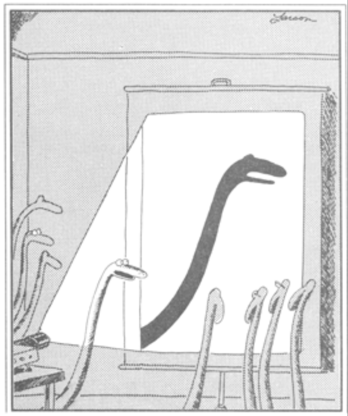
Shadows



"Now this is…this is…well, I guess it's another snake."

Shadows

MIT EECS 6.837

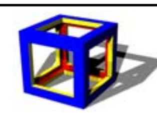
Frédo Durand and Seth Teller

Final projects

- Presentations next week
- Tentative schedule (web form soon)
  - Wednesday 10-12 and 2-4
  - Thursday 10-12 and 1-2
  - Friday 10-12 and 2-4
- 20 minutes presentation + 5 minutes Q&A
- Final report due on Friday Dec 6

Special topics

- Today:
  Shadows

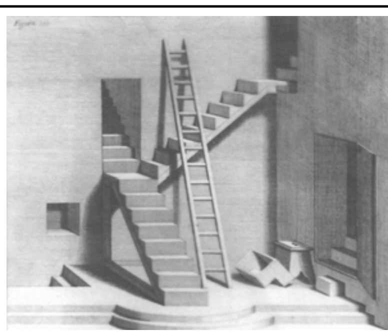


- Tuesday Dec 3:
  Graphics hardware

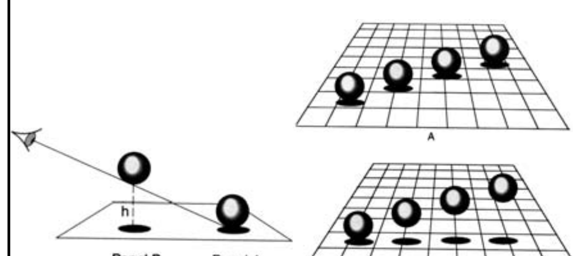
- Thursday Dec. 5:
  Image-based modeling
  & rendering

Shadows

- Realism
- Depth cue



Shadows as depth cue



Shadows and art

- Only in Western pictures (here Caravaggio)

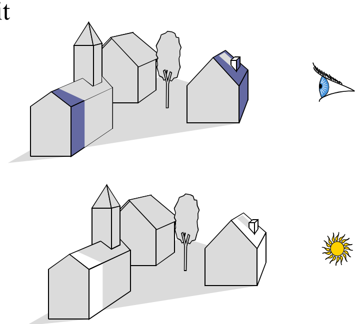
Shadows and art

- Shadows as the origin of painting

Plate 18
David Allan,
The Origin of Painting
(The Maid of Corinth),
1775. Oil on wood,
38.7 x 31 cm. Edinburgh,
National Gallery of
Scotland.

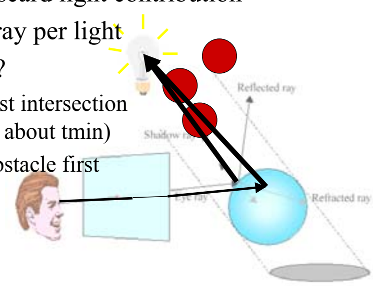
Duality shadow-view

- A point is lit if it is visible from the light source
- Shadow computation very similar to view computation



Shadow ray

- Ray from visible point to light source
- If blocked, discard light contribution
- One shadow ray per light
- Optimization?
  - Stop after first intersection (don't worry about tmin)
  - Test latest obstacle first



Ray-casting shadows

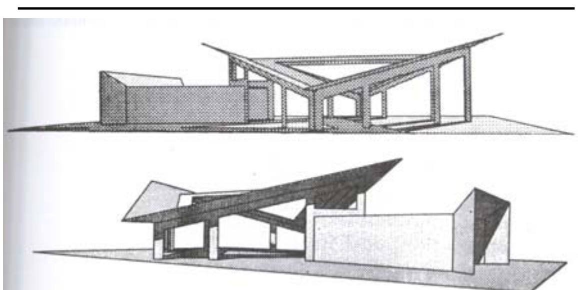
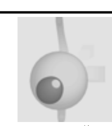


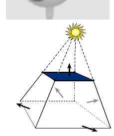
Fig. 16.52 Early pictures rendered with ray tracing. (Courtesy of Arthur Appel, IBM T.J. Watson Research Center.)

Overview

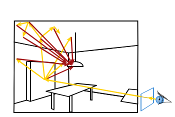
- Shadow map
  - Image-precision, texture mapping



- Shadow volume
  - Object space



- Soft shadows and Monte-Carlo ray tracing



Questions?

Fake shadows using textures

- Separate obstacle and receiver
- Compute b/w image of obstacle from light
- Use projective textures

Image from light source BW image of obstacle Final image

Figure from Moller & haines “Real Time Rendering”

Fake shadows using textures

- Limitations?

Image from light source BW image of obstacle Final image

Figure from Moller & haines “Real Time Rendering”

Shadow maps

- Use texture mapping but using depth
- 2 passes (at least)
  - Compute shadow map from light sourc
    - Store depth buffer (shadow map)
  - Compute final image
    - Look up the shadow map to know if points are in shadow

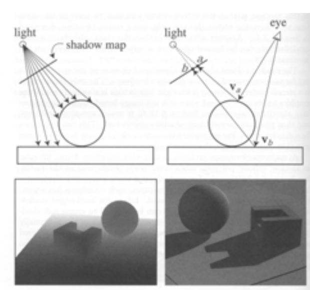


Figure from Foley et al. “Computer Graphics Principles and Practice”

Shadow map look up

- We have a 3D point x,y,z
- How do we look up the shadow map?

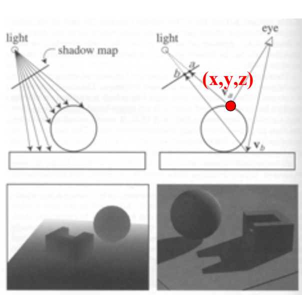


Figure from Foley et al. “Computer Graphics Principles and Practice”

Shadow map look up

- We have a 3D point x,y,z
- How do we look up the shadow map?
- Use the 4x4 camera matrix from the light source
- We get (x’,y’,z’)
- Test: ShadowMap(x’,y’)<z’

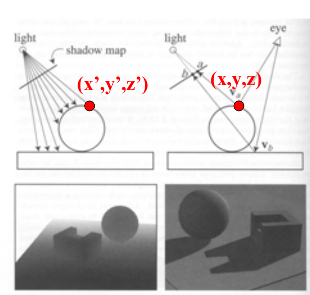


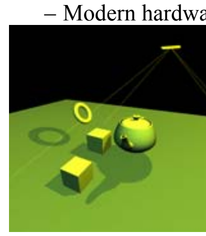
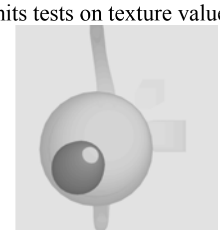
Figure from Foley et al. “Computer Graphics Principles and Practice”

Shadow maps

- In Renderman
  - (High-end production software)

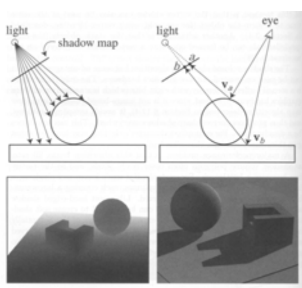

Shadow maps

- Can be done in hardware
- Using hardware texture mapping
  - Texture coordinates u,v,w generated using 4x4 matrix
  - Modern hardware permits tests on texture values

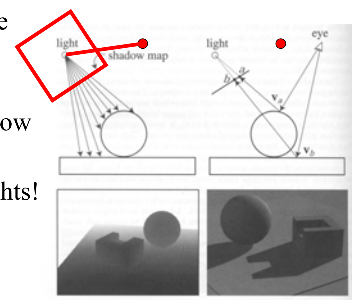
Problems with shadow maps?

- Field of view
- Bias
- Aliasing



Field of view problem

- What if point to shadow is outside field of view of shadow map?
- Use cubical shadow map
- Use only spot lights!

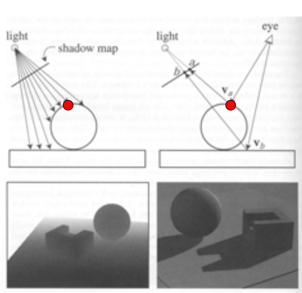


The bias nightmare

- For a point visible from the light source

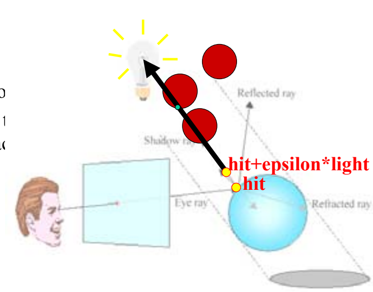
ShadowMap(x’,y’)≈z’

- Avoid erroneous self shadowing
- Remember the ray-tracing shadows in assignment 6



The bias nightmare

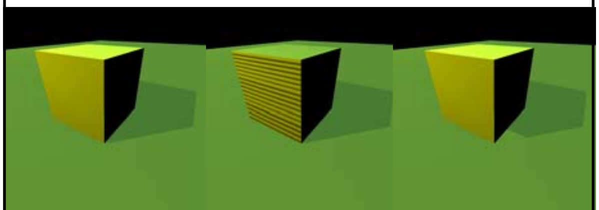
- Remember shadow ray casting
  - We started the ray at hit+light*epsilo
  - We added bias t avoid degenera
  - Yet another instance of geometric robustness



Bias for shadow maps

ShadowMap(x’,y’)+bias < z’

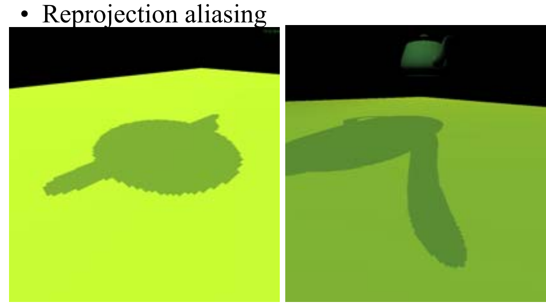
Choosing the good bias value can be very tricky



Correct image | Not enough bias | Too much bias bias

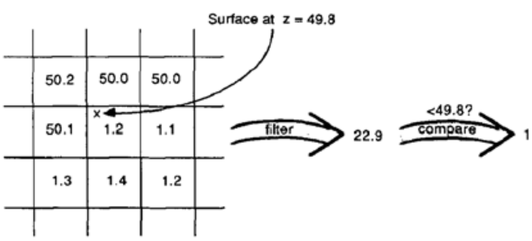
Shadow map aliasing

- Undersampling of shadow map
- Reprojection aliasing



Shadow map filtering

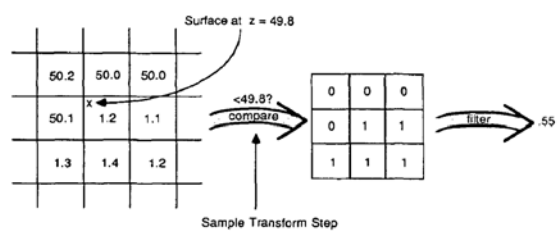
- Does not work!
- Filtering depth is not meaningfull



a) Ordinary texture map filtering. Does not work for depth maps.

Percentage closer filtering

- Filter the result of the test
- But makes the bias issue more tricky



Percentage closer filtering

- 5x5 samples
- Nice antialiased shadow
- Using a bigger filter produces fake soft shadows
- But makes the bias issue more tricky

Shadows in production

- Often use shadow maps
- Ray casting as fallback in case of robustness issues

Figure 12. Frame from *Luxo Jr.*

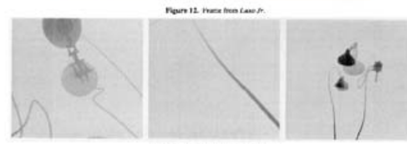
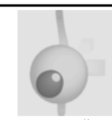


Figure 13. Shadow maps from *Luxo Jr.*

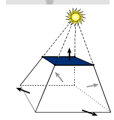
Questions?

Overview

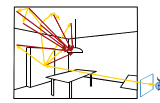
- Shadow map
  - Image-precision, texture mapping



- Shadow volume
  - Object space

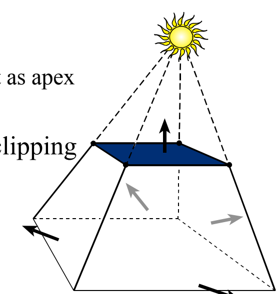


- Soft shadows and Monte-Carlo ray tracing



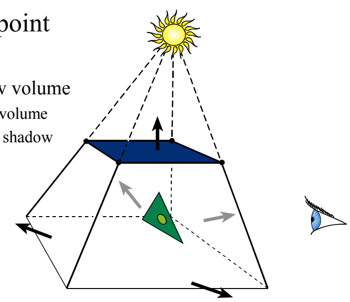
Shadow volumes

- Explicitly represent the volume of space in shadow
- For each polygon
  - Pyramid with point light as apex
  - Include polygon to cap
- Shadow test similar to clipping



Shadow volumes naïve rendering

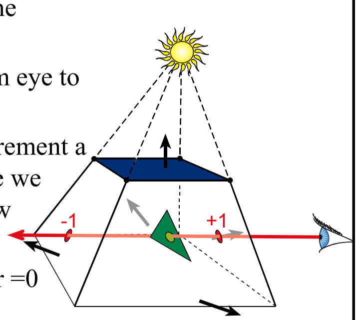
- Pick your favorite rendering algorithm
- For each visible point
  - For each light
    - For each shadow volume
      - If point inside volume
        - » Point is in shadow



Great but costly
(#poly * #light tests
for each visible point)

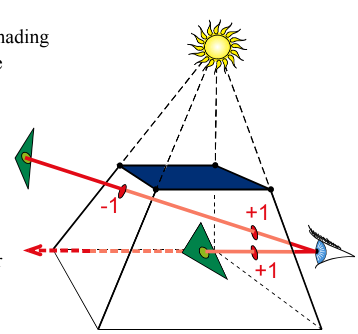
Shadow volumes smarter rendering

- New way to define inside/outside
- Consider ray from eye to visible point
- Increment or decrement a counter each time we intersect a shadow volume polygon
- Points lit: counter =0



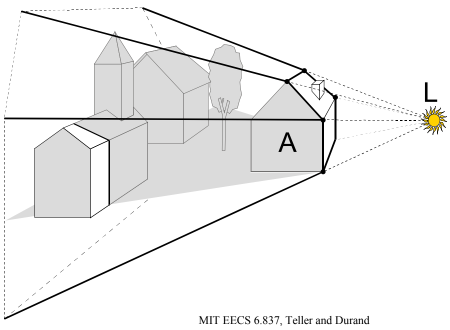
Hardware shadow volumes

- Add counter buffer
- Draw scene with no shading
- Turn off buffer update
- Draw frontfacing shadow polygons
  - If z-pass
  - Increment counter
- Draw backfacing shadow polygons
  - If z-pass
  - Decrement counter
- Compute shading
  - Lit Points have counter=0



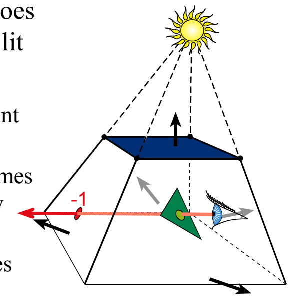
Optimizing shadow volumes

- Use silhouette edges only



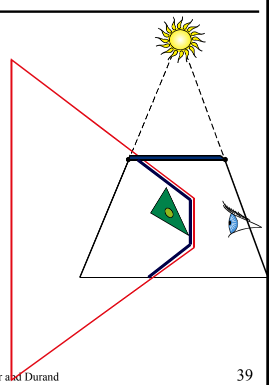
Problem if eye inside shadow

- Then a counter of 0 does not necessarily mean lit
- Three solutions
  - Explicitly test eye point wrt all volumes
  - Clip the shadow volumes and include these new polygons
  - Z-fail shadow volumes



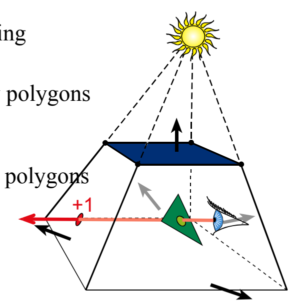
Problem if eye inside shadow

- Clip the shadow volumes and include these new polygons



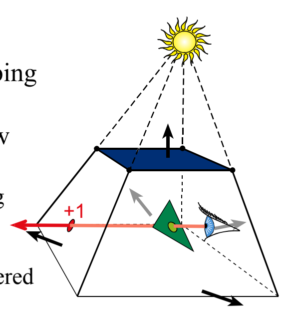
Z-fail shadow volume

- Count from infinity
- Draw scene with no shading
- Turn off buffer update
- Draw frontfacing shadow polygons
  - If z-**fail**
  - **De**crement counter
- Draw backfacing shadow polygons
  - If z-**fail**
  - **In**crement counter
- Compute shading
  - Lit points have counter=0



Z-fail shadow volume

- Count from infinity
- Then we can have problems with far clipping plane
- Can be solved with new hardware trick
  - Depth clamp at clipping stage
  - Instead of clipping a polygon, it can be rendered with maximum depth

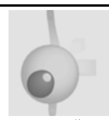


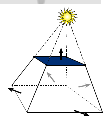
Questions?

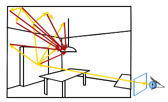
Plate 52 Grandville, *The Shadows (The French Cabinet)* from *La Caricature*, 1830.

Overview

- Shadow map
  - Image-precision, texture mapping
- Shadow volume
  - Object space
- Soft shadows and Monte-Carlo ray tracing

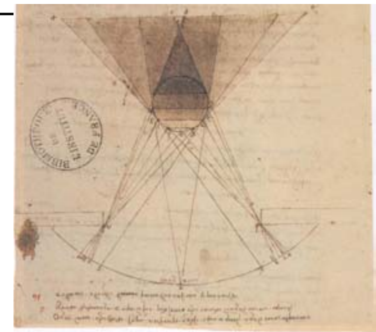






Soft shadows

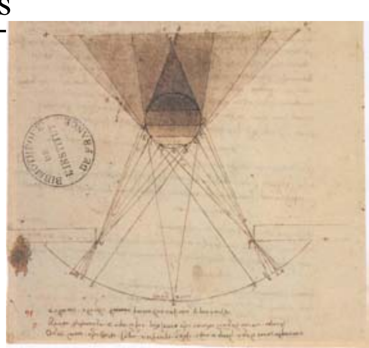
- Caused by extended light sources
- Umbra
  - source completely occluded
- Penumbra
  - Source partially occluded
- Fully lit



XVI. Léonard de Vinci (1452-1519). Lumière d'une fenêtre sur une sphère ombreuse avec (en partant du haut) ombre intermédiaire, primitive, dérivée et (sur la surface, en bas) portée. Plume et lavis sur pointe de métal sur papier. 24 x 38 cm. Paris, Bibliothèque de l'Institut de France (ms. 2185; B.N. 2038, f° 14 r°).

Soft shadows

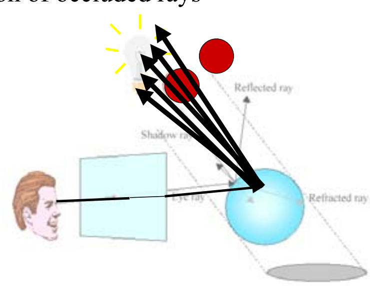
- Radiosity
- Shadow map filtering
  - Hack
  - Not accurate
  - Bias issue
- Sample the extended light source



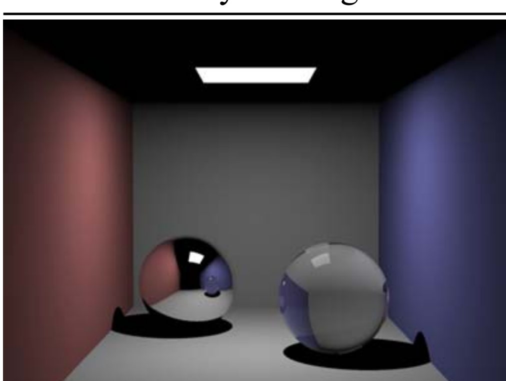
XVI. Léonard de Vinci (1452-1519). Lumière d'une fenêtre sur une sphère ombreuse avec (en partant du haut) ombre intermédiaire, primitive, dérivée et (sur la surface, en bas) portée. Plume et lavis sur pointe de métal sur papier. 24 x 38 cm. Paris, Bibliothèque de l'Institut de France (ms. 2185; B.N. 2038, f° 14 r°).

Soft shadows using ray-tracing

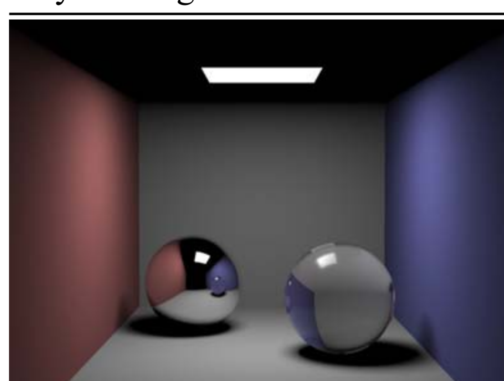
- Send multiple rays to sample the light source
- Use the fraction of occluded rays



Traditional Ray Tracing



Ray Tracing+soft shadows

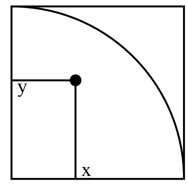


Monte-Carlo ray-tracing

- Probabilistic sampling approach
- Solve the complete light transport equation
- Probabilistic alternative to radiosity

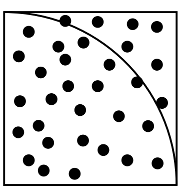
Monte-Carlo computation of π

- Take a square
- Take a random point (x,y) in the square
- Test if it is inside the ¼ disc ($x^2+y^2 < 1$)
- The probability is π /4



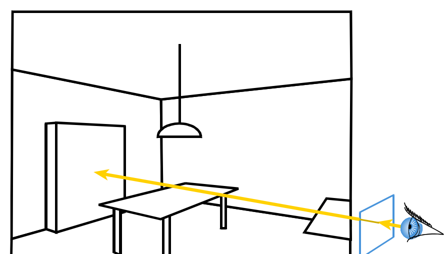
Monte-Carlo computation of π

- The probability is π /4
- Count the inside ratio n = # inside / total # trials
- $\pi \approx n * 4$
- The error depends on the number or trials



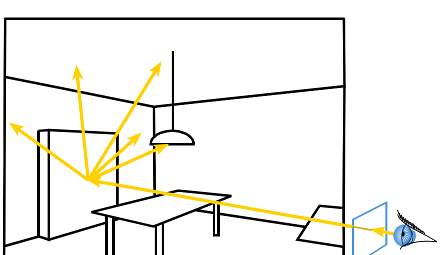
Monte-Carlo

- Cast a ray from the eye through each pixel



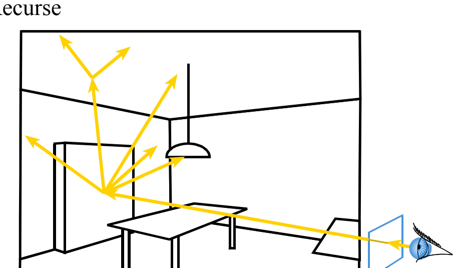
Monte-Carlo

- Cast a ray from the eye through each pixel
- Cast random rays from the visible point



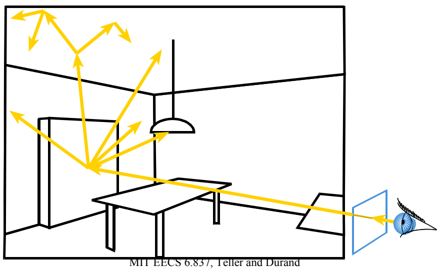
Monte-Carlo

- Cast a ray from the eye through each pixel
- Cast random rays from the visible point
- Recurse



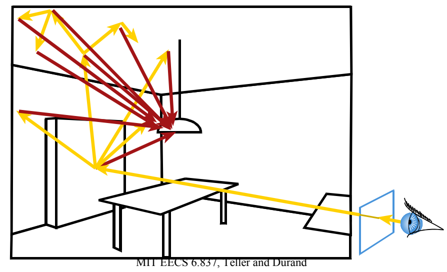
Monte-Carlo

- Cast a ray from the eye through each pixel
- Cast random rays from the visible point
- Recurse



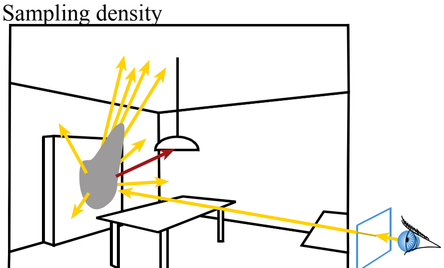
Monte-Carlo

- Systematically sample primary light

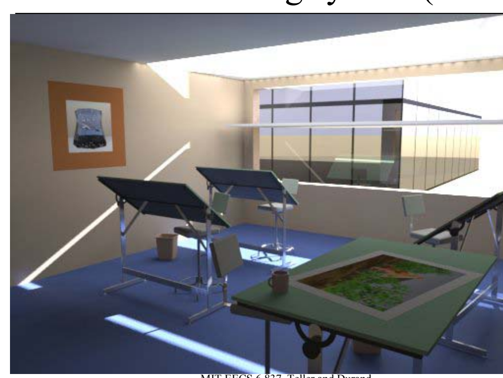


Monte-Carlo

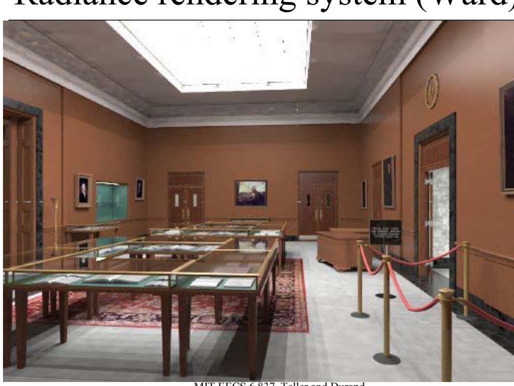
- Take BRD (e.g. Phong model) into account
  - Multiply incoming light
  - Sampling density



Radiance rendering system (Ward)



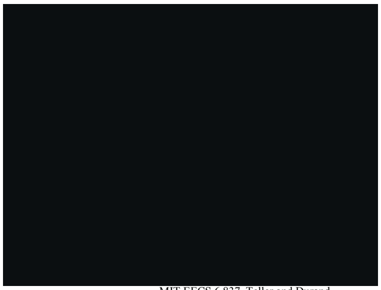
Radiance rendering system (Ward)



Radiance rendering system (Ward)

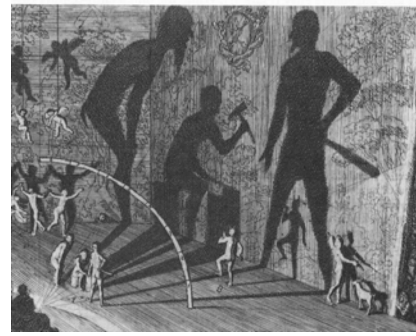
Variation: Photon mapping

- Animation by Henrik Wann Jensen



Questions?

Plate 50 Samuel van Hoogstraten, *Shadow Theatre*. From *Inleyding tot de hooghe schoole der schilderkonst* 1678.



Next week

- Graphics hardware

- Image-based modeling & rendering