3D Rendering

Adam Finkelstein
Princeton University
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Course Syllabus
I. Image processing
II. Rendering
III. Modeling
IV. Animation

Where Are We Now?
I. Image processing
II. Rendering
III. Modeling
IV. Animation

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 primitves
  o Point
  o Line segment
  o Polygon
  o Polyhedron
  o Curved surface
  o Solid object
  o etc.

3D Point

• Specifies a location
  o Represented by three coordinates
  o Infinitely small

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

(x,y,z)

3D Vector

• Specifies a direction and a magnitude
  o Represented by three coordinates
  o Magnitude ||V|| = sqrt(dx dx + dy dy + dz dz)
  o Has no location

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

(dx,dy,dz)
### 3D Vector
- Specifies a direction and a magnitude
  - Represented by three coordinates
  - Magnitude $|V| = \sqrt{dx^2 + dy^2 + dz^2}$
  - Has no location
- Dot product of two 3D vectors
  - $V_1 \cdot V_2 = dx_1dx_2 + dy_1dy_2 + dz_1dz_2$
  - $V_1 \cdot V_2 = |V_1||V_2|\cos(\theta)$

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

### 3D Line Segment
- Linear path between two points
- Use a linear combination of two points
  - Parametric representation:
    - $P = P_1 + t (P_2 - P_1), \quad (0 \leq t \leq 1)$

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

### 3D Ray
- Line segment with one endpoint at infinity
  - Parametric representation:
    - $P = P_1 + t V, \quad (0 \leq t < \infty)$

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

### 3D Line
- Line segment with both endpoints at infinity
  - Parametric representation:
    - $P = P_1 + t V, \quad (-\infty < t < \infty)$

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

### 3D Plane
- A linear combination of three points
3D Plane
- A linear combination of three points
  - Implicit representation:
    - \( P \cdot N + d = 0 \), or
    - \( ax + by + cz + d = 0 \)
- \( N \) is the plane “normal”
  - Unit-length vector
  - Perpendicular to plane

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

3D Polygon
- Area “inside” a sequence of coplanar points
  - Triangle
  - Quadrilateral
  - Convex
  - Star-shaped
  - Concave
  - Self-intersecting
- Points are in counter-clockwise order
  - Holes (use > 1 polygon struct)

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

3D Sphere
- All points at distance “\( r \)” from point “(\( cx, cy, cz \))”
  - Implicit representation:
    - \( (x - cx)^2 + (y - cy)^2 + (z - cz)^2 = r^2 \)
  - Parametric representation:
    - \( x = r \cos(\phi) \cos(\Theta) + cx \)
    - \( y = r \cos(\phi) \sin(\Theta) + cy \)
    - \( z = r \sin(\phi) + cz \)

```
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
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    - Visible surface determination
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```
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
```

```
View plane
Eye position (focal point)
```

```
H&B Figure 10.46
```
Camera Parameters

- What are the parameters of a camera?

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

Moving the camera

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Visible Surface Determination

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

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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 problem in sampling and reconstruction!

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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 Lecture

• Ray intersections
• Light and reflectance models
• Indirect illumination

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