University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2007

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# Clipping II, Hidden Surfaces I

## Week 8, Fri Mar 9

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

# Reading for This Time

- FCG Chap 12 Graphics Pipeline
  - only 12.1-12.4
- FCG Chap 8 Hidden Surfaces

# 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];
      ```

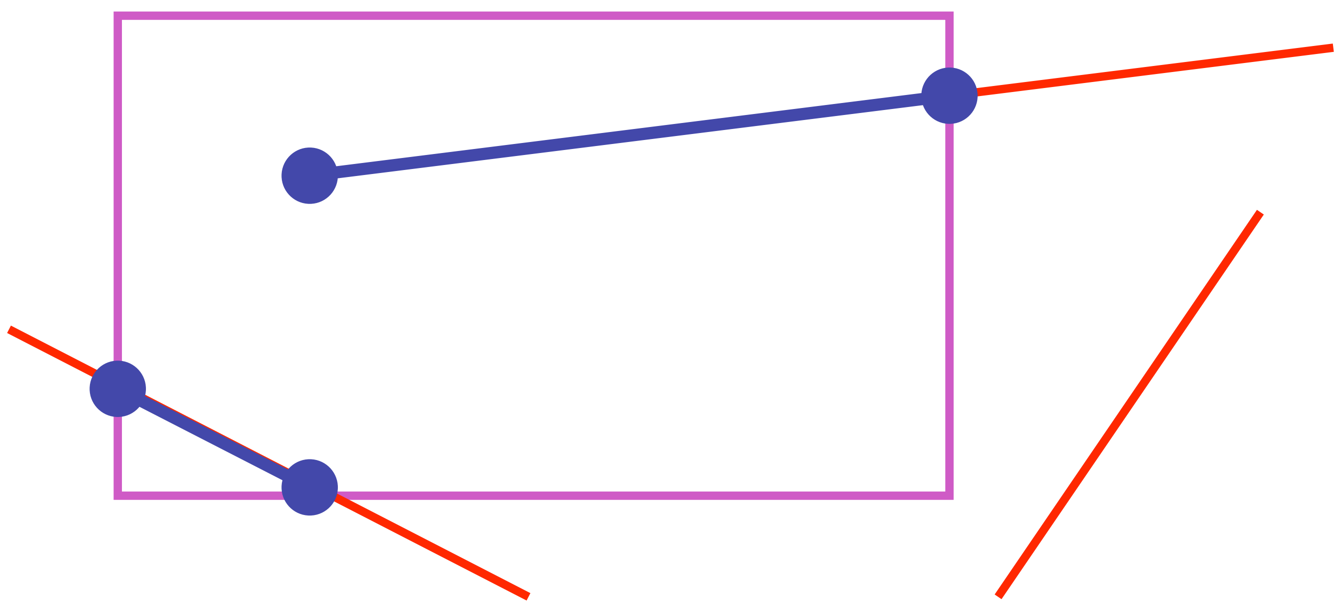
      to

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

      **OR**
    - implement resolution parsing

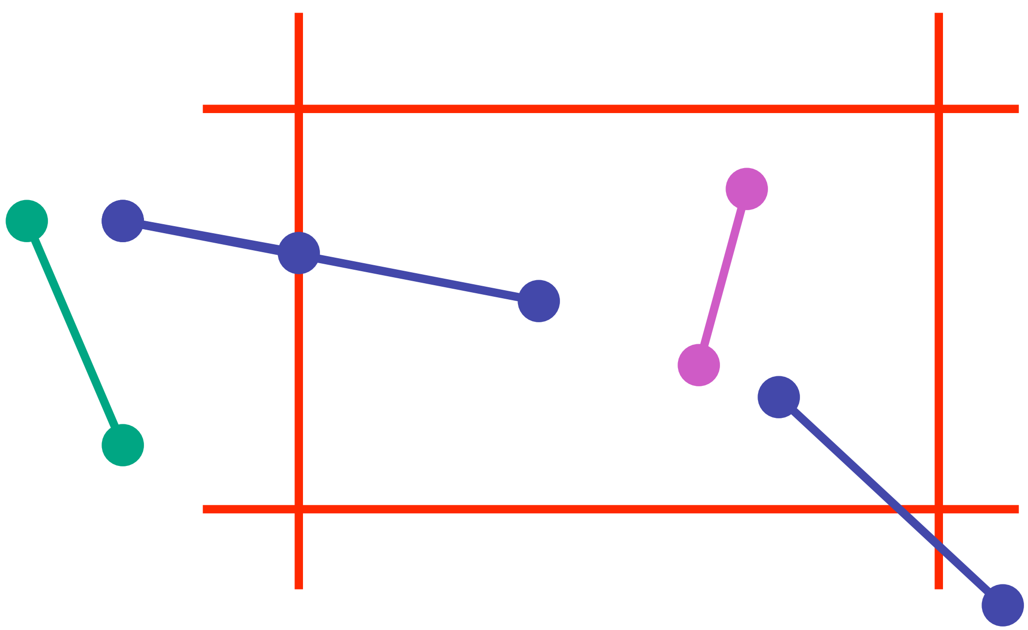
# Review: Clipping

- analytically calculating the portions of primitives within the viewport



# Review: Clipping Lines To Viewport

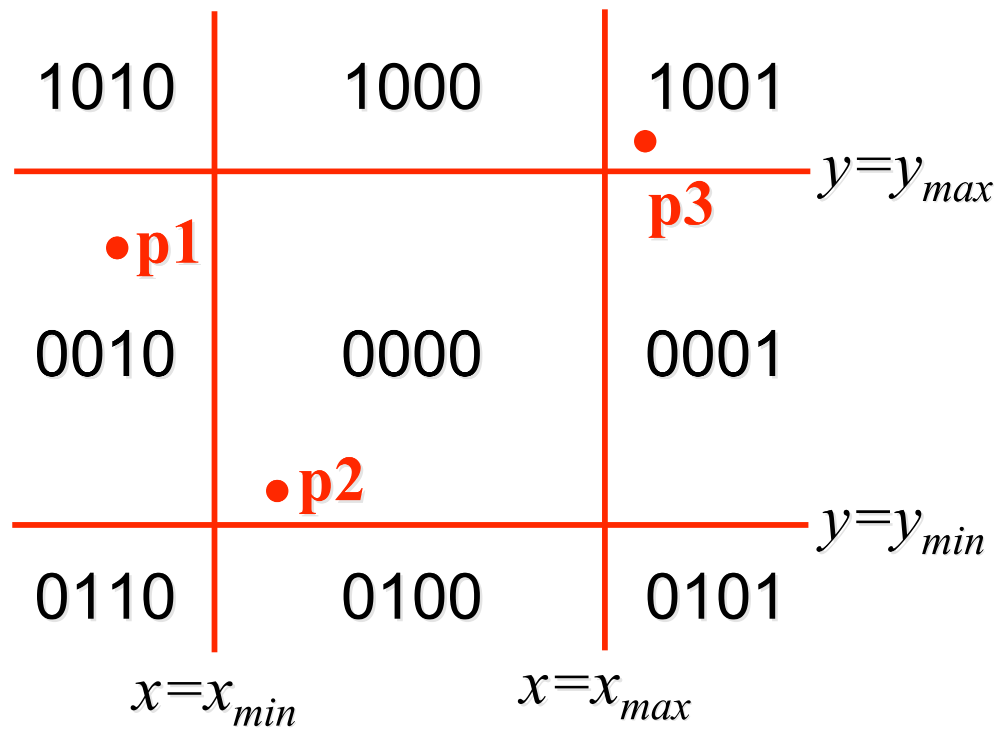
- combining trivial accepts/rejects
  - trivially accept lines with both endpoints inside all edges of the viewport
  - trivially reject lines with both endpoints outside the same edge of the viewport
  - otherwise, reduce to trivial cases by splitting into two segments



# Review: Cohen-Sutherland Line Clipping

- outcodes
  - 4 flags encoding position of a point relative to top, bottom, left, and right boundary

- OC(p1)== 0 && OC(p2)==0
  - trivial accept
- (OC(p1) & OC(p2))!= 0
  - trivial reject



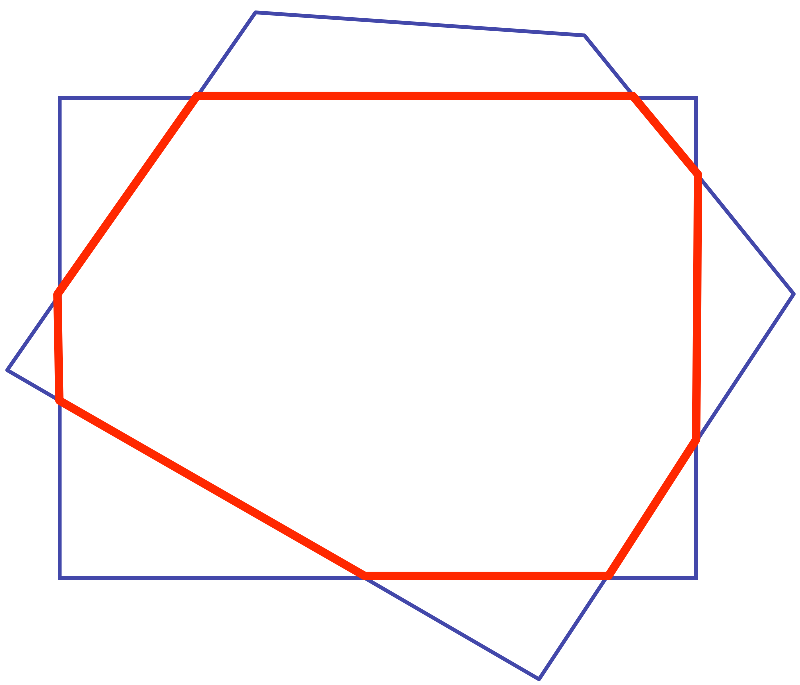
# Clipping II

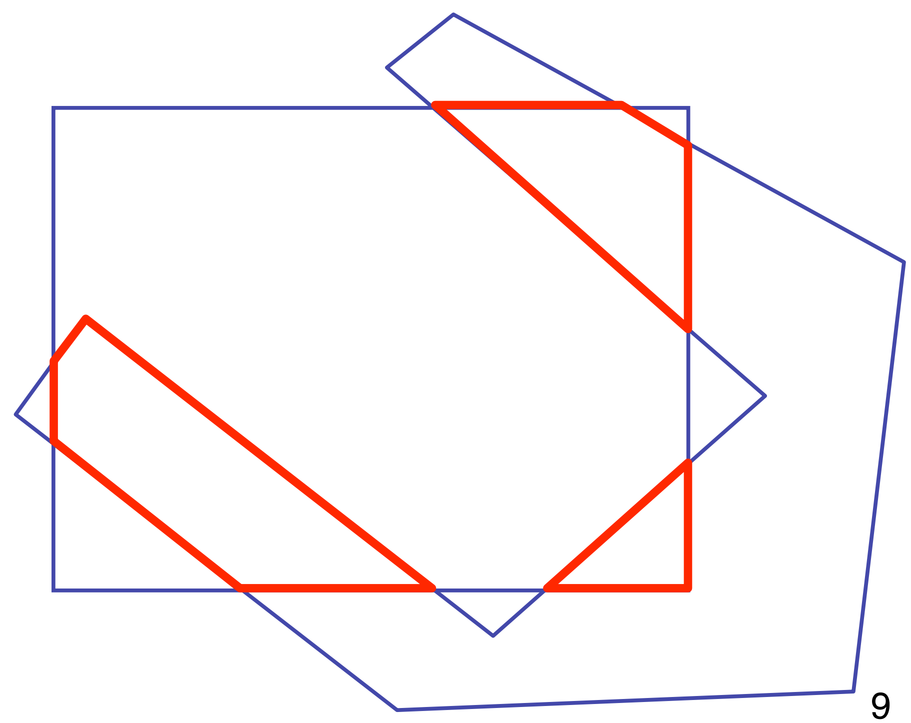
# Polygon Clipping

- 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

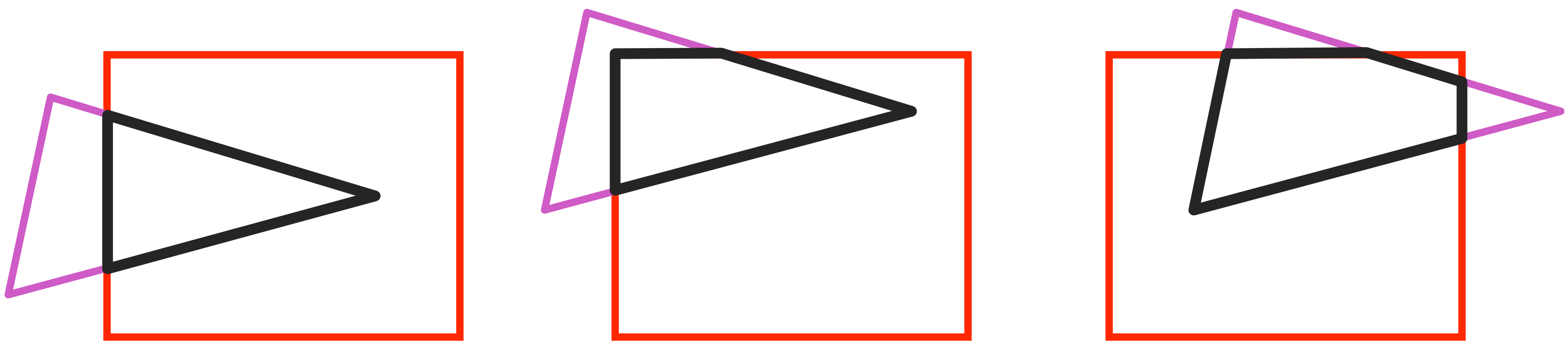
- not just clipping all boundary lines
- may have to introduce new line segments





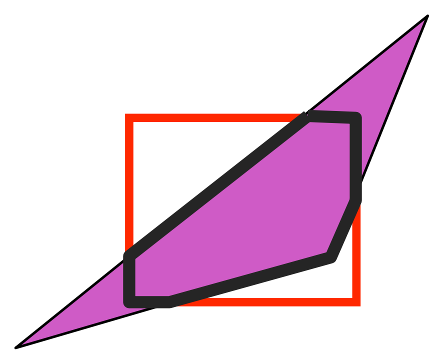
# Why Is Clipping Hard?

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



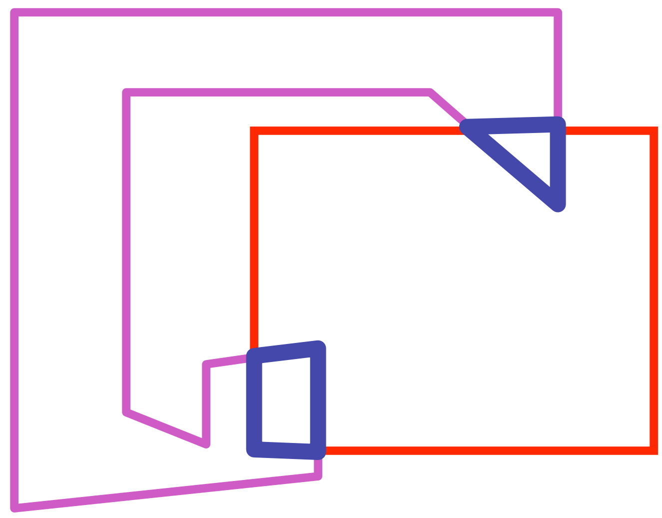
triangle to triangle triangle to quad triangle to 5-gon

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



# Why Is Clipping Hard?

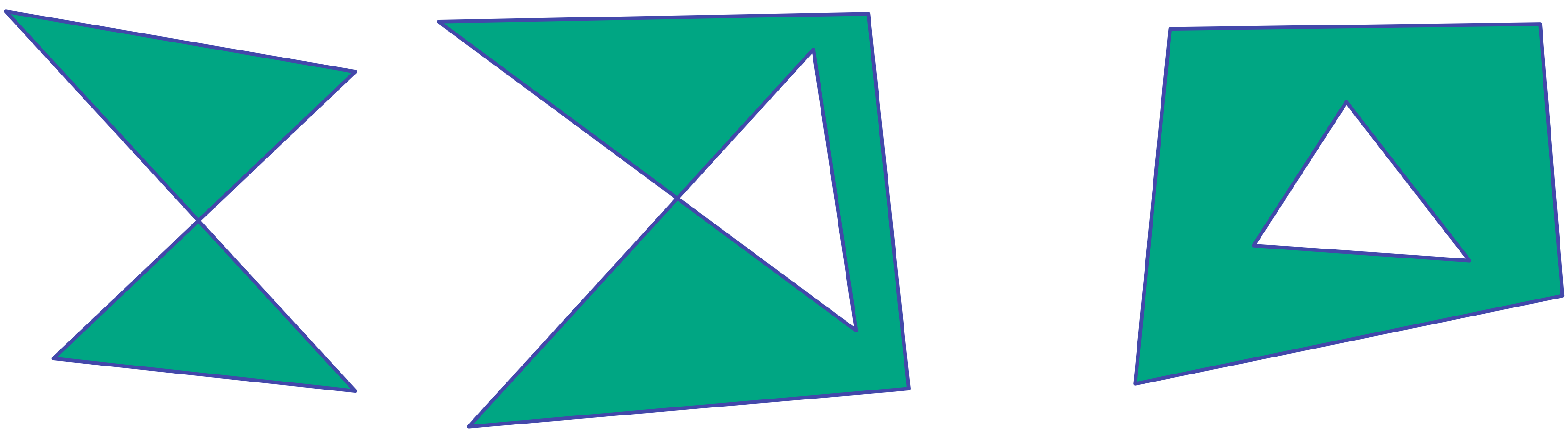
- a really tough case:



concave polygon to multiple polygons

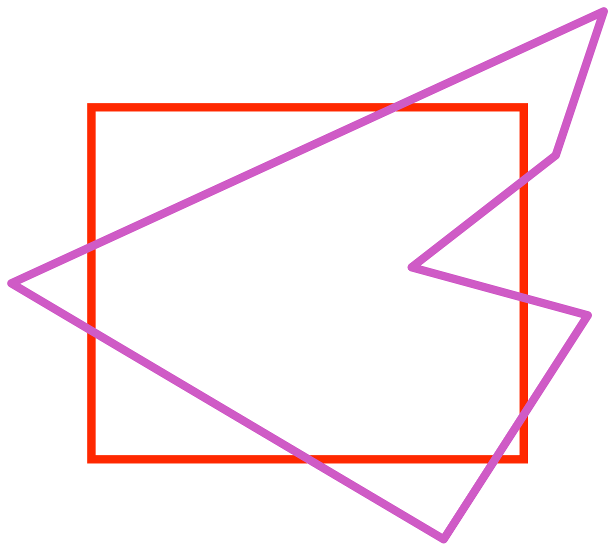
# Polygon Clipping

- 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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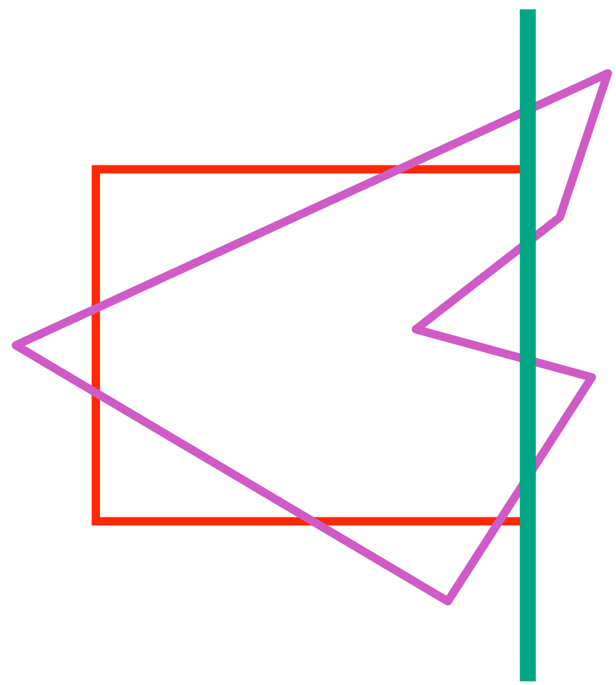

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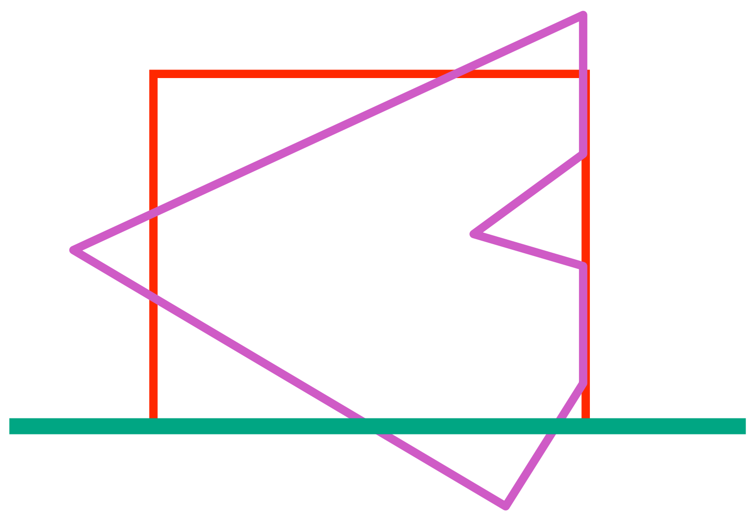

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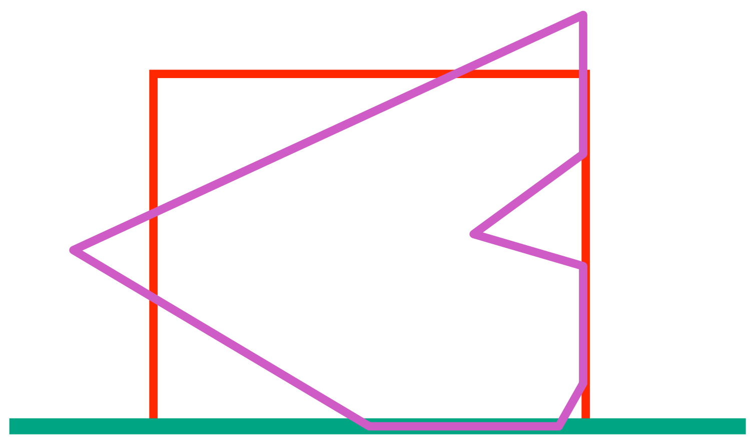

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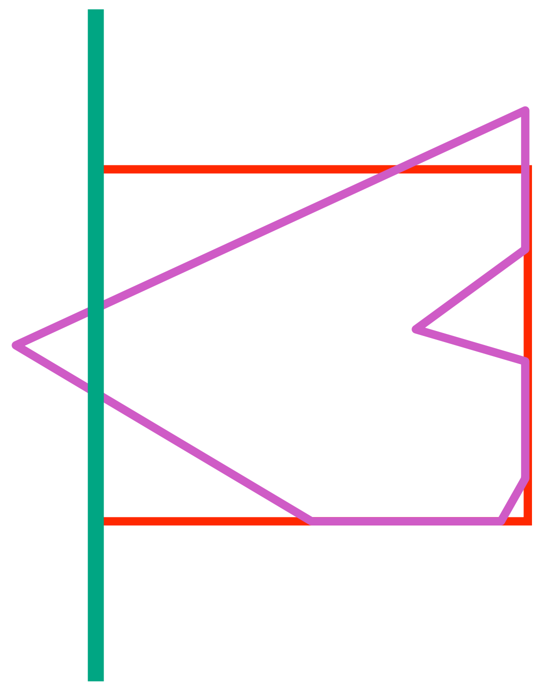

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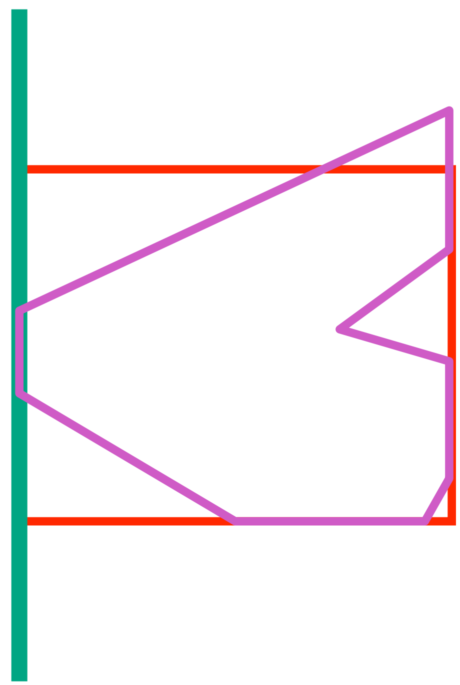

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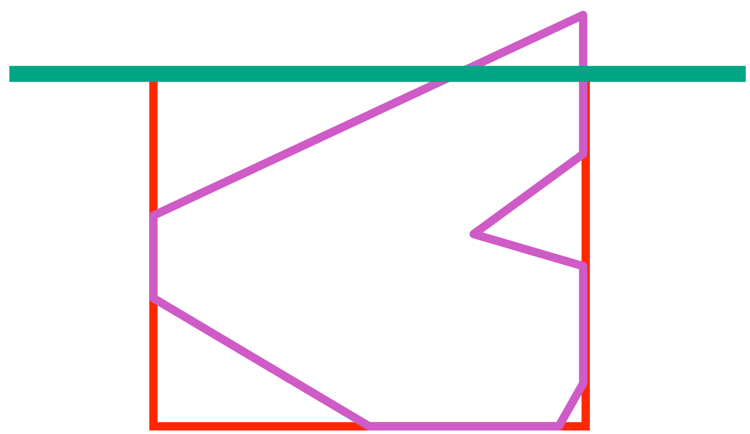

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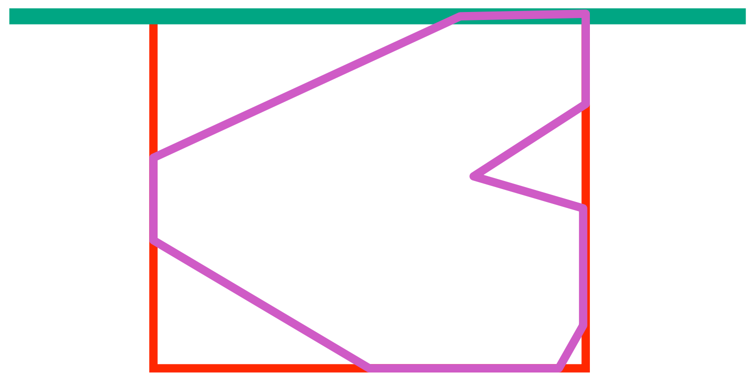

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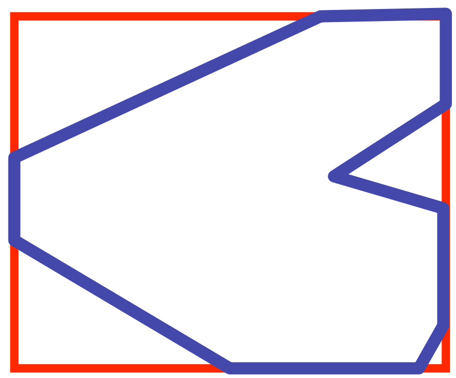
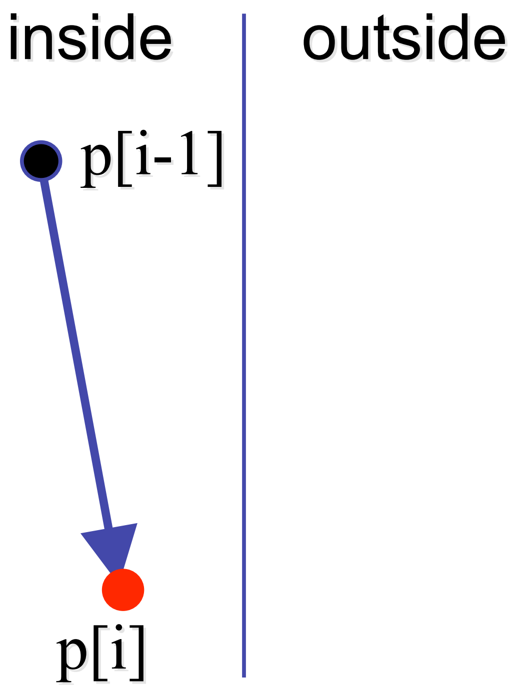


# Sutherland-Hodgeman Algorithm

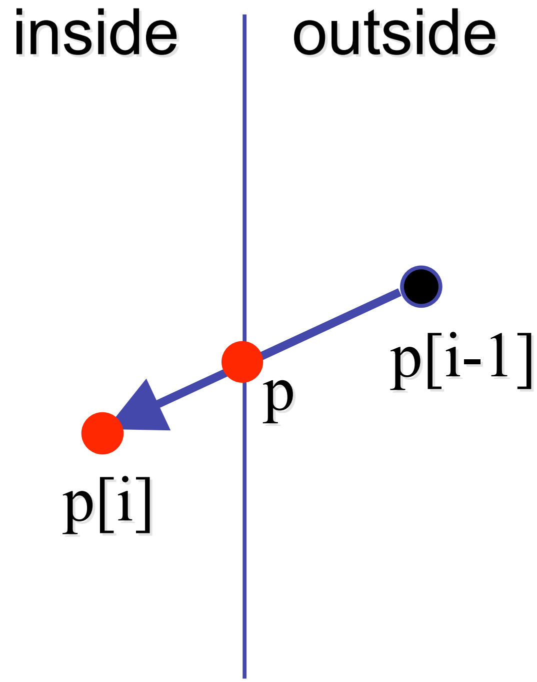
- input/output for whole algorithm
  - input: list of polygon vertices in order
  - output: list of clipped polygon vertices consisting of old vertices (maybe) and new vertices (maybe)
- input/output for each step
  - input: list of vertices
  - output: list of vertices, possibly with changes
- basic 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



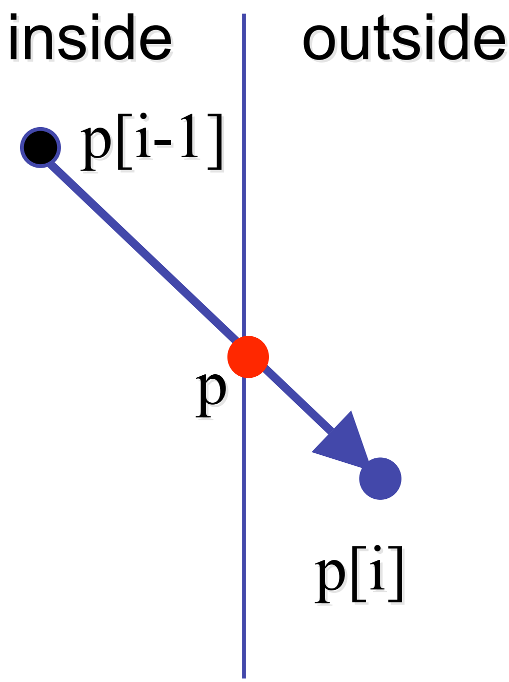

output: p[i]



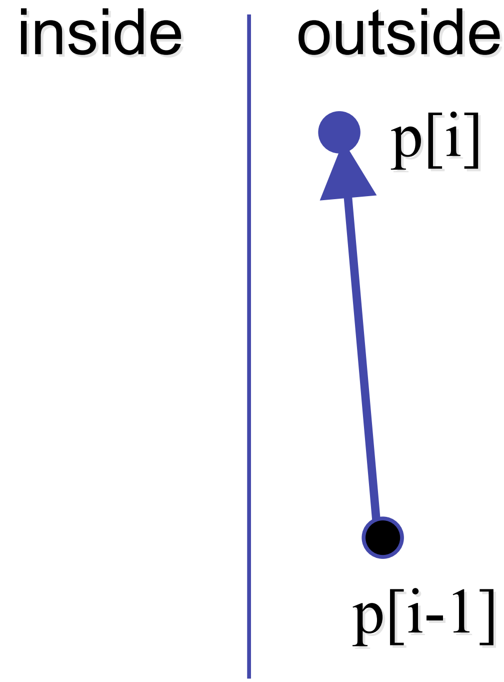

output: p, p[i]

# Clipping Against One Edge

- p[i] outside: 2 cases




output: p

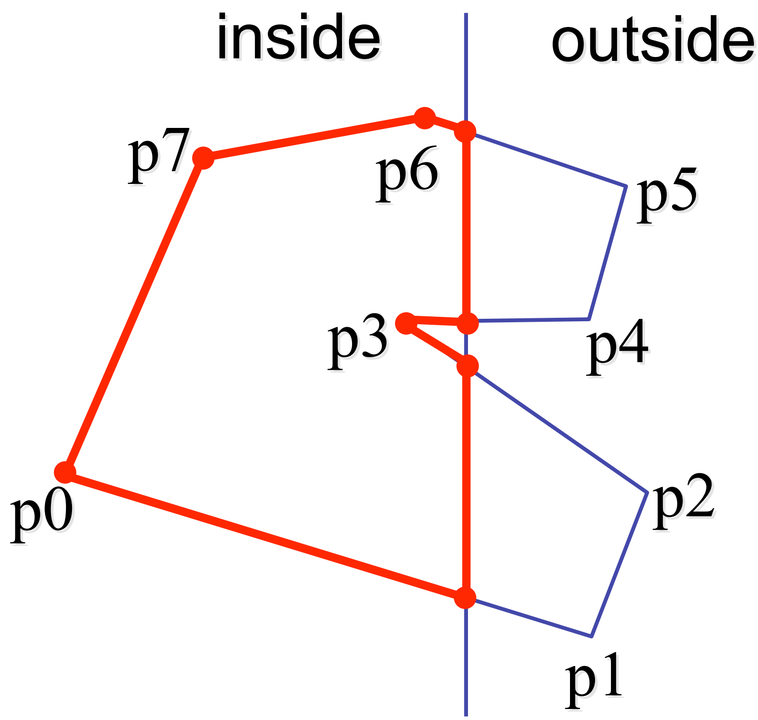



output: nothing

# 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



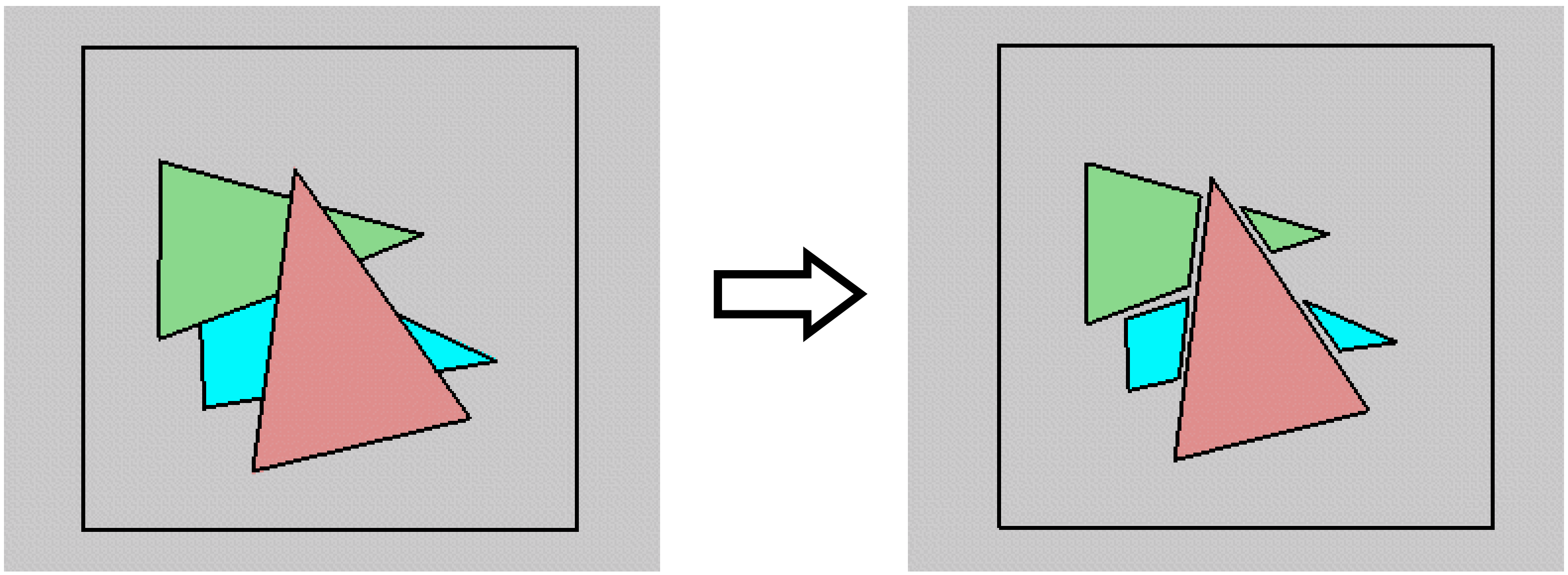
# Sutherland-Hodgeman Discussion

- 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

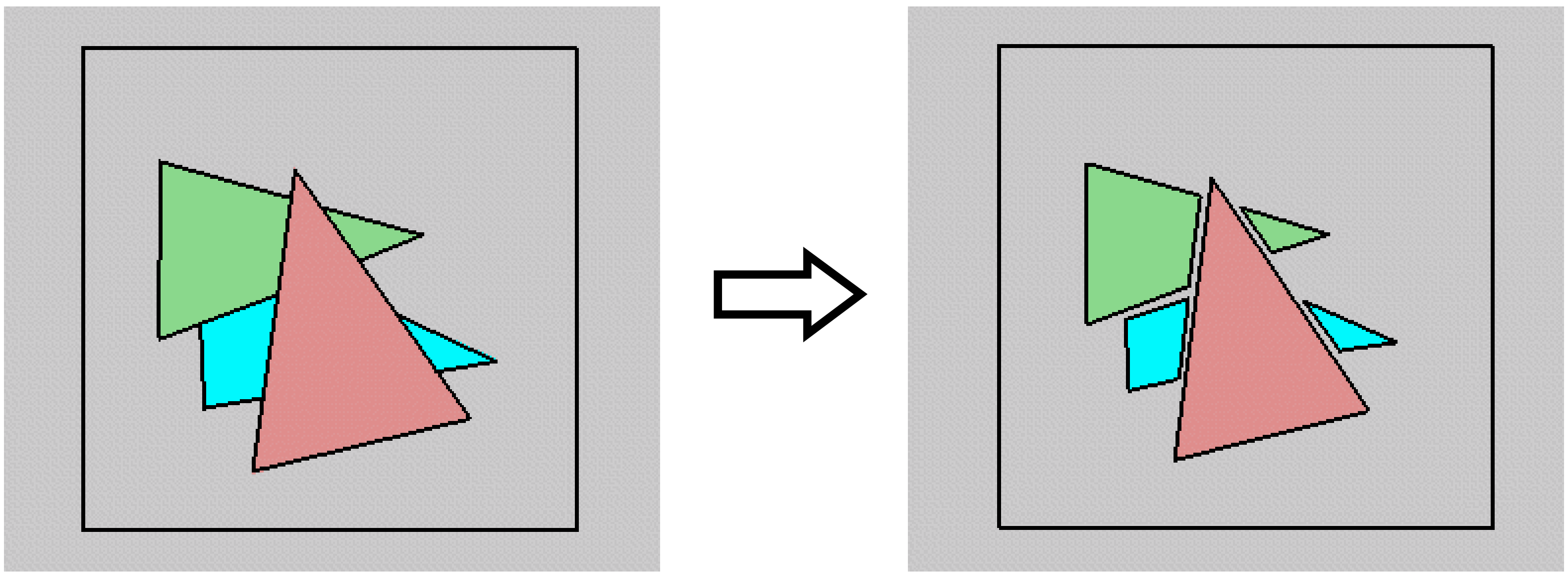
- for most interesting scenes, some polygons overlap



- 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



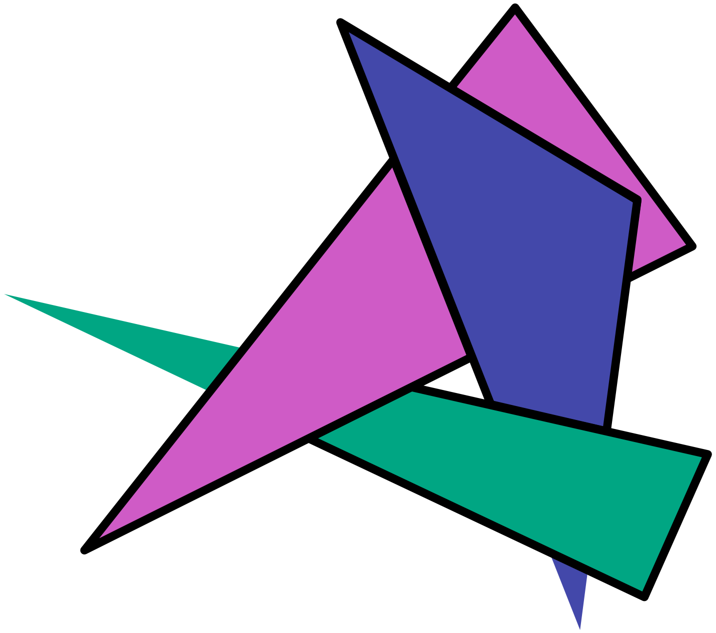
  - draw blue, then green, then orange
- will this work in the general case?

# Painter's Algorithm: Problems

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

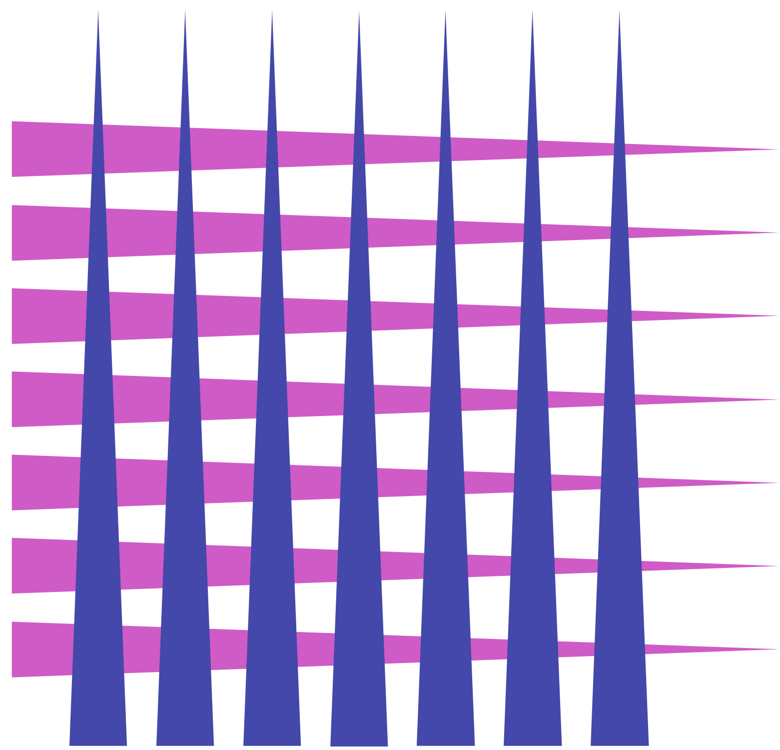
# Analytic Visibility Algorithms

- 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:
  $O(n^2)$



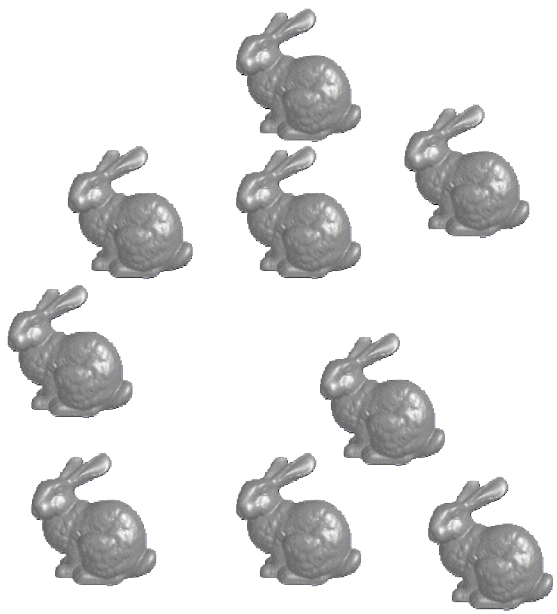
# Analytic Visibility Algorithms

- 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



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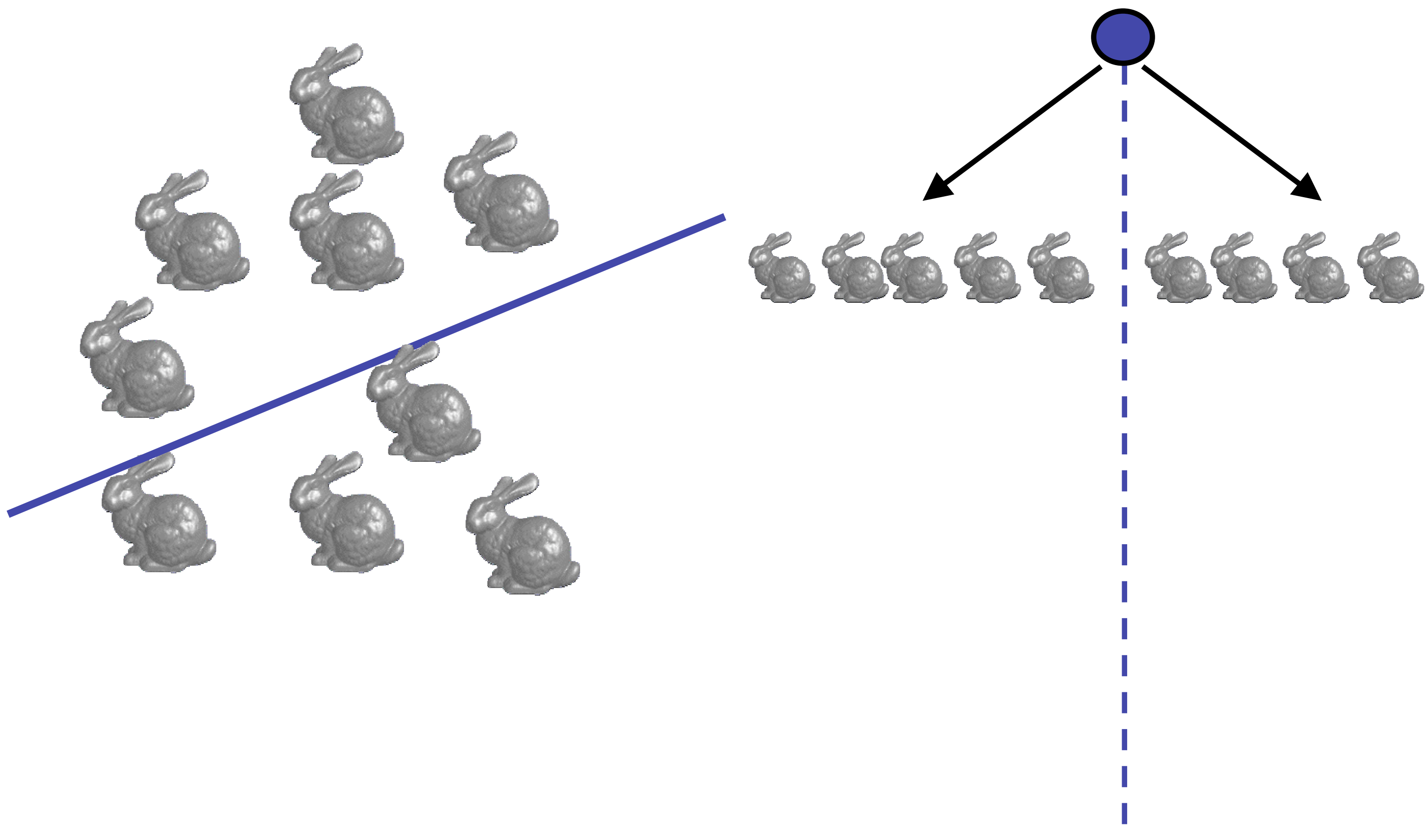

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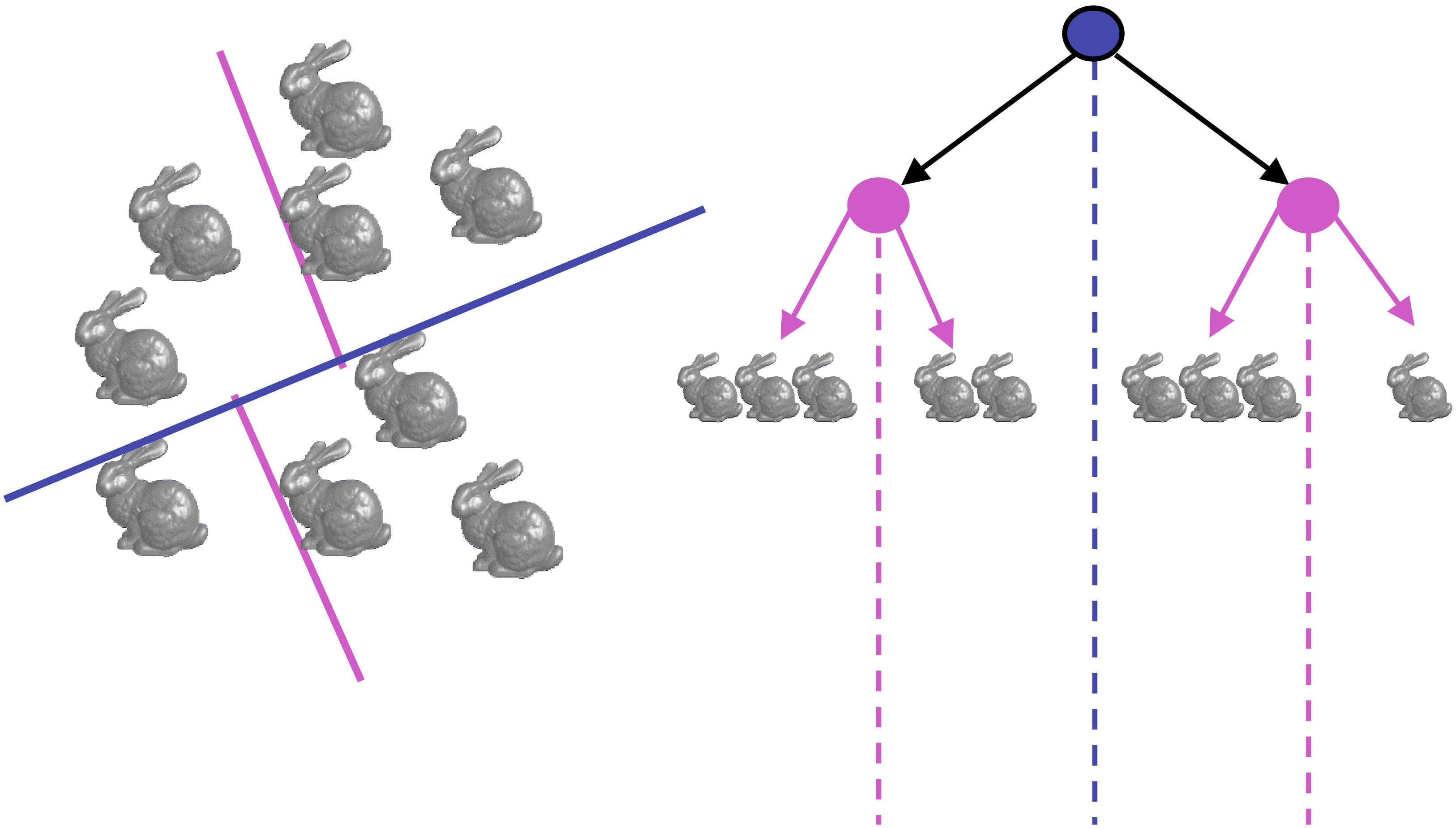

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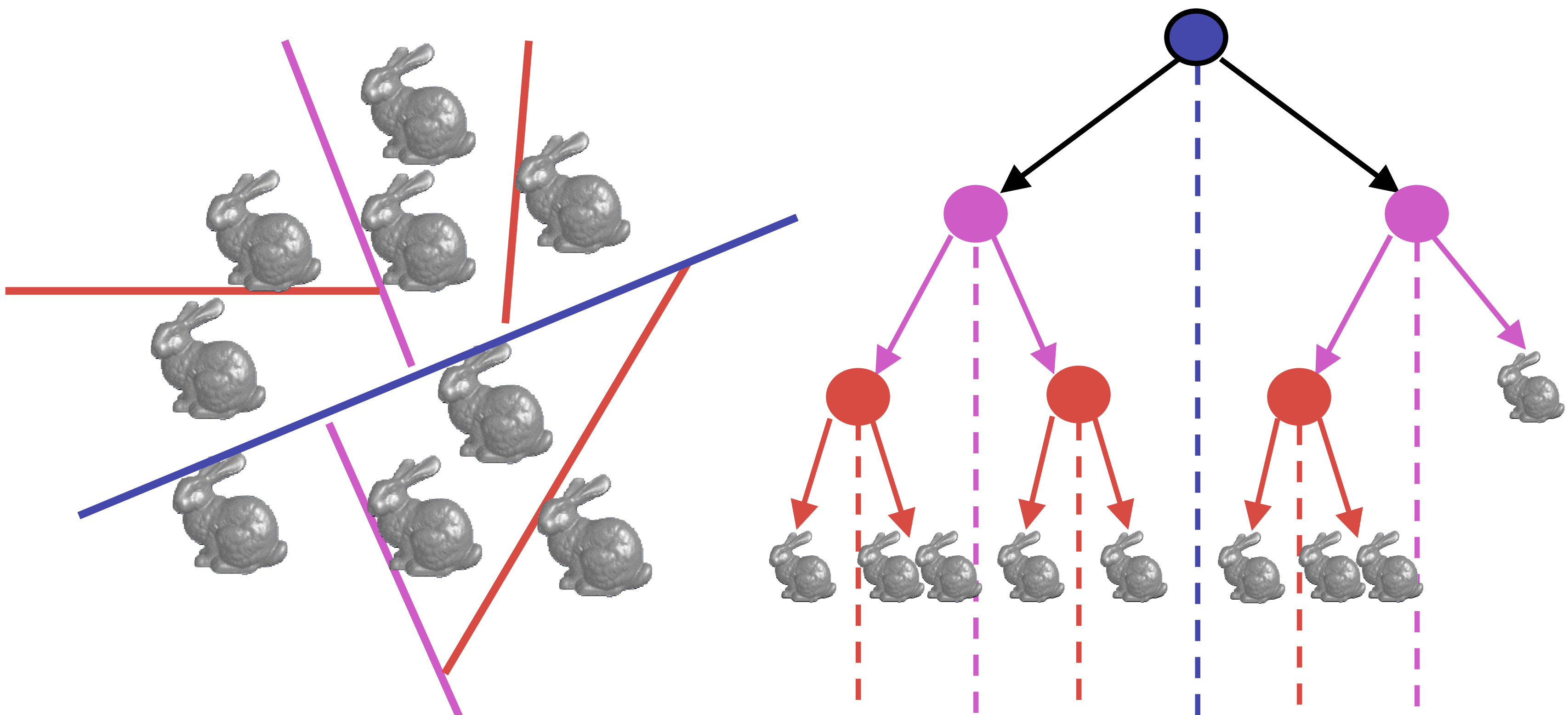

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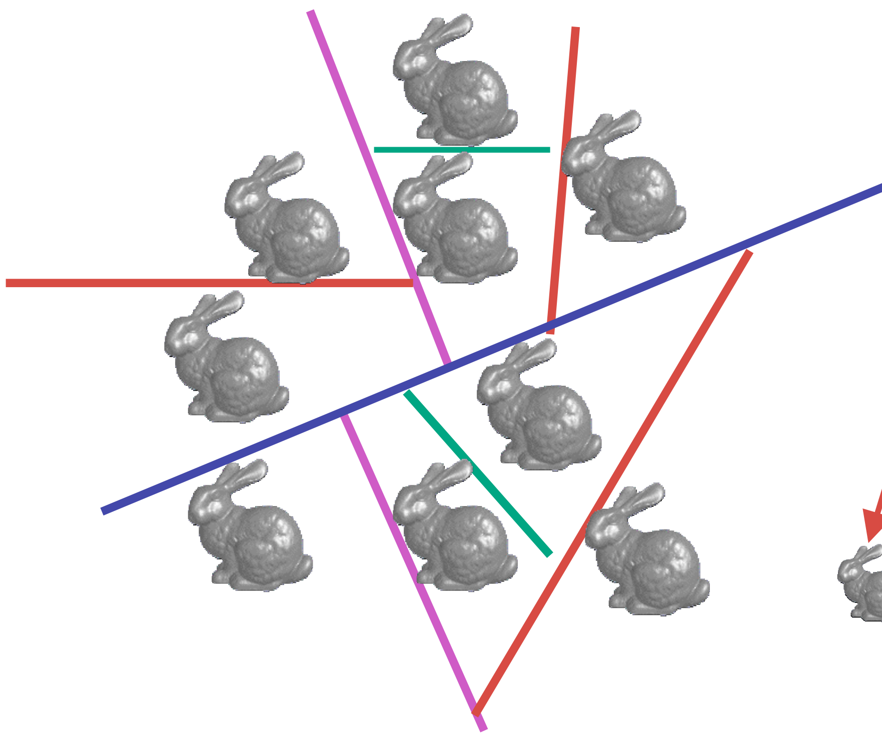
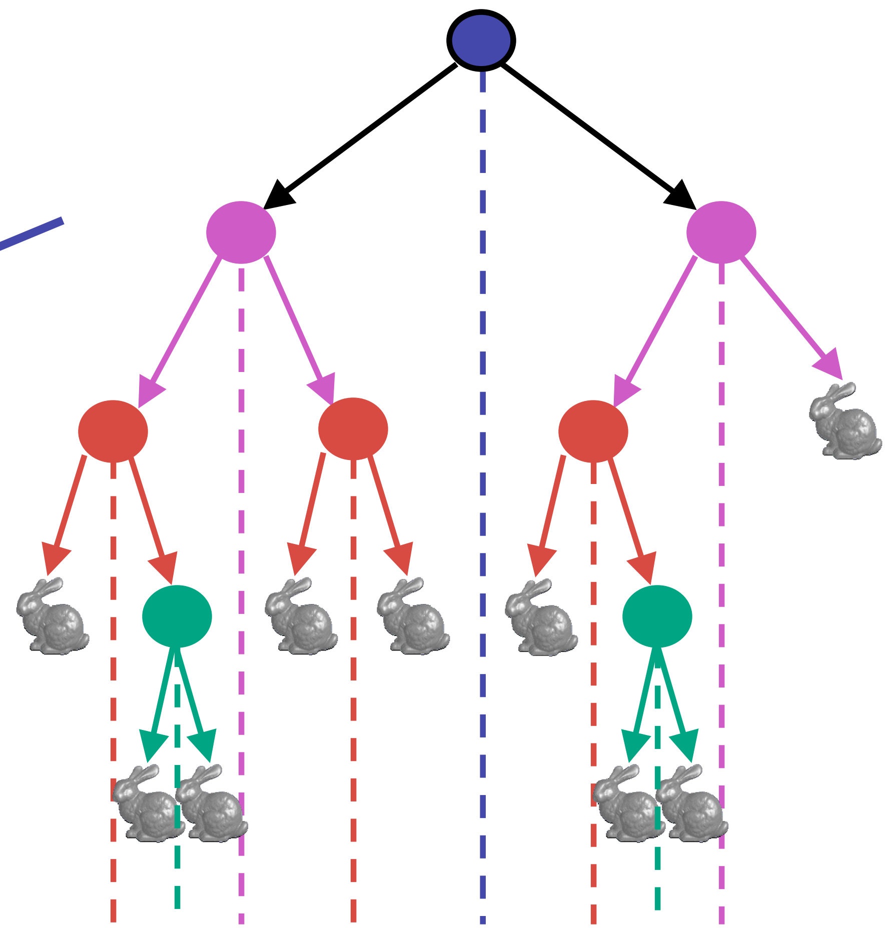
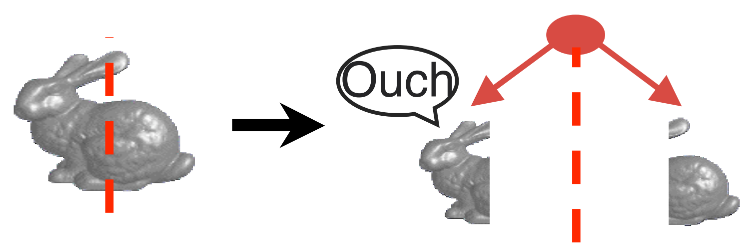




# Splitting Objects

- 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

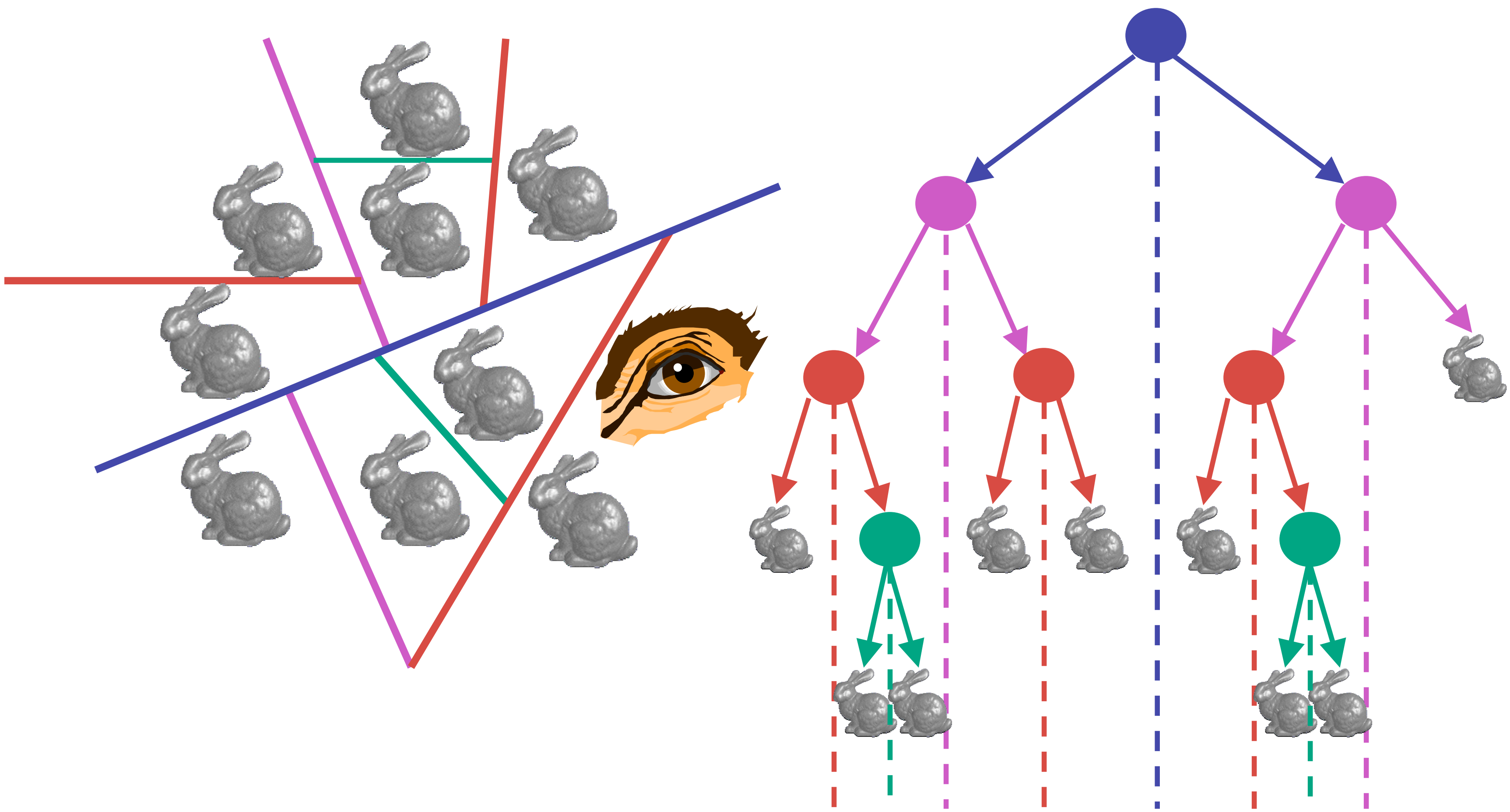
- tree creation independent of viewpoint
  - preprocessing step
- tree traversal uses viewpoint
  - runtime, happens for many different viewpoints
- each plane divides world into near and far
  - for given viewpoint, decide which side is near and which is far
    - check which side of plane viewpoint 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



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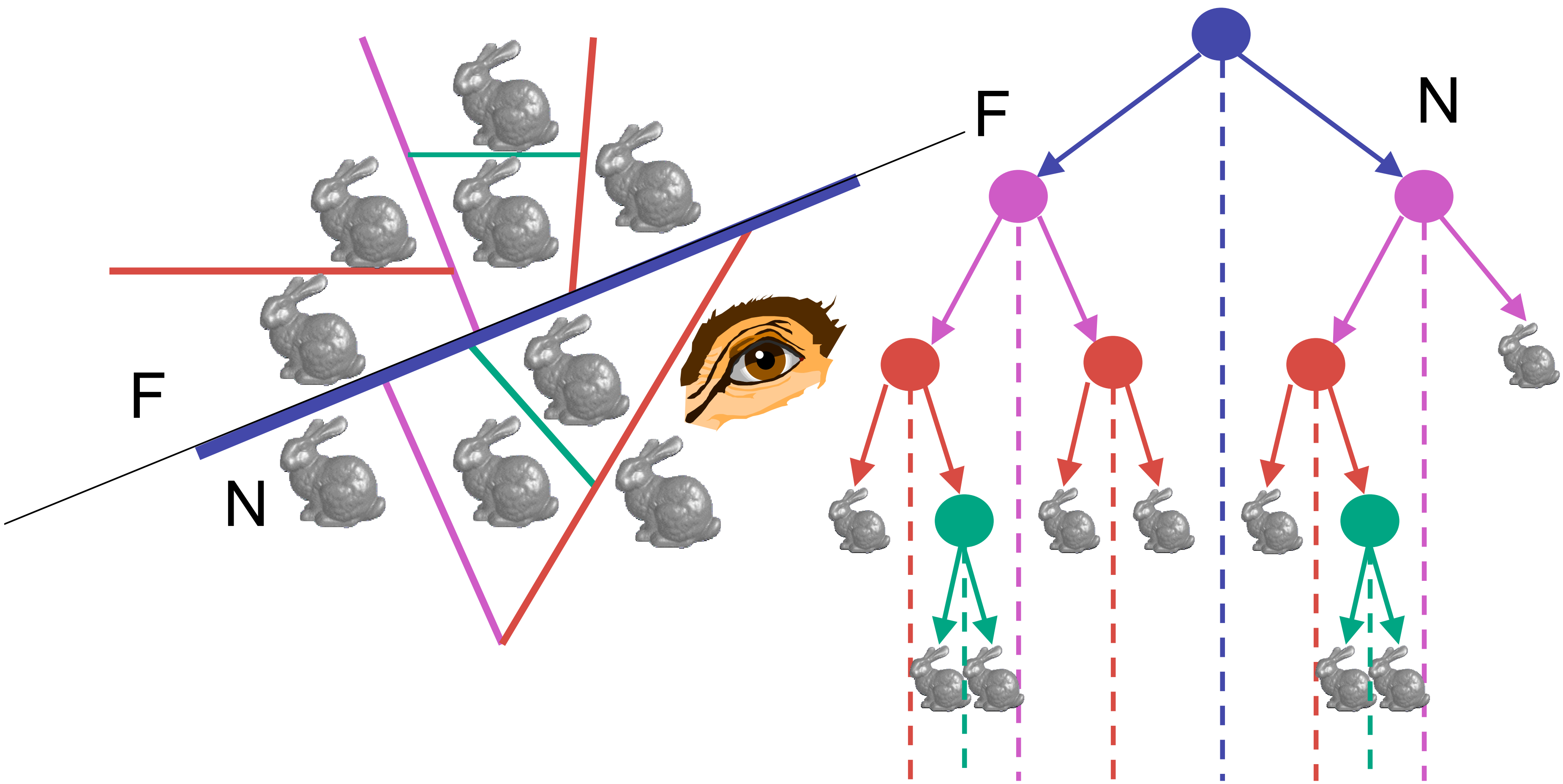

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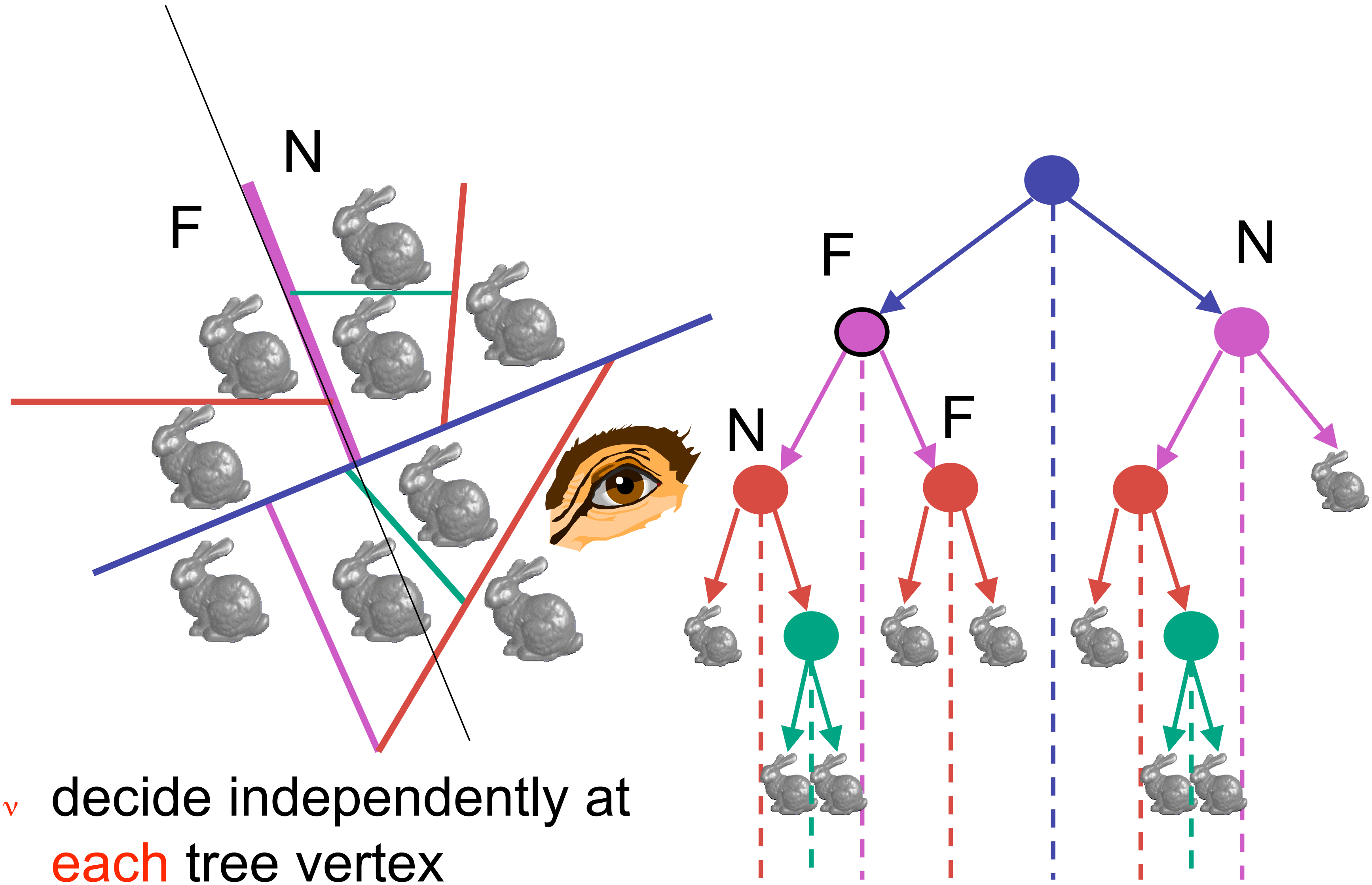


- decide independently at each tree vertex
- not just left or right child!

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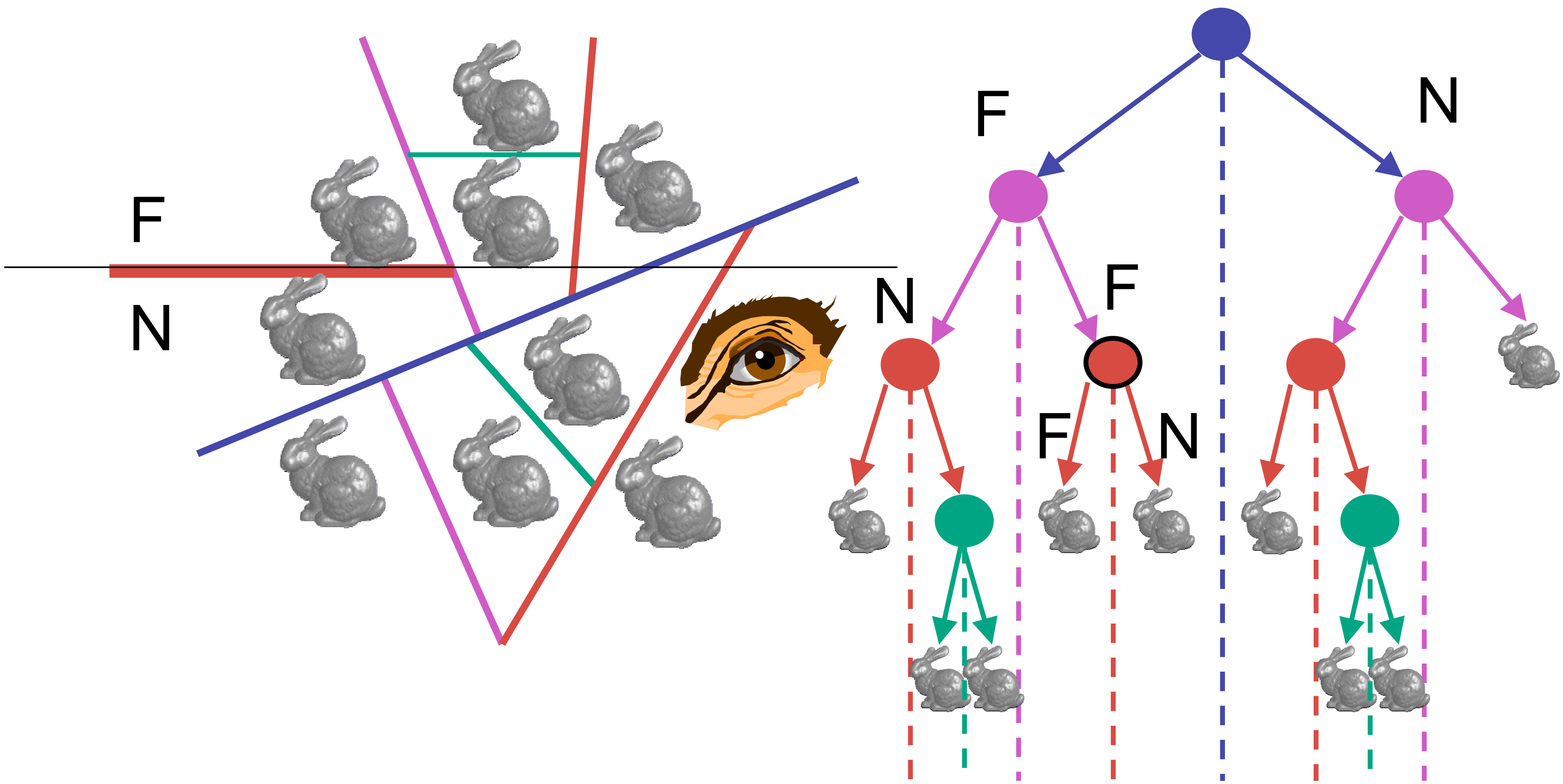

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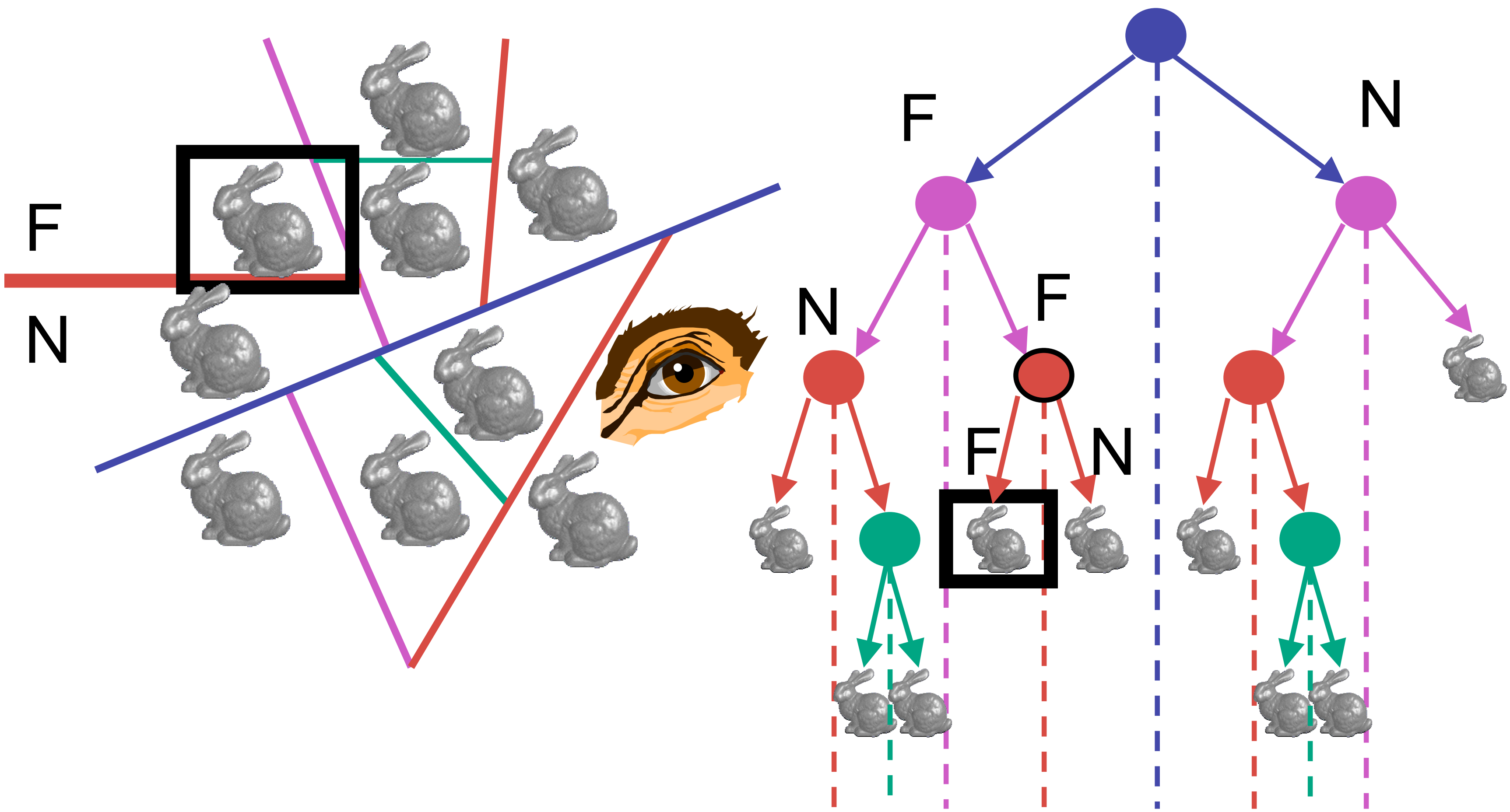

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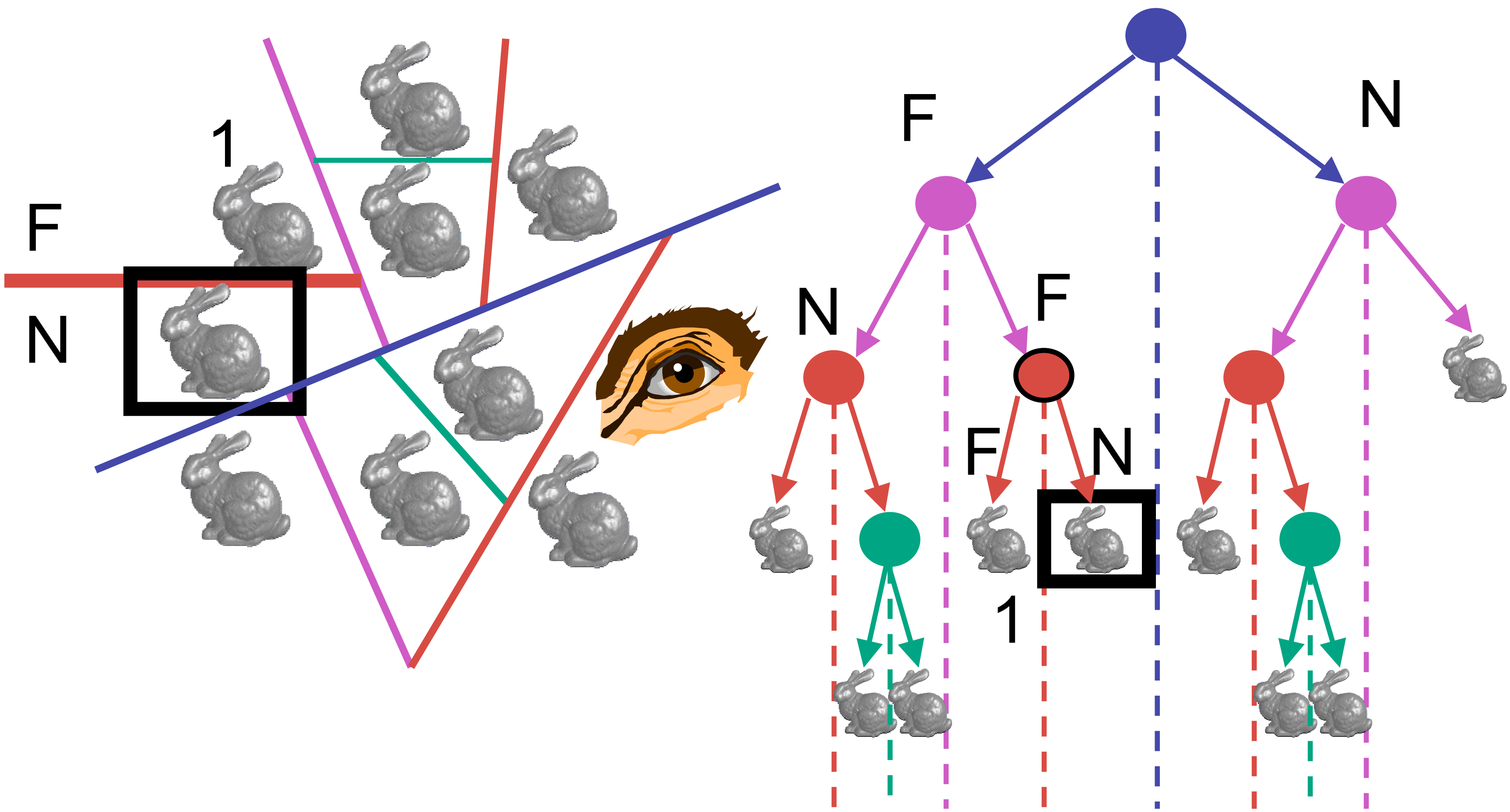

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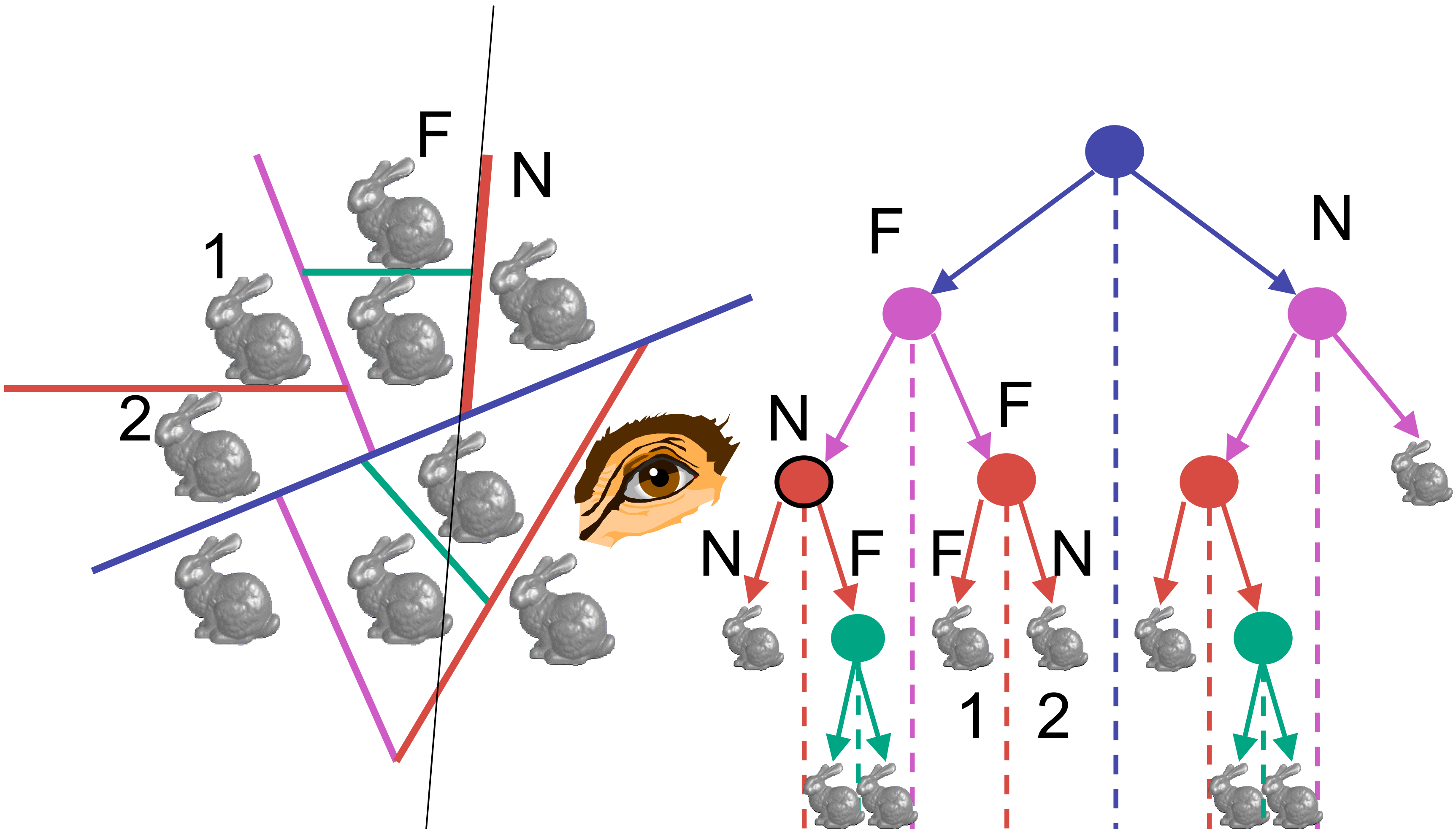

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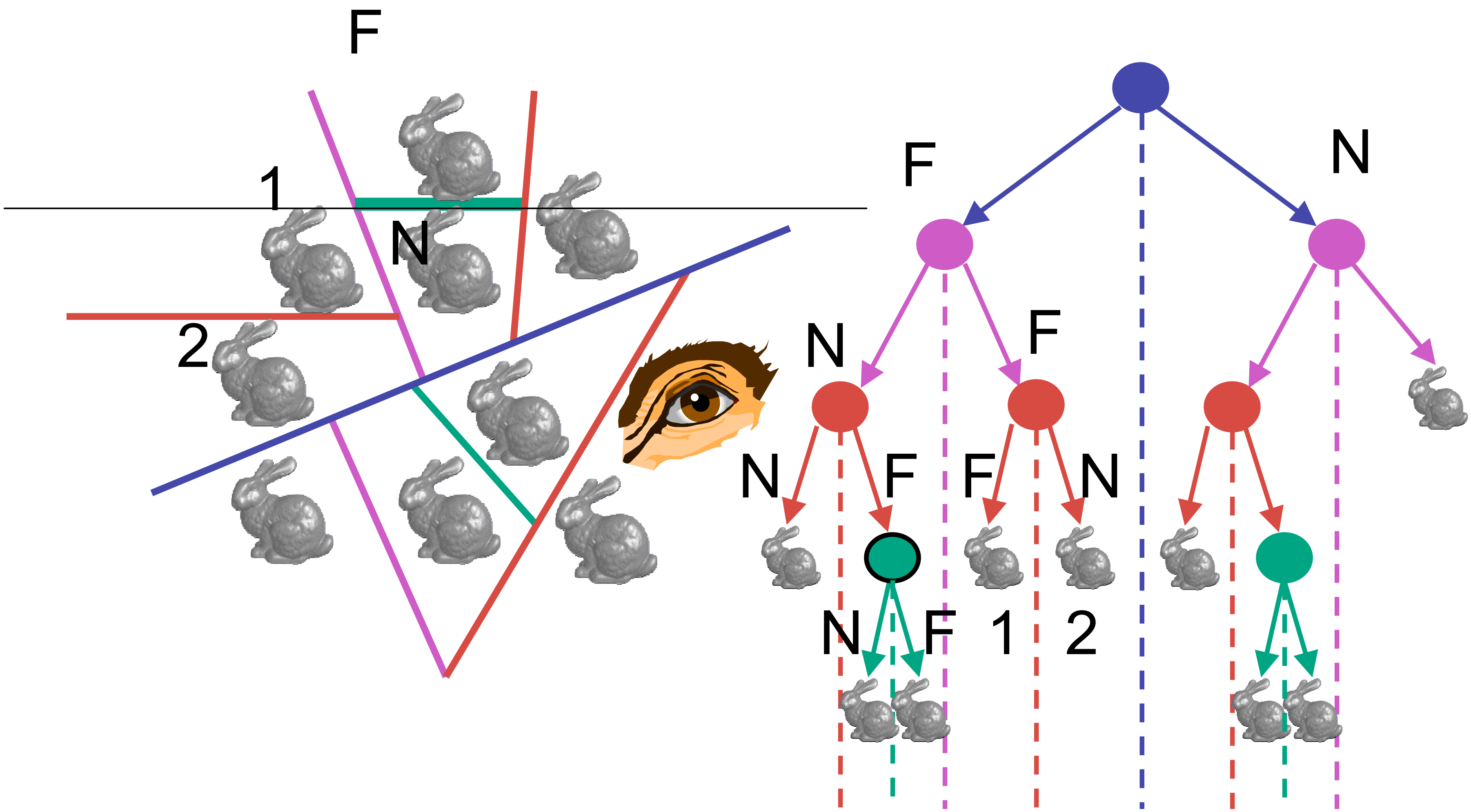

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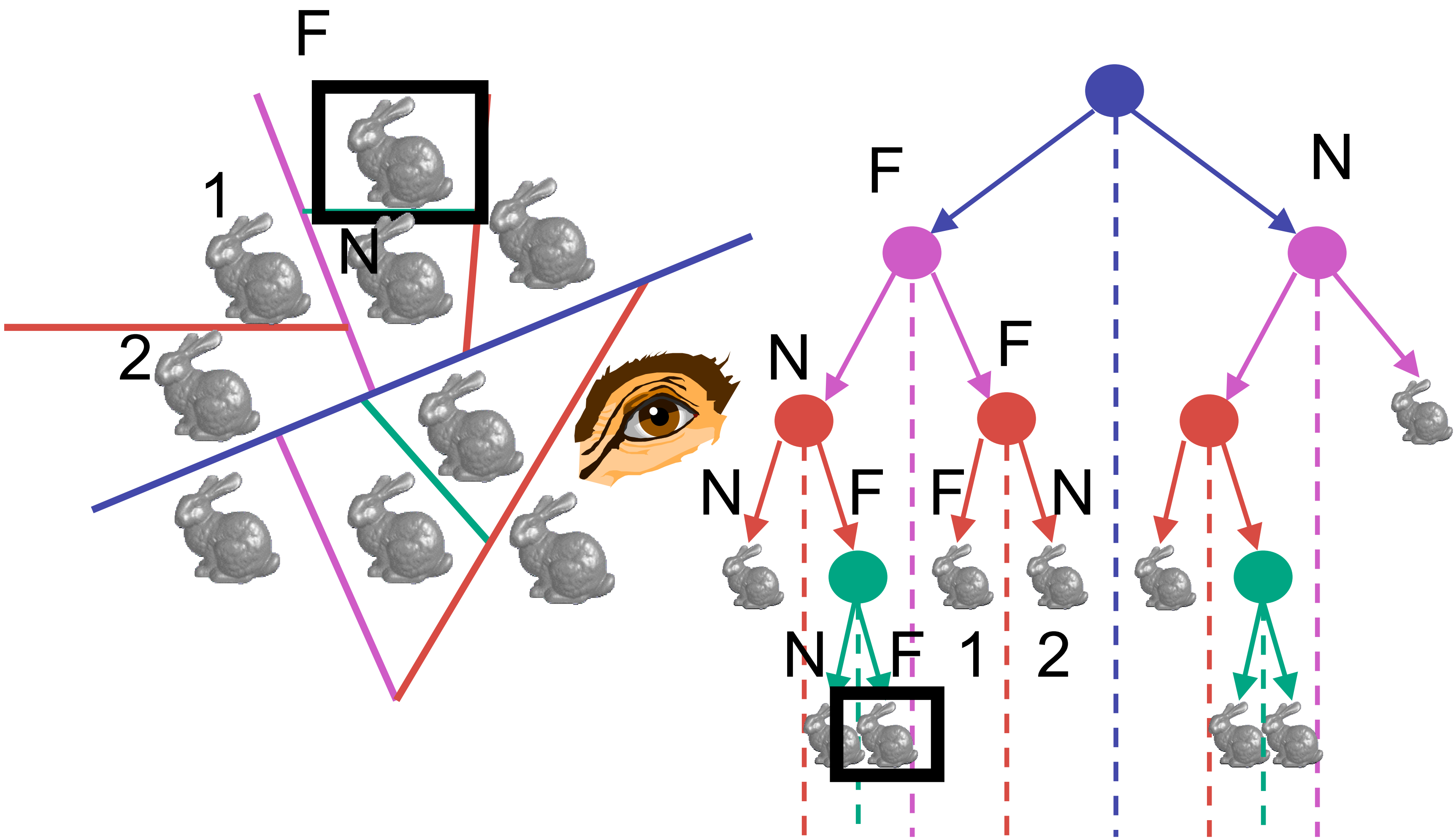

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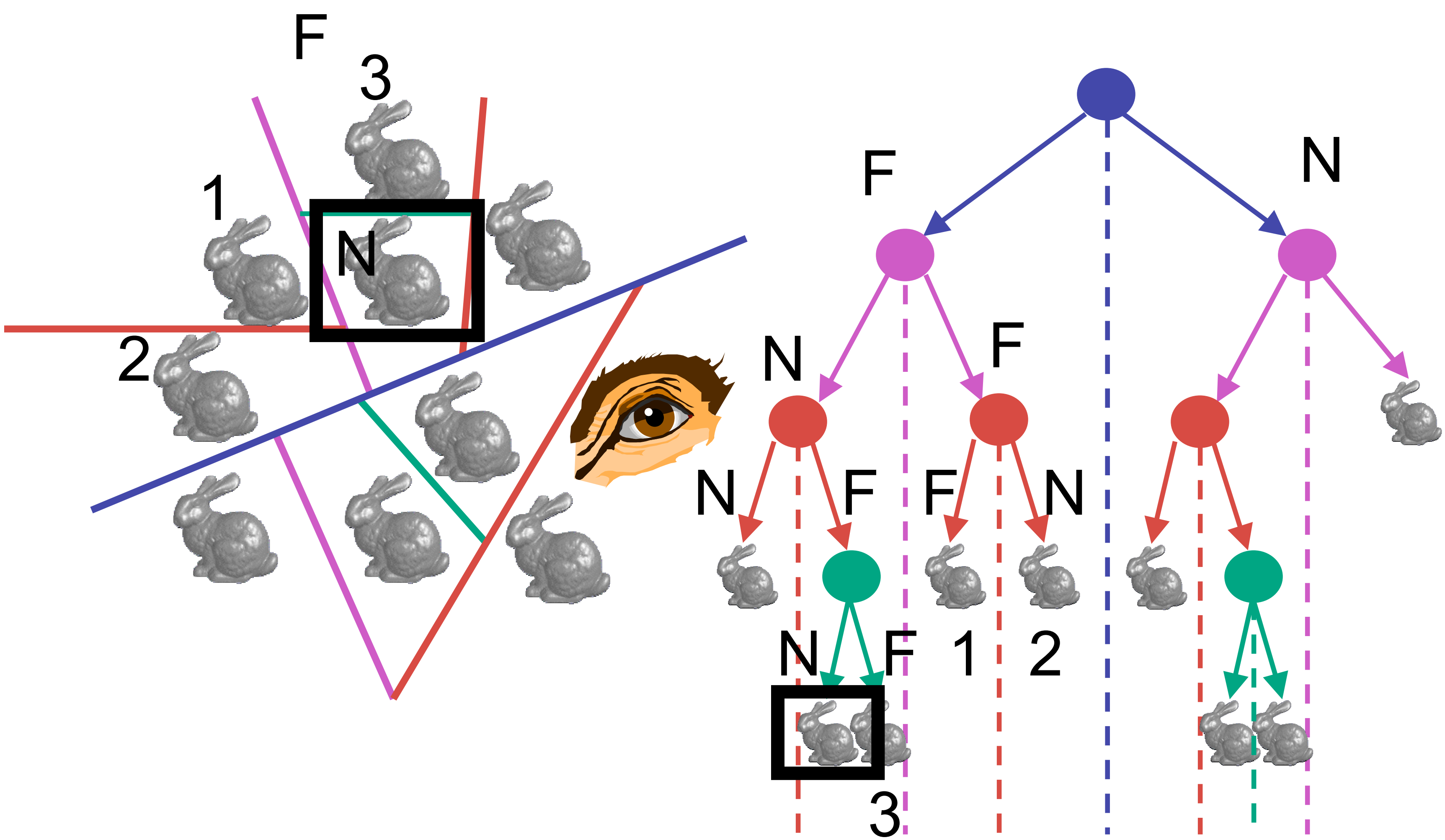

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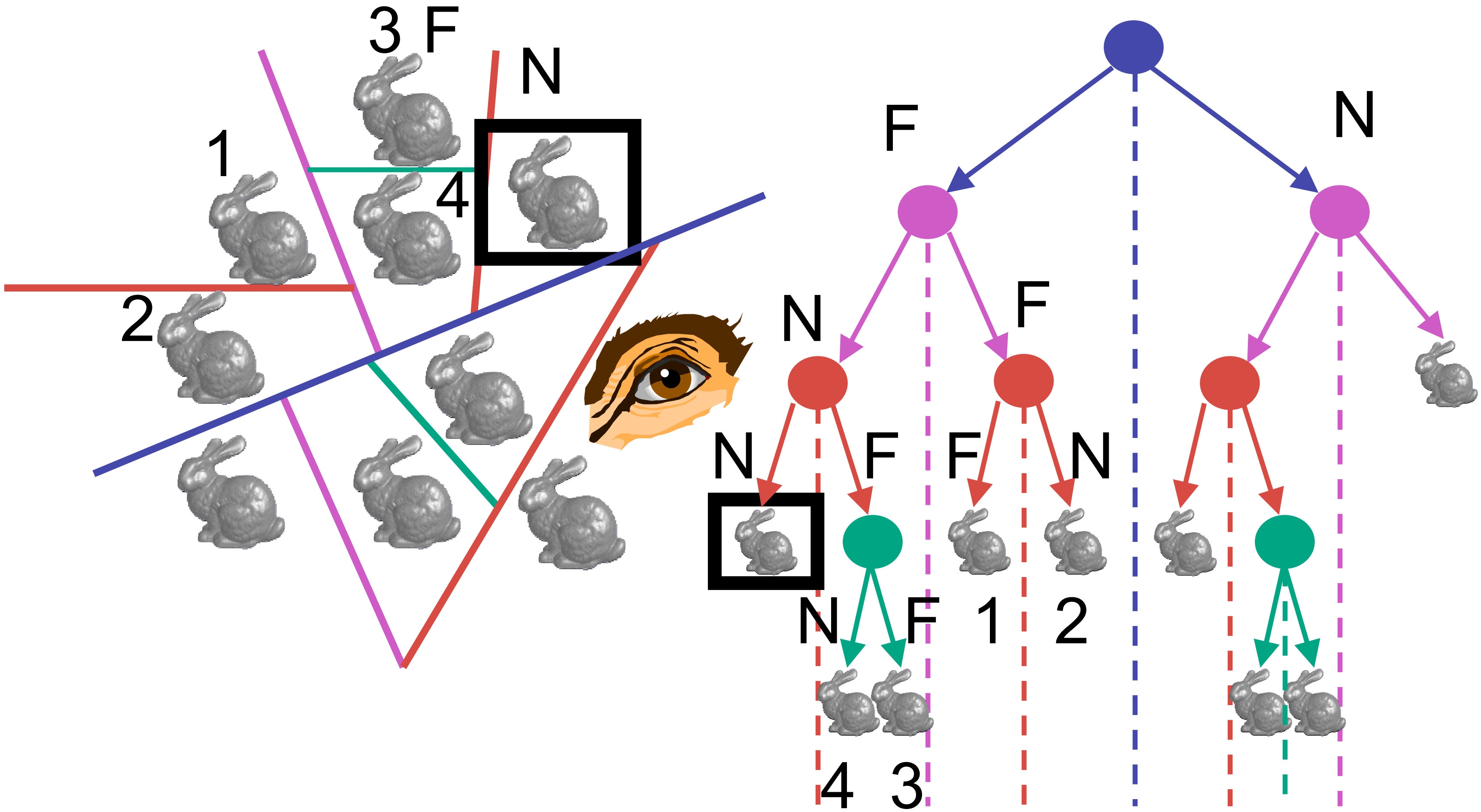

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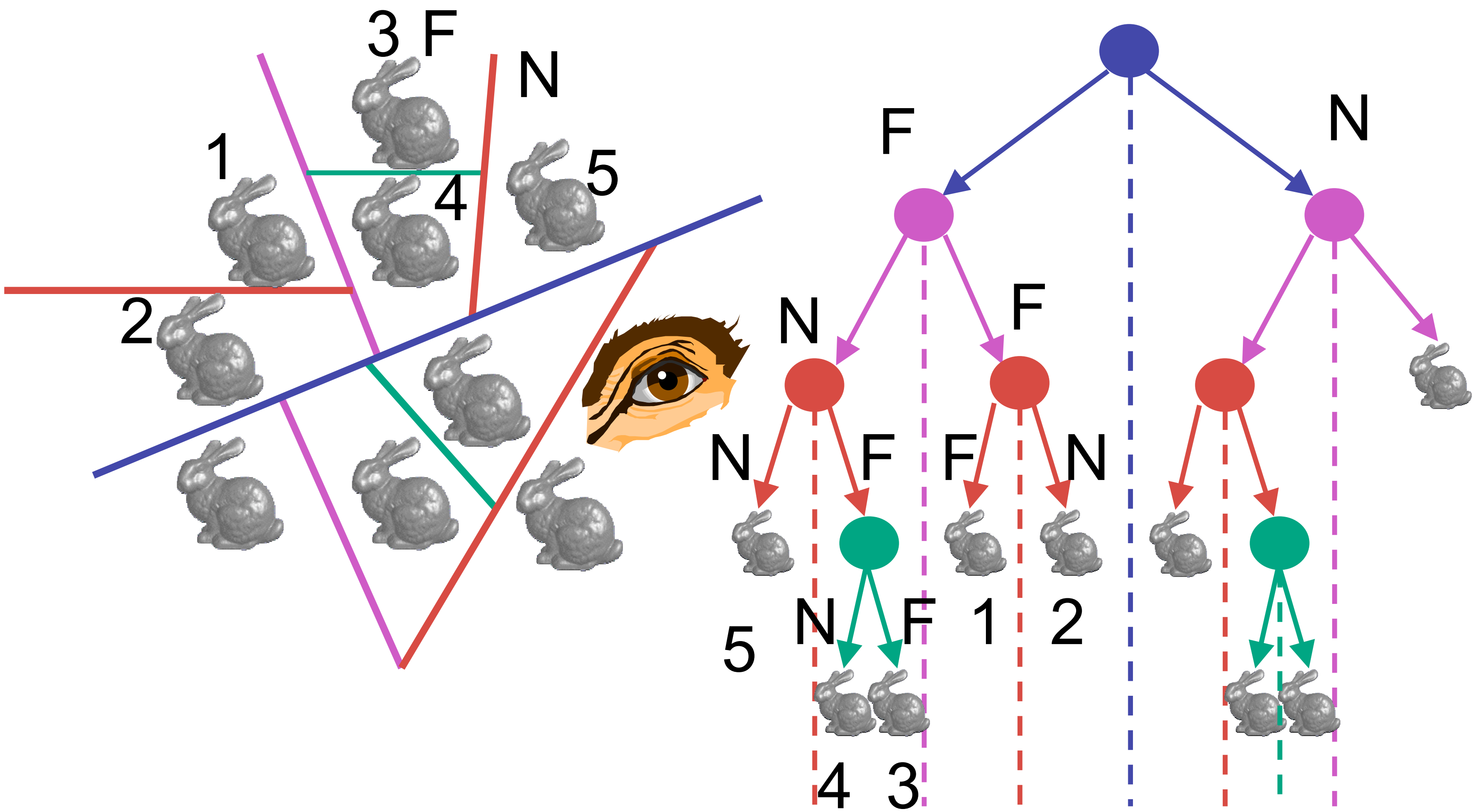
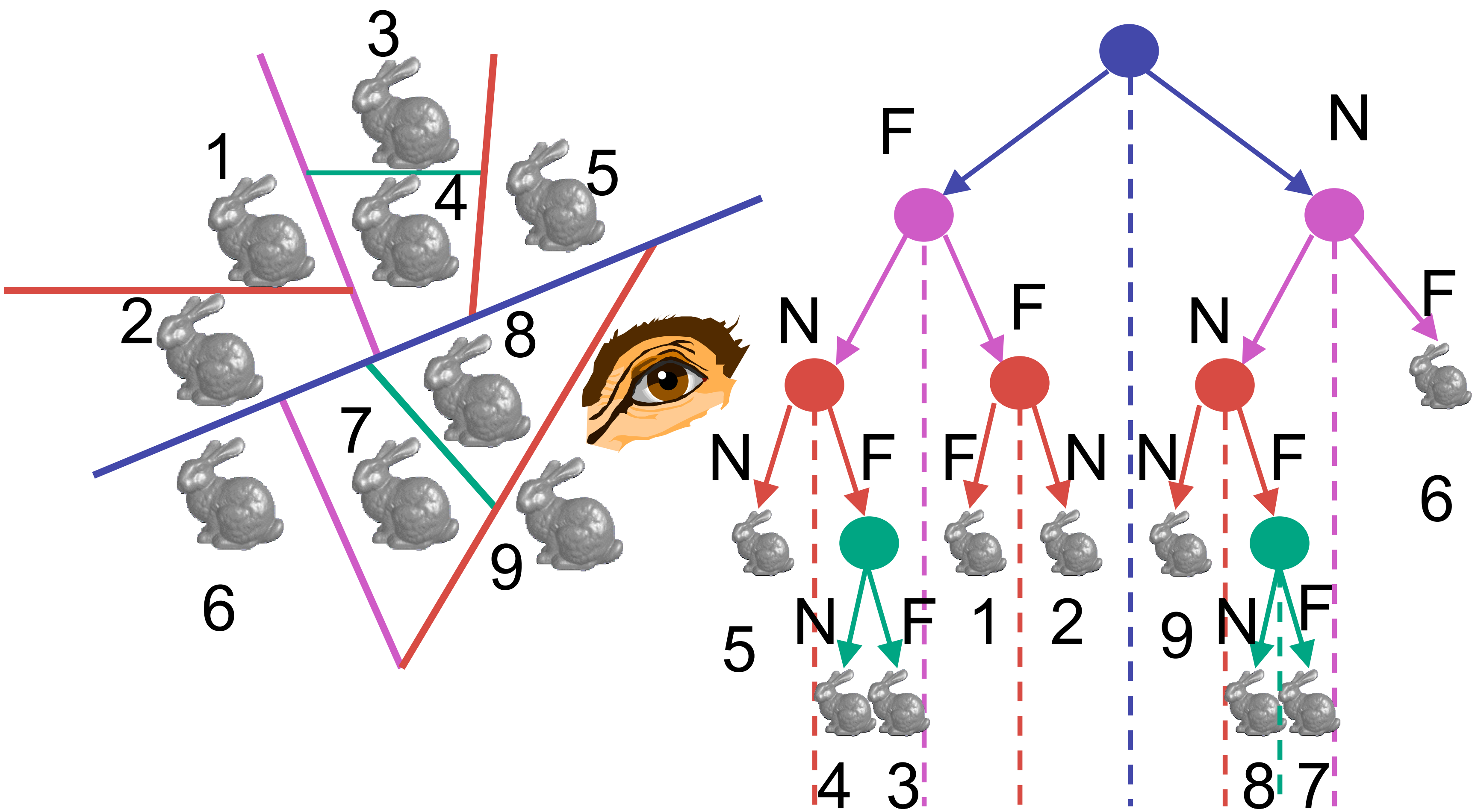
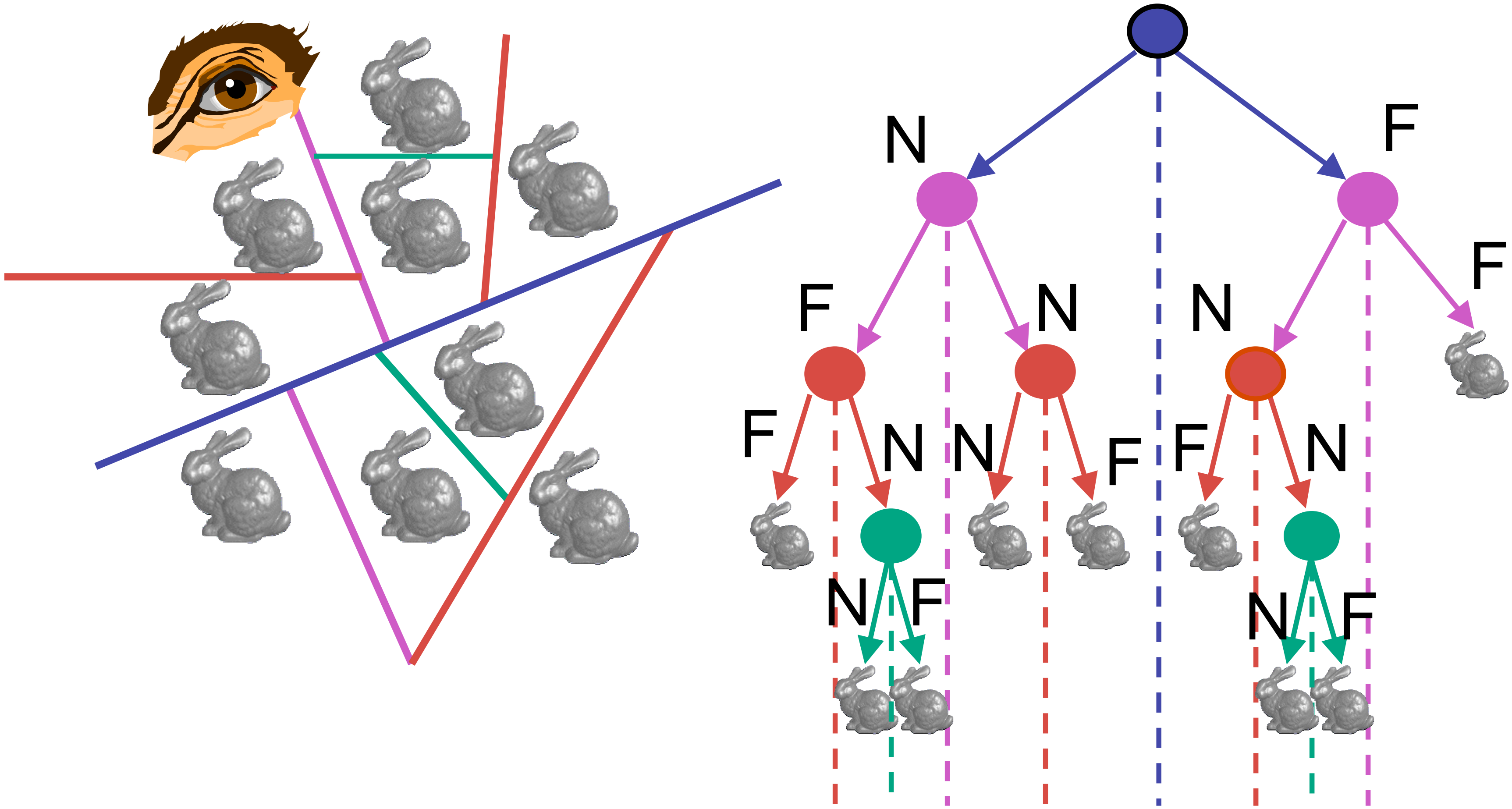


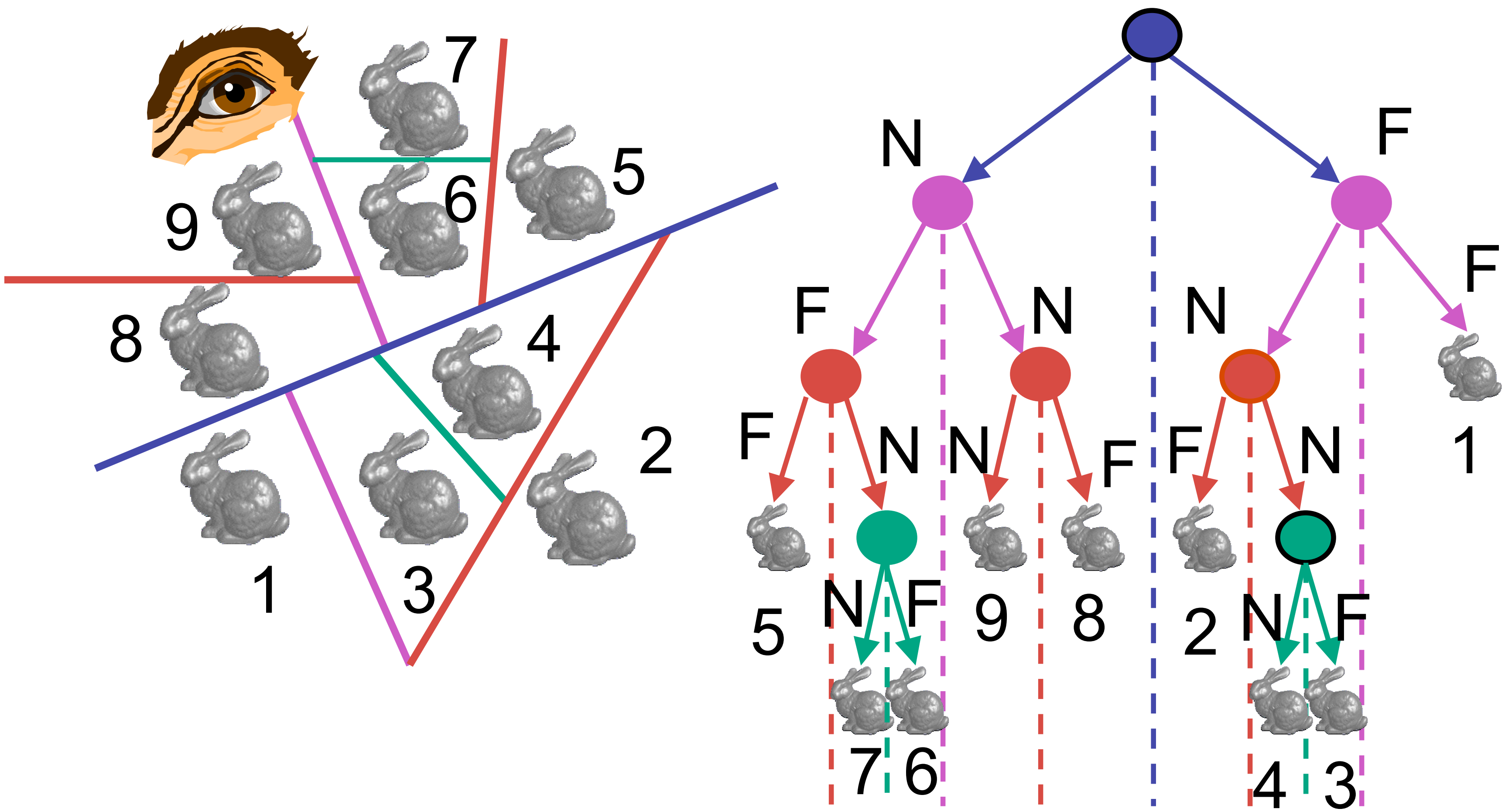
# BSP Trees : Viewpoint A



# BSP Trees : Viewpoint B



# BSP Trees : Viewpoint B



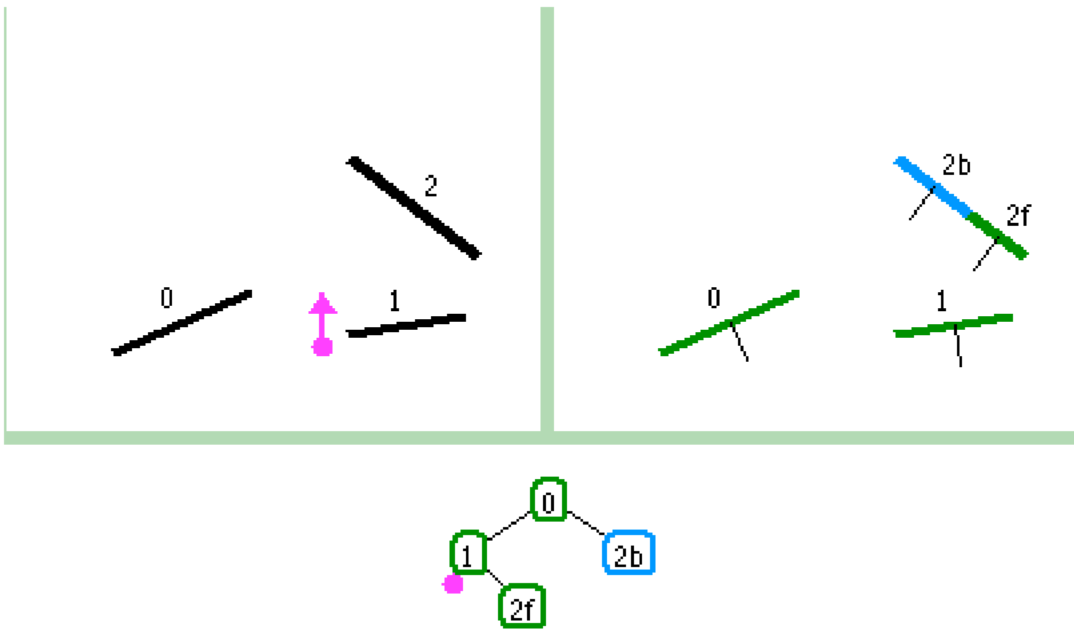
# BSP Tree Traversal: Polygons

- 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