University of British Columbia

CPSC 414 Computer Graphics

Texturing, Clipping

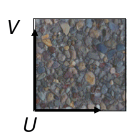
Week 9, Mon 27 Oct 2003

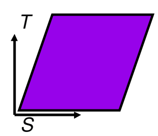
Reading

- Chapter 7.1-7.10: texturing
- Chapter 8.3-8.7: clipping
- bump mapping extra reading
  http://www.cs.wpi.edu/~matt/courses/cs563/talks/bump/bumpmap.html

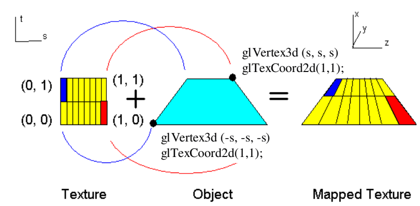
Texture Mapping

- texture map is an image, two-dimensional array of color values (texels)
- texels are specified by texture's (u,v) space
- at each screen pixel, texel can be used to substitute a polygon's surface property (color)
- we must map (u,v) space to polygon's (s, t) space



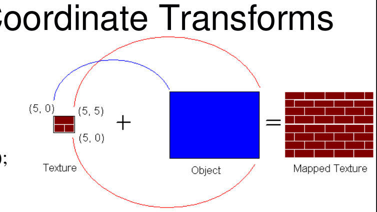


Example Texture Map

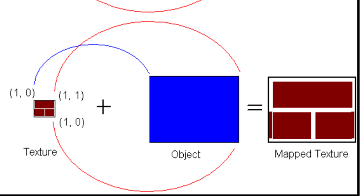


Texture Coordinate Transforms

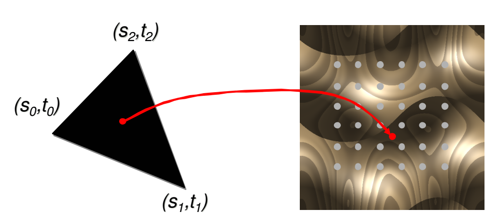
glVertex3d (s, s, s)
glTexCoord2d(5, 5);



glVertex3d (s, s, s)
glTexCoord2d(1, 1);



Texture Mapping



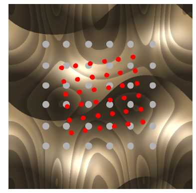
Texture Mapping and Filtering

- ideal algorithm:
  - given texture map as regular grid of texels, reconstruct continuous texture function using low pass filtering
  - map this continuous texture onto 3D surface
  - project surface onto image plane using model/view and perspective transformation
  - low-pass filter resulting continuous function according to desired image resolution (avoid aliasing)
  - sample filtered continuous image at pixel positions

Texture Mapping and Filtering

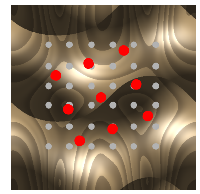
- in practice: 2 cases

texture magnification



interpolation

texture minification



averaging

- Texel
- Pixel

Texture Magnification

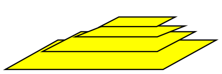
- synopsis
  - texture appears magnified on screen
  - only need to low-pass filter in texture space
    - that already removes frequencies higher than the Nyquist limit for the final image resolution
  - what filter to use?
    - nearest neighbor: just choose color of closest texel for every pixel
      - worst of all possible choices!
    - linear interpolation: interpolate from the closest samples (2 in 1D texture, 4 for 2D, 8 for 3D)

Texture Minification

- synopsis
  - texture appears reduced in size on screen
  - only need to low-pass filter in image space
    - will also remove all the high frequencies in texture space
  - same filter as magnification case?
    - problem: a lot of texels could fall within the support of the low-pass filter for a single image
      - e.g. when an object is very far away so that it maps to a single pixel in the final image
      - too expensive: have to evaluate filter function at an unbounded number of places and average results!

Texture Minification Filters

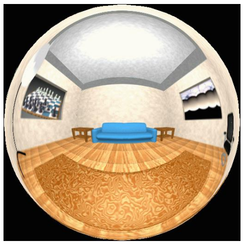
- solution: precomputation
  - MIP-Mapping (Multum In Parvo)
    - “many things in a small place”
    - store not <u>one</u> texture image, but whole pyramid
    - resolution from level to level varies by factor of two (original resolution … 1x1)
    - every level is correctly filtered for its resolution



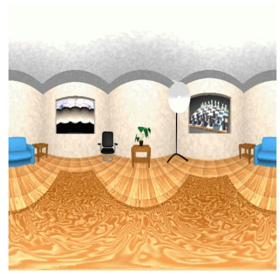
Environment Mapping

- used to model a object that reflects surrounding textures to the eye
  - polished sphere reflects walls and ceiling textures
  - cyborg in Terminator 2 reflects flaming destruction
- texture is distorted fish-eye view of environment
- spherical texture mapping creates texture coordinates that correctly index into this texture map

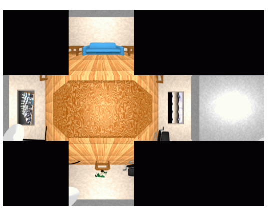
Sphere Mapping



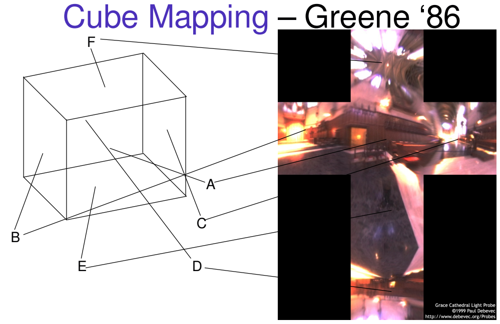
Blinn/Newell Latitude Mapping



Cube Mapping



Cube Mapping – Greene '86

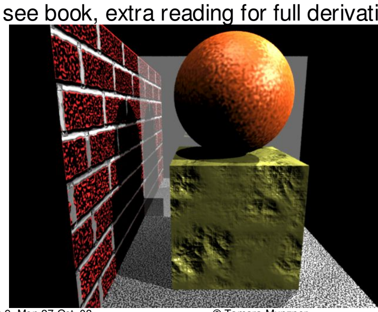


Cube Mapping – Greene '86

- direction of reflection vector *r* selects the face of the cube to be indexed
  - co-ordinate with largest magnitude
    - e.g., the vector (-0.2, 0.5, -0.84) selects the –Z face!
  - remaining two coordinates (normalized by the 3rd coordinate) selects the pixel from the face.
    - e.g., (-0.2, 0.5) gets mapped to (0.38, 0.80).
- difficulty in interpolating across faces!
- OpenGL support `GL_CUBE_MAP`

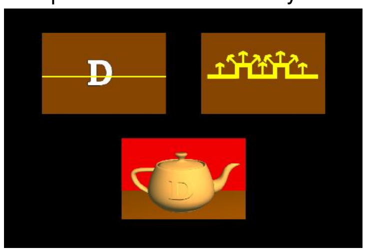
Bump Mapping

- image encodes normal change
  - see book, extra reading for full derivation



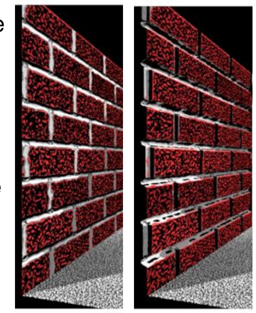
Embossing

- at transitions
  - rotate point's surface normal by θ or $-\theta$



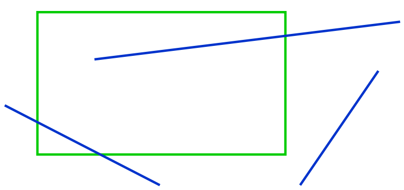
Displacement Mapping

- bump mapped normals are inconsistent with actual geometry.
  - problems: shadows, silhouettes
- displacement mapping actually affects the surface geometry



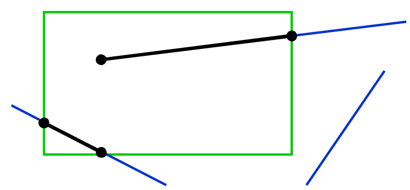
Next Topic: Clipping

- we've been assuming that all primitives (lines, triangles, polygons) lie entirely within the *viewport*
  - in general, this assumption will not hold:



Clipping

- analytically calculating the portions of primitives within the viewport



Why Clip?

- bad idea to rasterize outside of framebuffer bounds
- also, don't waste time scan converting pixels outside window
  - could be billions of pixels for very close objects!

Line Clipping

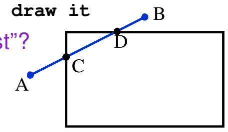
- 2D
  - determine portion of line inside an axis-aligned rectangle (screen or window)
- 3D
  - determine portion of line inside axis-ligned parallelpiped (viewing frustum in NDC)
  - simple extension to the 2D algorithms

Clipping

- naïve approach to clipping lines:

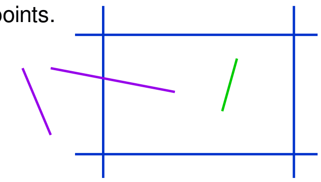
```
for each line segment
    for each edge of viewport
        find intersection point
        pick "nearest" point
    if anything is left, draw it
```

- what do we mean by "nearest"?
- how can we optimize this?



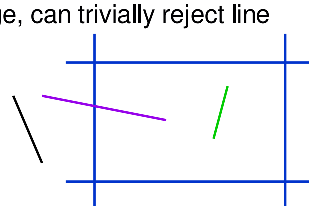
Trivial Accepts

- big optimization: trivial accept/rejects
- Q: how can we quickly determine whether a line segment is entirely inside the viewport?
- A: test both endpoints.



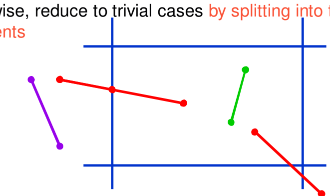
Trivial Rejects

- Q: how can we know a line is outside viewport?
- A: if both endpoints on wrong side of same edge, can trivially reject line



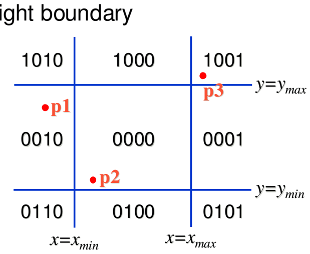
Clipping Lines To Viewport

- combining trivial accepts/rejects
  - trivially accept lines with both endpoints inside all edges of the viewport
  - trivially reject lines with both endpoints outside the same edge of the viewport
  - otherwise, reduce to trivial cases by splitting into two segments



Cohen-Sutherland Line Clipping

- outcodes
  - 4 flags encoding position of a point relative to top, bottom, left, and right boundary
    - *OC(p1)=0010*
    - *OC(p2)=0000*
    - *OC(p3)=1001*



Cohen-Sutherland Line Clipping

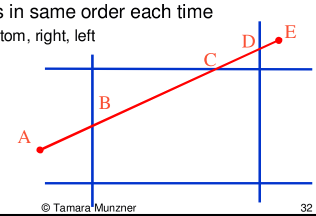
- assign outcode to each vertex of line to test
  - line segment: (**p1**,**p2**)
- trivial cases
  - OC(**p1**)== 0 && OC(**p2**)==0
    - both points inside window, thus line segment completely visible (trivial accept)
  - (OC(**p1**) & OC(**p2**))!= 0
    - there is (at least) one boundary for which both points are outside (same flag set in both outcodes)
    - thus line segment completely outside window (trivial reject)

Cohen-Sutherland Line Clipping

- if line cannot be trivially accepted or rejected, subdivide so that one or both segments can be discarded
- pick an edge that the line crosses (*how?*)
- intersect line with edge (*how?*)
- discard portion on wrong side of edge and assign outcode to new vertex
- apply trivial accept/reject tests; repeat if necessary

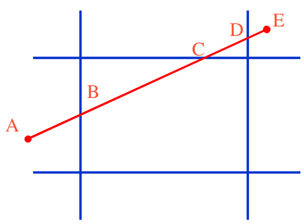
Cohen-Sutherland Line Clipping

- if line cannot be trivially accepted or rejected, subdivide so that one or both segments can be discarded
- pick an edge that the line crosses
  - check against edges in same order each time
    - for example: top, bottom, right, left



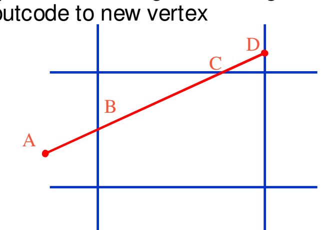
Cohen-Sutherland Line Clipping

- intersect line with edge (how?)



Cohen-Sutherland Line Clipping

- discard portion on wrong side of edge and assign outcode to new vertex



- apply trivial accept/reject tests and repeat if necessary

Viewport Intersection Code

- (x_1, y_1), (x_2, y_2) intersect with vertical edge at x_{right}
  - $y_{intersect} = y_1 + m(x_{right} – x1)$, $m=(y_2-y_1)/(x_2-x_1)$
- (x_1, y_1), (x_2, y_2) intersect with horizontal edge at y_{bottom}
  - $x_{intersect} = x_1 + (y_{bottom} – y1)/m$, $m=(y_2-y_1)/(x_2-x_1)$

Cohen-Sutherland Review

- use opcodes to quickly eliminate/include lines
  - best algorithm when trivial accepts/rejects are common
- must compute viewport clipping of remaining lines
  - non-trivial clipping cost
  - redundant clipping of some lines
- more efficient algorithms exist

Line Clipping in 3D

- approach:
  - clip against parallelpiped in NDC
    - *after* perspective transform
  - means that the clipping volume always the same
    - $x_{min}=y_{min}= -1$, $x_{max}=y_{max}= 1$ in OpenGL
  - boundary lines become boundary planes
    - but outcodes still work the same way
    - additional front and back clipping plane

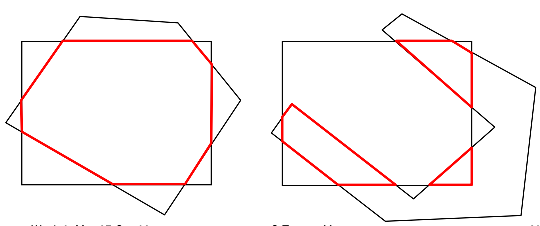
      $z_{min} = -1$, $z_{max} = 1$ in OpenGL

Polygon Clipping

- objective
  - 2D: clip polygon against rectangular window
    - or general convex polygons
    - extensions for non-convex or general polygons
  - 3D: clip polygon against parallelpiped

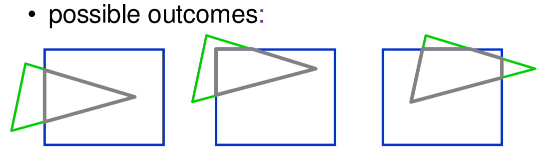
Polygon Clipping

- not just clipping all boundary lines
  - may have to introduce new line segments



Why Is Clipping Hard?

- what happens to a triangle during clipping?
- possible outcomes:

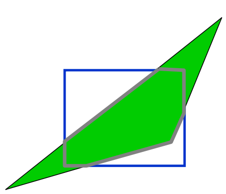


triangle ⇨ triangle   triangle ⇨ quad   triangle ⇨ 5-gon

- how many sides can a clipped triangle have?

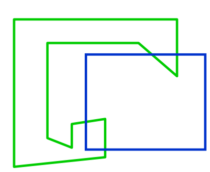
How Many Sides?

- seven…



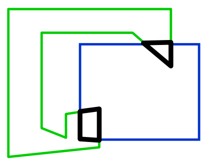
Why Is Clipping Hard?

- a really tough case:



Why Is Clipping Hard?

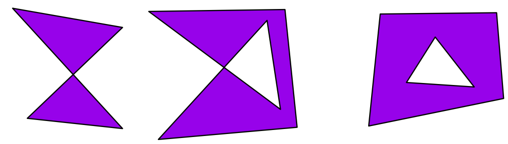
- a really tough case:



concave polygon ⇨ multiple polygons

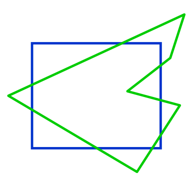
Polygon Clipping

- classes of polygons
  - triangles
  - convex
  - concave
  - holes and self-intersection



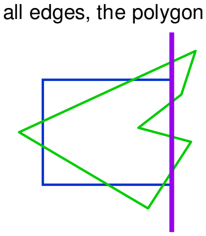
Sutherland-Hodgeman Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



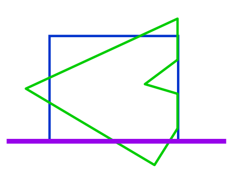
Sutherland-Hodgeman Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



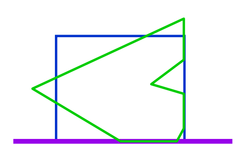
Sutherland-Hodgeman Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



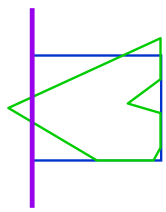
Sutherland-Hodgeman Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



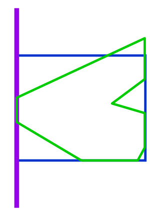
Sutherland-Hodgeman Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



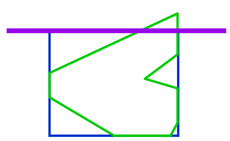
Sutherland-Hodgeman Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



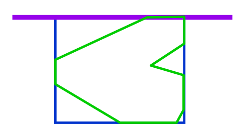
Sutherland-Hodgeman Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



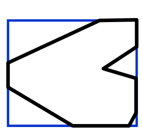
Sutherland-Hodgeman Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



Sutherland-Hodgeman Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



Sutherland-Hodgeman Algorithm

- input/output for algorithm:
  - input: list of polygon vertices in order
  - output: list of clipped poygon vertices consisting of old vertices (maybe) and new vertices (maybe)
- note: this is exactly what we expect from the clipping operation against each edge

Sutherland-Hodgeman Clipping

- Sutherland-Hodgman basic routine:
  - go around polygon one vertex at a time
  - current vertex has position *p*
  - previous vertex had position *s*, and it has been added to the output if appropriate

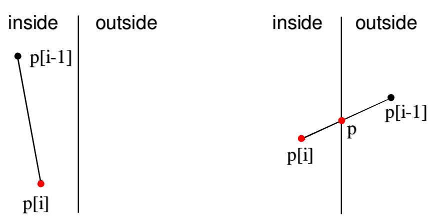
Polygon Clipping

- clipping against one edge:

```
clipPolygonToEdge( p[n], edge ) {
  for( i= 0 ; i< n ; i++ ) {
    if( p[i] inside edge ) {
      if( p[i-1] inside edge ) // p[-1]= p[n-1]
        output p[i];
      else {
        p= intersect( p[i-1], p[i], edge );
        output p, p[i];
      }
    } else…
```


Polygon Clipping

- clipping against one edge (cont)
  - p[i] inside: 2 cases



Output: p[i] Output: p, p[i]

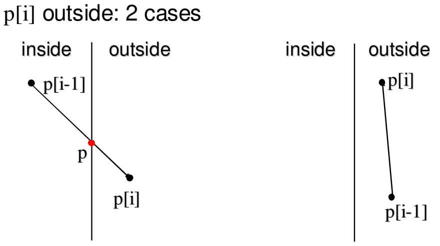
Polygon Clipping

- clipping against one edge (cont)

```
    …
    else {          // p[i] is outside edge
      if( p[i-1] inside edge ) {
        p= intersect(p[i-1], p[I], edge );
        output p;
      }
    }
} // end of algorithm
```


Polygon Clipping

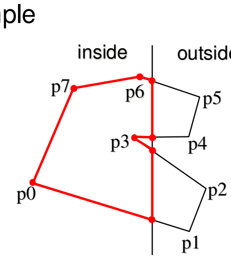
- clipping against one edge (cont)
  - p[i] outside: 2 cases



Output: p Output:nothing

Polygon Clipping

- example



Polygon Clipping

- Sutherland/Hodgeman Algorithm
  - inside/outside tests: outcodes
  - intersection of line segment with edge: window-edge coordinates
  - similar to Cohen/Sutherland algorithm for line clipping

Sutherland/Hodgeman Discussion

- clipping against individual edges independent
  - great for hardware (pipelining)
  - all vertices required in memory at the same time
    - not so good, but unavoidable
    - another reason for using triangles only in hardware rendering

Sutherland/Hodgeman Discussion

- for rendering pipeline:
  - re-triangulate resulting polygon
    (can be done for every individual clipping edge)