University of British Columbia
CPSC 314 Computer Graphics
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Hidden Surfaces II

Week 9, Mon Mar 12

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2007

Reading for This Time

- FCG Chap 12 Graphics Pipeline
  - only 12.1-12.4

News

- Project 3 update
  - Linux executable reposted
  - template update
    - download package again **OR**
    - just change line 31 of src/main.cpp from

      ```
      int resolution[2];
      ```

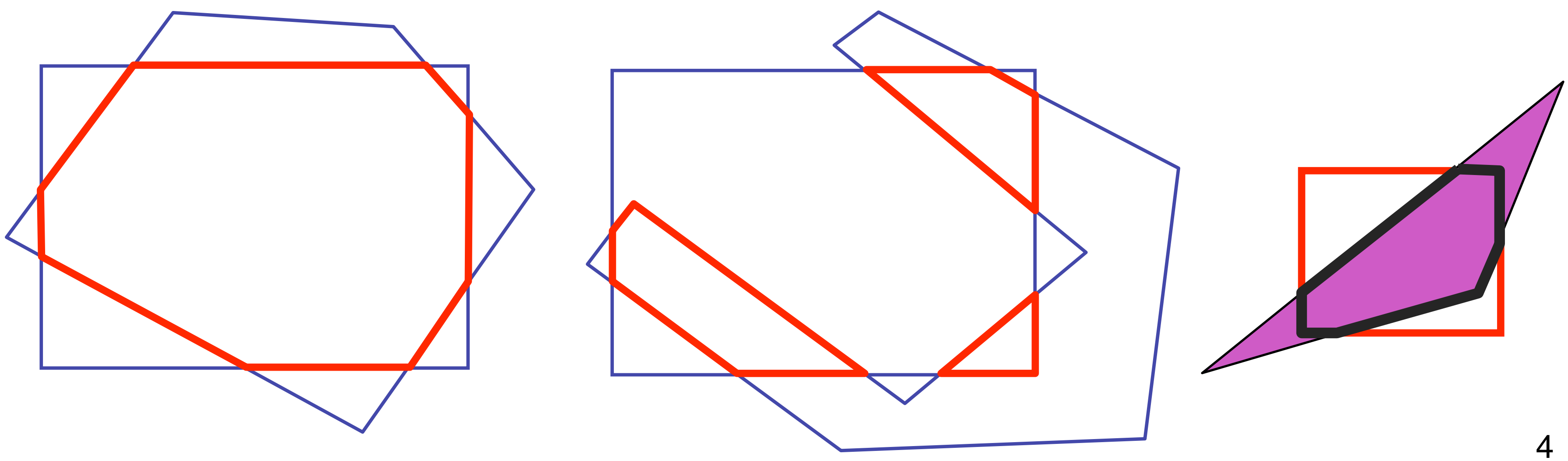
      to

      ```
      int resolution[] = {100,100};
      ```

      OR
    - implement resolution parsing

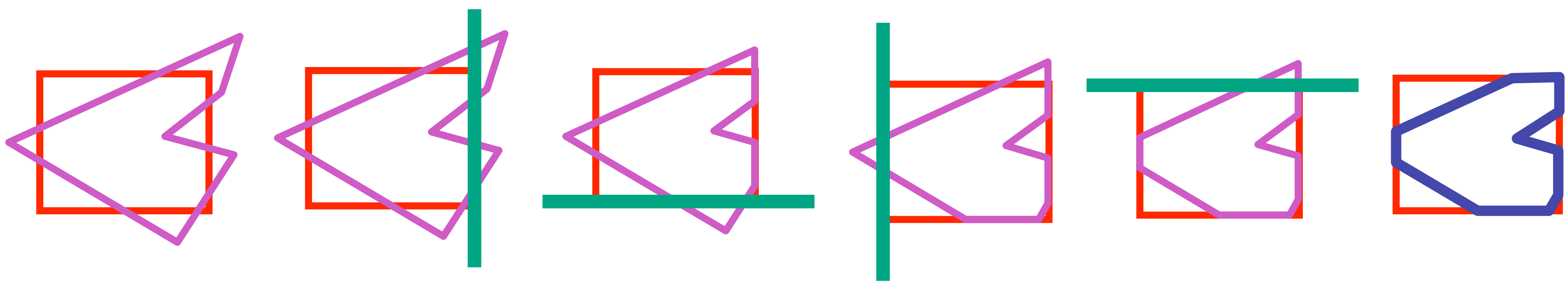
Review: Polygon Clipping

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



Review: Sutherland-Hodgeman Clipping

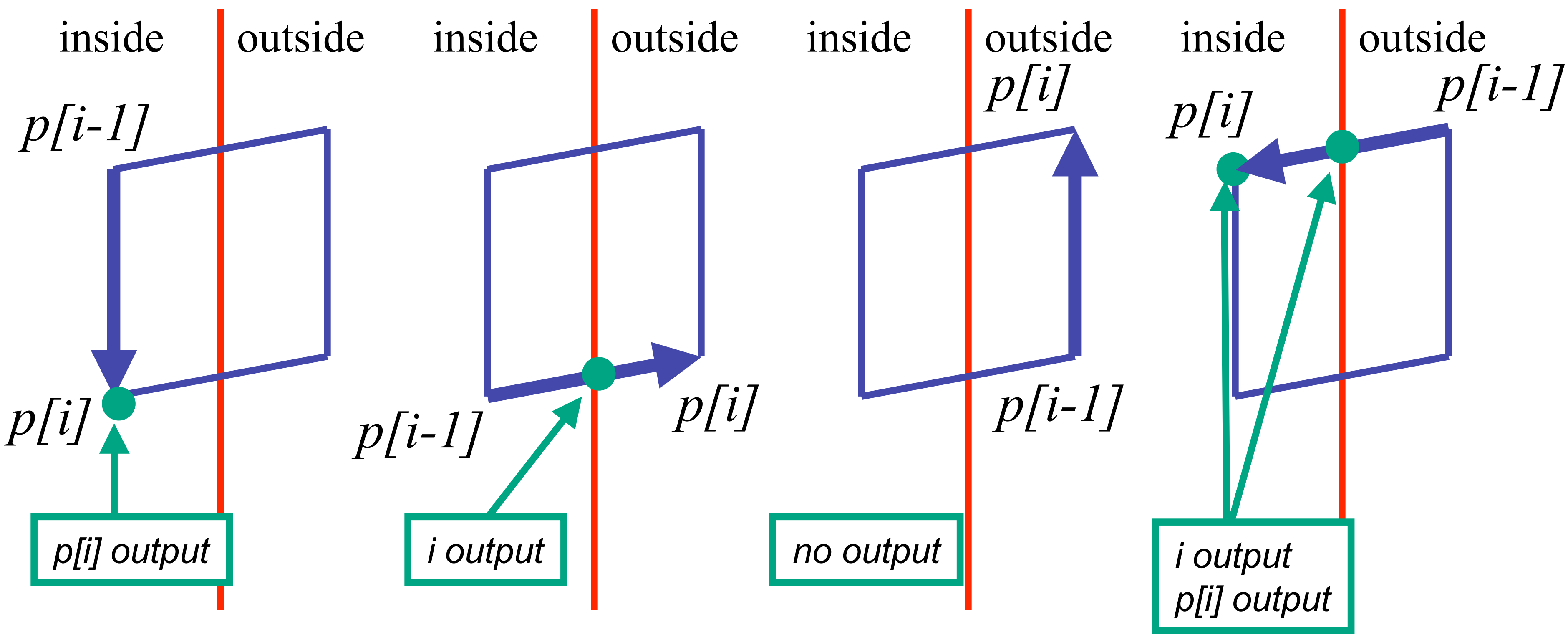
- for each viewport edge
  - clip the polygon against the edge equation for new vertex list
  - after doing all edges, the polygon is fully clipped



- for each polygon vertex
  - decide what to do based on 4 possibilities
    - is vertex inside or outside?
    - is previous vertex inside or outside?

Review: Sutherland-Hodgeman Clipping

- edge from *p[i-1]* to *p[i]* has four cases
  - decide what to add to output vertex list

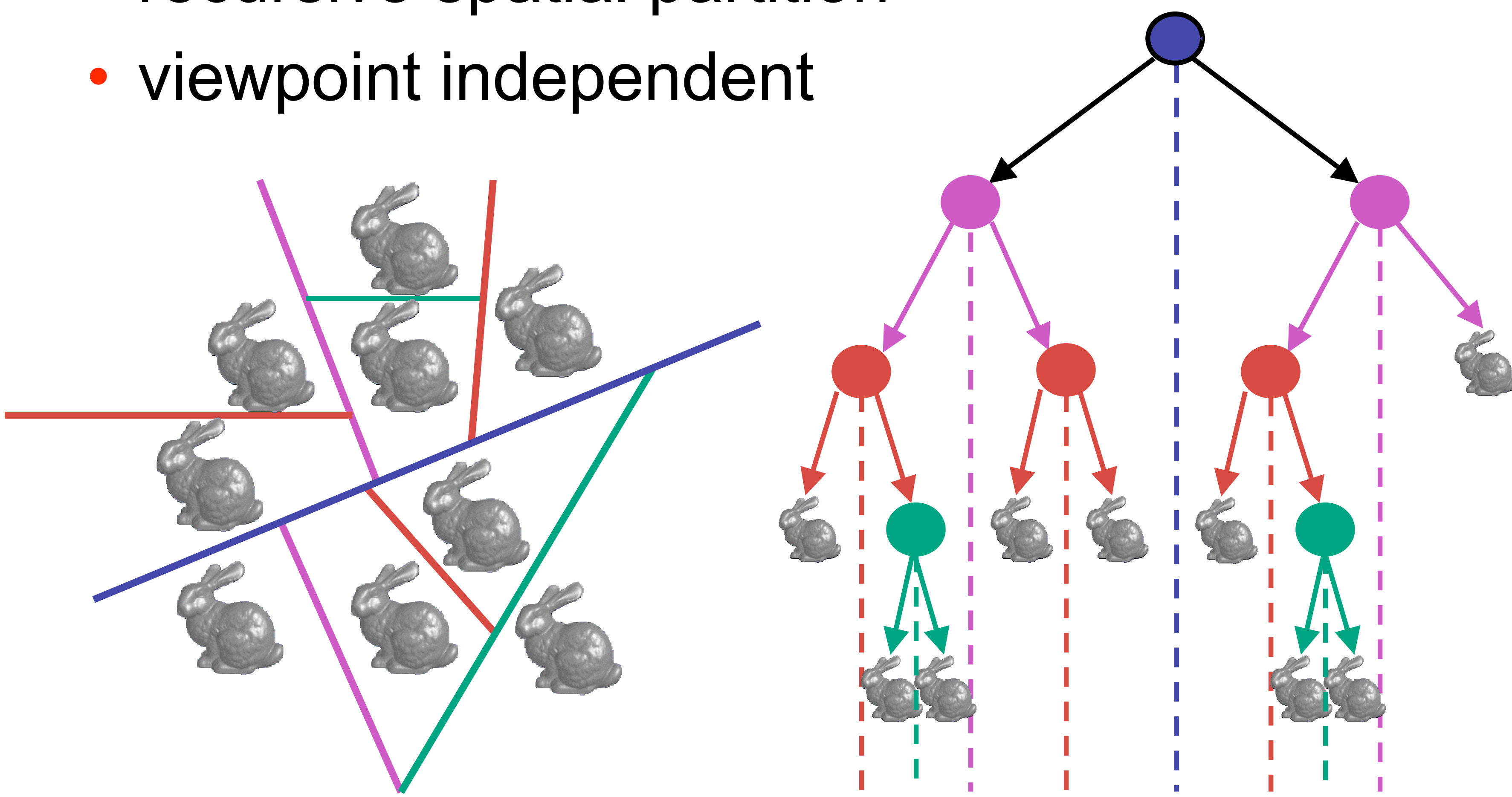


Review: Painter's Algorithm

- draw objects from back to front
- problems: no valid visibility order for
  - intersecting polygons
  - cycles of non-intersecting polygons possible

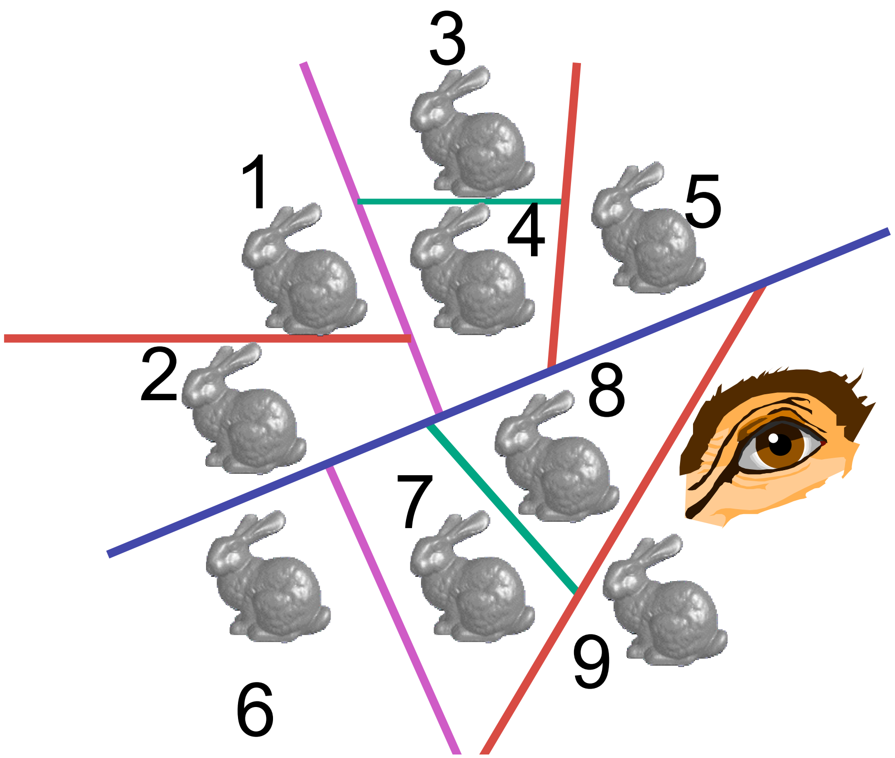
Review: BSP Trees

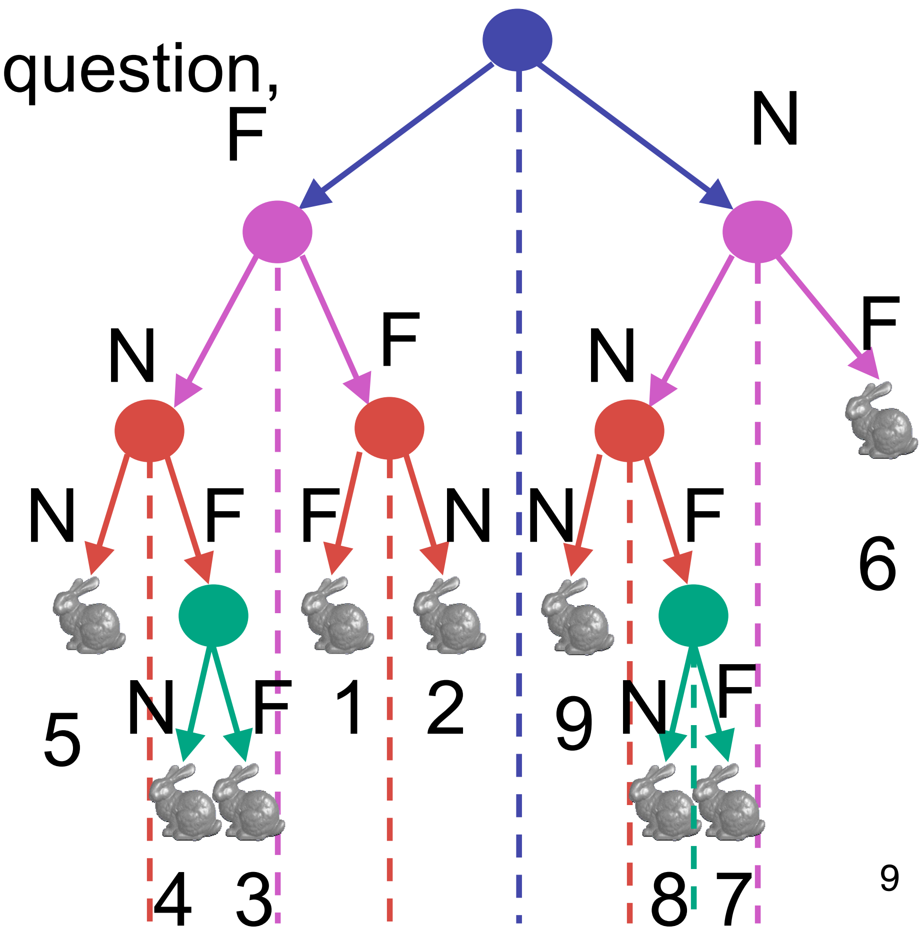
- preprocess: create binary tree
  - recursive spatial partition
  - viewpoint independent



Review: BSP Trees

- runtime: correctly traversing this tree enumerates objects from back to front
  - viewpoint dependent: check which side of plane viewpoint is on **at each node**
  - draw far, draw object in question, draw near



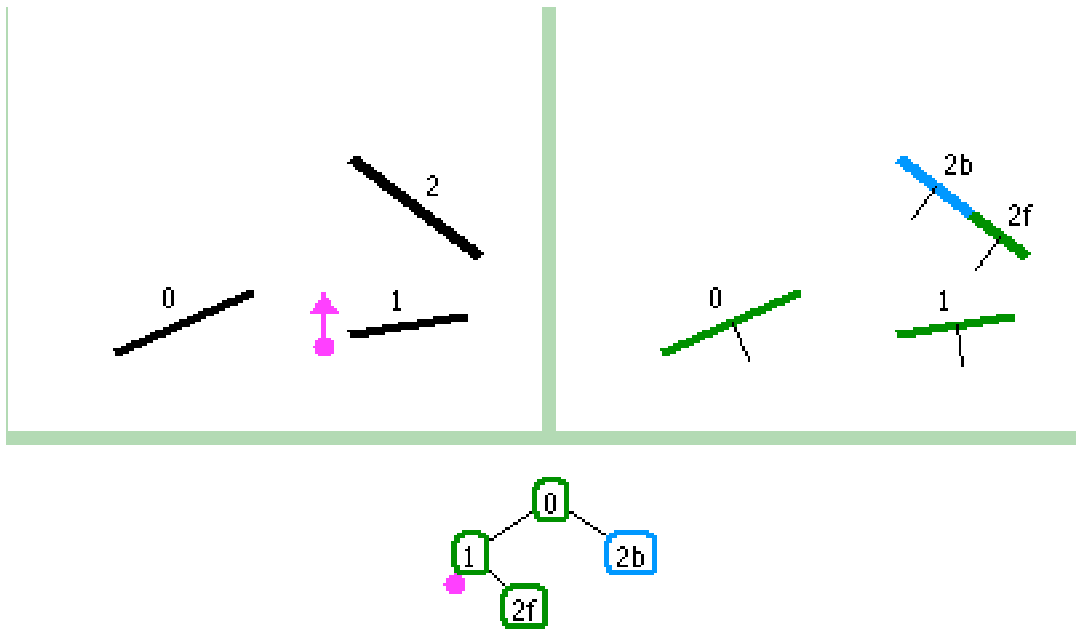


Hidden Surface Removal II

BSP Demo

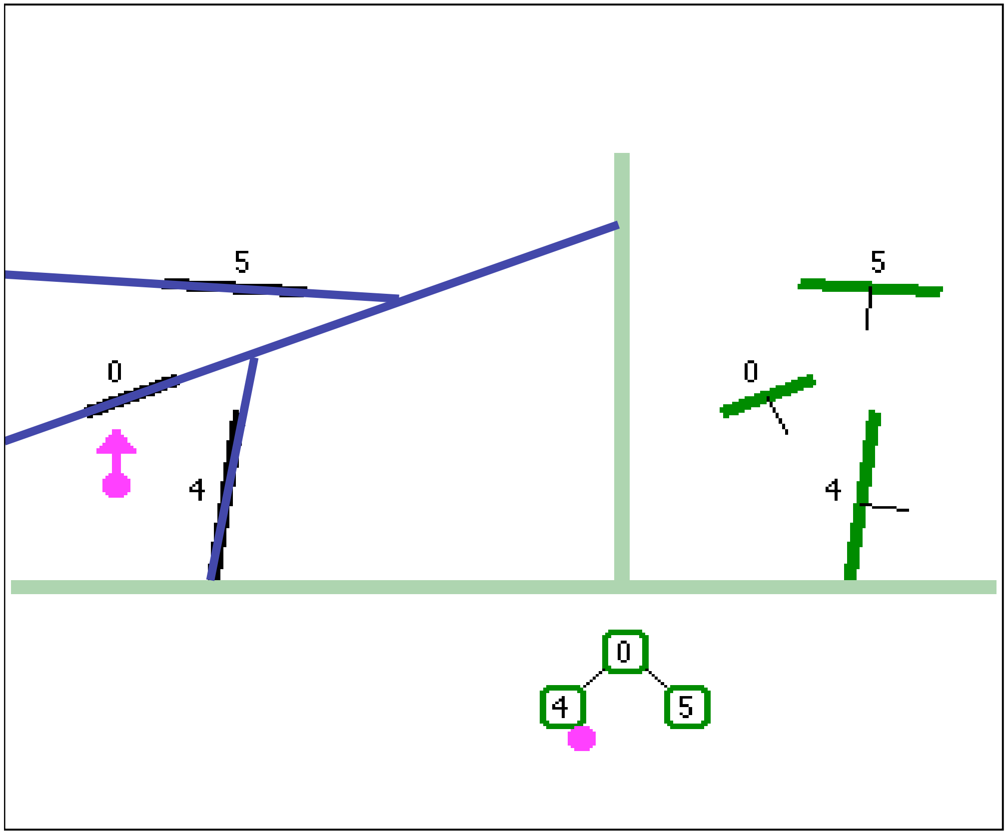
- useful demo:

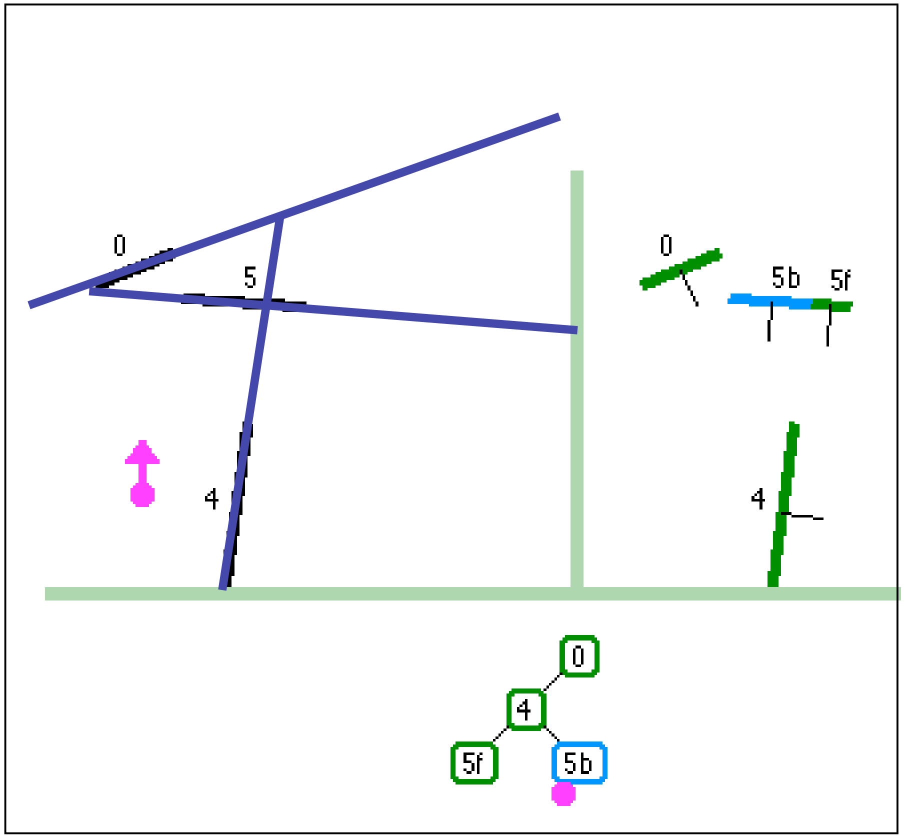
  http://symbolcraft.com/graphics/bsp



Clarification: BSP Demo

- order of insertion can affect half-plane extent





Summary: BSP Trees

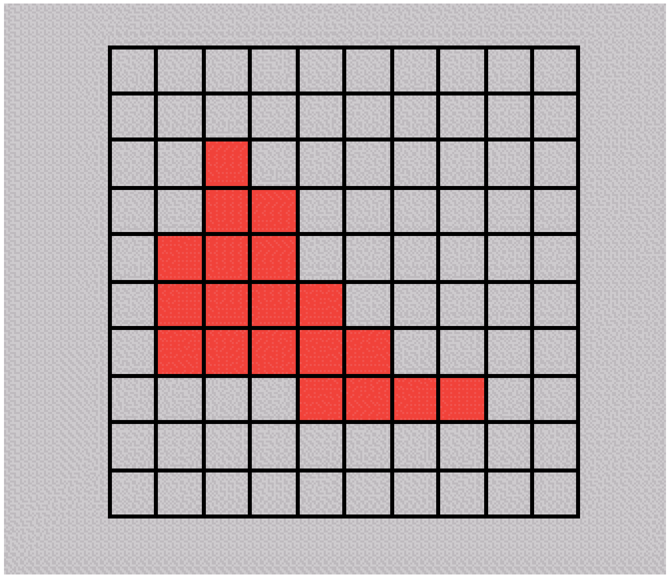
- pros:
  - simple, elegant scheme
  - correct version of painter's algorithm back-to-front rendering approach
  - was very popular for video games (but getting less so)
- cons:
  - slow to construct tree: O(n log n) to split, sort
  - splitting increases polygon count: $O(n^2)$ worst-case
  - computationally intense preprocessing stage restricts algorithm to static scenes

The Z-Buffer Algorithm (mid-70's)

- BSP trees proposed when memory was expensive
  - first 512x512 framebuffer was >$50,000!
- Ed Catmull proposed a radical new approach called z-buffering
- the big idea:
  - resolve visibility independently at each pixel

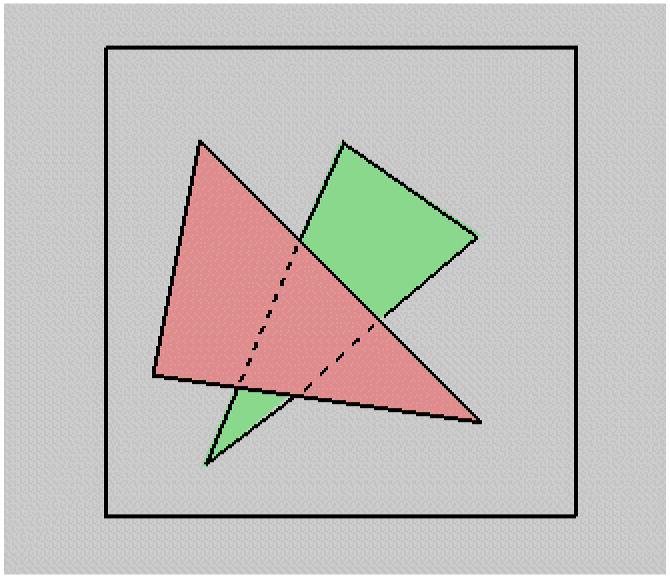
The Z-Buffer Algorithm

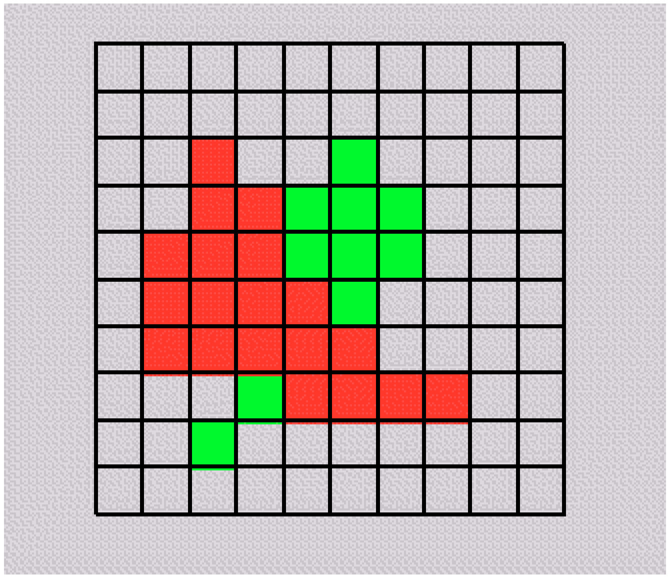
- we know how to rasterize polygons into an image discretized into pixels:



The Z-Buffer Algorithm

- what happens if multiple primitives occupy the same pixel on the screen?
  - which is allowed to paint the pixel?





The Z-Buffer Algorithm

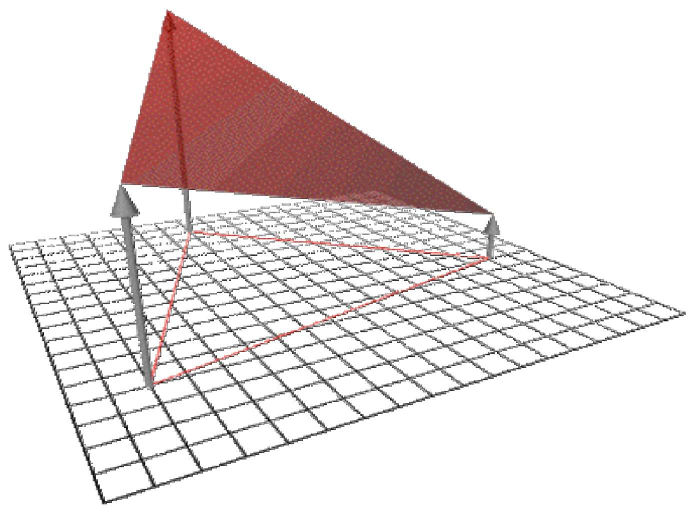
- idea: retain depth after projection transform
  - each vertex maintains z coordinate
    - relative to eye point
  - can do this with canonical viewing volumes

The Z-Buffer Algorithm

- augment color framebuffer with Z-buffer or depth buffer which stores Z value at each pixel
  - at frame beginning, initialize all pixel depths to ∞
  - when rasterizing, interpolate depth (Z) across polygon
  - check Z-buffer before storing pixel color in framebuffer and storing depth in Z-buffer
  - don’t write pixel if its Z value is more distant than the Z value already stored there

Interpolating Z

- barycentric coordinates
  - interpolate Z like other planar parameters



Z-Buffer

- store (r,g,b,z) for each pixel
  - typically 8+8+8+24 bits, can be more

```
for all i,j {
 Depth[i,j] = MAX_DEPTH
 Image[i,j] = BACKGROUND_COLOUR
}
for all polygons P {
  for all pixels in P {
    if (Z_pixel < Depth[i,j]) {
      Image[i,j] = C_pixel
      Depth[i,j] = Z_pixel
    }
  }
}
```

Depth Test Precision

- reminder: projective transformation maps eye-space *z* to generic *z*-range (NDC)
- simple example:

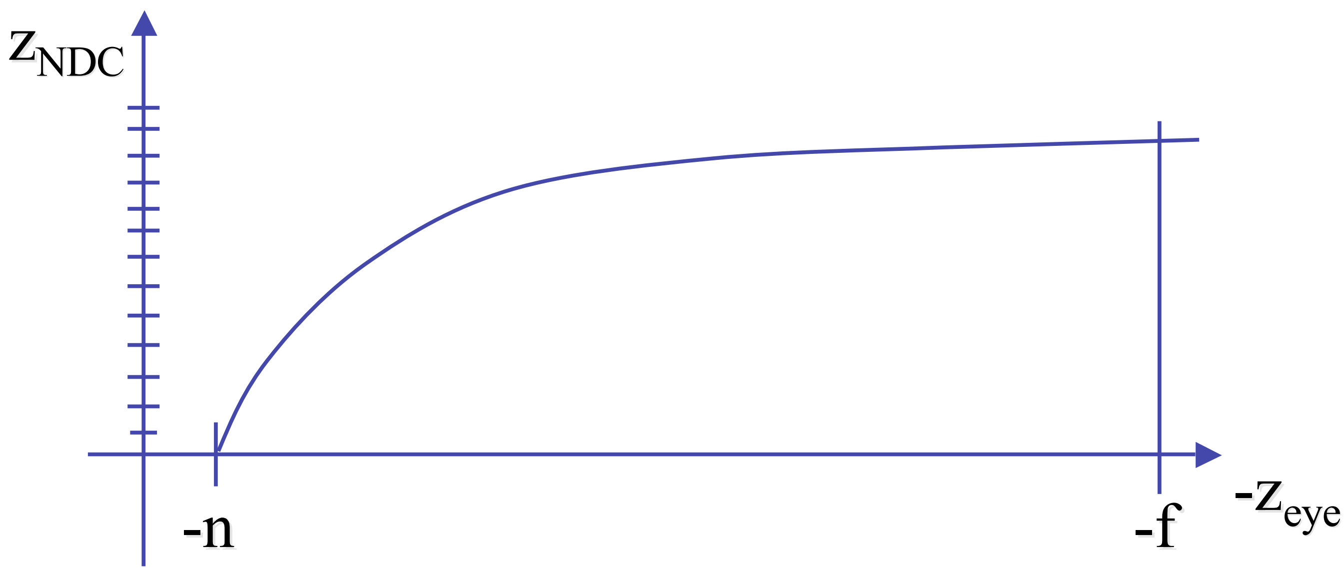
$$T\left(\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}\right) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & a & b \\ 0 & 0 & -1 & 0 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

- thus:

$$z_{NDC} = \frac{a \cdot z_{eye} + b}{z_{eye}} = a + \frac{b}{z_{eye}}$$

Depth Test Precision

- therefore, depth-buffer essentially stores 1/z, rather than z!
- issue with integer depth buffers
  - high precision for near objects
  - low precision for far objects



Depth Test Precision

- low precision can lead to depth fighting for far objects
  - two different depths in eye space get mapped to same depth in framebuffer
  - which object “wins” depends on drawing order and scan-conversion
- gets worse for larger ratios $f{:}n$
  - *rule of thumb:* $\mathrm{f{:}n} < 1000$ *for 24 bit depth buffer*
- with 16 bits cannot discern millimeter differences in objects at 1 km distance
- demo: sjbaker.org/steve/omniv/love_your_z_buffer.html

Z-Buffer Algorithm Questions

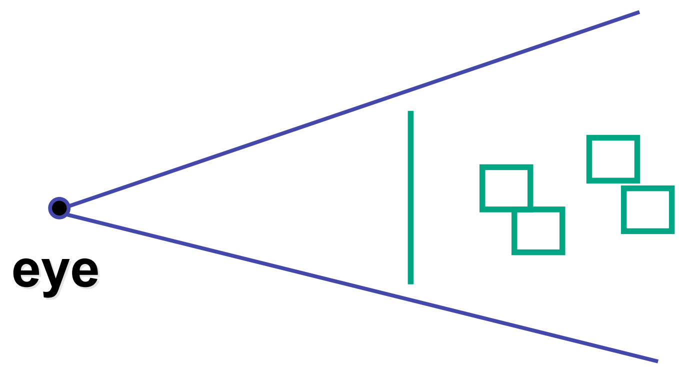
- how much memory does the Z-buffer use?
- does the image rendered depend on the drawing order?
- does the time to render the image depend on the drawing order?
- how does Z-buffer load scale with visible polygons? with framebuffer resolution?

Z-Buffer Pros

- simple!!!
- easy to implement in hardware
  - hardware support in all graphics cards today
- polygons can be processed in arbitrary order
- easily handles polygon interpenetration
- enables deferred shading
  - rasterize shading parameters (e.g., surface normal) and only shade final visible fragments

Z-Buffer Cons

- poor for scenes with high depth complexity
  - need to render all polygons, even if most are invisible



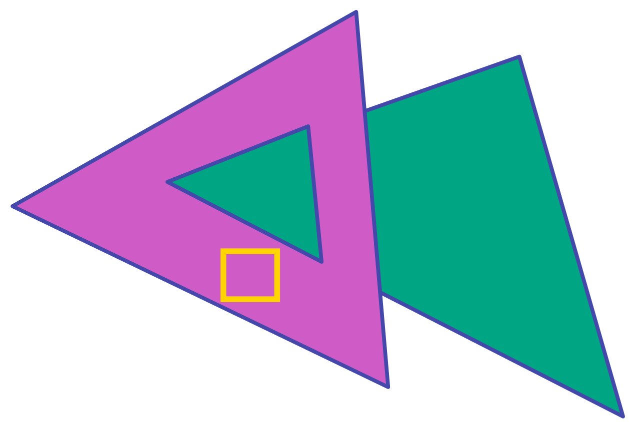
- shared edges are handled inconsistently
  - *ordering dependent*

Z-Buffer Cons

- requires lots of memory
  - (e.g. 1280x1024x32 bits)
- requires fast memory
  - Read-Modify-Write in inner loop
- hard to simulate translucent polygons
  - we throw away color of polygons behind closest one
  - works if polygons ordered back-to-front
    - extra work throws away much of the speed advantage

Hidden Surface Removal

- two kinds of visibility algorithms
  - object space methods
  - image space methods



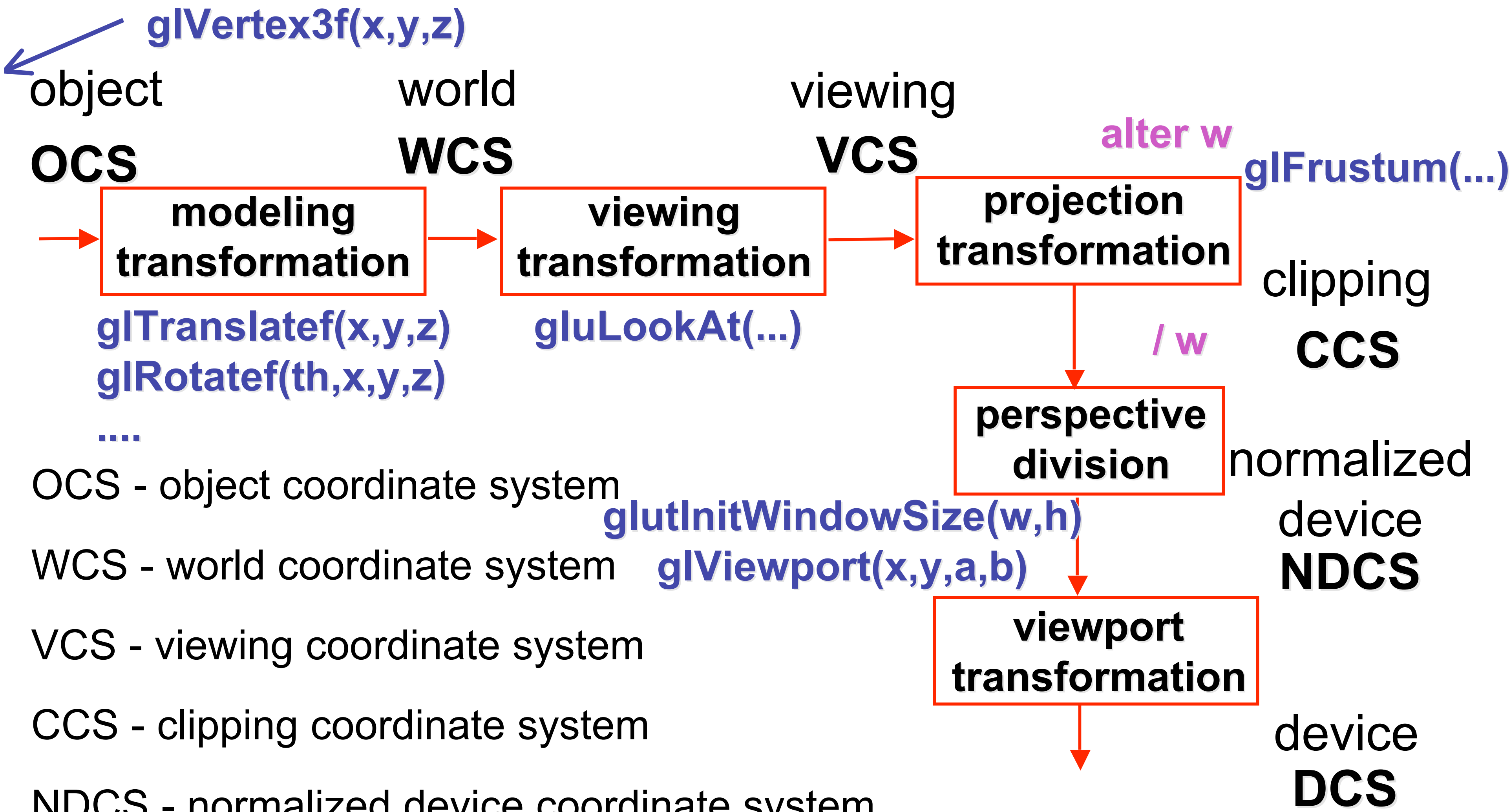
Object Space Algorithms

- determine visibility on object or polygon level
  - using camera coordinates
- resolution independent
  - explicitly compute visible portions of polygons
- early in pipeline
  - after clipping
- requires depth-sorting
  - painter's algorithm
  - BSP trees

Image Space Algorithms

- perform visibility test for in screen coordinates
  - limited to resolution of display
  - Z-buffer: check every pixel independently
- performed late in rendering pipeline

Projective Rendering Pipeline



OCS - object coordinate system

WCS - world coordinate system

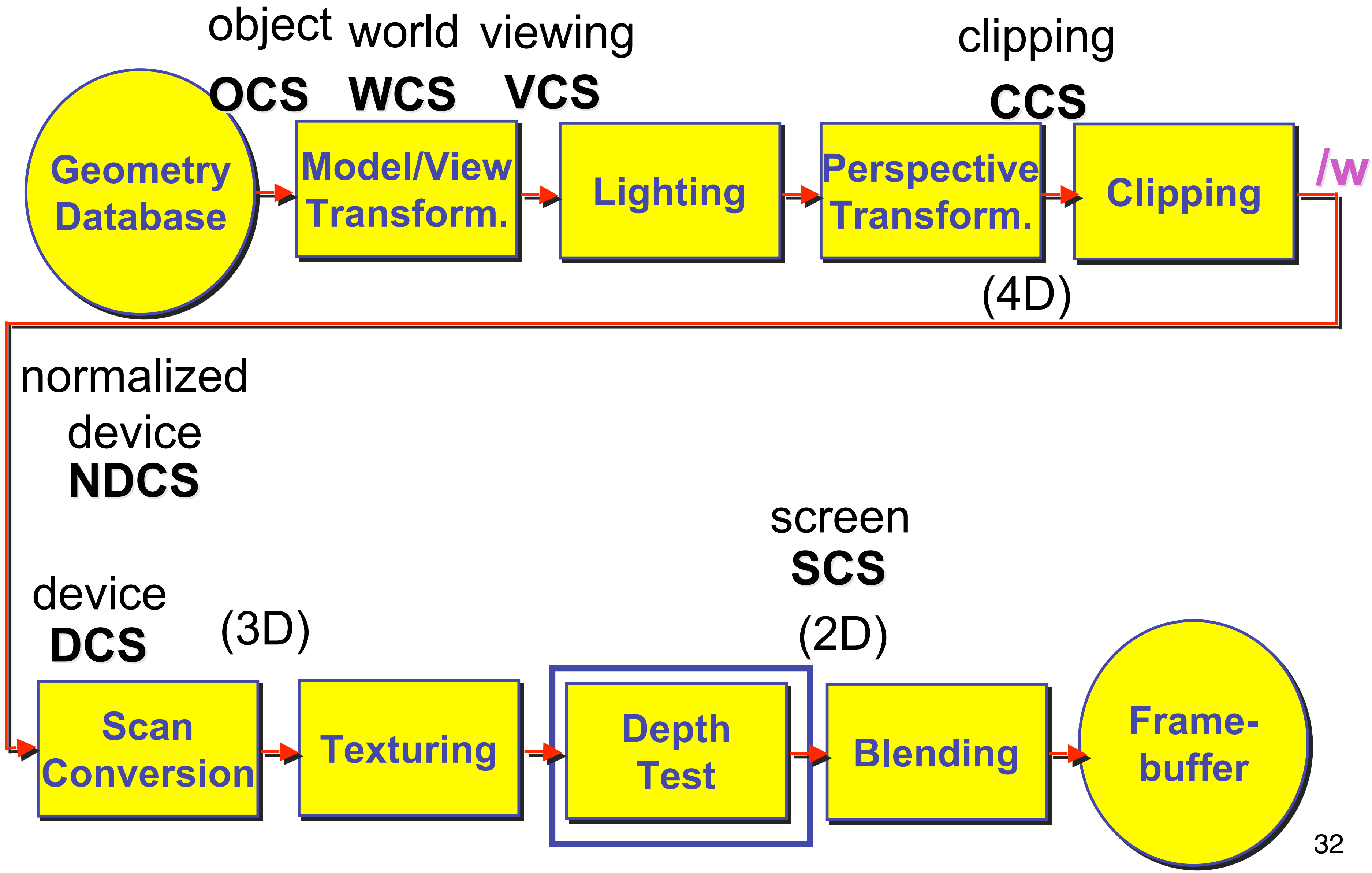
VCS - viewing coordinate system

CCS - clipping coordinate system

NDCS - normalized device coordinate system

DCS - device coordinate system

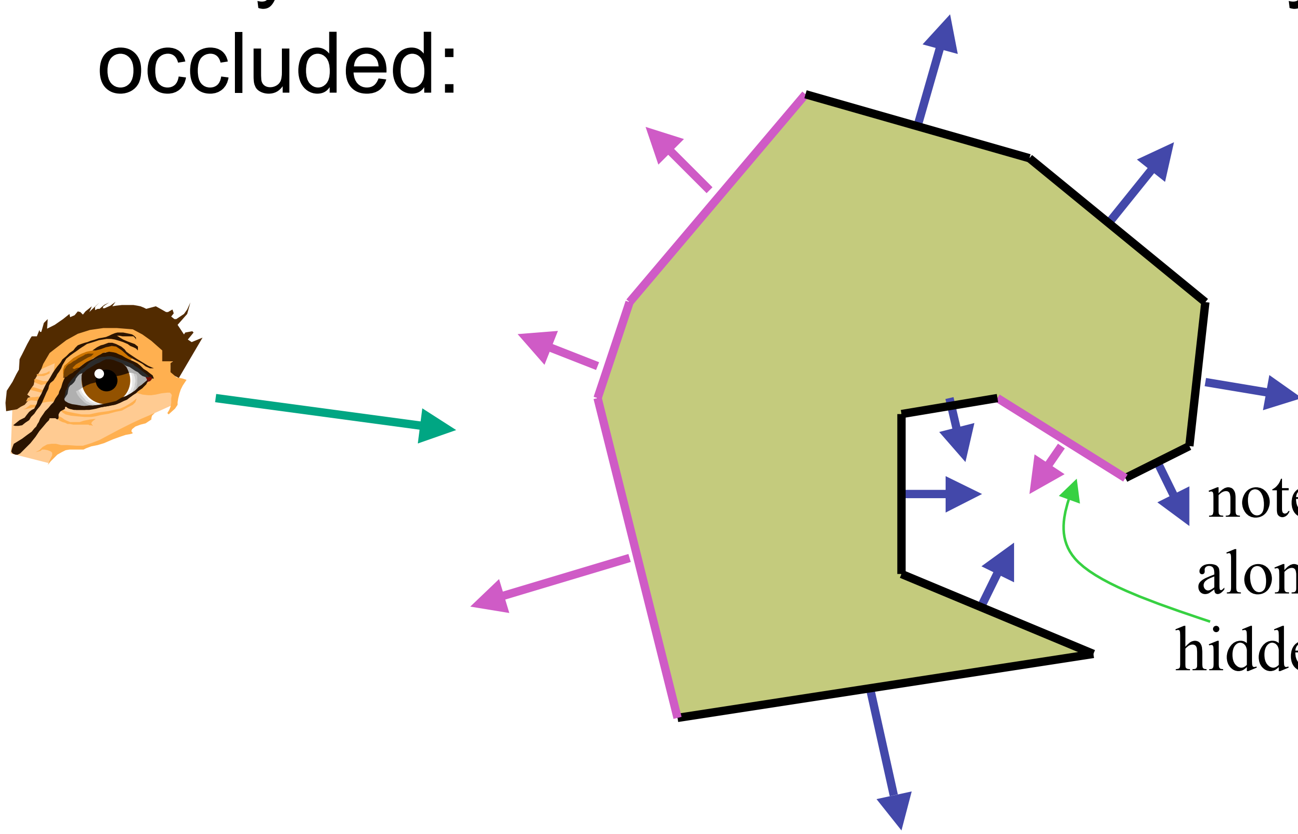
Rendering Pipeline



Backface Culling

Back-Face Culling

- on the surface of a closed orientable manifold, polygons whose normals point away from the camera are always occluded:



note: backface culling alone doesn't solve the hidden-surface problem!

Back-Face Culling

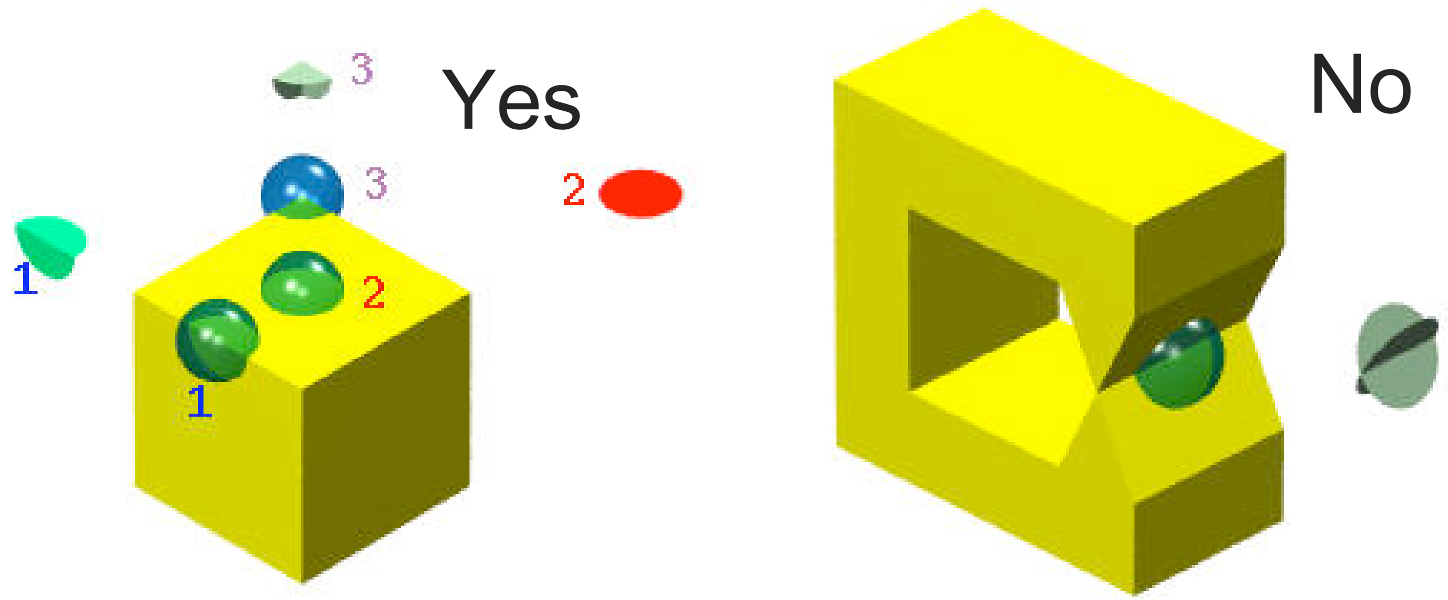
- not rendering backfacing polygons improves performance
  - by how much?
    - reduces by about half the number of polygons to be considered for each pixel
  - optimization when appropriate

Back-Face Culling

- most objects in scene are typically “solid”
- rigorously: orientable closed manifolds
  - orientable: must have two distinct sides
    - cannot self-intersect
    - a sphere is orientable since has two sides, 'inside' and 'outside'.
    - a Mobius strip or a Klein bottle is not orientable
  - closed: cannot “walk” from one side to the other
    - sphere is closed manifold
    - plane is not

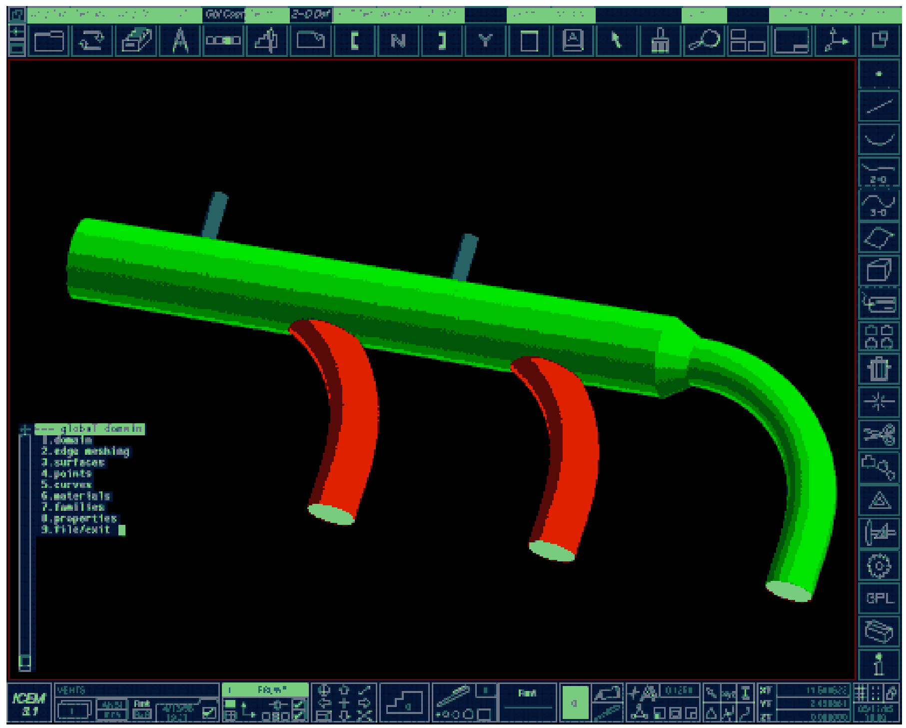
Back-Face Culling

- most objects in scene are typically “solid”
- rigorously: orientable closed manifolds
  - manifold: local neighborhood of all points isomorphic to disc
  - boundary partitions space into interior & exterior



Manifold

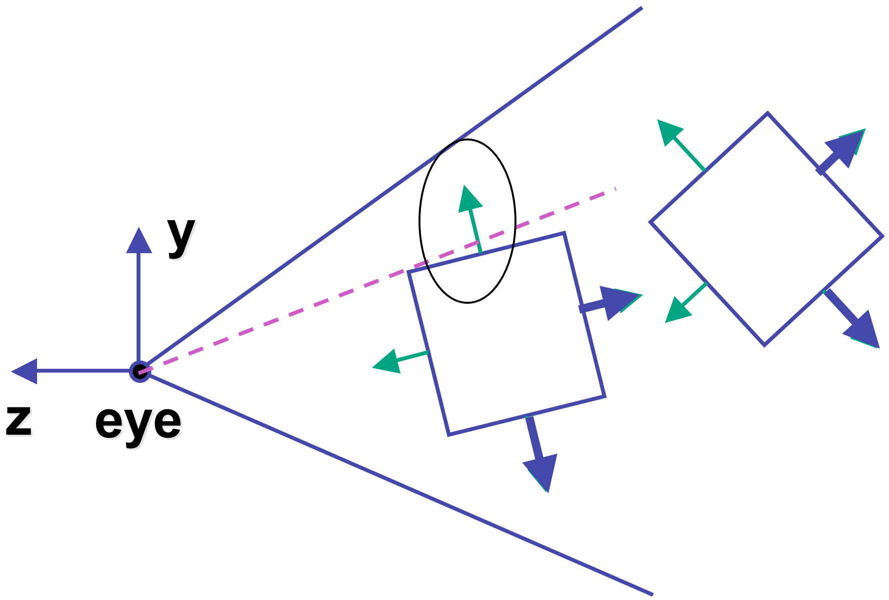
- examples of *manifold* objects:
  - sphere
  - torus
  - well-formed CAD part



Back-Face Culling

- examples of non-manifold objects:
  - a single polygon
  - a terrain or height field
  - polyhedron w/ missing face
  - anything with cracks or holes in boundary
  - one-polygon thick lampshade

Back-face Culling: VCS

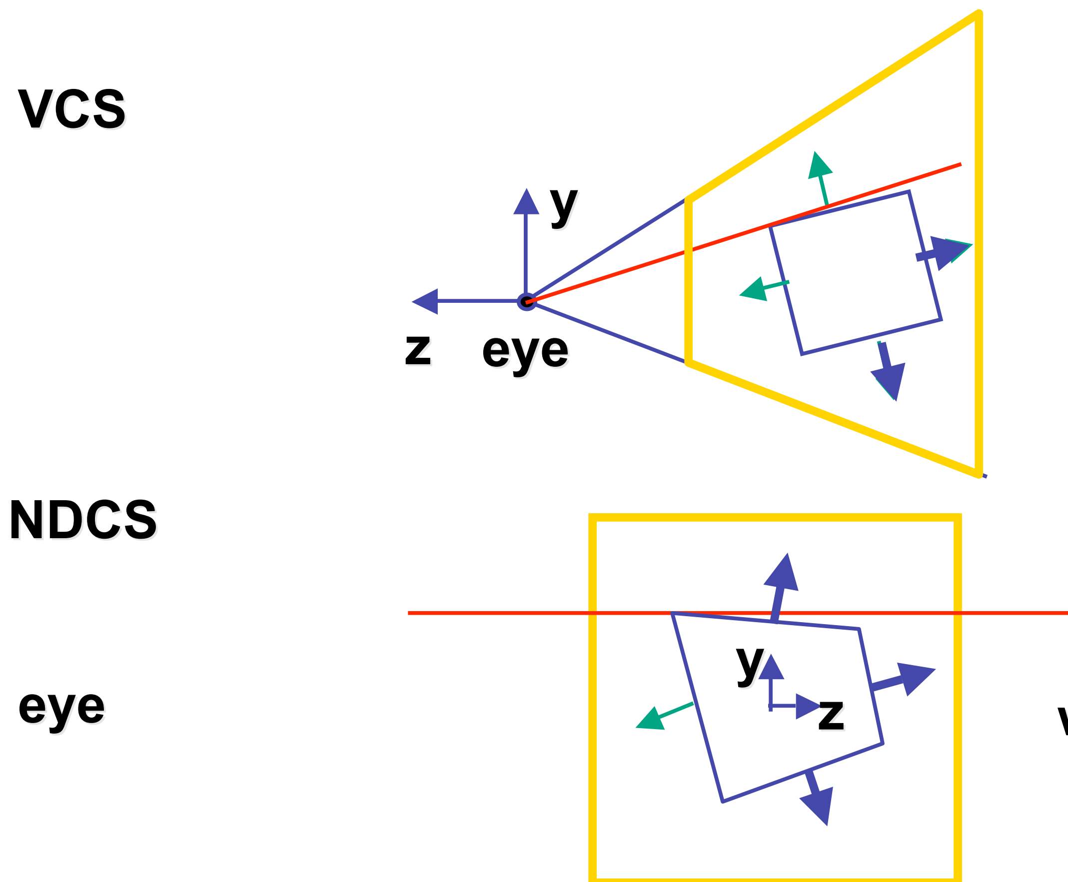


first idea:

cull if $N_Z < 0$

sometimes
misses polygons that
should be culled

Back-face Culling: NDCS



works to cull if $N_Z > 0$

Invisible Primitives

- *why might a polygon be invisible?*
  - polygon outside the *field of view / frustum*
    - solved by clipping
  - polygon is *backfacing*
    - solved by backface culling
  - polygon is *occluded* by object(s) nearer the viewpoint
    - solved by hidden surface removal