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

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Hidden Surfaces II

Week 9, Mon Mar 15

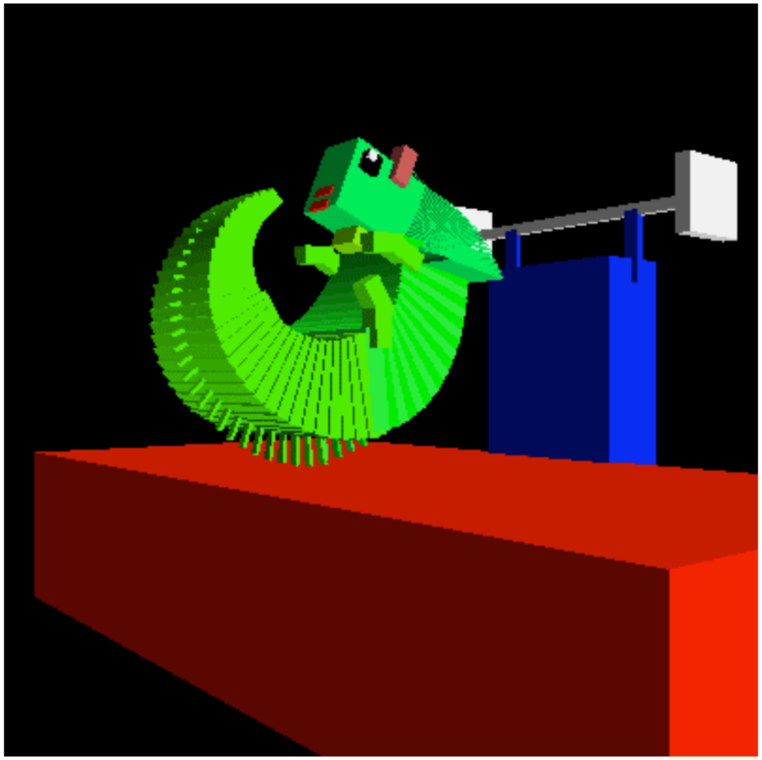
http://www.ugrad.cs.ubc.ca/~cs314/Vjan2010

News

- yes, I'm granting the request for course marking scheme change
  - old scheme: midterm 20%, final 25%
    - 45% of grade is exam marks
    - argument: midterm is 50 minutes, final is 150 minutes, so want 25/75% division vs 45/55%
  - new scheme: midterm 12%, final 33%
  - we'll check - if you would get a better grade in course with old scheme, we'll use that instead

Correction: P1 Hall of Fame: Winner

Sung-Hoon (Nick) Kim



Further Clarification: Blinn-Phong Model

- only change vs Phong model is to have the specular calculation to use $(\mathbf{h} \bullet \mathbf{n})$ instead of $(\mathbf{v} \bullet \mathbf{r})$

- full Blinn-Phong lighting model equation has ambient, diffuse, specular terms

$$\mathbf{I}_{\mathbf{total}} = \mathbf{k}_{\mathbf{a}} \mathbf{I}_{\mathbf{ambient}} + \sum_{i=1}^{\#\,lights} \mathbf{I}_{\mathbf{i}} (\mathbf{k}_{\mathbf{d}} (\mathbf{n} \bullet \mathbf{l}_{\mathbf{i}}) + \mathbf{k}_{\mathbf{s}} (\mathbf{n} \bullet \mathbf{h}_{\mathbf{i}})^{n_{shiny}})$$

- just like full Phong model equation

$$\mathbf{I}_{\mathbf{total}} = \mathbf{k}_{\mathbf{a}} \mathbf{I}_{\mathbf{ambient}} + \sum_{i=1}^{\#\,lights} \mathbf{I}_{\mathbf{i}} (\mathbf{k}_{\mathbf{d}} (\mathbf{n} \bullet \mathbf{l}_{\mathbf{i}}) + \mathbf{k}_{\mathbf{s}} (\mathbf{v} \bullet \mathbf{r}_{\mathbf{i}})^{n_{shiny}})$$

Reading for Hidden Surfaces

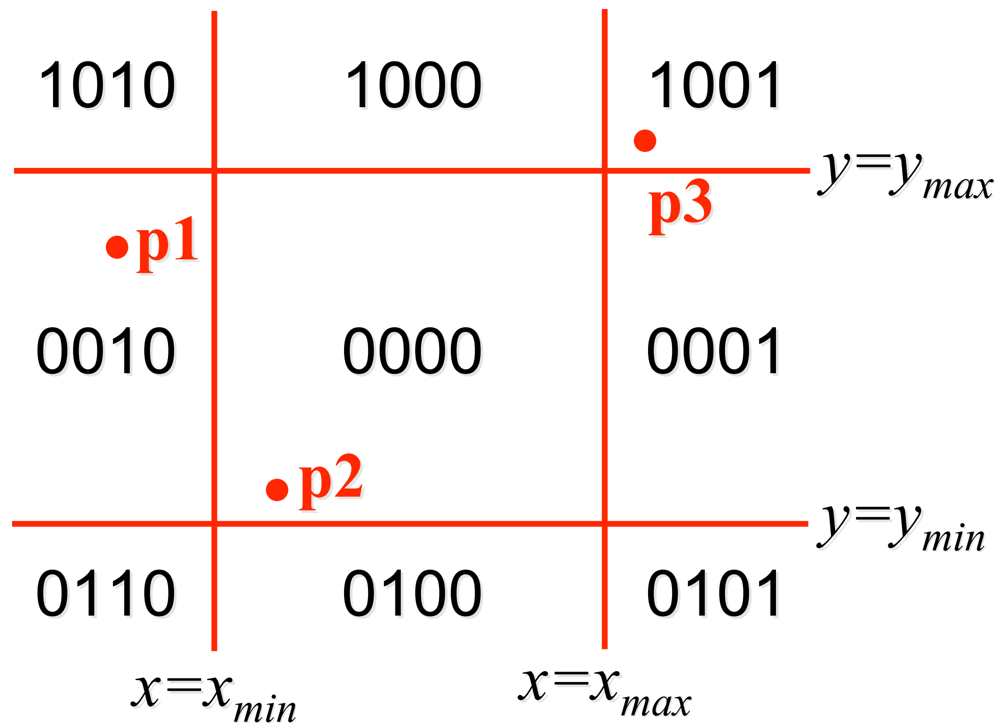
- FCG Sect 8.2.3 Z-Buffer
- FCG Sect 12.4 BSP Trees

- (8.1, 8.2 2nd ed)

Review: Cohen-Sutherland Line Clipping

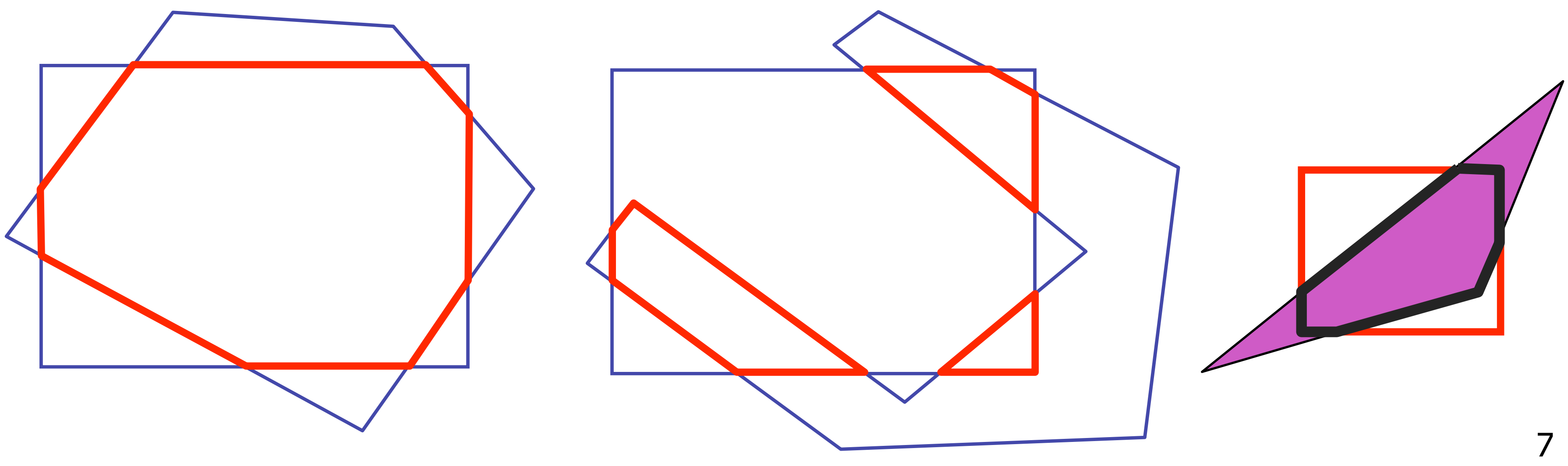
- outcodes
  - 4 flags encoding position of a point relative to top, bottom, left, and right boundary

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



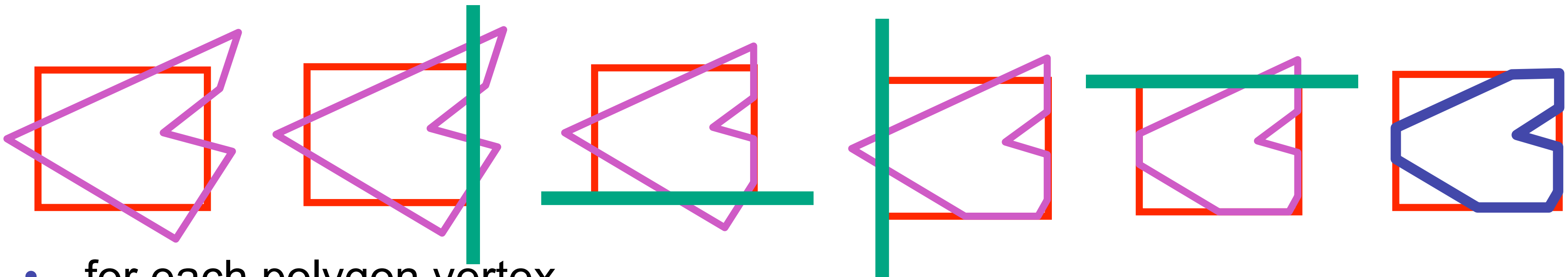
Review: Polygon Clipping

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



Review: Sutherland-Hodgeman Clipping

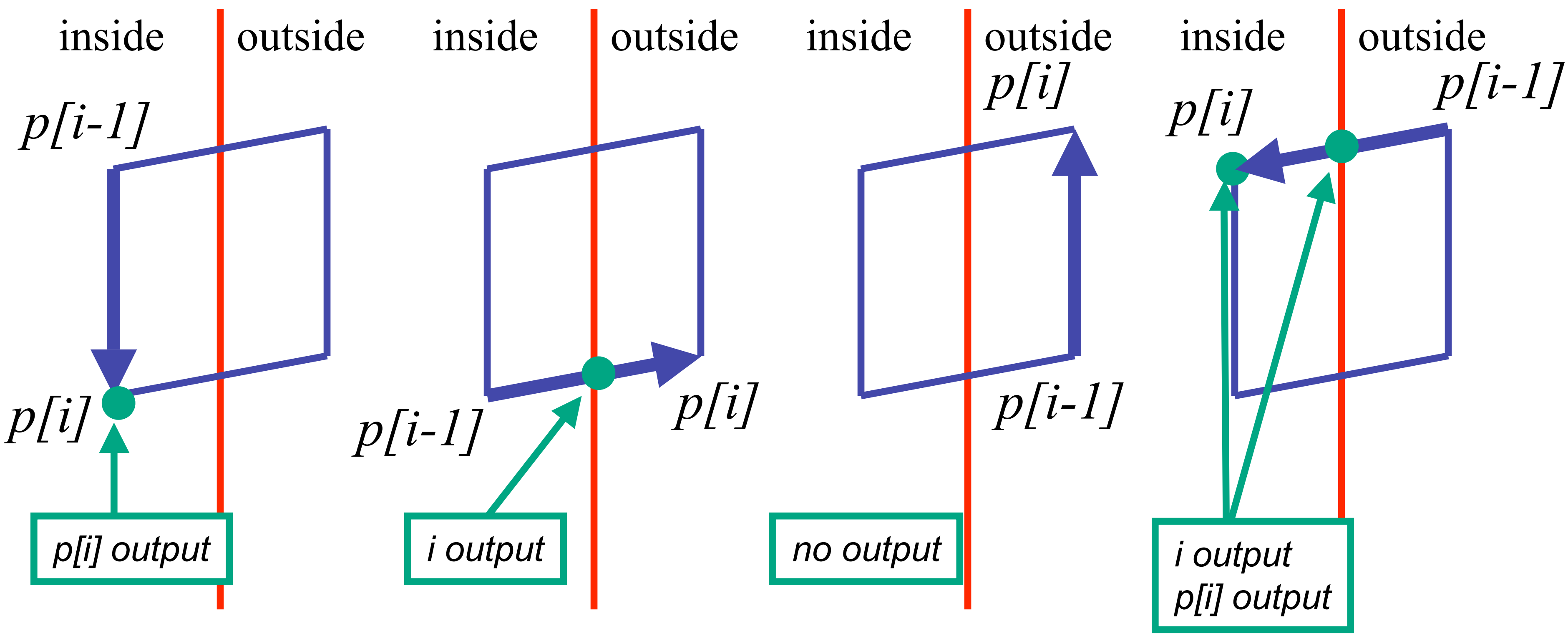
- for each viewport edge
  - clip the polygon against the edge equation for new vertex list
  - after doing all edges, the polygon is fully clipped



- 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



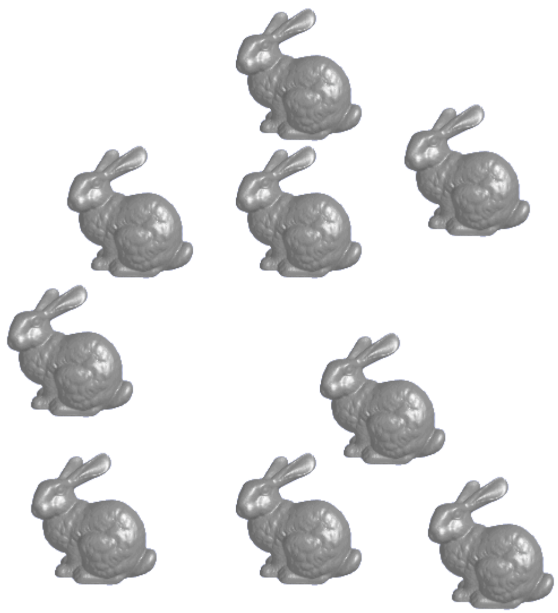
Review: Painter's Algorithm

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

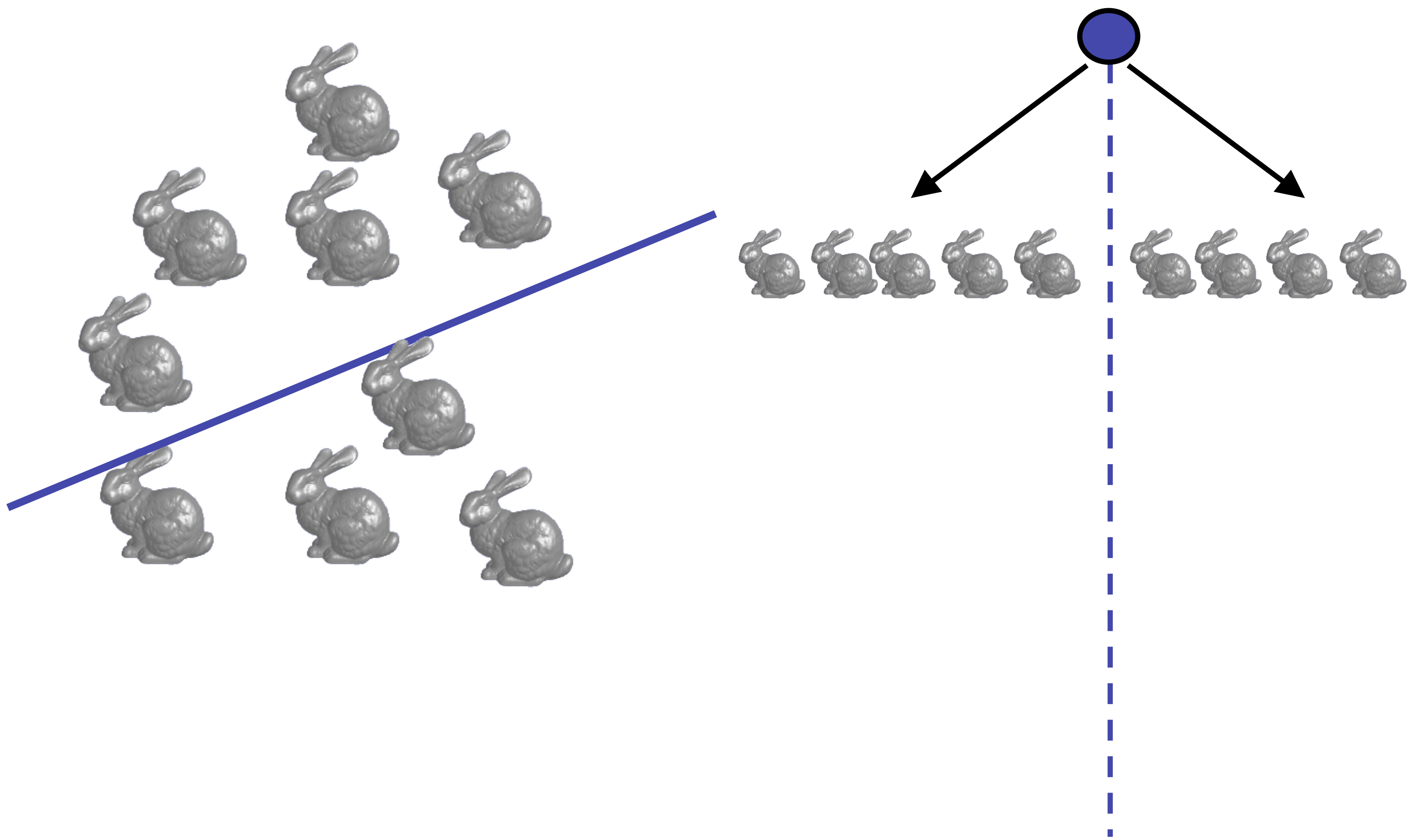
Binary Space Partition Trees (1979)

- 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



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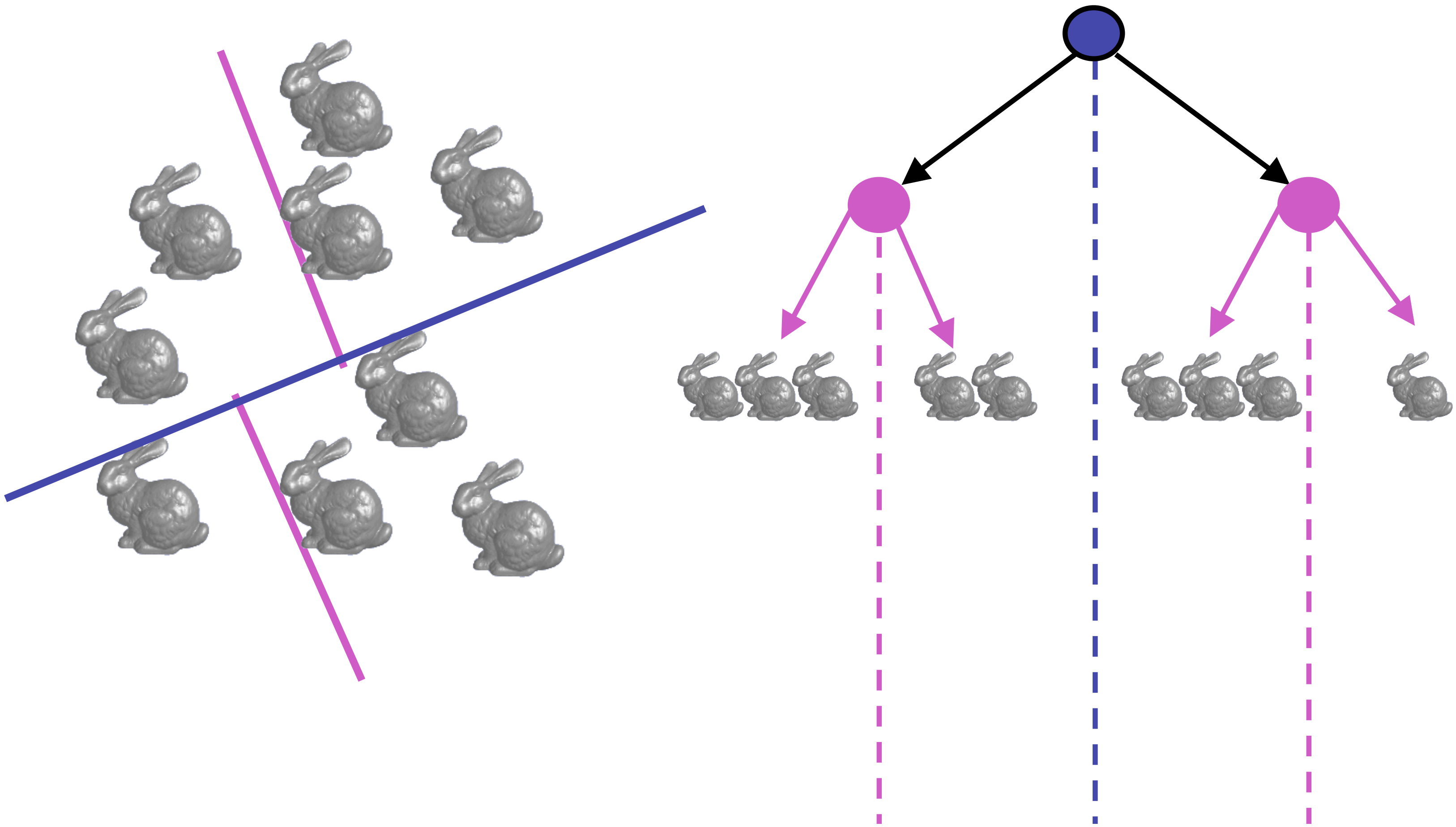

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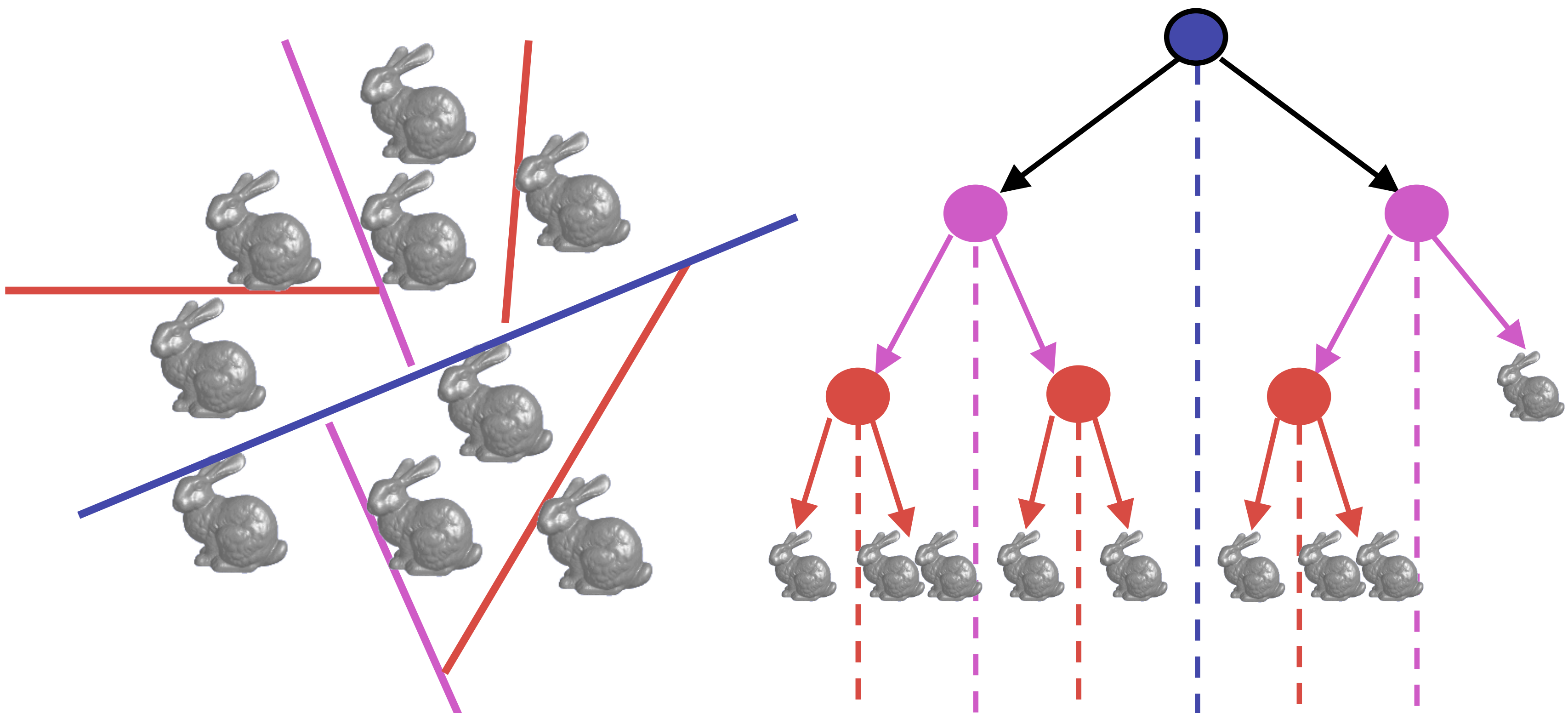

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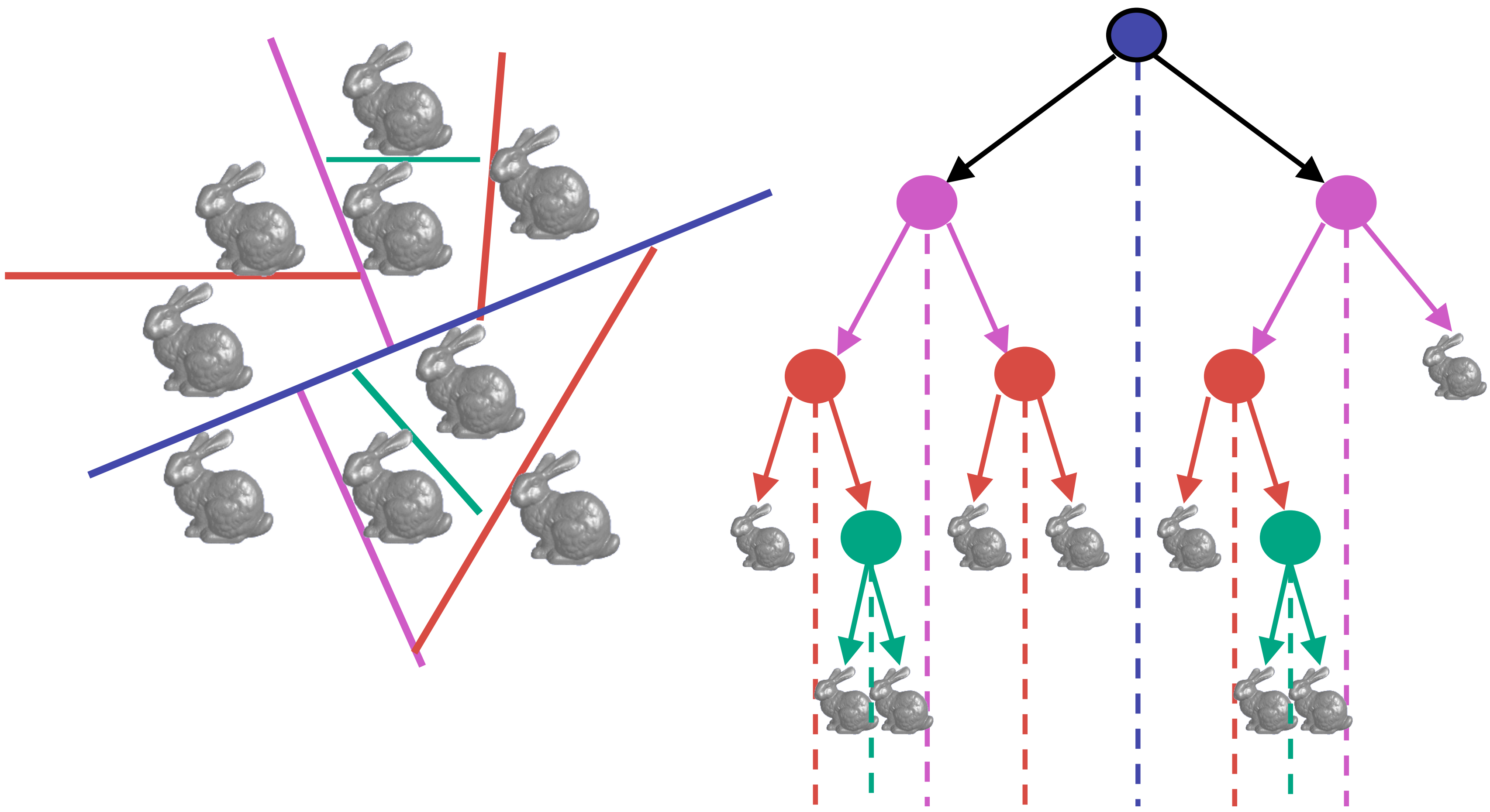
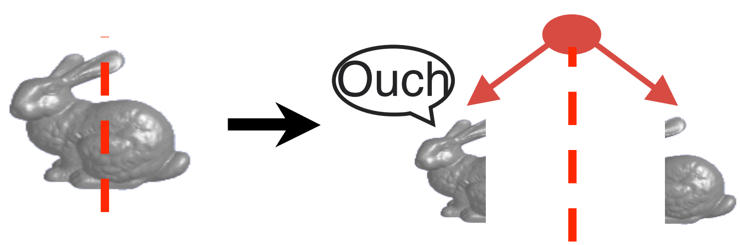


Splitting Objects

- 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

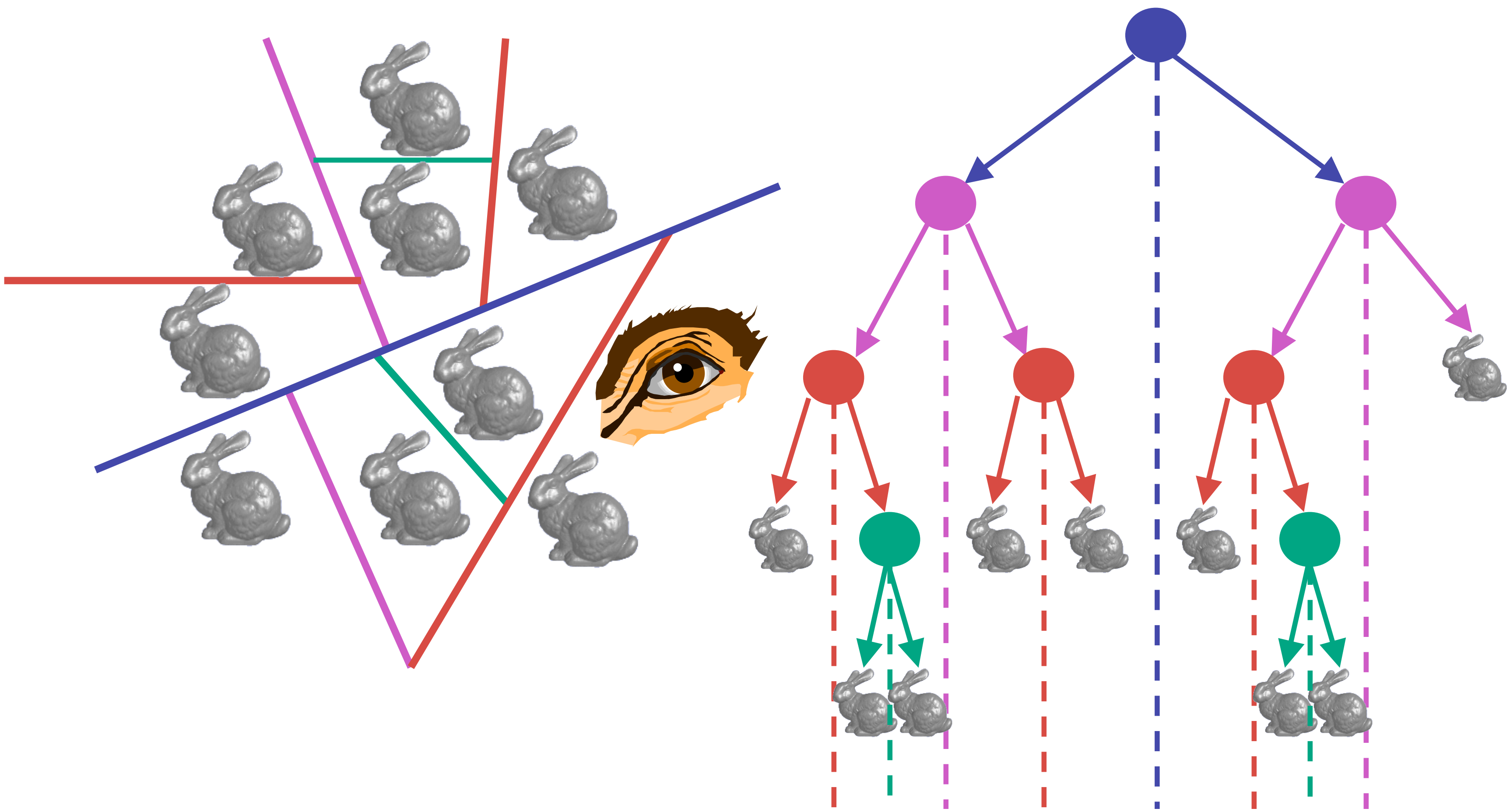
- tree creation independent of viewpoint
  - preprocessing step
- tree traversal uses viewpoint
  - runtime, happens for many different viewpoints
- each plane divides world into near and far
  - for given viewpoint, decide which side is near and which is far
    - check which side of plane viewpoint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

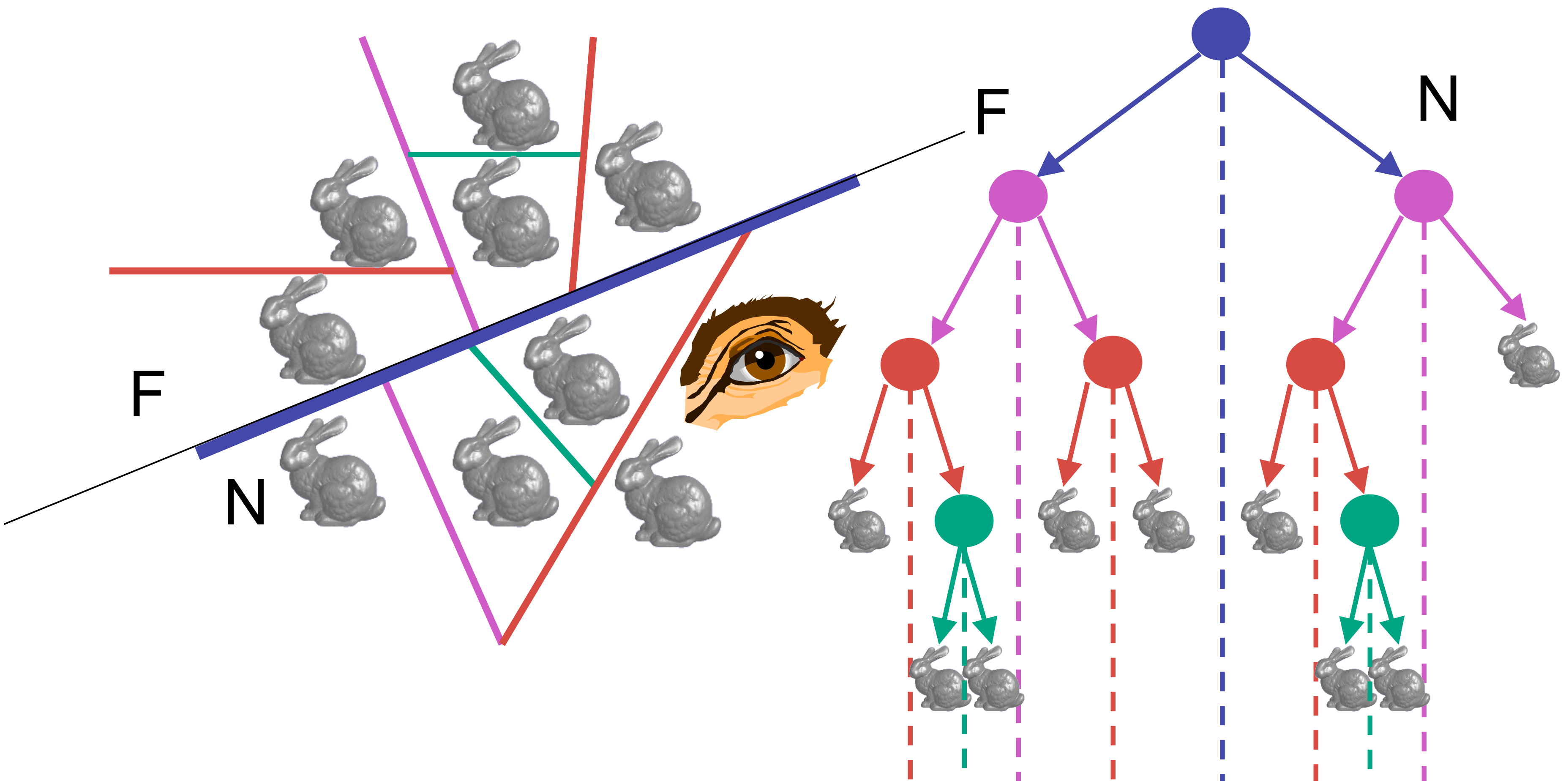
query: given a viewpoint, produce an ordered list of (possibly split) objects from back to front:

```
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);
```

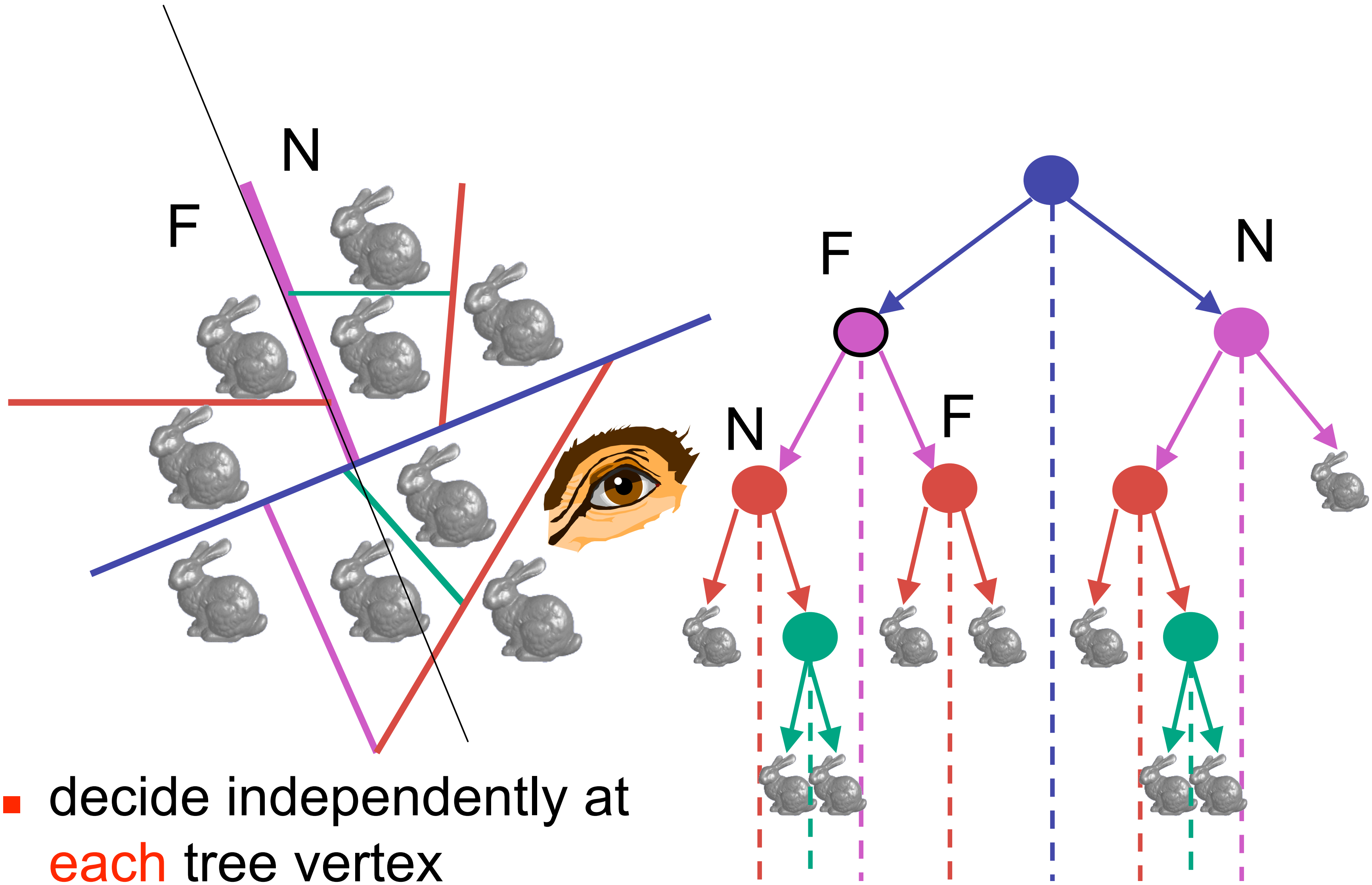
BSP Trees : Viewpoint A



BSP Trees : Viewpoint A

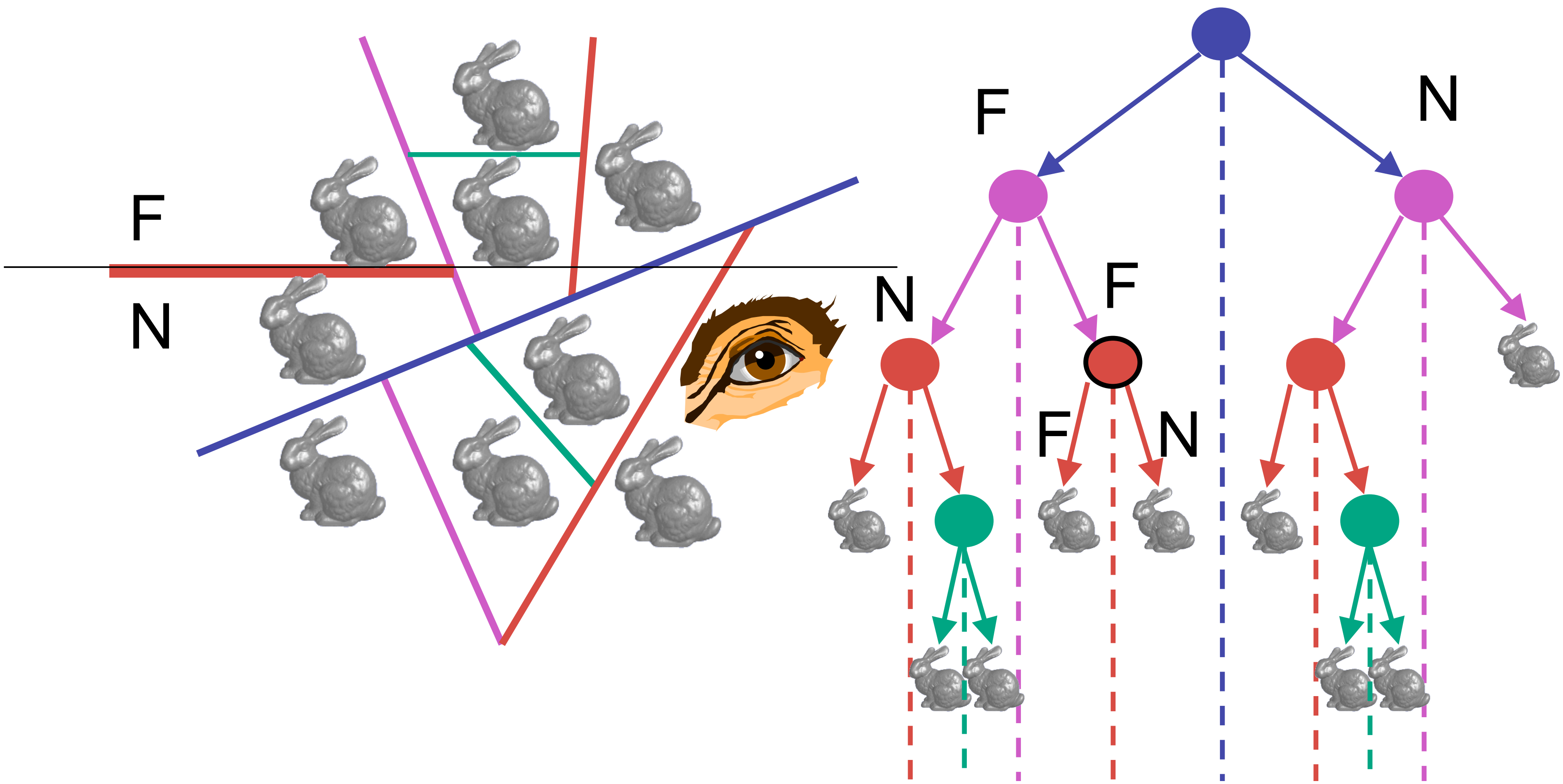


BSP Trees : Viewpoint A

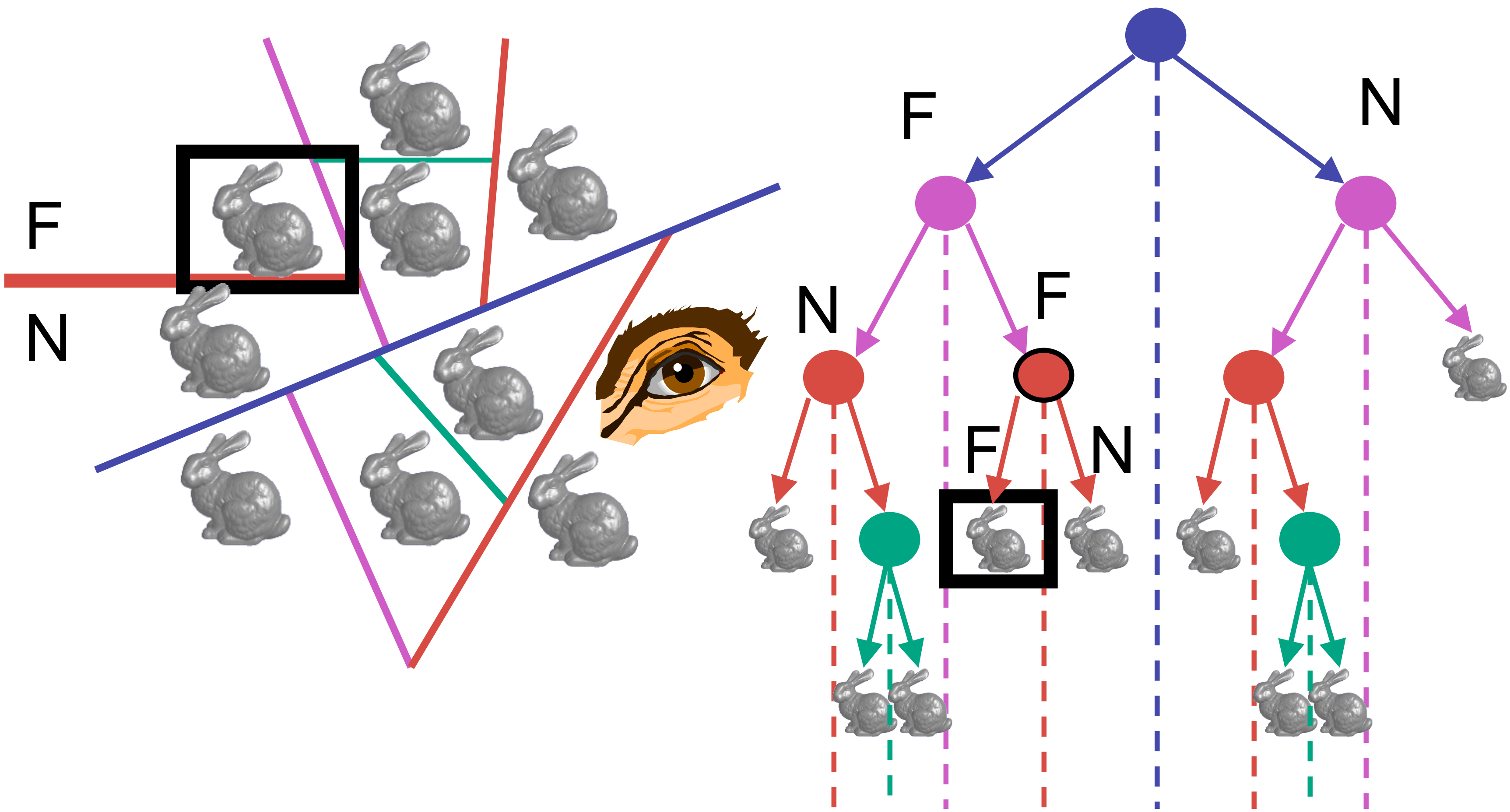


- decide independently at each tree vertex
- not just left or right child!

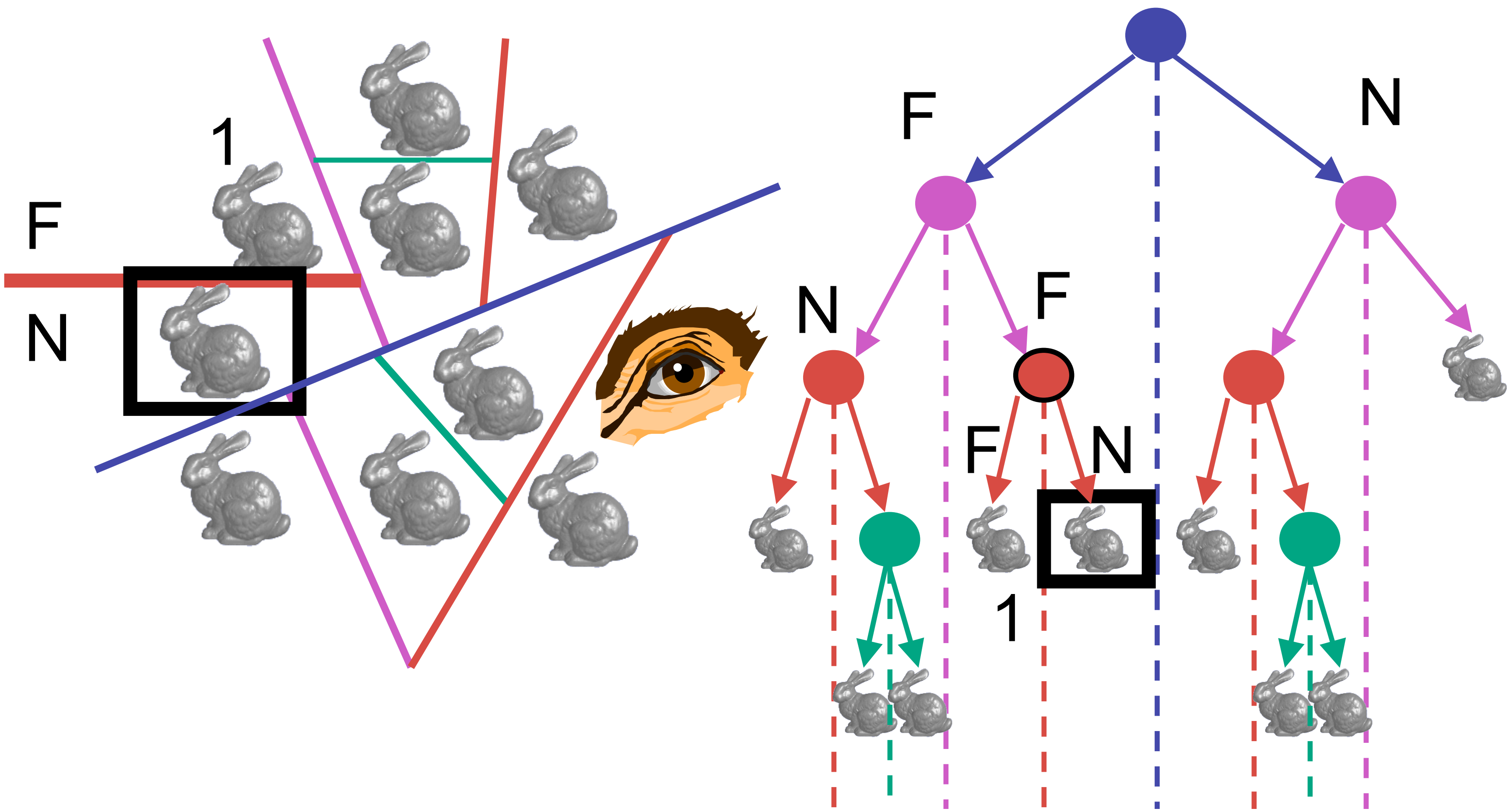
BSP Trees : Viewpoint A



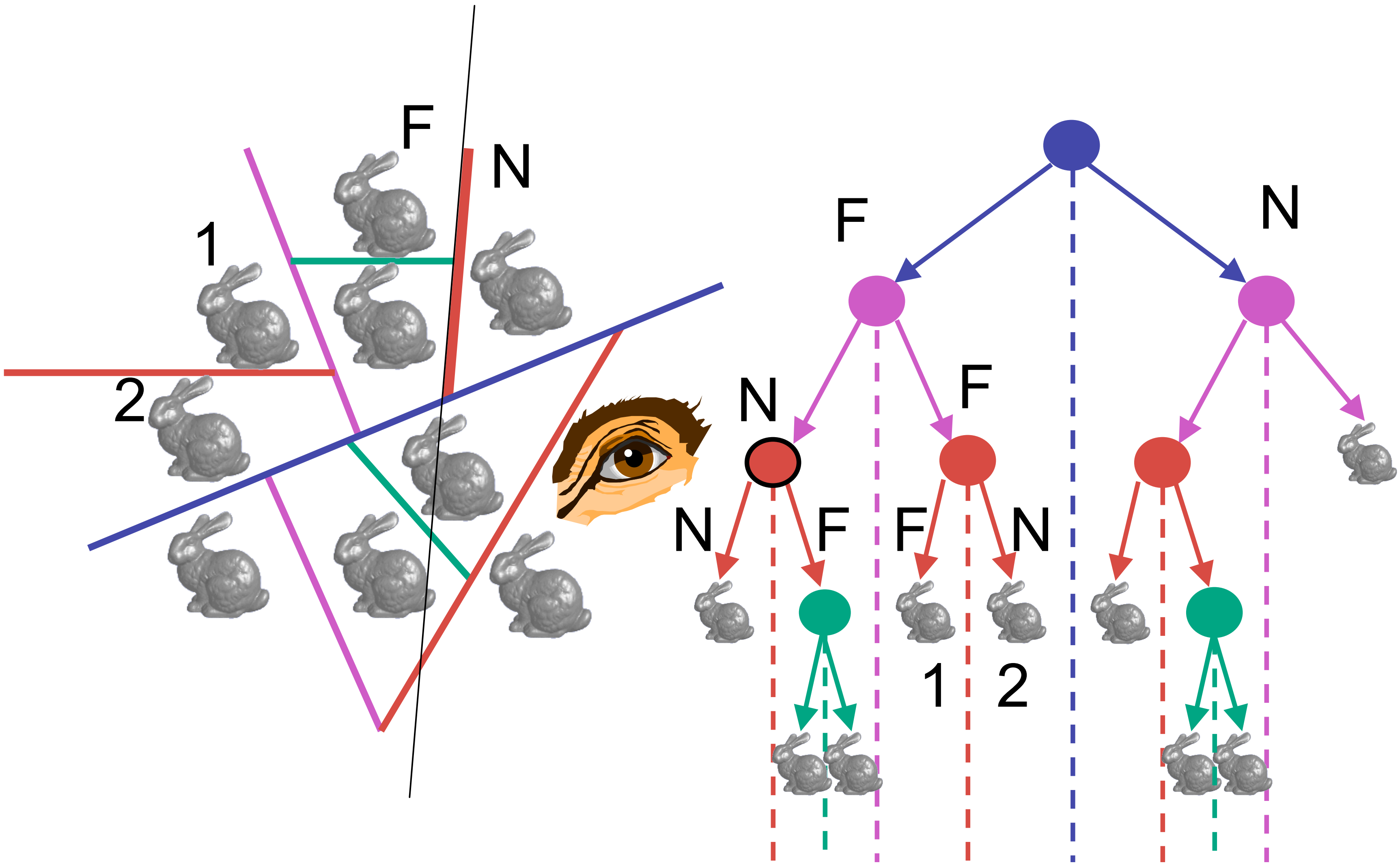
BSP Trees : Viewpoint A



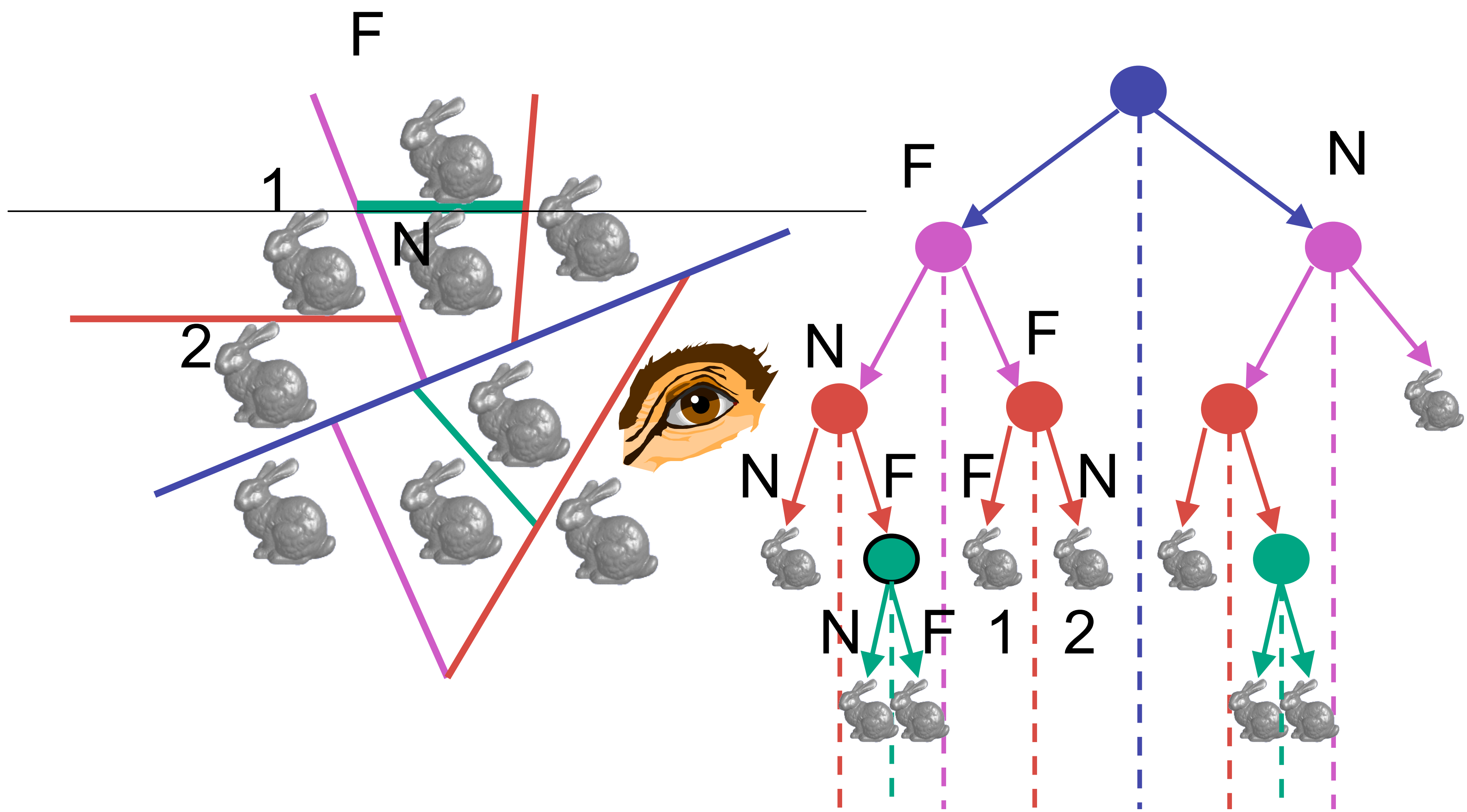
BSP Trees : Viewpoint A



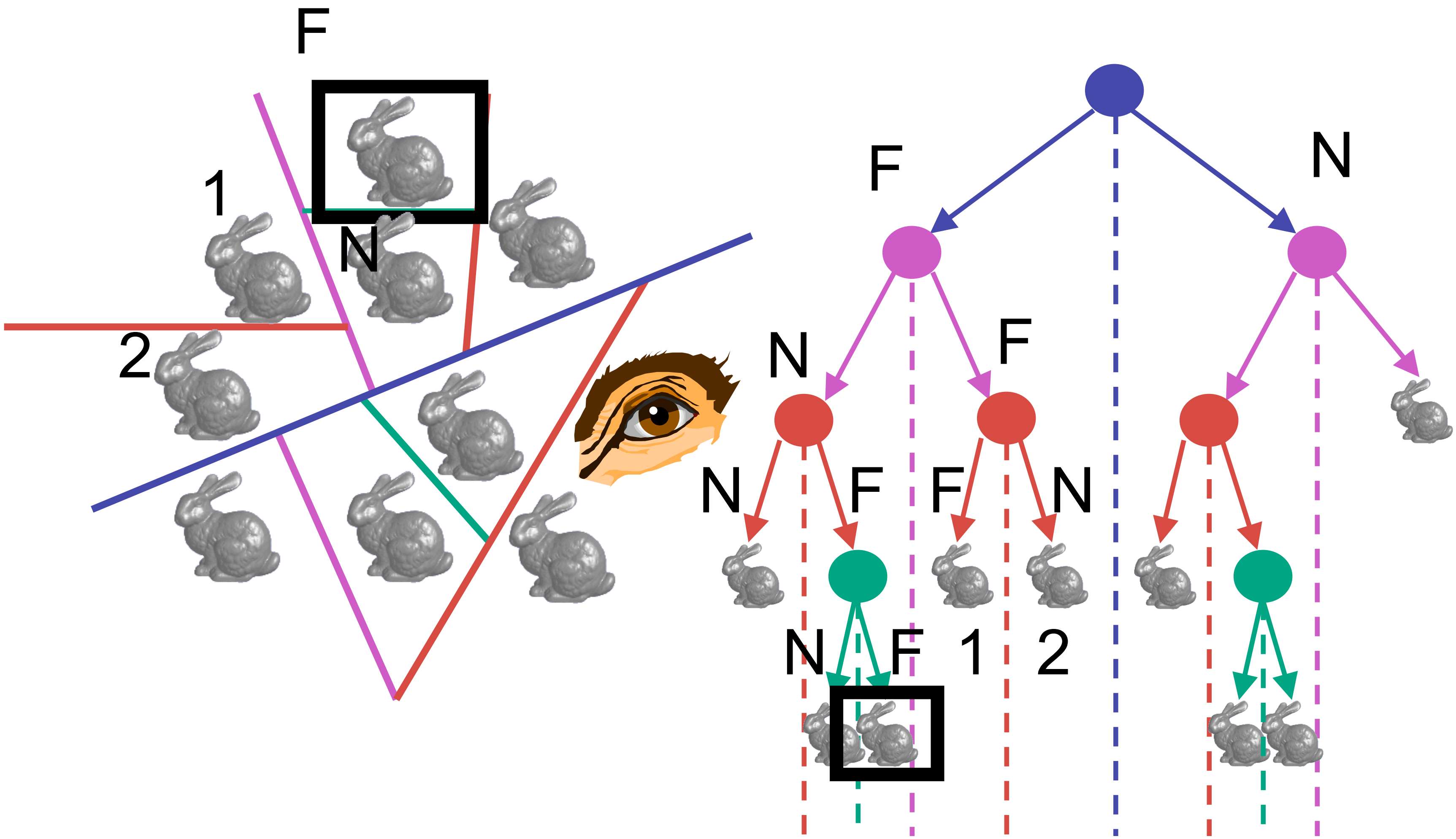
BSP Trees : Viewpoint A



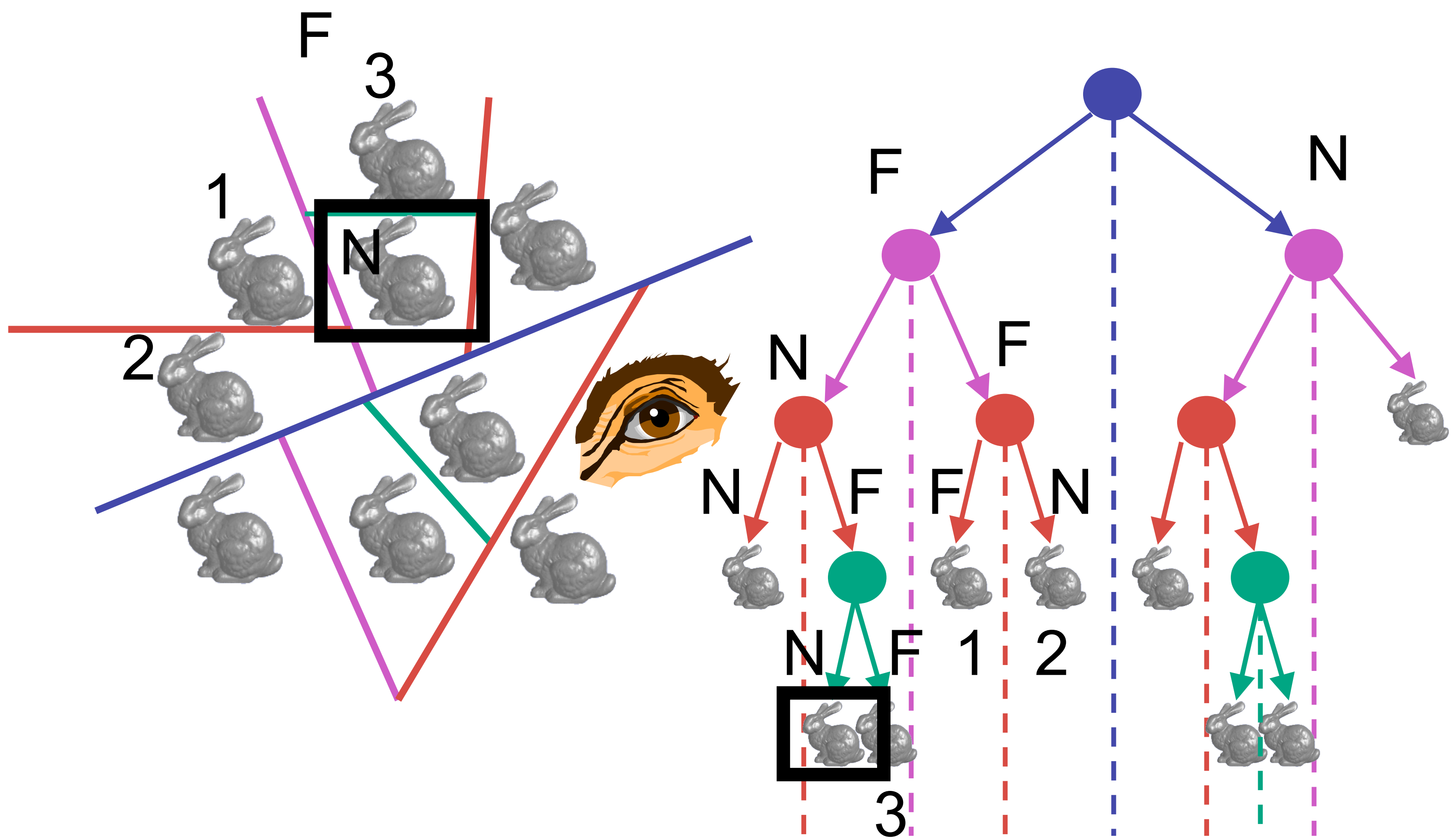
BSP Trees : Viewpoint A



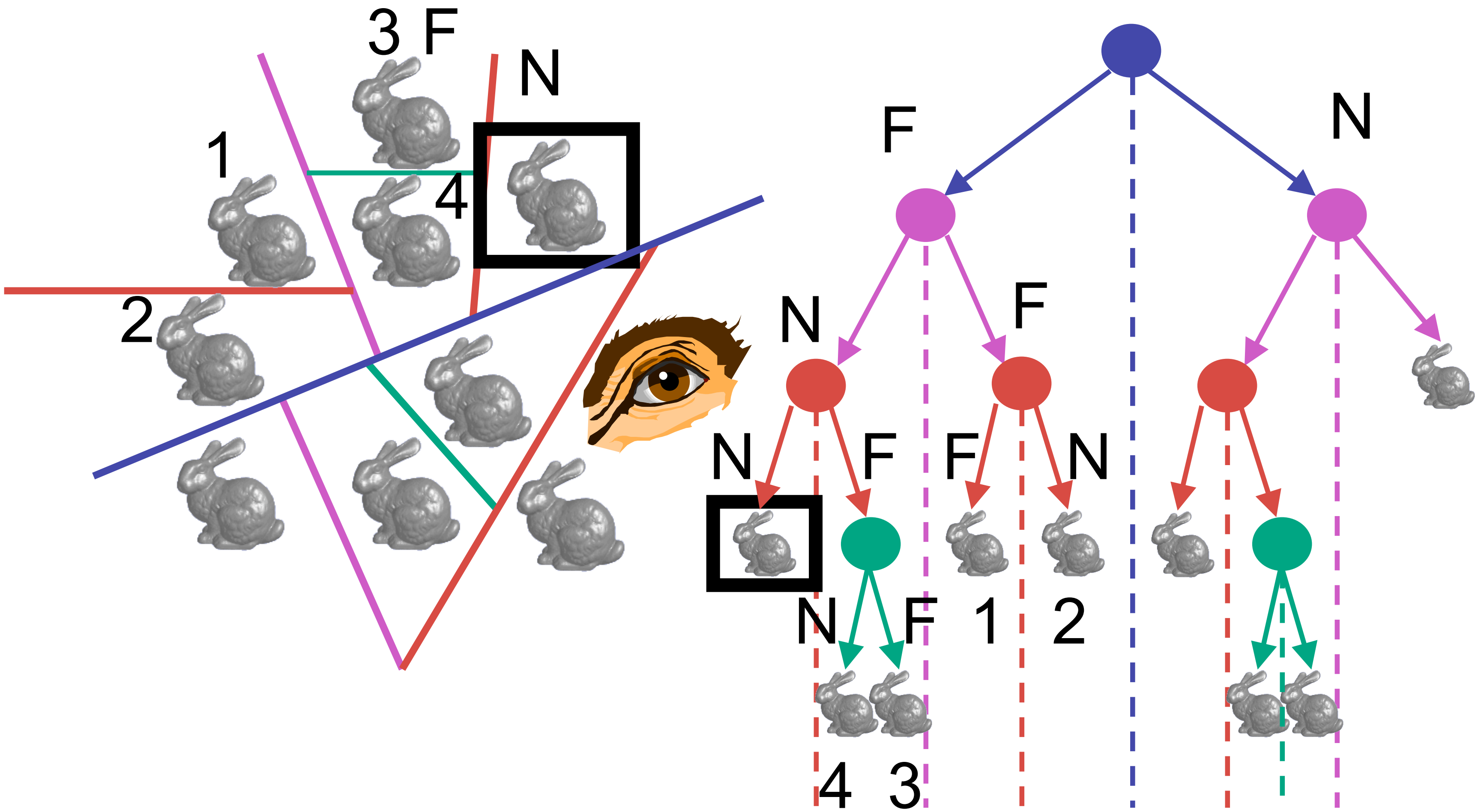
BSP Trees : Viewpoint A



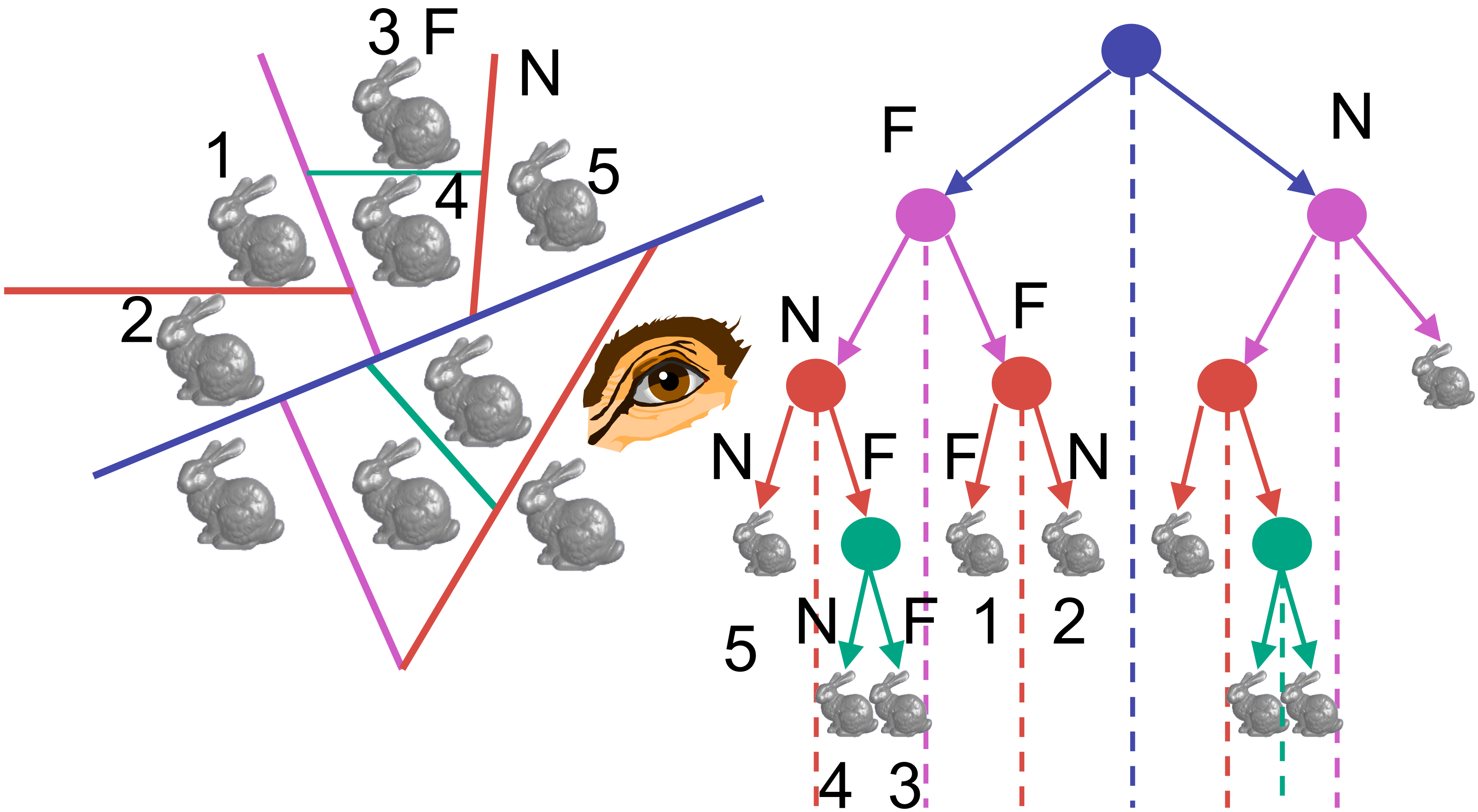
BSP Trees : Viewpoint A



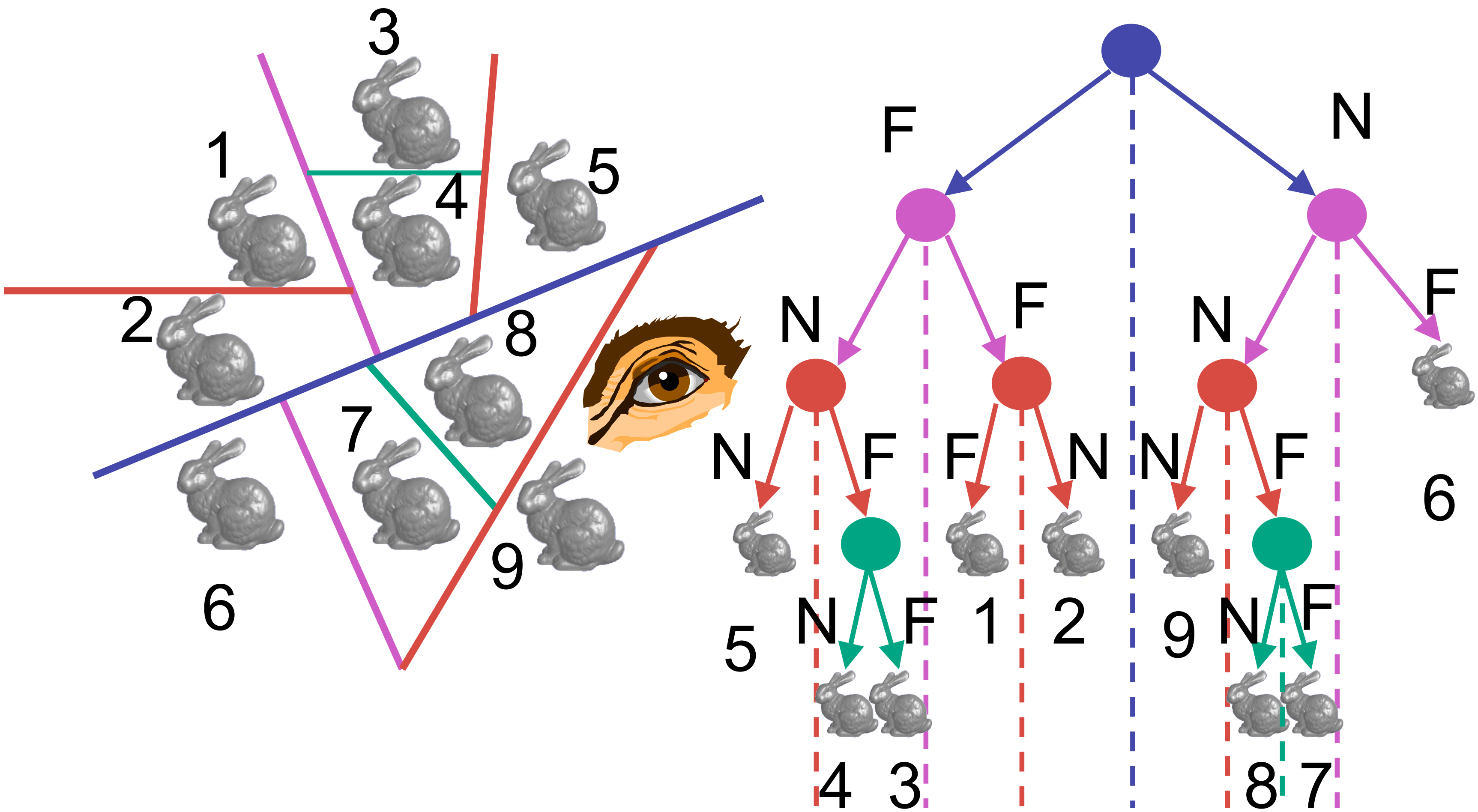
BSP Trees : Viewpoint A



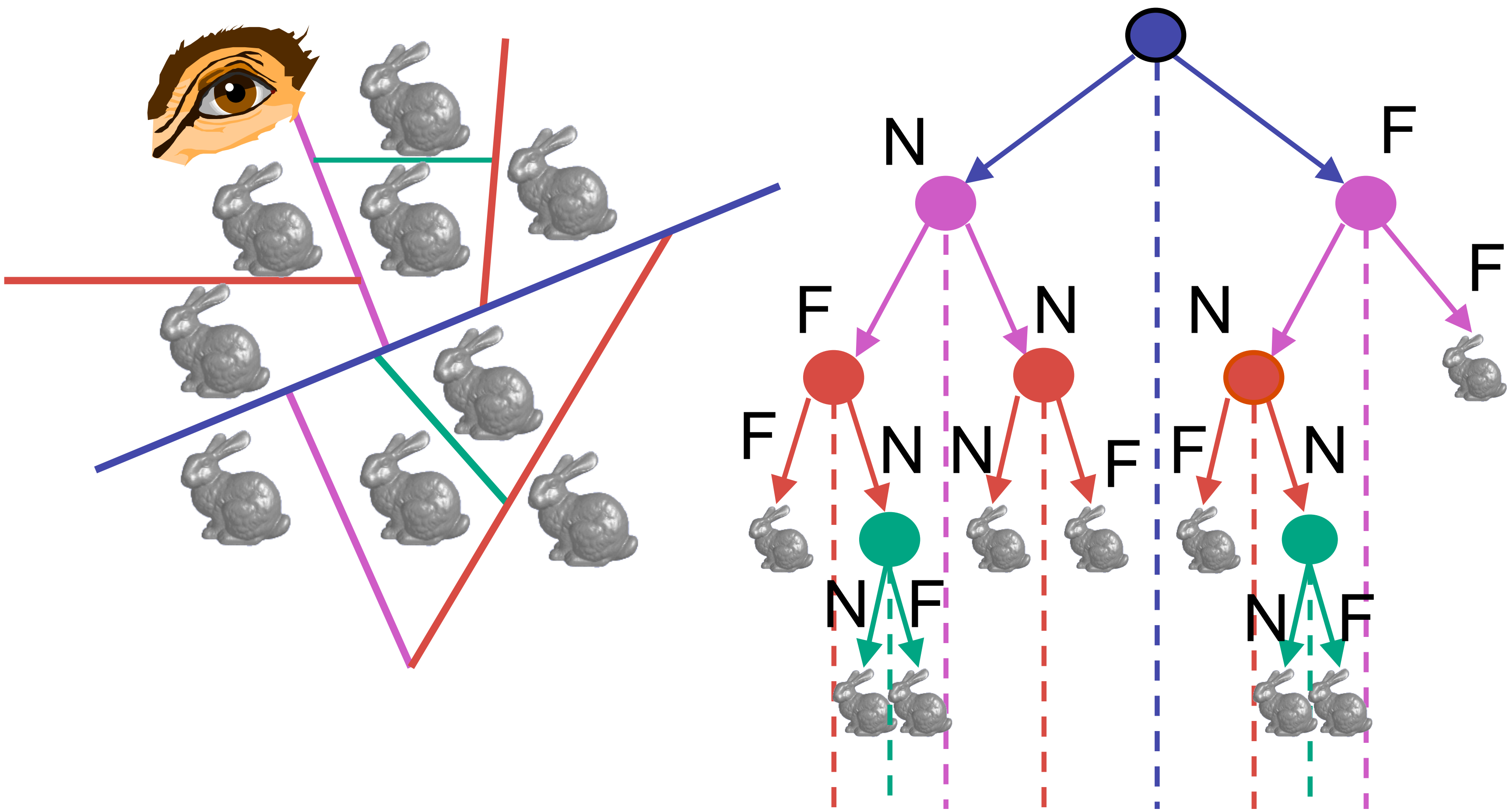
BSP Trees : Viewpoint A



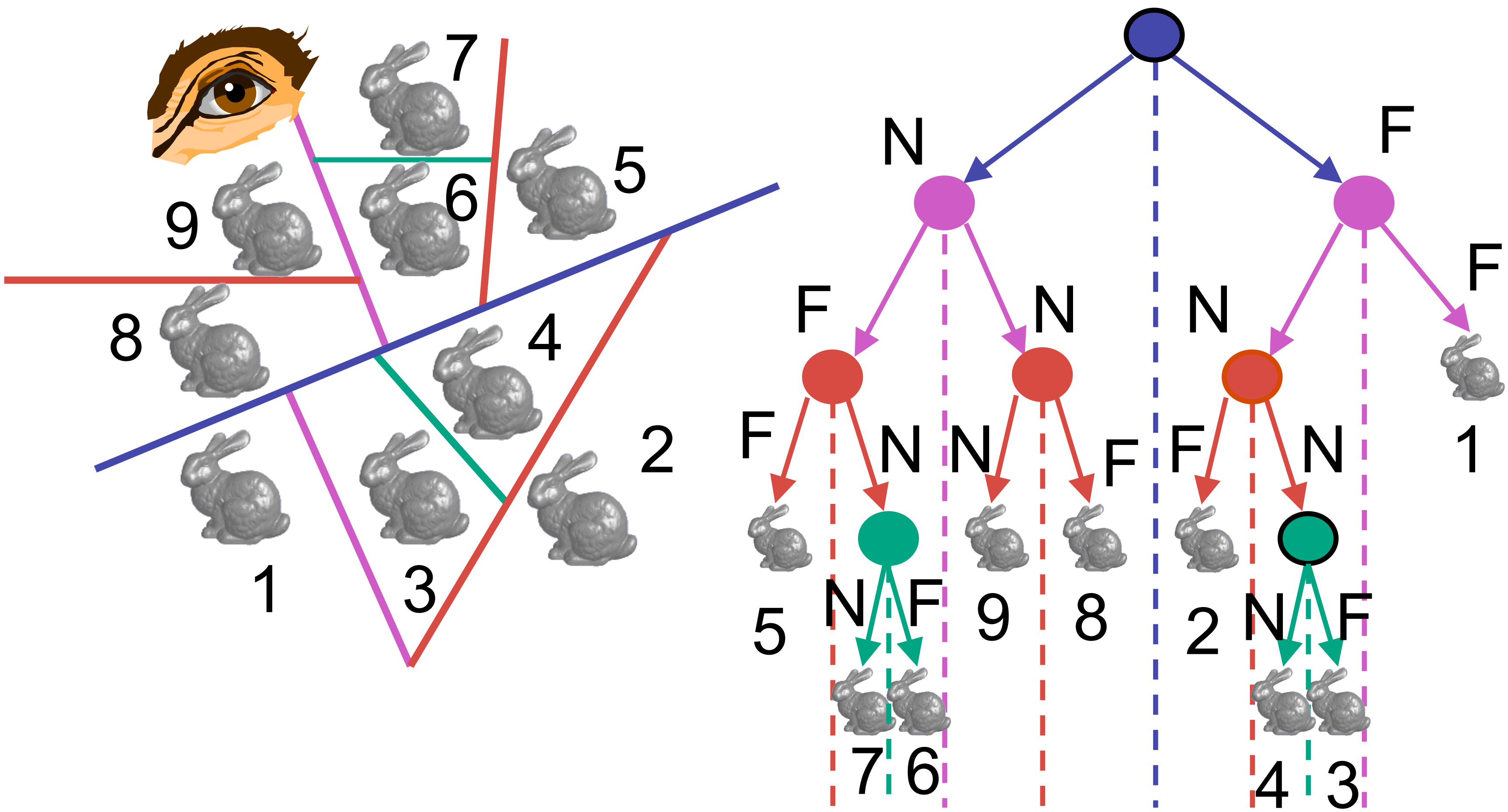
BSP Trees : Viewpoint A



BSP Trees : Viewpoint B



BSP Trees : Viewpoint B



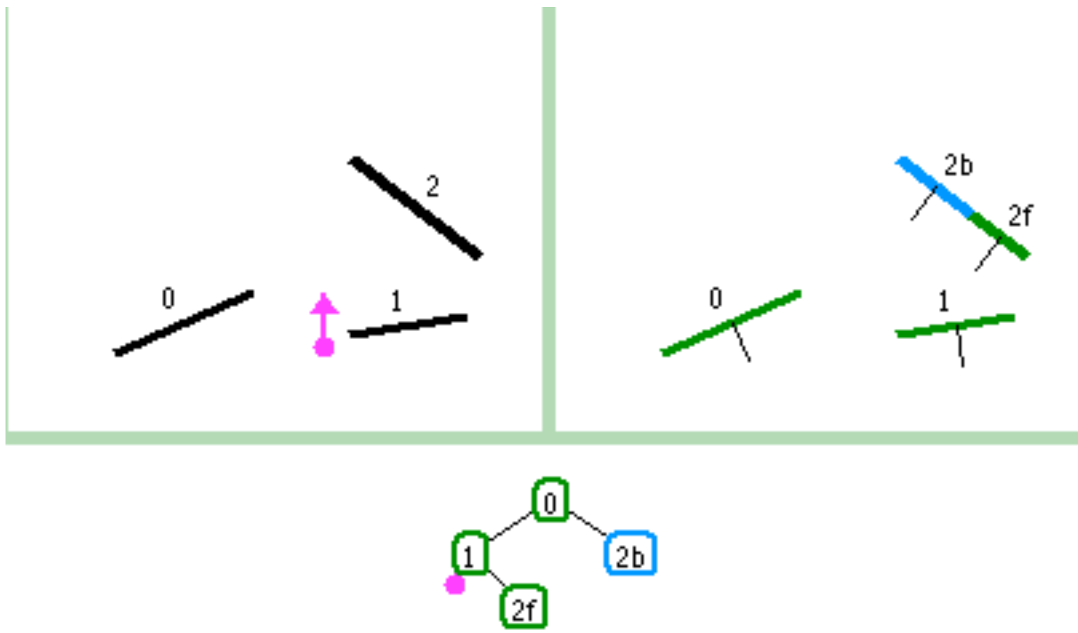
BSP Tree Traversal: Polygons

- 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

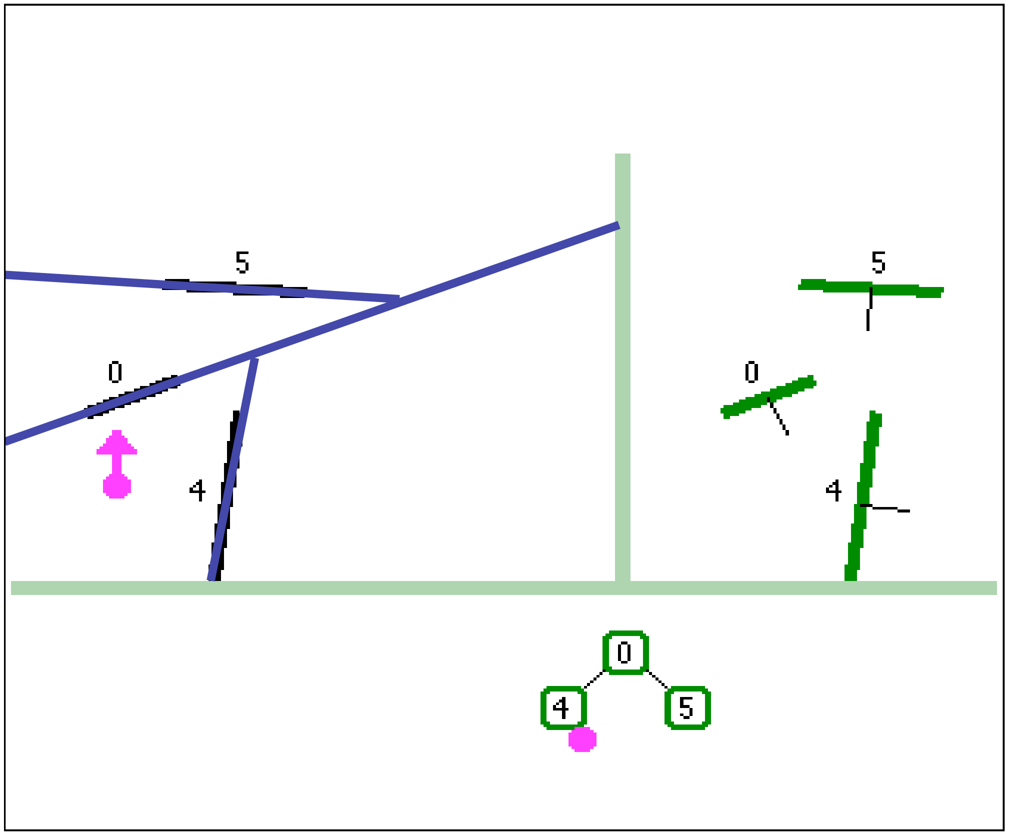


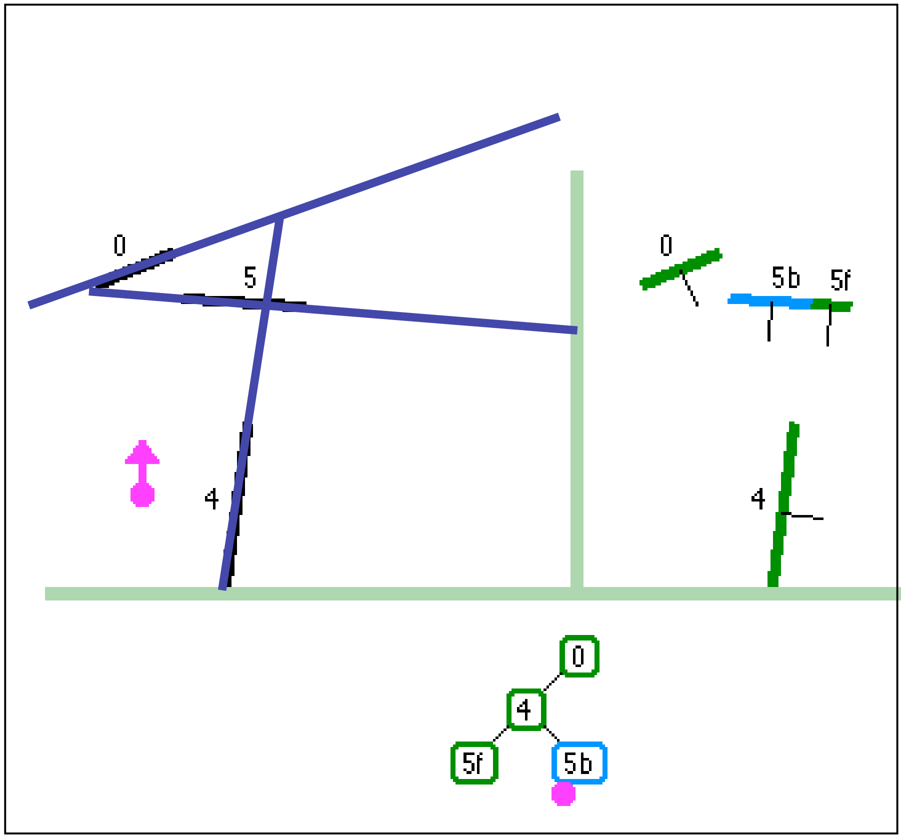
Summary: BSP Trees

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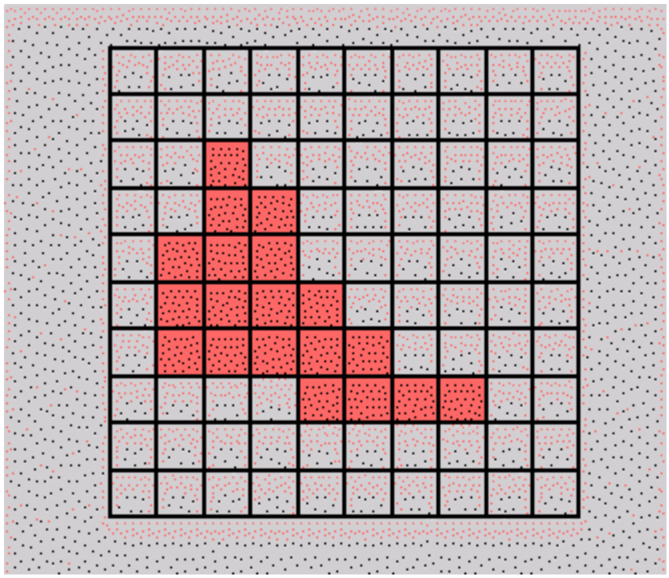
The Z-Buffer Algorithm (mid-70's)

- 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

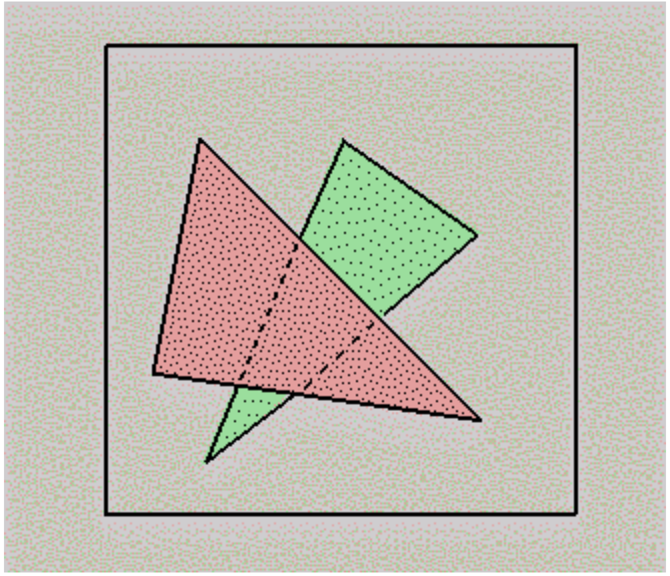
The Z-Buffer Algorithm

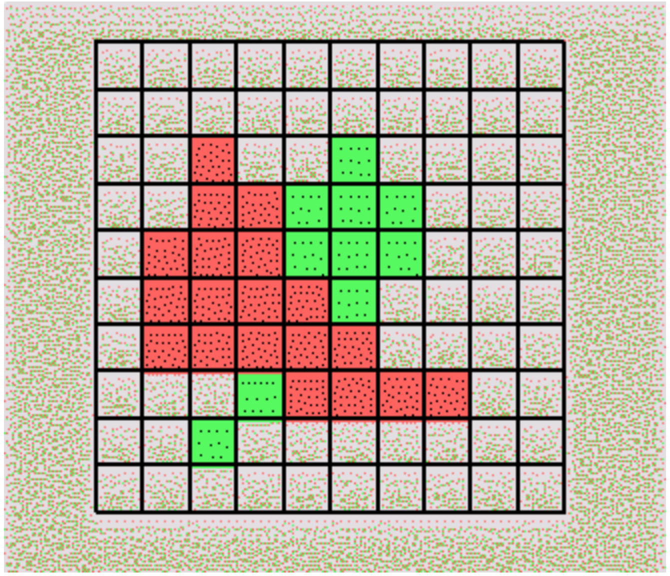
- we know how to rasterize polygons into an image discretized into pixels:



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

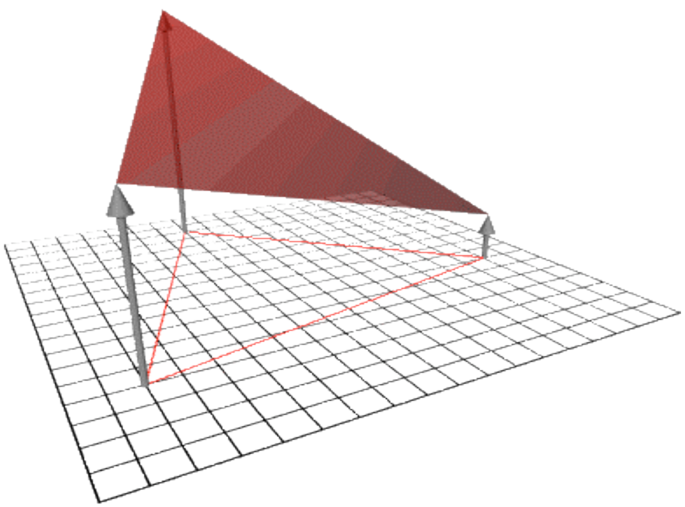
- idea: retain depth after projection transform
  - each vertex maintains z coordinate
    - relative to eye point
  - can do this with canonical viewing volumes

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: perspective transformation maps eye-space (view) *z* to NDC *z*

$$\begin{bmatrix} E & 0 & A & 0 \\ 0 & F & B & 0 \\ 0 & 0 & C & D \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} Ex + Az \\ Fy + Bz \\ Cz + D \\ -z \end{bmatrix} = \begin{bmatrix} -\left(\frac{Ex}{z} + Az \right) \\ -\left(\frac{Fy}{z} + Bz \right) \\ -\left(C + \frac{D}{z} \right) \\ 1 \end{bmatrix}$$

- thus: $$z_{NDC} = -\left(C + \frac{D}{z_{eye}} \right)$$

Correction: Ortho Camera Projection

week4.day2, slide 18

- camera's back plane parallel to lens
- infinite focal length
- no perspective convergence
- ~~just throw away z values~~
- x and y coordinates do not change with respect to z in this projection

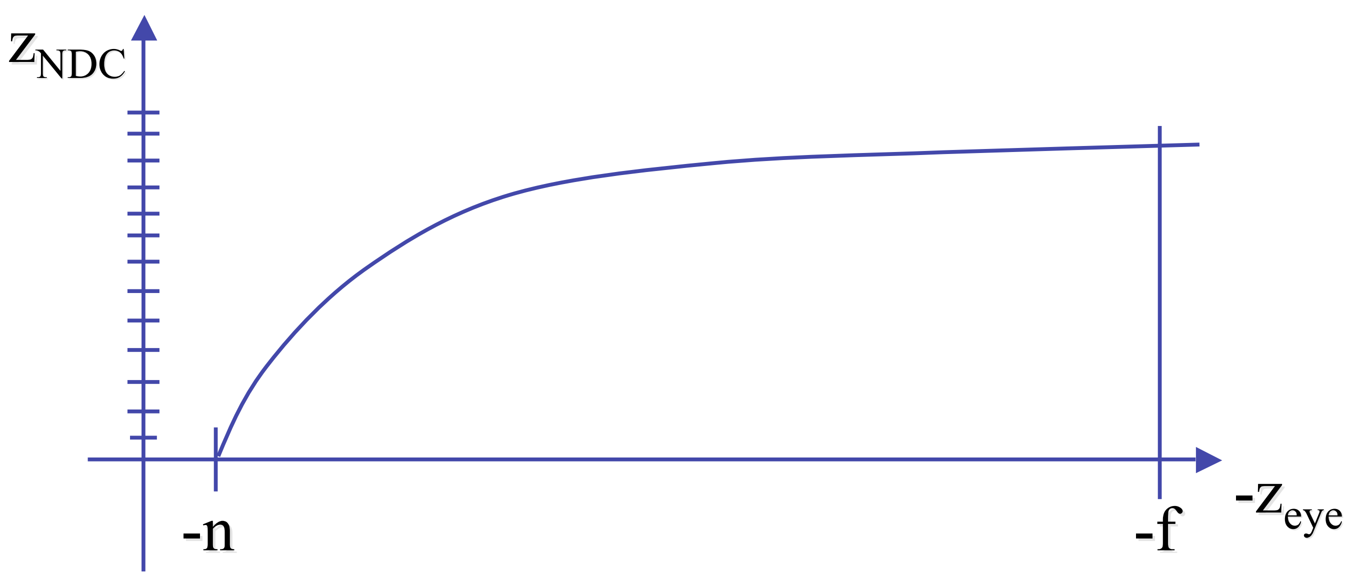
$$\cancel{\begin{bmatrix} x_p \\ y_p \\ z_p \end{bmatrix} = \begin{bmatrix} x \\ y \\ 0 \end{bmatrix} \quad \begin{bmatrix} x_p \\ y_p \\ z_p \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}}$$

$$P' = \begin{bmatrix} \frac{2}{right-left} & 0 & 0 & -\frac{right+left}{right-left} \\ 0 & \frac{2}{top-bot} & 0 & -\frac{top+bot}{top-bot} \\ 0 & 0 & \frac{-2}{far-near} & -\frac{far+near}{far-near} \\ 0 & 0 & 0 & 1 \end{bmatrix} P$$

$$\begin{bmatrix} D & 0 & 0 & A \\ 0 & E & 0 & B \\ 0 & 0 & F & C \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} Dx + A \\ Ey + B \\ Fz + C \\ 1 \end{bmatrix}$$

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

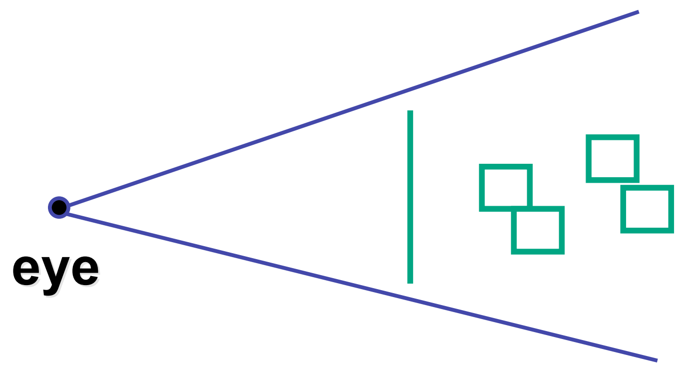
- how much memory does the Z-buffer use?
- does the image rendered depend on the drawing order?
- does the time to render the image depend on the drawing order?
- how does Z-buffer load scale with visible polygons? with framebuffer resolution?

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



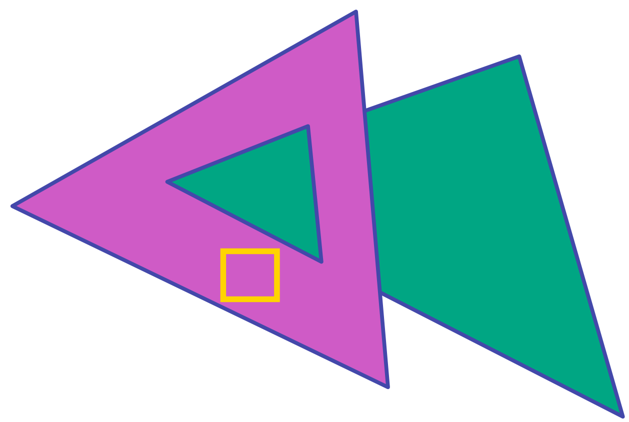
- shared edges are handled inconsistently
  - *ordering dependent*

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

glVertex3f(x,y,z)

object
OCS

world
WCS

viewing
VCS

alter w

glFrustum(...)

modeling transformation → **viewing transformation** → **projection transformation**

glTranslatef(x,y,z)
glRotatef(th,x,y,z)
....

gluLookAt(...)

/ w

clipping
CCS

perspective division

normalized device
NDCS

glutInitWindowSize(w,h)
glViewport(x,y,a,b)

viewport transformation

device
DCS

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