Pipeline, Rasterization, and Antialising

Readings: Chapter 8
(math: section 2.7)

Announcements

- Proj 2 due Oct 4th 11 pm
- Midterm: Oct 15

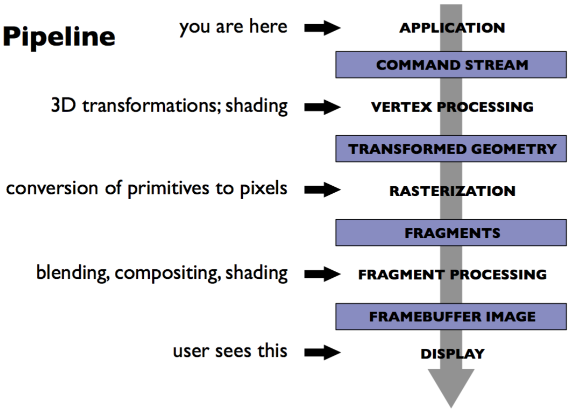
- Adjusted the schedule a little bit to fit our progress

Pipeline

The graphics pipeline

- The stand approach to object-order graphics
- Many versions exist
  - Software, e.g., Pixar’s EYYES architecture
  - Hardware, e.g., graphcs card (Nvidia)
    - Amazing performance: millions of triangles per frame
- Our focus: abstract version of hardware pipeline
- “Pipeline” because of many stages
  - easy to parallel
  - Remarkable performance of graphics card

Pipeline



you are here → APPLICATION

COMMAND STREAM

3D transformations; shading → VERTEX PROCESSING

TRANSFORMED GEOMETRY

conversion of primitives to pixels → RASTERIZATION

FRAGMENTS

blending, compositing, shading → FRAGMENT PROCESSING

FRAMEBUFFER IMAGE

user sees this → DISPLAY

Primitives

- Points
- Line segments
  - And chains of connected line segments
  - Triangles
- And that is all!
  - Curves? Approximate them with chains of line segments
  - Polygons? Break them up into triangles
  - Curved regions? Approximate them with triangles.
- Trend has been toward minimal primitives
  - Simple, uniform, repetitive: good for parallelism

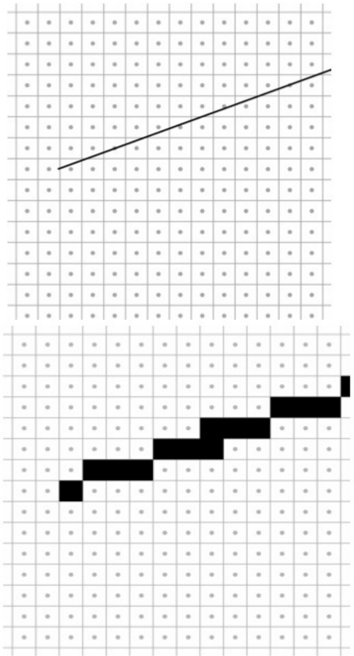
Rasterization

Primitives

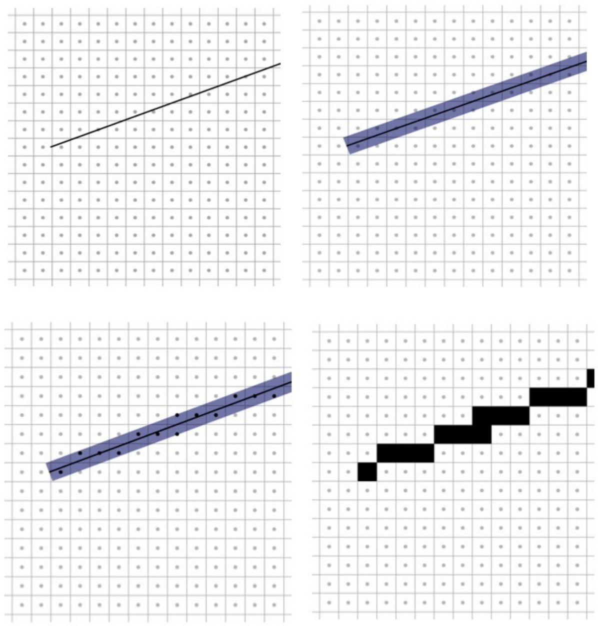
- First job: enumerate the pixels covered by a primitive
  - Simple, aliased definition: pixels whose centers fall inside
- Second job: interpolate values across the primitive
  - E.g., colors computed at vertices
  - Normals at vertices
  - Will see applications later on

Rasterizing lines

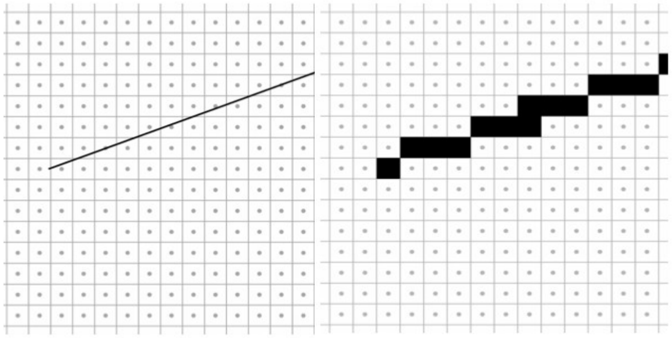
Rasterizing lines



Point sampling



Rasterizing lines algorithm

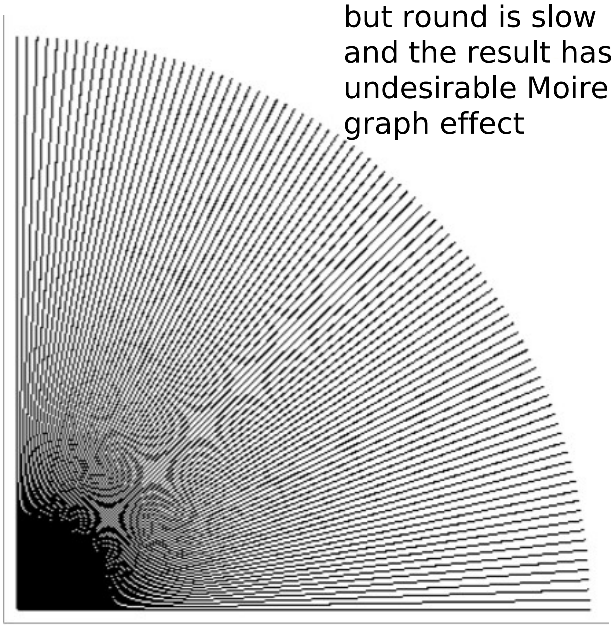


Line equation: $y = b + mx$

Simple algorithm:

```
//Evaluate line equation per column:
for x=ceil(x0) to floor (x1)
   y = b + m * x
   output (x, round(y));
```

Point sampling result



but round is slow and the result has undesirable Moire graph effect

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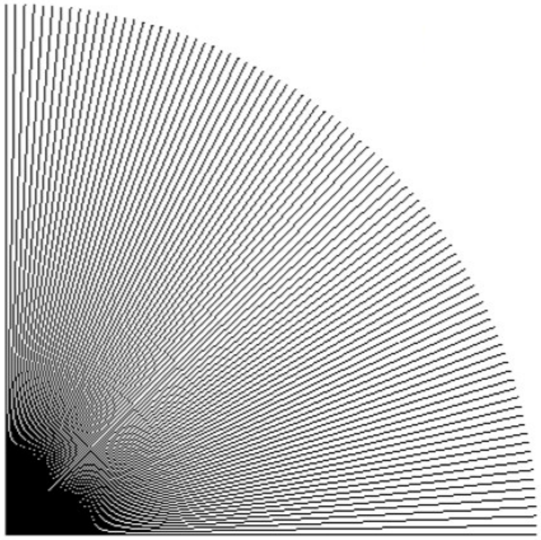
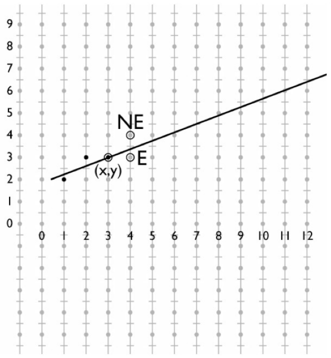
Optimizing line drawing: Bresenham lines result (midpoint algorithm)



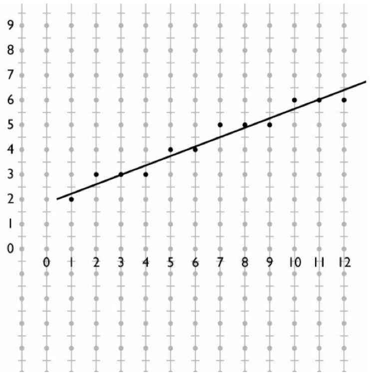
Midpoint algorithm

- At each pixel the only options are E and NE
- d = m(x+1) + b-y
- d>0.5 decides between E and NE
  - Only need to update d for integer steps in x and y; we can do that with addition



Midpoint algorithm

```
x = ceil(x0)
y = round(m*x + b)
d = m*(x+1)+b-y
while x<floor(x1)
 if d>0.5
   y+=1
   d-=1
x+=1
d+=m
Output(x,y)
```



Attributes interpolation

- Attributes:
  - Color
  - Normal vector

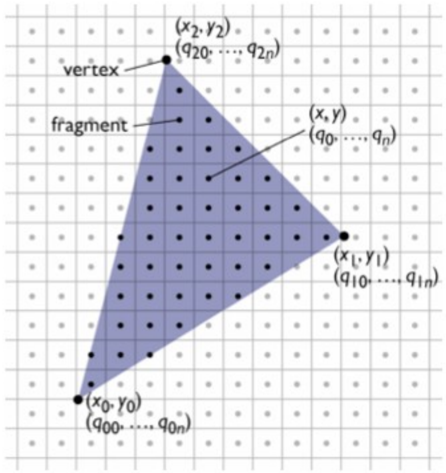
Rasterizing triangles

- The most common case in most applications
- Simple way to think of algorithm follows the pixel-walk interpretation of line rasterization
  - Walk from pixel to pixel over (at least the polygon’s area)
  - Evaluate linear functions as you go
  - User those functions to decide which pixels are inside

Rasterizing triangles

- Input:
  - Three 2D points (the triangle coordinates in pixel space)
  - parameter attributes at each vertex
- Output
  - A list of fragments, each with
    - The integer pixel coordinates (x, y)
    - Interpolated parameter values

Rasterizing triangles



(See class notes for the drawing algorithm.)

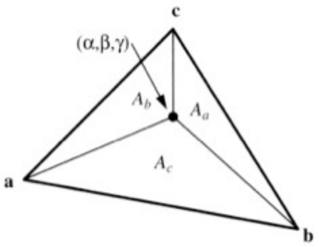
Barycentric coordinates

- A coordinate system that does not use orthogonal basis
  - Algebraic viewpoint:

$$\mathbf{p} = \alpha\mathbf{a} + \beta\mathbf{b} + \gamma\mathbf{c}$$

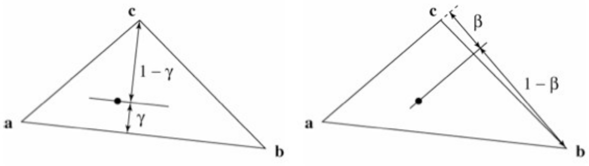
$$\alpha + \beta + \gamma = 1$$

  - Geometric viewpoint (areas)
    - (refer to in-class notes)



Barycentric coordinates

- Properties
  - Geometric viewpoint: distances



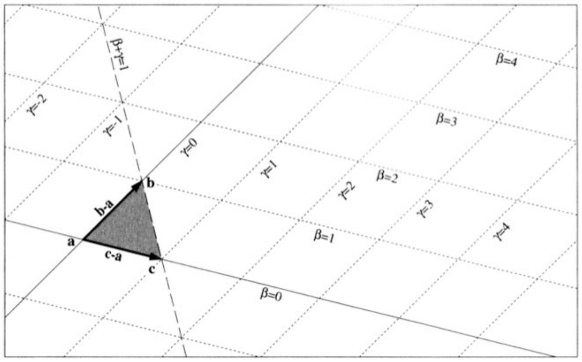
  - Linear viewpoint: basis of edges

$$\alpha = 1 - \beta - \gamma$$

$$\mathbf{p} = \mathbf{a} + \beta(\mathbf{b} - \mathbf{a}) + \gamma(\mathbf{c} - \mathbf{a})$$

Barycentric coordinates

- Properties
  - Basis for the plane

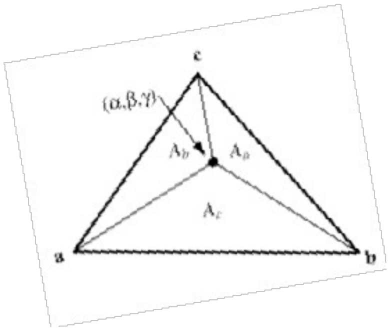


  - Triangle interior test:

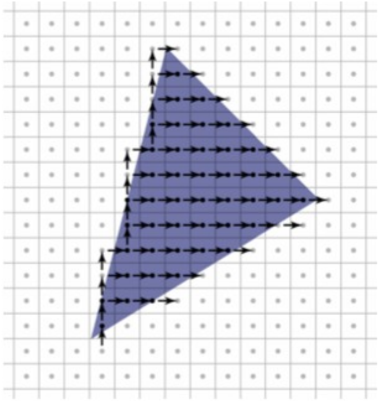
$$\beta > 0; \quad \gamma > 0; \quad \beta + \gamma < 1$$

Barycentric coordinates

- Calculation (derivation in class)
- Example: take a triangle and a point in this triangle and see how we calculate the point barycentric coordinates.



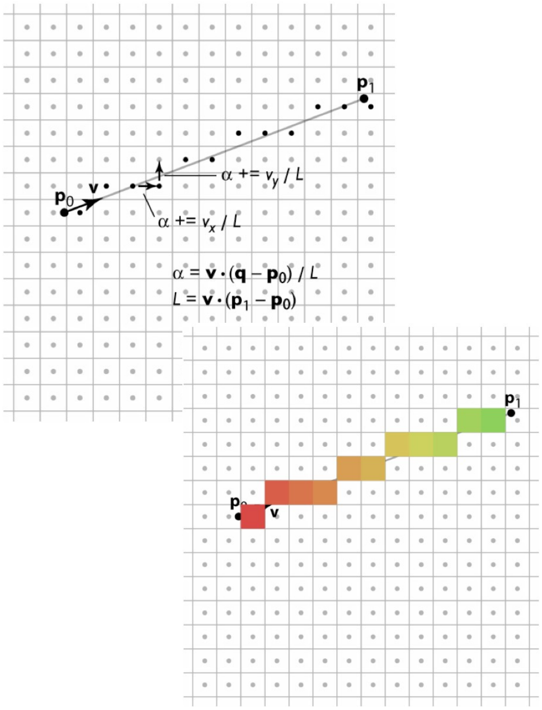
Pixel-walk rasterization



Primitives

- First job: enumerate the pixels covered by a primitive
  - Simple, aliased definition: pixels whose centers fall inside
- Second job: interpolate values across the primitive
  - E.g., colors computed at vertices
  - Normals at vertices
  - Will see applications later on

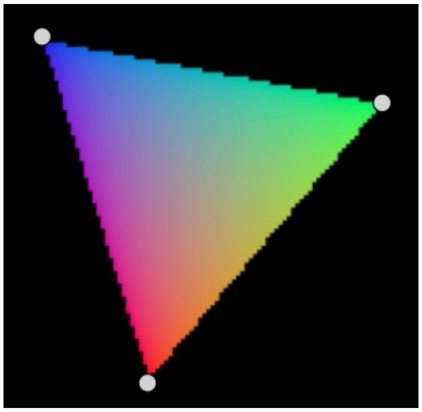
Compute colors



Linear interpolation

- Pixels are not exactly on the line
- Define 2D function by projection on line
  - Linear in 2D
  - Use linear interpolation as the vertex calculation

Triangle coloring interpolation result

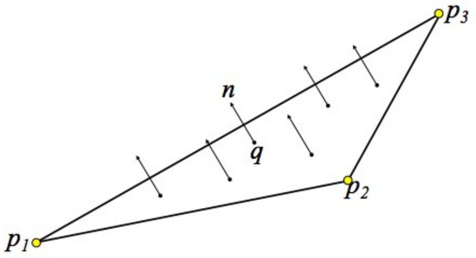


Compute normals

Insert normal

- We could associate the same normal/color to every point on the face of a triangle by computing

$$n = \frac{(p_2 - p_1)\times(p_3 - p_1)}{\left\|(p_2 - p_1)\times(p_3 - p_1)\right\|}$$



Insert normal

- For example, we could associate the same normal/color to every **point** on the face of a triangle by computing

$$n = \frac{(p_2 - p_1) \times (p_3 - p_1)}{\|(p_2 - p_1) \times (p_3 - p_1)\|}$$

Triangle Normals

This gives rise to flat shading/ coloring across the faces

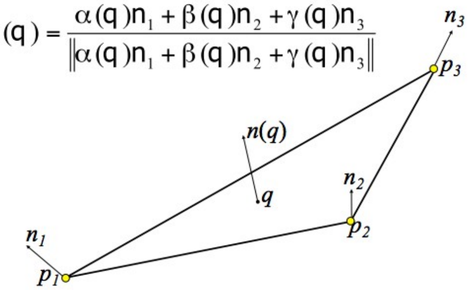
Insert normal

- Instead
  - We could associate **normals** to every vertex:

$$T = ((p_1, n_1), (p_2, n_2), (p_3, n_3))$$

so that the normal at point q in the triangle is the interpolation of the **normals** at the vertices

$$n(q) = \frac{\alpha(q)n_1 + \beta(q)n_2 + \gamma(q)n_3}{\|\alpha(q)n_1 + \beta(q)n_2 + \gamma(q)n_3\|}$$



Insert normals

Two insertion results: which is better?

Triangle Normals

Interpolated Point Normals

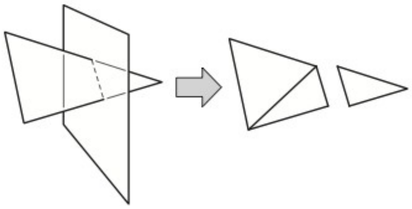
More uses: texture mapping

Clipping

- Rasterization tends to assume the triangles are on screen
  - Particularly problematic to have triangles crossing the plane Z=0
- After projection, before perspective divide
    - Clip against the 6 planes

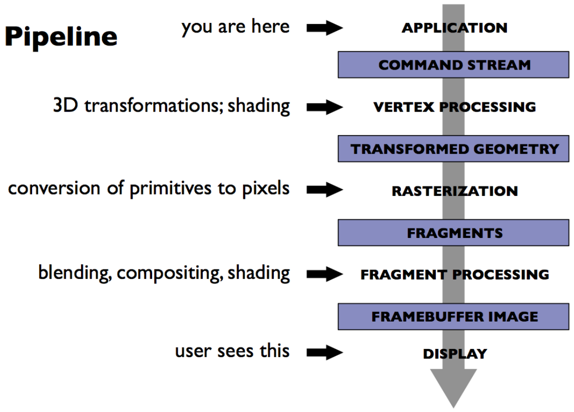
Clipping a triangle against a plane

- 4 cases, based on the sidedness of vertices
  - All in (keep)
  - All out (discard)
  - One in, two out (one clipped triangle)
  - Two in, one out (two clipped triangle)



Operations before and after rasterization

Pipeline revisited



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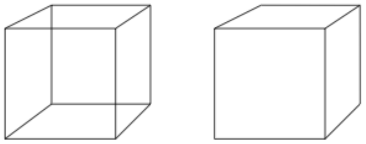
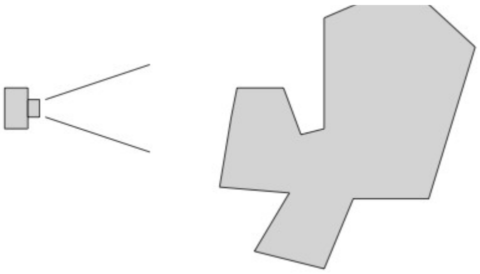
Hidden surface removal

- We have discussed how to map primitive to image space
  - Projection and perspective are depth cues
  - Occlusion is another very important cue



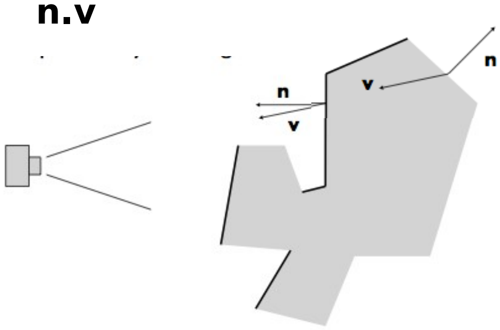
Back face culling

- For closed shapes you will never see the inside
  - Therefore only draw surfaces that face the camera



Back face culling

- For closed shapes you will never see the inside
  - Therefore only draw surfaces that face the camera
  - Implemented by checking **n.v**



The z buffer

- Draw in any order, keep track of closest
  - Allocate extra channel per pixel to keep track of closest depth so far
  - When drawing, compare object’s depth to current closest depth and discard if greater