3D Rendering

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Princeton University
C0S 426, Fall 2000

Course Syllabus

I. Image processing

II. Rendering

III. Modeling

IV. Animation

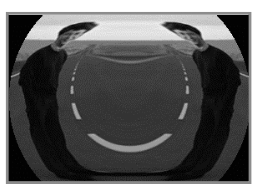
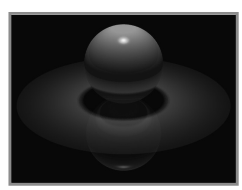
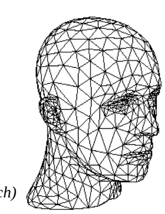


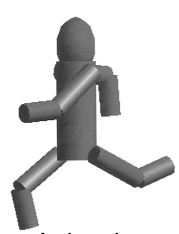
Image Processing
(Rusty Coleman, CS426, Fall99)



Rendering
(Michael Bostock, CS426, Fall99)



Modeling
(Dennis Zorin, CalTech)



Animation
(Angel, Plate 1)

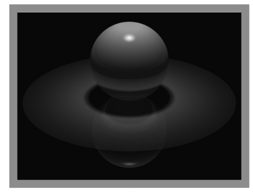
Where Are We Now?

I. Image processing

II. Rendering

III. Modeling

IV. Animation



Rendering

(Michael Bostock, CS426, Fall99)

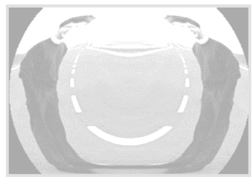
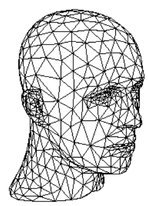


Image Processing

(Rusty Coleman, CS426, Fall99)



Modeling

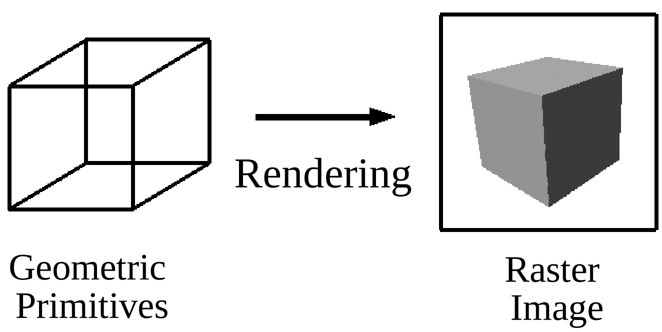
(Dennis Zorin, CalTech)

Animation

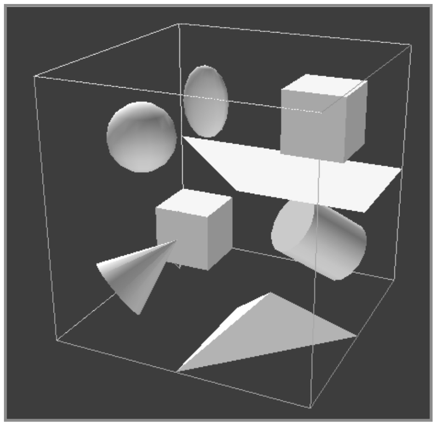
(Angel, Plate 1)

Rendering

- Generate an image from geometric primitives



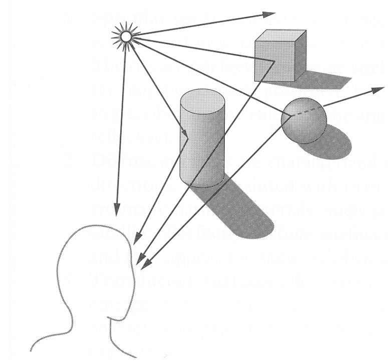
3D Rendering Example



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

Overview

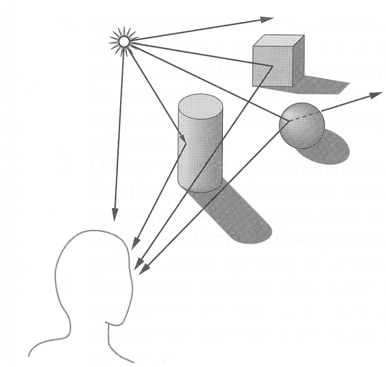
- 3D scene representation
- 3D viewer representation
- Visible surface determination
- Lighting simulation



Overview

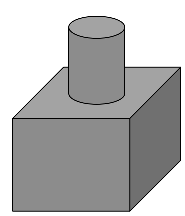
» **3D scene representation**
- 3D viewer representation
- Visible surface determination
- Lighting simulation

How is the 3D scene described in a computer?



3D Scene Representation

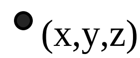
- Scene is usually approximated by 3D primitives
  - Point
  - Line segment
  - Polygon
  - Polyhedron
  - Curved surface
  - Solid object
  - etc.



3D Point

- Specifies a location
  - Represented by three coordinates
  - Infinitely small

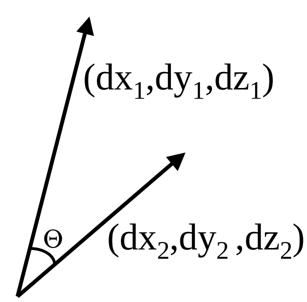
```
typedef struct {
    Coordinate x;
    Coordinate y;
    Coordinate z;
} Point;
```



3D Vector

- Specifies a direction and a magnitude
  - Represented by three coordinates
  - Magnitude ||V|| = sqrt(dxdx + dydy + dzdz)
  - Has no location

```
typedef struct {
    Coordinate dx;
    Coordinate dy;
    Coordinate dz;
} Vector;
```

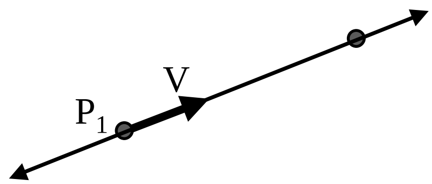


- Dot product of two 3D vectors
  - $V_1 \cdot V_2 = dx_1 dx_2 + dy_1 dy_2 + dz_1 dz_2$
  - $V_1 \cdot V_2 = ||V_1|| \, ||V_2|| \cos(\Theta)$

3D Line

- Line segment with both endpoints at infinity
  - Parametric representation:
    - » $P = P_1 + t\,V, \quad (-\infty < t < \infty)$

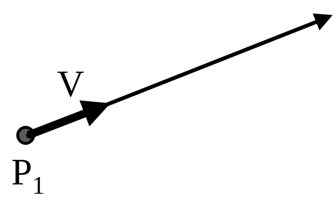
```
typedef struct {
    Point P1;
    Vector V;
} Line;
```



3D Ray

- Line segment with one endpoint at infinity
  - Parametric representation:
    - » $P = P_1 + t\,V, \quad (0 <= t < \infty)$

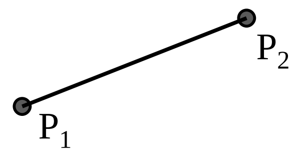
```
typedef struct {
    Point P1;
    Vector V;
} Ray;
```



3D Line Segment

- Specifies a linear combination of two points
  - Parametric representation:
    - » $P = P_1 + t\,(P_2 - P_1), \quad (0 \le t \le 1)$

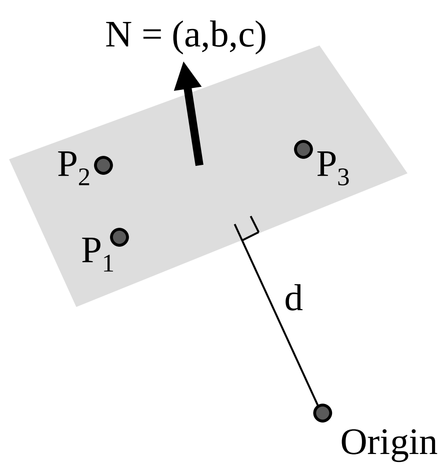
```
typedef struct {
    Point P1;
    Point P2;
} Segment;
```



3D Plane

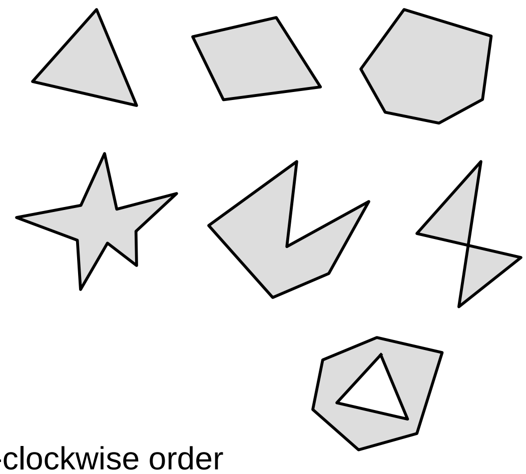
- Specifies a linear combination of three points
  - Implicit representation:
    - » $P \cdot N + d = 0$, or
    - » $ax + by + cz + d = 0$

```
typedef struct {
    Vector N;
    Distance d;
} Plane;
```



3D Polygon

- Area “inside” a sequence of coplanar points
  - Triangle
  - Quadrilateral
  - Convex
  - Star-shaped
  - Concave
  - Self-intersecting
  - Holes



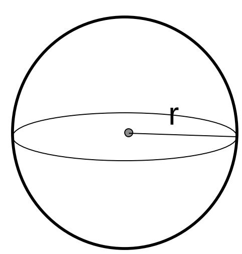
```
typedef struct {
    Point *points;
    int npoints;
} Polygon;
```

Points are in counter-clockwise order

3D Sphere

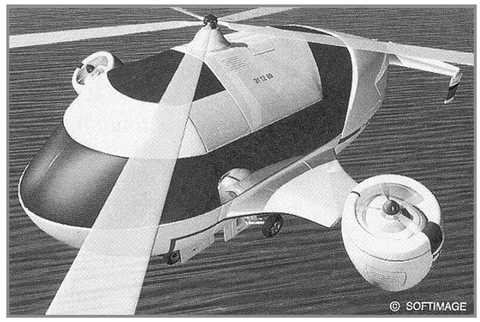
- All points at distance “r” from point “(c_x, c_y, c_z)”
  - Implicit representation:
    - » $(x - c_x)^2 + (y - c_y)^2 + (z - c_z)^2 = r^2$
  - Parametric representation:
    - » $x = r \cos(\phi) \cos(\Theta)$
    - » $y = r \cos(\phi) \sin(\Theta)$
    - » $z = r \sin(\phi)$

```
typedef struct {
    Point center;
    Distance radius;
} Sphere;
```



3D Geometric Primitives

- More detail on 3D modeling later in course
  - Point
  - Line segment
  - Polygon
  - Polyhedron
  - Curved surface
  - Solid object
  - etc.



H&B Figure 10.46

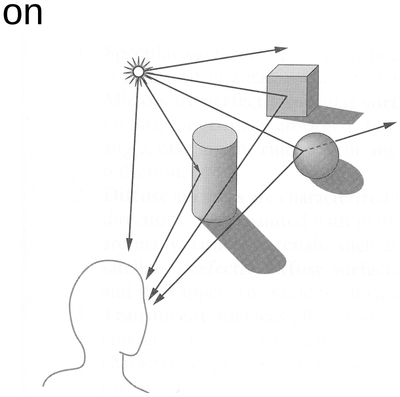
Overview

- 3D scene representation

» **3D viewer representation**

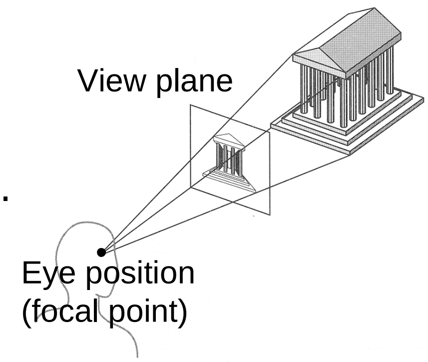
- Visible surface determination
- Lighting simulation

How is the viewing device described in a computer?



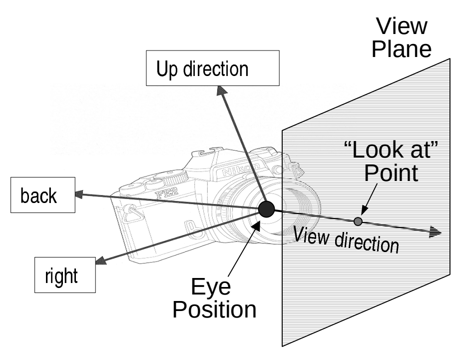
Camera Models

- The most common model is pin-hole camera
  - All captured light rays arrive along paths toward focal point without lens distortion (everything is in focus)
  - Sensor response proportional to radiance
- Other models consider ...
  - Depth of field
  - Motion blur
  - Lens distortion

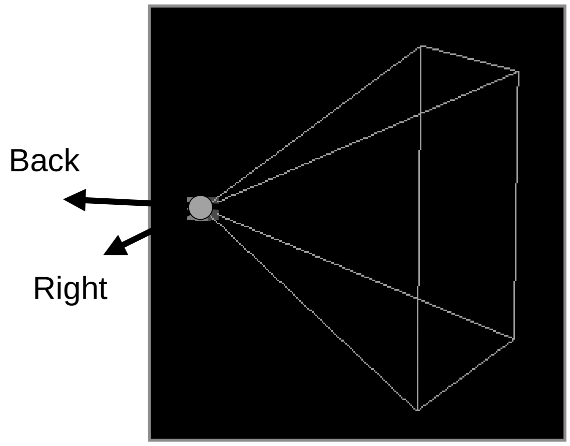


Camera Parameters

- Position
  - Eye position (px, py, pz)
- Orientation
  - View direction (dx, dy, dz)
  - Up direction (ux, uy, uz)
- Aperature
  - Field of view (xfov, yfov)
- Film plane
  - "Look at" point
  - View plane normal



Demo



View Frustum

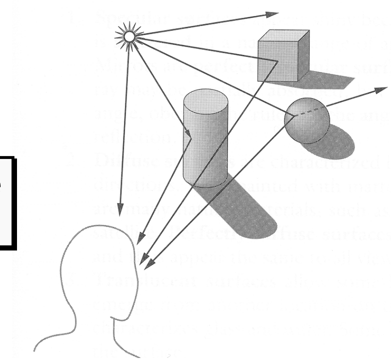
Overview

- 3D scene representation
- 3D viewer representation

» **Visible surface determination**

- Lighting simulation

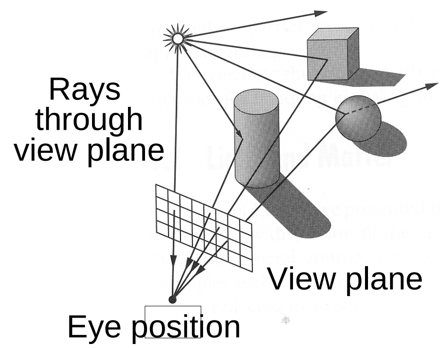
How can the front-most surface be found with an algorithm?



Visible Surface Determination

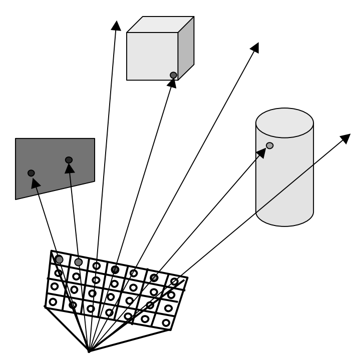
- The color of each pixel on the view plane depends on the radiance emanating from visible surfaces

Simplest method is ray casting



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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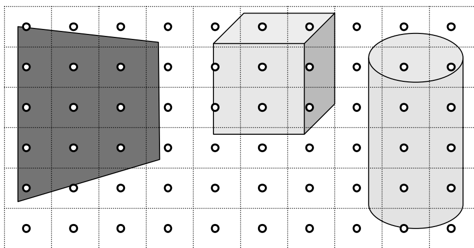

Visible Surface Determination

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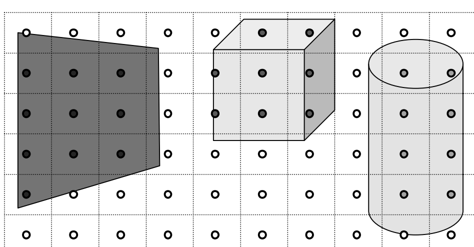
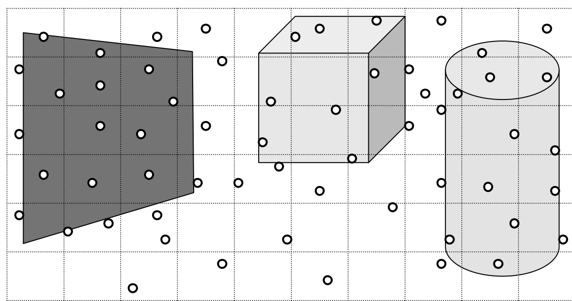


More efficient algorithms utilize spatial coherence!

Rendering Algorithms

- Rendering is a sampling and reconstruction problem!

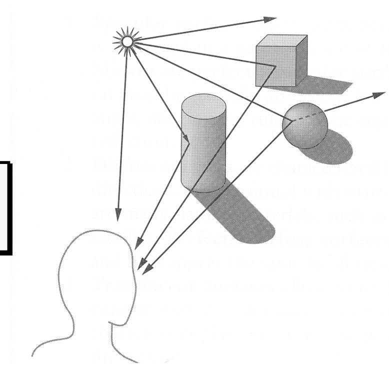


Overview

- 3D scene representation
- 3D viewer representation
- Visible surface determination

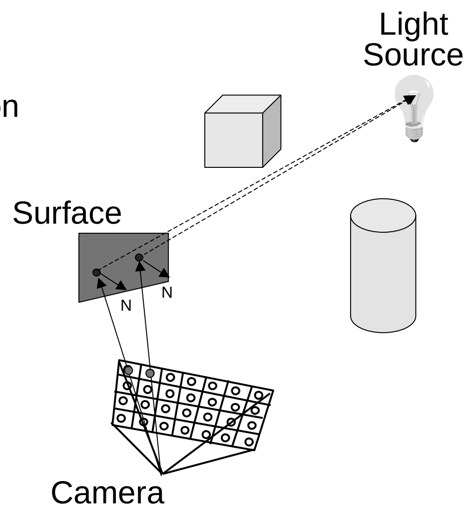
» **Lighting simulation**

How do we compute the radiance for each sample ray?



Lighting Simulation

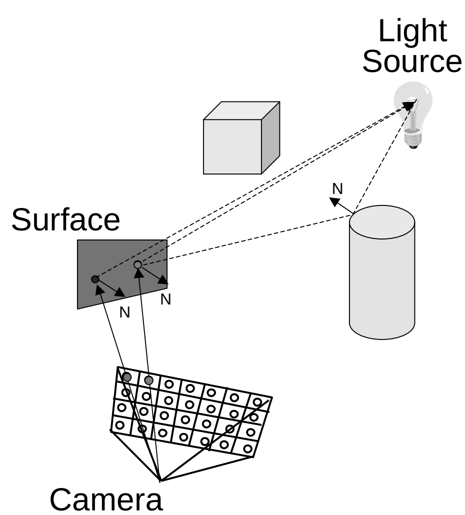
- Lighting parameters
  - Light source emission
  - Surface reflectance
  - Atmospheric attenuation
  - Camera response



Lighting Simulation

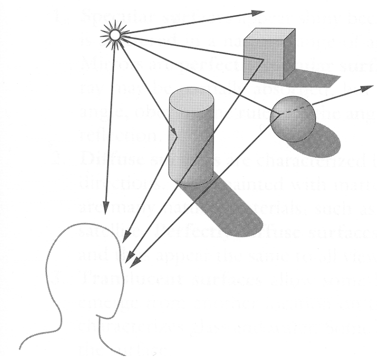
- Direct illumination
  - Ray casting
  - Polygon shading
- Global illumination
  - Ray tracing
  - Monte Carlo methods
  - Radiosity methods

More on these methods later!



Summary

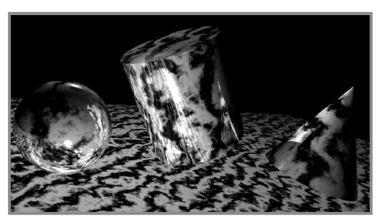
- Major issues in 3D rendering
  - 3D scene representation
  - 3D viewer representation
  - Visible surface determination
  - Lighting simulation



- Concluding note
  - Accurate physical simulation is complex and intractable
    - » Rendering algorithms apply many approximations to simplify representations and computations

Next Week

- Ray intersections
- Light and reflectance models
- Indirect illumination



Render Boy
(R. Kalnins & H. Oki, Assignment 5, CS 426, Fall98, Princeton University)

For assignment #2, you will write a ray tracer!