Lecture 20?
Drawing in 3D

Recap...

- Lecture 17: Meshes and appearance
- "Lecture 17" (old 17/18): Texture Basics
    - object appearence by **color maps**
    - texture coordinates, lookups
    - filtering
- "Lecture 18" (old 18/19): Advanced Textures
    - object shape by bump, normal, displacement **maps**
    - tricks for maps (wrapping, scaling, layering, ...)
    - complex lighting by environment and shadow **maps**

Today: Why/How?

- Why just triangles?
- Why maps not more triangles?
- Why **hacks** to get shape and lighting?

1. Really understand the model
    - need it to use it well / efficiently
    - need it to understand shaders
2. See some of the algorithms underneath
    - they explain why things work the way they do

The Assumptions of Interactive 3D

1. Triangles (primitives)
2. Triangles are **independent** (Local Shading)

What controls appearance

At a point:

1. Surface Color (and properties)
2. Light Color (and properties)

Lighting: Local vs. Global

Local:

- consider what happens at one point
- given what light arrives, what color do we see

Global:

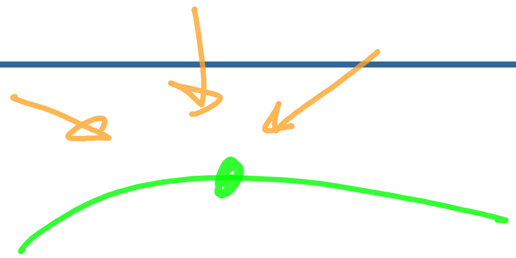
- what light gets to the point
- how do different points interact

Global Lighting Effects

- Shadows
- Reflections (mirror)
- Spill
- Indirect lighting
- Refraction
- Complex combinations (e.g., caustics)

1. Simulate **transport**
2. Use Hacks

Local Lighting Model



Consider one point

Each light contributes

- simple: each light gives 1 direction/colors
- complex: light over a range of directions

Bi-directional Reflectance Distribution Function (BRDF)

Why local lighting?

Compute each triangle independently
(each point on each triangle)

Need:

- Light at point
- Color (surface properties at point)

Never consider all triangles together

But why and how triangles?

Triangles: the primitive

Possibly points and lines as well

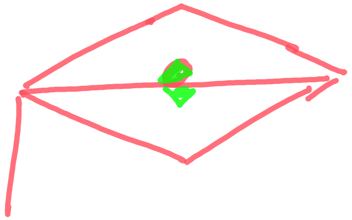
1. Projection of a triangle is a triangle
    - just transform the vertices (insides might change)
2. Barycentric coordinates
3. Fast Algorithms to Draw

Colors per triangle

- 1 (face, split vertices)
- 3 (vertex, interpolation)
- lots (texture)

Why not model everything?

Actual geometry?



Dot on dice:

- triangles on top of each other?
- floating dot?
- divide up face?

Very small triangles are bad:

- many triangles per pixel (how to pick?)
- hard to know which is in front
- hard to author (design, store, maintain, ...)

Texture Mapping Review

1. Need coordinates **per pixel** — fragment
2. UV mapping
    - specify at vertices and interpolate
3. other coordinates: computed (environment), solid
4. lookup color based on coordinates
5. Filter/Interpolate (each pixel is a region of the texture)
    - use mip maps for speed

How do we actually draw?

(or, how does the hardware do it for us?)

Categories of methods (rough, one way to divide it) ...

1. Per-primitive methods (used for interactive graphics) Triangle
2. Image-space methods Pixels
3. World-space methods Photons

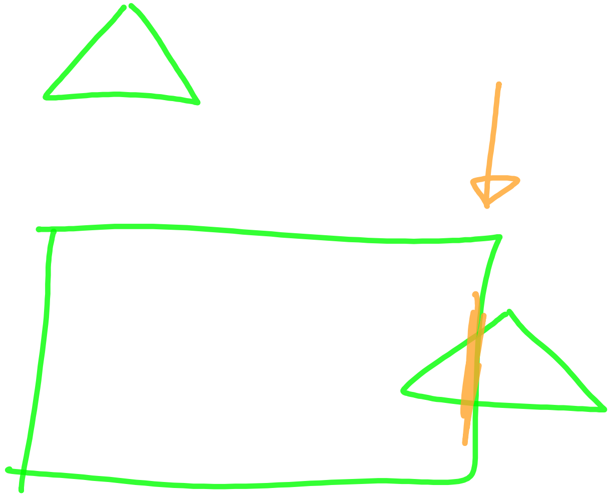
Most (all?) graphics hardware (and high-performance interactive) rendering is done with **per-primitive** methods.

The Process of Drawing in 3D

1. Triangles (in 3D)
2. Transform (the triangles to 2D) - **viewing**
3. Convert triangles to pixels - **rasterization**
4. Color Each Pixel - **shading** (lighting, texturing, ...)

along the way...

- decide if the triangle is on the screen - **clipping**
- decide if another triangle blocks the pixel - **visibility**



Transformation (Modeling, Viewing)

Convert the 3D Triangle to a 2D triangle

Model

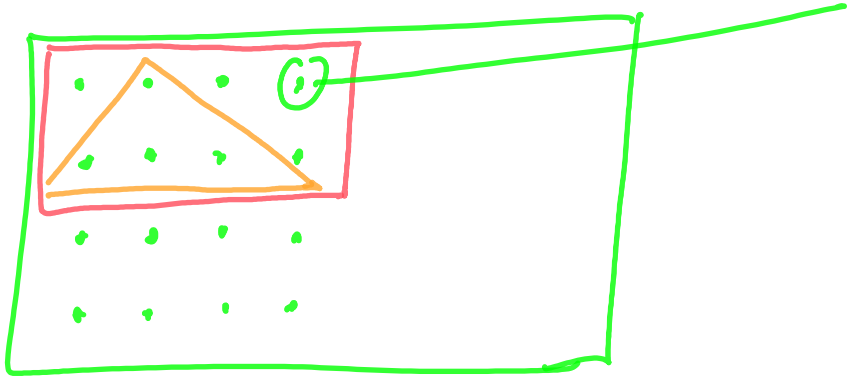
View
↑
camera

Projection
↓
convert to 2D

Rasterization

What pixels does a triangle cover

- since we will "fill" these pixels



compute baricentric coordinates

test $0 \le \alpha \beta \gamma \le 1$

Do we always draw all triangles?

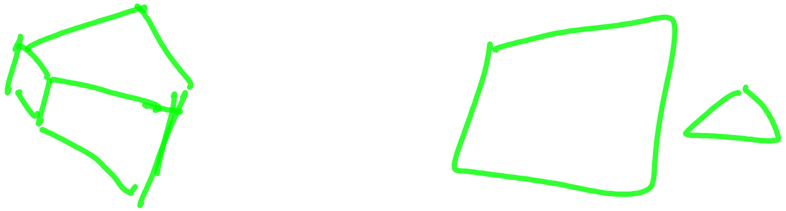
Clipping vs. Visibility

3

3 reason you might not see a triangle

Clipping is skipping triangles that are off screen

- clip to the frustum
- includes near and far



Visibility is having near things block farther ones

- can't know until you look at all of the triangles
- immediate mode might draw in any order

Culling is skipping primitives based on fast decisions

When do we get rid of things?

Clipping can happen after the triangle is transformed

Visibility depends on the algorithm (often per-pixel, after coloring)

Culling should happen early

- discard a whole group of triangles (triangles in another room)
- backface culling (after the normal is transformed)
- and many others

Visibility: The Problem

Assume objects are **solid** and **not-transparent**

Closer objects occlude farther ones

This is not **clipping** - we assume things are in-view

Visibility is important!

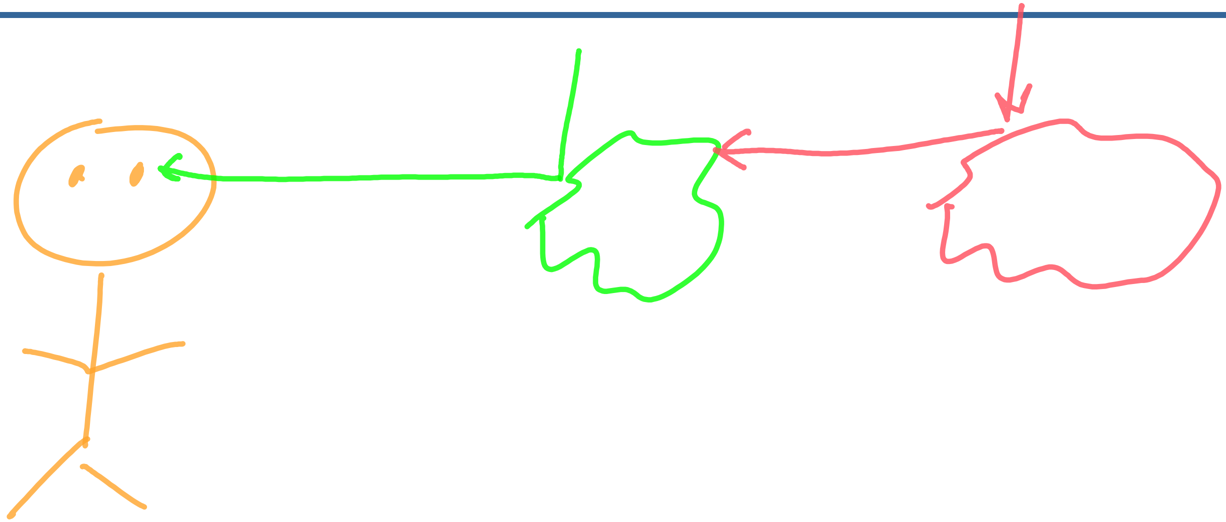
An important cue to making things look realistic!

Visibility Algorithms

- Painters Algorithm - important in concept
- Z-Buffer Algorithm - used in practice

We often use ideas from the painter's algorithm

How does this work in the real world?



How does a painter do it?

Paint each object

Paint new objects **on top of** older ones

Order matters

paint back to front

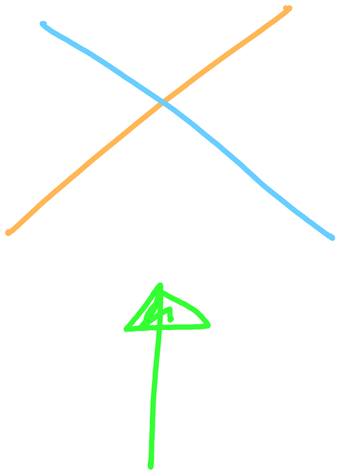
The Painters Algorithm

1. Collect all objects
2. Sort from back to front ←
3. Draw objects in order (back to front)

Problems with the Painter's Algorithm

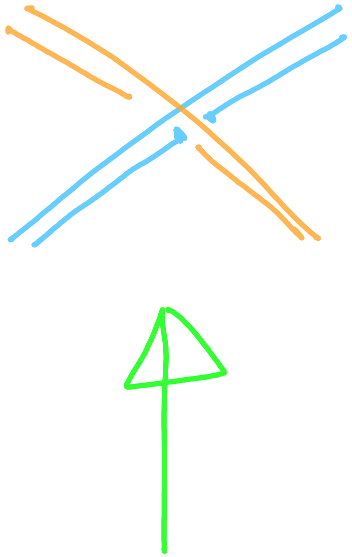
1. Need all objects to sort (not immediate mode)
2. What happens with Ties?
3. What happens with intersecting objects?
4. Inefficiency - resort when camera moves
5. Inefficiency - draw things that get covered

overdraw ~



Dealing with Ties: Cutting Objects

If two objects (triangles) intersect, cut them



Avoiding Re-Sorting

Use fancy data structures!

Binary Space Partitioning Tree (BSP-Trees)

Very important in old (pre-graphics hardware) video games

Not very important now (we use hardware)

The Z-Buffer Algorithm

Goals:

- order independent
- immediate mode (1 triangle at a time)

Idea:

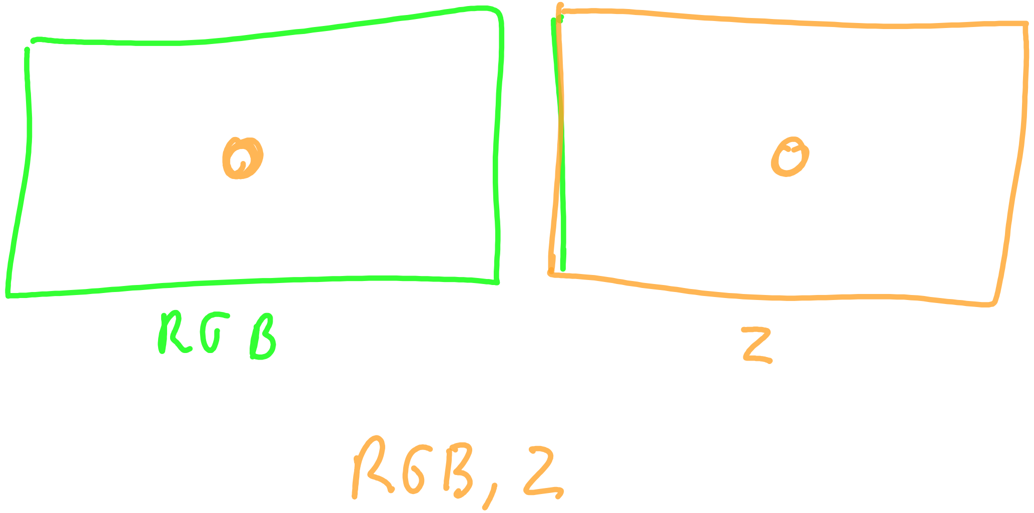
- Store the depth per-pixel

The Z-Buffer

An extra number per-pixel

color buffer (RGB)

z-Buffer (Z)



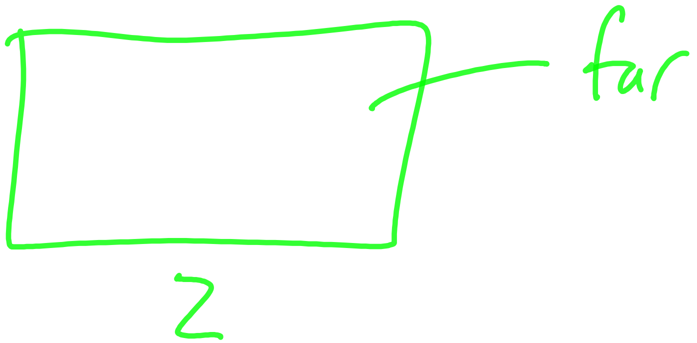
Clearing the Z-Buffer

Start with all pixels at max distance

Anything that will be drawn will be in front of the background

Why the **far** distance of the camera is important

Historically: limited precision (16 bits), avoid making far too big



Drawing

Draw pixel (x,y) with color (c) and depth (z)

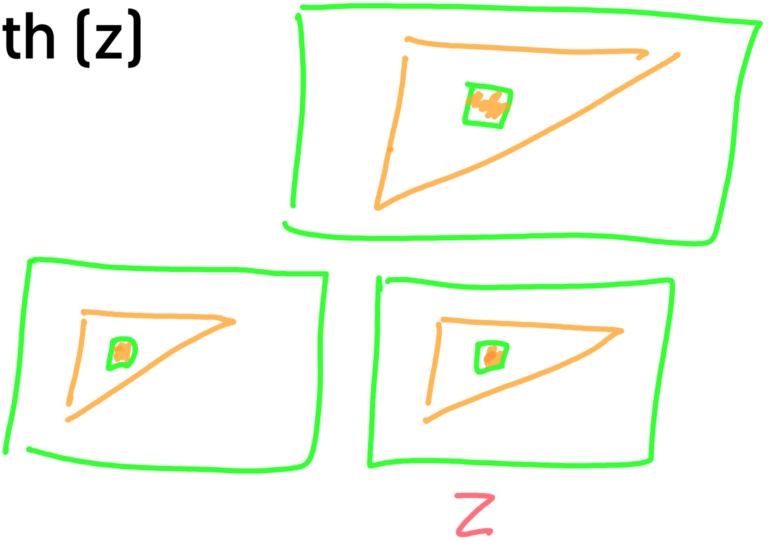
Frame buffer FB, Z-Buffer (ZB)

Old - no Z-Buffer (write pixel):

```
  FB(x,y) = c
```

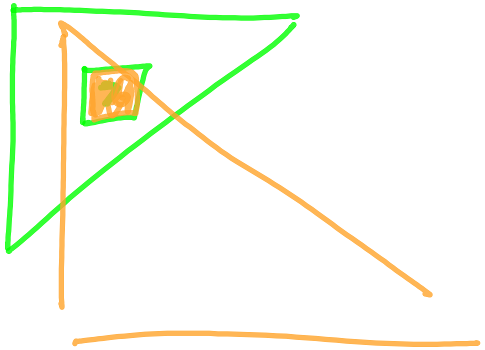
New - Z-buffer (read/test/write):

```
  pz = ZB(x,y)
  if z < pz:
    FB(x,y) = c
    ZB(x,y) = z
```

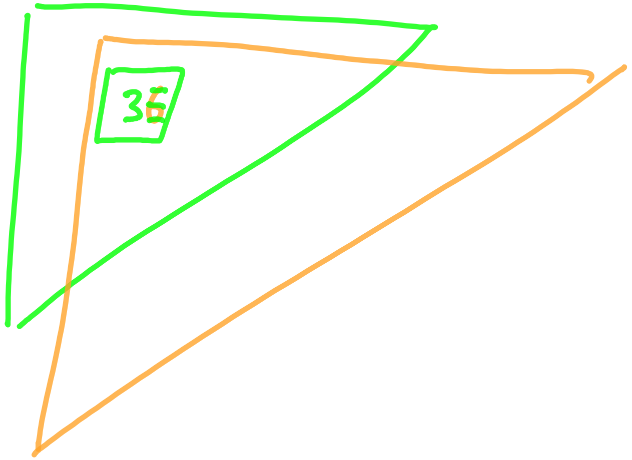


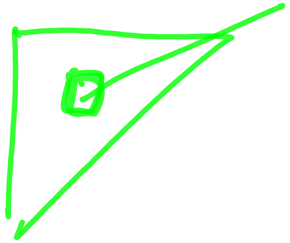
Order independent

Far object first



Close object first





check old z
if it's closer
stop!

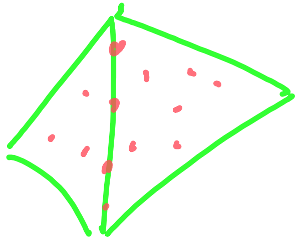
What could go wrong?

- Requires memory
- Requires read/modify/write
  - memory reads can be slow
  - need to wait until prior writes are done
- Requires storing distances
  - old days: 16 bits (scaling issues)
- things we care about…

What happens in a tie?

Decide if < or <=

Order matters



Z-Fighting

overlap & close

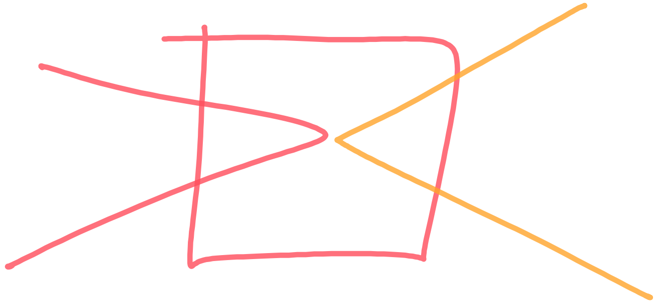
Two objects are very similar distances

- might be a tie (drawing order matters)
- numerical noise might break the tie

What if a triangle partially fills a pixel?

Z-Buffer test is yes/no

Doesn't consider partial filling



Aliasing!

Anti-aliasing the edges of objects is hard

(warning - we haven't discussed aliasing yet)

Overdraw Efficiency

- Throw away pixel after it is computed
- After we have computed the color!
- Wasted effort!
- Overwrite is even more wasteful than Z-Fail

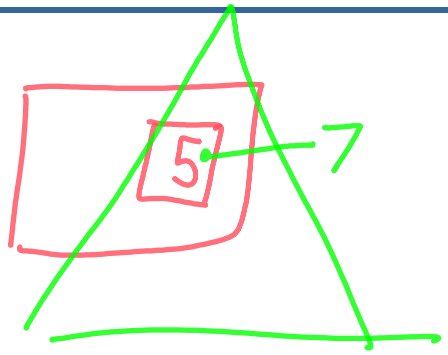
Future: ways to avoid the inefficiency

Semi-Transparent Objects?

Alpha-Blending?

Back object needs to be drawn first:

- need to blend with correct background
- close object prevents objects behind from being drawn



Solution:

- sort objects (basically painters algorithm)
- transparent objects last

Z-Buffer Summary

1. Clear Z-Buffer to Max Distance
2. Replace pixel write with read/test/write

Good Parts

- Simple
- Uses memory (now cheap)
- Generally order independent
- Don't need objects ahead of time
- Easy to implement in hardware
- Invented by Ed Catmull ←

Problems

1. Sometimes order matters
2. Can have efficiency issues
3. Z-Fighting Problems
4. Aliasing
5. Doesn't handle transparency

The Drawing Process ("Pipeline")

Draw each triangle - somewhat order independent (parallel)

1. Transform triangles into 2D (with Z values)
2. Rasterize triangles (into fragments (pixels), with Z-values)
3. Figure out the color of those fragments
4. Write those fragments to the image (with Z-Test)

What's next?

- program steps 1 and 3! (shaders)