CS 428: Fall 2010

Introduction to Computer Graphics

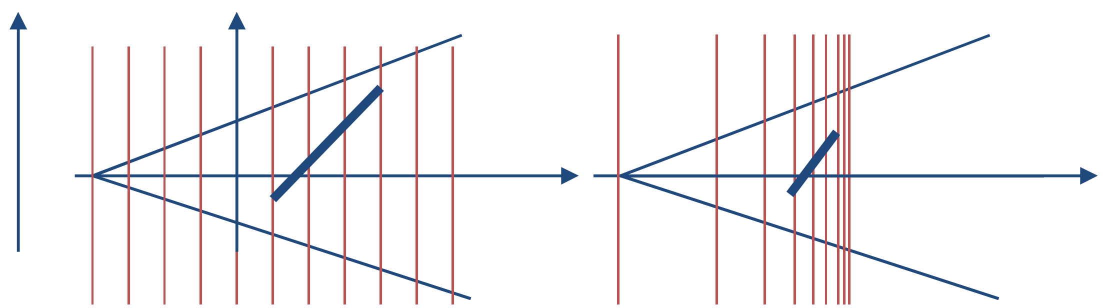
Polygon rendering: additional topics

z-buffer algorithm

- The depth buffer was suggested in 1974 but not implemented (too expensive)
- For each pixel store a z-value (depth image)
- Initialization
  - Frame buffer = clear color
  - z-buffer » maximal z-value
- Raster all scene objects sequentially
  - The order is not essential (for opaque objects)

z-buffer algorithm

- For each point(x,y) of each polygon
  - Compute z(x,y)
    - Perspective transformation



  - If z(x,y) is smaller than the stored value at (x,y)
    - Write z(x,y) into z-buffer, and write the associated color value at (x,y) into the frame buffer
- After this terminates, only visible parts of the surface(s) are visible in the frame buffer

z-buffer algorithm

Advantages

- Any scene with any object representation can be handled (entirely image-based)
- Complexity is independent of depth complexity
- Objects can be added into a rendered scene
  - Interesting when adding objects to camera shots
- Simple to implement in hardware

z-buffer algorithm

Drawbacks

- Only one object stored per image pixel
  - Resulting sampling errors can be reduced by supersampling [higher image resolution], but not entirely removed
- Transparency is not possible with an active depth test
- The precision of the z-buffer is limited
  - Separate objects have the same z-value
  - The pixel color is then entirely determined by the rendering order (and **`glDepthFunc(…)`**)

z-buffer algorithm

OpenGL details

- Active when **GL_DEPTH_TEST** is enabled
  - Initially, depth testing is disabled
- **glDepthFunc(**GLenum *func***)** determines the nature of the depth test
  - The initial value of *func* is **GL_LESS**
  - Also available **GL_NEVER**, **GL_EQUAL**, **GL_LEQUAL**, **GL_GREATER**, **GL_NOTEQUAL**, **GL_GEQUAL**, and **GL_ALWAYS**

OpenGL polygon rendering modes

- Determined by
  `glPolygonMode` **(***face*, *mode***)**

  - *face*
    GL_FRONT, GL_BACK,
    GL_FRONT_AND _BACK

  - *mode*
    GL_POINT, GL_LINE, GL_FILL

Preventing *z-fighting*

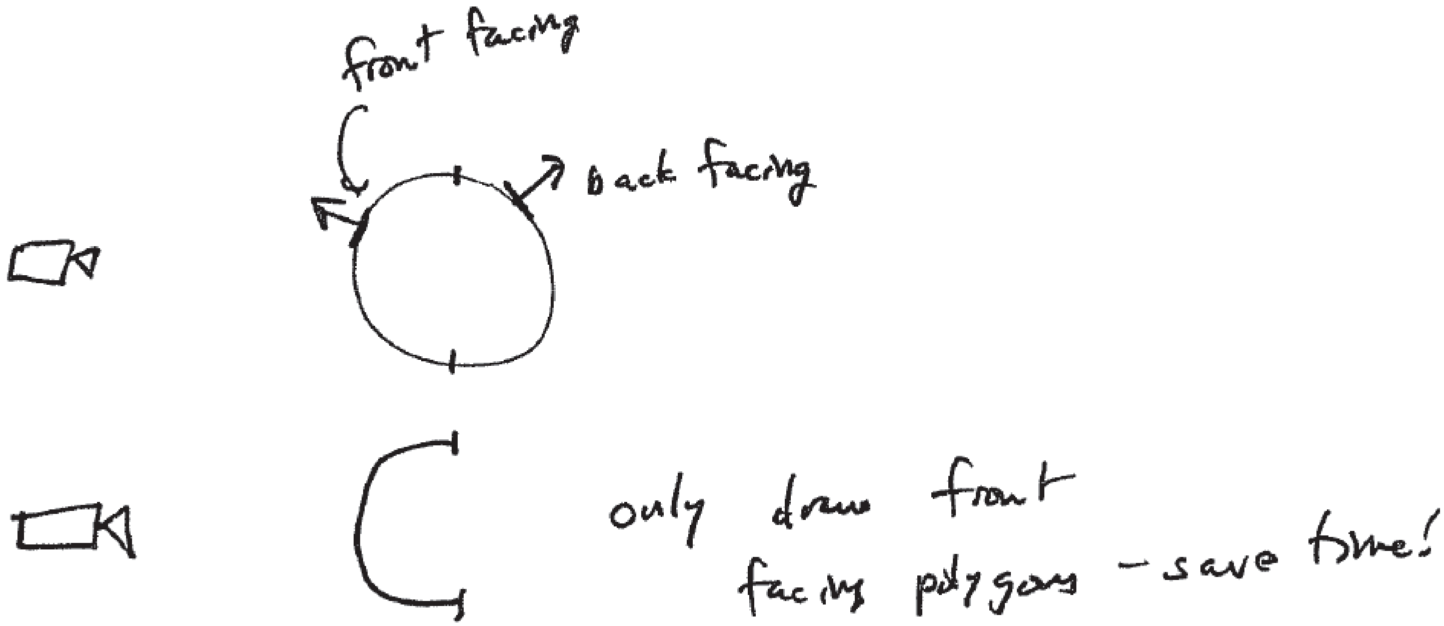
- Use **`glPolygonOffset(`***factor*, *units***`)`**
  - Adds offset = (Δz · *factor* + r · *units*) to the **depth buffer** value **before** the depth test
  - Δz = Δdepth / area (per primitive/polygon)
  - r = z-buffer precision (hardware dependent)
  - Use *factor* in project 2
    - **`glEnable(GL_POLYGON_OFFSET_FILL)`**

Color and depth masks

- **`glColorMask(`***r*, *g*, *b*, *a***`)`**
  - *r*, *g*, *b*, *a* are GLboolean values (**`true`** by default)
  - Selectively enable/disable writing to the frame buffer during rendering
- **`glDepthMask(`***d***`)`**
  - *d* is a GLboolean value (**`true`** by default)
  - enable/disable writing to the z-buffer during rendering

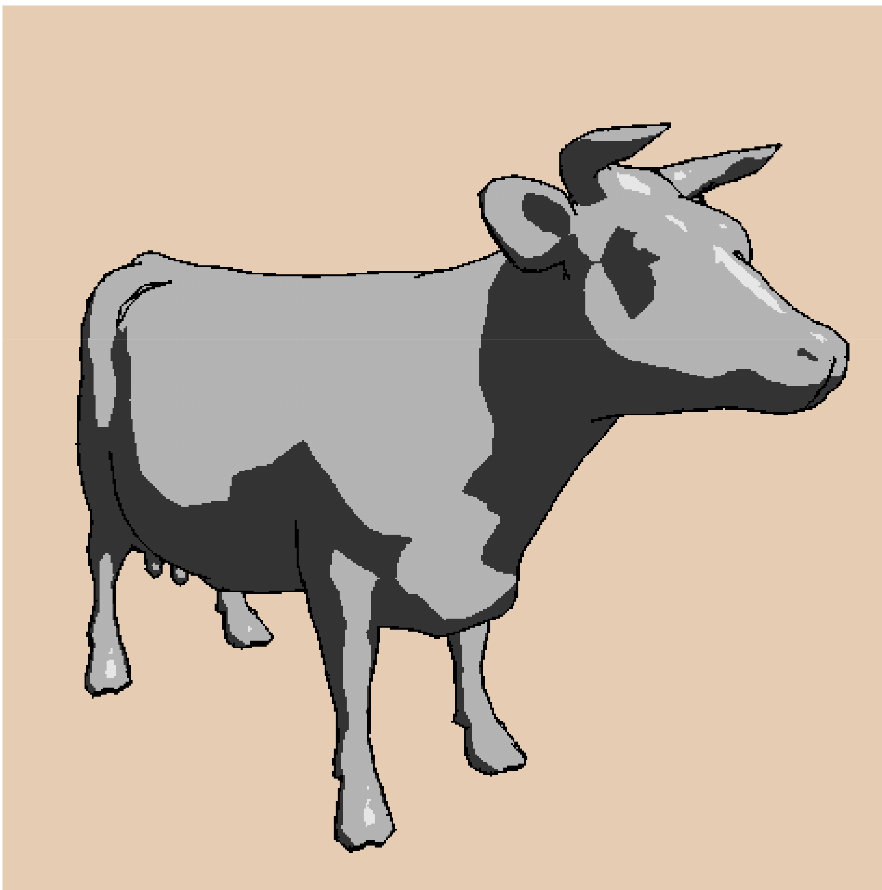
Face culling

- Given consistent polygon orientation (CCW)



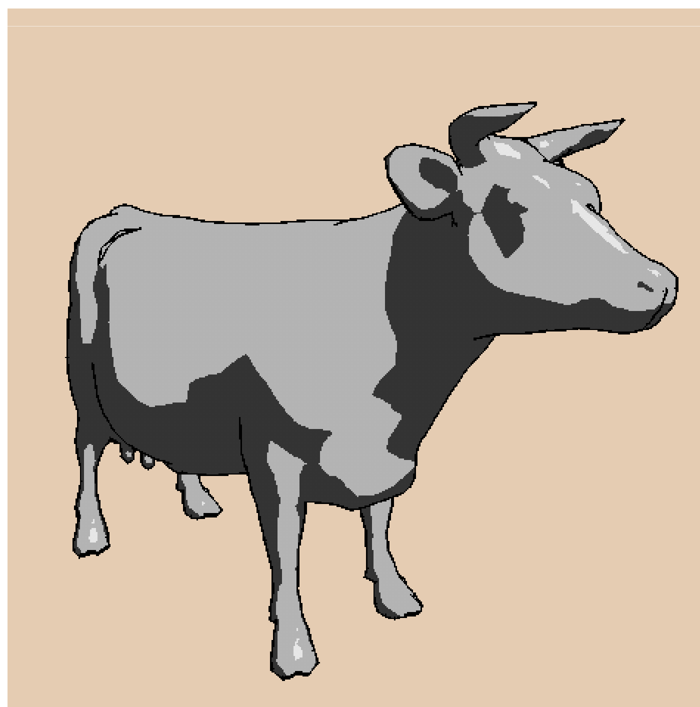
- **glCullFace([GL_FRONT|GL_BACK])**
- Only when **GL_CULL_FACE** in enabled

Non-photorealistic rendering (NPR)

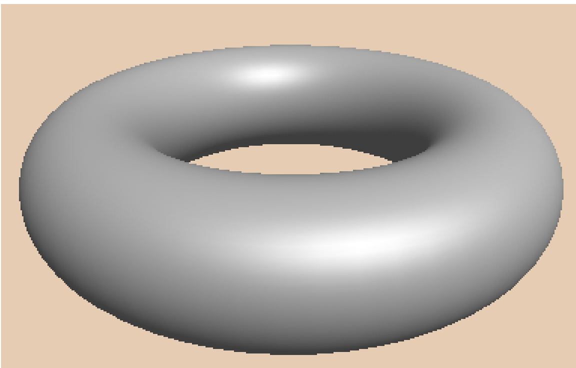


Non-photorealistic rendering (NPR)

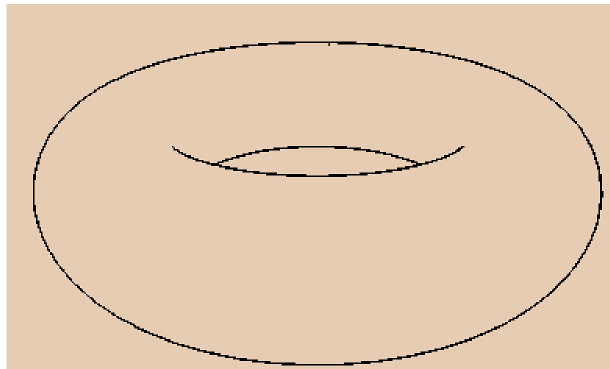
- Lines
  - Silhouettes, creases
- Shading
  - Toon shading
  - Hatching



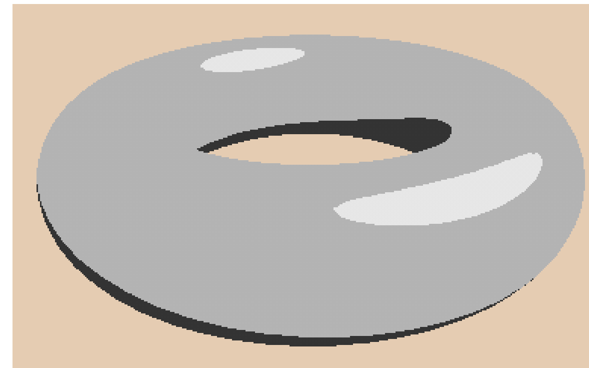
Silhouettes and Toon shading



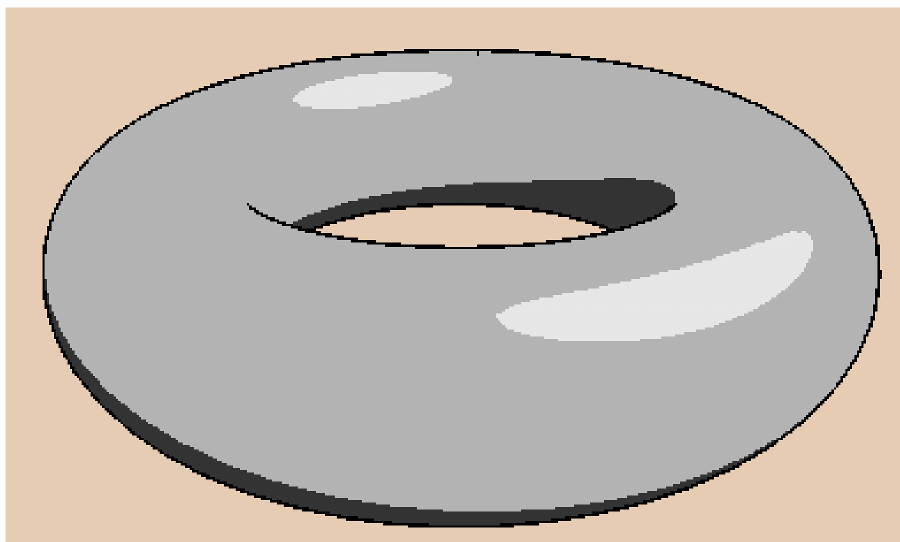
Normal shading



Silhouettes



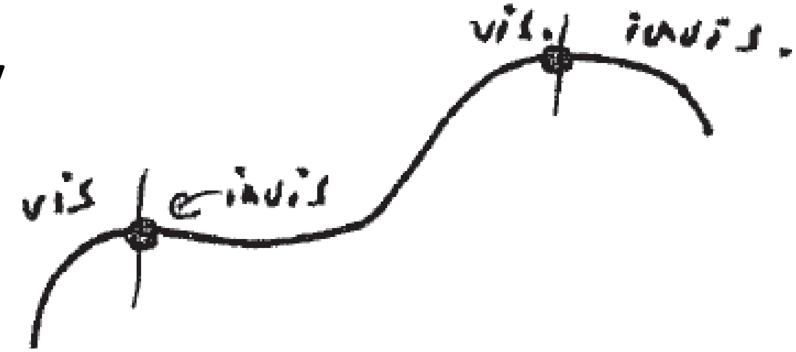
Toon shading



Silhouettes + toon shading

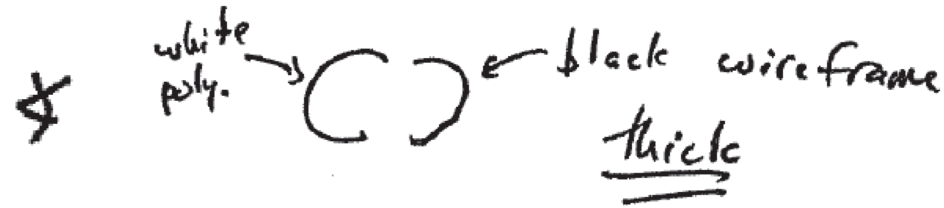
Silhouettes (a.k.a. contours)

- Mark changes in visibility



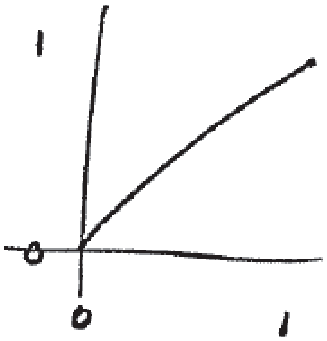
- Separate front and back facing polygons

- Direct: compute sil edges + render visible ones
- Indirect: render scene so that sils are visible

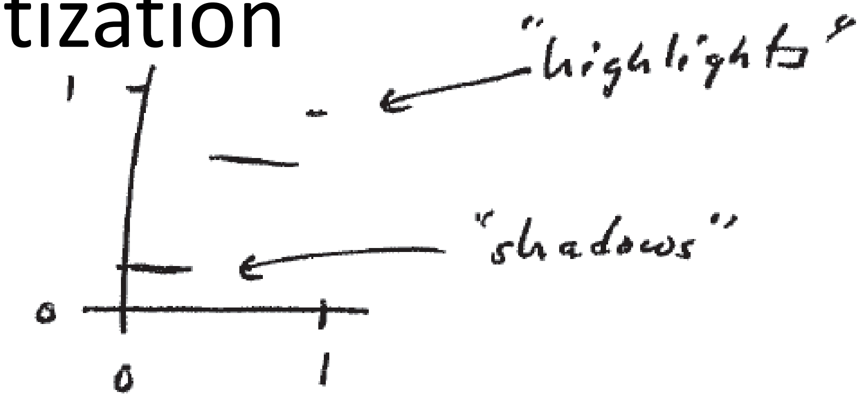


Toon shading

- A form of color quantization

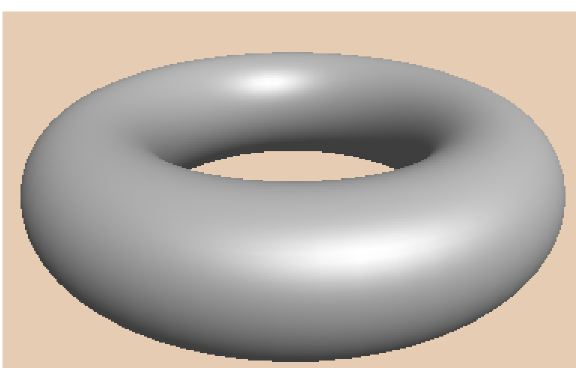


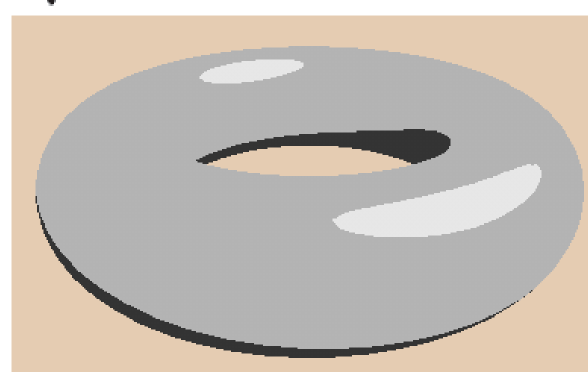
normal shading



toon shading

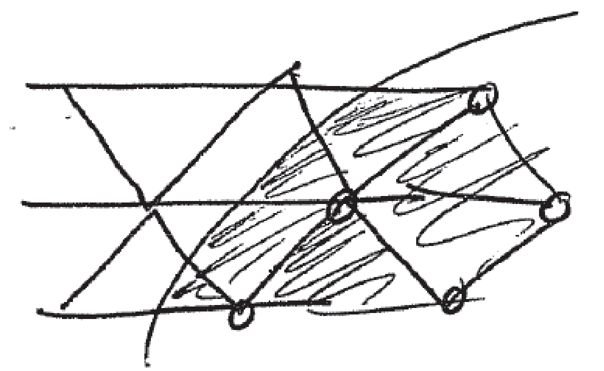
maps [0,1) → [0,1]



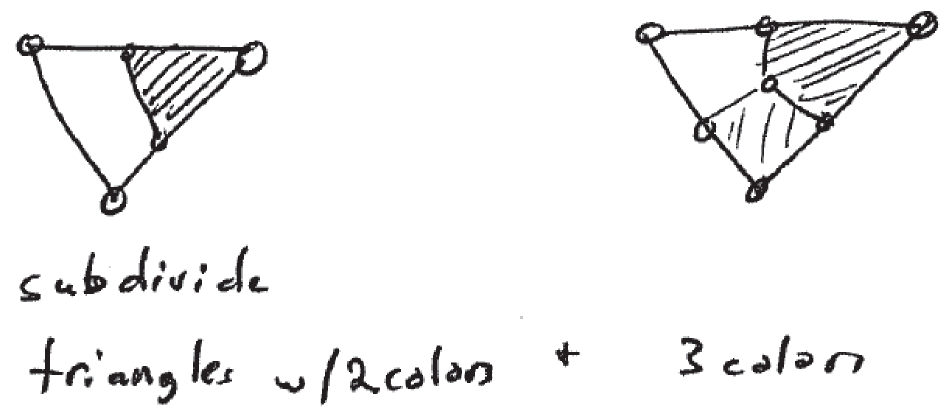


Toon shading in OpenGL

- Turn off OpenGL lighting and use **`glColor`** directly

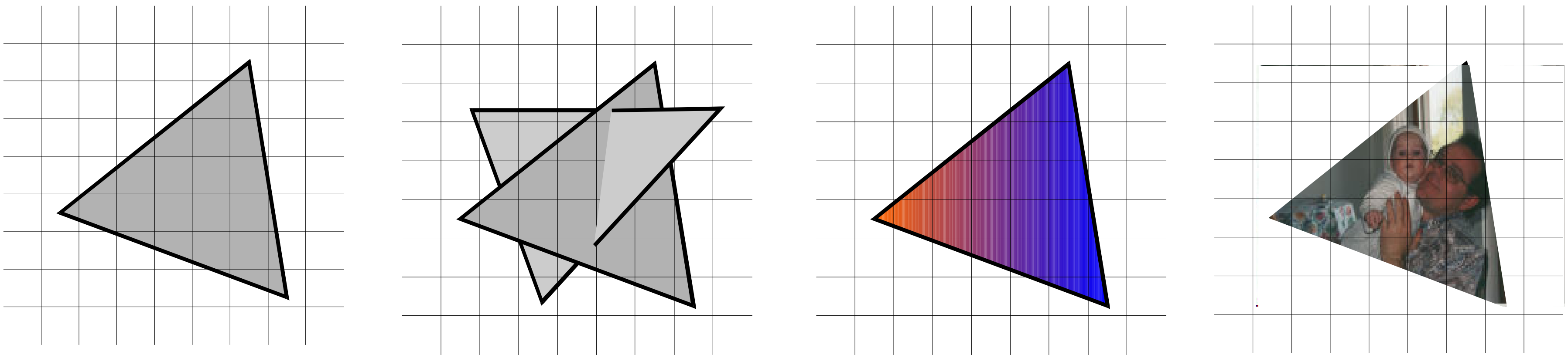


- Not necessary when using GLSL
  - Instead, compute local lighting and mapping per pixel



Excursion: rasterization

- Rasterization
  - Primitives (lines, polygons) are mapped to pixels



- Additional operations per pixel
  - Visibility (including transparency)
  - Shading and
  - Texturing

Rasterization of lines

Differential Digital Analyzer

- Lines, where start and endpoints lie on the grid

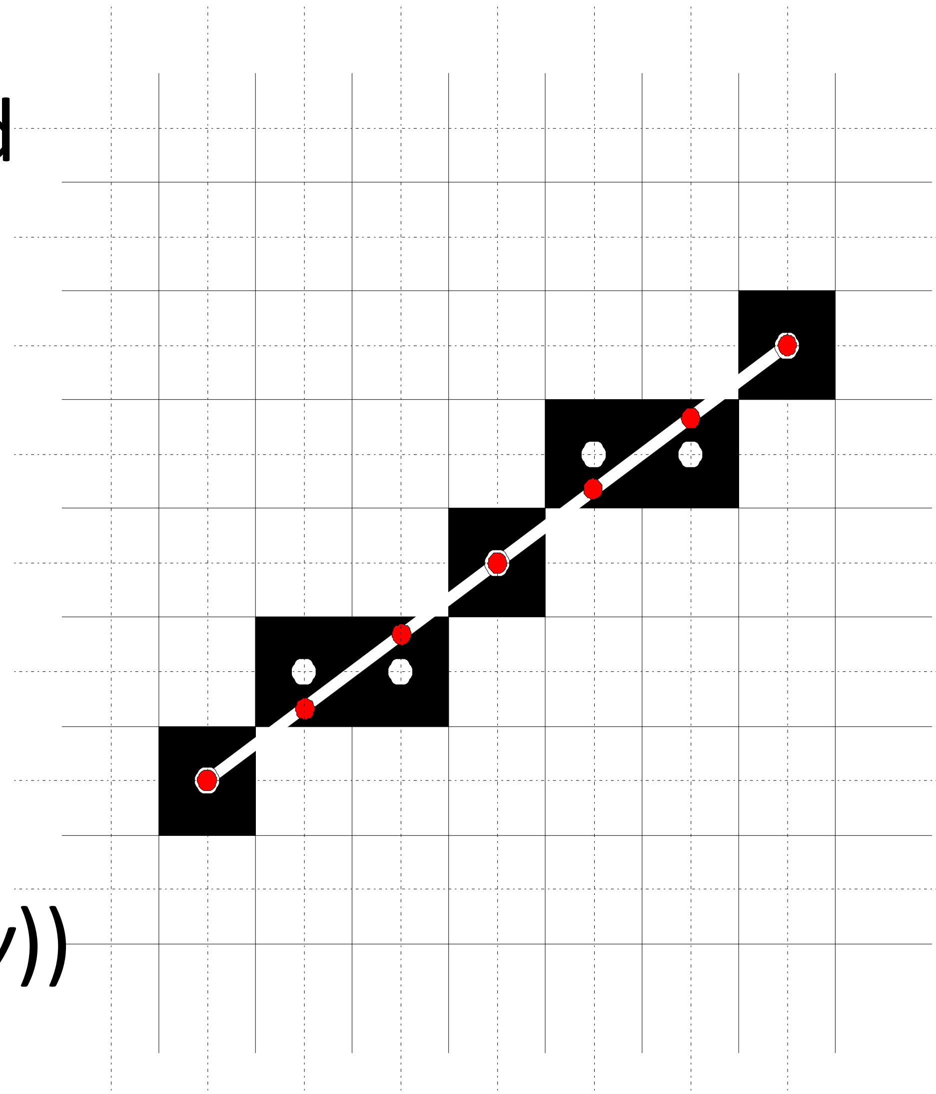
$$\Delta x = x_2 - x_1, \quad \Delta y = y_2 - y_1, \qquad -1 \le \frac{\Delta x}{\Delta y} \le 1$$

- Compute

$$y_i = \frac{\Delta y}{\Delta x} * x_i + b,$$

$$x_i = x_1 + i, \; i = 1, \ldots, \Delta x$$

- Draw pixel at (*x*, round(*y*))



Rasterization of lines

Differential Digital Analyzer

- Not efficient: every pixel operation requires
  - fp multiplication + Addition + Rounding
- Idea: incremental Algorithm

$$y_{i+1} = \frac{\Delta y}{\Delta x} * x_{i+1} + b$$

$$= \frac{\Delta y}{\Delta x}(x_i + (x_{i+1} - x_i) + b$$

$$= y_i + \frac{\Delta y}{\Delta x}(x_{i+1} - x_i)$$

$$\Delta x = x_2 - x_1;\ \Delta y = y_2 - y_1;$$

$$m = \frac{\Delta y}{\Delta x}$$

$$x = x_1;\ y = y_1;$$

$$\text{for } (x = x_1, x \le x_2, x{+}{+})\{$$

$$\text{DrawPixel } (x, y);$$

$$y = round\ (y+m);\}$$

- For x_{i+1}-x_i=1 we have

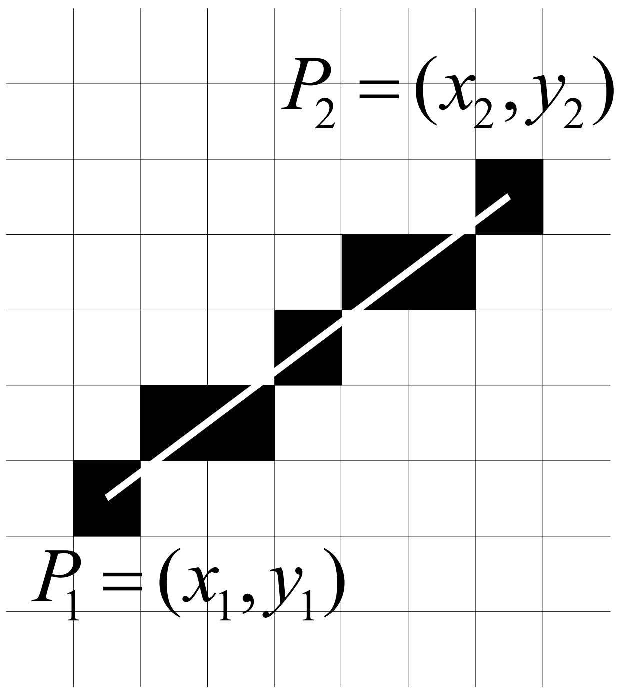
$$y_{i+1} = y_i + \frac{\Delta y}{\Delta x}$$

Rasterization of lines

Bresenham's algorithm

- First integer-algorithm for line drawing
  - Bresenham (1965)
- Derivation
  - Begin and endpoint on the grid
  - Slope between 0 and 1

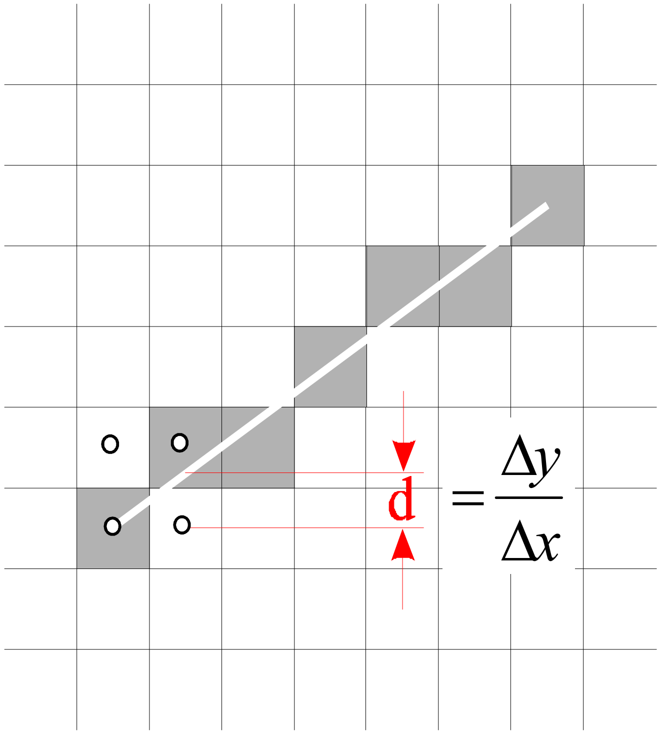
$$\Delta x = x_2 - x_1 \geq 0,$$
$$\Delta y = y_2 - y_1 \geq 0,$$
$$\Delta x \geq \Delta y.$$



Rasterization of lines

Bresenham's algorithm

- Which pixel center is closer to the line?
  Is d ≤ 1/2 or is d > 1/2?
  - Decision variable $E := \frac{\Delta y}{\Delta x} - \frac{1}{2}$



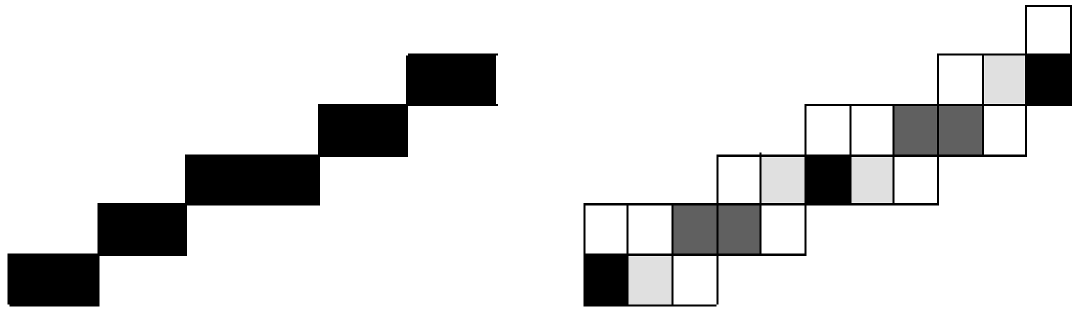
$$E' := 2\Delta x E = 2\Delta y - \Delta x$$

$E \le 0$:	$E > 0$:
$x := x + 1$	$x := x + 1$
	$y := y + 1$
$E := E + \frac{\Delta y}{\Delta x}$	$E := E + \frac{\Delta y}{\Delta x} - 1$
$E' := E' + 2\Delta y$	$E' := E' + 2\Delta y - 2\Delta x$

Rasterization of lines

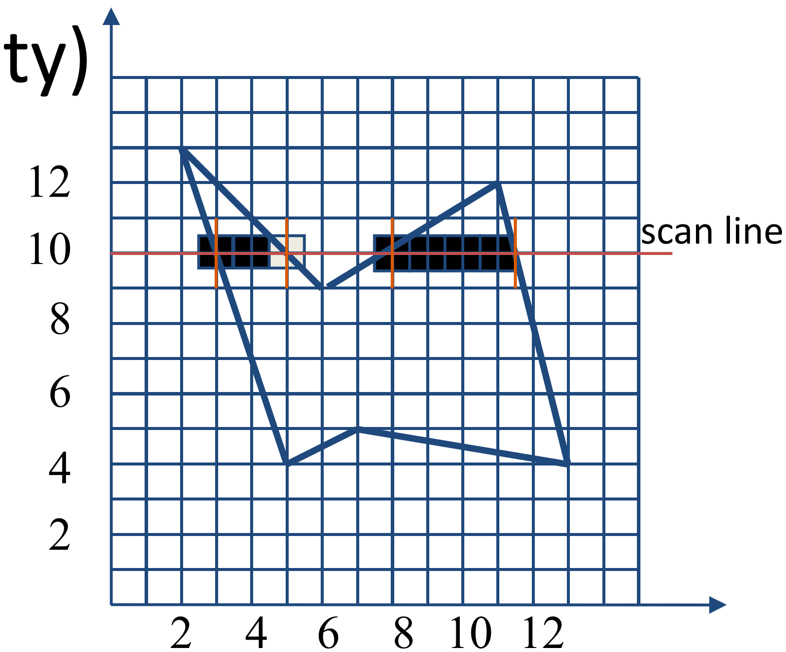
Smoothing

- For each x-value (columns) two pixels are colored
- Brightness in each column is equal
- Distribution proportional to the distance of each pixel to the ideal position
- Brightness decreases linearly with distance



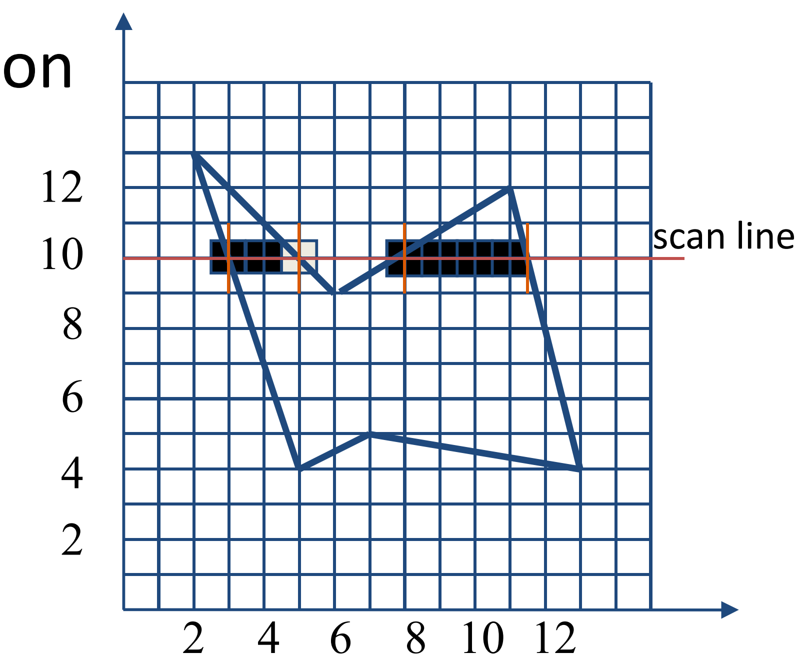
Rasterization of polygons

- Scanline algorithm
  - Intersect scan line with all edges of the polygon
  - Sort intersections by x-coordinate
  - Fill pixels between pairs of subsequent intersections (Rule of odd parity)
    - Parity is initially 0
    - Every intersection increases parity by 1
    - Draw pixel when parity is odd



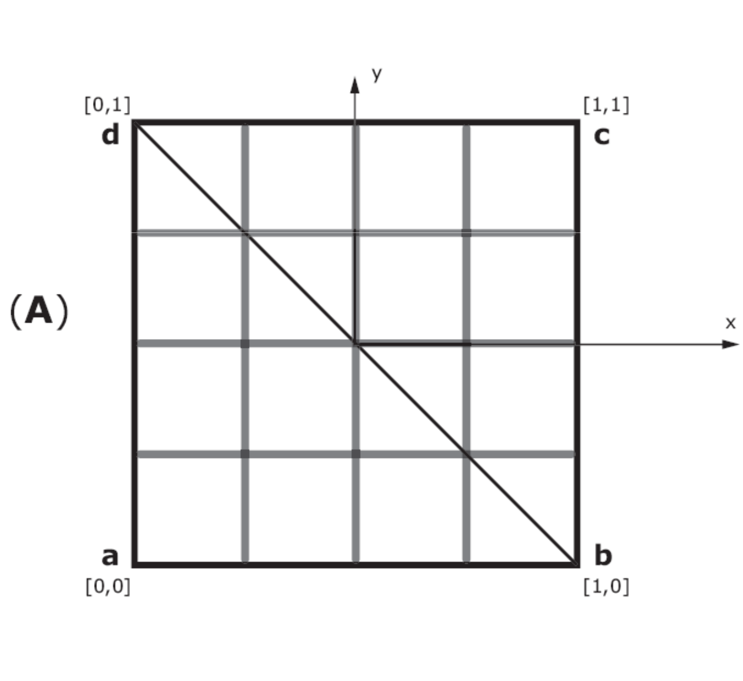
Rasterization of polygons

- Quantities from vertices are interpolated to the pixels
  - Colors (linear interpolation in screen space)
  - Texture coordinates (non-linear interpolation!)
    - Texture look-up after rasterization (e.g. in fragment shader)
- Next week
  - Texture mapping
  - Texture filtering (sampling)



Linear interpolation in screen coordinates (image space)

- Texture coordinates need special treatment



2D texture | **Object space interpolation** | **Image space interpolation**

Linear interpolation in screen coordinates (image space)

- Linear interpolation in screen space works for (fake) lighting interpolation
  - But this breaks along T-joints (avoid them!)

A "T" joint