3D Rendering

COS 426, Spring 2016

Princeton University

Syllabus

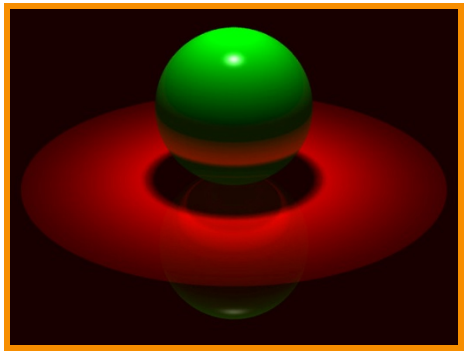
I. Image processing

II. Modeling

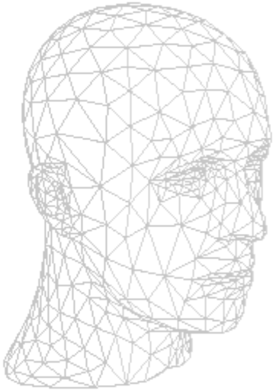
III. Rendering

IV. Animation

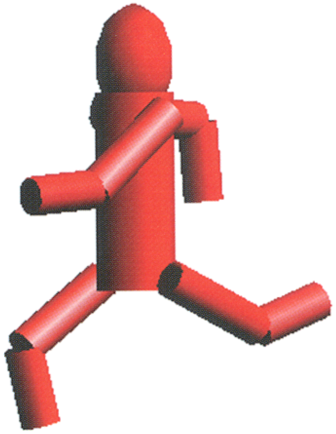
Image Processing
(Rusty Coleman, CS426, Fall99)



Rendering
(Michael Bostock, CS426, Fall99)



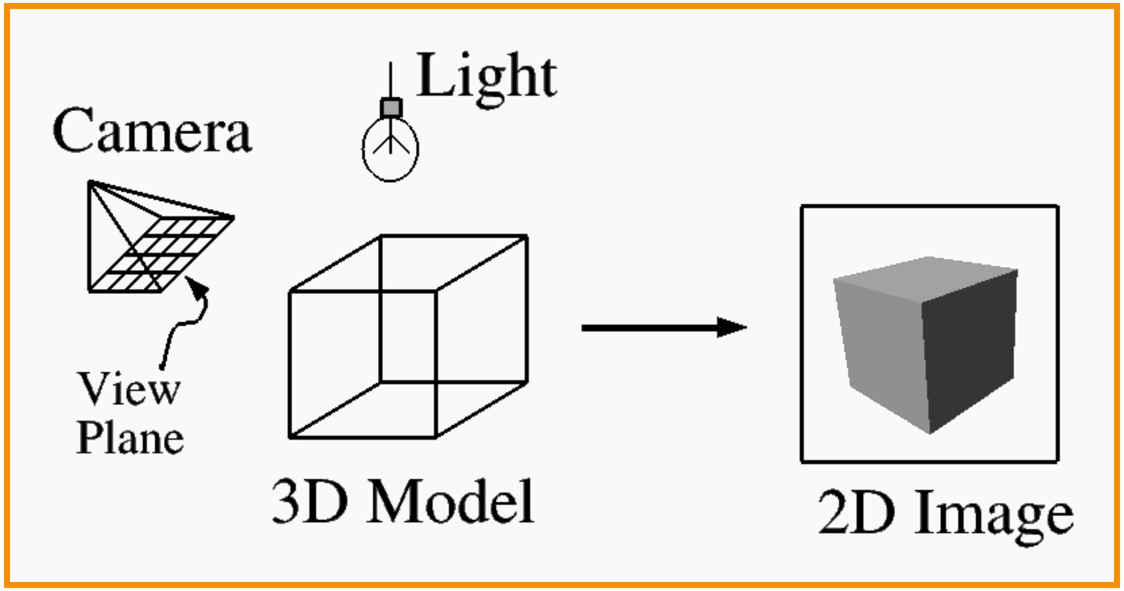
Modeling
(Dennis Zorin, CalTech)



Animation
(Angel, Plate 1)

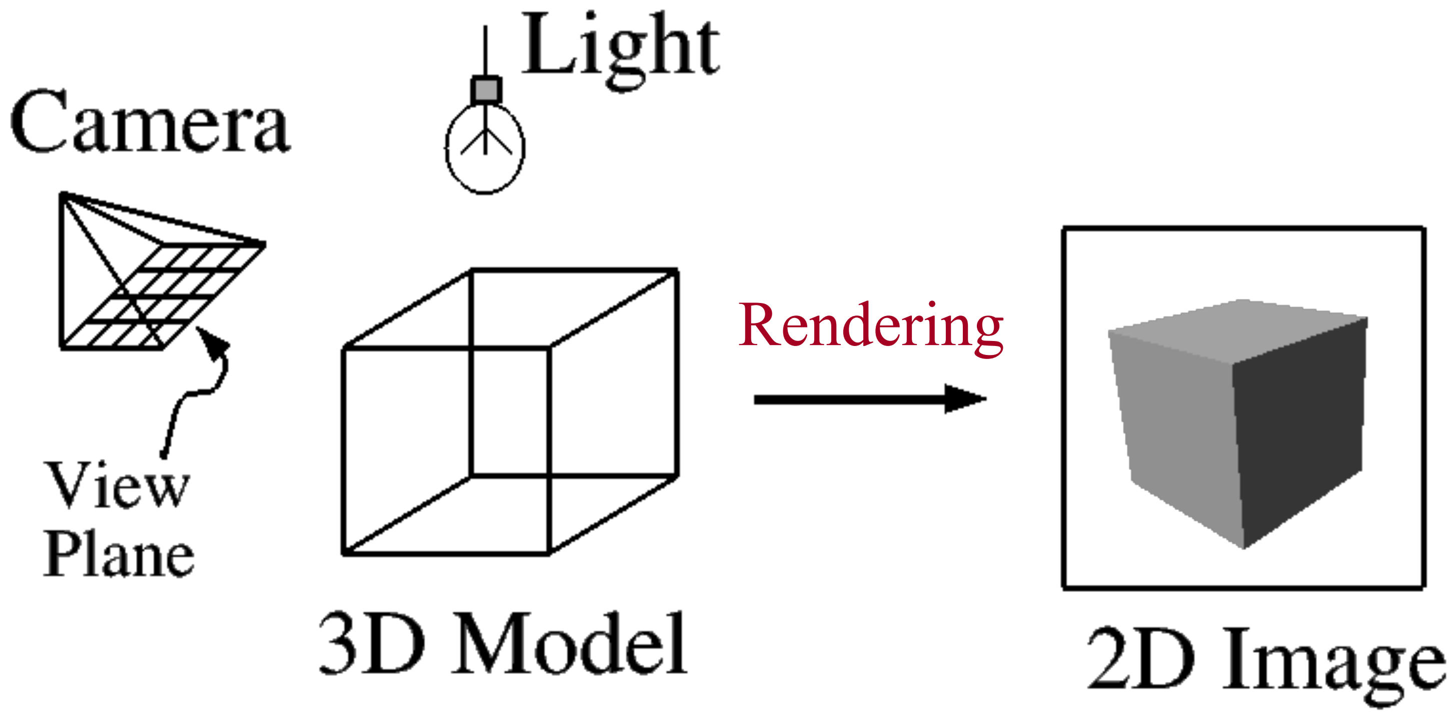
What is 3D Rendering?

- Topics in computer graphics
  - Imaging = *representing 2D images*
  - Modeling = *representing 3D objects*
  - Rendering = *constructing 2D images from 3D models*
  - Animation = *simulating changes over time*



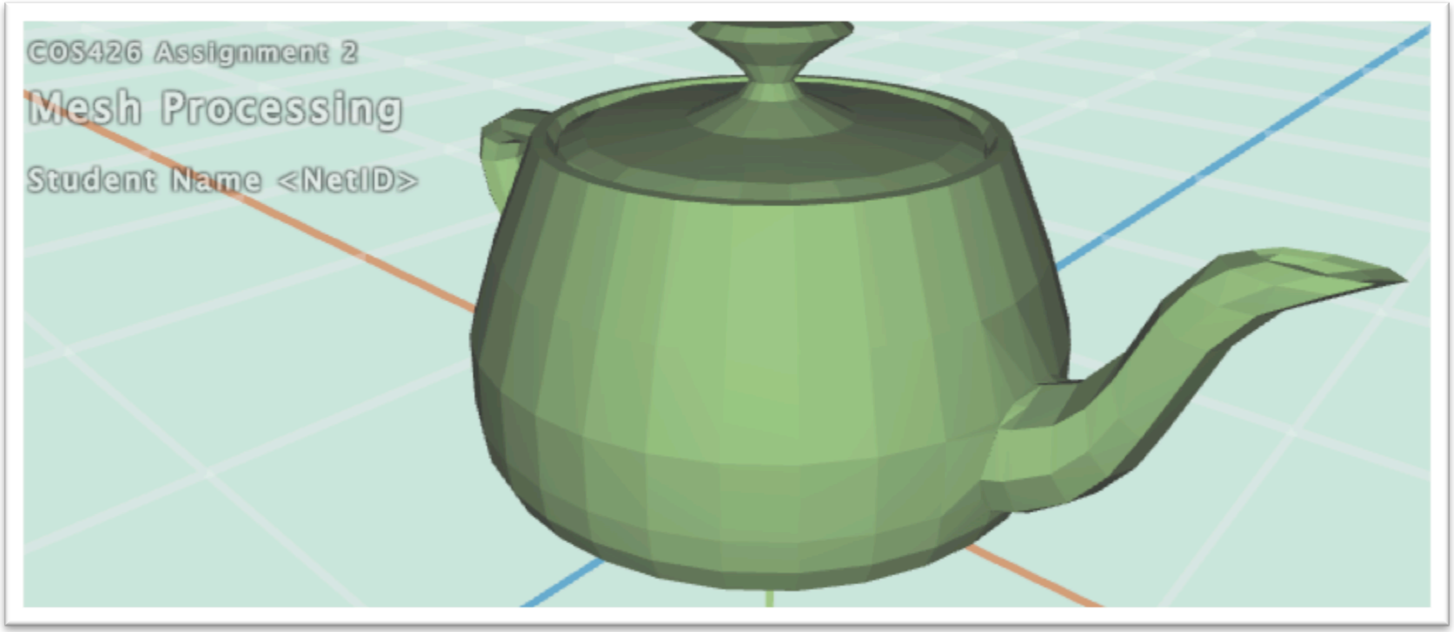
What is 3D Rendering?

- Construct image from 3D model



3D Rendering Scenario I

- Interactive
  - Images generated in fraction of a second (e.g., 1/30) as user controls rendering parameters (e.g., camera)
    - Achieve highest quality possible in given time
    - Useful for visualization, games, etc.



3D Rendering Scenario II

- Offline
  - One image generated with as much quality as possible for a particular set of rendering parameters
    - Take as much time as is needed (minutes)
    - Photorealisism: movies, cut scenes, etc.

Avatar

3D Rendering Issues

- What issues must be addressed by a 3D rendering system?

3D Rendering Example

Pixar

3D Rendering Issues

- What issues must be addressed by a 3D rendering system?

3D Rendering Issues

- What issues must be addressed by a 3D rendering system?
  - Camera
  - Visible surface determinaton
  - Lights
  - Reflectance
  - Shadows
  - Indirect illumination
  - Sampling
  - etc.

3D Rendering Issues

- What issues must be addressed by a 3D rendering system?
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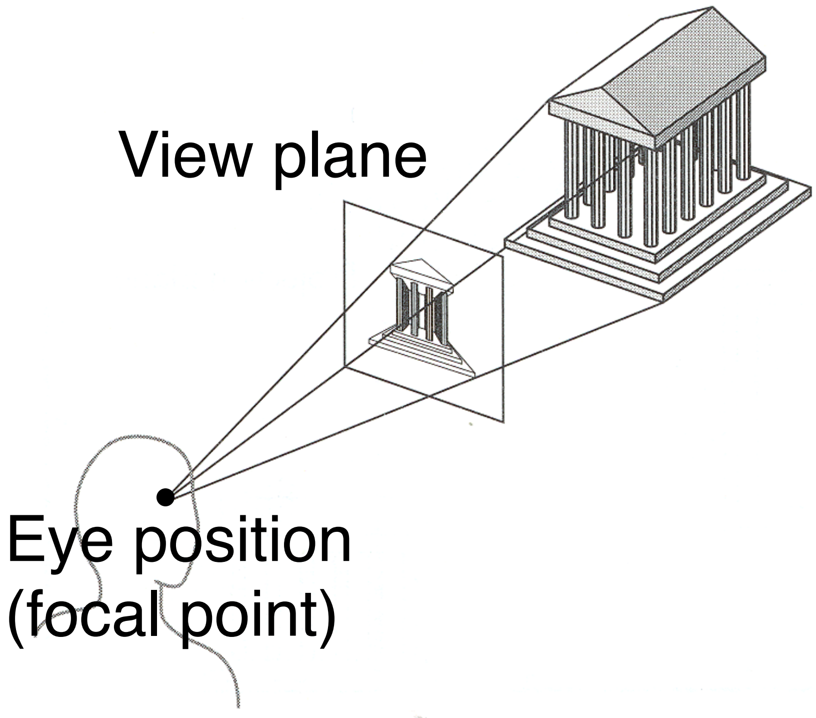
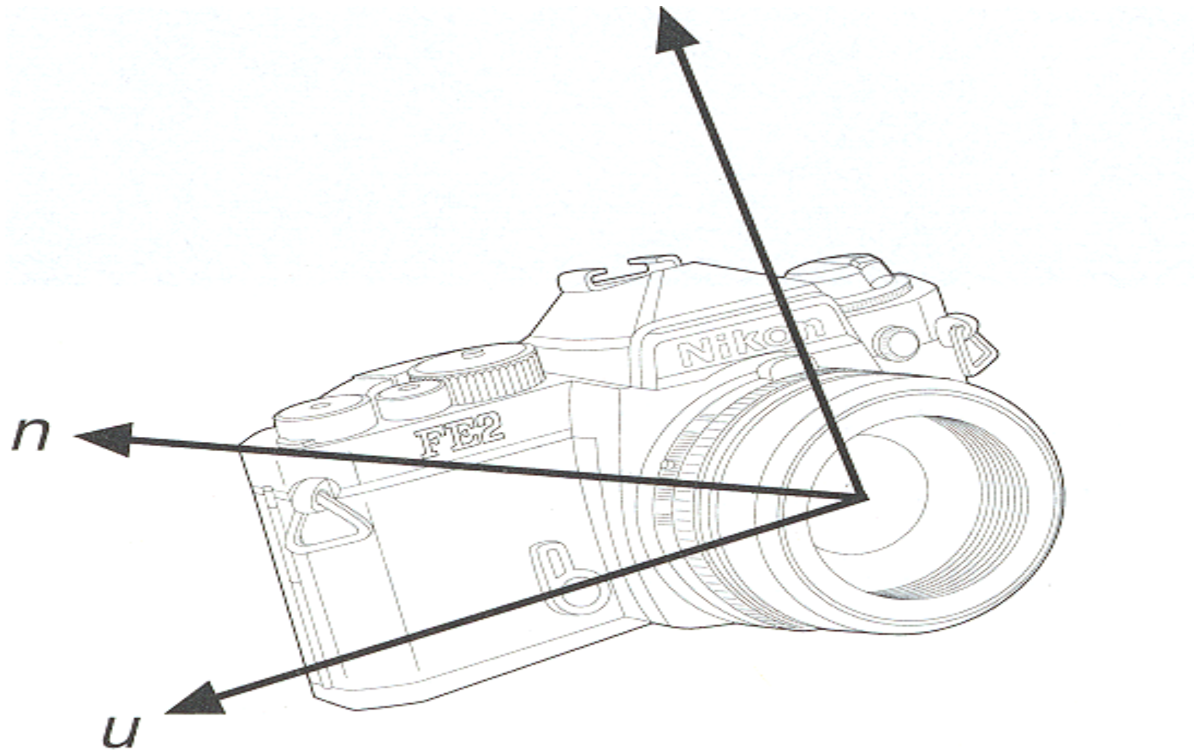
Camera Models

- The most common model is pin-hole camera
  - Light rays arrive along paths toward focal point
  - No lens effects (e.g., everything in focus)



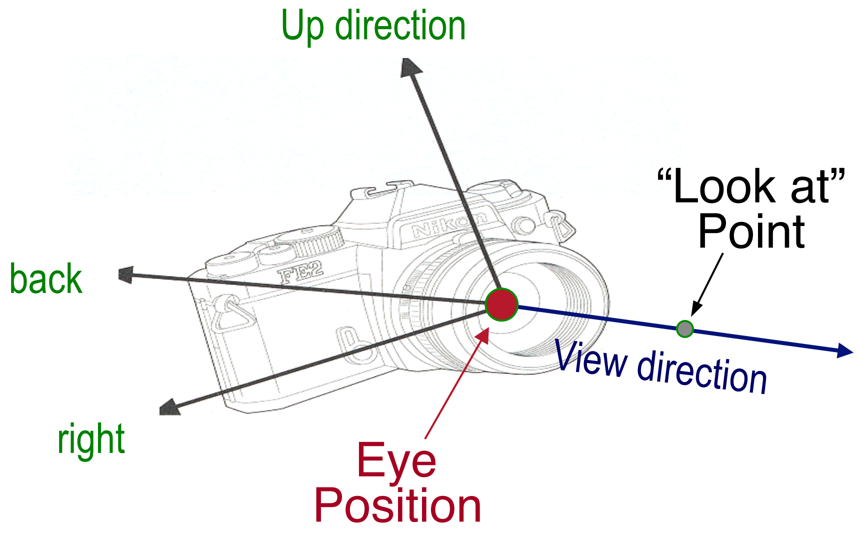
Camera Parameters

- What are the parameters of a pin-hole camera?

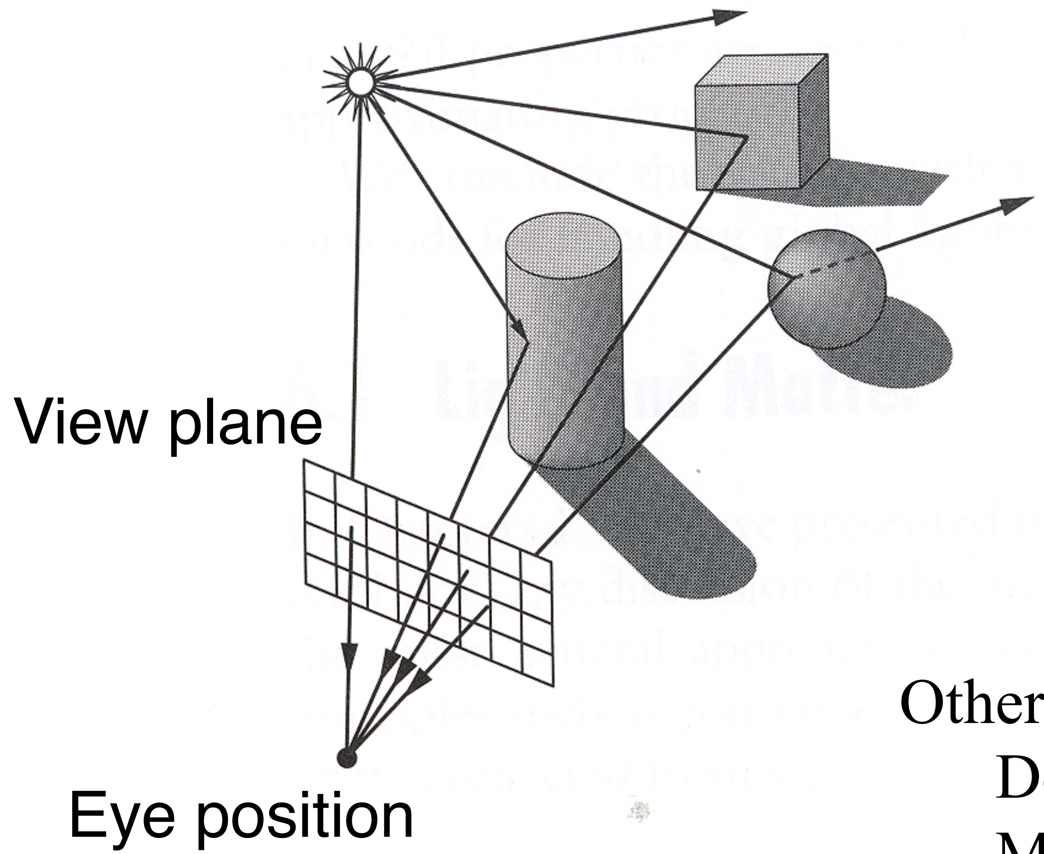


Pinhole Camera Parameters

- Position
  - Eye position (p_x, p_y, p_z)
- Orientation
  - View direction (d_x, d_y, d_z) or “look at” point
  - Up direction (u_x, u_y, u_z)
- Coverage
  - Field of view (fov_x, fov_y)
- Resolution
  - x and y



View Plane



Other camera models consider ...

Depth of field

Motion blur

Lens distortion

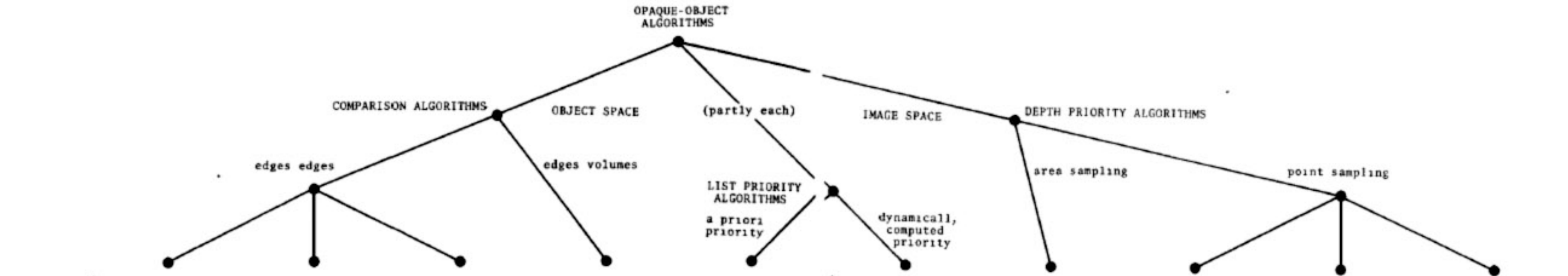
3D Rendering Issues

- What issues must be addressed by a 3D rendering system?
  - Camera
  - Visible surface determination
  - Lights
  - Reflectance
  - Shadows
  - Indirect illumination
  - Sampling
  - etc.

Visible Surface Determination

- The color of each pixel on the view plane depends on the radiance ("amount of light") emanating from visible surfaces

How find visible surfaces?



	APPEL 1967	GALIMBERTI, et al 1969	LOUTREL 1967	ROBERTS 1963	SCHUMACKER, et al 1969
RESTRICTIONS	TP, NP	TP, NP	TP, NP	TP, CC, CF, NP	CF, NP, LS (TP)
COHERENCE	Promote visibility of a vertex to all edges at vertex	Promote visibility of a vertex to all edges at vertex	Promote visibility of a vertex to all edges at vertex		Frame coherence in depth No X coherence used
SORTING (1) What, what property (2) Method (3) Type (4) Result structure (5) Number per frame, number of objects (merge) Number of new entries per frame, length of list (search) Number of searches, length of list	**Back Edge Cull** 1) Edges separating back-facing planes 2) Dot product with normals & topology 3) Cull 4) List of edges, E_s 5) 1, E_t	**Back Edge Cull** 1) Edges separating back-facing planes 2) Dot product with normals & topology 3) Cull 4) List of edges, E_s 5) 1, E_t	**Back Edge Cull** 1) Edges separating back-facing planes 2) Dot product with normals & topology 3) Cull 4) List of edges, E_s 5) 1, E_t	**Back Edge Cull** 1) Edges separating back-facing planes 2) Dot product with normals & topology 3) Cull 4) List of edges, E_s 5) 1, E_t	**Intra-Cluster Priority** 1) Faces - visibility 2) Dot product with normals 3) Exhaustive search 4) Ordered table 5) 0, (off-line)
	Contour Edge Cull 1) Edges separating front & back faces 2) Dot product with normals & topology 3) Cull 4) List, E_c 5) 1, E_t	(Omitted)	(Omitted)	**Clipping Cull** 1) Intersect edge with visible volume 2) 3) Cull 4) E_s 5) 1^s, E_s	**Inter-Cluster Priority** 1) Clusters 2) Dot product with separating planes 3) Prefix scan binary tree 4) ordered table 5) 1, C_t
	Initial Visibility 1) Ray to vertex against all faces 2) Depth, Surroundedness 3) Exhaustive search 4) Quantitative visibility of vertex 5) # Objects, F_r	**Initial Visibility** 1) Ray to vertex against all faces 2) Depth, surroundedness 3) Exhaustive search 4) Quantitative visibility of vertex 5) #objects, F_r	**Initial Visibility** 1) Ray to vertex against all faces 2) Betweenness, surroundedness 3) Exhaustive search 4) Quantitative visibility of vertex 5) #objects, F_r	**Edge/Volume Test** 1) Edges, visibility relative to volumes 2) Linear Programming 3) Mini-max sort 4) Answer 5) E_s + split edges, #objects	**Back-Face Cull** 1) Faces 2) Dot product with face normal 3) Cull 4) Smaller ordered table 5) 1, F_t
	Edge Intersection 1) Intersect one E_s with all E_c 2) Penetration with sweep triangle 3) Cull (unordered) 4) Intersection list 5) E_s, E_c	**Edge Intersection** 1) Intersect one E_s with all E_c 2) Intersect in picture plane, depth 3) Cull (unordered) 4) Intersection list 5) E_s, $E_s - 1$	**Edge Intersection** 1) Intersect one E_s with all E_c 2) Intersect in picture plane, depth 3) Cull (unordered) 4) Intersection list 5) E_s, $E_s - 1$		**Y Cull** 1) Faces by Y extent 2) Mini-max on X intercepts 3) Cull (unordered) 4) X intercepts of relevant segments 5) n, E_s
	Sort Along Edge 1) Intersections on edge, ordering 2) Comparison 3) Bubble 4) Answer 5) E_s, X_v/E_s (Omit if well hidden)	**Sort Along Edge** 1) Intersections on edge, ordering 2) 3) 4) Answer 5) E_s, X_v/E_s (must be done)	**Sort Along Edge** 1) Intersections on edge, ordering 2) 3) 4) Answer 5) E_s, X_v/E_s (Omit if well hidden)		**X Sort** 1) Segments 2) Counters 3) Hardware 4) Segments at this X 5) nm, S_ℓ
					Priority Search 1) Segments, priority 2) Logic network 3) Logic network 4) Visible segment 5) nm, S_ℓ

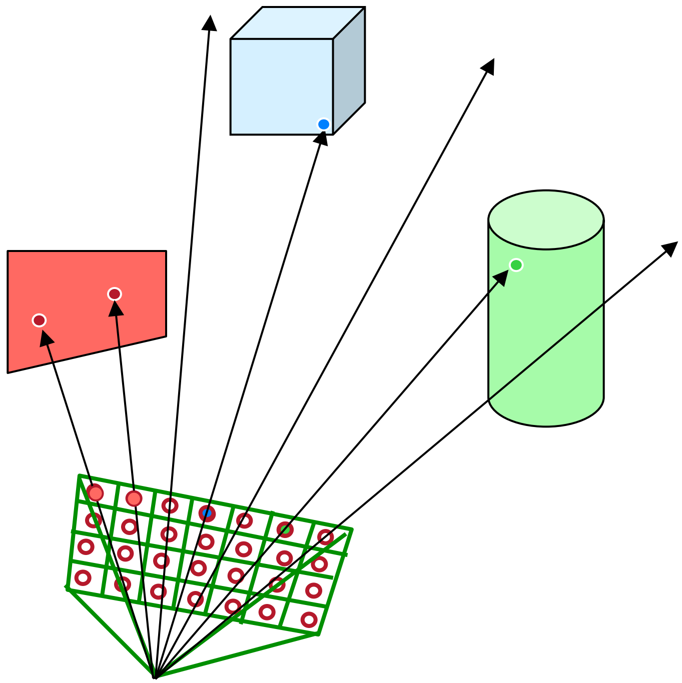
	NEWELL, et al 1972	WARNOCK 1968	WATKINS 1970	ROMNEY, et al 1967	BOUKNIGHT 1969
RESTRICTIONS	None	(TR) None	None	TR, CF, NP	
COHERENCE	None used	Area coherence	Scanline X coherence	Scanline Depth Coherence	Scanline X Coherence
SORTING	**Z Sort** 1) Faces, max Z 2) Comparison of max points 3) n log m 4) Ordered table 5) 1, F_r	**Z Sort (Opt.)** 1) Faces, max Z 2) Comparison of max points 3) n log m 4) Ordered table 5) 1, F_r	**Y Sort** 1) Edges, min Y 2) Comparison 3) Bucket 4) Table of Lists 5) 1, E_r	**Y Sort** 1) Polygons, Y endpoints 2) Comparison 3) 2 bucket 4) Table of lists 5) 1, F_r	**Y Sort** 1) Edges, Min Y 2) Comparison 3) Bucket 4) Table of lists 5) 1, E_r
	Newell Special 1) Faces, pairwise visibility 2) Depth, bounding boxes, separation 3) Bubble, splitting 4) Ordered table 5) 1, F_r+split faces	**Warnock Special** 1) Faces with window 2) Depth, mini-max in X and Y, sum of angles 3) Radix 4 subdivision with overlap 4) Stacks of unordered tables 5) L_v, F_r/factor 1	**X Merge** 1) Edges, X value 2) Comparison 3) Merge (ordred) 4) 2-way linked list 5) E_r, S_ℓ	**X Sort** 1) Edges, X value 2) Comparison 3) 2 bucket 4) Table of lists 5) n, S_ℓ	**X Merge** 1) Edges, X value 2) Comparison 3) Merge (ordered) 4) Linked list 5) E_r, $2S_\ell$ (edges)
	Y Sort 1) Face segment by Y range 2) Y intercept 3) Bucket 4) None 5) F_r + split faces H_f	**Depth Search** 1) Surrounder faces 2) 4-corner compare 3) Exhaustive 4) Answer/failure 5) L_v, F_r/factor 2	**X Sort** 1) Segments, X left 2) Comparison 3) Bubble 4) 2-way linked list 5) n, S_ℓ	**X Priority Search** 1) Edges, X value 2) Comparison 3) Priority search 4) Active segment list 5) n, m	**X Sort** 1) Edges, X value 2) Comparison 3) Bubble 4) 1-way linked list 5) N, $2S_\ell$ (edges)
	X Merge 1) Segments, X intercept 2) Comparison 3) Ordered merge 4) Ordered list 5) S_r, $S_v/2$	**TV Sort (Opt.)** Sort windows into scan-line order if needed	**Span Cull** 1) Segments, overlap with sample span 2) Double comparison 3) Cull ordered list 4) Active list 5) $n{*}S_v * f\ (>1)$, S_ℓ	**Z Search** 1) Segments, depth 2) Linear equations and comparison 3) Search (unordered) 4) Visible segment 5) $n{*}2S_\ell$, D_c (Omitted if X priorities same as last time)	**Z Search** 1) Segments, depth 2) Linear equations and comparison 3) Search of unordered active list 4) Visible segment 5) $n{*}2S_\ell$, D_c
			Z Search 1) Segments, Z 2) Depth by logarithmic search 3) Search (unordered) 4) Visible segment 5) $n{*}S_v{*}f(>1)$, D_c		

Figure 29. Characterization of ten opaque-object algorithms b. Comparison of the algorithms.

ACM Comput. Surv. 6, 1 (March 1974)

Ray Casting

- For each sample …
  - Construct ray from eye position through view plane
  - Find first surface intersected by ray through pixel
  - Compute color of sample based on surface radiance



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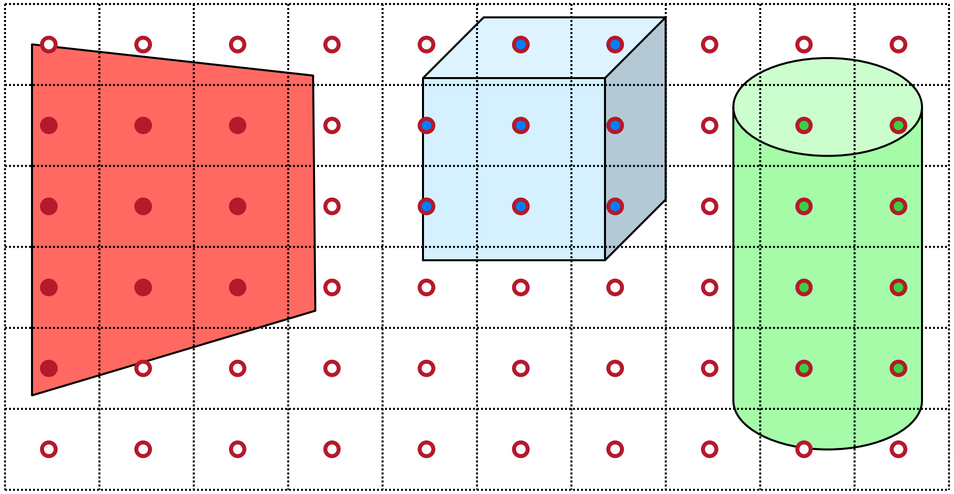
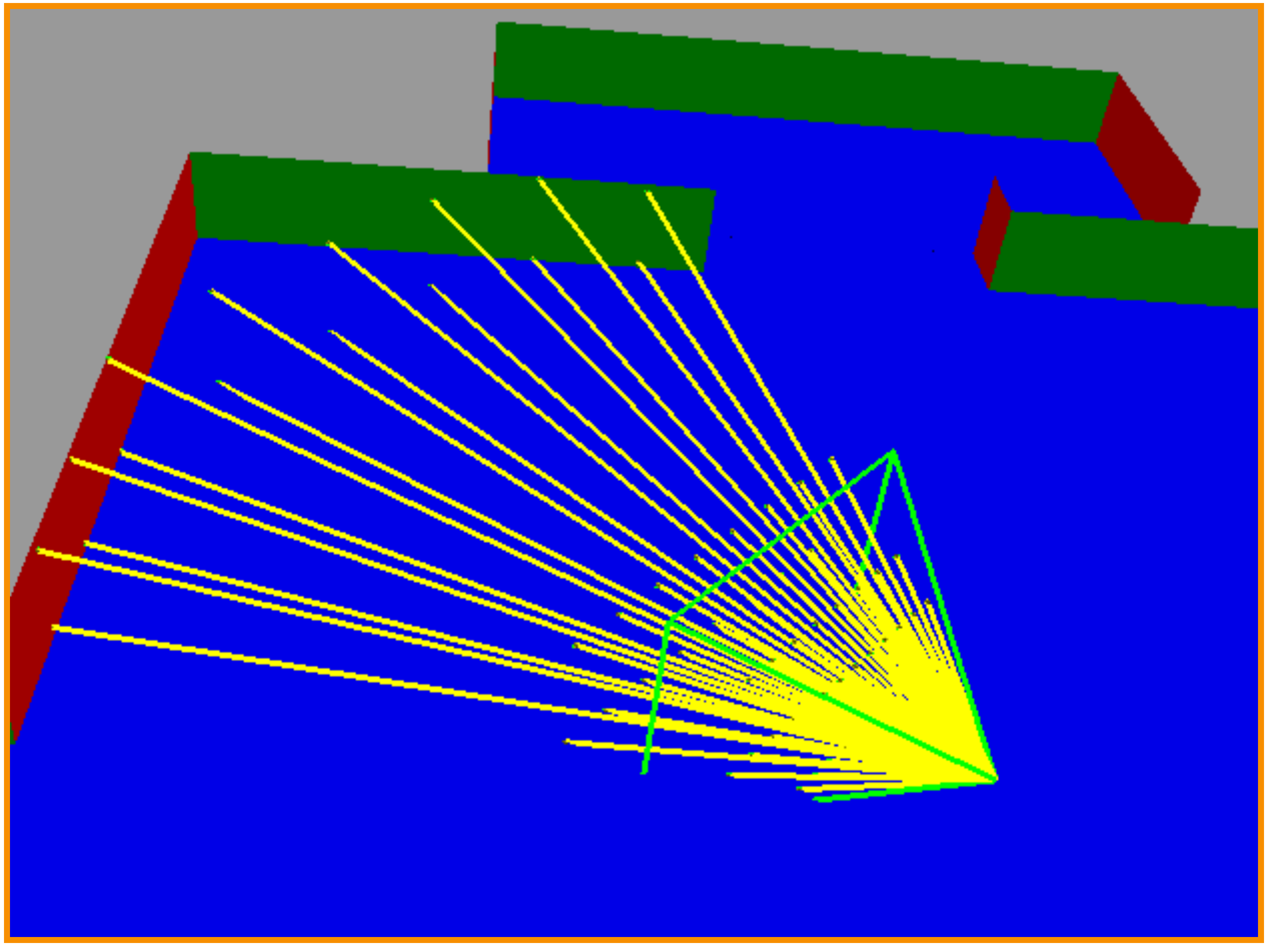


Ray Casting Example



Rays from camera in simple scene

3D Rendering Issues

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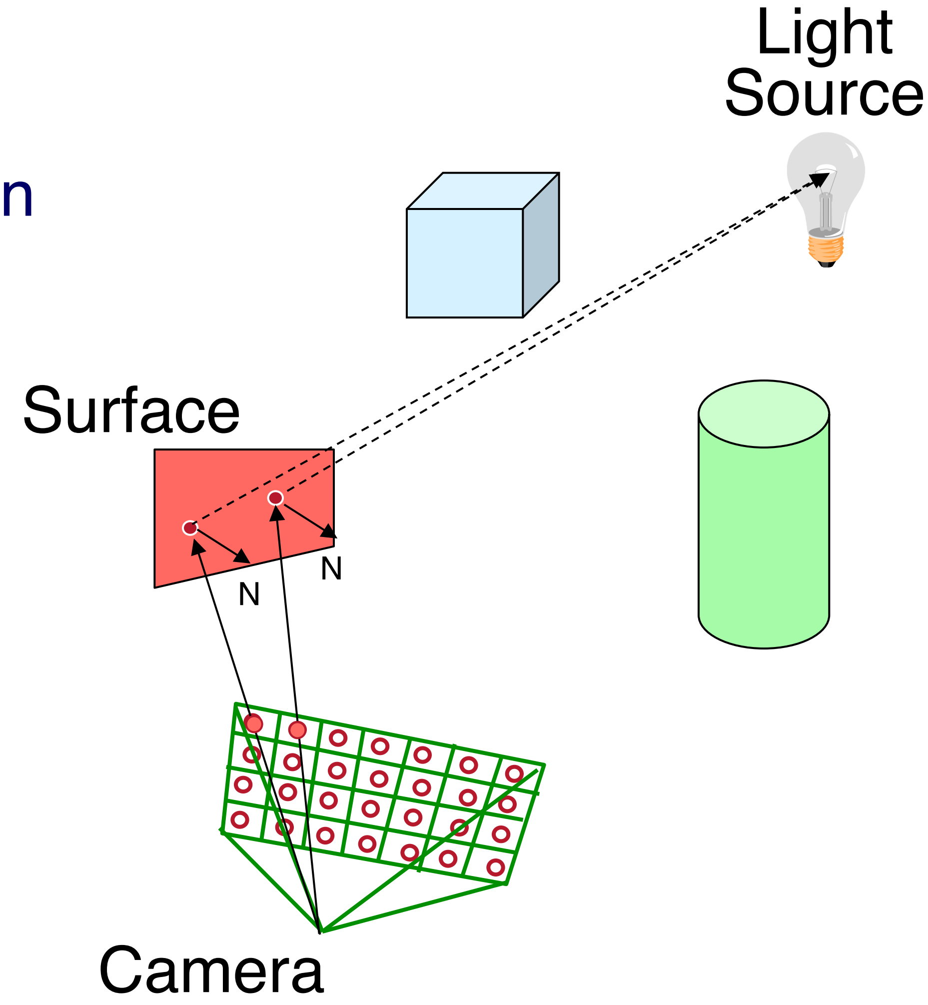
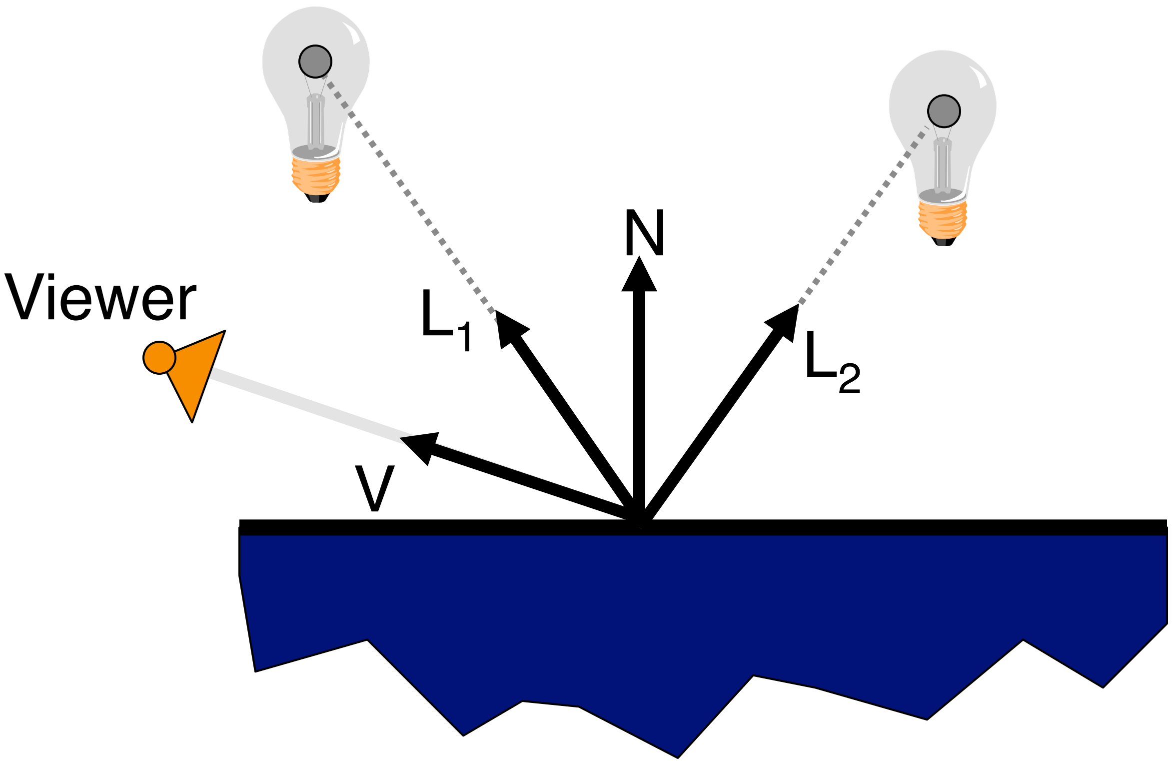
  - Sampling
  - etc.

Lighting Simulation

- Lighting parameters
  - Light source emission
  - Surface reflectance
  - Atmospheric attenuation
  - Camera response



Lighting Simulation



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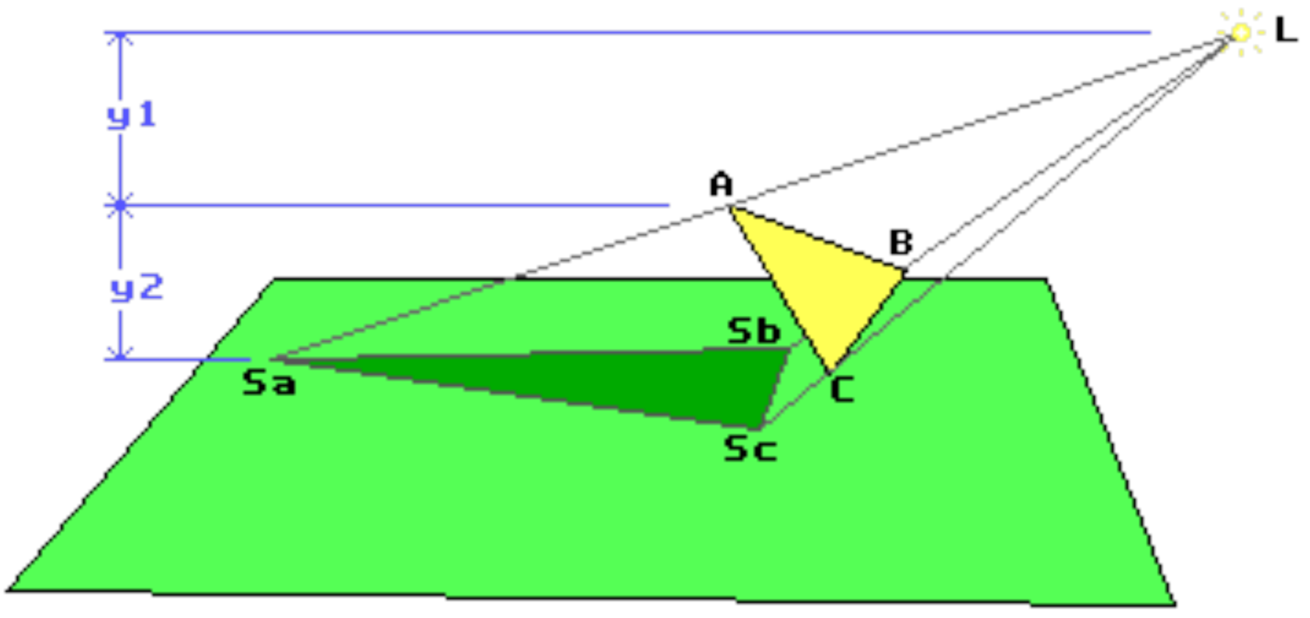
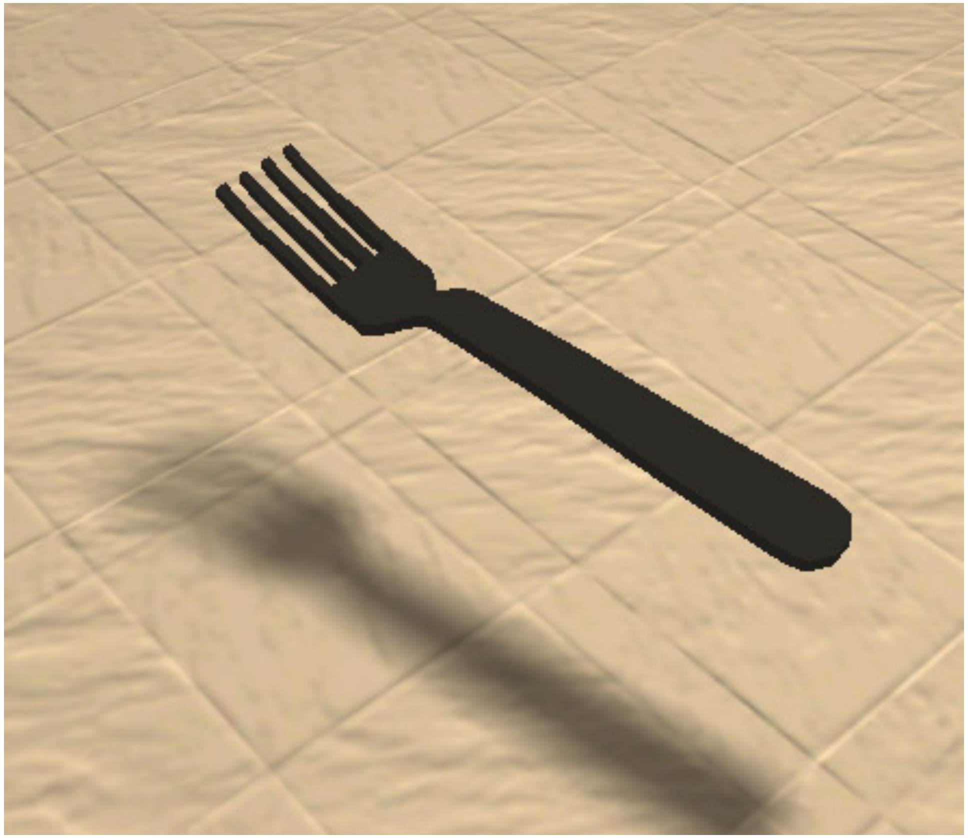
Shadows

- Occlusions from light sources



Shadows

- Occlusions from light sources
  - Soft shadows with area light source



Moller

Shadows

Herf

3D Rendering Issues

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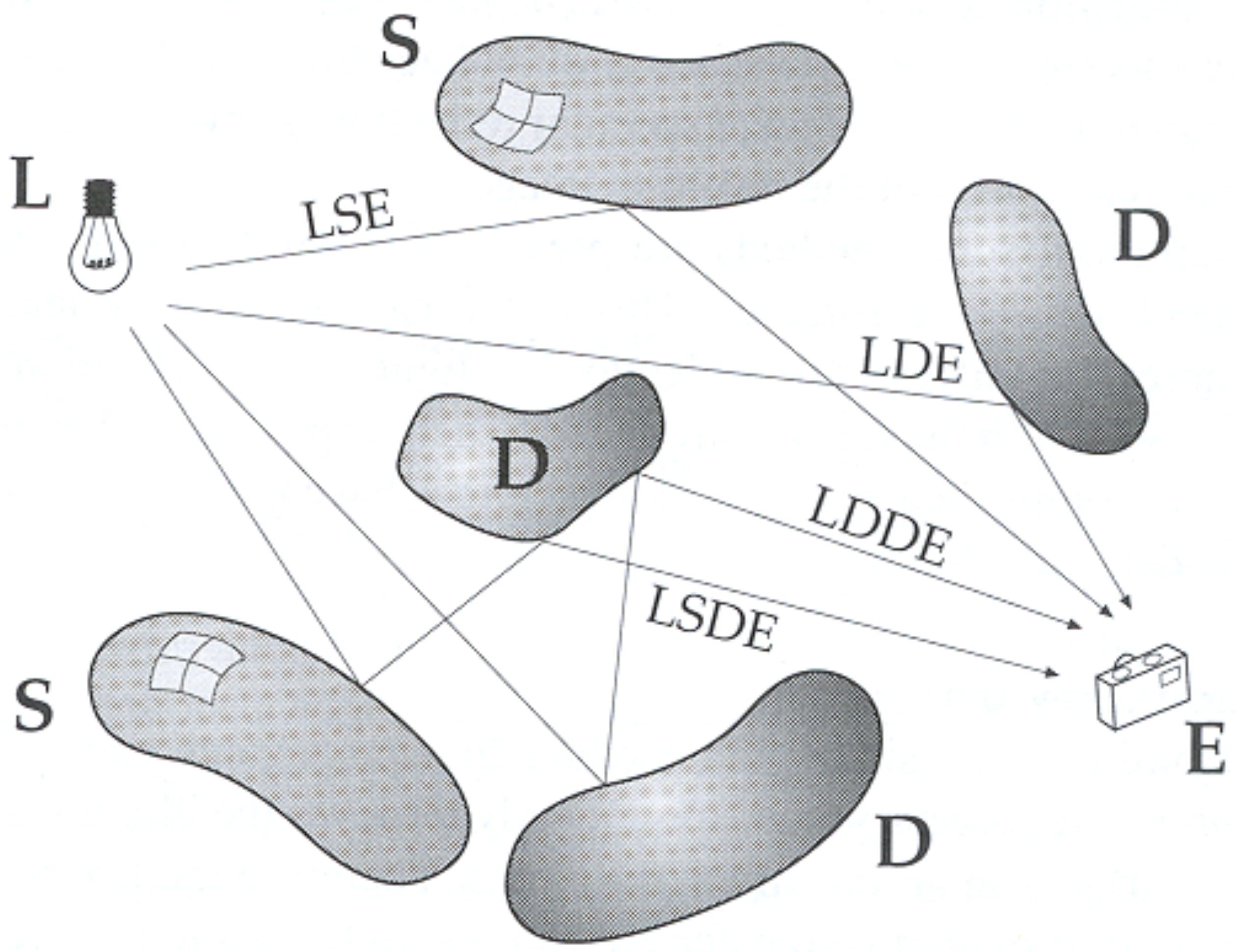
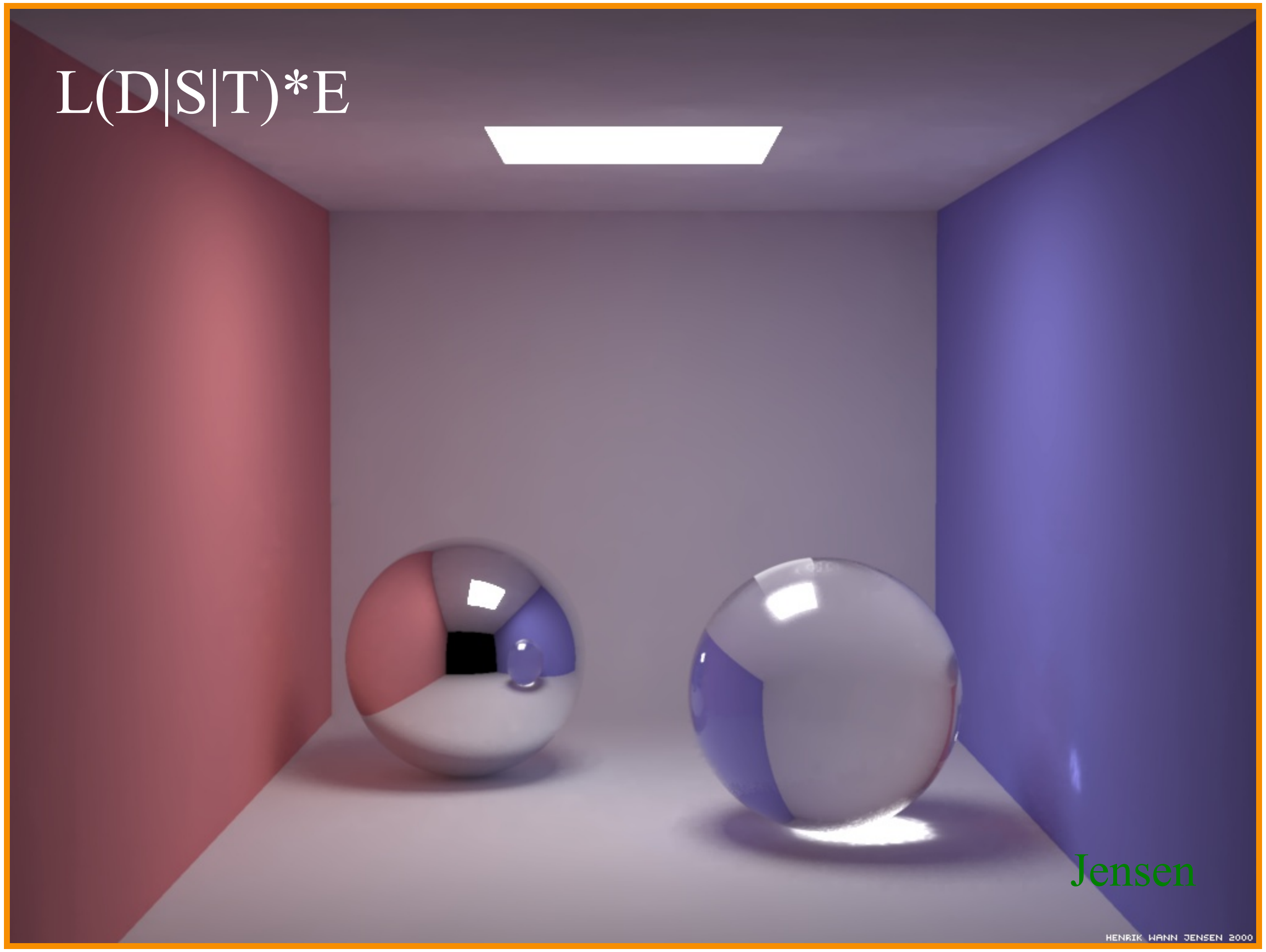
Indirect Illumination



Indirect Illumination



+ indirect diffuse illumination

Henrik Wann Jensen

3D Rendering Issues

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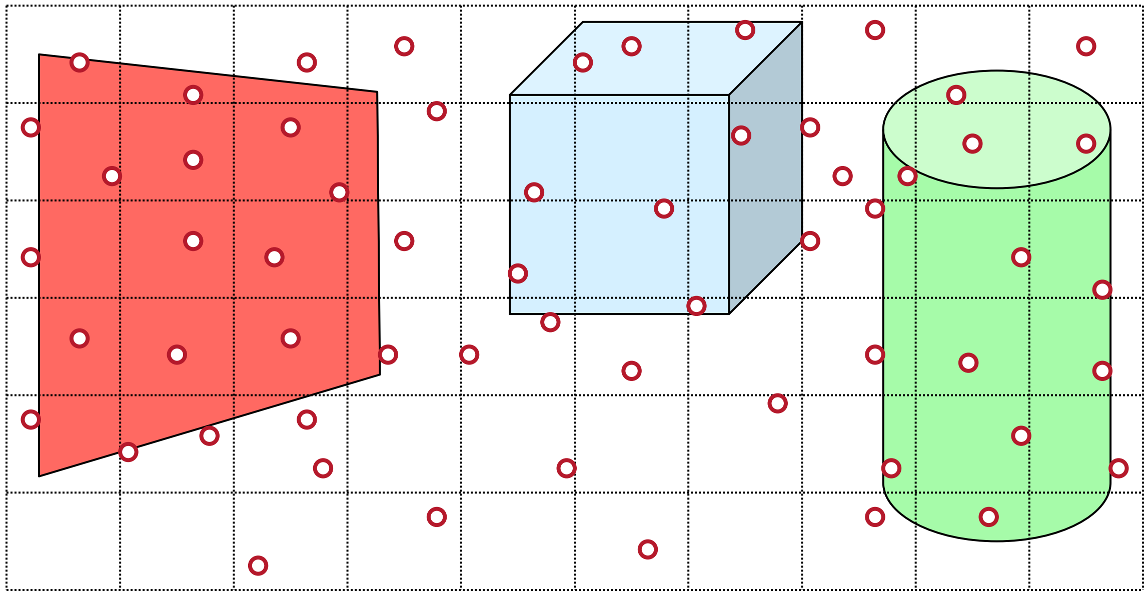
Sampling

- Scene can be sampled with any ray
  - Rendering is a problem in sampling and reconstruction



Summary

- Topics for after spring break
  - Camera
  - Visible surface determinaton
  - Shadows
  - Reflectance
  - Indirect illumination
  - Sampling
  - etc.

Tricycle
(James Percy, CS 426, Fall99)