Time High Quality Rendering

GAMES202, Lingqi Yan, UC Santa Barbara

Lecture 3: Real-Time Shadows 1

Announcement

- Enjoying assignment 0?
- Assignment 1 will be released this week
  - Ideally together with Lecture 4
- Adjusted orders of some contents
- The RTR book



Last Lecture

- Recap of CG Basics
  - Basic GPU hardware pipeline
  - OpenGL
  - OpenGL Shading Language (GLSL)
  - The Rendering Equation
  - Calculus

Today

- Recap: shadow mapping
  [slides courtesy of Prof. Ravi Ramamoorthi]
  - Issues from shadow mapping and solutions
- The math behind shadow mapping
- Percentage closer soft shadows
- Basic filtering techniques

Shadow Mapping

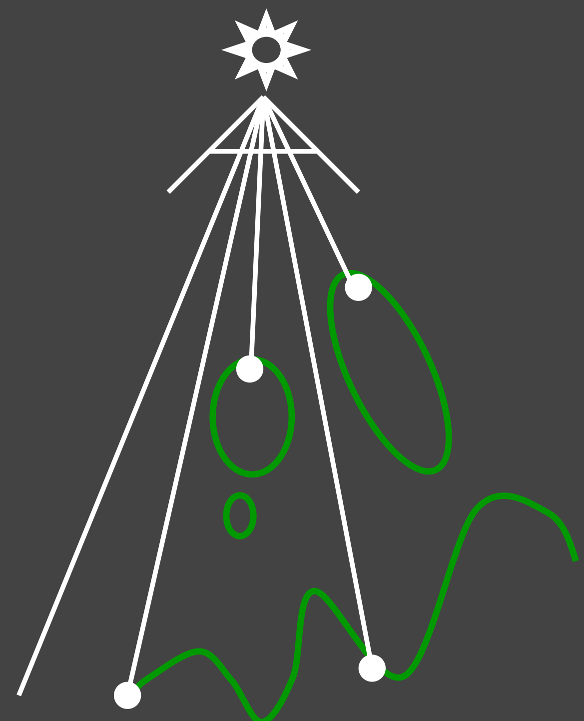
- A 2-Pass Algorithm
  - The light pass generates the SM
  - The camera pass uses the SM (recall last lecture)

- An image-space algorithm
  - Pro: no knowledge of scene’s geometry is required
  - Con: causing self occlusion and aliasing issues

- Well known shadow rendering technique
  - Basic shadowing technique even for early offline renderings, e.g., Toy Story

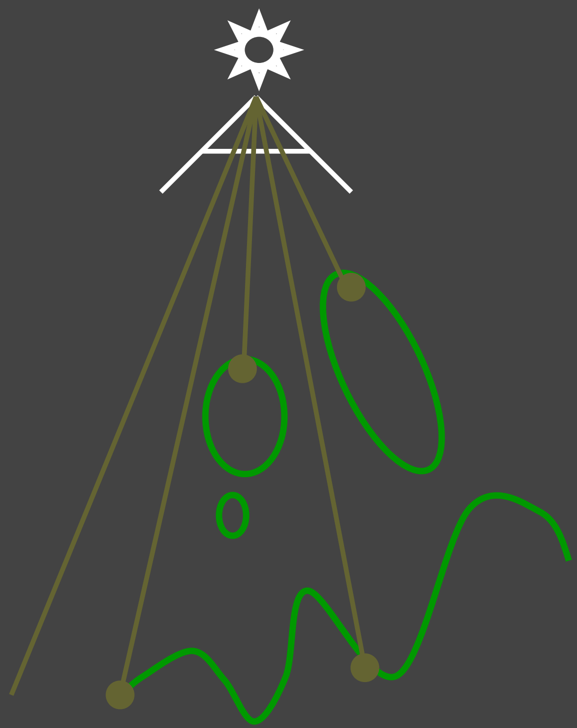
Pass 1: Render from Light

- Output a “depth texture” from the light source



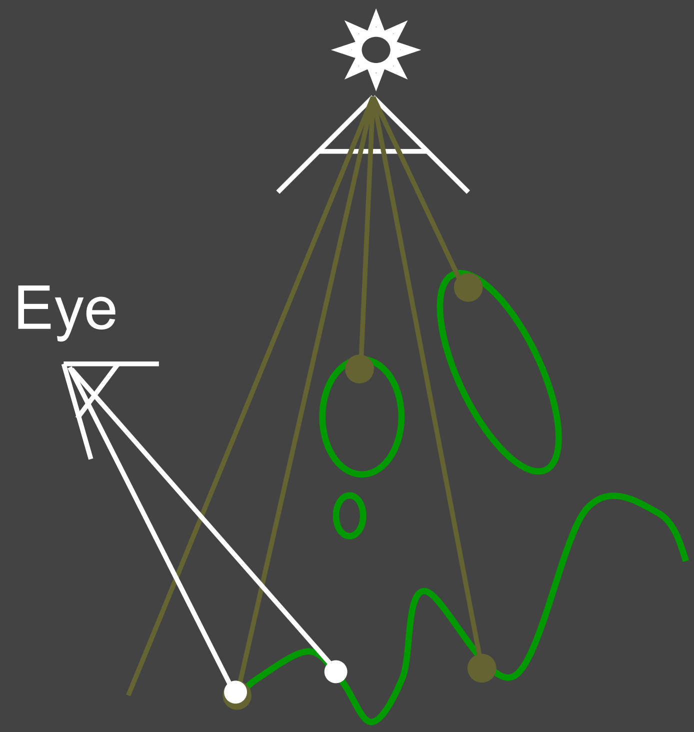
Pass 1: Render from Light

- Output a “depth texture” from the light source



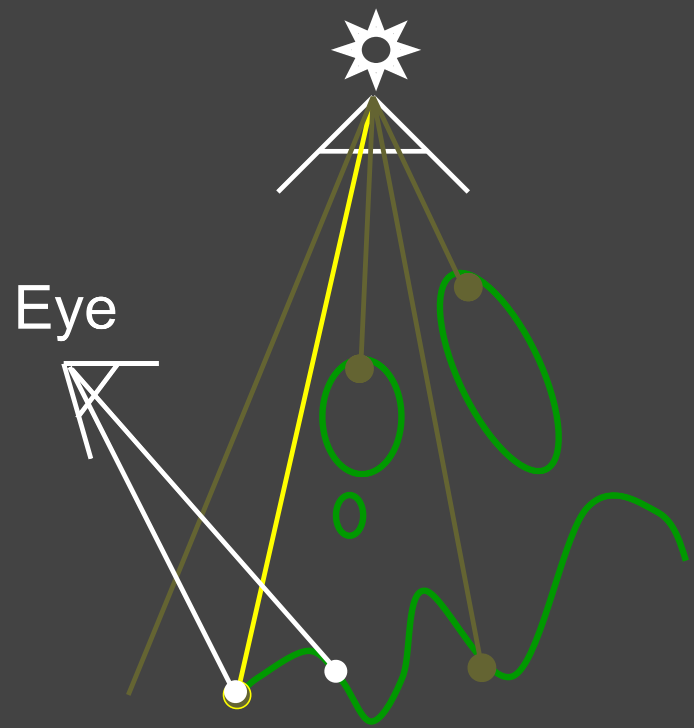
Pass 2: Render from Eye

- Render a standard image from the eye



Pass 2: Project to light for shadows

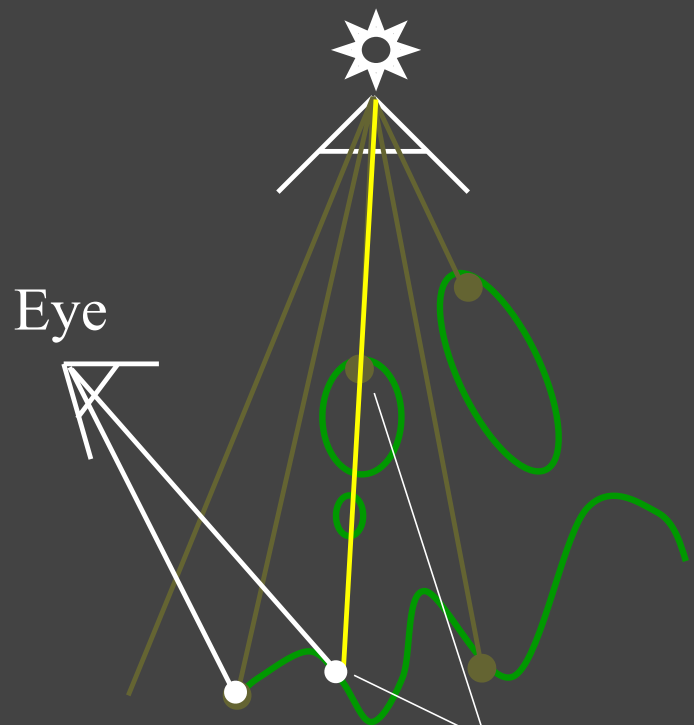
- Project visible points in eye view back to light source



(Reprojected) depths match for light and eye. VISIBLE

Pass 2: Project to light for shadows

- Project visible points in eye view back to light source

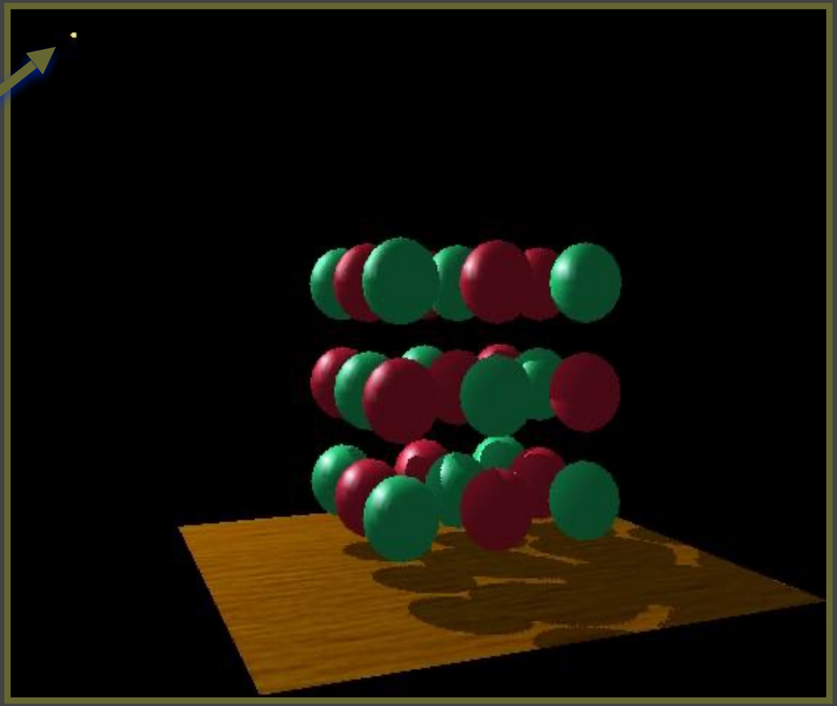


(Reprojected) depths from light, eye not the same. BLOCKED!!

Shadow Mapping Results

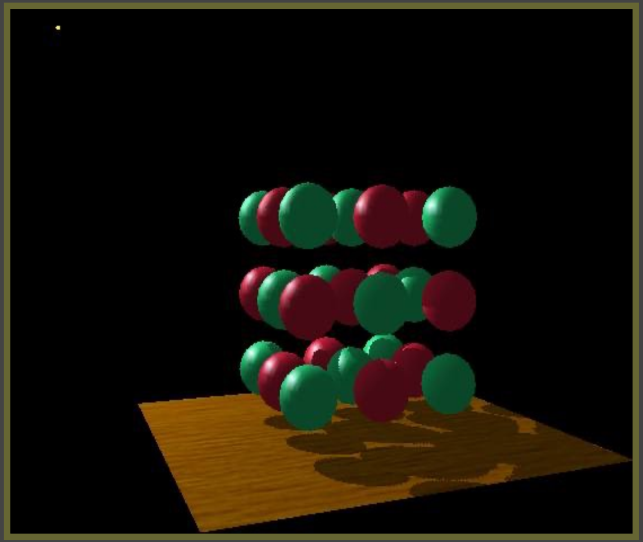
- A fairly complex scene with shadows

the point light source

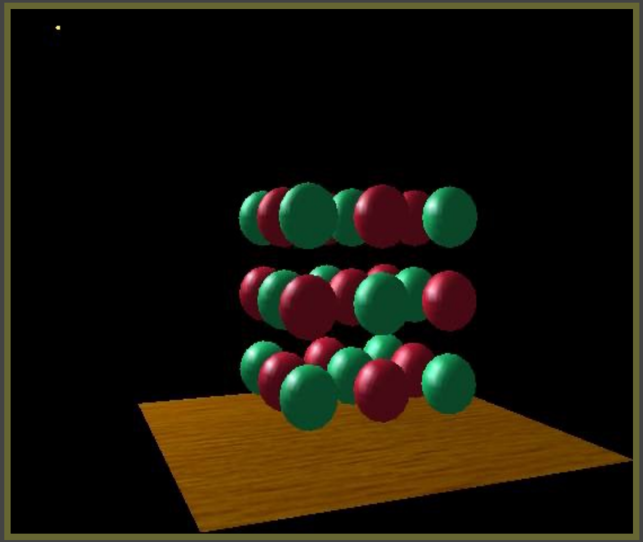


Shadow Mapping Results

- Compare with and without shadows



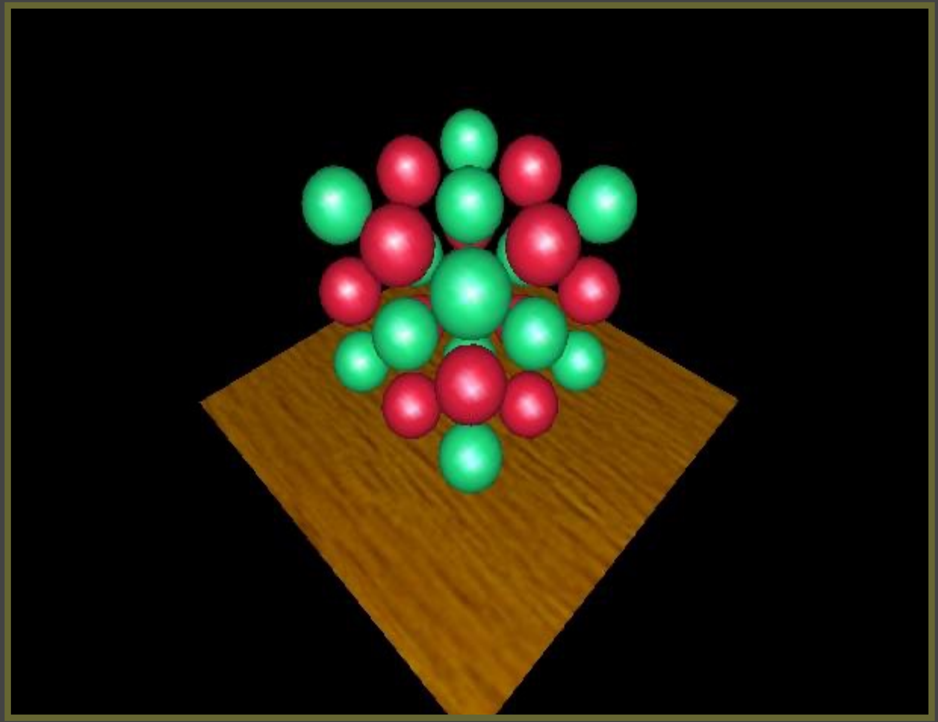
with shadows

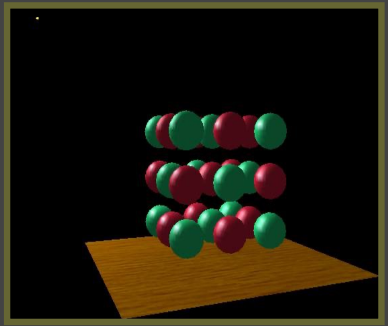


without shadows

Visualizing Shadow Mapping

- The scene from the light's point-of-view

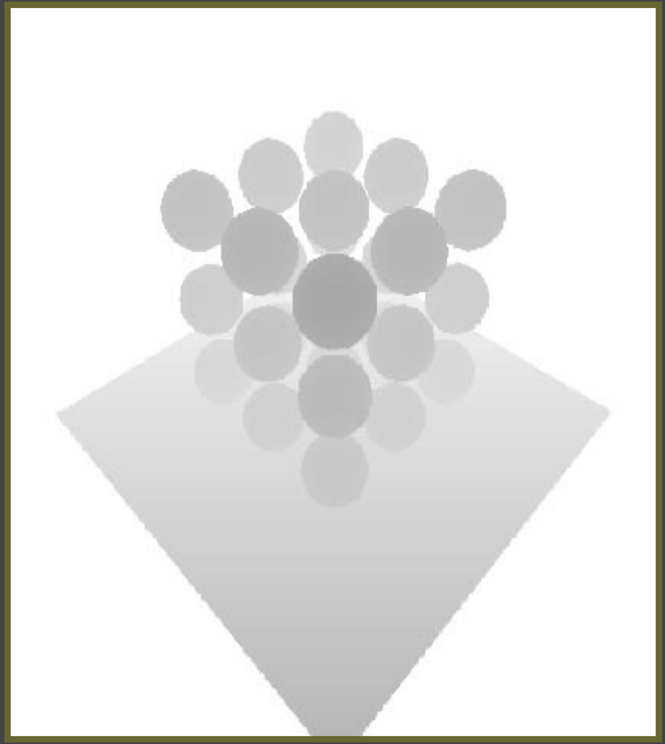


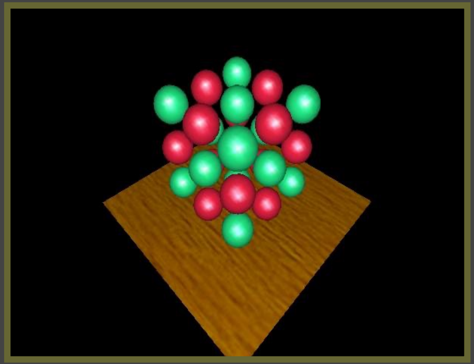


FYI: from the eye's point-of-view again

Visualizing Shadow Mapping

- The depth buffer from the light's point-of-view

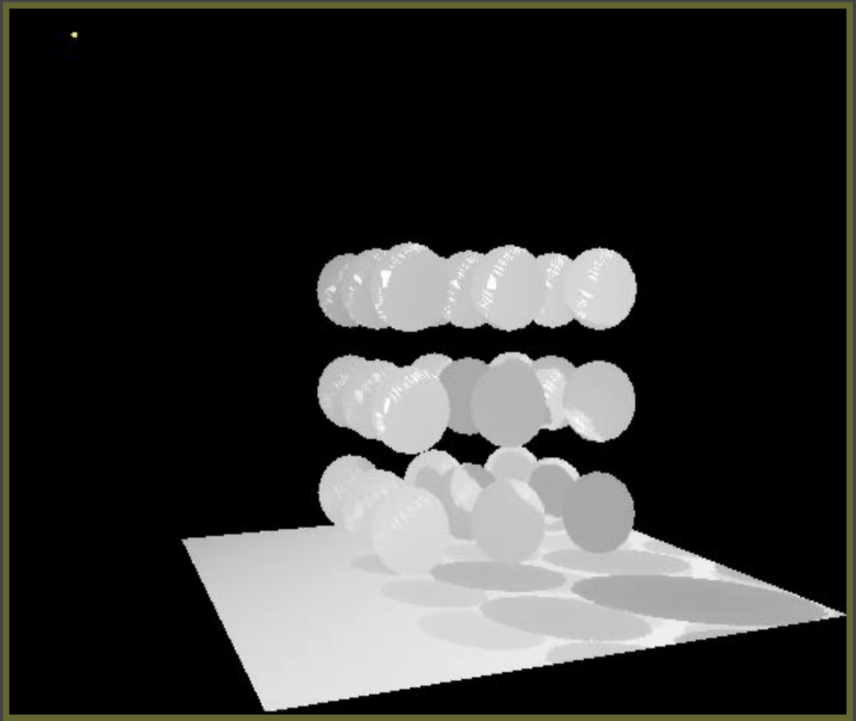


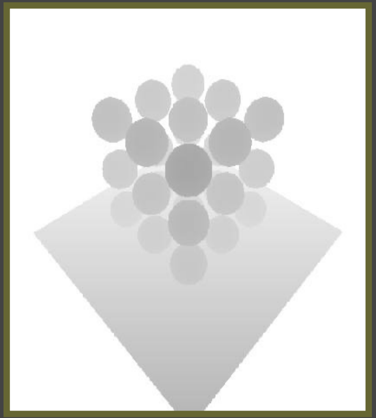


FYI: from the light's point-of-view again

Visualizing Shadow Mapping

- Projecting the depth map onto the eye's view



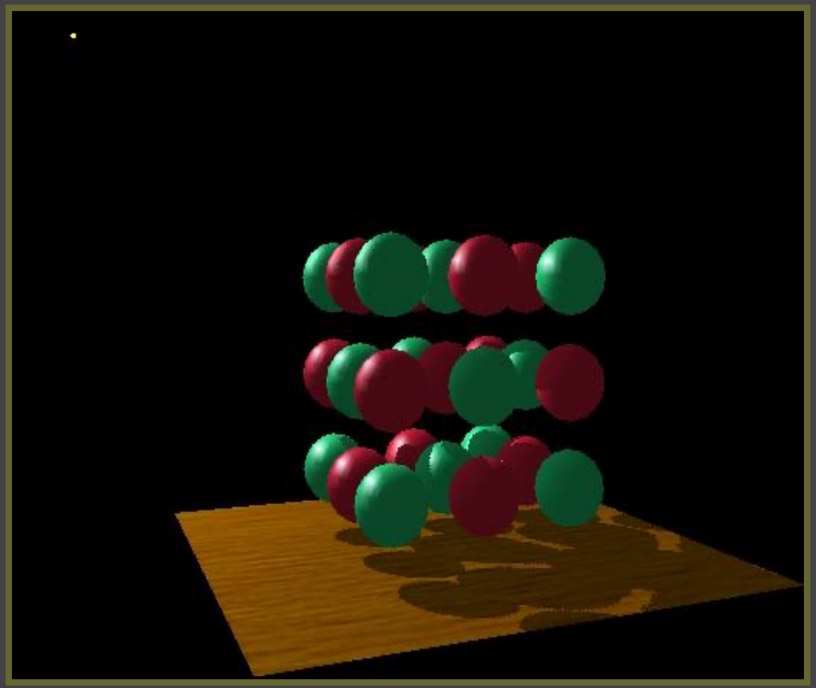


FYI: depth map for light's point-of-view again

Visualizing Shadow Mapping

- Scene with shadows

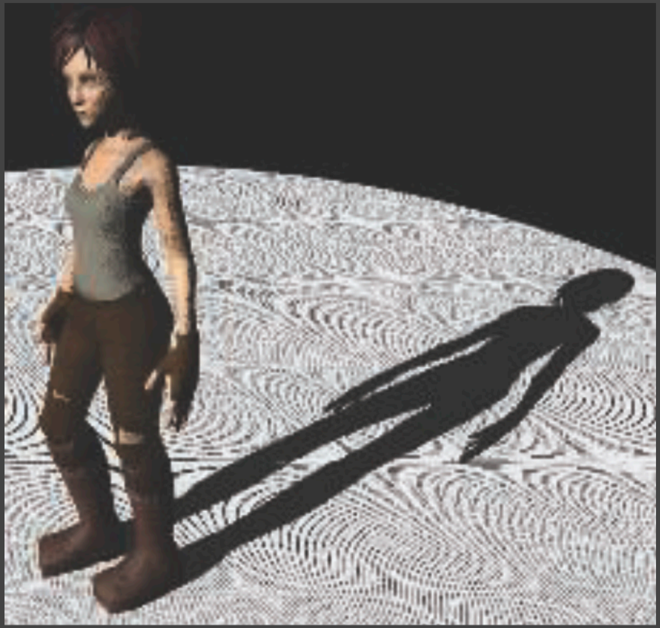
Notice how specular highlights never appear in shadows



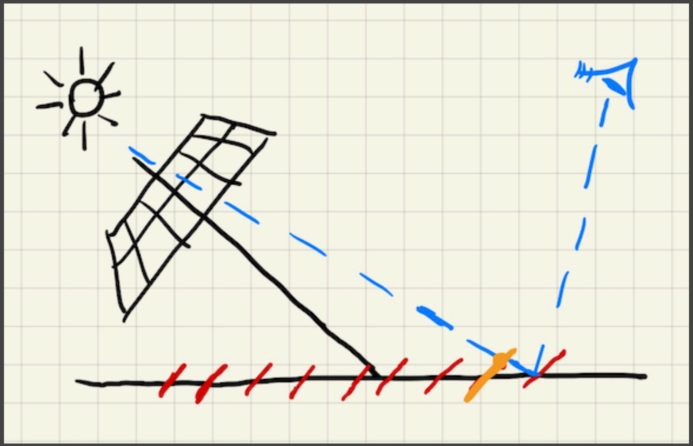
Notice how curved surfaces cast shadows on each other

Issues in Shadow Mapping

- Self occlusion
  - When is it most severe?



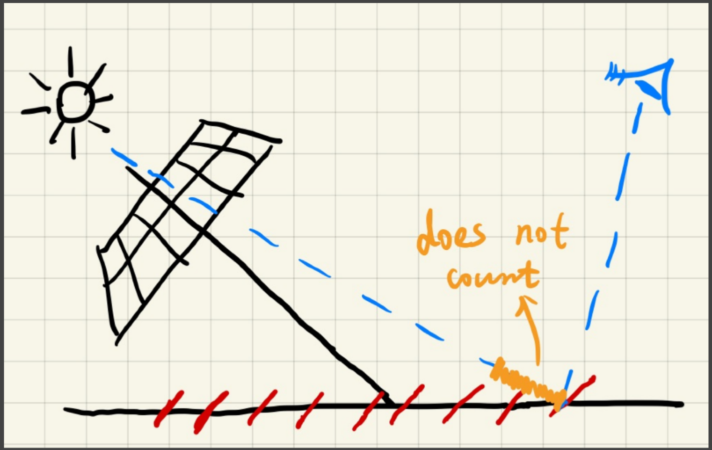
[Image from RTR4]



Issues in Shadow Mapping

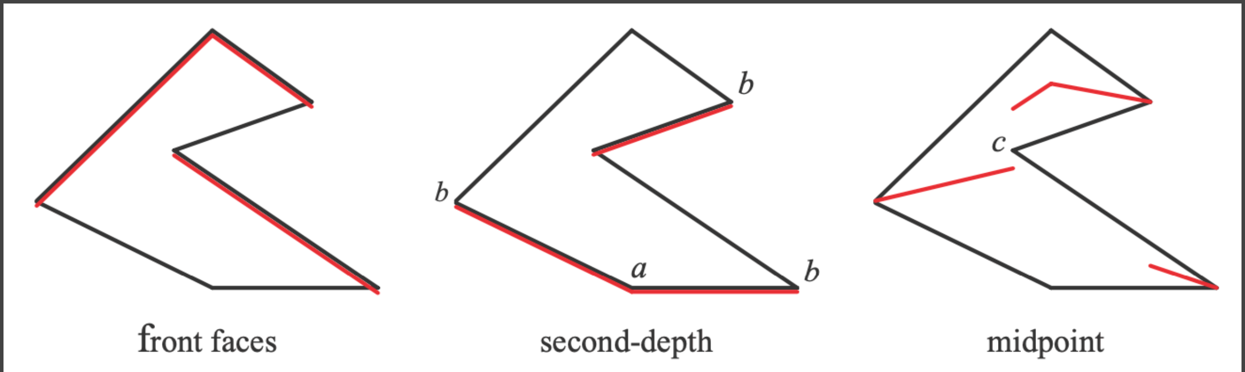
- Adding a (variable) bias to reduce self occlusion
  - But introducing detached shadow issue

[Image from RTR4]



Issues in Shadow Mapping

- Second-depth shadow mapping*
  - Using the midpoint between first and second depths in SM
  - Unfortunately, requires objects to be watertight
  - And the overhead may not worth it



[Image from RTR4]

RTR does not trust in COMPLEXITY

Issues in Shadow Mapping

- Aliasing

[https://developer.download.nvidia.com/books/HTML/gpugems/gpugems_ch11.html]

Questions?

Today

- Recap: shadow mapping
  - Issues from shadow mapping and solutions
- The math behind shadow mapping
- Percentage closer soft shadows
- Basic filtering techniques

Inequalities in Calculus

- There are a lot of useful inequalities in calculus

12. 设 $f(x)$和 $g(x)$在$[a,b]$上都可积，证明不等式：

(1)(Schwarz 不等式) $\left[\int_a^b f(x)g(x)\mathrm{d}x\right]^2 \leqslant \int_a^b f^2(x)\mathrm{d}x \cdot \int_a^b g^2(x)\mathrm{d}x$；

(2)(Minkowski 不等式)

$$\left\{\int_a^b [f(x)+g(x)]^2\mathrm{d}x\right\}^{\frac{1}{2}} \leqslant \left\{\int_a^b f^2(x)\mathrm{d}x\right\}^{\frac{1}{2}} + \left\{\int_a^b g^2(x)\mathrm{d}x\right\}^{\frac{1}{2}}。$$

Approximation in RTR

近似相等

- But in RTR, we care more about “approximately equal”
- An important approximation throughout RTR

$$\int_{\Omega} f(x)g(x)\,\mathrm{d}x \approx \frac{\int_{\Omega} f(x)\,\mathrm{d}x}{\int_{\Omega}\mathrm{d}x} \cdot \int_{\Omega} g(x)\,\mathrm{d}x$$

归一化，使功率不变.

- When is it (more) accurate?

1. 积分域小的时候 Ω
2. $g(x)$ 足够光滑 smooth 变化不大.

In Shadow Mapping

- Recall: the rendering equation with explicit visibility

$$L_o(\mathrm{p}, \omega_o) = \int_{\Omega+} \boxed{L_i(\mathrm{p}, \omega_i)} \boxed{f_r(\mathrm{p}, \omega_i, \omega_o) \cos\theta_i} \boxed{V(\mathrm{p}, \omega_i)} \, \mathrm{d}\omega_i$$

- Approximated as

$$L_o(\mathrm{p}, \omega_o) \approx \boxed{\frac{\int_{\Omega+} V(\mathrm{p}, \omega_i) \, \mathrm{d}\omega_i}{\int_{\Omega+} \mathrm{d}\omega_i}} \cdot \int_{\Omega+} L_i(\mathrm{p}, \omega_i) f_r(\mathrm{p}, \omega_i, \omega_o) \cos\theta_i \, \mathrm{d}\omega_i$$

Visibility x. <单纯shading>

In Shadow Mapping

$$L_o(\mathrm{p},\omega_o) \approx \boxed{\frac{\int_{\Omega^+} V(\mathrm{p},\omega_i)\,\mathrm{d}\omega_i}{\int_{\Omega^+} \mathrm{d}\omega_i}} \cdot \int_{\Omega^+} L_i(\mathrm{p},\omega_i) f_r(\mathrm{p},\omega_i,\omega_o)\,\cos\theta_i\,\mathrm{d}\omega_i$$

基于之前可行性分析，我们得知
1. 当使用点光源/方向光源是准确的
<此时Ω是很小的，只有1个点或Δω>

- When is it accurate?
  - Small support
    (point / directional lighting)
  - Smooth integrand
    (diffuse bsdf / constant radiance area lighting)

只要求其中1个

g(x) 很光滑. g(x): 光照. BRDF.

面光源，光照有什么变化、
uniform 光照
shading point 是 diffuse.

- We'll see it again in Ambient Occlusions, etc.

环境遮挡

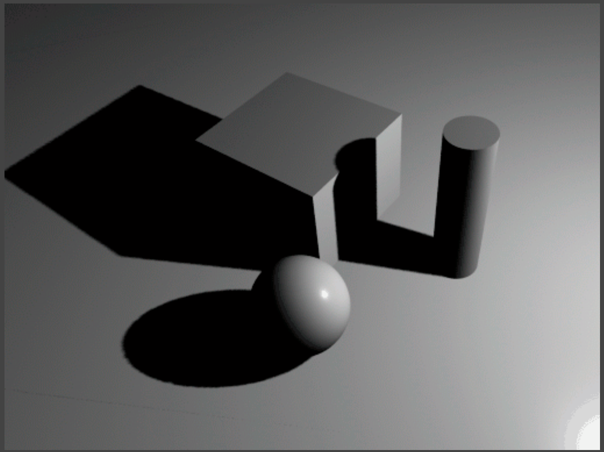
Questions?

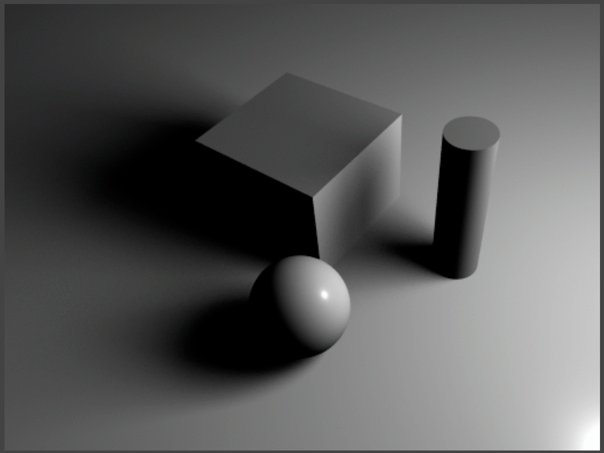
Today

- Recap: shadow mapping
  - Issues from shadow mapping and solutions
- The math behind shadow mapping
- Percentage closer soft shadows PCSS

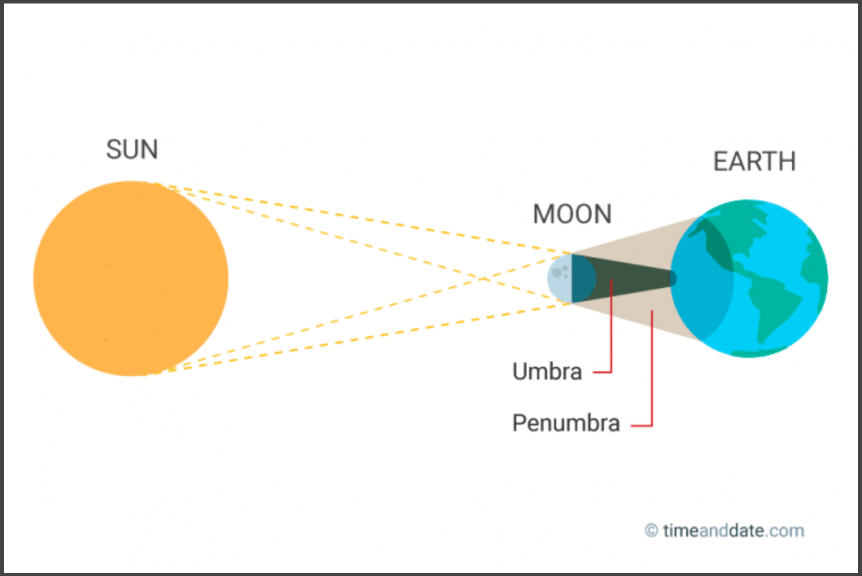
  软阴影
- Basic filtering techniques

From Hard Shadows to Soft Shadows





[RenderMan]



[https://www.timeanddate.com/eclipse/umbra-shadow.html]

Percentage Closer Filtering (PCF)

反走样　　　　在阴影边缘

- Provides anti-aliasing at shadows' edges
  - Not for soft shadows (PCSS is, introducing later)
  - Filtering the results of shadow comparisons

- Why not filtering the shadow map?
  - Texture filtering just averages color components, i.e. you'll get blurred shadow map first
  - Averaging depth values, then comparing, you still get a binary visibility

PCF

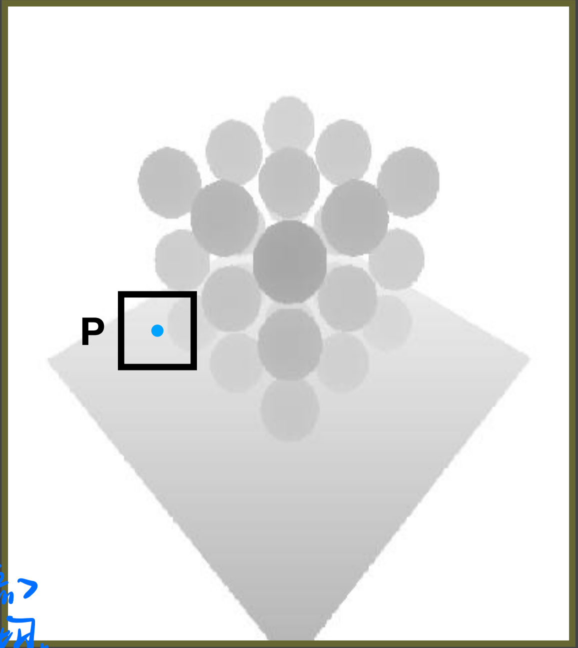
1. 在做阴影判断时进行filting 而非已经得到shadow map, 对其进行模糊.

2. 不是纹理过滤, 这只是对颜色分量进行平均, 会得到模糊的阴影贴图.

<已产生锯齿的阴影>

Percentage Closer Filtering (PCF)

- Solution [Reeves, SIGGARPH 87]
  - Perform multiple (e.g. 7x7) depth comparisons for each fragment
  - Then, averages **results of** comparisons
  - e.g. for point P on the floor,
    (1) compare its depth with all pixels
    in the red box, e.g. 3x3
    (2) get the compared results, e.g.
    1, 0, 1,
    1, 0, 1,
    1, 1, 0,
    (3) take avg. to get visibility, e.g. 0.667

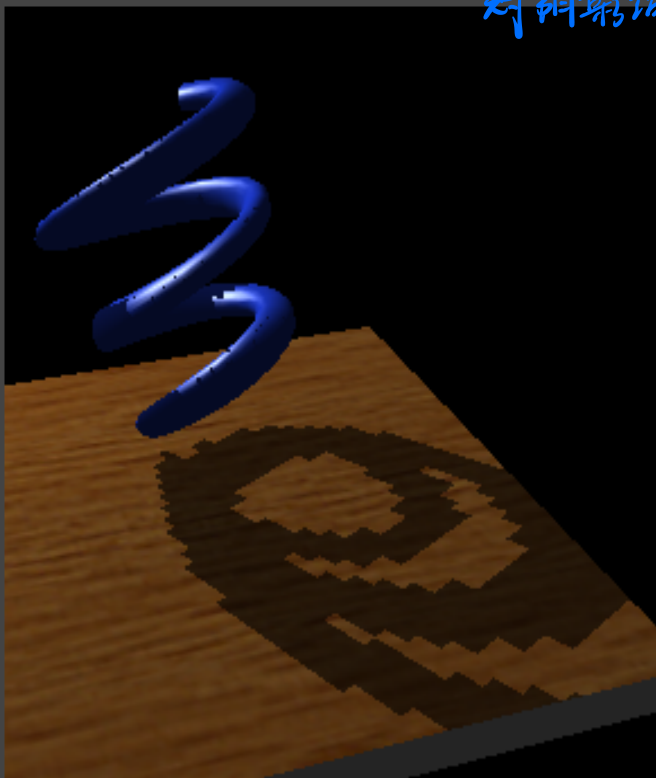


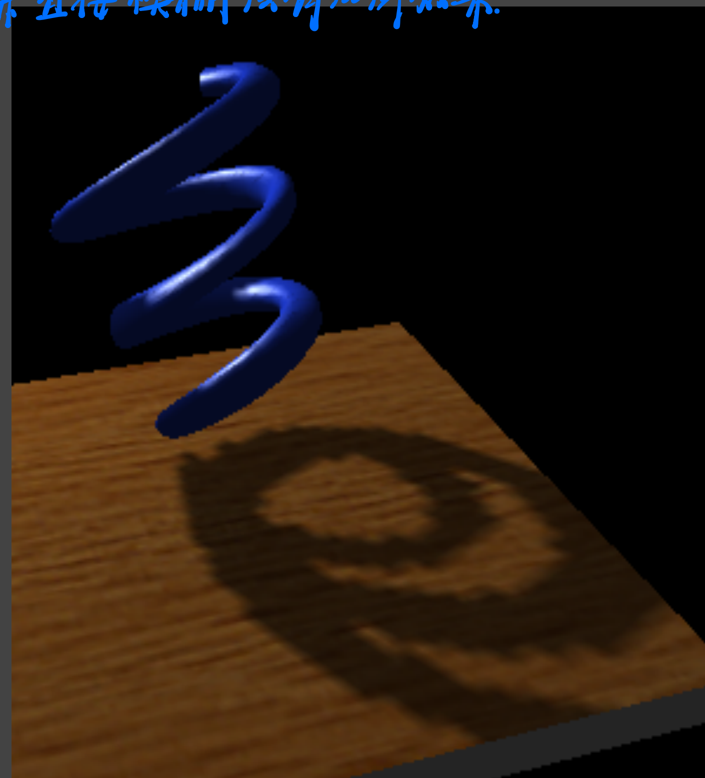
对某个点进行检测. 映射到 shadow map 上. <蓝点>
对其周围7x7个像素进行比较. 并对结果进行平均.
周围区域

Percentage Closer Filtering

Again, not soft shadows in the umbra/penumbra sense

对阴影结果直接模糊没有什么好效果.





Percentage Closer Filtering

<PCF>

锯齿消失. ✓

[https://developer.nvidia.com/gpugems/GPUGems3/gpugems3_ch08.html]

Percentage Closer Filtering

- Does filtering size matter?
  - Small -> sharper
  - Large -> softer
- Can we use PCF to achieve soft shadow effects?
- Key thoughts
  - From hard shadows to soft shadows
  - What's the correct size to filter?
  - Is it uniform?

Percentage Closer Soft Shadows

- Key observation [Fernando et al.]
  - Where is sharper? Where is softer?

[https://graphicdesign.stackexchange.com/questions/71734/transfer-the-shadow-of-an-object-on-white-paper-to-ruled-paper]

Percentage Closer Soft Shadows

- Key conclusion
  - Filter size <-> blocker distance
  - More accurately, relative average projected blocker depth!

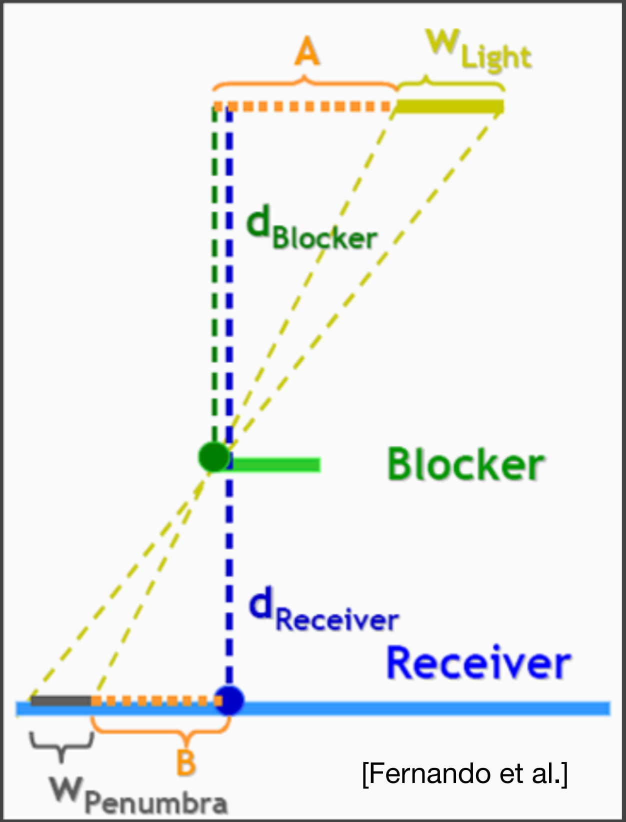
相对平均投影拦截深度.

- A mathematical "translation"

$$w_{Penumbra} = (d_{Receiver} - d_{Blocker}) \cdot w_{Light} / d_{Blocker}$$

半影

"越大越软"
"越小越硬".

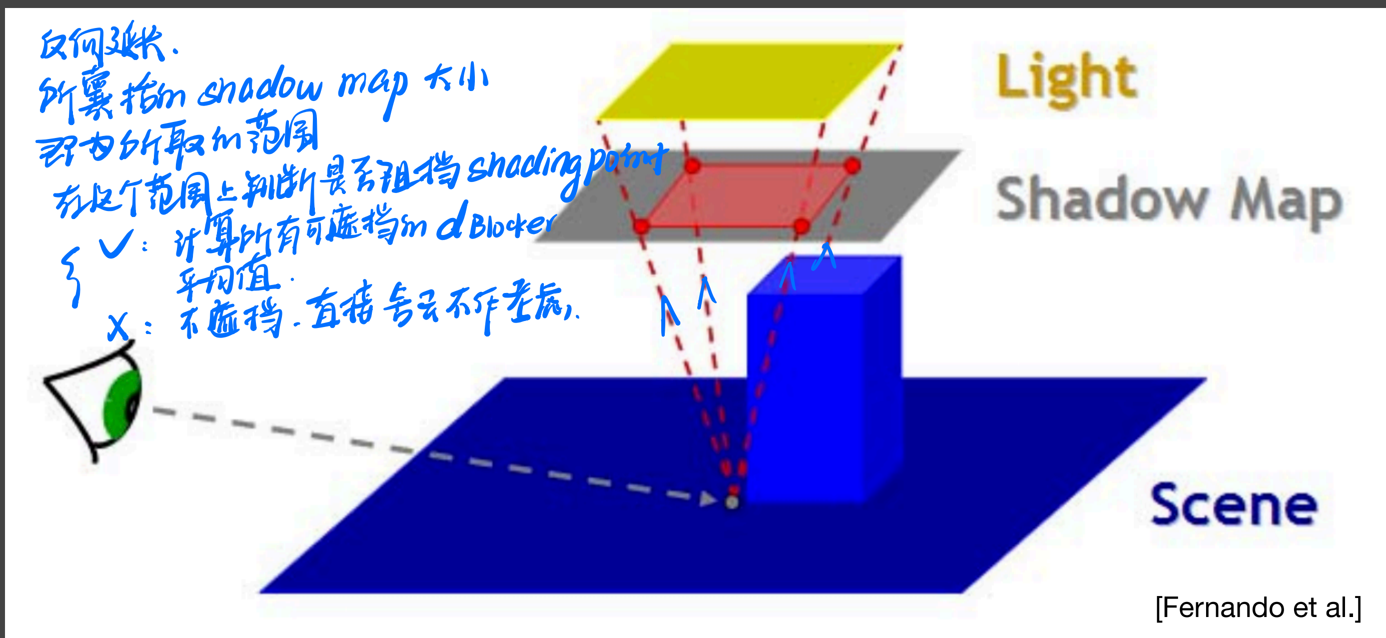


Percentage Closer Soft Shadows

- Now the only question:
  - What's the blocker depth $d_{Blocker}$
- The complete algorithm of PCSS
  - Step 1: Blocker search
    (getting the average blocker depth in a certain region)
  - Step 2: Penumbra estimation
    (use the average blocker depth to determine filter size) $w_{penumbra}$
  - Step 3: Percentage Closer Filtering "PCF"
- Which region to perform blocker search?
  - Can be set constant (e.g. 5x5), but can be better with heuristics

Percentage Closer Soft Shadows

- Which region (on the shadow map) to perform blocker search?
  - depends on the light size
  - and receiver's distance from the light



反向延长.
所覆盖的 shadow map 大小
即为所取的范围
在这个范围上判断是否阻挡 shading point
✓: 计算所有可遮挡的 d Blocker 平均值.
✗: 不遮挡. 直接舍去不作考虑.

[Fernando et al.]

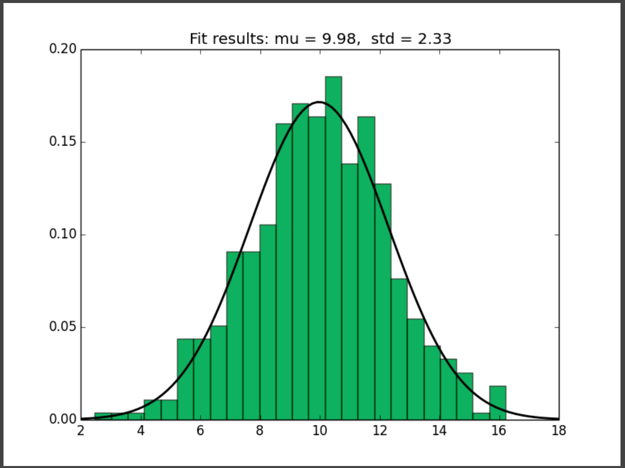
Percentage Closer Soft Shadows

Video game: Dying Light

Questions?

Next Lecture

- Basic filtering techniques
- Variance soft shadow mapping
- MIPMAP and Summed-Area Variance Shadow Maps
- Moment shadow mapping



Thank you!