Scan Conversion of Lines

Raster devices

Most device that are used to produce images are raster devices, that is, use rectangular arrays of dots (pixels) to display the image. This includes CRT monitors, LCDs, laser and dot-matrix printers.

Examples of non-raster output devices include vector displays (not used anymore) and plotters still widely used.

Scan conversion = converting a continuous object such as a line or a circle into discrete pixels

Scan conversion of lines

Given two points with integer coordinates $p_1 = [x_1, y_1]$, and $p_2 = [x_2, y_2]$ the algorithm has to find a sequence of pixels approximating the line.

Slope: $(y_2 - y_1)/(x_2 - x_1)$

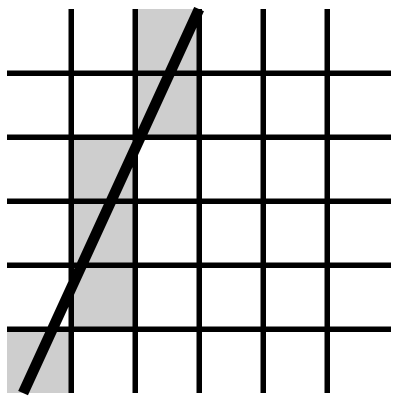
We can always reorder p_1 and p_2 so that $x_2 - x_1$

is nonnegative. It is convenient to look at only nonnegative slopes; if the slope is negative,

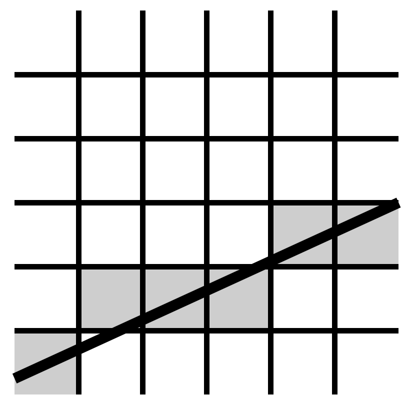
change the sign of y.

Slope

Slope reduction: it is convenient to have the slope of the line between 0 and 1; then we are able to step along x axis.



slope > 1, cannot step along x



slope < 1, can step along x

To handle slope > 1, swap x and y

DDA

Assume that the slope is between 0 and 1

Simplest algorithm (pompously called differential digital analyzer):

Step along x, increment y by slope at each step.

Round y to nearest pixel.

```
float y = y1;

float slope = (y2-y1)/(float)(x2-x1);

int x;

for(x = x1; x <= x2; x++) {

   drawpixel(x, floor(y));

   y += slope;

}
```

Bresenham Algorithm

What is wrong with DDA?

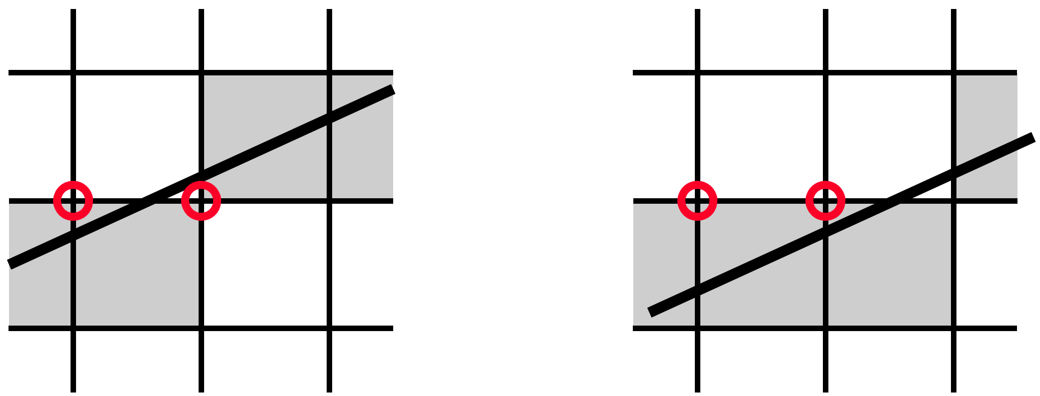
It requires floating-point operations.

These operations are expensive to implement in hardware.

They are not really necessary if the endpoints are integers.

Idea: instead of incrementing y and rounding it at each step, decide if we just go to the right, or to the right and up using only integer quantities.

Increment decision



pixel corners on
different sides of the line
increment both x and y

pixel corners on
the same side of the line
increment only x

Need: fast way to determine on which side of a line
a point is.

Half-plane test

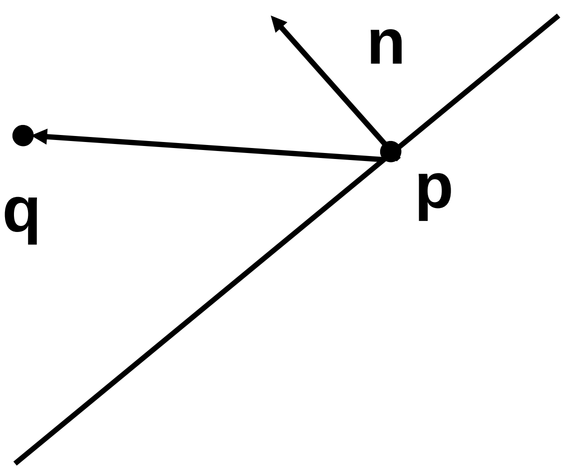
Implicit equation can be used to perform the test.

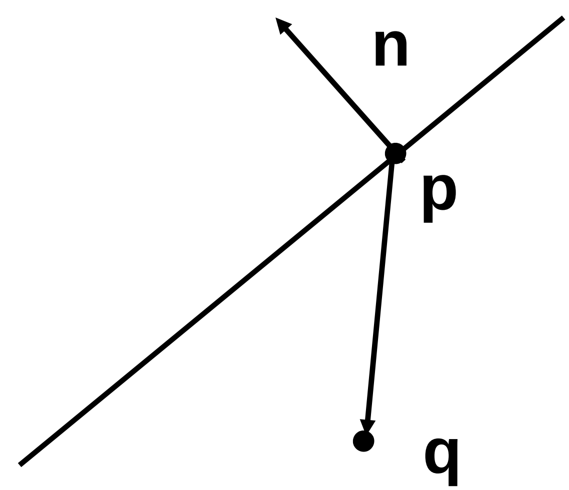
$$(\mathbf{n}\cdot(\mathbf{q}-\mathbf{p})) > 0$$

the point on the same side with the normal

$$(\mathbf{n}\cdot(\mathbf{q}-\mathbf{p})) < 0$$

the point on the other side





Implicit line equation

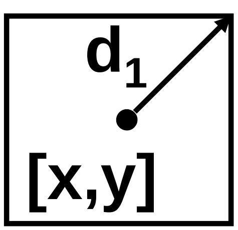
The implicit equation of the line through

$p_1 = [x_1, y_1]$, and $p_2 = [x_2, y_2]$ is

$(n, q - p_1) = 0$, with $n = [y_{2,} - y_1, x_{1,} - x_2]$

We need to test on which side of the line is the point

$q + d_1 = [x, y] + [1/2, 1/2]$



To do this, we need to determine the sign of
$F = (n, 2q + 2d_1 - 2p_1)$
Note that multiplication by two makes everything integer again!
Key idea: compute this quantity incrementally.

Incremental computation

At each step $q = [x,y]$ changes either to $[x+1,y]$

(step to the right) or to $[x+1,y+1]$ (step to the right and up); in vector form, the new value of q is

either $q + D_1$ or $q+D_2$, with $D_1=[1,0]$ and $D_2=[1,1]$

$Fnext = (n,2q+2D + 2d_1 -2p_1) = (n,2q+ 2d_1 -2p_1) + 2(n,D)$

$= F + 2(n,D)$, where D is D_1 or D_2

At each step, to get new F we have to increment

old F either by (n,D_1) or (n,D_2)

$(n,D_1) = y_2-y_1$

$(n,D_2) = (y_2-y_1) - (x_2-x_1)$

Bresenham algorithm

Assume the slope to be between 0 and 1.

```
int y = y1;  int dy = y2-y1;
int dxdy = y2-y1+x1-x2;
int F = y2-y1+x1-x2; int x;
for( x = x1; x < =x2; x++ ) {
   drawpixel(x,y);
   if( F < 0 ) {
      F += dy;
   } else {
      y++; F+= dxdy;
   }
}
```

Bresenham algorithm

In your implementation you need to handle all slopes!

First, reorder endpoints so that $x_{1,} <= x_2$

Then consider 4 cases:

$y_{2,}-y_1 >= 0$, $x_{2,}-x_1 >= y_{2,}-y_1$ positive slope <= 1

$y_{2,}-y_1 >= 0$, $x_{2,}-x_1 < y_{2,}-y_1$ positive slope > 1

$y_{2,}-y_1 < 0$, $x_{2,}-x_1 >= y_{1,}-y_2$ negative slope >= -1

$y_{2,}-y_1 < 0$, $x_{2,}-x_1 < y_{1,}-y_2$ negative slope < -1

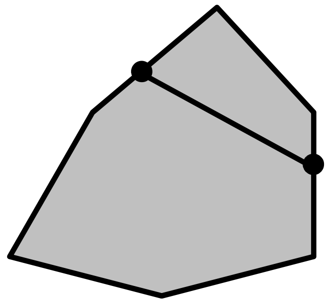
In each case, make appropriate substitutions in

the algorithm.

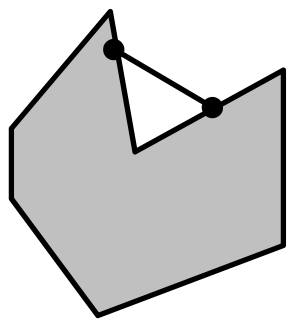
Scan converting polygons

Polygons

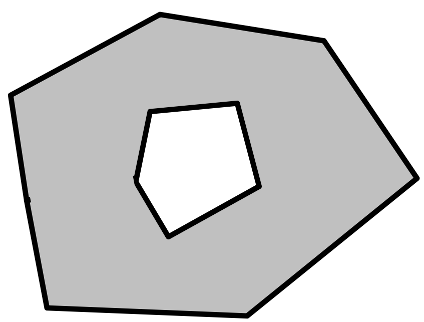
convex



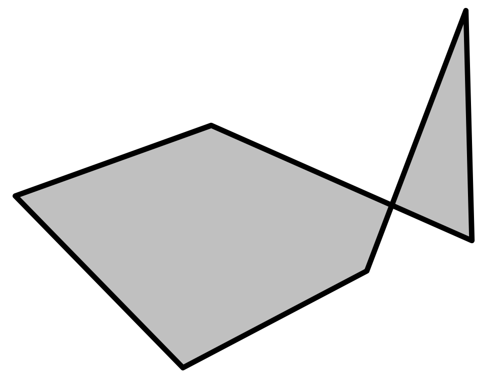
non-convex



with holes



with self-intersections



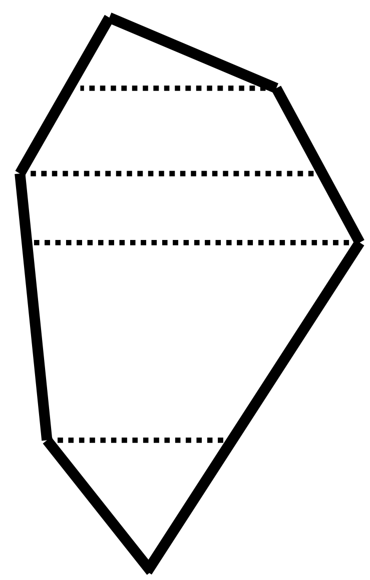
We focus on the convex case

Scan Conversion of Convex Polygons

General idea:

decompose polygon into tiles

scan convert each tile, moving along one edge



Convex Polygons

Scan convert a convex polygon:

```
void ScanY( Vertex2D v[], int num_vertices, int bottom_index)
```

array of vertices in counterclockwise order

array size

number of the vertex with min. y coordinate

1. Find left edge of a tile:

•go around **clockwise,** starting from v[bot], until find an edge such that it is not contained inside a scan line:

2. Similarly, find the right edge of a tile.
3. Scan convert all scan lines going from left to right edges

Convex Polygons

```
void ScanY( Vertex2D v[], int num_vertices, int bottom_index) {
```

Initialize variables

```
  remaining_vertices = num_vertices;
  while(remaining_vertices > 0)
  {
```

Find the left top row candidate

Determine the slope and starting x location for the left tile edge

Find the right top row candidate

Determine the slope and starting x location for the right tile edge

```
    for(row = bottom_row; row < left_top_row &&
        row < right_top_row; row++)
    {
      ScanX(ceil(left_pos),ceil(right_pos),row);
      left_pos += left_step;
      right_pos += right_step;
    }
    bottom_row = row;
  }
}
```

Initialization

Keep track of the numbers of the vertices on the left and on the right:

```
int left_edge_end = bottom_index;
int right_edge_end= bottom_index;
```

This is the first row of a tile:

```
int bottom_row = ceil(v[bottom_index].y);
```

These are used to store the candidates for the top row of a tile:

```
int left_top_row  = bottom_row;
int right_top_row = bottom_row;
```

Keep track of the intersections of left and right edges of a tile with horizontal integer lines:

```
float left_pos, right_pos, left_step, right_step;
```

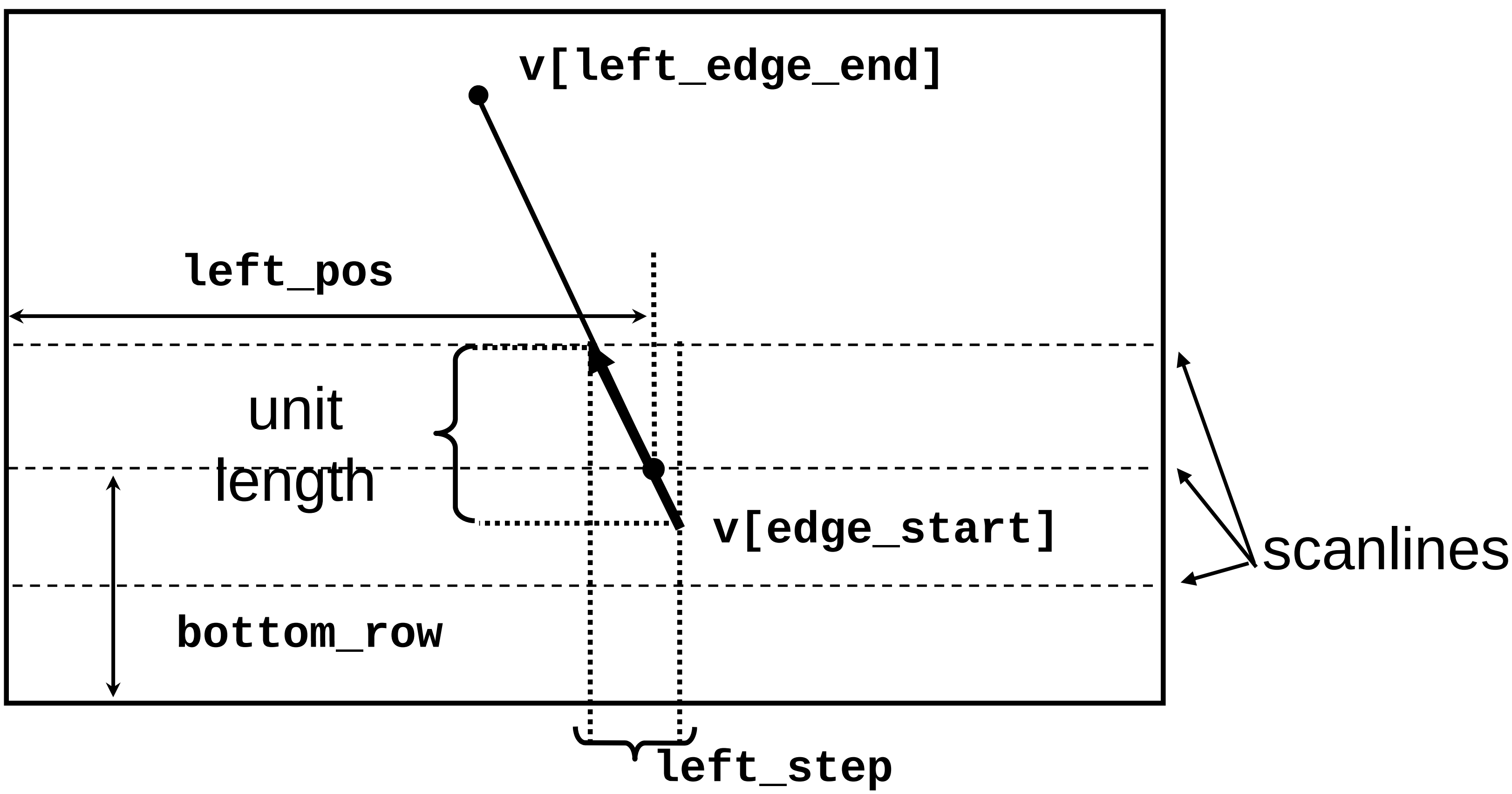
Number of remaining vertices:

```
int remaining_vertices;
```

A couple of auxilary variables: `int edge_start;  int row;`

Find a tile

Compute increment in y direction and starting/ending (left/right) point for the first scan of a tile



Find a tile

Find the left top row candidate

```
while( left_top_row <= bottom_row && remaining_vertices > 0)
{ Move to next edge:
  edge_start = left_edge_end;
```

Be careful with C % operator, (N-1) % M will give -1 for N = 0, need to use (N+M-1) % M to get (N-1) mod M = N-1

```
  left_edge_end = (left_edge_end+num_vertices-1)%num_vertices;
  left_top_row = ceil(v[left_edge_end].y);
  remaining_vertices--;
```

We found the first edge that sticks out over `bottom_row`

determine the slope and starting x location for the left tile edge.

```
  if(left_top_row > bottom_row )
  {
    left_step = (v[left_edge_end].x - v[edge_start].x)/
                     (v[left_edge_end].y - v[edge_start].y);
    left_pos = v[edge_start].x +
                   (bottom_row-v[edge_start].y)*left_step;
  }
}
```

Find a tile

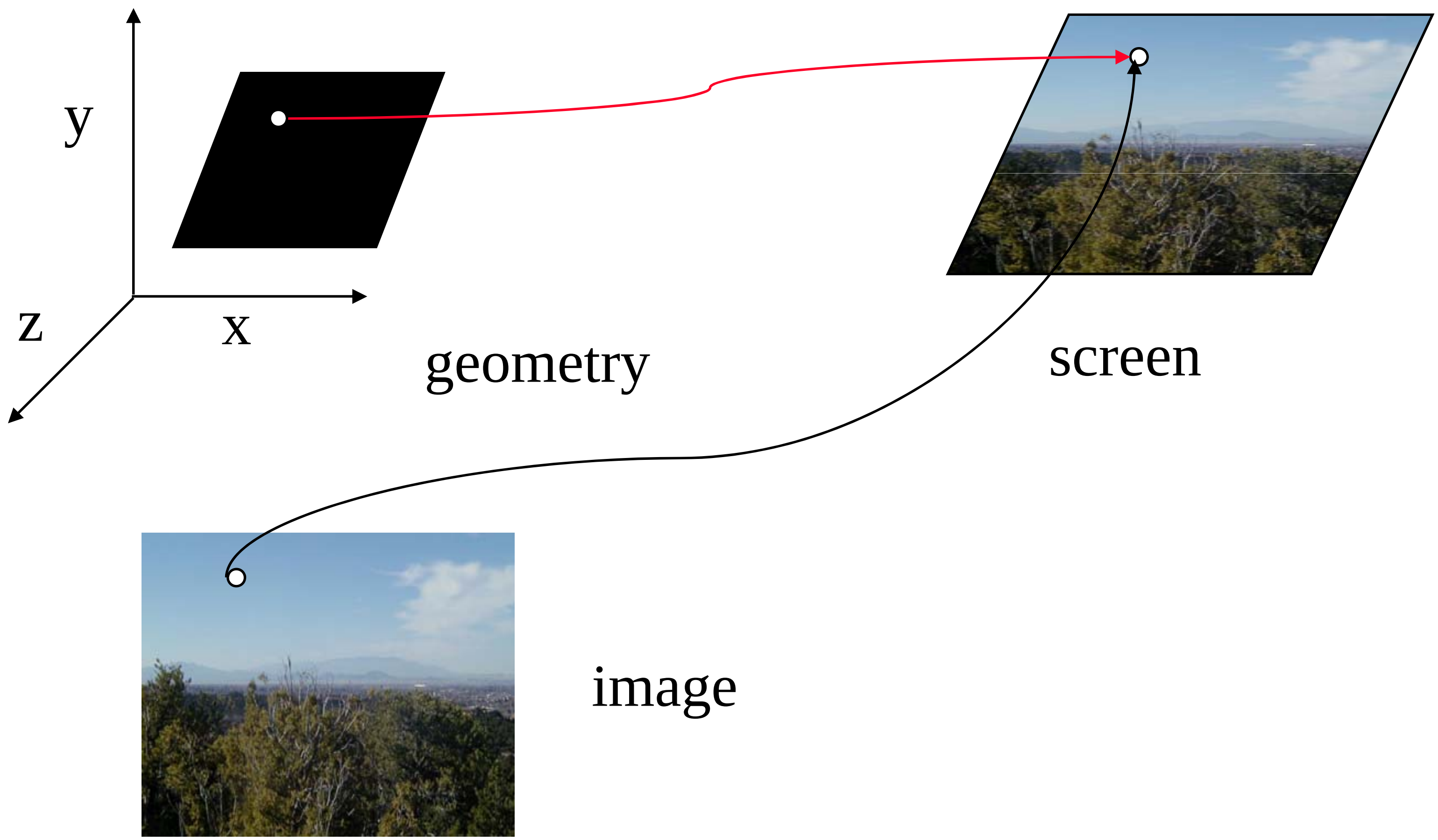
Find the right top row candidate;
determine the slope and starting x location for the right tile edge.
Exactly as for the left edge.

Scan convert a single row:

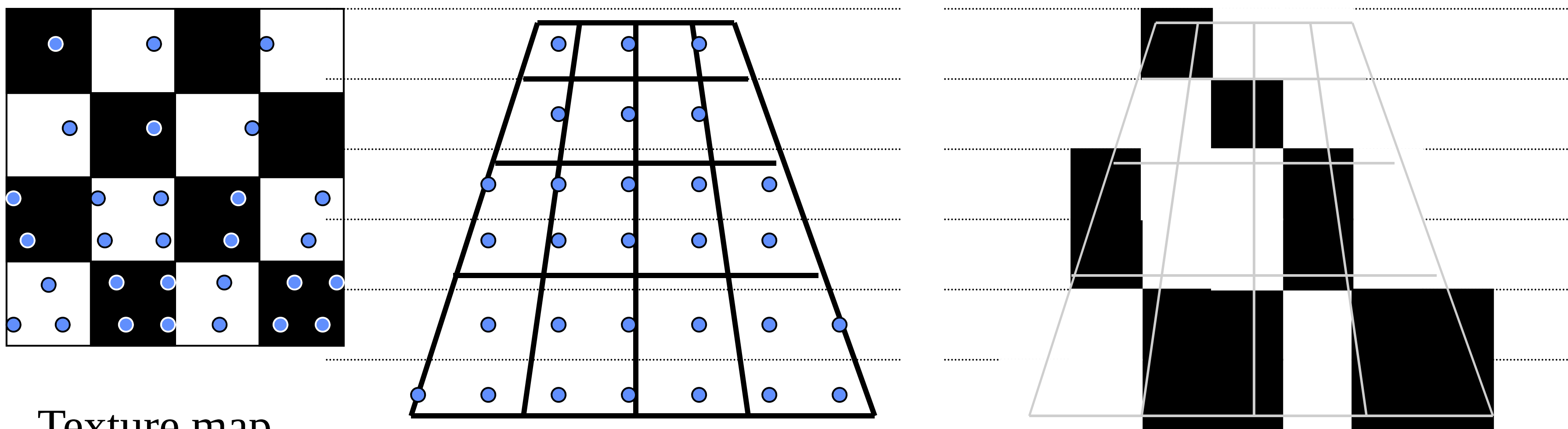
```
void ScanX(int left_col, int  right_col, int row, int R,
    int G, int B) {
  if( left_col < right_col) {
    for( int x = left_col; x < right_col; x++) {
       draw_pixel(x,y);
    }
  }
}
```

Texture mapping

Texture slides are based on E. Angel's slides



Sampling texture maps



Texture map

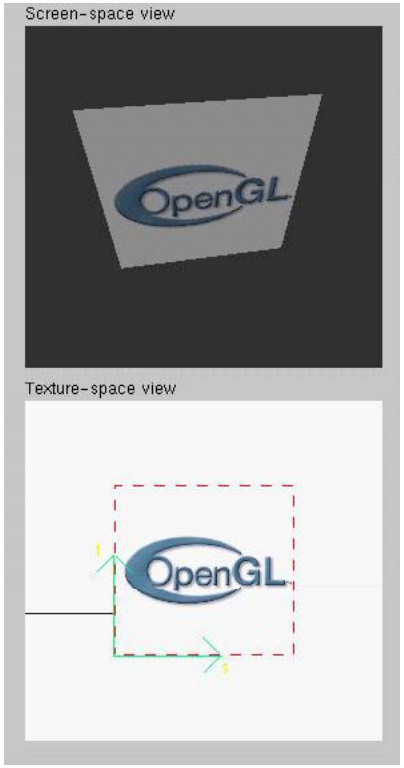
Polygon far from the viewer in perspective projection

Rasterized and textured

the back row is a very poor representation of the true image

Texture Example

The texture (below) is a 256 x 256 image that has been mapped to a rectangular polygon which is viewed in perspective



Applying Textures I

Three steps

① **specify texture**

- **read or generate image**
- **assign to texture**

② **assign texture coordinates to vertices**

③ **specify texture parameters**

- **wrapping, filtering**

Applying Textures II

- specify textures in texture objects
- set texture filter
- set texture function
- set texture wrap mode
- set optional perspective correction hint
- bind texture object
- enable texturing
- supply texture coordinates for vertex
  - coordinates can also be generated

Texture Objects

Like display lists for texture images

- one image per texture object
- may be shared by several graphics contexts

Generate texture names

```
glGenTextures( n, *texIds );
```

Bind textures before using

```
glBindTexture( target, id );
```

Specify Texture Image

Define a texture image from an array of texels in CPU memory

```
glTexImage2D( target, level, components,
      w, h, border, format, type, *texels );
```

- dimensions of image must be powers of 2

Texel colors are processed by pixel pipeline

- pixel scales, biases and lookups can be done

Converting A Texture Image

If dimensions of image are not power of 2

```
gluScaleImage( format, w_in, h_in,
    type_in, *data_in, w_out, h_out,
        type_out, *data_out );
```

- ***_in** *is for source image*
- ***_out** *is for destination image*

Image interpolated and filtered during scaling

Specifying a Texture:Other Methods

Use frame buffer as source of texture image

- uses current buffer as source image

```
glCopyTexImage2D(...)
glCopyTexImage1D(...)
```

Modify part of a defined texture

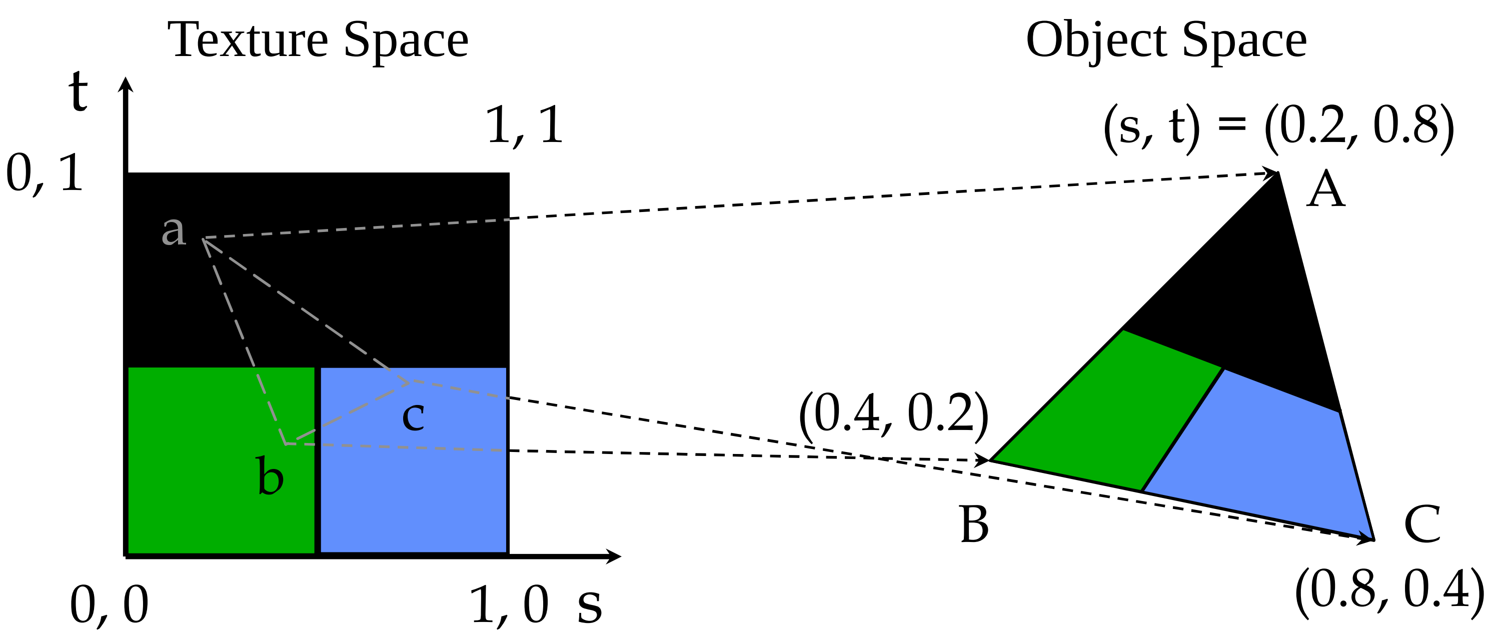
```
glTexSubImage2D(...)
glTexSubImage1D(...)
```

Do both with ***`glCopyTexSubImage2D(...)`***, etc.

Mapping a Texture

Based on parametric texture coordinates

`glTexCoord*()` specified at each vertex



Generating Texture Coordinates

Automatically generate texture coords

`glTexGen{ifd}[v]()`

specify a plane

- **generate texture coordinates based upon distance from plane**

generation modes

$$Ax + By + Cz + D = 0$$

- `GL_OBJECT_LINEAR`
- `GL_EYE_LINEAR`
- `GL_SPHERE_MAP`

Texture Application Methods

Filter Modes

- minification or magnification
- special mipmap minification filters

Wrap Modes

- clamping or repeating

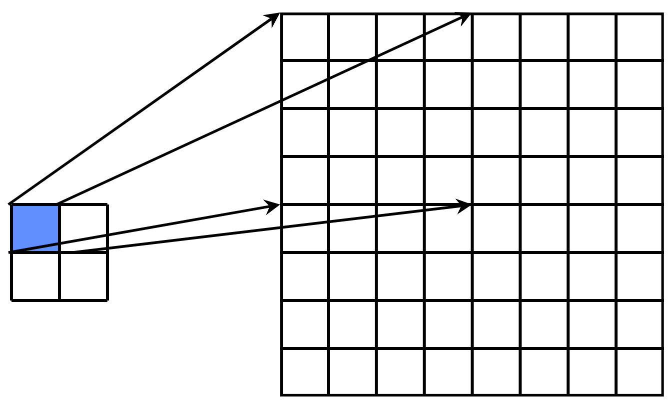
Texture Functions

- how to mix primitive’s color with texture’s color
  - blend, modulate or replace texels

Filter Modes

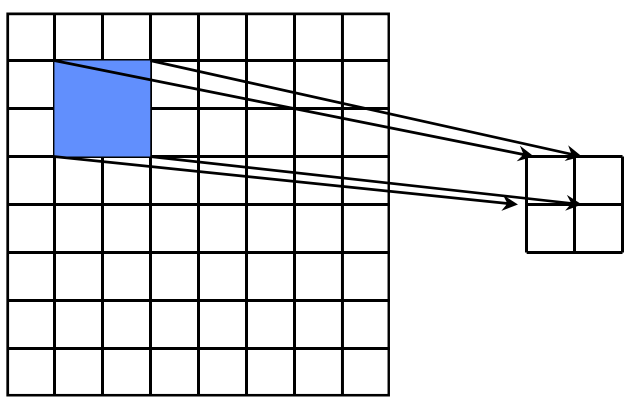
Example:

`glTexParameteri( target, type, mode );`



Texture Polygon

Magnification



Texture Polygon

Minification

Mipmapped Textures

Mipmap allows for prefiltered texture maps of decreasing resolutions

Lessens interpolation errors for smaller textured objects

Declare mipmap level during texture definition

```
glTexImage*D( GL_TEXTURE_*D, level, … )
```

GLU mipmap builder routines

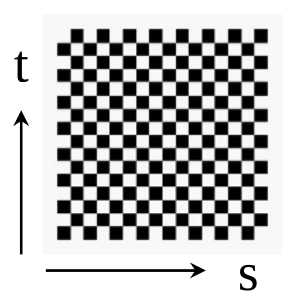
```
gluBuild*DMipmaps( … )
```

OpenGL 1.2 introduces advanced LOD controls

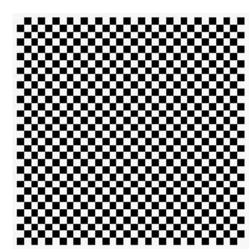
Wrapping Mode

Example:

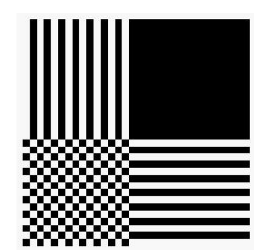
```
glTexParameteri( GL_TEXTURE_2D,
     GL_TEXTURE_WRAP_S, GL_CLAMP )

glTexParameteri( GL_TEXTURE_2D,
     GL_TEXTURE_WRAP_T, GL_REPEAT )
```



texture



GL_REPEAT
wrapping



GL_CLAMP
wrapping

Texture Functions

Controls how texture is applied

```
glTexEnv{fi}[v]( GL_TEXTURE_ENV, prop, param )
```

***GL_TEXTURE_ENV_MODE* modes**

- GL_MODULATE
- GL_BLEND
- GL_REPLACE

Set blend color with *GL_TEXTURE_ENV_COLOR*

Perspective Correction Hint

Texture coordinate and color interpolation

- **either linearly in screen space**
- **or using depth/perspective values (slower)**

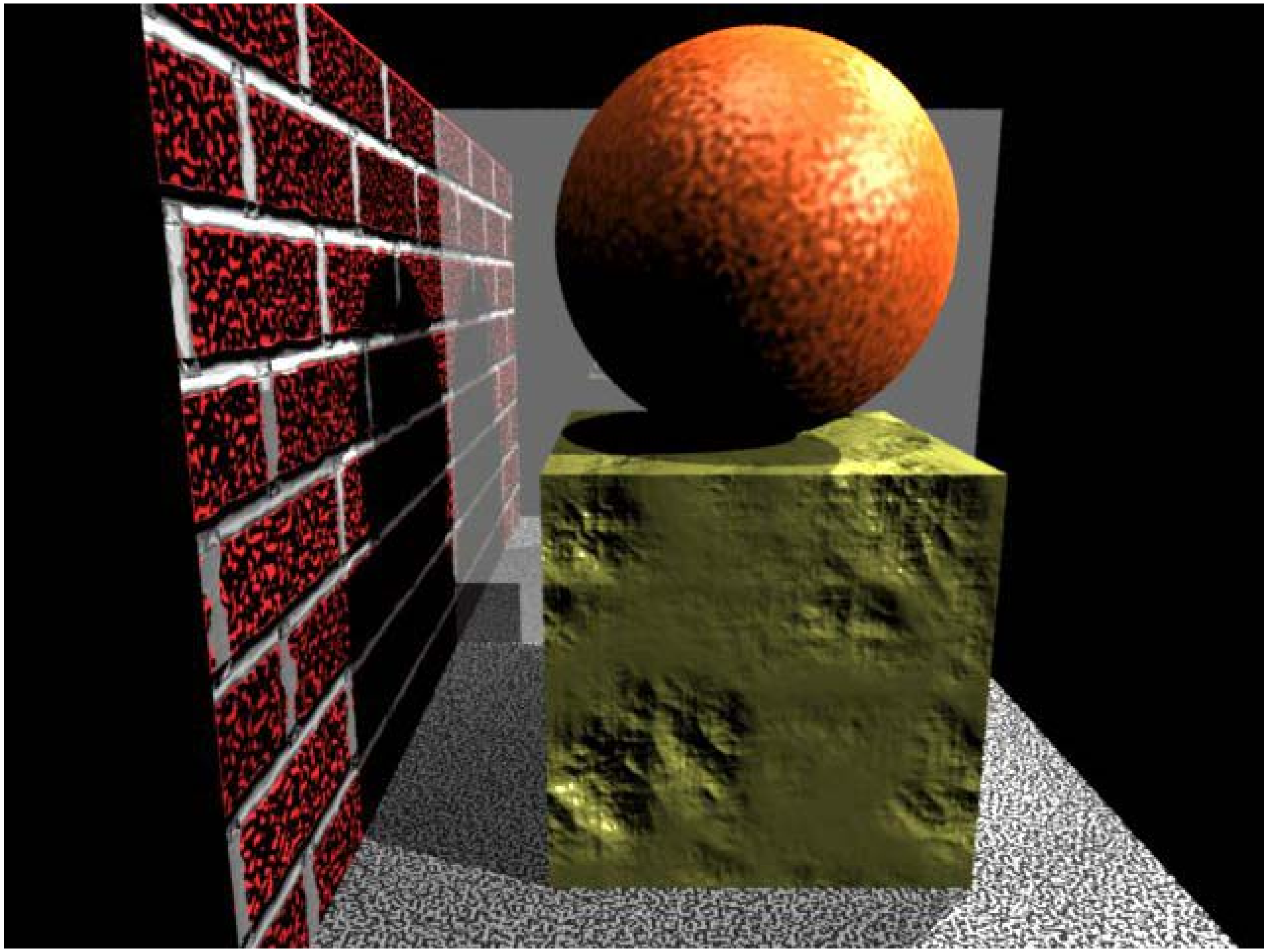
Noticeable for polygons "on edge"

```
glHint( GL_PERSPECTIVE_CORRECTION_HINT, hint )
```

where *`hint`* **is one of**

- *GL_DONT_CARE*
- *GL_NICEST*
- *GL_FASTEST*

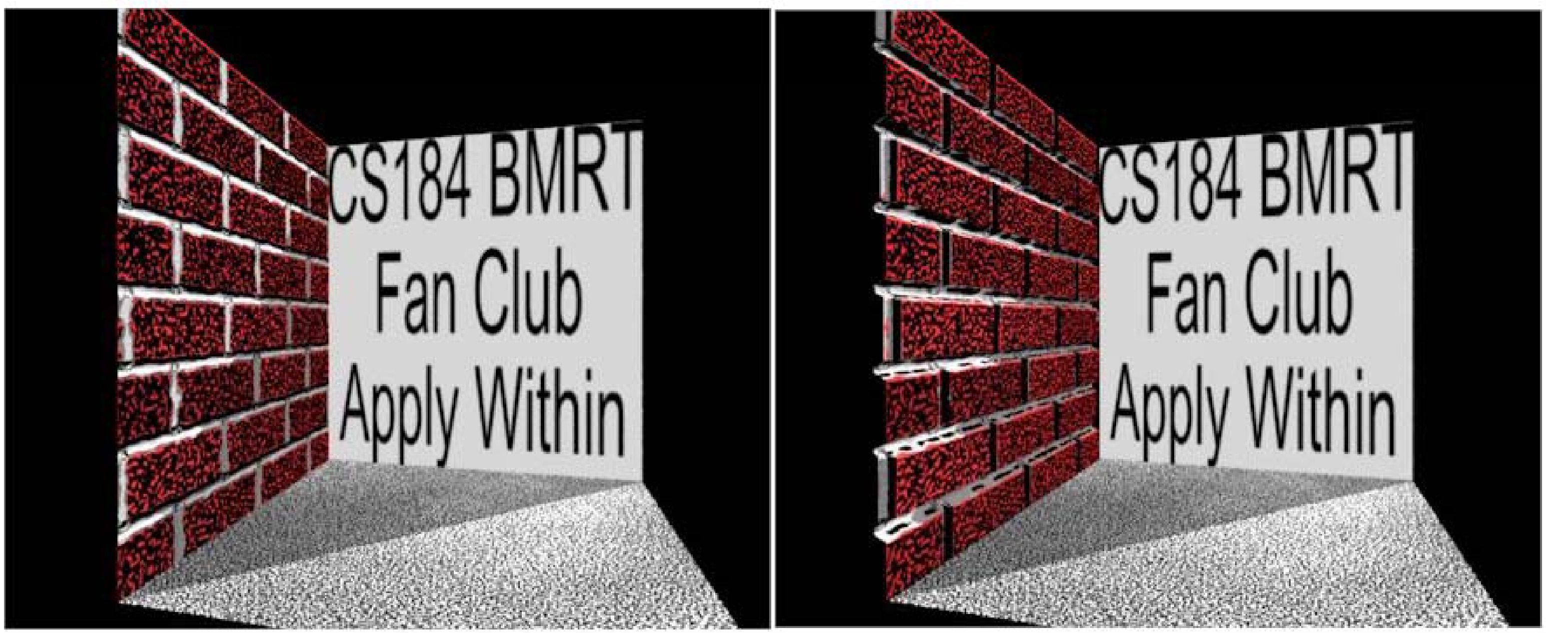
Bump Mapping



Displacement Mapping

Bump mapped normals are inconsistent with actual geometry.
Problems arise (shadows).

Displacement mapping actually affects the surface geometry



Mipmaps

multum in parvo **-- many things in a small place**

A texture LOD technique

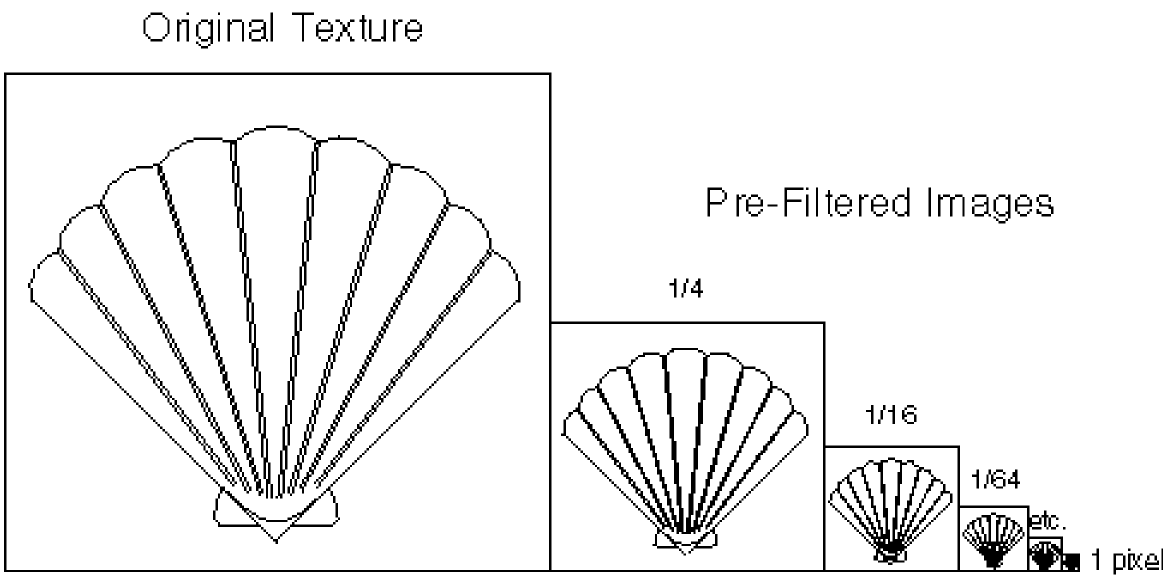
Prespecify a series of prefiltered texture maps of decreasing resolutions

Requires more texture storage

Eliminates shimmering and flashing as objects move

MIPMAPS

Arrange different versions into one block of memory



MIPMAPS

With versus without MIPMAP