Visibility

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- view volume culling
- view volume clipping
- backface culling
- z-buffer occlusion test
- painter's algorithm & BSP trees
- occlusion culling
- raytracing

(1): view volume culling, view volume clipping

(2): backface culling, z-buffer occlusion test, painter's algorithm & BSP trees, occlusion culling

raytracing → (1), (2)

How to efficiently compute what can and cannot be seen.

(1) outside of view volume

(2) occluded by other objects

View Volume Culling

VV

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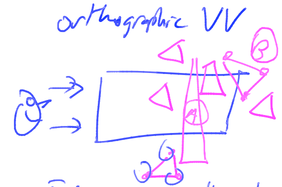
polygons outside the view volume ?

orthographic VV



(B) If all vertices "outside" wrt any one plane then cull.

Idea: If all vertices "outside", then cull the polygon

Problem: fails sometimes (A), (B)

Fix: (1) For each vertex V

(2) For each plane P

(3) compute vertex V is inside/outside wrt P

"outcodes"

View Volume Culling

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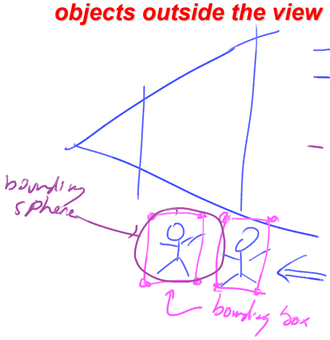
objects outside the view volume ?



- inefficient to cull individual △s
- if all bbox vertices are "outside" wrt any plane, then cull
- if distance from sphere centre to the view volume > r, then cull.

View Volume Clipping

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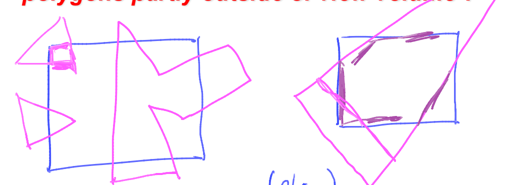
polygons partly outside of view volume ?



even a clipped triangle can have 7 edges in 2D

Idea: clip against one edge (plane) at a time

2D vertices → clip T → clip B → clip R → clip L → clipped polygon

3D → near → far → L → R → T → B →

View Volume Clipping

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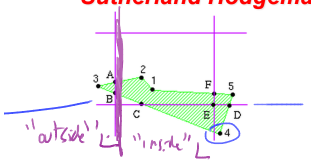
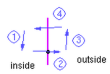
Sutherland Hodgeman clipping



original : 1, 2, 3, 4, 5, 1
clip L : 1, 2, A, B, 4, 5, 1
clip B : 1, 2, A, B, C, D, 5, 1
clip R : 1, 2, A, B, C, E, F, 1 ⟸ final
clip T : (unchanged)

```
for each side of clipping window
   for each edge of polygon
      output points based upon the following table
```



case #	first point	second point	output point(s)
1	inside	inside	second point
2	inside	outside	intersection point
3	outside	outside	none
4	outside	inside	intersection point and second point

later: line-plane intersections.

Clipping in VCS

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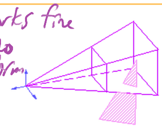
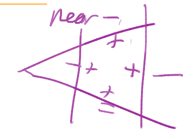
VCS

– clipping here works fine
– but there is no canonical form





plane eq'ns for orthographic view volume

```
left:     x - left = 0
right:   -x + right = 0
bottom:   y - bottom = 0
top:     -y + top = 0
front:   -z - near = 0
back:     z + far = 0
```

Implicit plane equations for view frustum

```
left:     x + left*z/near = 0
right:   -x - right*z/near = 0
top:     -y - top*z/near = 0
bottom:   y + bottom*z/near = 0
front:   -z - near = 0
back:     z + far = 0
```

$F(x,y,z) \geq$ inside
$F(x,y,z) <$ outside

– canonical plane eq'ns ✓
– problem: points behind eye cause problems

Clipping in NDCS

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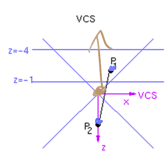
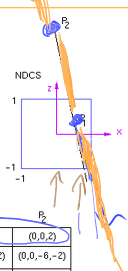
NDCS





fix: clip against near in VCS first

$$M_{proj} = \begin{bmatrix} 1 & & & \\ & 1 & & \\ & & -5/3 & -8/3 \\ & & -1 & \end{bmatrix}$$

	P_1	P_2
VCS	(1, 0, –2)	(0,0,2)
CCS	(1, 0, 2/3, 2)	(0,0,–6,–2)
NDCS	(1/2, 0, 1/3)	(0, 0, 3)

– canonical frame ✓
– before /h ✓

Clipping in CCS

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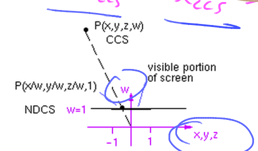
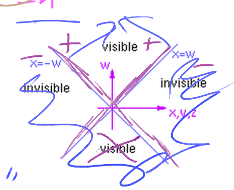
$\boxed{w \equiv h}$

Clipping usually done here

NDCS: $-1 \leq \frac{x_{ccs}}{h_{ccs}} \leq 1$

CCS: $-h_{ccs} \leq x_{ccs} \leq h_{ccs}$





plane equations:

L $x + w = 0 = F(x,y,z,w)$
R $-x + w = 0 = F(\ )$
B $y + w = 0$
T $-y + w = 0$
N $z + w = 0$
F $-z + w = 0$

$F(x,y,z,w) \geq 0$ "inside"
$F(x,y,z,w) < 0$ "outside"

Line-Plane intersection

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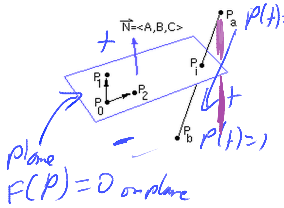

plane equation:

① $Ax + By + Cz + D = 0 = F(P)$

$\langle A,B,C\rangle \cdot \langle x,y,z\rangle + D = 0$

$N \cdot P + D = 0$

② $P(t) = P_a + t(P_b - P_a)$

subst. into to get intersect. pt.

$N\cdot(P_a + t(P_b - P_a)) + D = 0$

$N\cdot P_a + t(N\cdot P_b - N\cdot P_a) + D = 0$

$t = \frac{-D - N\cdot P_a}{N\cdot P_b - N\cdot P_a} = \frac{-F(P_a)}{F(P_b) - F(P_a)}$

Backface Culling in VCS

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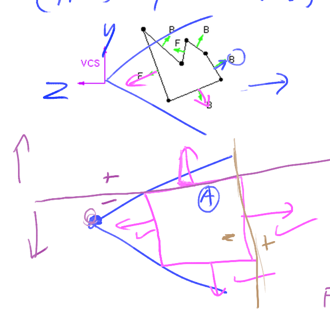
(applies only to "closed" objects, or objects that have well defined front/back faces)



Idea: cull if $N_z < 0$

Problem: polygon A would not be culled.

Fix: test to see if eye is below plane. If below, then cull.

Plane: $Ax + By + Cz + D = F(x,y,z)$

$N \cdot P + D = 0$

For eye: $P(0,0,0)$ $D = -N\cdot P_1$

If $D<0$ then cull, ie, if $-N\cdot P_1 < 0$ then cull

Backface Culling in NDCS

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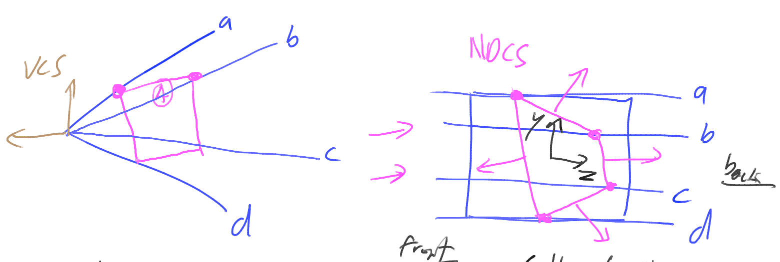

Cull if $N_z > 0$

can cull in either VCS (plane check) or NDCS (N_z check)

Computing Surface Normals

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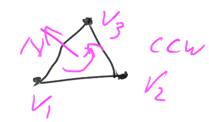
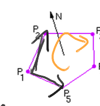




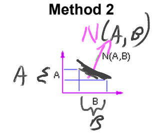
clockwise numbering when seen from the front side

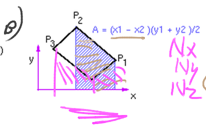
(more often use CCW)

Method 1

cross product $N = (P_3 - P_1)\times(P_2 - P_1)$

Method 2





$N_x = \sum_{i=1}^{n}(y_i - y_j)(z_i + z_j)/2$ = area projected onto yz-plane

$N_y = \sum_{i=1}^{n}(z_i - z_j)(x_i + x_j)/2$ = area on xz plane

$N_z = \sum_{i=1}^{n}(x_i - x_j)(y_i + y_j)/2$ = area on xy plane.

Occlusion

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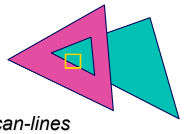
view occluded by objects in front of a given pixel or polygon ?

most common, OpenGL



- image space algorithms:
  - *operate on pixels or scan-lines*
  - *visibility resolved to the precision of the display*
  - *e.g.: Z-buffer*
- object space algorithms:
  - *explicitly compute visible portions of polygons*
  - *painter's algorithm: depth-sorting, BSP trees*

Z-buffer

classic projective rendering, ie OpenGL

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store (r,g,b,z) for each pixel

```
for all i,j {
 Depth[i,j] = MAX_DEPTH
 Image[i,j] = BACKGROUND_COLOUR
}
for all polygons P {
  project vertices into screen-space, i.e., DCS
  for all pixels in P {
    if (Z_pixel < Depth[i,j]) {
      Image[i,j] = C_pixel
      Depth[i,j] = Z_pixel
    }
  }
}
```

overwrite pixel & update depth

Z-buffer

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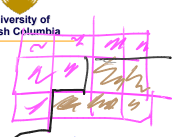
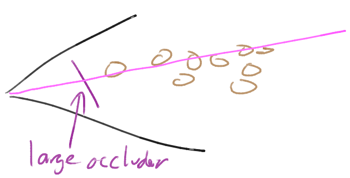
- hardware support
- limitations:



- extra memory
- jaggies ie, steps along intersecting geometry
- poor performance for high depth complexity scenes



solution: occlusion culling

Painter's Algorithm

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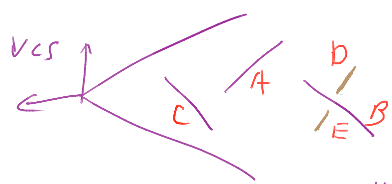

Draw the polygons from back to front

eg: B, A, C

⇒ sort by z →

problems: - which z value to use ?
- cyclic overlap ?
- intersecting geometry ?

Fix: use BSP tree "Binary Space Partitioning"

Binary Space Partition (BSP) trees

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- object-space method
- produces a back-to-front ordering
- build the BSP tree once
- traverse the BSP in a view-dependent fashion

(skip)

BSP trees (example)

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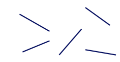

Building a BSP tree

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```
BSPtree *BSPmaketree(polygon list) {
  choose a polygon as the tree root
  for all other polygons {
    if polygon is in front, add to front list
    if polygon is behind, add to behind list
    else split polygon and add one part to each list
  }
  BSPtree = BSPcombinetree(BSPmaketree(front list),
            root, BSPmaketree(behind list) )
}
```


Using a BSP tree

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producing a back-to-front ordering

```
DrawTree(BSPtree) {
  if (eye is in front of root) {
    DrawTree(BSPtree->behind)
    DrawPoly(BSPtree->root)
    DrawPoly(BSPtree->front)
  } else {
    DrawTree(BSPtree->front)
    DrawPoly(BSPtree->root)
    DrawTree(BSPtree->behind)
  }
}
```

Occlusion Culling

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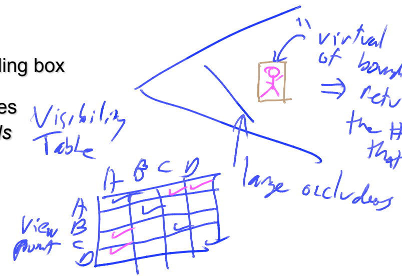
- occlusion queries
  - virtual render of bounding box
- precomputed visibility tables
  - *store a list of visible cells*
- horizon maps
  - *for terrain models*



"virtual render" of bounding box ⇒ returns the # pixels that would have appeared.

Visibility in Practice: WebGL, OpenGL

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OpenGL support? ⟶ no need to add in shader

- view volume culling ⟶ polygons get culled anyhow, but no bbox checks, etc.
- view volume clipping
- backface culling
- z-buffer occlusion test
- painter's ~~algorithm~~ & BSP trees — need to do this yourself, if desired
- occlusion culling ⟶ virtual render of a bbox to see if pixels would have appeared on screen. (sometimes supported)

Raycasting and Raytracing

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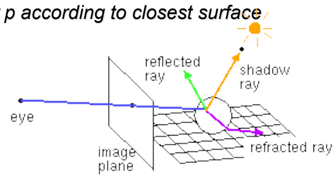
alternative to projective rendering

- for each pixel p
  - *construct ray r from eye through p*
  - *intersect r with all polygons or objects*
  - *color p according to closest surface*

(skip for now)



Transforming Normals

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rotations & scales

translations

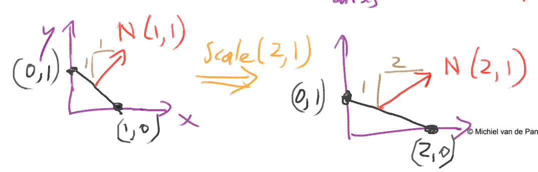
Using h=0

$$\begin{bmatrix}N_x'\\N_y'\\N_z'\\0\end{bmatrix} = \begin{bmatrix} & & & \\ & & & \\ & & & \\ 0&0&0&1\end{bmatrix}\begin{bmatrix}N_x\\N_y\\N_z\\0\end{bmatrix}$$

this often works

h=1 for points

Problem non-uniform scales



$M_N = (M_p^{-1})^T$ ← matrix to transform normals.

Transforming Normals

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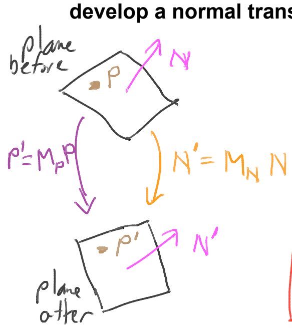
develop a normal transformation matrix:



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

$$\underbrace{[A \quad B \quad C \quad D]}_{N^T} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = 0 \quad \leftarrow p$$

$N^T p = 0$ before

$N'^T p' = 0$ after

$$(M_N N)^T M_p p = 0$$

$$N^T \underline{M_N^T M_p} \, p = 0$$

deduce $M_N^T M_p = I$

$M_N = (M_p^{-1})^T$