University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2010

Tamara Munzner

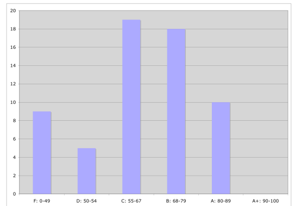
Clipping II, Hidden Surfaces I

Week 8, Fri Mar 12

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2010

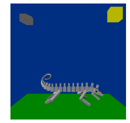
News

- midterms returned, solutions out
- unscaled average 52, scaled average 62

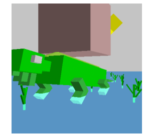


P1 Hall of Fame: Honorable Mentions

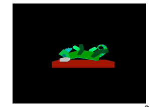
Pierre Jondeau



Shawn Luo

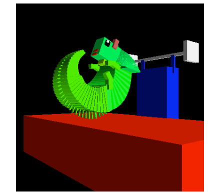


David Roodnick



P1 Hall of Fame: Winner

Sung-Hoo Kim

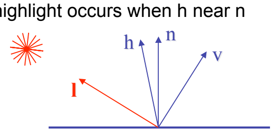


Correction: Blinn-Phong Model

- variation with better physical interpretation
  - Jim Blinn, 1977

$$I_{out}(\mathbf{x}) = \boxed{I_{in}(\mathbf{x})}(\mathbf{k}_s(\mathbf{h} \bullet \mathbf{n})^{n_{shiny}}); \text{with } \mathbf{h} = (\mathbf{l} + \mathbf{v})/2$$

- ***h***: halfway vector
  - h must also be explicitly normalized: h / |h|
  - highlight occurs when h near n

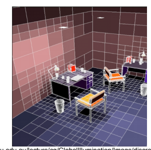


Review: Ray Tracing

- issues:
  - generation of rays
  - intersection of rays with geometric primitives
  - geometric transformations
  - lighting and shading
  - efficient data structures so we don't have to test intersection with *every* object

Review: Radiosity

- capture indirect diffuse-diffuse light exchange
- model light transport as flow with conservation of energy until convergence
  - view-independent, calculate for whole scene then browse from any viewpoint
- divide surfaces into small patches
- loop: check for light exchange between all pairs
  - form factor: orientation of one patch wrt other patch (n x n matrix)

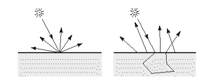


escience.anu.edu.au/lecture/cg/GlobalIllumination/Image/discrete.jpg

escience.anu.edu.au/lecture/cg/GlobalIllumination/Image/continuous.jpg

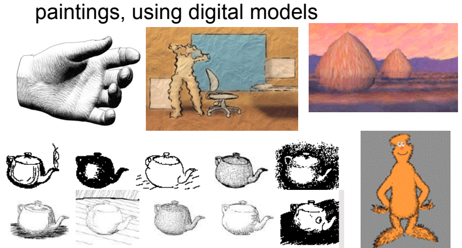
Review: Subsurface Scattering

- light enters and leaves at *different* locations on the surface
  - bounces around inside
- technical Academy Award, 2003
  - Jensen, Marschner, Hanrahan



Review: Non-Photorealistic Rendering

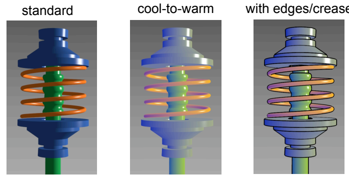
- simulate look of hand-drawn sketches or paintings, using digital models



www.red3d.com/cwr/npr/

Review: Non-Photorealistic Shading

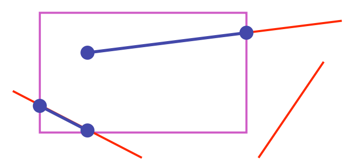
- cool-to-warm shading: $k_w = \frac{1+\mathbf{n}\cdot\mathbf{l}}{2}, c = k_w c_w + (1-k_w)c_c$
- draw silhouettes: if $(\mathbf{e}\cdot\mathbf{n_0})(\mathbf{e}\cdot\mathbf{n_1}) \leq 0$, **e**=edge-eye vector
- draw creases: if $(\mathbf{n_0}\cdot\mathbf{n_1}) \leq threshold$



http://www.cs.utah.edu/~gooch/SIG98/paper/drawing.html

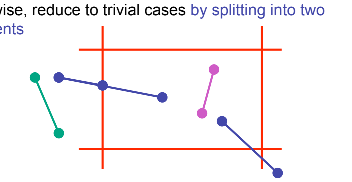
Review: Clipping

- analytically calculating the portions of primitives within the viewport



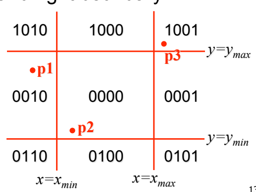
Review: Clipping Lines To Viewport

- 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

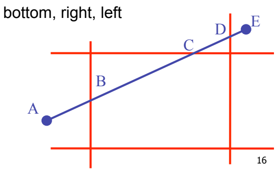
- assign outcode to each vertex of line to test
  - line segment: (**p1**,**p2**)
- trivial cases
  - OC(**p1**)== 0 && OC(**p2**)==0
    - both points inside window, thus line segment completely visible (trivial accept)
  - (OC(**p1**) & OC(**p2**))!= 0
    - there is (at least) one boundary for which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

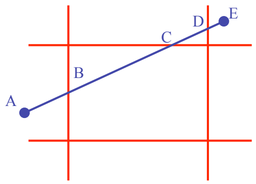
Cohen-Sutherland Line Clipping

- 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



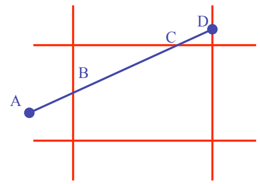
Cohen-Sutherland Line Clipping

- intersect line with edge



Cohen-Sutherland Line Clipping

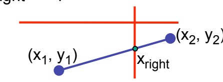
- discard portion on wrong side of edge and assign outcode to new vertex



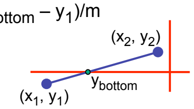
- apply trivial accept/reject tests and repeat if necessary

Viewport Intersection Code

- (x_1, y_1), (x_2, y_2) intersect vertical edge at x_{right}
  - $y_{intersect} = y_1 + m(x_{right} - x_1)$
  - $m=(y_2-y_1)/(x_2-x_1)$



- (x_1, y_1), (x_2, y_2) intersect horiz edge at y_{bottom}
  - $x_{intersect} = x_1 + (y_{bottom} - y_1)/m$
  - $m=(y_2-y_1)/(x_2-x_1)$



Cohen-Sutherland Discussion

- key concepts
  - 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
- basic idea, more efficient algorithms exist

Line Clipping in 3D

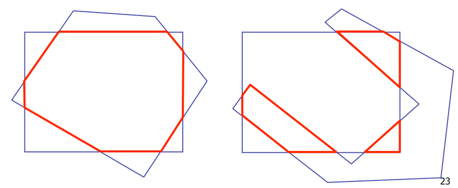
- approach
  - clip against parallelpiped in NDC
    - after perspective transform
  - means that clipping volume always the same
    - xmin=ymin= -1, xmax=ymax= 1 in OpenGL
  - boundary lines become boundary planes
    - but outcodes still work the same way
    - additional front and back clipping plane
      - zmin = -1, zmax = 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

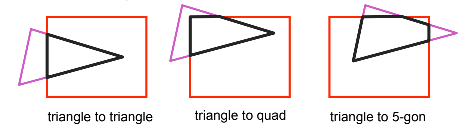
Polygon Clipping

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

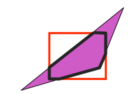


Why Is Clipping Hard?

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

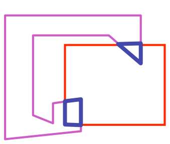


- how many sides can result from a triangle?
  - seven



Why Is Clipping Hard?

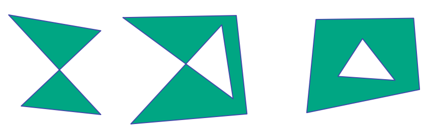
- a really tough case:



concave polygon to multiple polygons

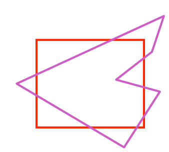
Polygon Clipping

- 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



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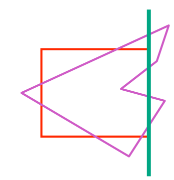

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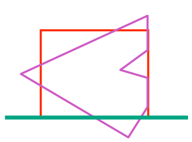

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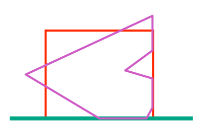

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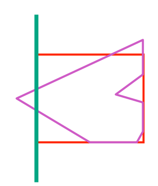

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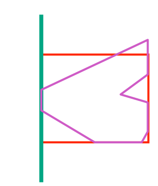

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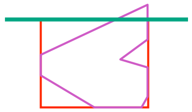

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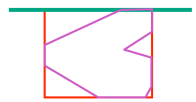

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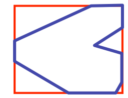
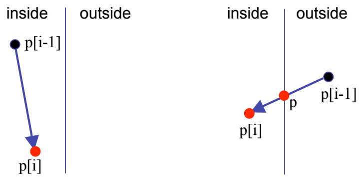


Sutherland-Hodgeman Algorithm

- input/output for whole algorithm
  - input: list of polygon vertices in order
  - output: list of clipped polygon vertices consisting of old vertices (maybe) and new vertices (maybe)
- input/output for each step
  - input: list of vertices
  - output: list of vertices, possibly with changes
- basic routine
  - go around polygon one vertex at a time
  - decide what to do based on 4 possibilities
    - is vertex inside or outside?
    - is previous vertex inside or outside?

Clipping Against One Edge

- p[i] inside: 2 cases

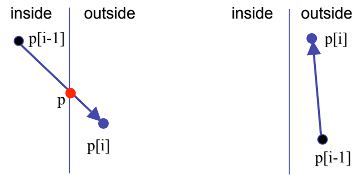


output: p[i]

output: p, p[i]

Clipping Against One Edge

- p[i] outside: 2 cases



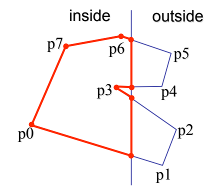
output: p

output: nothing

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


Sutherland-Hodgeman Example



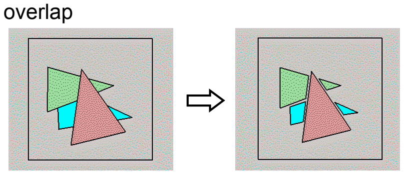
Sutherland-Hodgeman Discussion

- similar to Cohen/Sutherland line clipping
  - inside/outside tests: outcodes
  - intersection of line segment with edge: window-edge coordinates
- clipping against individual edges independent
  - great for hardware (pipelining)
  - all vertices required in memory at same time
    - not so good, but unavoidable
    - another reason for using triangles only in hardware rendering

Hidden Surface Removal

Occlusion

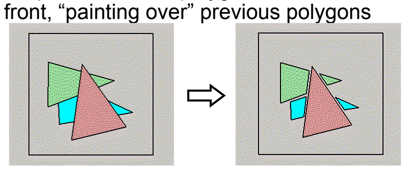
- for most interesting scenes, some polygons overlap



- to render the correct image, we need to determine which polygons occlude which

Painter's Algorithm

- simple: render the polygons from back to front, "painting over" previous polygons



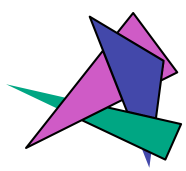
  - draw blue, then green, then orange
- will this work in the general case?

Painter's Algorithm: Problems

- *intersecting polygons* present a problem
- even non-intersecting polygons can form a cycle with no valid visibility order:

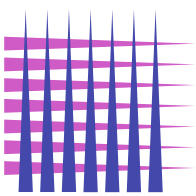
Analytic Visibility Algorithms

- early visibility algorithms computed the set of visible polygon *fragments* directly, then rendered the fragments to a display:



Analytic Visibility Algorithms

- *what is the minimum worst-case cost of computing the fragments for a scene composed of* n *polygons?*
- answer: $O(n^2)$



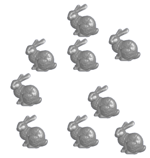
Analytic Visibility Algorithms

- so, for about a decade (late 60s to late 70s) there was intense interest in finding efficient algorithms for hidden surface removal
- we'll talk about one:
  - *Binary Space Partition (BSP) Trees*

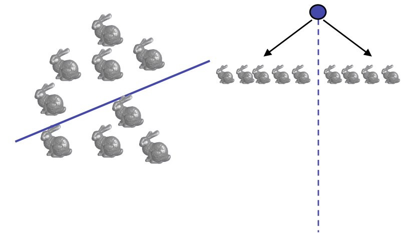
Binary Space Partition Trees (1979)

- BSP Tree: partition space with binary tree of planes
  - idea: divide space recursively into half-spaces by choosing splitting planes that separate objects in scene
  - preprocessing: create binary tree of planes
  - runtime: correctly traversing this tree enumerates objects from back to front

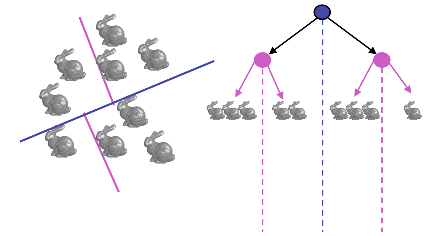
Creating BSP Trees: Objects



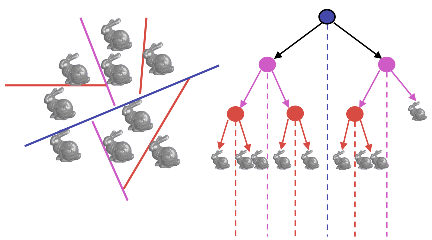
Creating BSP Trees: Objects



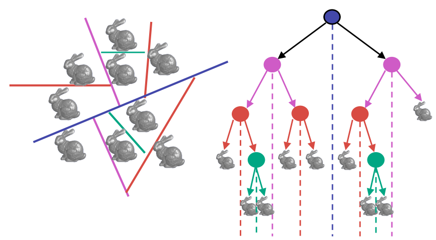
Creating BSP Trees: Objects



Creating BSP Trees: Objects

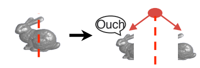


Creating BSP Trees: Objects



Splitting Objects

- no bunnies were harmed in previous example
- but what if a splitting plane passes through an object?
  - split the object; give half to each node



Traversing BSP Trees

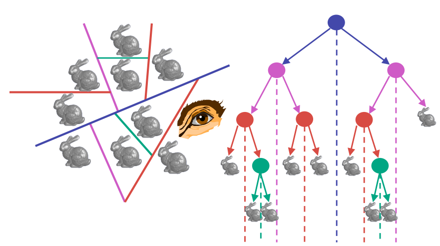
- tree creation independent of viewpoint
  - preprocessing step
- tree traversal uses viewpoint
  - runtime, happens for many different viewpoints
- each plane divides world into near and far
  - for given viewpoint, decide which side is near and which is far
    - check which side of plane viewpoint is on independently for each tree vertex
    - tree traversal differs depending on viewpoint!
  - recursive algorithm
    - recurse on far side
    - draw object
    - recurse on near side

Traversing BSP Trees

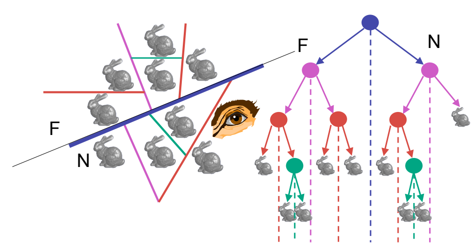
query: given a viewpoint, produce an ordered list of (possibly split) objects from back to front:

```
renderBSP(BSPtree *T)
  BSPtree *near, *far;
  if (eye on left side of T->plane)
     near = T->left; far = T->right;
  else
     near = T->right; far = T->left;
  renderBSP(far);
  if (T is a leaf node)
     renderObject(T)
  renderBSP(near);
```

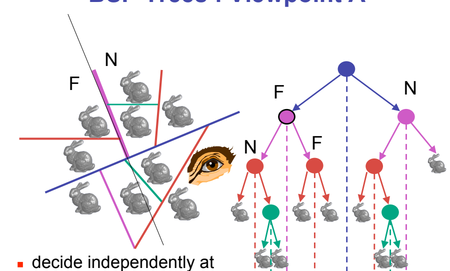

BSP Trees : Viewpoint A



BSP Trees : Viewpoint A

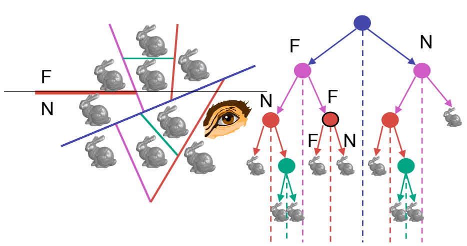


BSP Trees : Viewpoint A

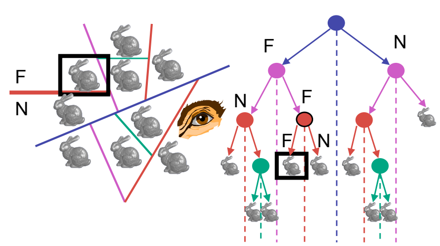


- decide independently at each tree vertex
- not just left or right child!

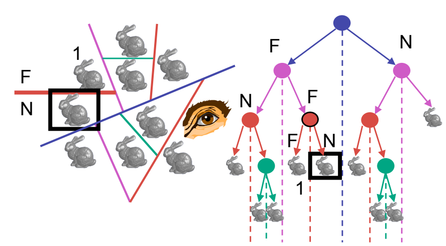
BSP Trees : Viewpoint A



BSP Trees : Viewpoint A



BSP Trees : Viewpoint A



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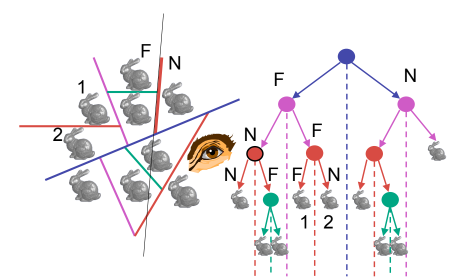
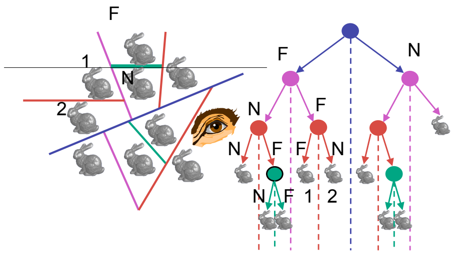
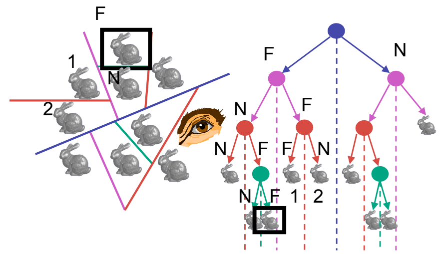


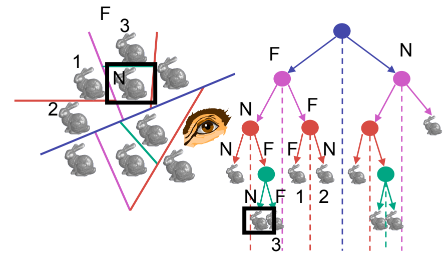
BSP Trees : Viewpoint A



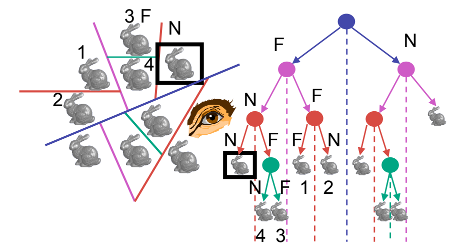
BSP Trees : Viewpoint A



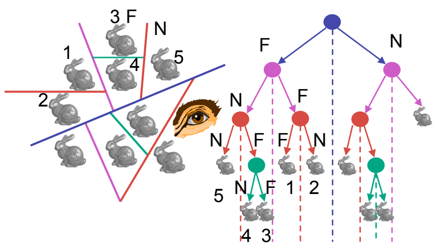
BSP Trees : Viewpoint A



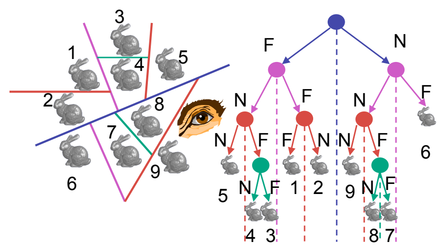
BSP Trees : Viewpoint A



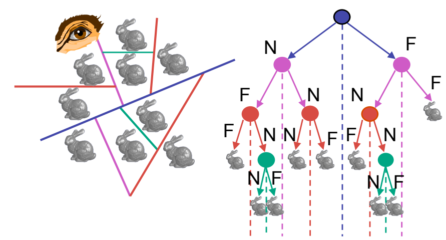
BSP Trees : Viewpoint A



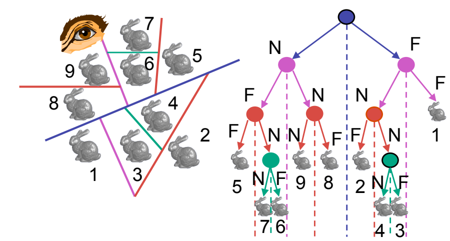
BSP Trees : Viewpoint A



BSP Trees : Viewpoint B



BSP Trees : Viewpoint B

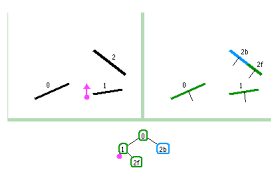


BSP Tree Traversal: Polygons

- split along the plane defined by any polygon from scene
- classify all polygons into positive or negative half-space of the plane
  - if a polygon intersects plane, split polygon into two and classify them both
- recurse down the negative half-space
- recurse down the positive half-space

BSP Demo

- useful demo:
  http://symbolcraft.com/graphics/bsp

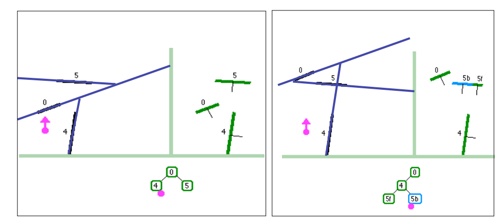


Summary: BSP Trees

- 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

Clarification: BSP Demo

- order of insertion can affect half-plane extent



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