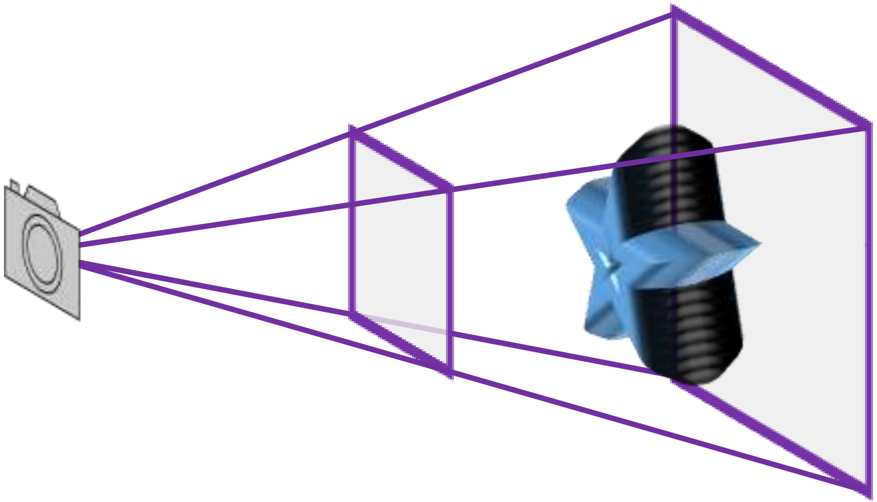
Basics of 3D Rendering

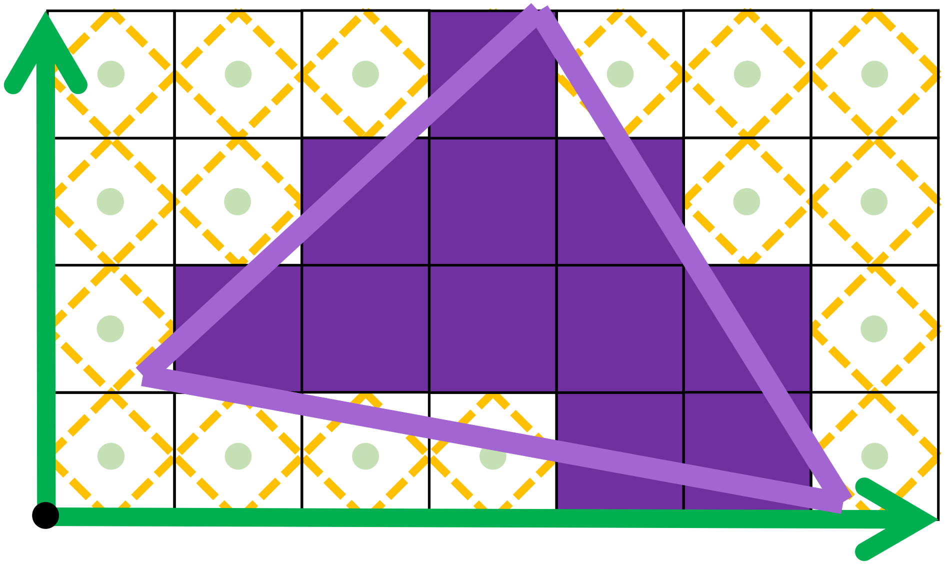
CS 148: Summer 2016
Introduction of Graphics and Imaging
Zahid Hossain

http://www.pling.org.uk/cs/cgv.html

What We Have So Far

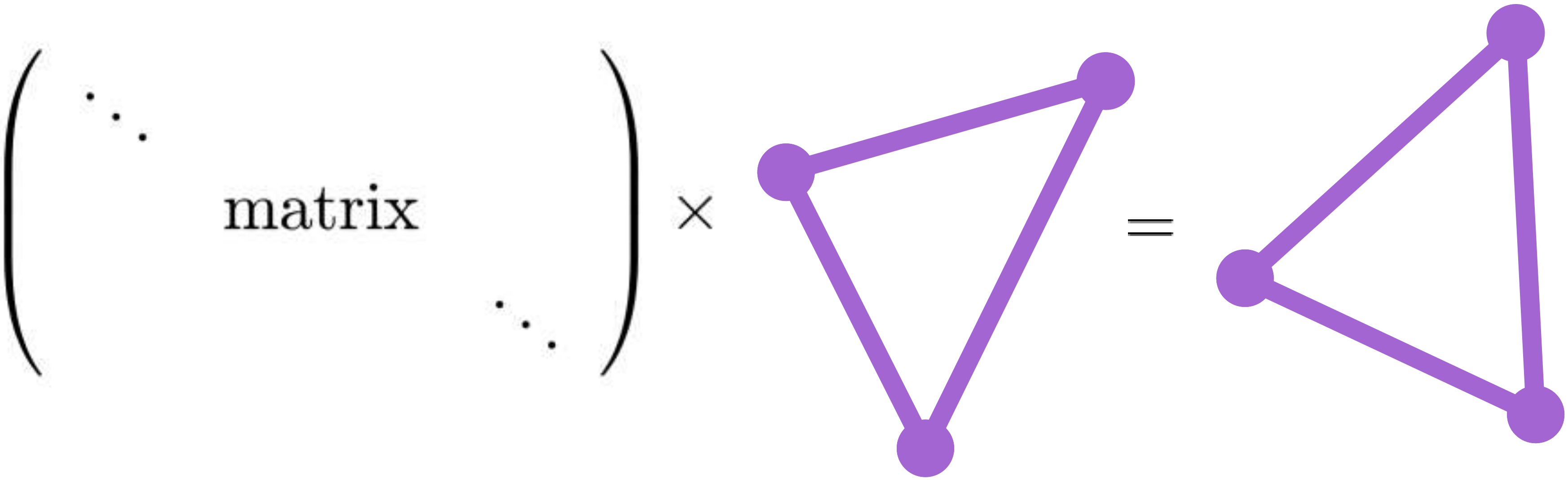


3D geometry



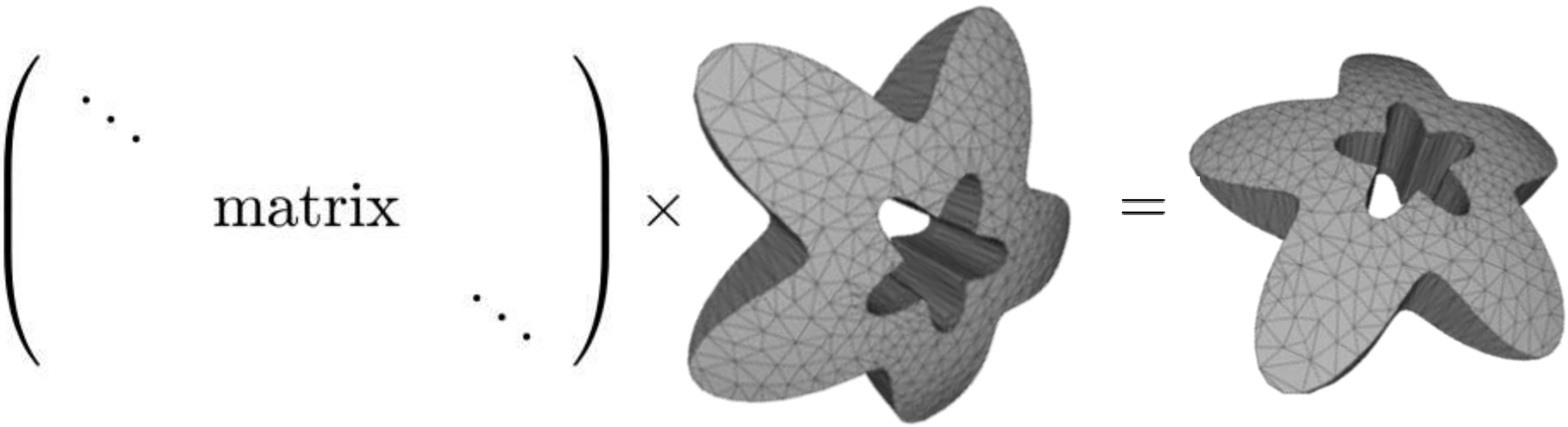
2D pipeline

Handy Fact



Matrices preserve flat geometry

Handy Fact



Matrices preserve flat geometry

So What?

3D triangles look like 2D triangles under camera transformations.

So What?

3D triangles look like 2D triangles under camera transformations.

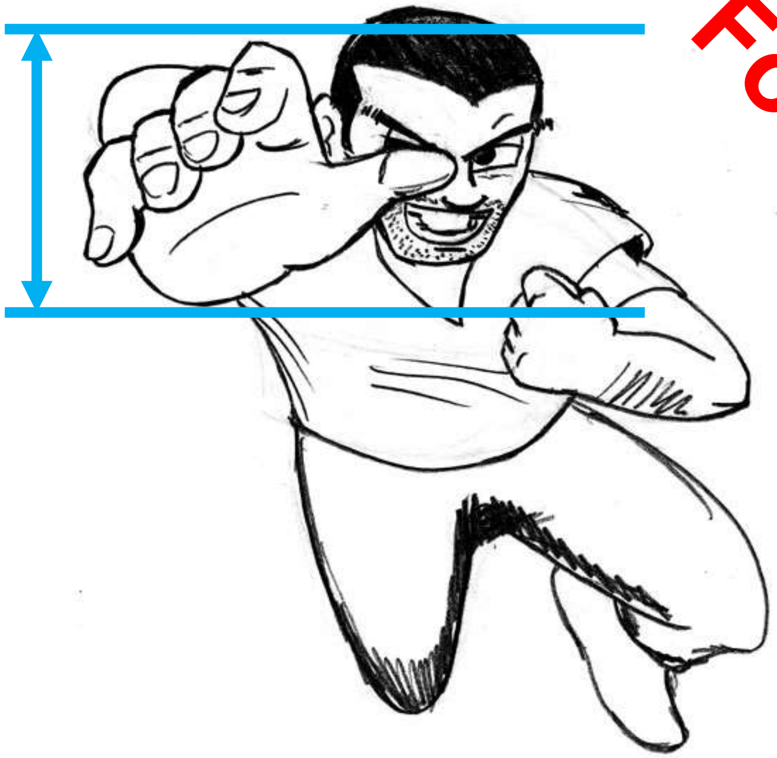
Use 2D pipeline for 3D Rendering !

Side Note

Only true for flat shapes

http://drawntothis.com/wp-content/uploads/2010/09/Random_Guy.jpg

Side Note



Only true for flat shapes

http://drawntothis.com/wp-content/uploads/2010/09/Random_Guy.jpg

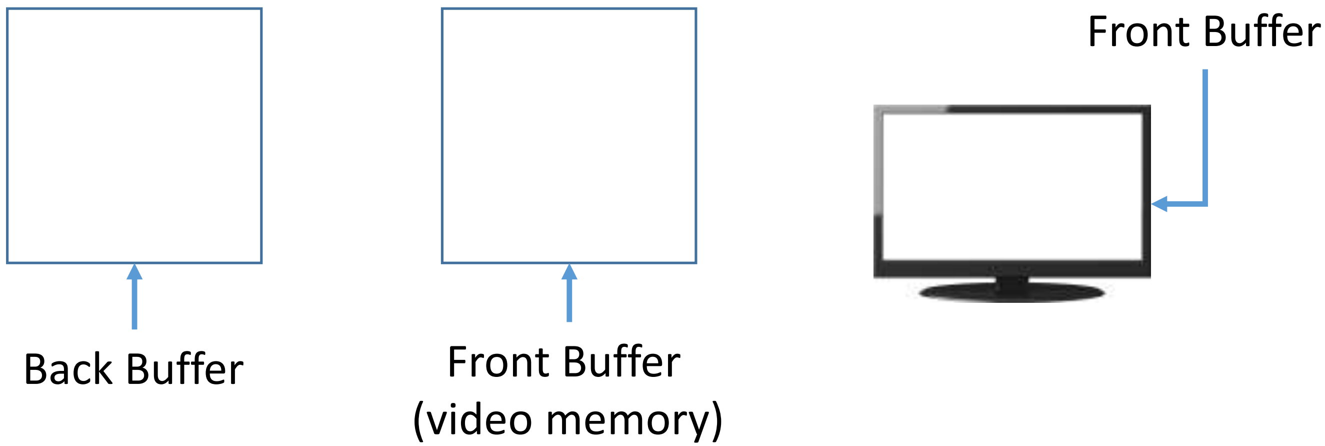
Frame Buffering

Double and Triple Buffering

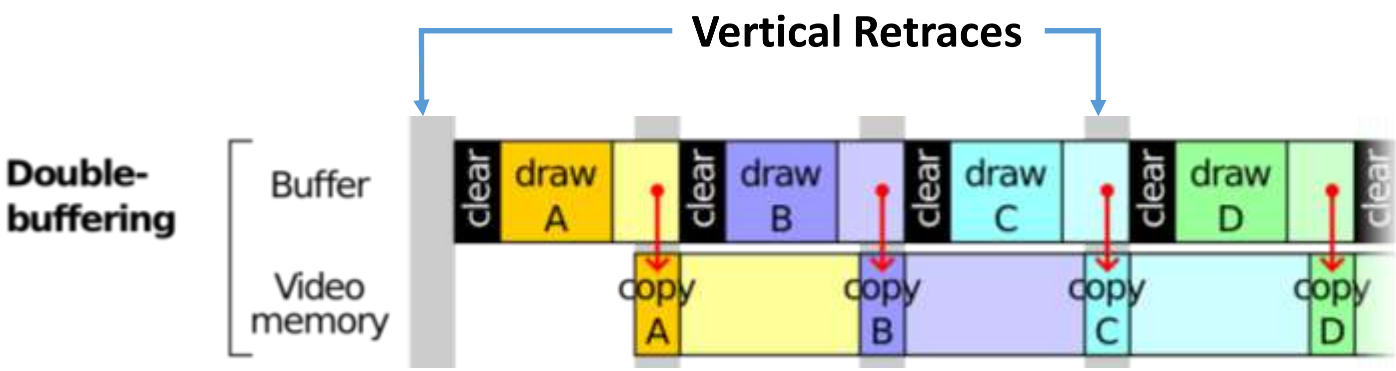
Tearing : Data from multiple frames appear on the screen at the same time. This happens when GPU rendering rate and monitor refresh rate are not synced.

http://www.newcluster.com/wp-content/uploads/2015/01/g-sync_diagram_0.jpgitokgxy9kpos

Double Buffering with V-Sync



SwapBuffer: Either copy Back Buffer to Front Buffer, or Swap Pointers (Usually in Fullscreen mode).



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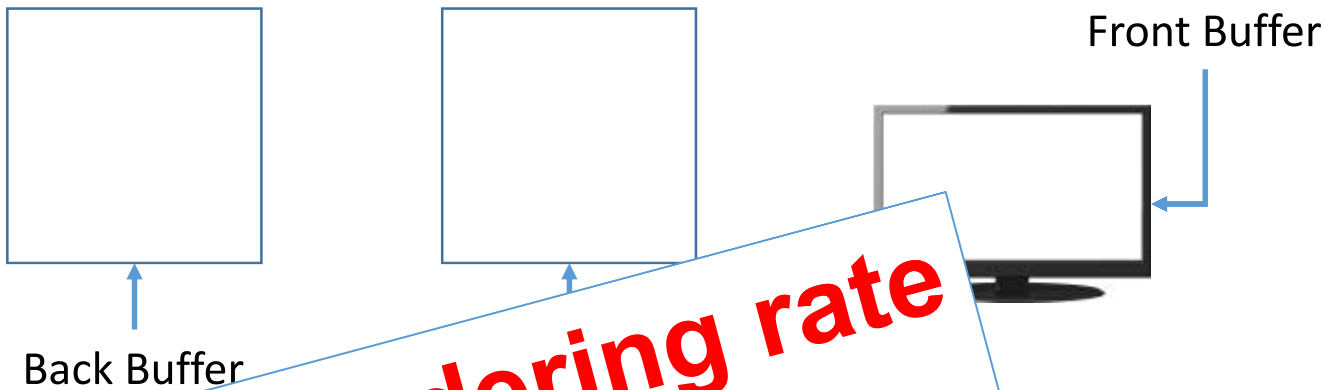
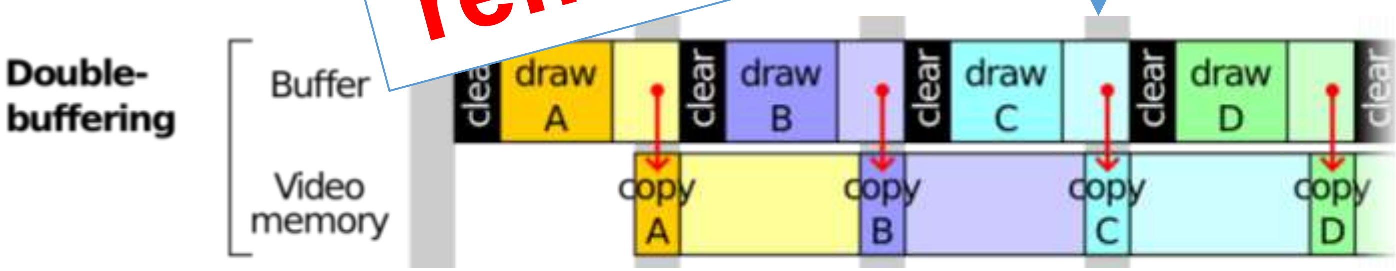
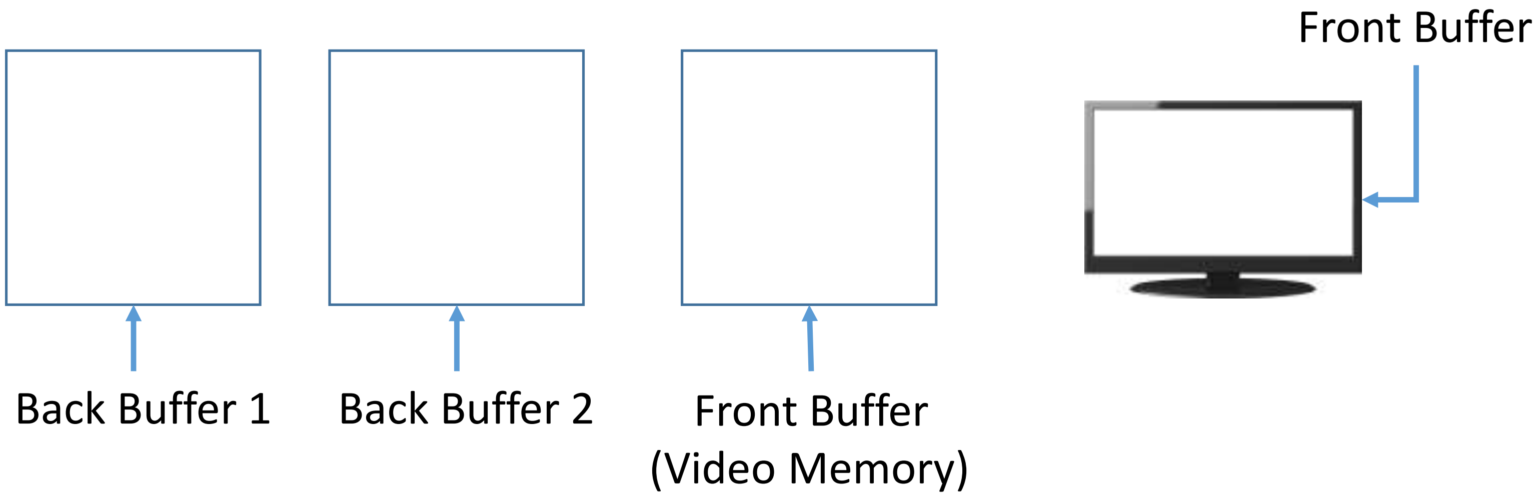


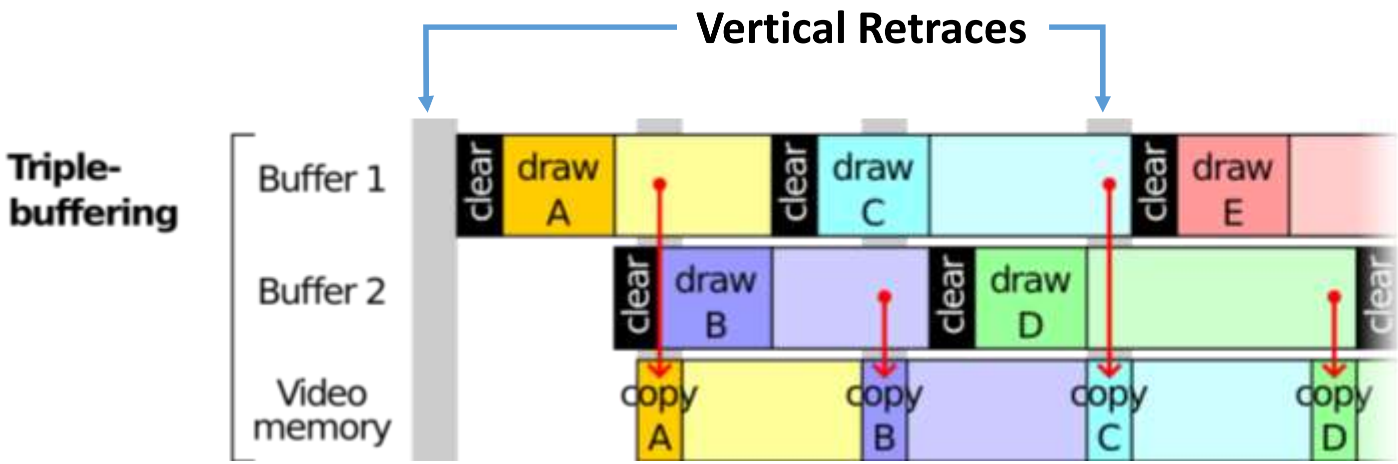
SwapBuffer: Eithe
or Swap Pointers (

Rendering rate limited by refresh rate ☹

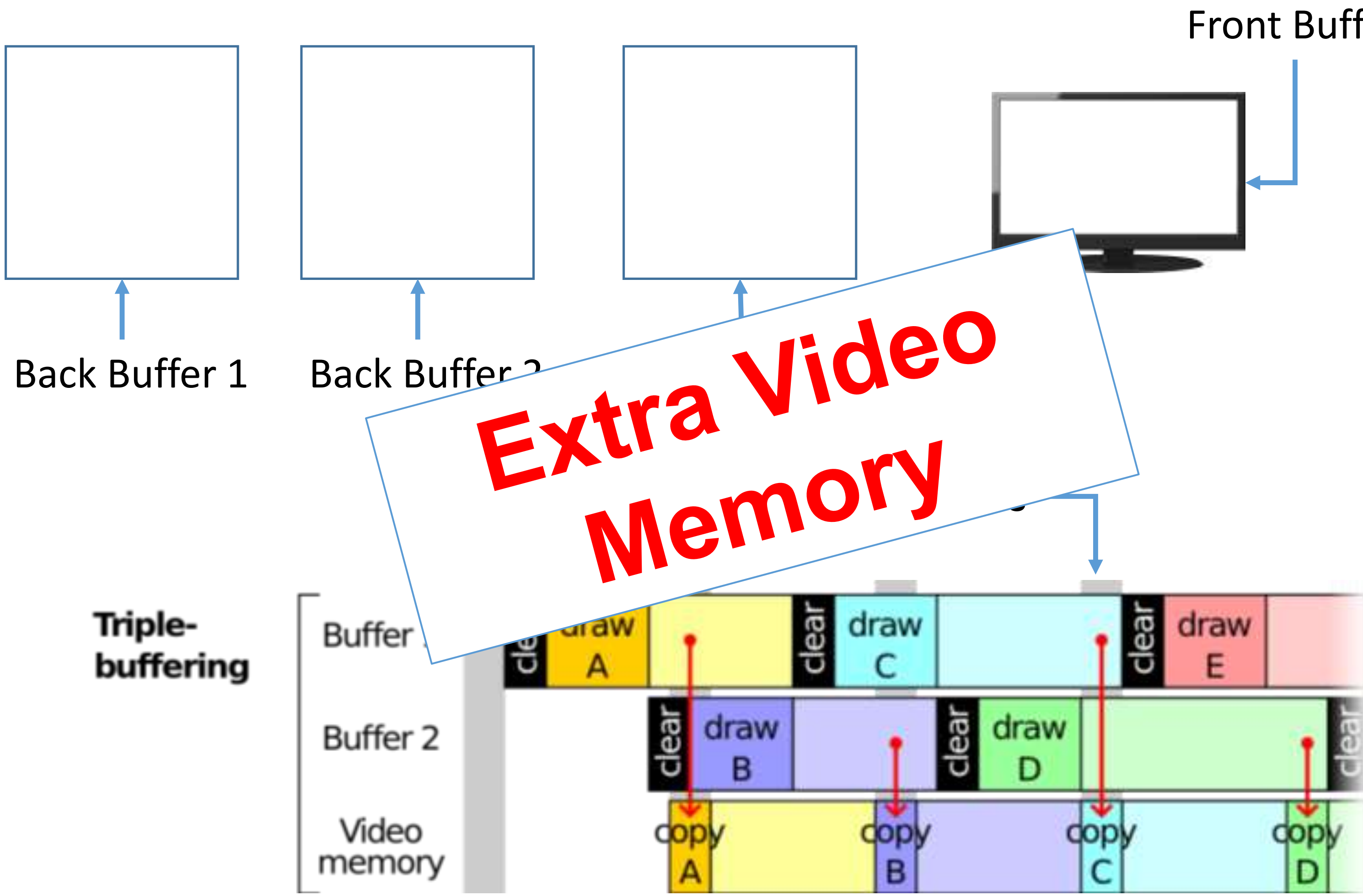


Triple Buffering with V-Sync



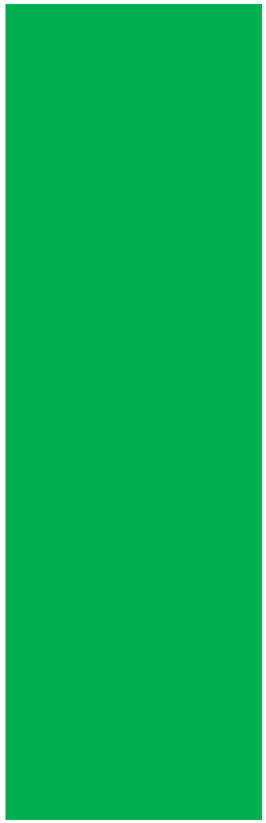


Triple Buffering with V-Sync



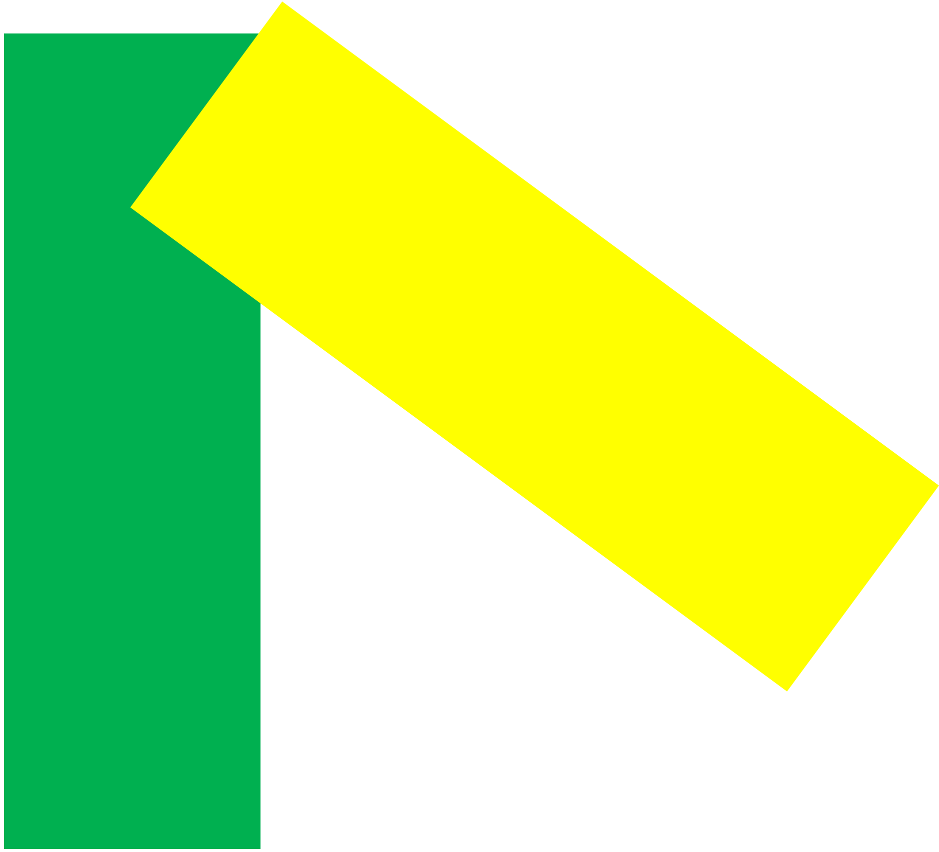
Occulusion

Painter’s Algorithm



Draw items one at a time

Painter's Algorithm



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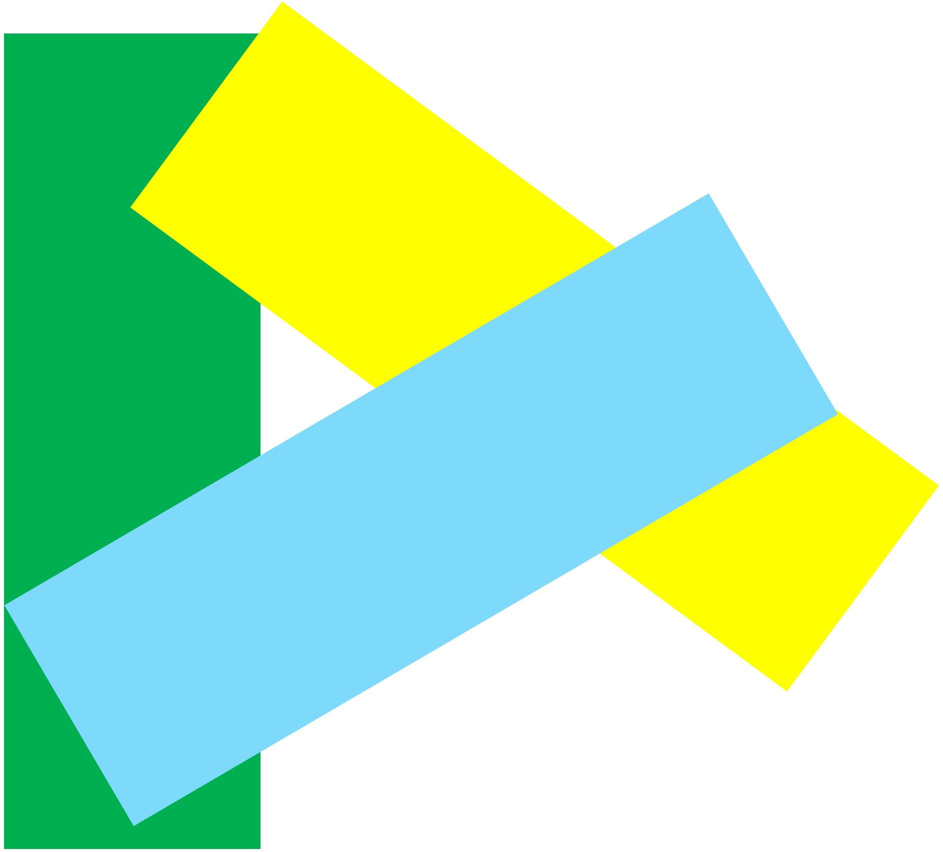

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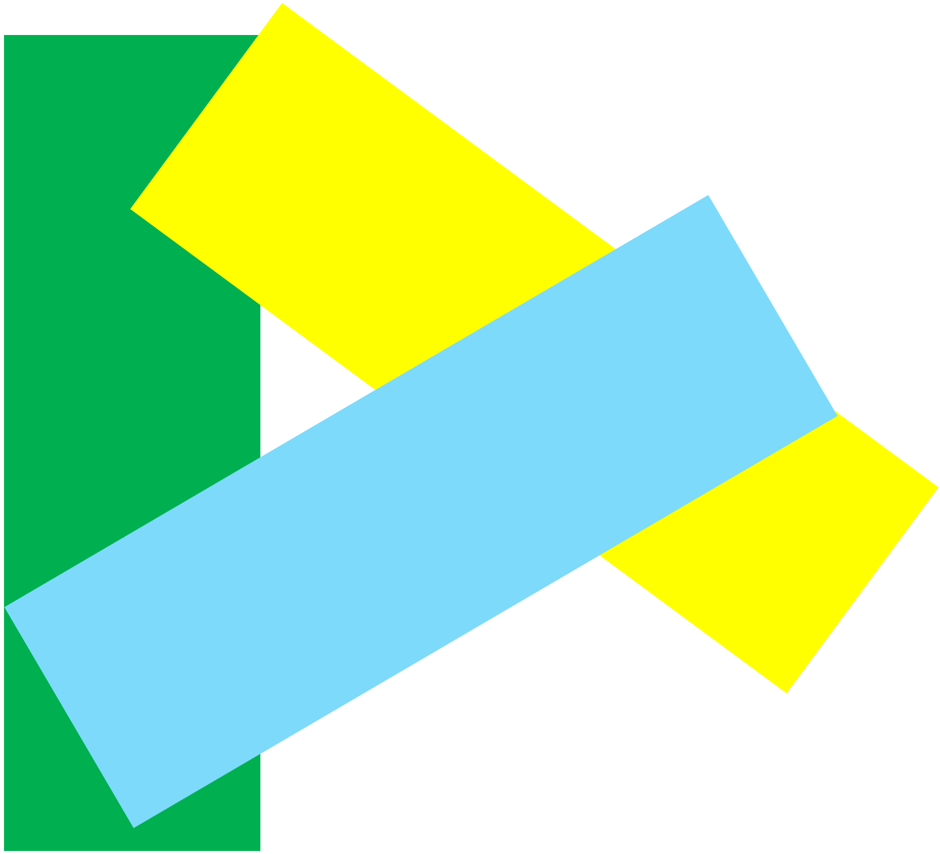
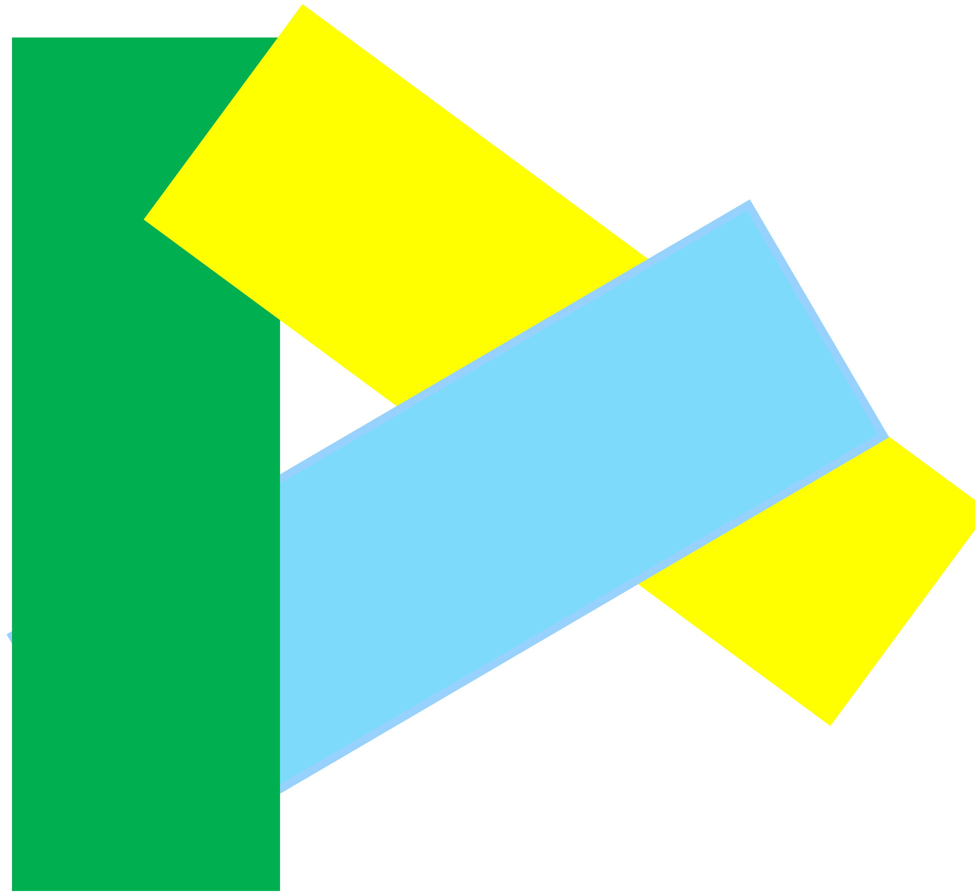


Draw items one at a time

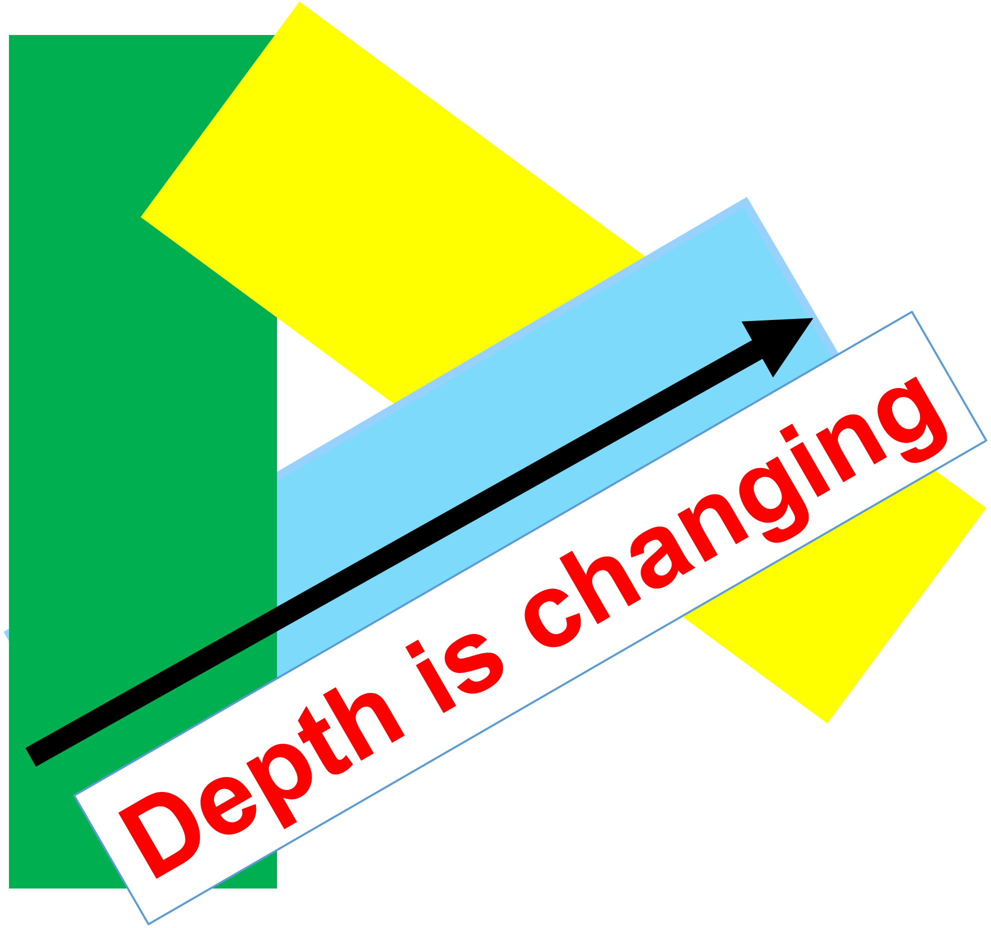
Painter's Algorithm

Draw items one at a time

What Order?



What Order?



Early Hidden Surface Approaches

- Pre-compute rendering order
- Cut geometry as needed
- …

A Characterization of Ten Hidden-Surface Algorithms

IVAN E. SUTHERLAND*, ROBERT F. SPROULL**, AND ROBERT A. SCHUMACKER*

This paper discusses the hidden-surface problem from the point of view of sorting. The various surfaces of an object to be shown in hidden-surface

Observation

Each pixel can decide what is on top independently.

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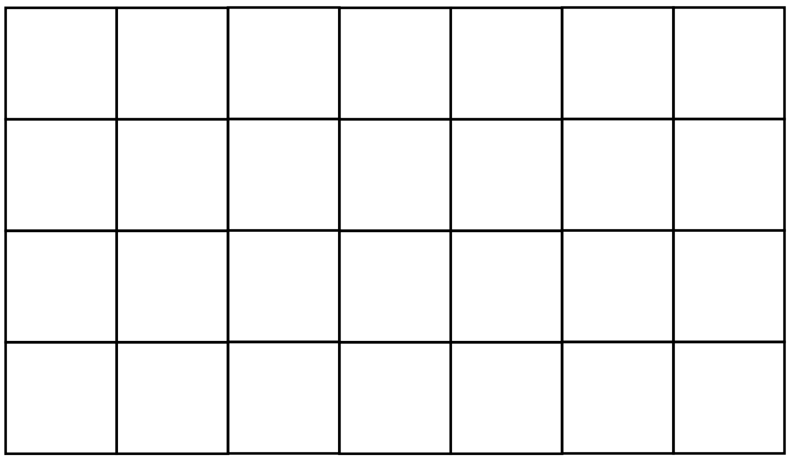
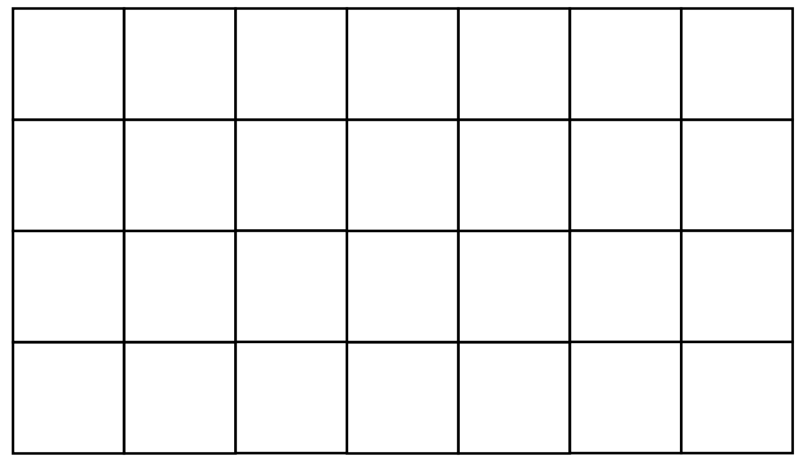
Ed Catmull

Wolfgang Straßer

Z Buffer

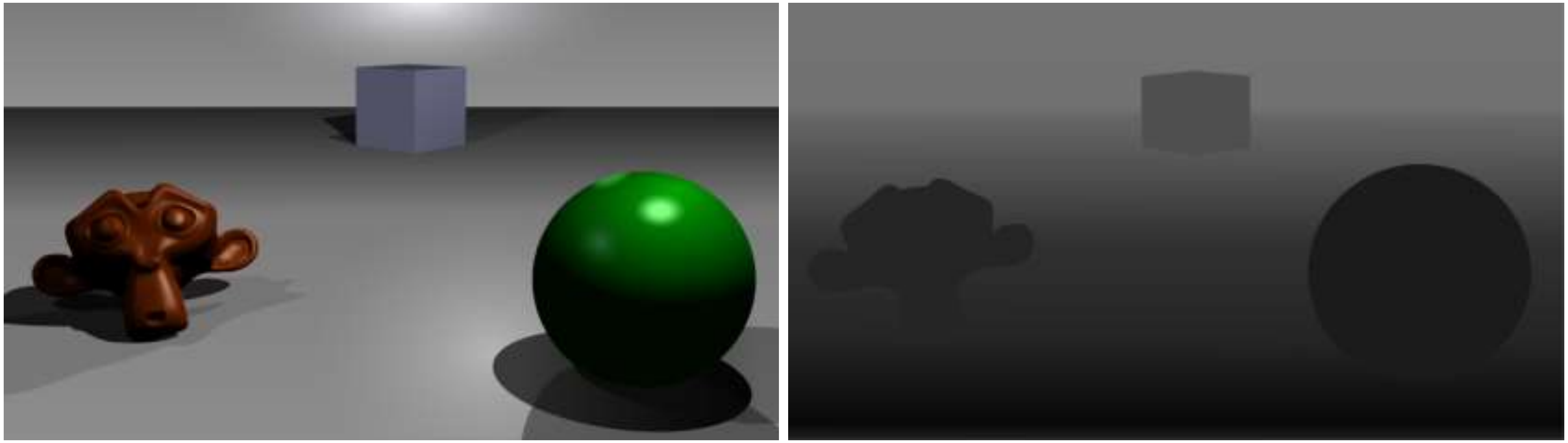


Color Buffer (RGB each cell)



Depth buffer (one number each cell)

Z-Buffer



http://upload.wikimedia.org/wikipedia/commons/4/4e/Z_buffer.svg

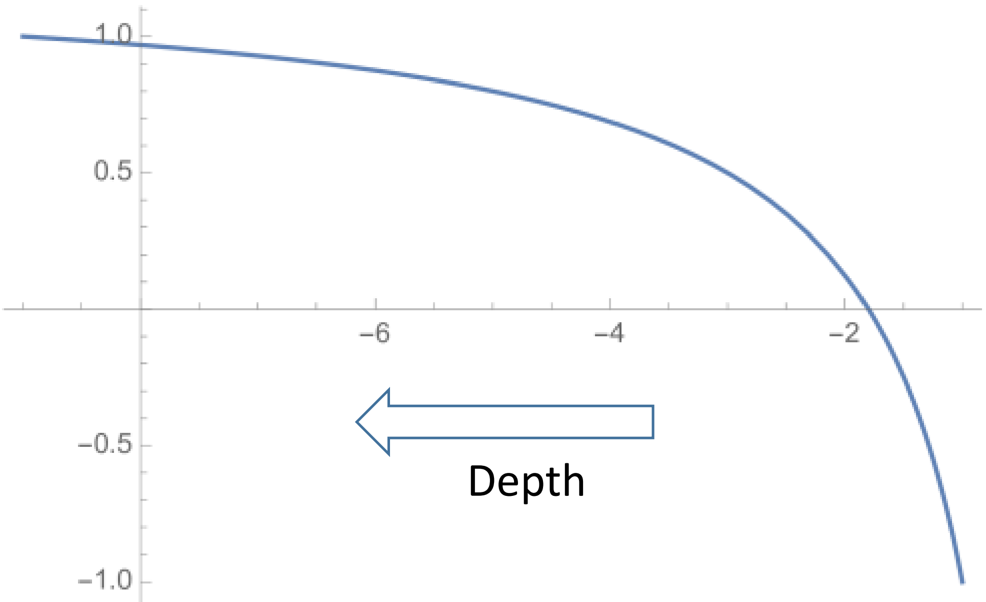
Z-Buffer Issues: Resolution

$$z_{\text{ndc}} = \frac{\text{far} + \text{near}}{\text{far} - \text{near}} + \frac{2 \cdot \text{far} \cdot \text{near}}{(\text{far} - \text{near})\, z_{\text{world}}}$$

Non linear !

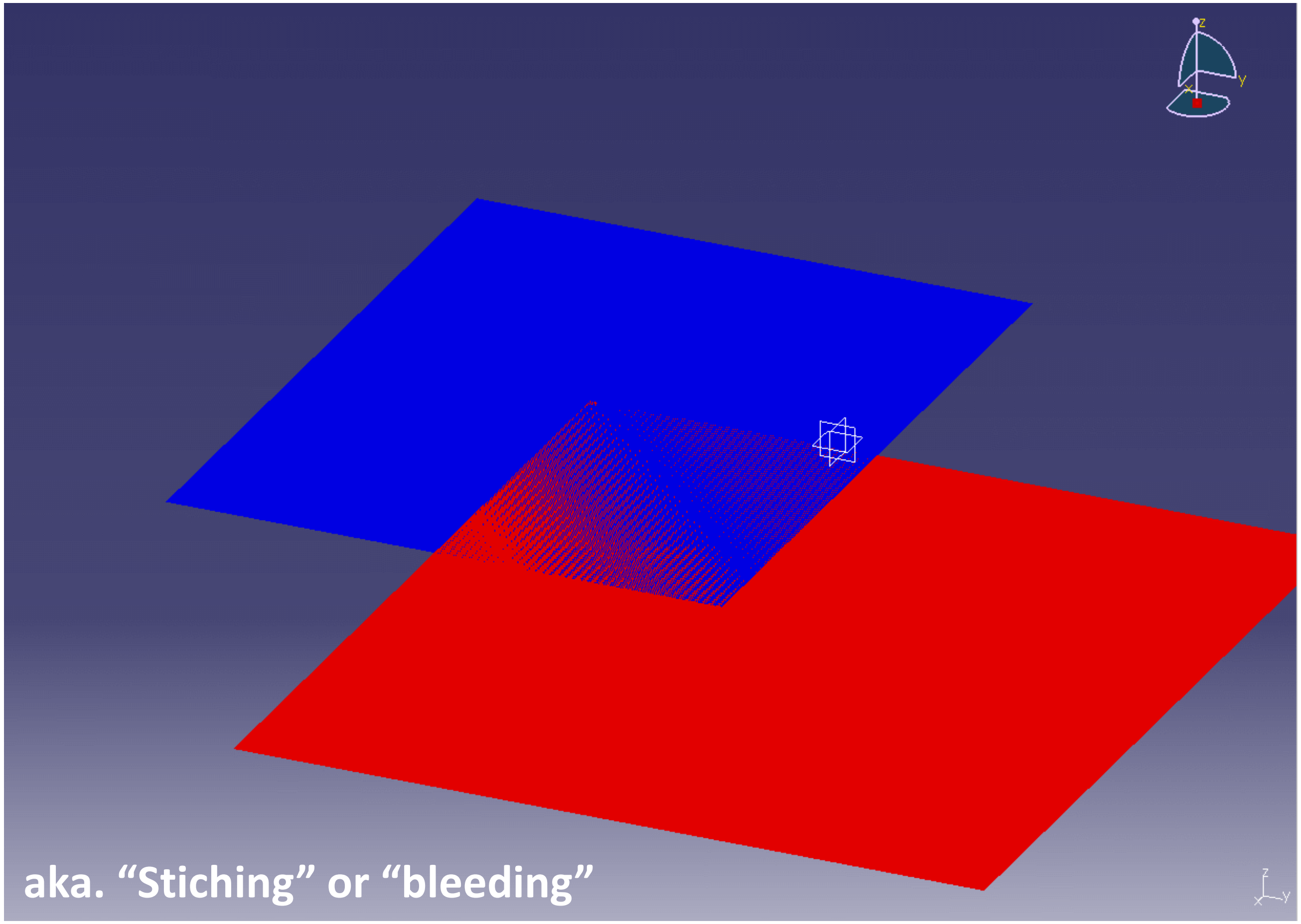
Z-Buffer Issues: Resolution

$$z_{\text{ndc}} = \frac{\text{far} + \text{near}}{\text{far} - \text{near}} + \frac{2 \cdot \text{far} \cdot \text{near}}{(\text{far} - \text{near})\, z_{\text{world}}}$$



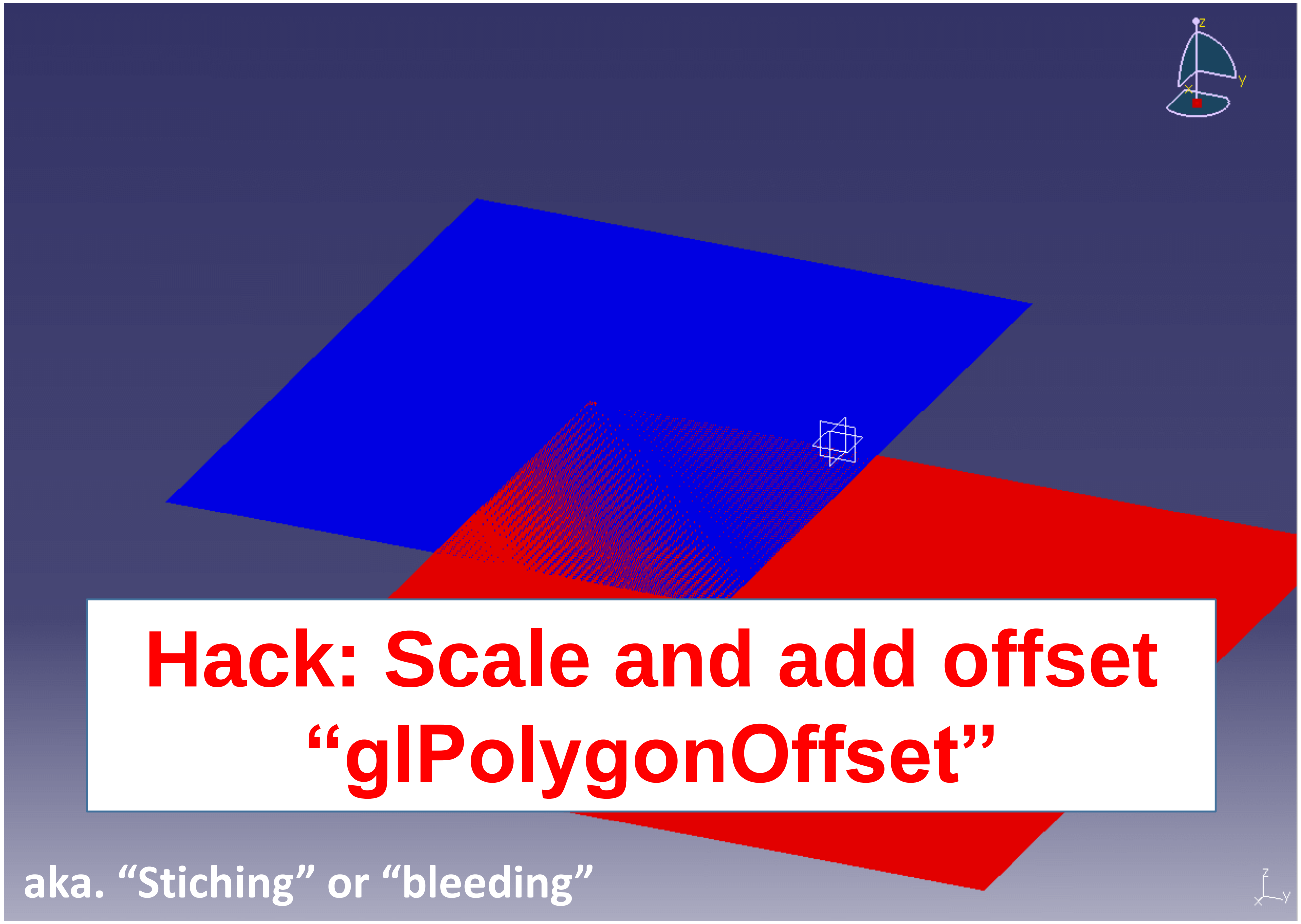
$$\frac{\mathrm{d}z_{\text{ndc}}}{\mathrm{d}z_{\text{world}}} \propto \frac{1}{z_{\text{world}}^2}$$

Z-Buffer Issues: Depth Fighting



http://ps-2.kev009.com/CATIA-B18/basug_C2/basugbt1510.htm

Z-Buffer Issues: Depth Fighting



http://ps-2.kev009.com/CATIA-B18/basug_C2/basugbt1510.htm

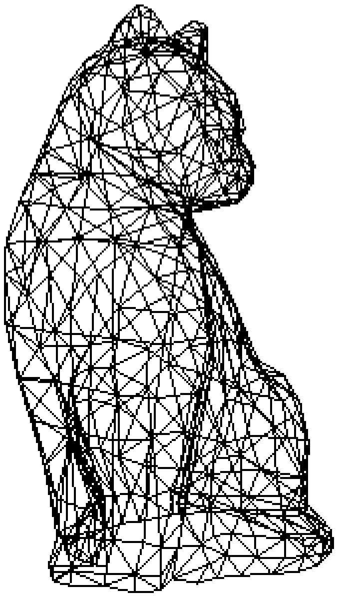
Cull [kuhl]:

To identify and throw away invisible geometry to save processing time.

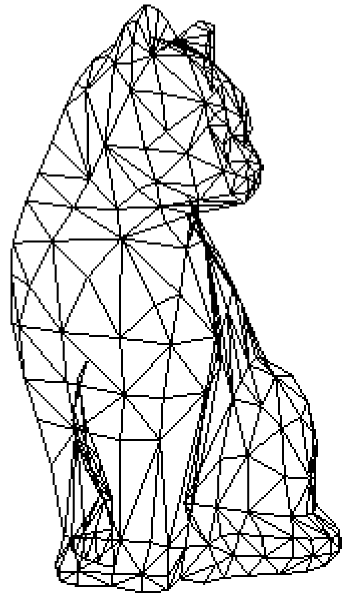
Basic Culling Strategies

- **Backface culling**: remove geometry facing away from the camera
- **View volume culling**: remove geometry outside frustum
- **Occlusion culling**: remove invisible geometry

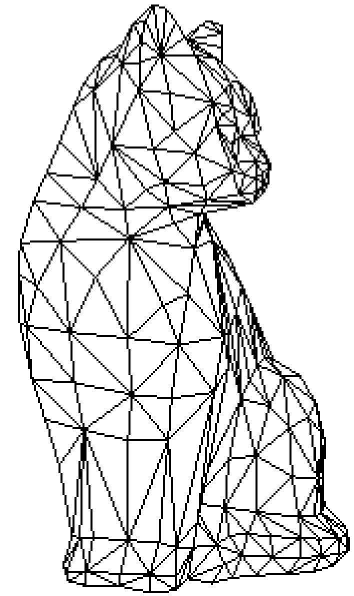
Backface Culling



None



Backface culling



Hidden surface removal

http://medialab.di.unipi.it/web/IUM/Waterloo/node70.html

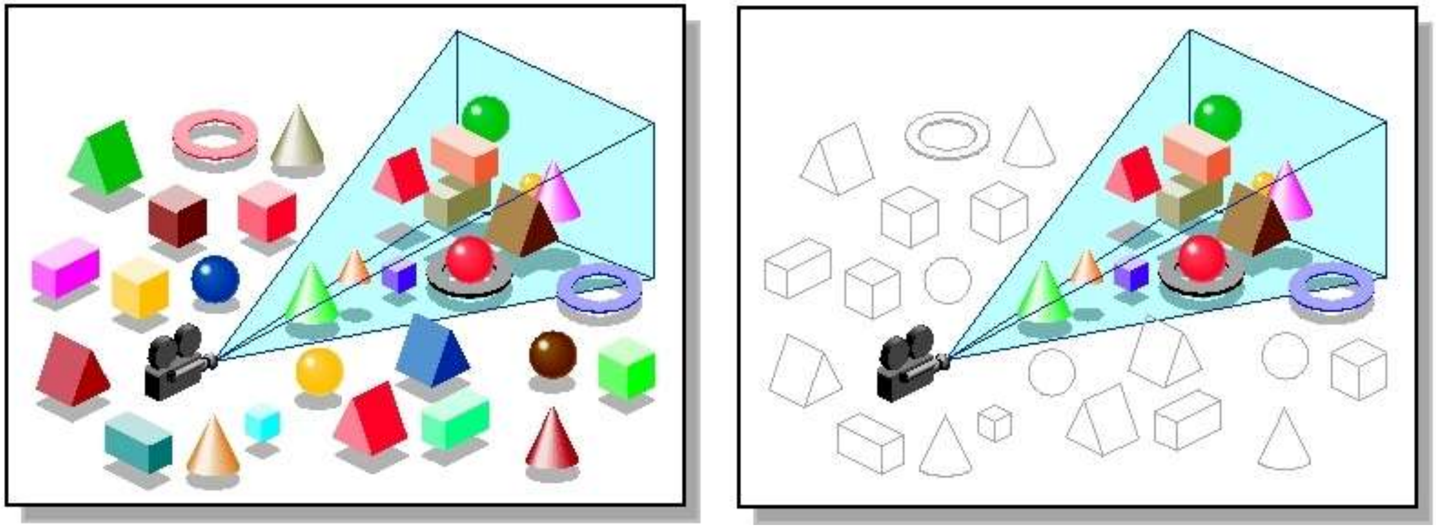
Specifying Triangle Orientation

`glDisable/glEnable(GL_CULL_FACE)`

Default:

`glFrontFace(GL_CCW)`

View Volume Culling



Potential strategies:

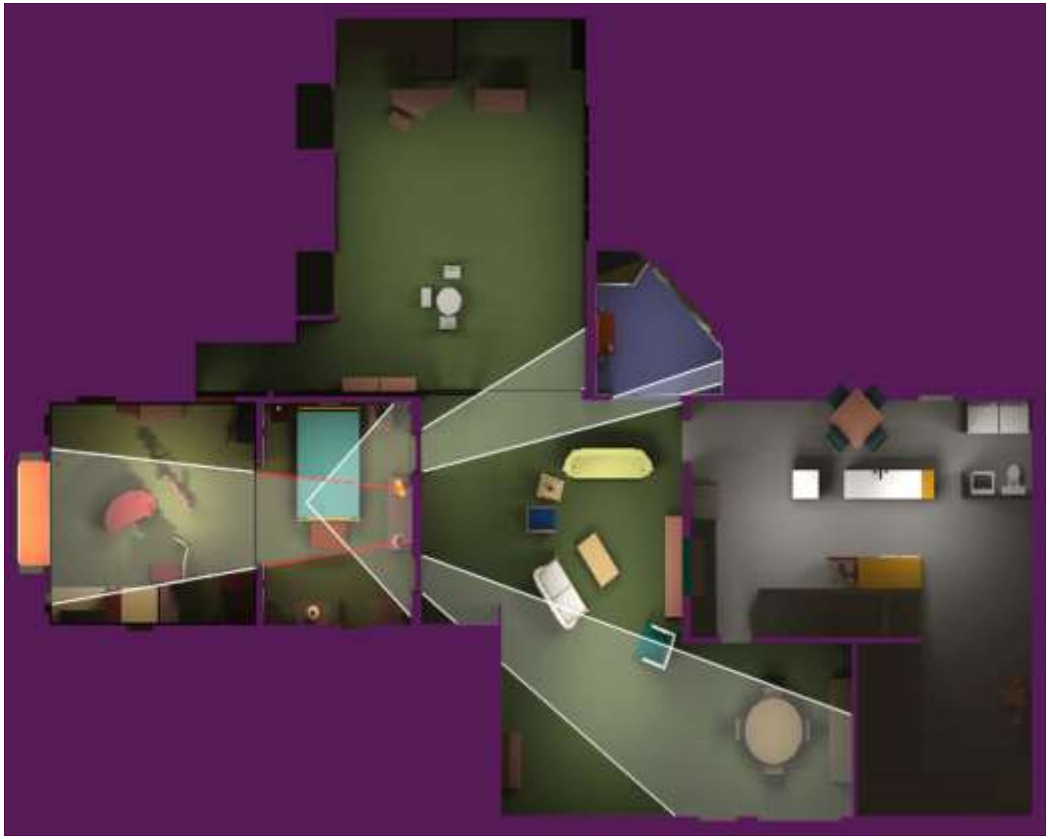
- Store scene hierarchically
  - With bounding volumes
- Compute viewing frustrum
  - Don’t render volumes that are clearly outside frustrum

http://i.minus.com/i75qjiyFQzVCI.jpg

Occlusion Culling: Portal Rendering

http://www.aaid.ca/flash/media/hkmh/images/floor1/000a-geology-portal-cg-rendering.jpg

Occlusion Culling: Portal Rendering



Potentially Visible Set

http://www.cs.virginia.edu/~luebke/publications/portals.html

Occlusion Culling: Portal Rendering

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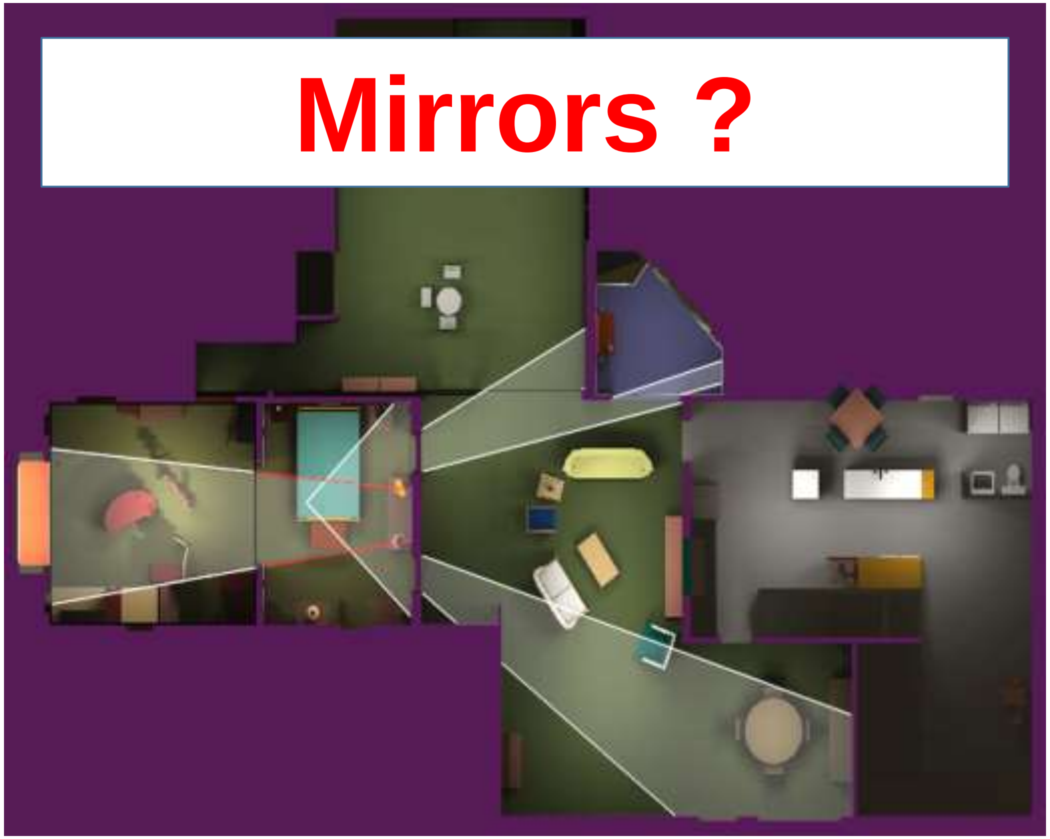
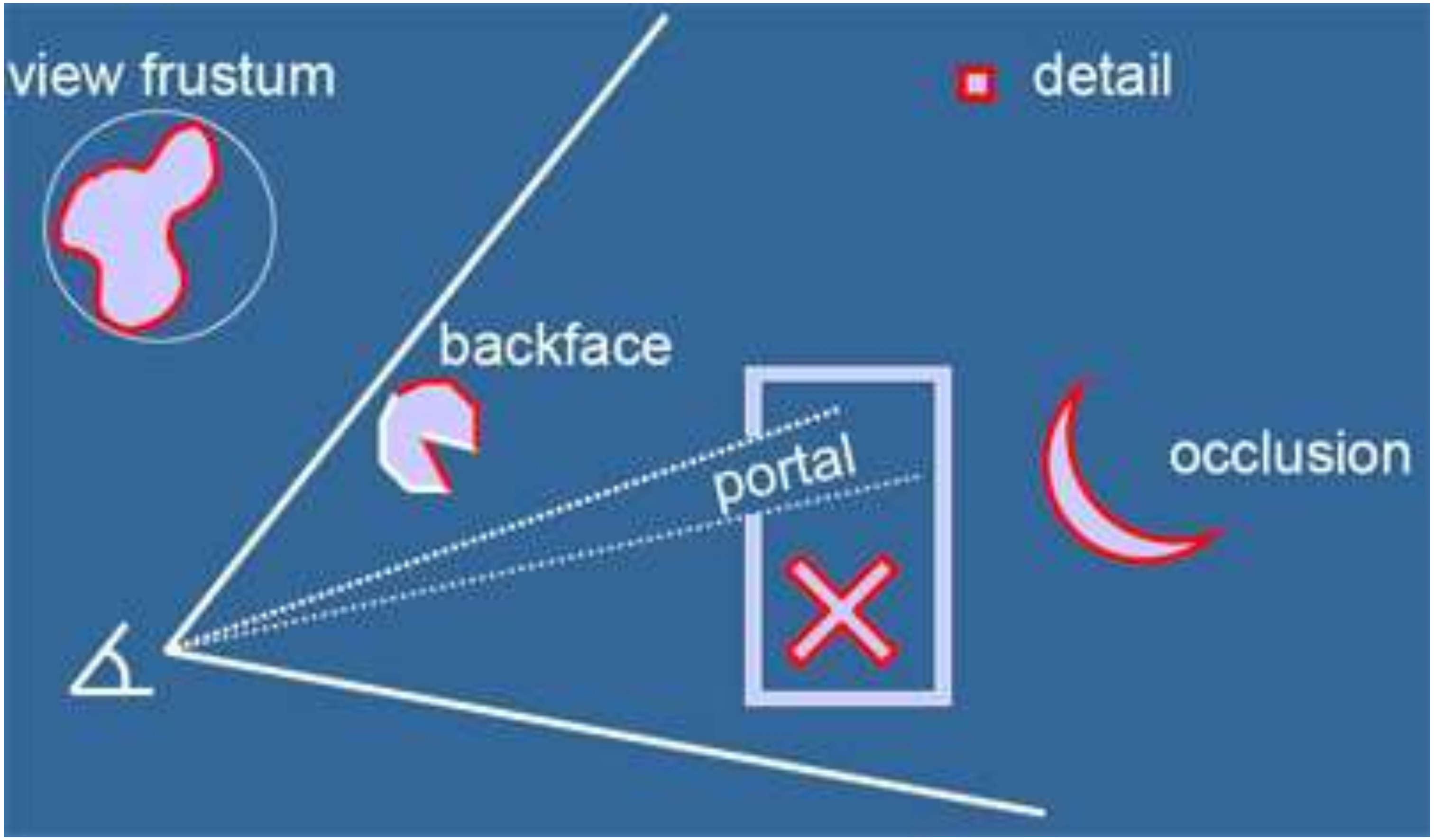
Occlusion Culling: Portal Rendering



Potentially Visible Set (PVS)

http://www.cs.virginia.edu/~luebke/publications/portals.html

Summary of Culling Techniques

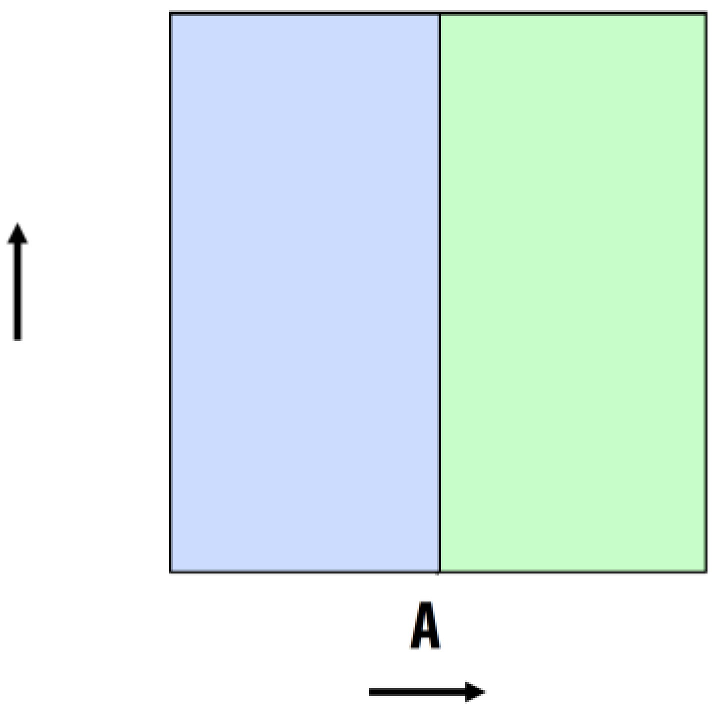


Acceleration Structures

Goal of Acceleration Structures

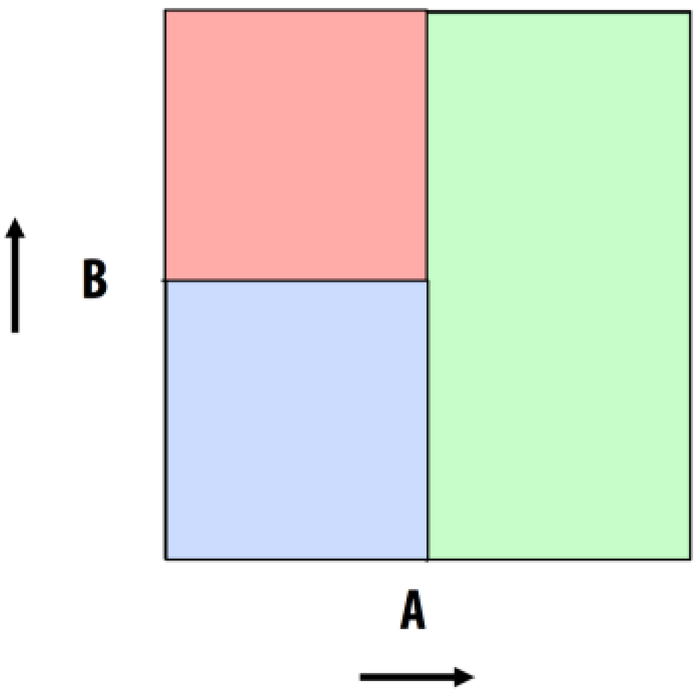
- Quickly reject objects that are outside the viewing volume
- Query for intersections efficiently

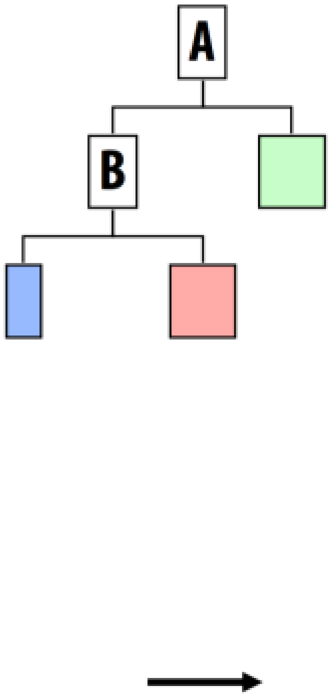
Spatial Hierarchies



Letters correspond to planes (A)

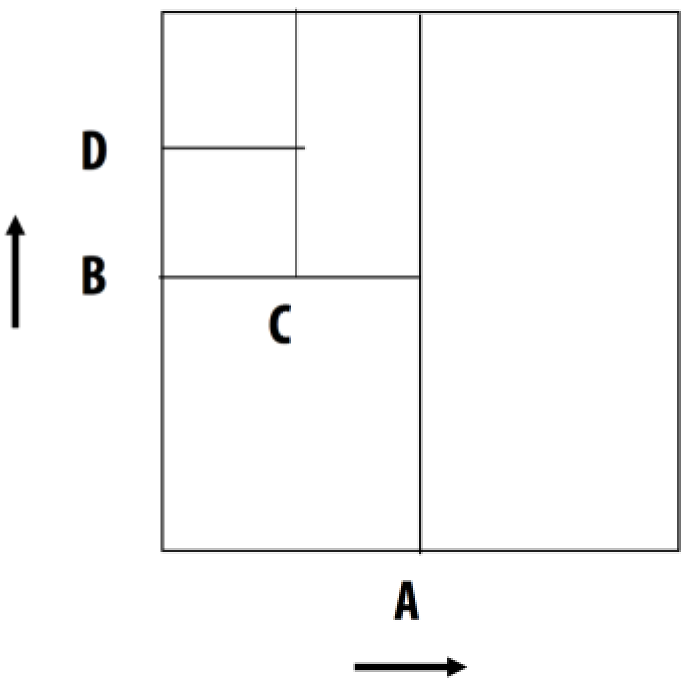
Spatial Hierarchies

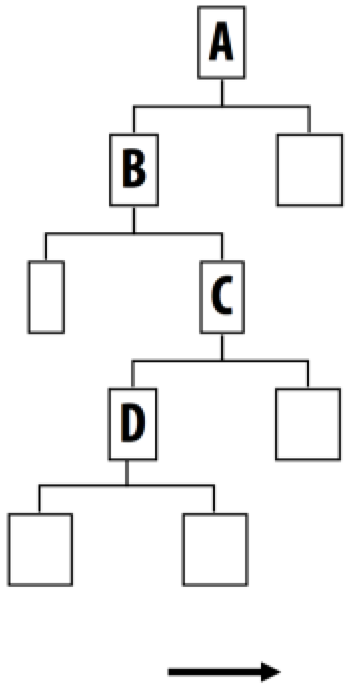




Letters correspond to planes (A,B)

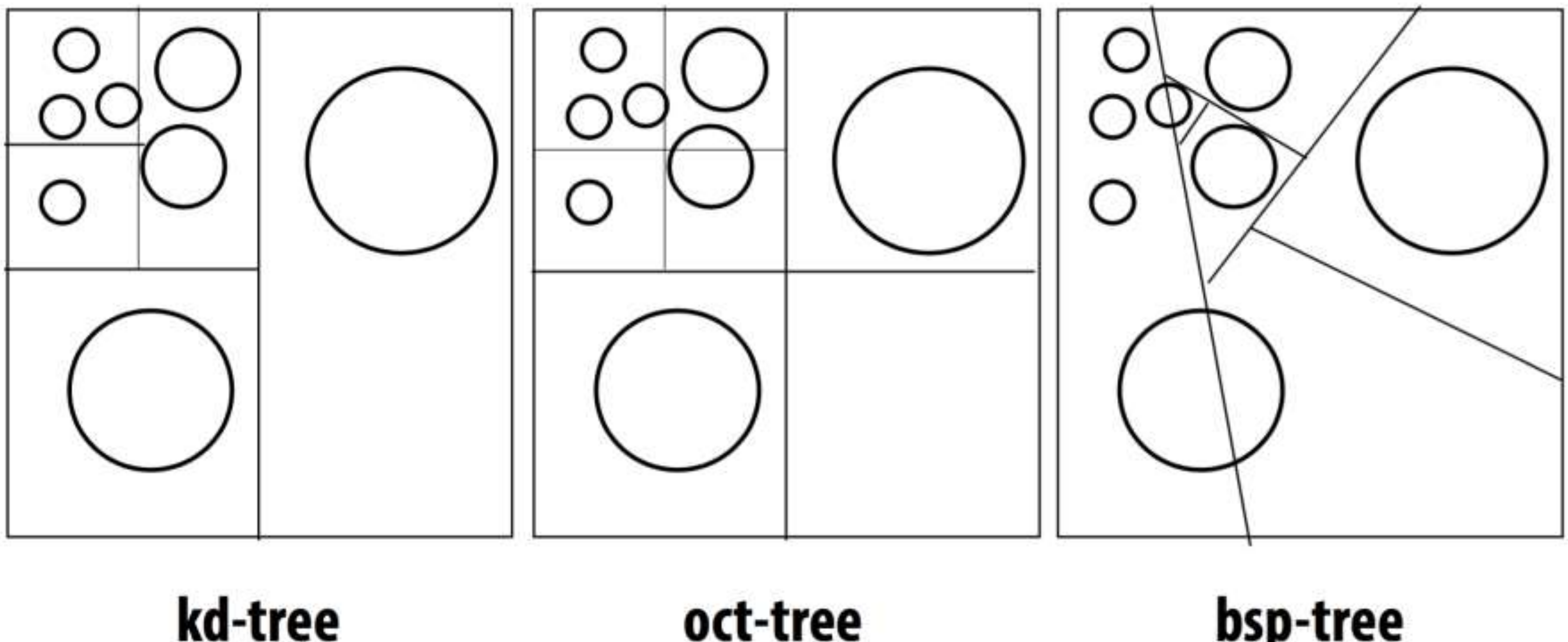
Spatial Hierarchies





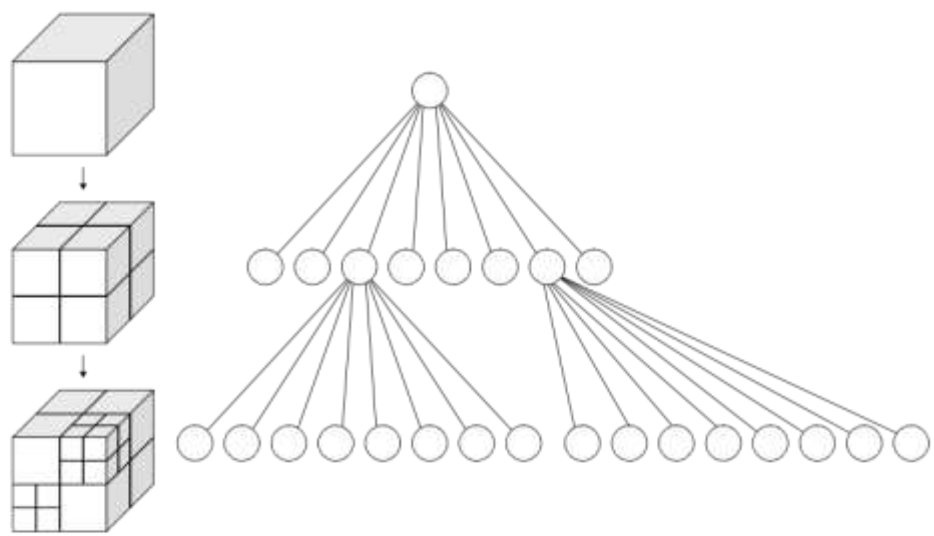
Letters correspond to planes (A,B,C,D)

Spatial Hierarchies: Variations



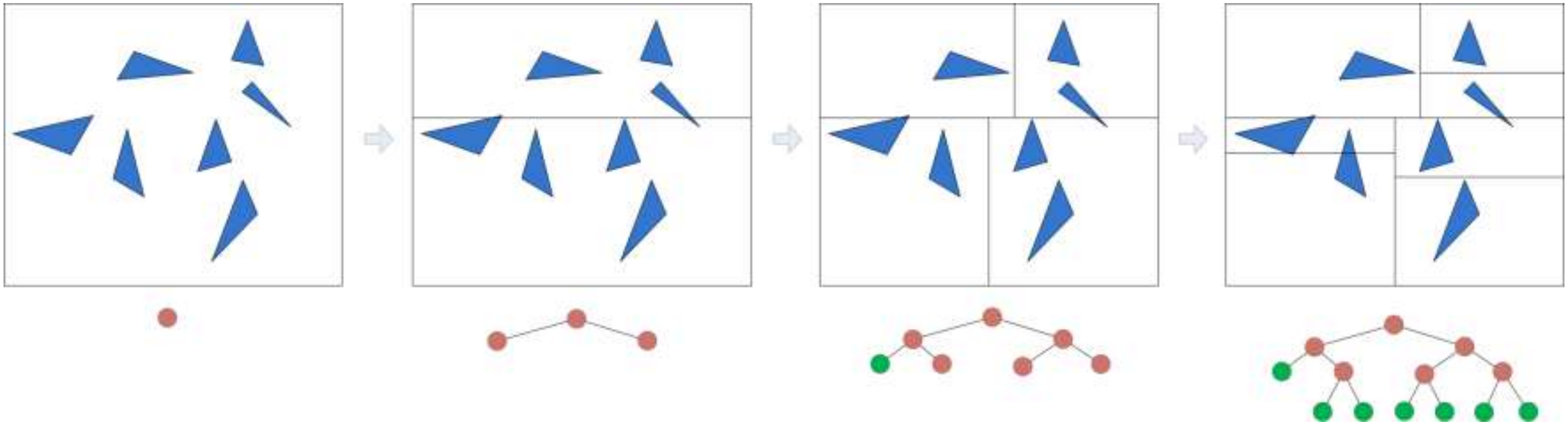
Octree

- Each node has 0 or 8 children
  - Each node can equally subdivide its space (an AABB) into eight subboxes by 3 midplanes
  - Children of a node are contained within the box of the node itself
  - Stop subdividing when number of objects/primitives falls below a threshold or maximum depth has reached.
- Recursively render cells that intersects with the viewing volume



K-d Tree

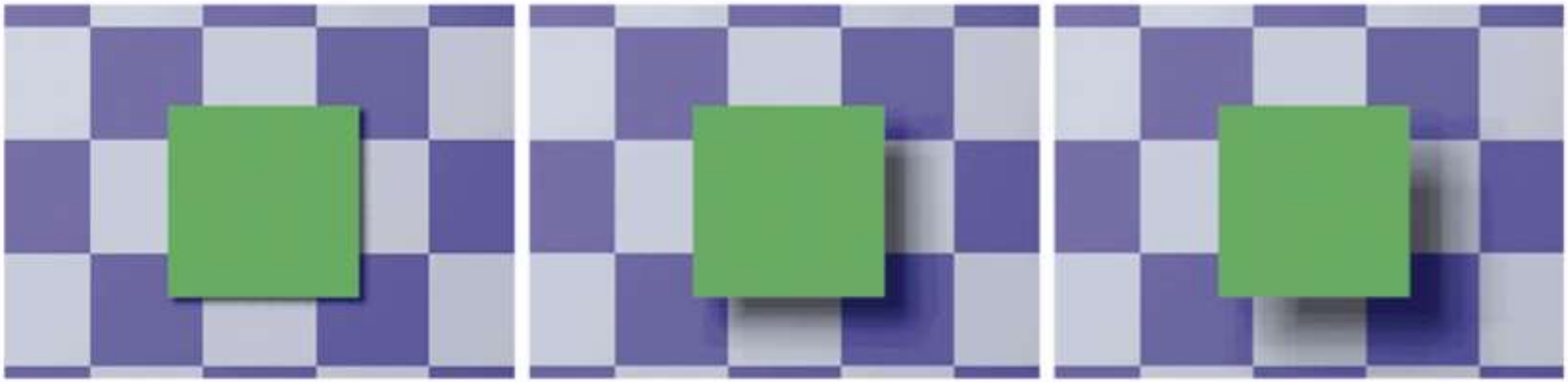
- Begin with the global bounding box containing all primitives.
- Choose an axis and a splitting plane perpendicular to that axis
- Subdivide the primitives on both sides of the plane into two groups
  - Usually done in a balanced manner
- Stop when the number of primitives in each single group is below a threshold



Shadows

Shadows

Shadows: Spatial Cue

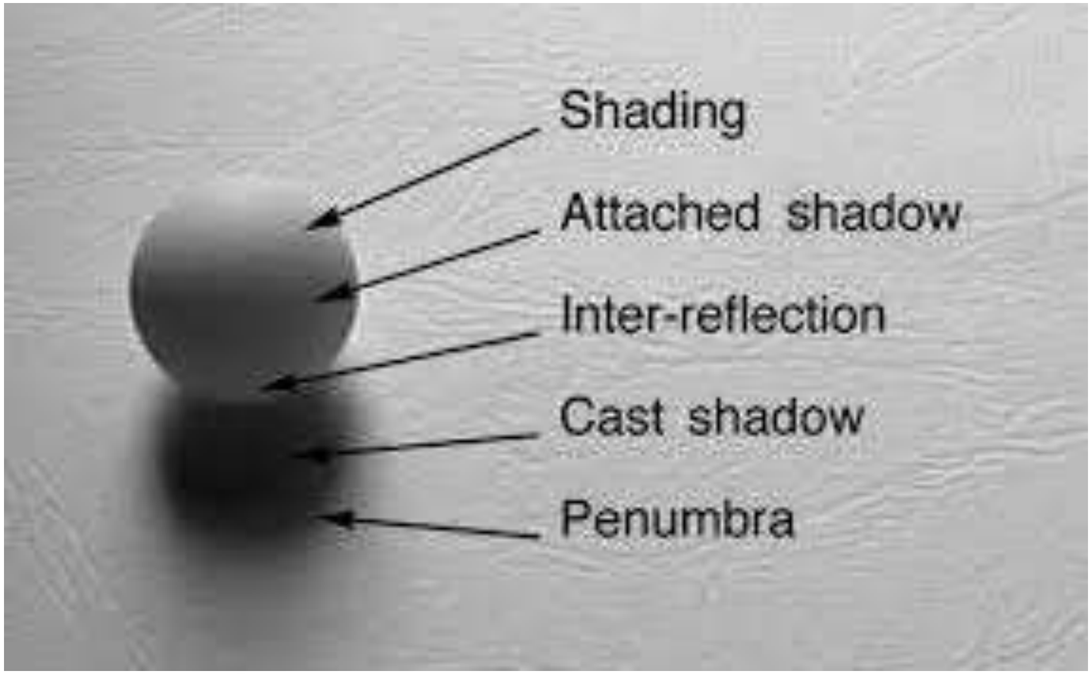


http://mamassian.free.fr/papers/mamassian_tics98.pdf

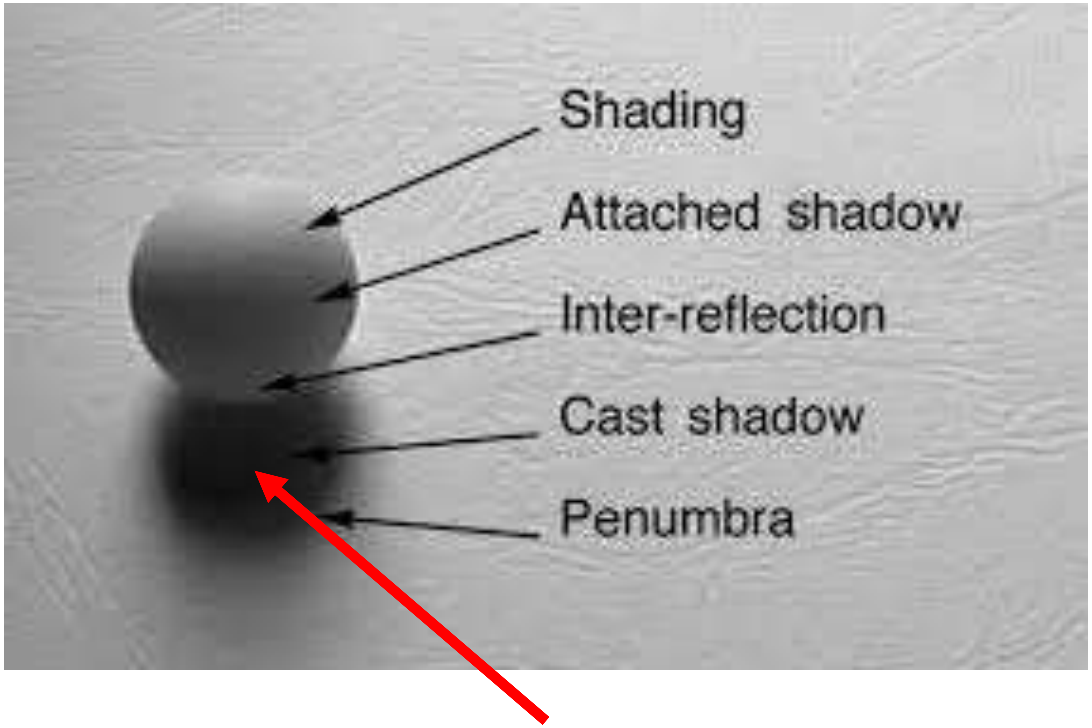
Shadows: Realism

http://ivl.calit2.net/wiki/images/5/55/17_ShadowMappingS15.pdf

Shadow


Shading
Attached shadow
Inter-reflection
Cast shadow
Penumbra

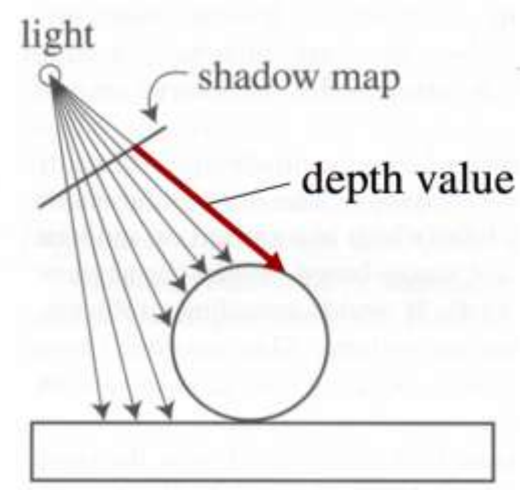
Shadow



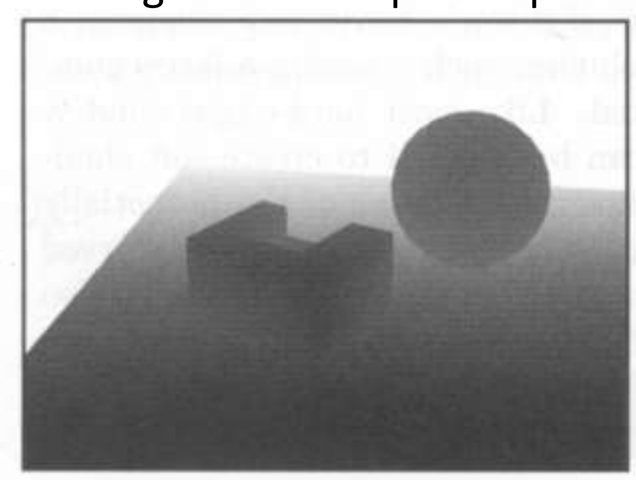
We will only concentrate on hard-shadows

Shadow Mapping

- **First Pass**
  - Render the Scene from the light Source
    - Pretend the light is the “camera”
  - Store the depth buffer as a texture
    - Heightfield – tells us the “distance” of the nearest points from the light source.



Light’s POV depth map



Shadow Mapping

- **Second Pass**
  - Project the depth buffer texture from the light's P.O.V
  - Render the scene from the camera position

Recall Projective Texturing

Projective Texturing (RECALL)

- Map NDC (-1 , 1) to Texture Coordinate space (0-1)
  - Scale and add Bias

$$\begin{bmatrix} s'' \\ t'' \\ r'' \\ q'' \end{bmatrix}_{\text{TextureSpace}} = \begin{bmatrix} 0.5 & 0 & 0 & 0.5 \\ 0 & 0.5 & 0 & 0.5 \\ 0 & 0 & 0.5 & 0.5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} s' \\ t' \\ r' \\ q' \end{bmatrix}_{\text{NDC}}$$

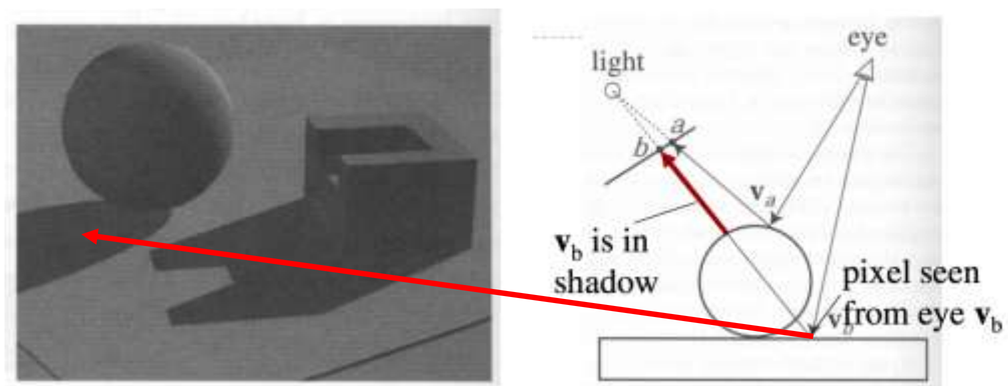
Final texture coordinates after perspective-correct interpolation of (s'', t'', r'', q'')

$$\left(\frac{s''}{q''}, \frac{t''}{q''}, \boxed{\frac{r''}{q''}} \right)$$

Compare this with depth

Shadow Mapping

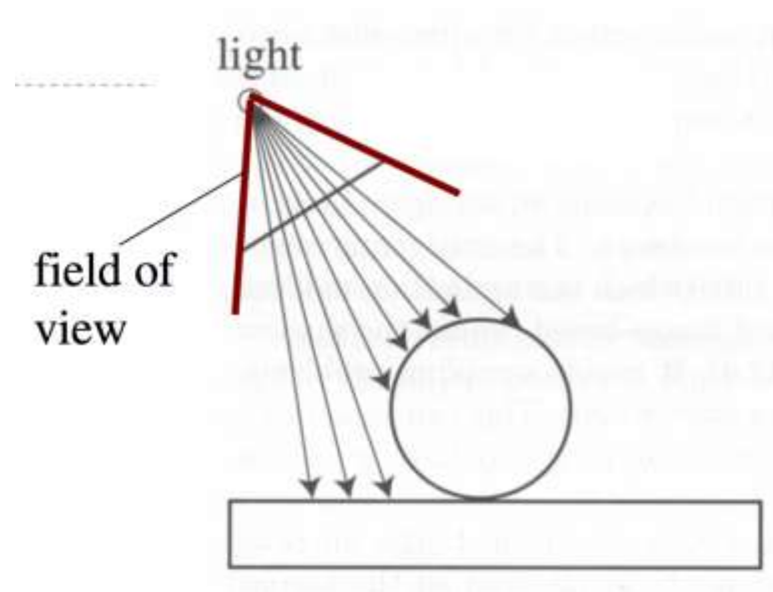
- **Second Pass**
  - Project the depth buffer texture from the light's P.O.V
  - Render the scene from the camera position
  - Compare fragment's depth (projected r texture coordinate) to the depth stored in texture




```
// GLSL
depthMapValue = texture( depthTexture, projCoords.st / projCoords.q );
fragmentDepth = (projCoords.r / projCoords.q);
float shadow =  fragmentDepth > depthMapValue ? 1 : 0;
```

Shadow Mapping: Issues

- Limited field of view of depth map



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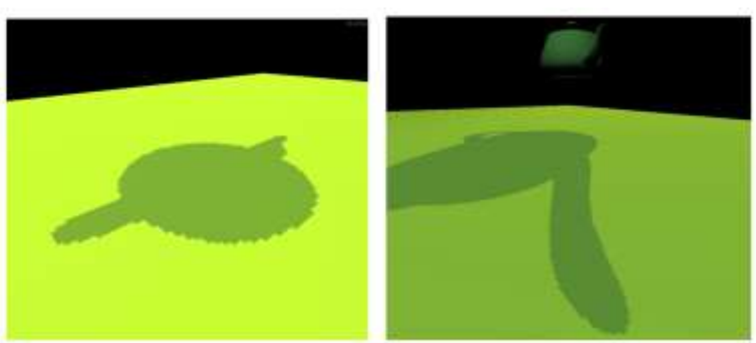
  - Add scale and bias – similar to glPolygonOffset
  - Getting it right is complicated

Shadow Mapping: Issues

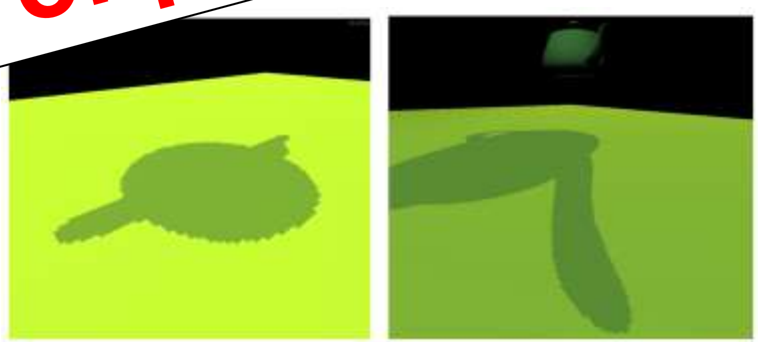
- Limited field of view of depth map
- Z-Fighting
  - Add scale and bias – similar to glPolygonOffset
  - Getting it right is complicated
- Sampling problem (aliasing)
  - Larger depth map may mitigate some of it



Shadow Mapping: Issues

- Limited field of view of depth map
- Z-Fighting
  - Add scale and bias – similar to glPolygon
  - Getting it right is complicate
- Sampling probl
  - may mitigate some of it

Lots of paper about soft shadows



Deferred Rendering

a.k.a Deferred Shading

Deferred Rendering

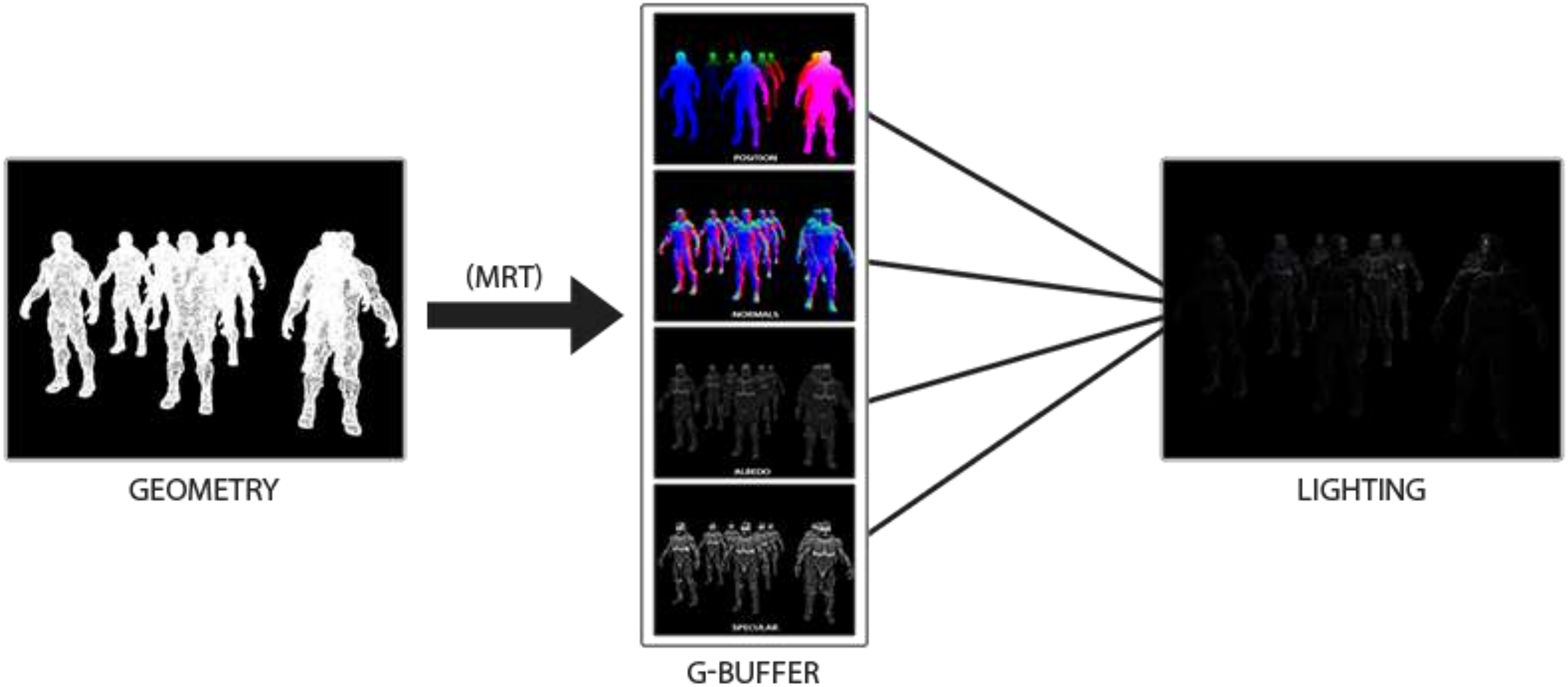
- So far: we did **Forward Rendering**
- Lots of fragments are wasted due to overdraw
  - Complex Lighting/Shading computation wasted
- Solution: “Defer” lighting computation until we have figured out all the pixels that end up on the screen
- Deferred Rendering can handle lots of lights
- Complexity:
  - Forward Rendering: Num_Objects * Num_Light
  - Deferred Rendering: Num_Object + Num_Light

http://learnopengl.com/#!Advanced-Lighting/Deferred-Shading

Deferred Rendering

Two Pass

1. Geometry Pass
2. Lighting Pass



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Deferred Rendering

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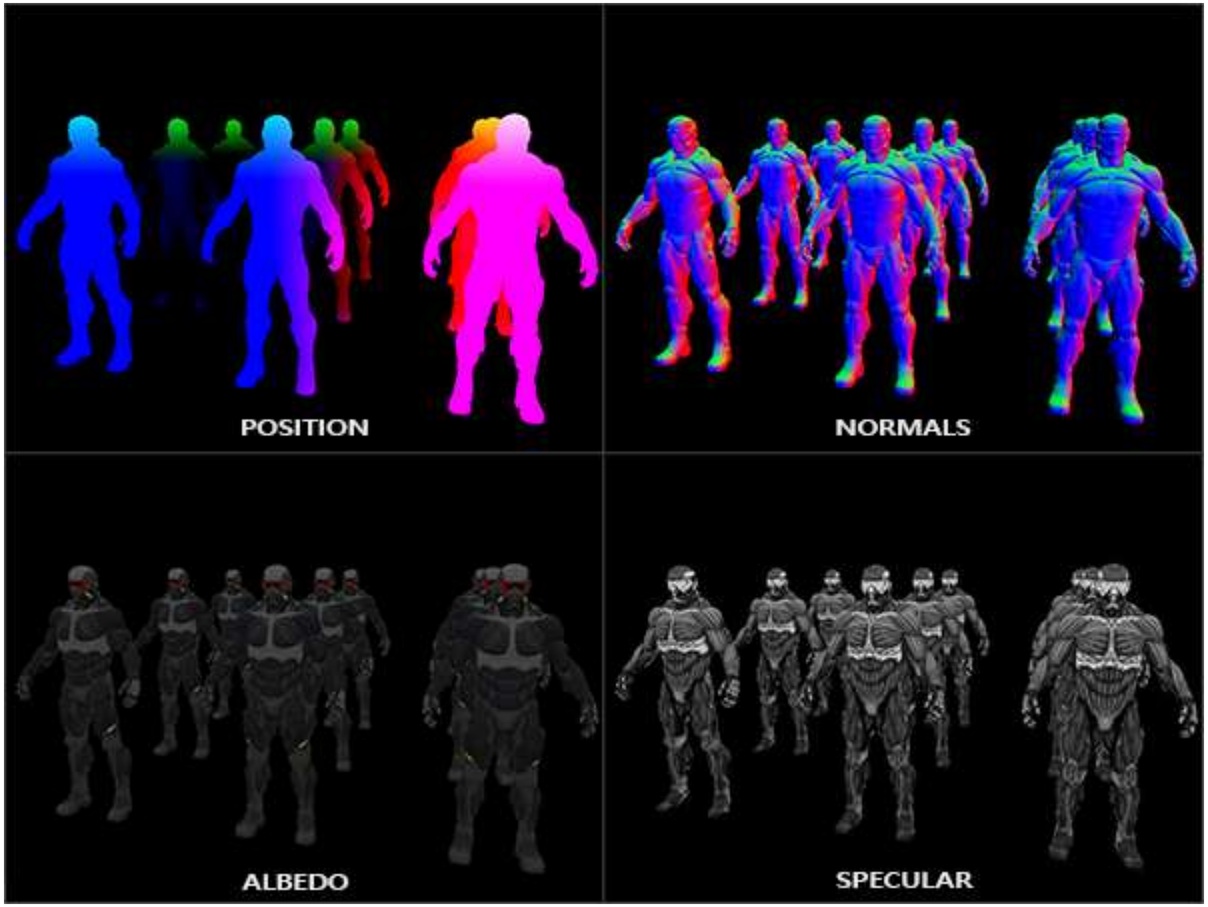


http://learnopengl.com/#!Advanced-Lighting/Deferred-Shading

Deferred Rendering

- Transparency still done through Forward Rendering
  - Need to copy the Depth Buffer.

http://learnopengl.com/#!Advanced-Lighting/Deferred-Shading

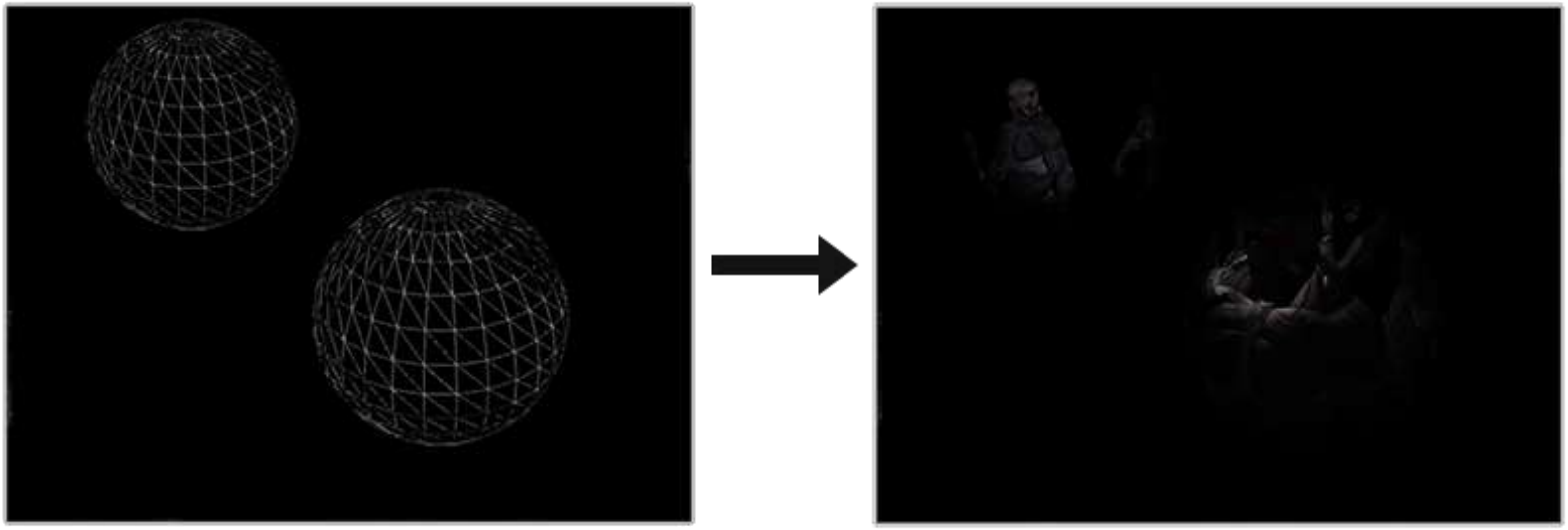
Deferred Rendering: Lots of Light

- Can handle lots of light: key is **Light Volume**
  - Shade pixels that are close to a light
  - Why does not “if-else” branch work for this on the GPU?

http://learnopengl.com/#!Advanced-Lighting/Deferred-Shading

Deferred Rendering: Lots of Light

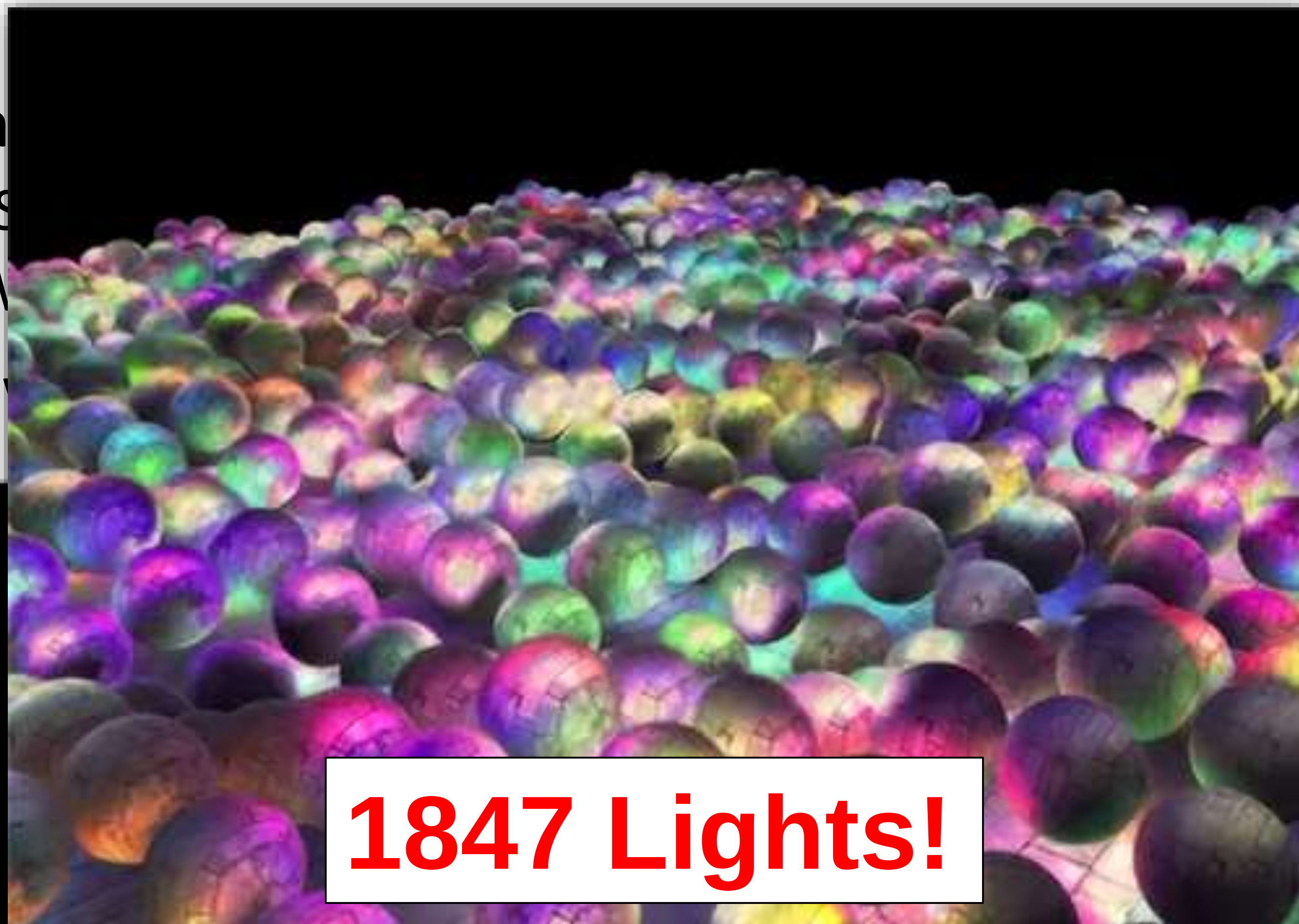
- Can handle lots of light: key is **Light Volume**
  - Shade pixels that are close to a light
  - Why does not "if-else" branch work for this on the GPU?
- Draw one light volume at a time: accumulate colors



http://learnopengl.com/#!Advanced-Lighting/Deferred-Shading

Deferred Rendering: Lots of Light

- Can
  - S
  - V GPU?
- Dra lors



http://learnopengl.com/#!Advanced-Lighting/Deferred-Shading

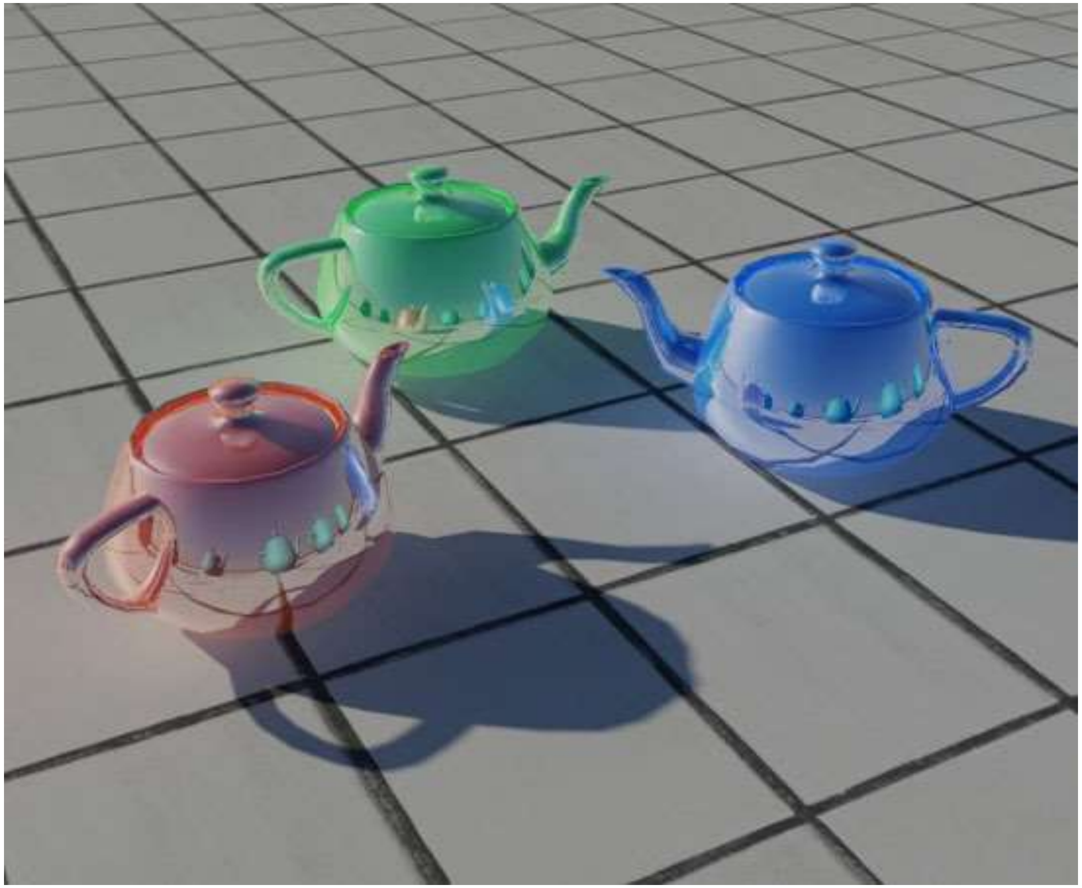
Deferred Rendering: Challenges

- Doesn’t support MSAA (Multiple Sample Anti-Aliasing)
- Extra frame buffer memory
- Transparencies need to be done with Forward Rendering

http://learnopengl.com/#!Advanced-Lighting/Deferred-Shading

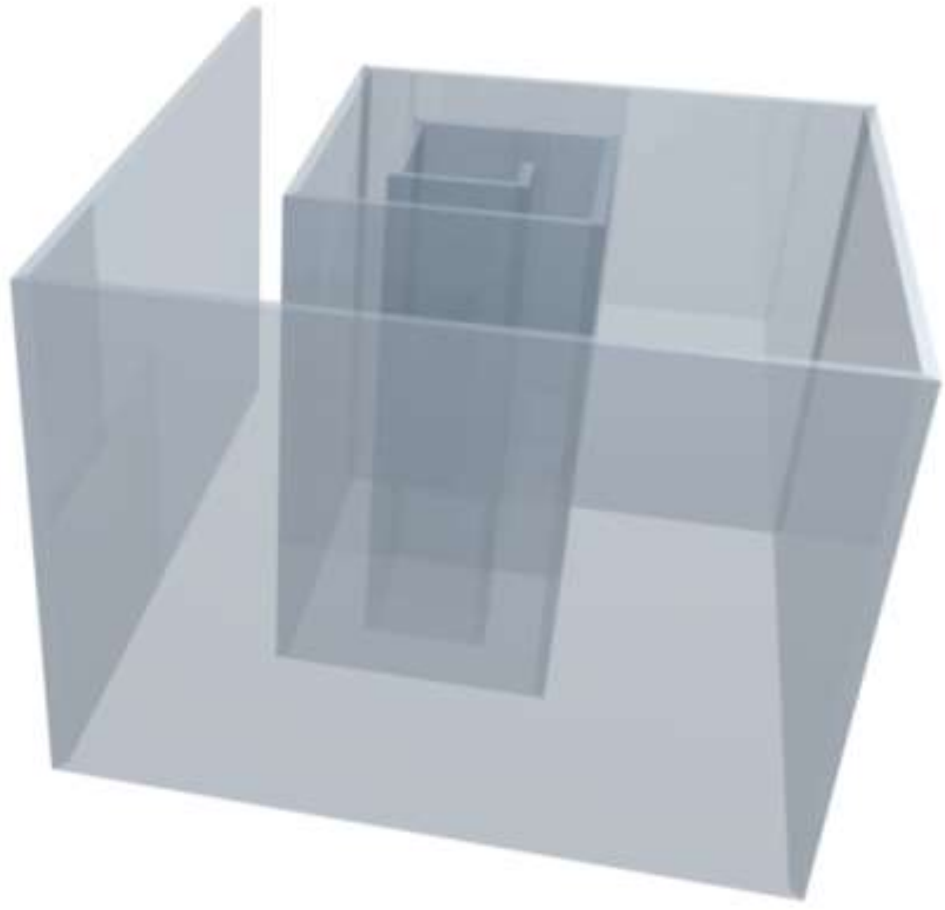
Challenges of Rasterizers

Shadows and Reflections



http://artist-3d.com/free_3d_models/uploads/mantalray.jpg

Transparencies



http://www.archicadwiki.com/Bugs/TransparencyIn3dWindow

Depth of Field

http://www.seemsartless.com/guides/camera-dof-cars-fast-360.jpg

Basics of 3D Rendering

CS 148: Summer 2016
Introduction of Graphics and Imaging
Zahid Hossain

http://www.pling.org.uk/cs/cgv.html