Lighting
Scan Conversion

Wolfgang Heidrich

Course News

Assignment 2

- Due Monday, Feb 28

Homework 3

- Discussed in labs next wee

Quiz 1

- Discussed in labs this week

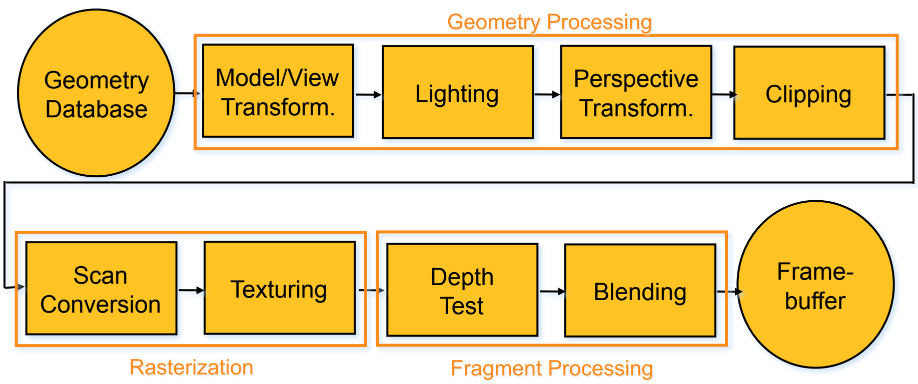
Reading

- Chapter 9, 3

Out of Town Friday

- Anika will fill in for me

The Rendering Pipeline



Wolfgang Heidrich

Lighting

Goal

- Model the interaction of light with surfaces to render realistic images

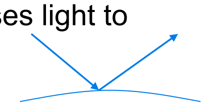
Contributing Factors

- Light sources
  - *Shape and color*
- Surface materials
  - *How surfaces reflect light*
- Transport of light
  - *How light moves in a scene (global illumination, later in the course)*

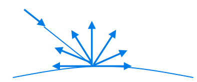
Wolfgang Heidrich

Types of Reflection

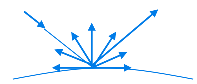
- *Specular* (a.k.a. *mirror* or *regular*) reflection causes light to propagate without scattering.



- *Diffuse* reflection sends light in all directions with equal energy.

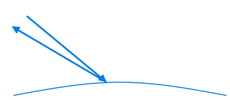


- *Mixed* reflection is a weighted combination of specular and diffuse.

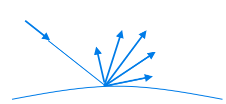


Types of Reflection

- *retro-reflection* occurs when incident energy reflects in directions close to the incident direction, for a wide range of incident directions.

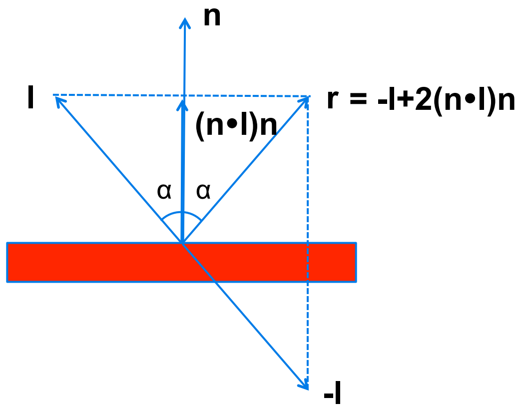


- *gloss* is the property of a material surface that involves mixed reflection and is responsible for the mirror like appearance of rough surfaces.

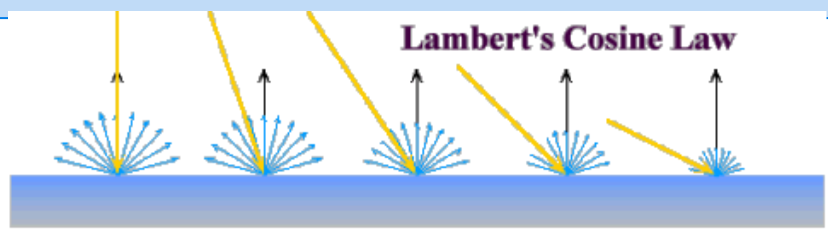


Specular Reflection

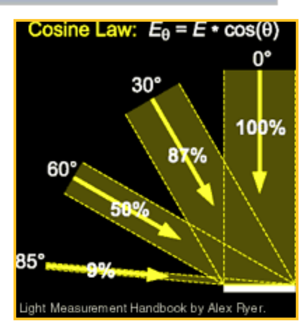
Geometry of specular (mirror) reflection



Lambert's "Law"

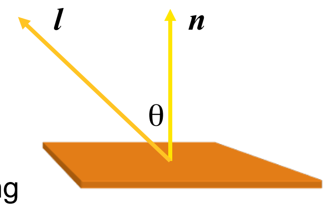


Intuitively: cross-sectional area of the "beam" intersecting an element of surface area is smaller for greater angles with the normal.



Computing Diffuse Reflection

- Depends on angle of incidence: angle between surface normal and incoming light
  - $I_{diffuse} = k_d I_{light} \cos\theta$
- In practice use vector arithmetic
  - $I_{diffuse} = k_d I_{light} (\mathbf{n} \bullet \mathbf{l})$

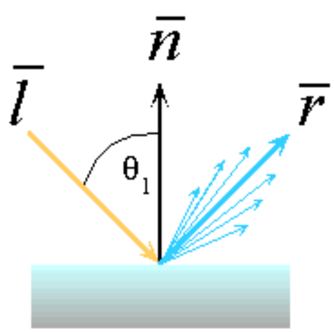


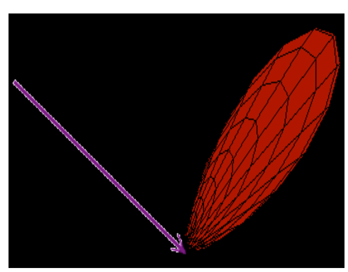
- Always normalize vectors used in lighting
  - $\mathbf{n}$, $\mathbf{l}$ *should be unit vectors*
- Scalar (B/W intensity) or 3-tuple or 4-tuple (color)
  - k_d: *diffuse coefficient, surface color*
  - I_{light}: *incoming light intensity*
  - $I_{diffuse}$: *outgoing light intensity (for diffuse reflection)*

Wolfgang Heidrich

Glossy Materials – Empirical Approximation

Angular falloff





how might we model this falloff?

Wolfgang Heidrich

Phong Lighting

Most common lighting model in computer graphics

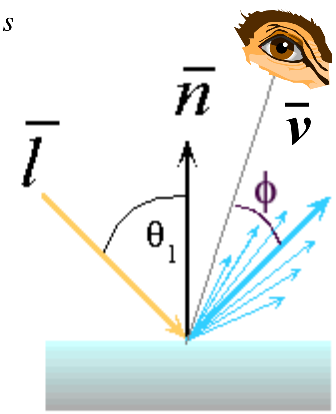
- *(Phong Bui-Tuong, 1975)*

$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_{\mathbf{s}}\mathbf{I}_{\mathbf{light}}(\cos\phi)^{n_s}$$

n_s : purely empirical constant, varies rate of falloff

k_s: specular coefficient, highlight color

no physical basis, works ok in practice

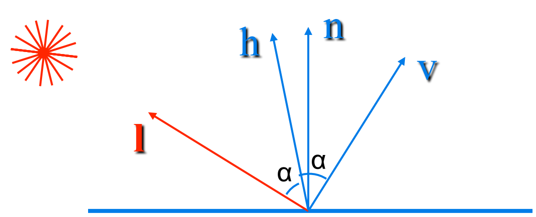


Alternative Model

Blinn-Phong model (Jim Blinn, 1977)

- Variation with better physical interpretation
  - **h**: *halfway vector;* r*: roughness*

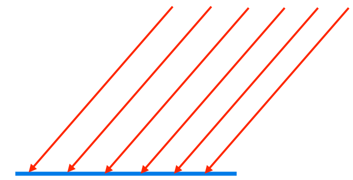
$$I_{out}(\mathbf{x}) = k_s \cdot (\mathbf{h}\cdot\mathbf{n})^{1/r} \cdot I_{in}(\mathbf{x}); \text{with } \mathbf{h} = (\mathbf{l}+\mathbf{v})/2$$



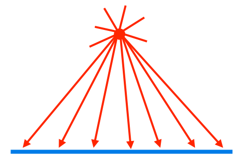
Simple Light Sources

Types of light sources

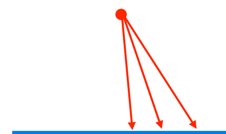
- Directional/parallel lights
  - *E.g.sun*
  - *Homogeneous vector*



- (Homogeneous) point lights
  - *Same intensity in all directions*
  - *Homogeneous point*



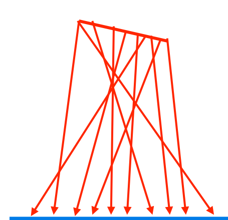
- Spot lights
  - *Limited set of directions*
  - *Point+direction+cutoff angle*



Light Sources

Area lights:

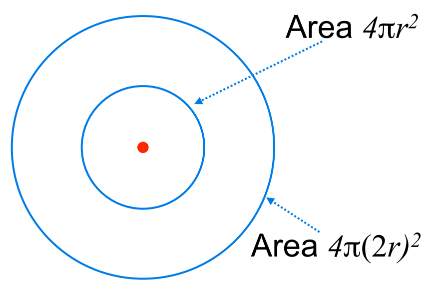
- Light sources with a finite area
- Can be considered a continuum of point lights
- Not available in many rendering systems



Light Source Falloff

Quadratic falloff (point- and spot lights)

- Brightness of objects depends on power per unit area that hits the object
- The power per unit area for a point or spot light decreases quadratically with distance



Wolfgang Heidrich

Light Source Falloff

Non-quadratic falloff

- Many systems allow for other falloffs
- Allows for faking effect of area light sources
- OpenGL / graphics hardware
  - I_o: *intensity of light source*
  - $\mathbf{x}$: *object point*
  - r: *distance of light from* $\mathbf{x}$

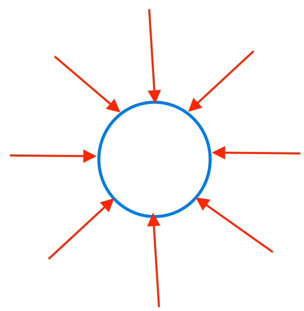
$$I_{in}(\mathbf{x}) = \frac{1}{ar^2 + br + c} \cdot I_0$$

Wolfgang Heidrich

Light Sources

Ambient lights

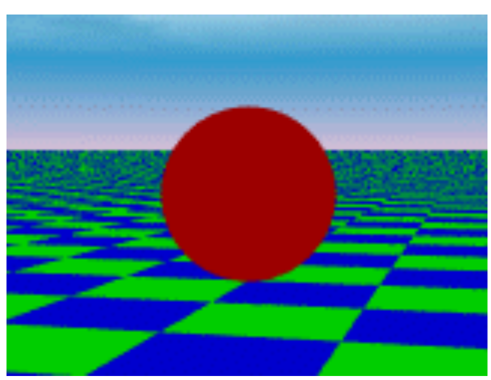
- No identifiable source or direction
- Hack for replacing true global illumination
  - *(light bouncing off from other objects)*



Wolfgang Heidrich

Ambient Light Sources

- Scene lit only with an ambient light source



Light Position Not Important

Viewer Position Not Important

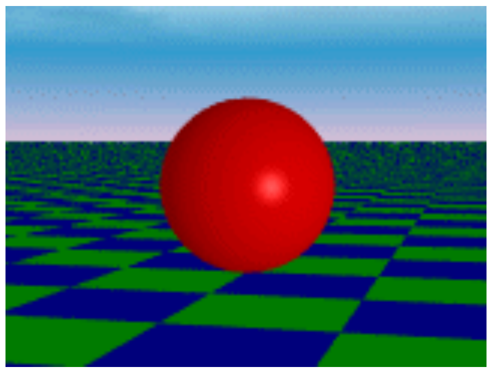
Surface Angle Not Important

Wolfgang Heidrich

Directional Light Sources

- Scene lit with directional and ambient light

Surface Angle Important



Light Position Not Important

Viewer Position Not Important

Wolfgang Heidrich

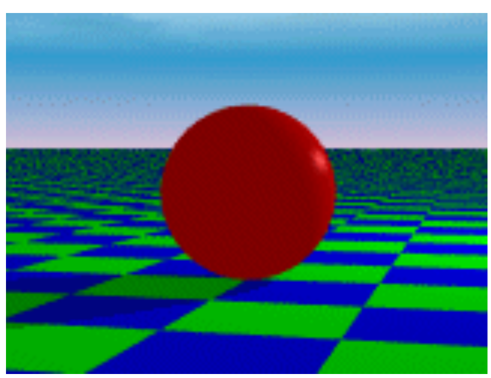
Point Light Sources

- Scene lit with ambient and point light source

Light Position Important

Viewer Position Important

Surface Angle Important



Wolfgang Heidrich

Light Sources & Transformations

Geometry: positions and directions

- Standard: world coordinate system
  - *Effect: lights fixed wrt world geometry*
  - *Demo: http://www.xmission.com/~nate/tutors.html*
- Alternative: camera coordinate system
  - *Effect: lights attached to camera (car headlights)*
- Points and directions undergo normal model/view transformation

Illumination calculations: camera coords

Wolfgang Heidrich

Lighting Review

Lighting models

- Ambient
  - *Normals don't matter*
- Lambert/diffuse
  - *Angle between surface normal and light*
- Phong/specular
  - *Surface normal, light, and viewpoint*

Wolfgang Heidrich

Lighting in OpenGL

Light source: amount of RGB light emitted

- Value represents percentage of full intensity
  E.g., (1.0,0.5,0.5)
- Every light source emits ambient, diffuse, and specular light

Materials: amount of RGB light reflected

- Value represents percentage reflected
  e.g., (0.0,1.0,0.5)

Interaction: multiply components

- Red light (1,0,0) x green surface (0,1,0) = black (0,0,0)

Wolfgang Heidrich

Lighting in OpenGL

```
glLightfv(GL_LIGHT0, GL_AMBIENT, amb_light_rgba );
glLightfv(GL_LIGHT0, GL_DIFFUSE, dif_light_rgba );
glLightfv(GL_LIGHT0, GL_SPECULAR, spec_light_rgba );
glLightfv(GL_LIGHT0, GL_POSITION, position);
glEnable(GL_LIGHT0);

glMaterialfv( GL_FRONT, GL_AMBIENT, ambient_rgba );
glMaterialfv( GL_FRONT, GL_DIFFUSE, diffuse_rgba );
glMaterialfv( GL_FRONT, GL_SPECULAR, specular_rgba );
glMaterialfv( GL_FRONT, GL_SHININESS, n );
```

Wolfgang Heidrich

Lighting in Rendering Pipeline

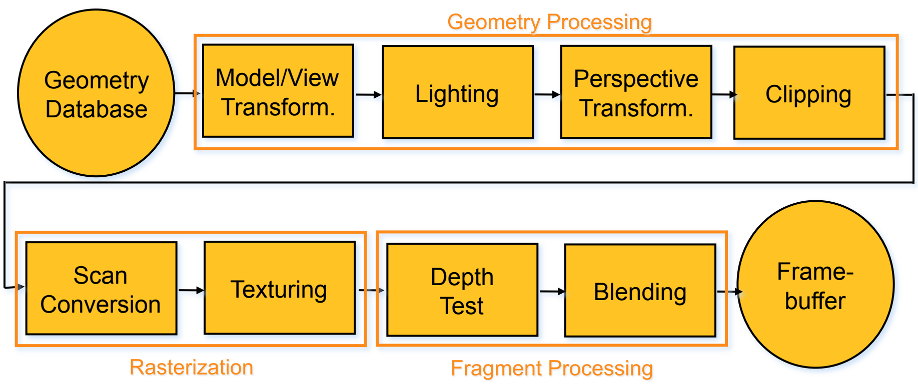
Notes:

- Lighting is applied to every **vertex**
  - *i.e. the three vertices in a triangle*
  - *Per-vertex lighting*
- Will later see how the interior points of the triangle obtain their color
  - *This process is called* ***shading***
  - *Will discuss in the context of* scan conversion

Scan Conversion

Wolfgang Heidrich

The Rendering Pipeline



Wolfgang Heidrich

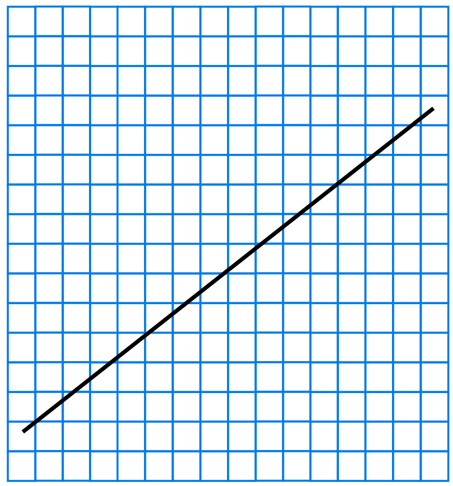
Scan Conversion - Rasterization

Convert continuous rendering primitives into discrete fragments/pixels

- Lines
  - *Midpoint/Bresenham*
- Triangles
  - *Flood fill*
  - *Scanline*
  - *Implicit formulation*
- Interpolation

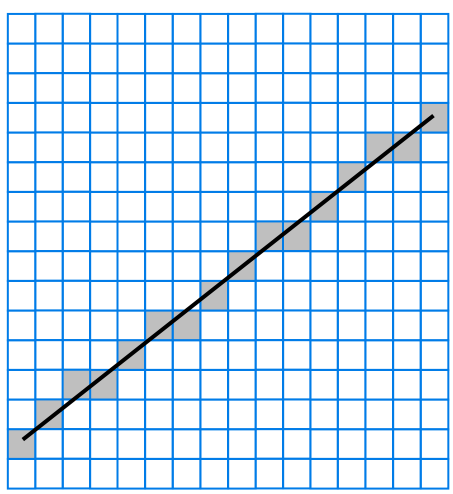
Wolfgang Heidrich

Scan Conversion - Lines



Wolfgang Heidrich

Scan Conversion - Lines



Wolfgang Heidrich

Scan Conversion - Lines

First Attempt:

- Line (s,e) given in device coordinates
- Create the thinnest line that connects start point and end point without gap

Assumptions for now:

- Start point to the left of end point: xs< xe
- Slope of the line between 0 and 1 (I.e. elevation between 0 and 45 degrees:

$$0 \le \frac{ye - ys}{xe - xs} \le 1$$

Wolfgang Heidrich

Scan Conversion of Lines - Digital Differential Analyzer

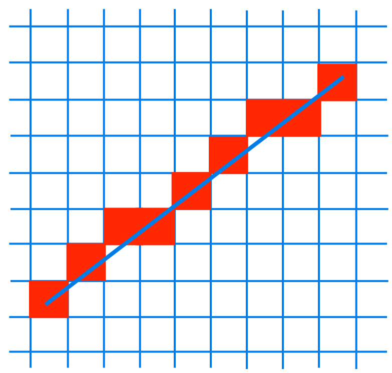
First Attempt:

```
dda( float xs, ys, xe, ye ) {
  // assume xs < xe, and slope m between 0 and 1
  float m= (ye-ys)/(xe-xs);
  float y= round( ys );
  for( int x= round( xs ) ; x<= xe ; x++ ) {
    drawPixel( x, round( y ) );
    y= y+m;
  }
}
```

Wolfgang Heidrich

Scan Conversion of Lines

DDA:

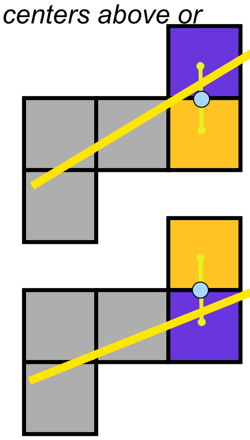


Wolfgang Heidrich

Scan Conversion of Lines
Midpoint Algorithm

Moving horizontally along x direction

- Draw at current y value, or move up vertically to y+1?
  - *Check if midpoint between two possible pixel centers above or below line*



Candidates

- Top pixel: (x+1,y+1)
- Bottom pixel: (x+1, y)

Midpoint: (x+1, y+.5)

Check if midpoint above or below line

- Below: top pixel
- Above: bottom pixel

Key idea behind Bresenham Alg.

Wolfgang Heidrich

Scan Conversion of Lines

Idea: decision variable

```
dda( float xs, ys, xe, ye ) {
    float d= 0.0;
    float m= (ye-ys)/(xe-xs);
    int y= round( ys );
    for( int x= round( xs ) ; x<= xe ; x++ ) {
        drawPixel( x, y );
        d= d+m;
        if( d>= 0.5 ) { d= d-1.0; y++; }
    }
}
```

Wolfgang Heidrich

Scan Conversion of Lines
Bresenham Algorithm ('63)

- Use decision variable to generate purely integer algorithm
- Explicit line equation:

$$y = \frac{(y_e - y_s)}{(x_e - x_s)}(x - x_s) + y_s$$

- Implicit version:

$$L(x,y) = \frac{(y_e - y_s)}{(x_e - x_s)}(x - x_s) - (y - y_s) = 0$$

- In particular for specific x, y, we have
  - *L(x,y)>0 if (x,y) below the line, and*
  - *L(x,y)<0 if (x,y) above the line*

Wolfgang Heidrich

Scan Conversion of Lines
Bresenham Algorithm

- Decision variable: after drawing point (x,y) decide whether to draw
  - $(x+1,y)$: *case E (for "east")*
  - $(x+1,y+1)$: *case NE (for "north-east")*
- Check whether $(x+1,y+1/2)$ is above or below line

$$d = L(x+1, y+\frac{1}{2})$$

- Point above line if and only if $d<0$

Wolfgang Heidrich

Scan Conversion of Lines

Bresenham Algorithm

- Problem: how to update d?
- Case E (point above line, $d<=0$)
  - *x= x+1;*
  - d= L$(x+2, y+1/2)$= $d+ (y_e-y_s)/(x_e-x_s)$
- Case NE (point below line, $d>0$)
  - *x= x+1; y= y+1;*
  - d= L$(x+2, y+3/2)$= $d+ (y_e-y_s)/(x_e-x_s)$ -1
- Initialization:
  - d= L$(x_s+1, y_s+1/2)$= $(y_e-y_s)/(x_e-x_s) -1/2$

Wolfgang Heidrich

Scan Conversion of Lines

Bresenham Algorithm

- This is still floating point
- But: only sign of d matters
- Thus: can multiply everything by $2(x_e - x_s)$

Wolfgang Heidrich

Scan Conversion of Lines

Bresenham Algorithm

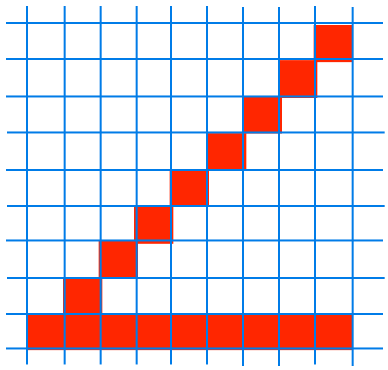
```
Bresenham( int xs, ys, xe, ye ) {
    int y= ys;
    incrE= 2(ye - ys);
    incrNE= 2((ye - ys) – (xe-xs));
    for( int x= xs ; x<= xe ; x++ ) {
        drawPixel( x, y );
        if( d<= 0 ) d+= incrE;
        else { d+= incrNE; y++; }
    }
}
```

Wolfgang Heidrich

Scan Conversion of Lines

Discussion

- Bresenham sets same pixels as DDA
- Intensity of line varies with its angle!

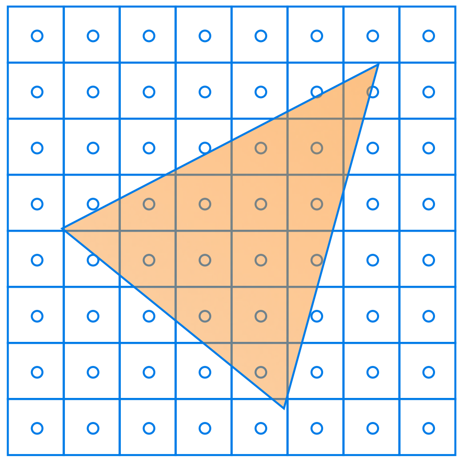


Scan Conversion of Lines

Discussion

- Bresenham
  - *Good for hardware implementations (integer!)*
- DDA
  - *May be faster for software (depends on system)!*
  - *Floating point ops higher parallelized (pipelined)*
    - E.g. RISC CPUs from MIPS, SUN
  - *No if statements in inner loop*
    - More efficient use of processor pipelining

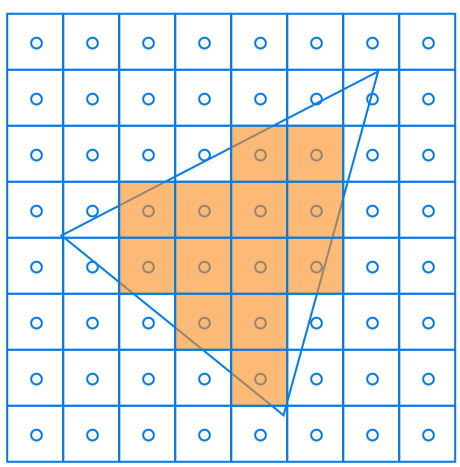
Scan Conversion of Polygons



Wolfgang Heidrich

Scan Conversion of Polygons

One possible scan conversion

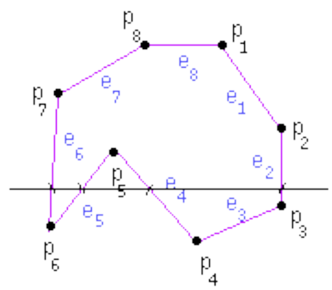


Wolfgang Heidrich

Scan Conversion of Polygons

A General Algorithm

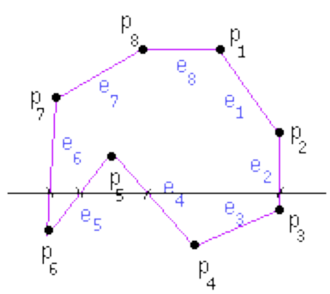
- Intersect each scanline with all edges
- Sort intersections in x
- Calculate parity to determine in/out
- Fill the 'in' pixels



Wolfgang Heidrich

Scan Conversion of Polygons

- Works for arbitrary polygons
- Efficiency improvement:
  - *Exploit row-to-row coherence using "edge table"*



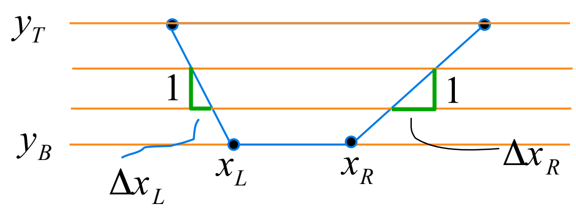
Wolfgang Heidrich

Edge Walking

Past graphics hardware

- Exploit continuous L and R edges on trapezoid

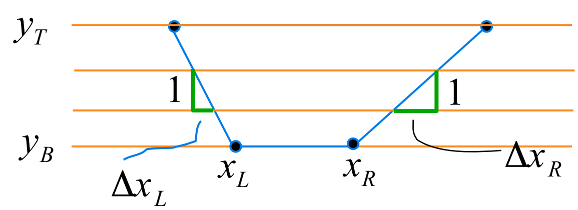
scanTrapezoid($x_L, x_R, y_B, y_T, \Delta x_L, \Delta x_R$)



Wolfgang Heidrich

Edge Walking

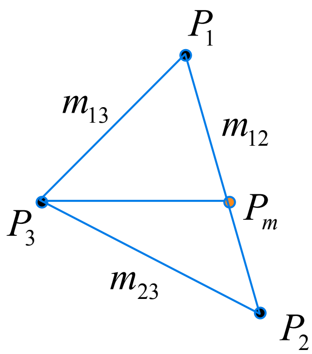
```
for (y=yB; y<=yT; y++) {
 for (x=xL; x<=xR; x++)
     setPixel(x,y);
 xL += DxL;
 xR += DxR;
}
```



Wolfgang Heidrich

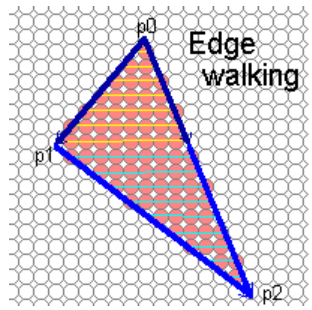
Edge Walking Triangles

- Split triangles into two regions with continuous left and right edges



scanTrapezoid($x_3, x_m, y_3, y_1, \frac{1}{m_{13}}, \frac{1}{m_{12}}$ **)**

scanTrapezoid($x_2, x_2, y_2, y_3, \frac{1}{m_{23}}, \frac{1}{m_{12}}$ **)**



Edge Walking Triangles

Issues

- Many applications have small triangles
  - *Setup cost is non-trivial*
- Clipping triangles produces non-triangles
  - *This can be avoided through re-triangulation, as discussed*

Coming Up:

Friday

- More scan conversion
- Lecture by Anika

Wolfgang Heidrich