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# **Computer Graphics**

## **13 - Rasterization & Visibility**

Yoonsang Lee  
Spring 2021

# 기말고사 모의테스트 1 분석 결과

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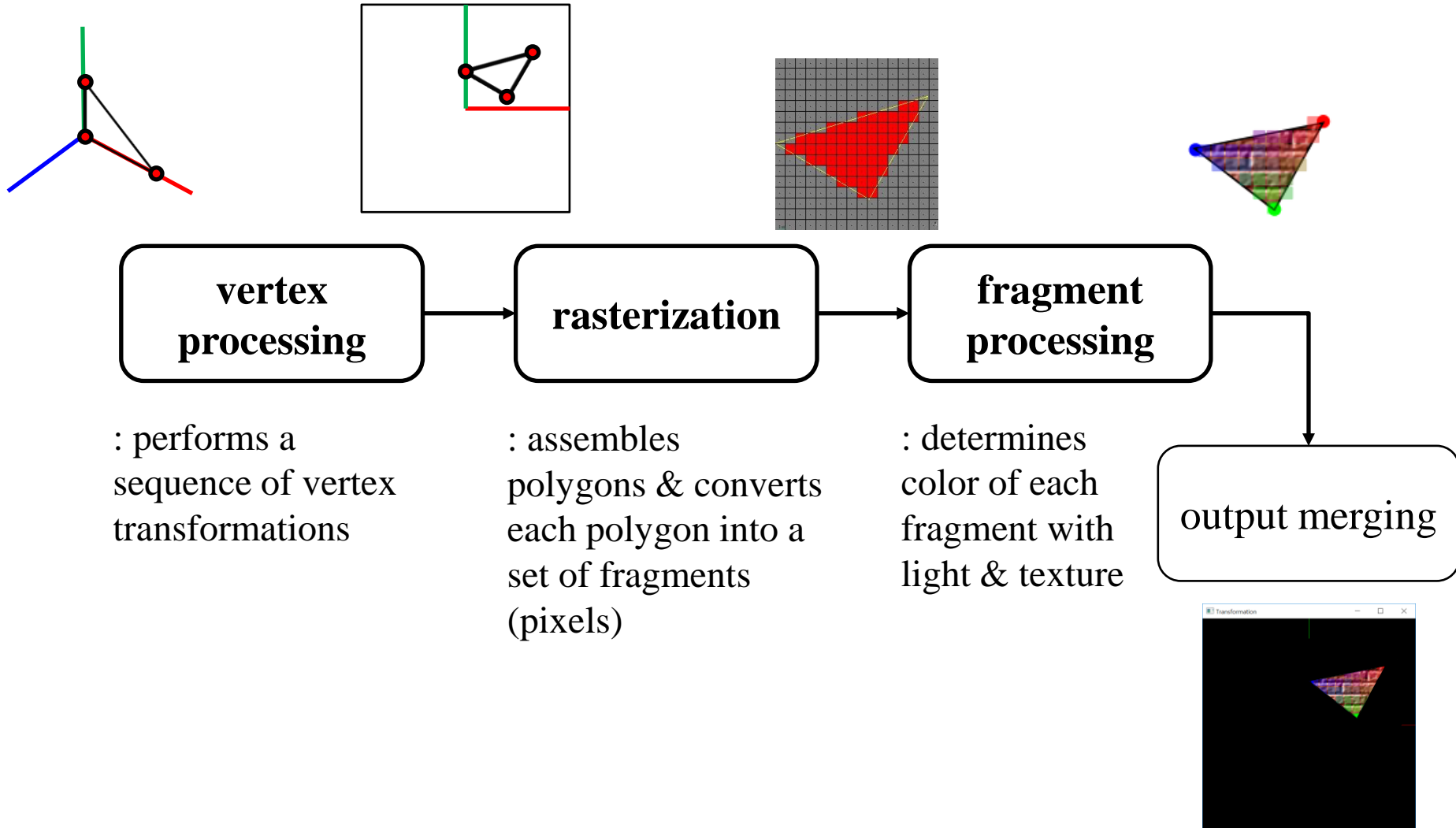
- 다음과 같은 부정행위로 간주될 수 있는 사례들이 있었음.
  - 시험 도중 손이나 머리가 카메라에 잘 보이지 않음 - 3명+
  - 카메라 혹은 모니터 각도로 인해 화면이 잘 보이지 않음 - 6명+
  - 빛이나 모니터 밝기에 의해 화면이 잘 보이지 않음 - 9명+
  - 녹화된 영상이 90도 회전해 있음 - 2명+
  - 주변에 다른 디바이스 스크린이 존재 - 6명+
  - 시험 종료 시간 전에 PC로 다른 작업을 함 - 5명+
  - 카메라가 준비되지 않음 - 10명+
- 
- 내일 있을 모의테스트 2에 모두 성실히 임해주기 바랍니다.
    - 미응시하는 경우 실습 결석으로 체크할 예정

# Topics Covered

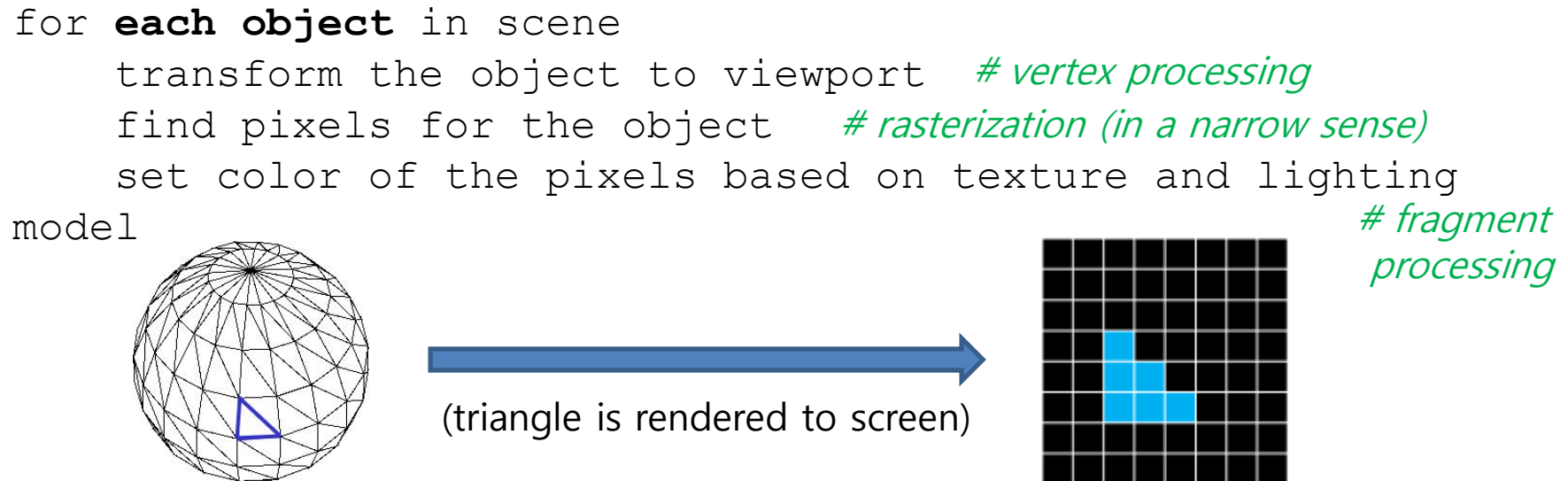
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- Two Approaches for Rendering
  - Object-oriented (Rasterization)
  - Image-oriented (Raytracing)
- Rasterization (in a narrow sense)
  - Line / Polygon Drawing
- Visibility Problem
  - Clipping (Viewing frustum culling)
  - Back-face culling
  - Hidden surface removal
- Rendering (Graphics) Pipeline Again
- Course Wrap-up

# Recall: Rendering (Graphics) Pipeline



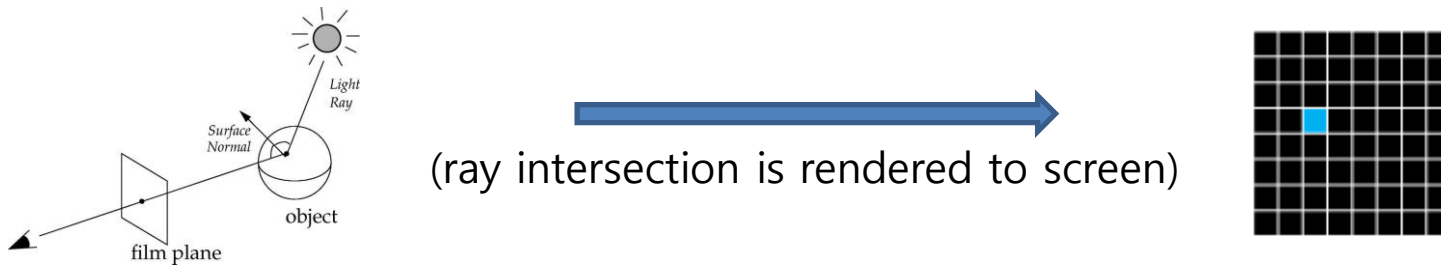
# Two Approaches for Rendering - 1



- This is called **rendering (graphics) pipeline**
- or **rasterization** (in a broad sense)
- or **object-oriented rendering**.

# Two Approaches for Rendering - 2

for **each pixel** in image(film plane)  
determine which object should be shown at the pixel  
set color of the pixel based on texture and lighting model



- This is called **ray tracing**
- or **image-oriented rendering**.
- We'll skip ray tracing part, see *13 - reference-RayTracing.pdf* for more information about it.

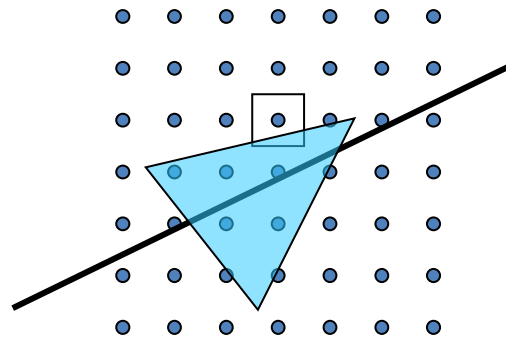
# Rasterization (in a broad sense) & Ray Tracing in this Course

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- Most topics we've covered are *fundamental concepts* of computer graphics, regardless of these two rendering approaches.
  - Transformations, Hierarchical Modeling, Orientation & Rotation, Kinematics & Animation
  - Mesh, Lighting & Shading, Curves, Texture Mapping
- Except some topics:
  - Rendering Pipeline, Viewing / Projection / Viewport transformations
  - Rasterization & Visibility (today's topic)
- are specific to **rasterization** (in a broad sense).

# Rasterization (in a narrow sense)

- Rasterization converts vertex representation to pixel representation (fragments)



- First job: Compute which pixels belong to a primitive
  - to enumerate the pixels covered by the primitive
- Second job: Interpolate values across the primitive
  - e.g. colors computed at vertices
  - e.g. normals at vertices



# Rasterization (in a narrow sense)

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- A primitive can be a point, line, or polygon
- Line drawing algorithms
  - Digital differential analyzer (DDA)
  - Bresenham's (a.k.a. Midpoint)
  - Xiaolin Wu's
- Polygon drawing algorithms
  - Scanline
  - Boundary fill
  - Flood fill

# Rasterization (in a narrow sense)

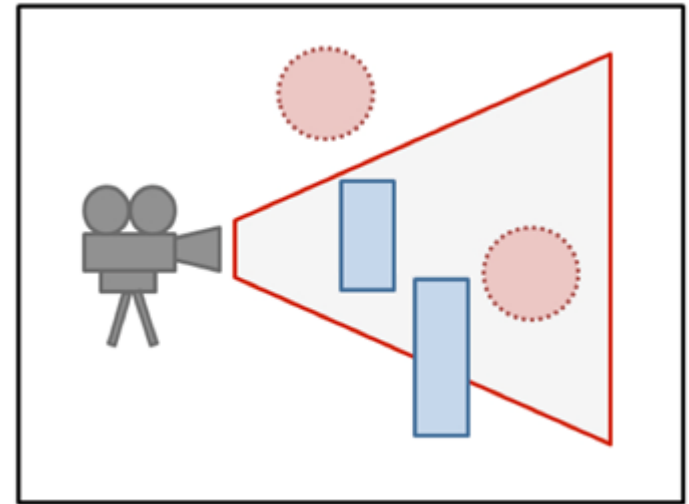
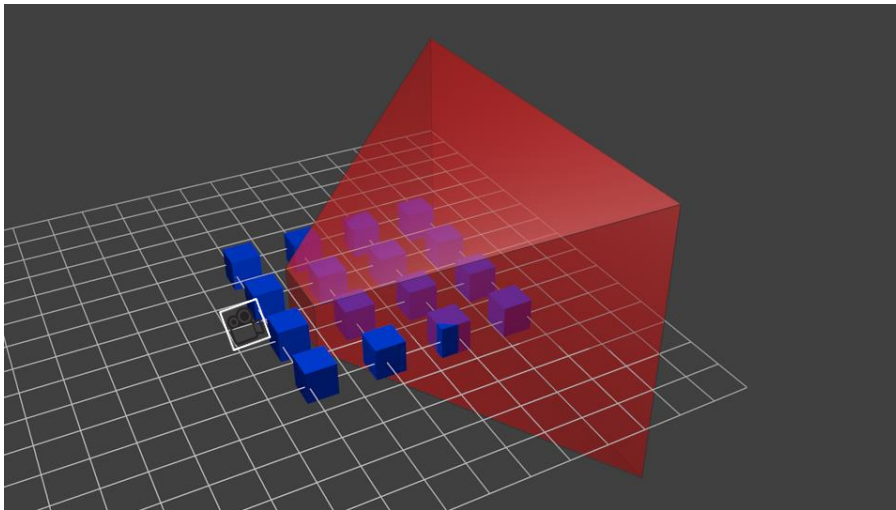
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- But, we'll just skip details of these algorithms.
- Actually, line drawing and polygon drawing are not so easy as one might think.
  - Computational efficiency, anti-aliasing, ...
- But most graphics APIs (including OpenGL) basically support these operations.
  - These algorithms were intensively studied in early days of computer graphics, so quite mature now.
  - Now basic algorithms are implemented in graphics hardware (GPU) and you can use them by calling such graphics APIs.
- So nowadays you can think lines and polygons as “primitives” that are basically rendered.

# Visibility Problem

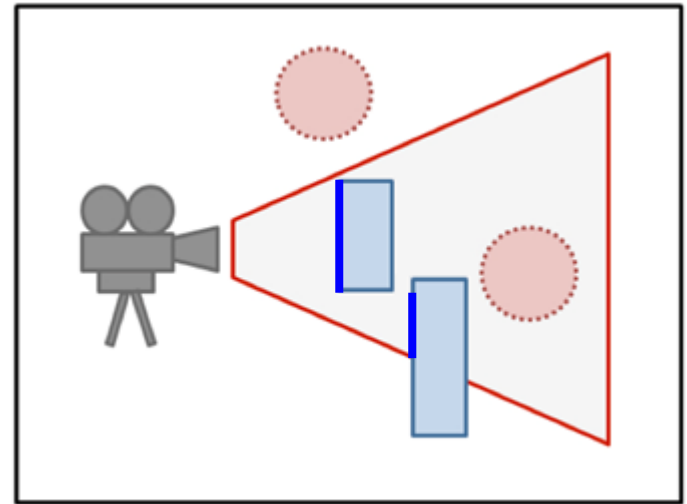
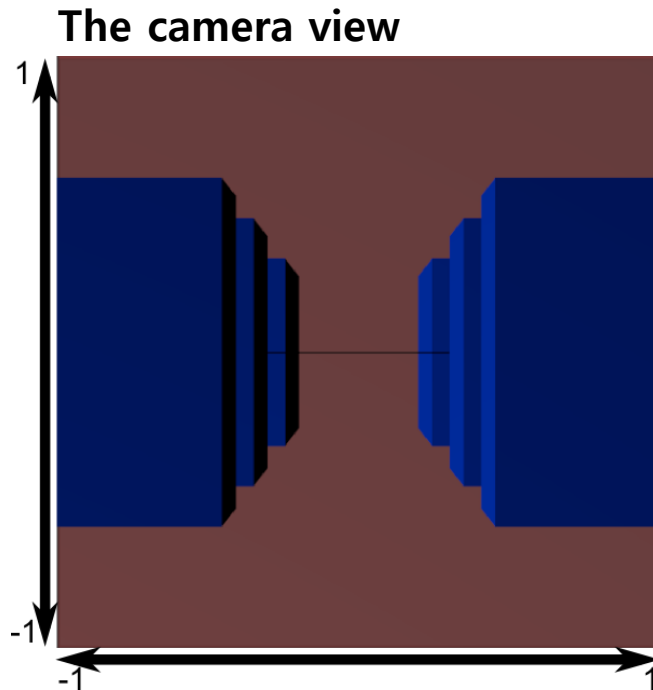
- What is VISIBLE?

Red: viewing frustum, Blue: objects



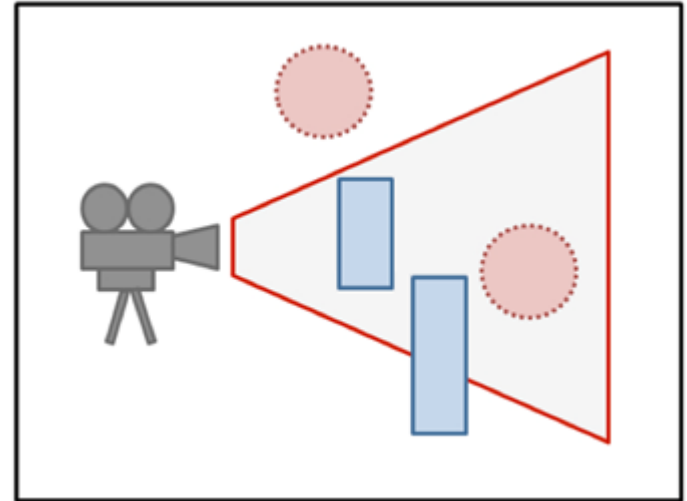
# Visibility Problem

- The answer is:



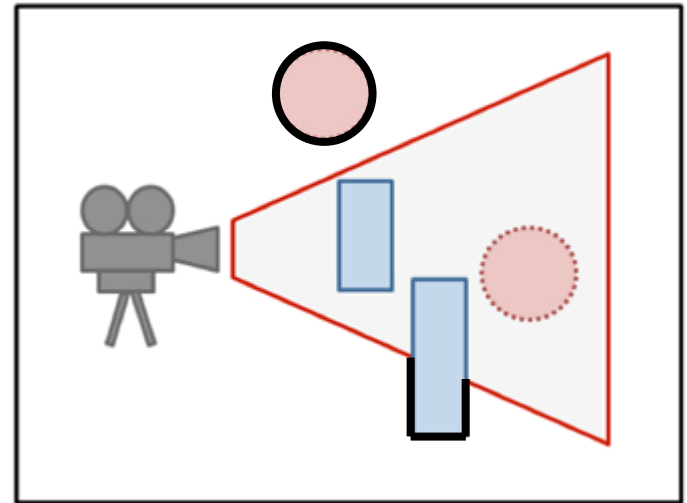
# Visibility Problem

- What is NOT VISIBLE?



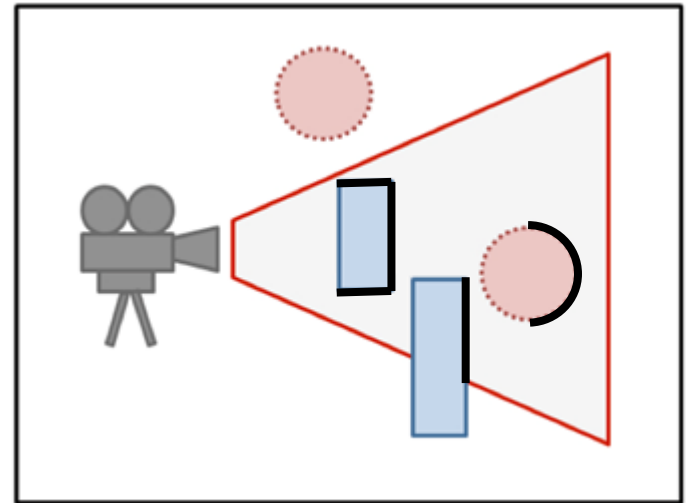
# Visibility Problem

- What is NOT VISIBLE?
- **Primitives outside of the viewing frustum**



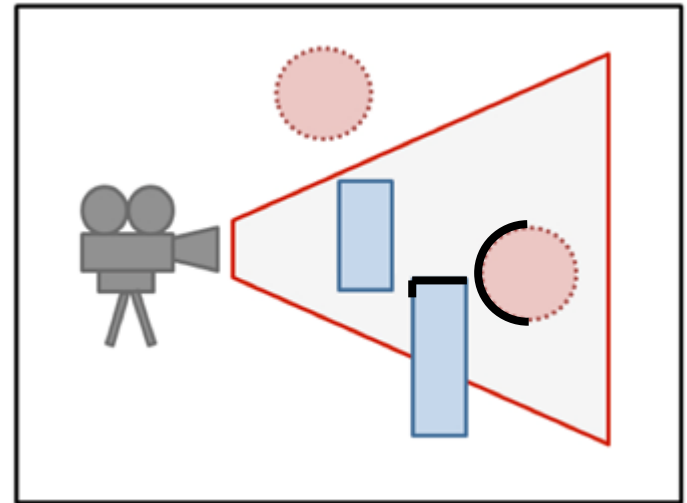
# Visibility Problem

- What is NOT VISIBLE?
- Primitives outside of the viewing frustum
- **Back-facing primitives**



# Visibility Problem

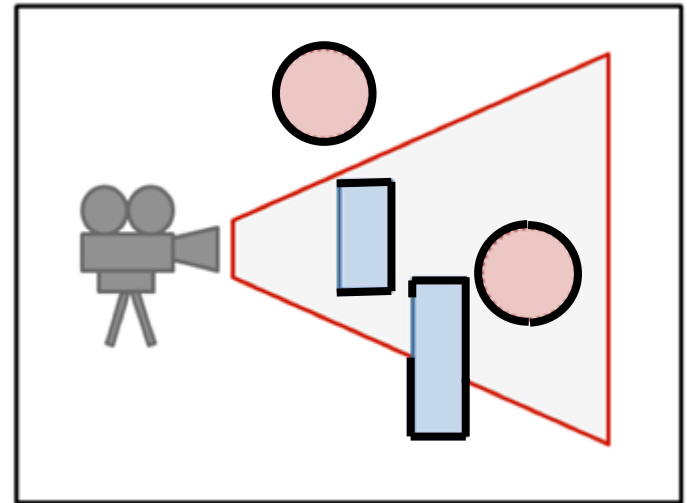
- What is NOT VISIBLE?
- Primitives outside of the viewing frustum
- Back-facing primitives
- **Primitives occluded by other objects closer to the camera**





# Visibility Problem

- These **invisible primitives** should be removed because...
- No need to spend time to process invisible vertices and polygons.
- A close object must hide a farther one.
- So, removing these primitives is required for efficient and correct rendering.



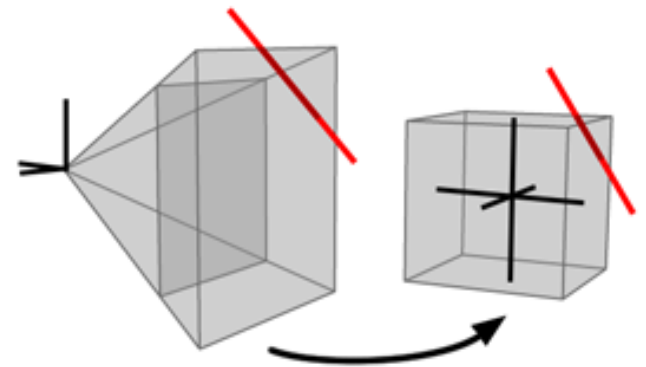
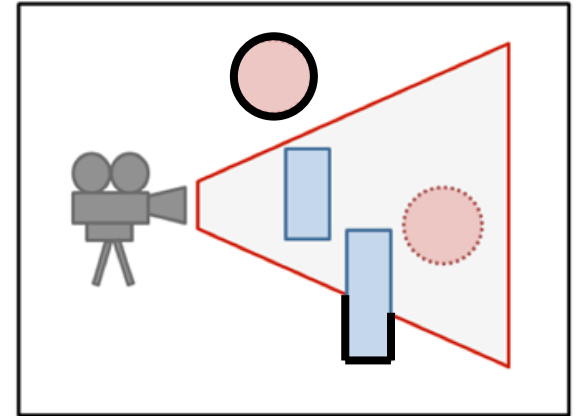
# Visibility Problem

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- Removing...
- Primitives outside of the viewing frustum
- → **Clipping (Viewing frustum culling)**
- Back-facing primitives
- → **Back-face culling**
- Primitives occluded by other objects closer to the camera
- → **Hidden surface removal**

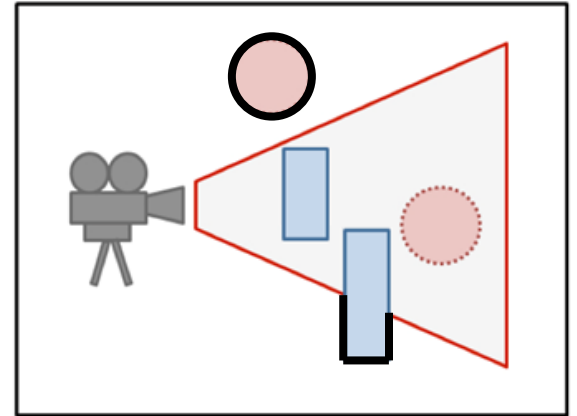
# Clipping (Viewing Frustum Culling)

- Removing primitives outside of the viewing frustum
- Clipping is much easier with canonical view volume.
  - actually done in *clip space*



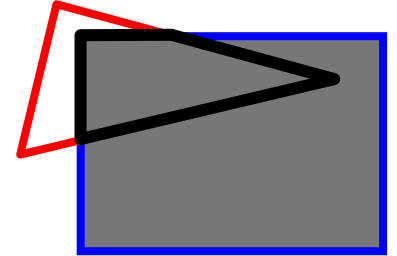
# Clipping (Viewing Frustum Culling)

- Line clipping algorithms
  - Cohen–Sutherland
  - Liang–Barsky
  - Cyrus–Beck
- Polygon clipping algorithms
  - Sutherland–Hodgman
  - Weiler–Atherton



# Clipping (Viewing Frustum Culling)

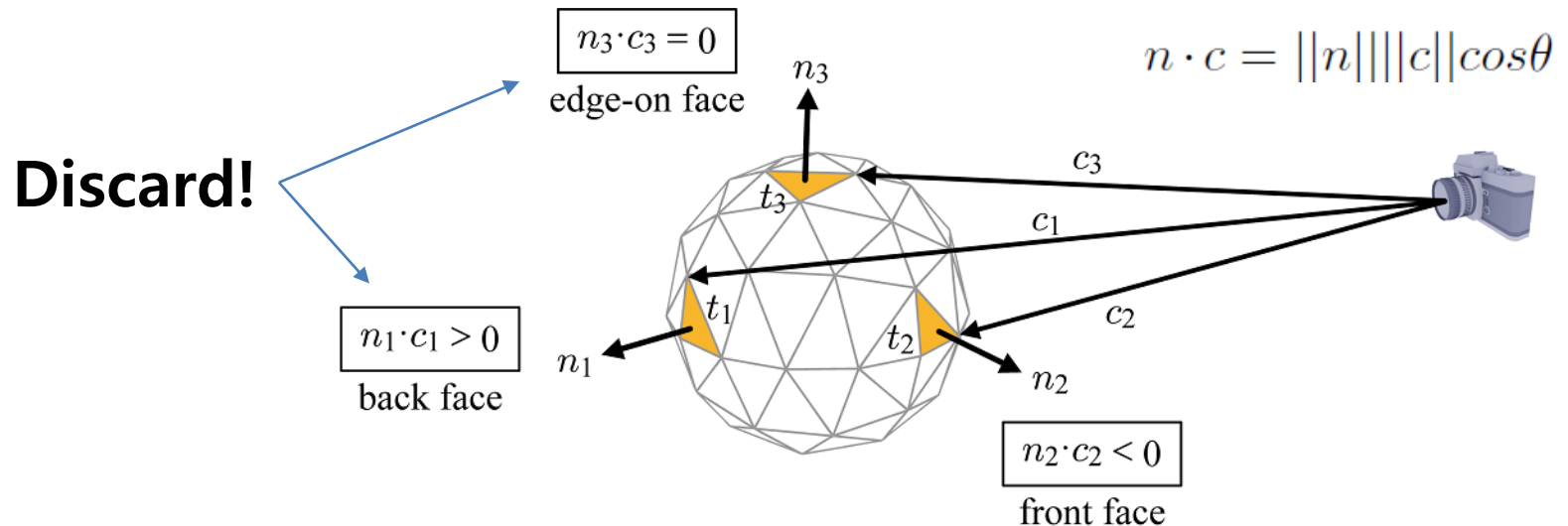
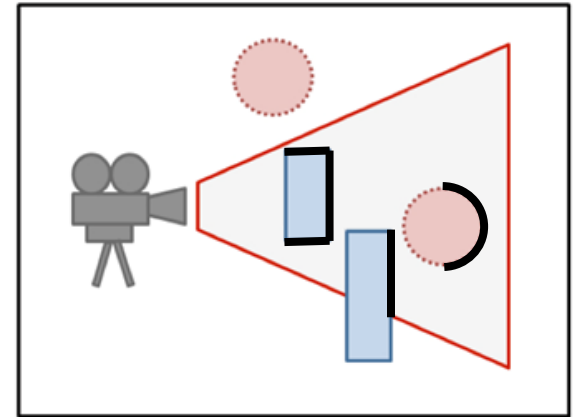
- Polygon clipping algorithms are more complicated.
  - Vertices may be added to or deleted from the triangle.
- Again, let's just skip details of these algorithms.
- Most graphics APIs (including OpenGL) performs clipping by default.
  - You just set the view frustum, then OpenGL will do clipping for you.
- *13 - reference-rasterization,clipping.pdf* has brief slides about DDA (line drawing) & Cohen-Sutherland algorithms (line clipping). If you're interested, please refer it.



triangle → quad

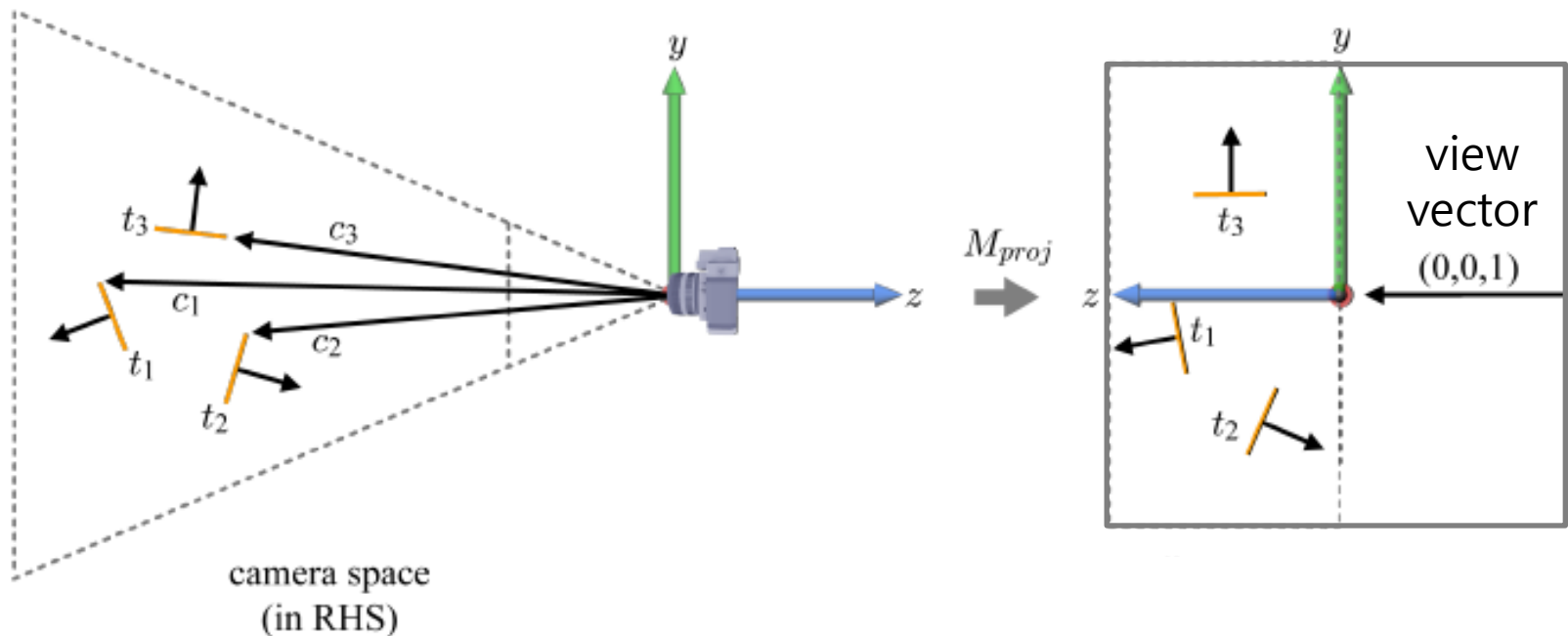
# Back-Face Culling

- Removing back-facing primitives
- Determined by the dot product of normal and view (camera) vectors.

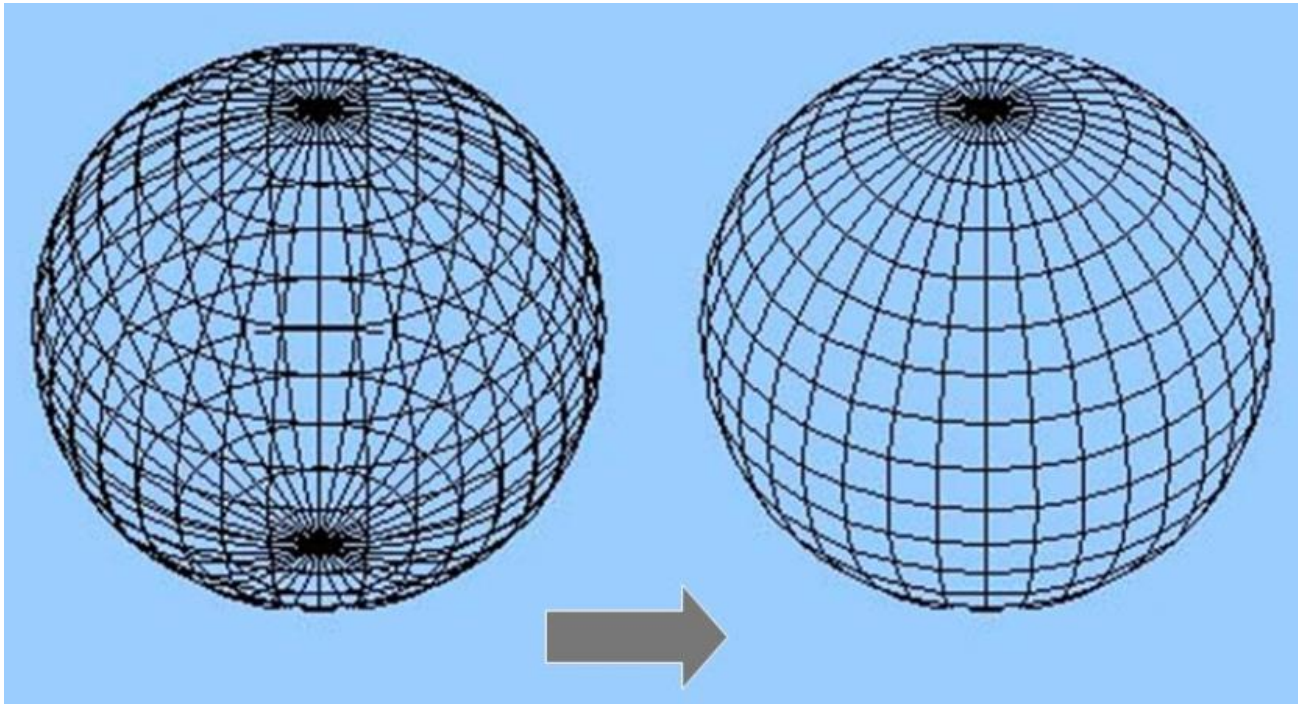


# Back-Face Culling

- Back-face culling is much more efficient when performed in canonical view volume.
  - Because in canonical view volume, we can use a single view vector,  $(0,0,1)$ .



# Back-Face Culling



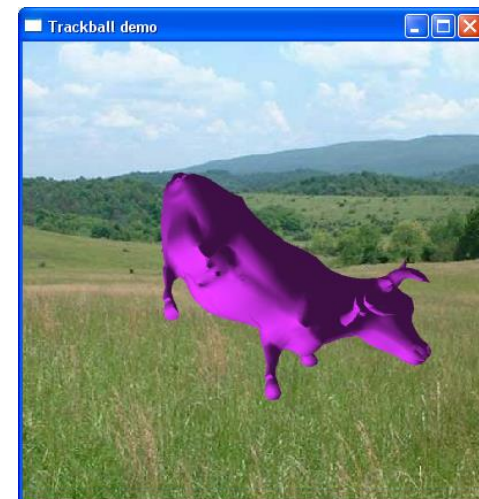


# Back-Face Culling in OpenGL

- Can cull front faces or back faces
- Back-face culling can sometimes double performance

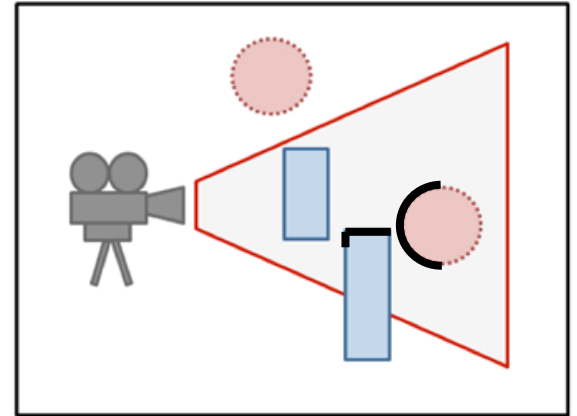
```
if (cull):  
    glFrontFace(GL_CCW)           (initial value: GL_CCW)  
    glEnable(GL_CULL_FACE)       # define winding order  
    glCullFace(GL_BACK)          # enable Culling (initially disabled)  
                                # which faces to cull  
else:  
    glDisable(GL_CULL_FACE)
```

You can also do front-face culling!



# Hidden Surface Removal

- Removing primitives occluded by other objects closer to the camera
- Also known as
  - Hidden Surface Elimination
  - Hidden Surface Determination
  - Visible Surface Determination
  - Occlusion Culling



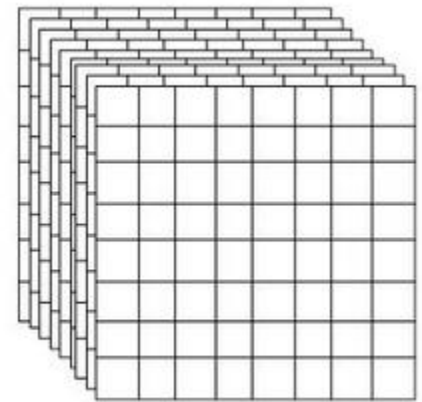
# Hidden Surface Removal

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- Many algorithms
  - Z-buffer (Depth buffer)
  - Painter's algorithm
  - BSP tree
  - ...
- Z-buffer is the standard method.
- Let's see the ideas of Painter's algorithm & Z-buffer.

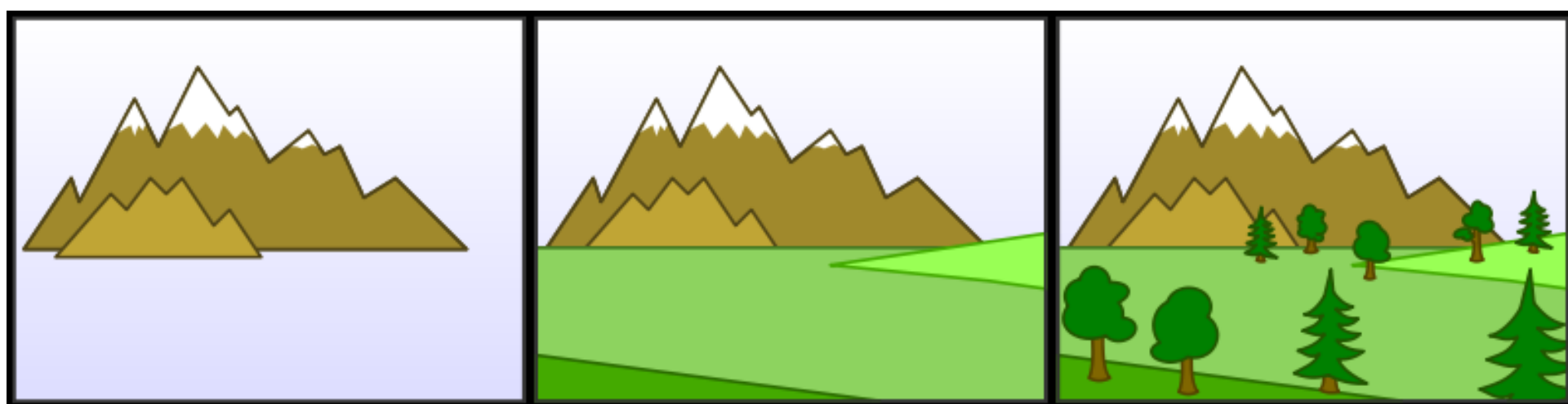
# Frame Buffer (background knowledge for understanding HSR algorithms)

- Frame buffer is the portion of memory to hold the bitmapped image that is sent to the (raster) display device.
- A frame buffer is characterized by its width, height, and depth.
  - E.g. The frame buffer size for 4K UHD resolution with 32bit color depth =  $3840 \times 2160 \times 32$  bits
- Typically stored on the graphic card's memory.
  - But integrated graphics (e.g. Intel HD Graphics) use the main memory to store the frame buffer.



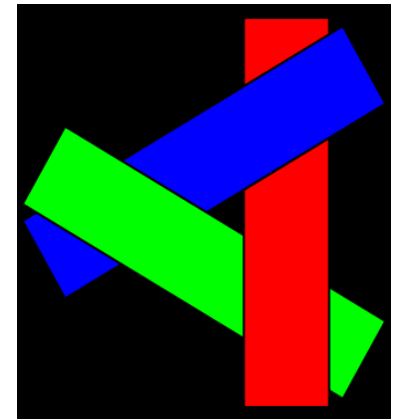
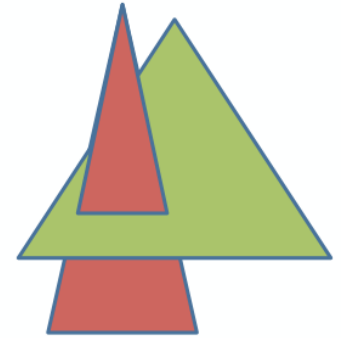
# Painter's algorithm

- Simplest way to do hidden surfaces
- Draw from back to front, use overwriting in framebuffer
- Requires sorting all polygons by their depth



# Weakness of Painter's Algorithm

- What if there are cycles in the sorted graph?
  - The only solution is dividing these polygons into small pieces.
- Need to update the sorted graph whenever camera or object location is changed.
- → Time-consuming!



# The z buffer

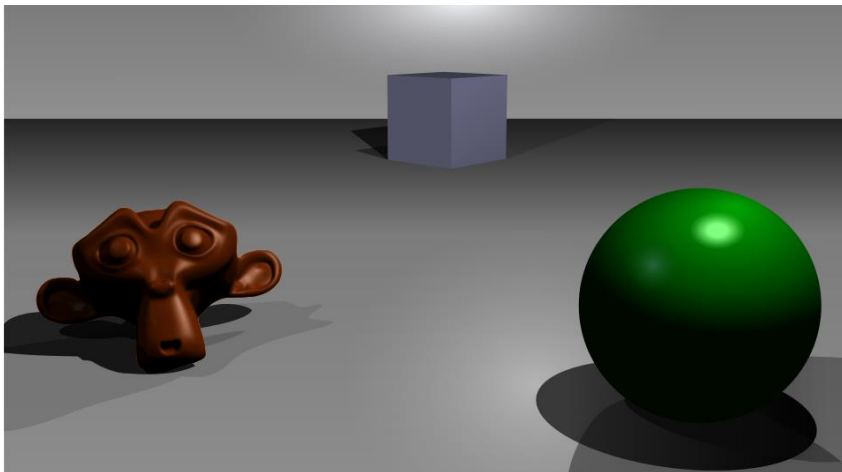
- In many (most) applications maintaining a z sort is too expensive
  - changes all the time when the view changes
  - many data structures exist, but complex
- Solution: draw in any order, keep track of closest
  - Z-buffer keeps track of closest depth so far
  - when drawing, compare object's depth to current closest depth and discard if greater

# Z-Buffering: Algorithm

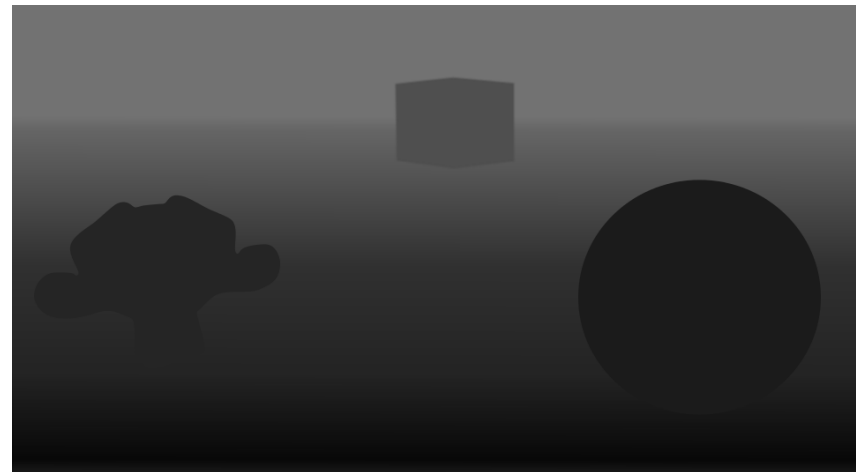
```
allocate depth_buffer;           // Allocate depth buffer → Same size as viewport.

for each pixel (x,y)             // For each pixel in viewport.
    write_frame_buffer(x,y,backgrnd_color); // Initialize color.
    write_depth_buffer(x,y,farPlane_depth); // Initialize depth (z) buffer.

for each polygon                 // Draw each polygon (in any order).
    for each pixel (x,y) in polygon // Rasterize polygon.
        color = polygon's color at (x,y);
         $p_z$  = polygon's z-value at (x,y); // Interpolate z-value at (x, y).
        if ( $p_z$  < read_depth_buffer(x,y)) // If new depth is closer:
            write_frame_buffer(x,y,color); // Write new (polygon) color.
            write_depth_buffer(x,y, $p_z$ ); // Write new depth.
```



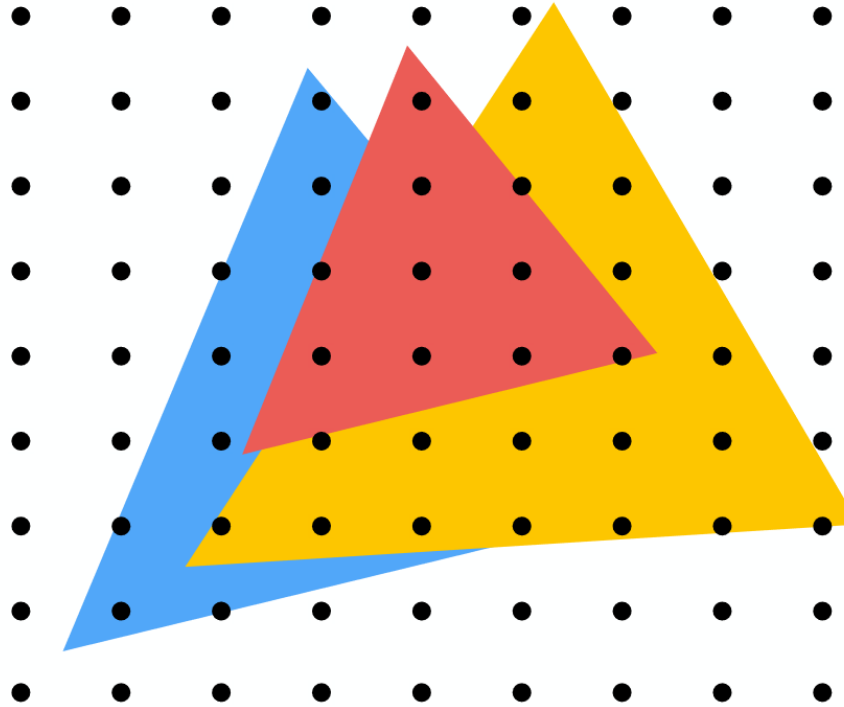
Frame buffer



Z-buffer (Depth buffer)

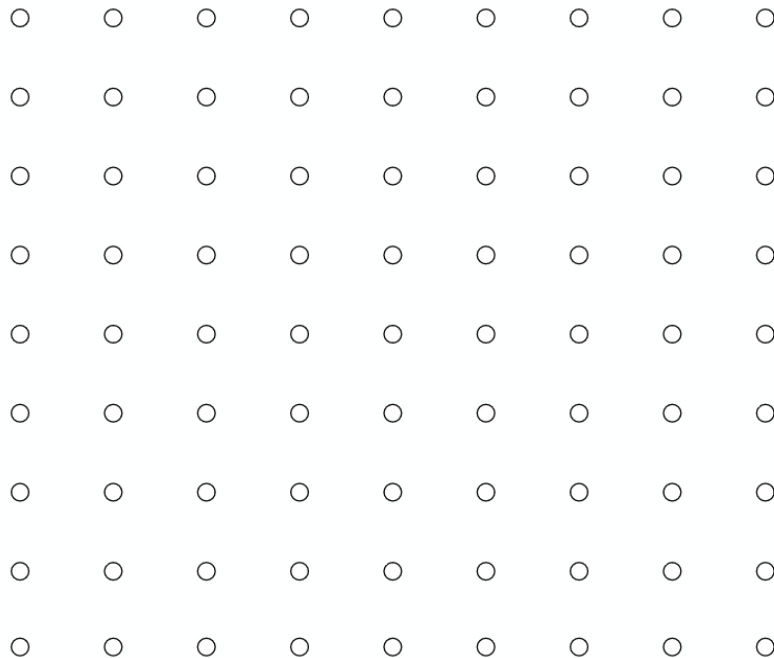


# Example: rendering three opaque triangles



# Occlusion using the depth-buffer (Z-buffer)

Processing yellow triangle:  
depth = 0.5



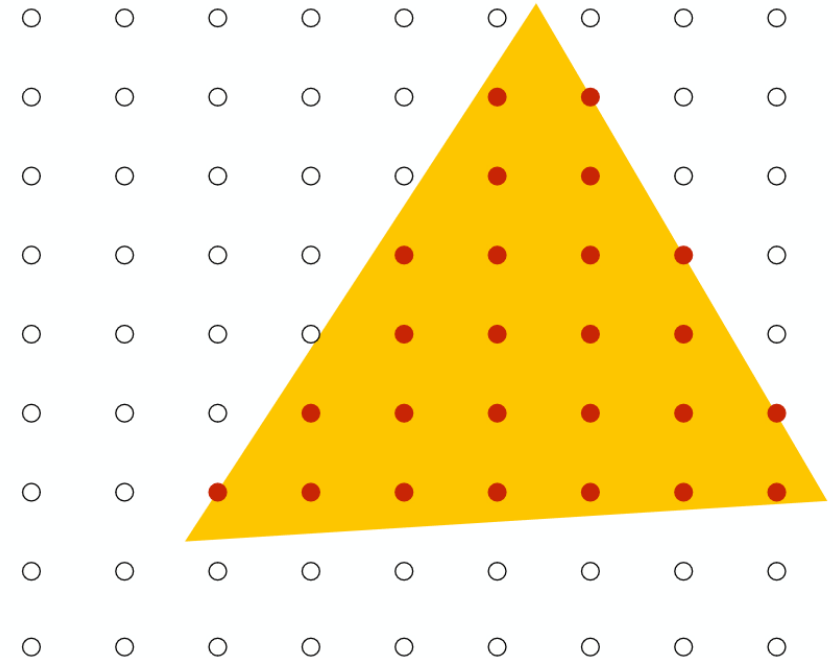
Color buffer contents

Grayscale value of sample point  
used to indicate distance

White = large distance

Black = small distance

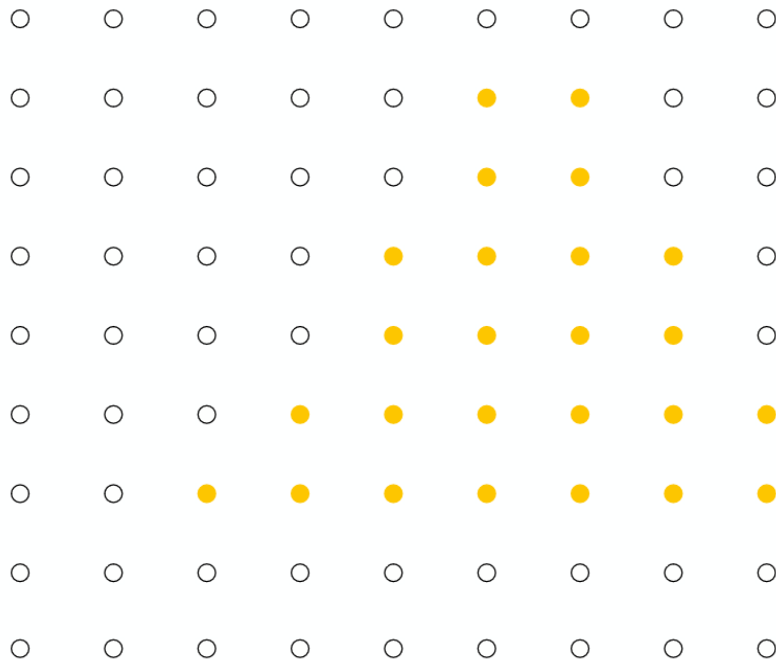
Red = sample passed depth test



Depth buffer contents

# Occlusion using the depth-buffer (Z-buffer)

After processing yellow triangle:



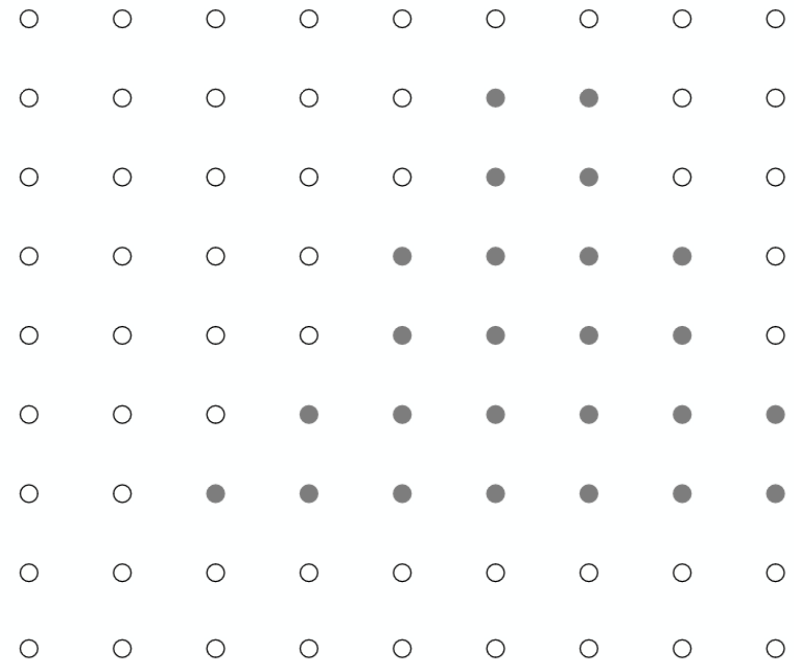
Color buffer contents

Grayscale value of sample point  
used to indicate distance

White = large distance

Black = small distance

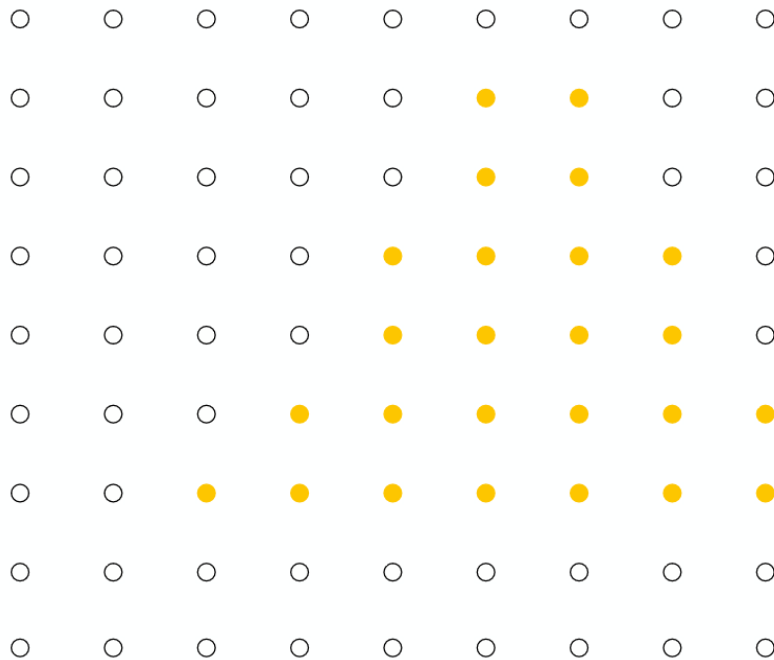
Red = sample passed depth test



Depth buffer contents

# Occlusion using the depth-buffer (Z-buffer)

Processing blue triangle:  
depth = 0.75



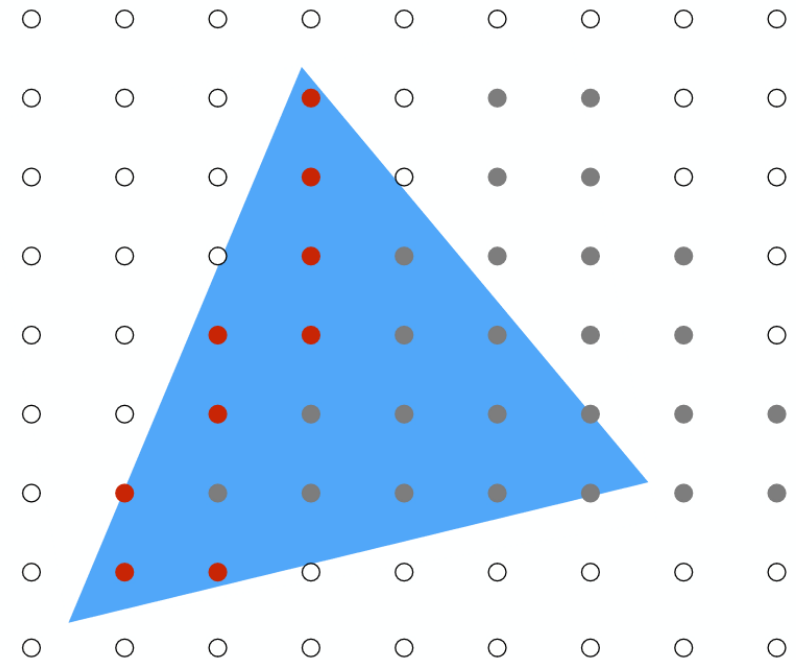
Color buffer contents

Grayscale value of sample point  
used to indicate distance

White = large distance

Black = small distance

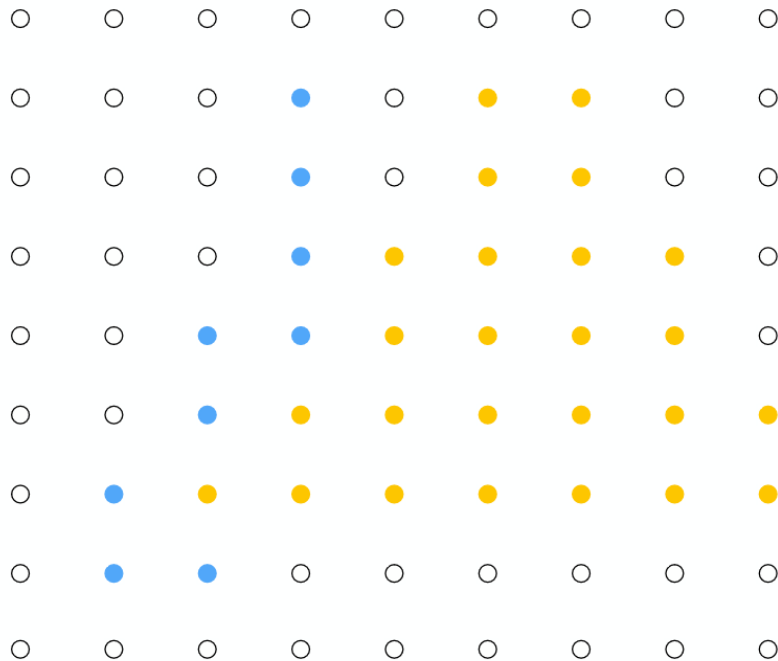
Red = sample passed depth test



Depth buffer contents

# Occlusion using the depth-buffer (Z-buffer)

After processing blue triangle:



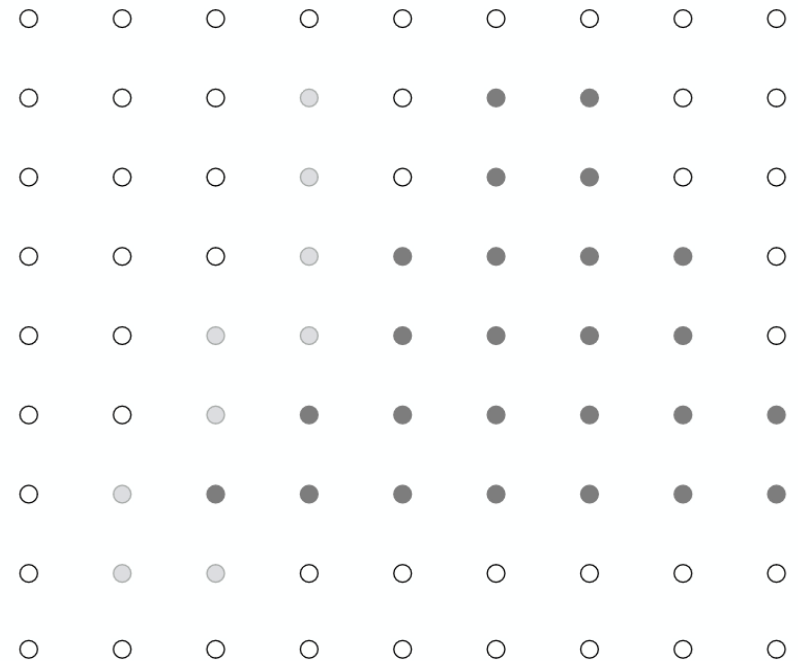
Color buffer contents

Grayscale value of sample point  
used to indicate distance

White = large distance

Black = small distance

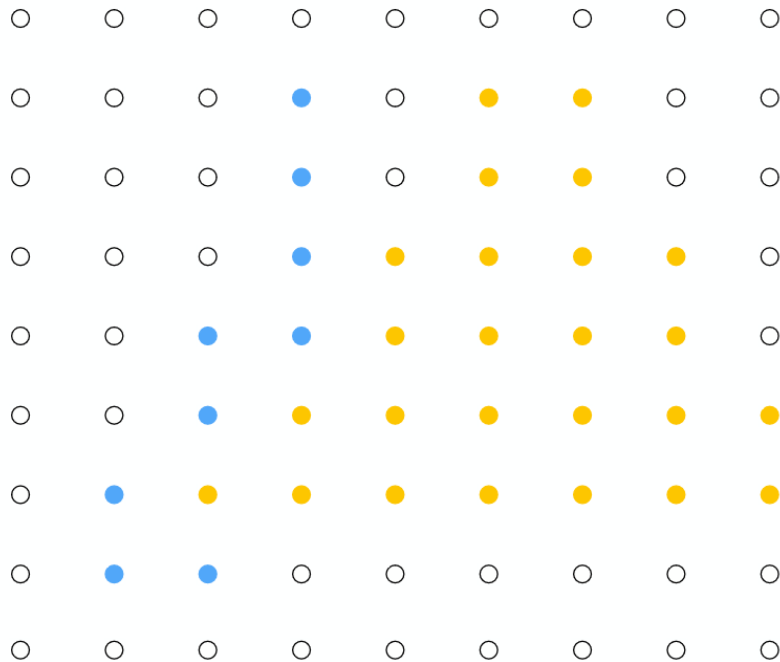
Red = sample passed depth test



Depth buffer contents

# Occlusion using the depth-buffer (Z-buffer)

Processing red triangle:  
 $\text{depth} = 0.25$



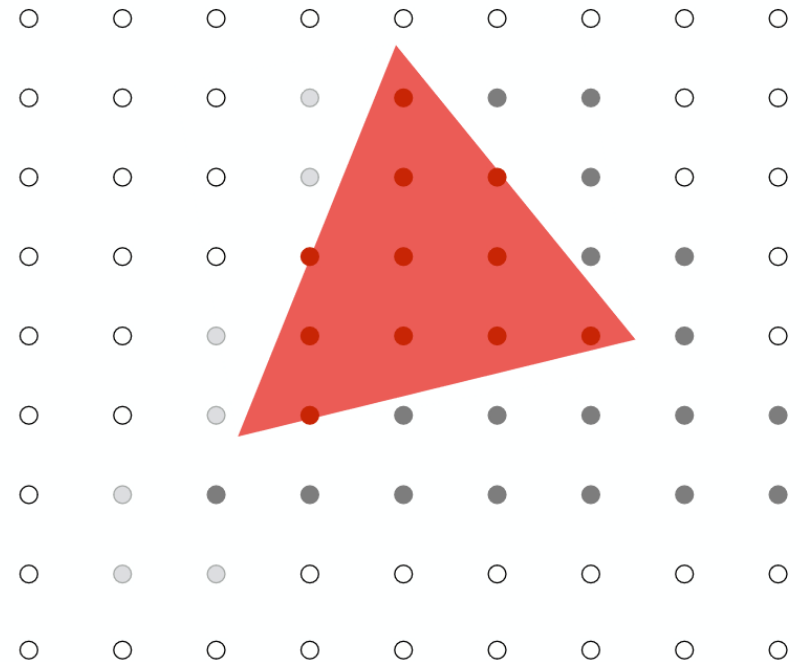
Color buffer contents

Grayscale value of sample point  
used to indicate distance

White = large distance

Black = small distance

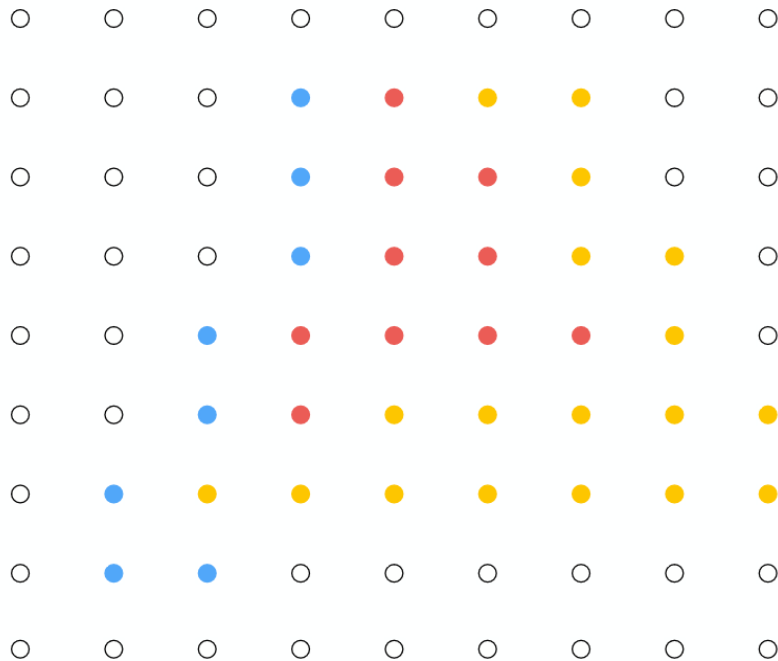
Red = sample passed depth test



Depth buffer contents

# Occlusion using the depth-buffer (Z-buffer)

After processing red triangle:



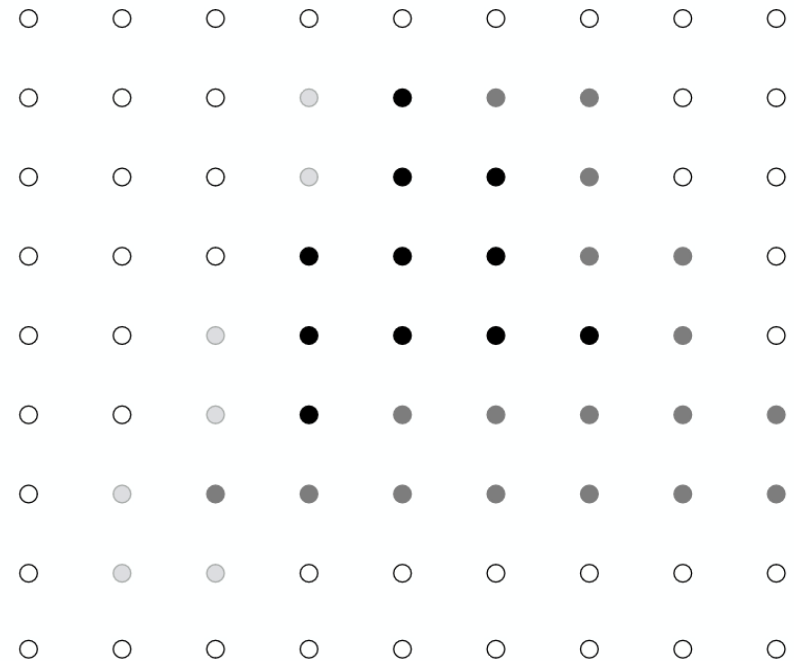
Color buffer contents

Grayscale value of sample point  
used to indicate distance

White = large distance

Black = small distance

Red = sample passed depth test

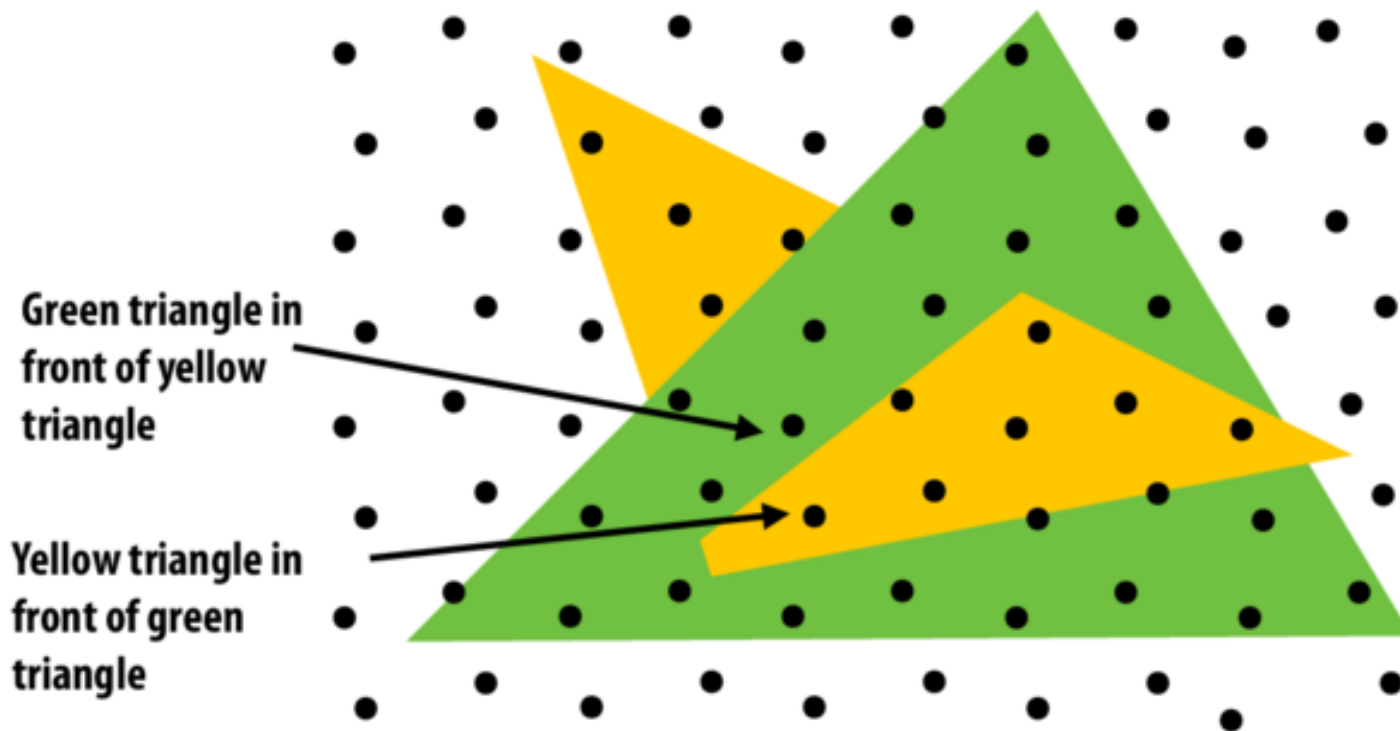


Depth buffer contents

# Does depth-buffer algorithm handle interpenetrating surfaces?

Of course!

Occlusion test is based on depth of triangles at a given sample point. The relative depth of triangles may be different at different sample points.

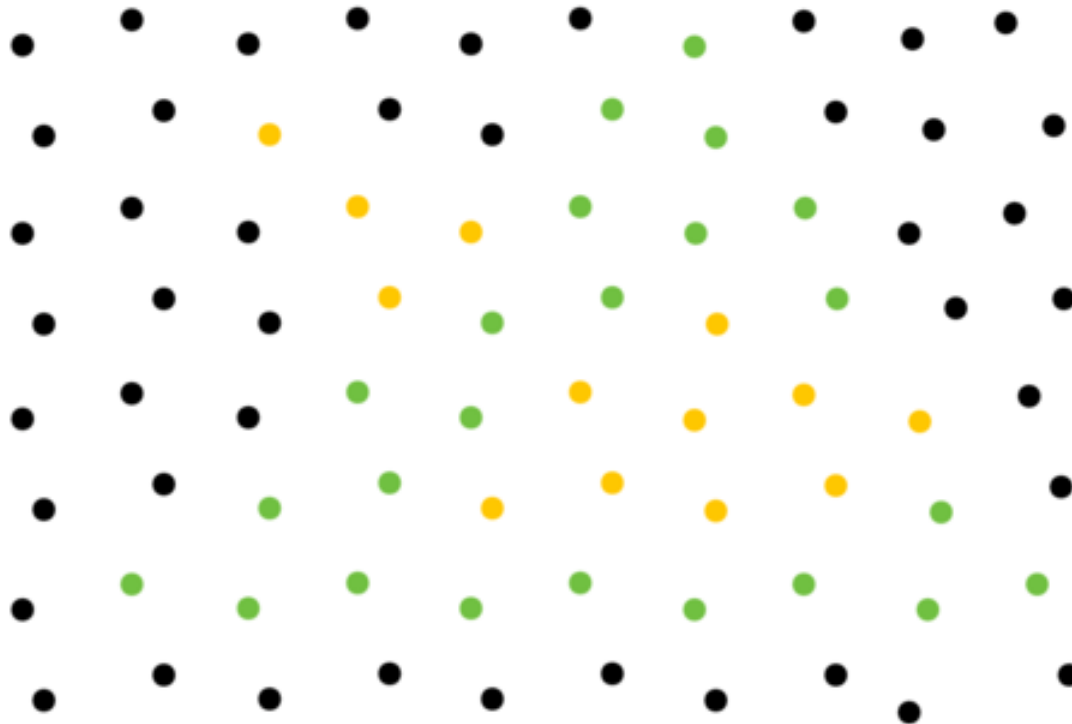




# Does depth-buffer algorithm handle interpenetrating surfaces?

Of course!

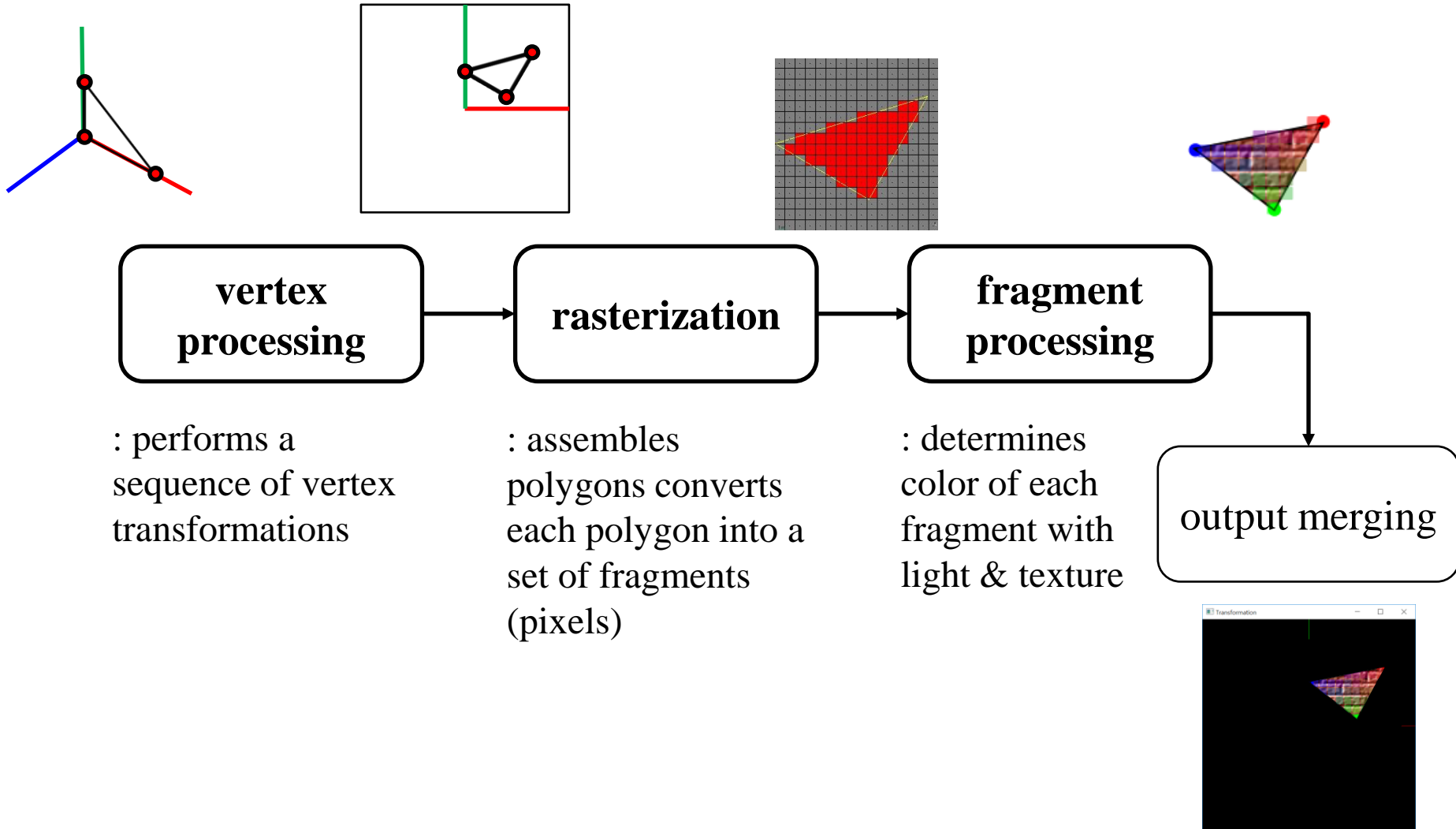
Occlusion test is based on depth of triangles at a given sample point. The relative depth of triangles may be different at different sample points.



# Z-Buffering : Summary

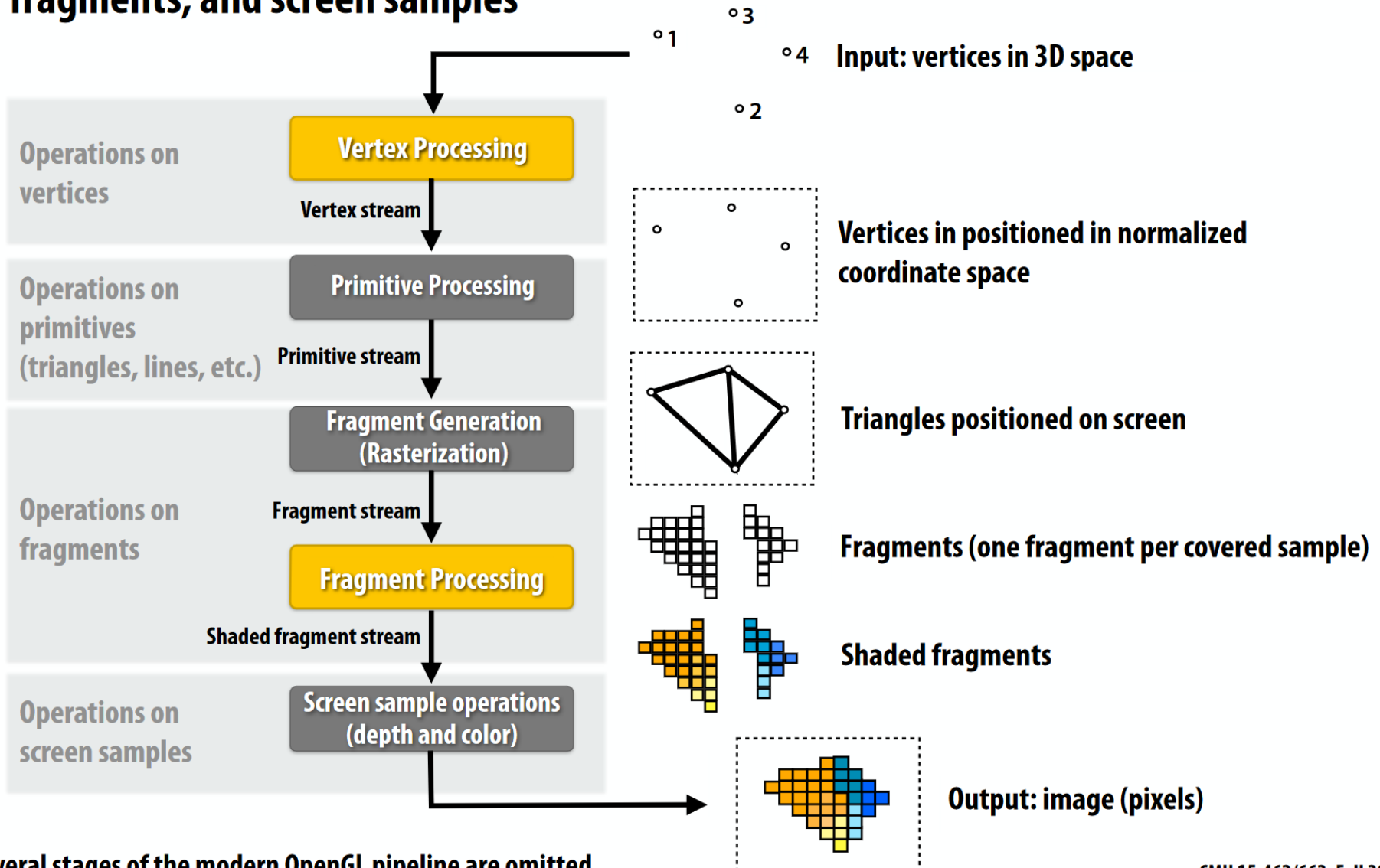
- Current standard algorithm that is implemented on all graphics hardwares
- Advantages / Disadvantages:
  - Easy to implement
  - Fast with hardware support → Fast depth buffer memory
  - Polygons can be drawn in any order
  - Extra memory required for z-buffer
    - not a problem anymore

# Rendering (Graphics) Pipeline Again



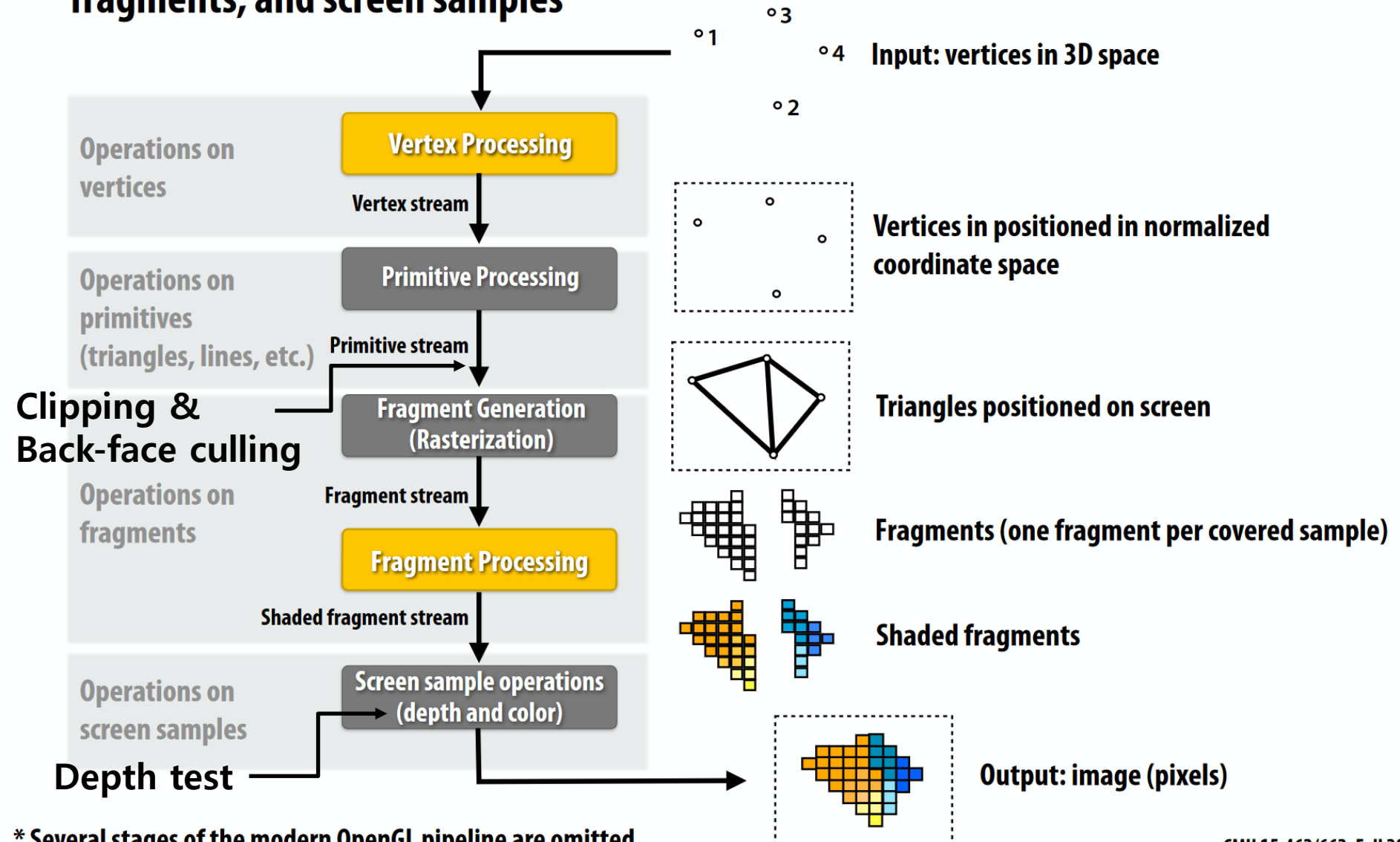
# OpenGL/Direct3D graphics pipeline \*

Structures rendering computation as a series of operations on vertices, primitives, fragments, and screen samples

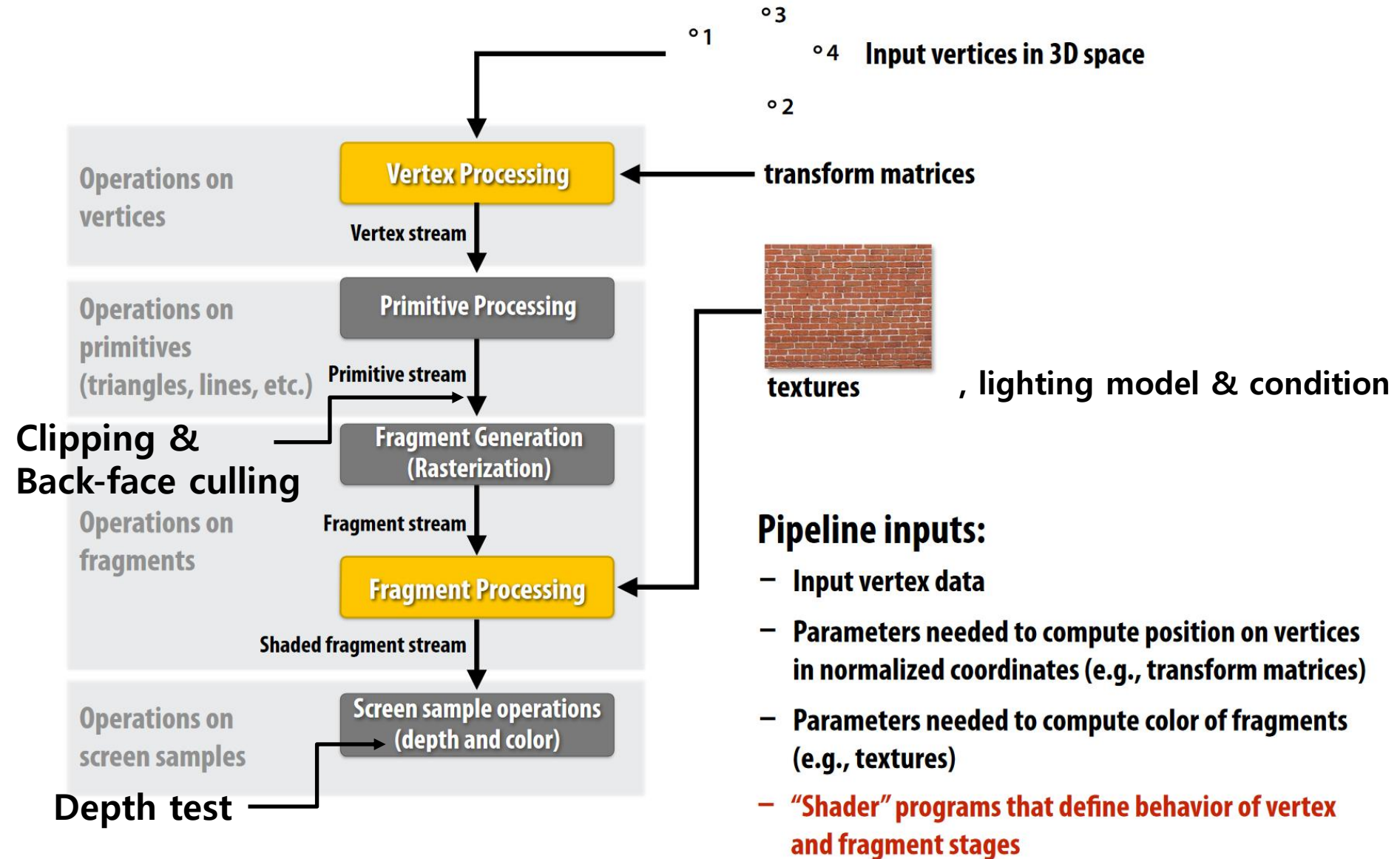


# OpenGL/Direct3D graphics pipeline \*

Structures rendering computation as a series of operations on vertices, primitives, fragments, and screen samples

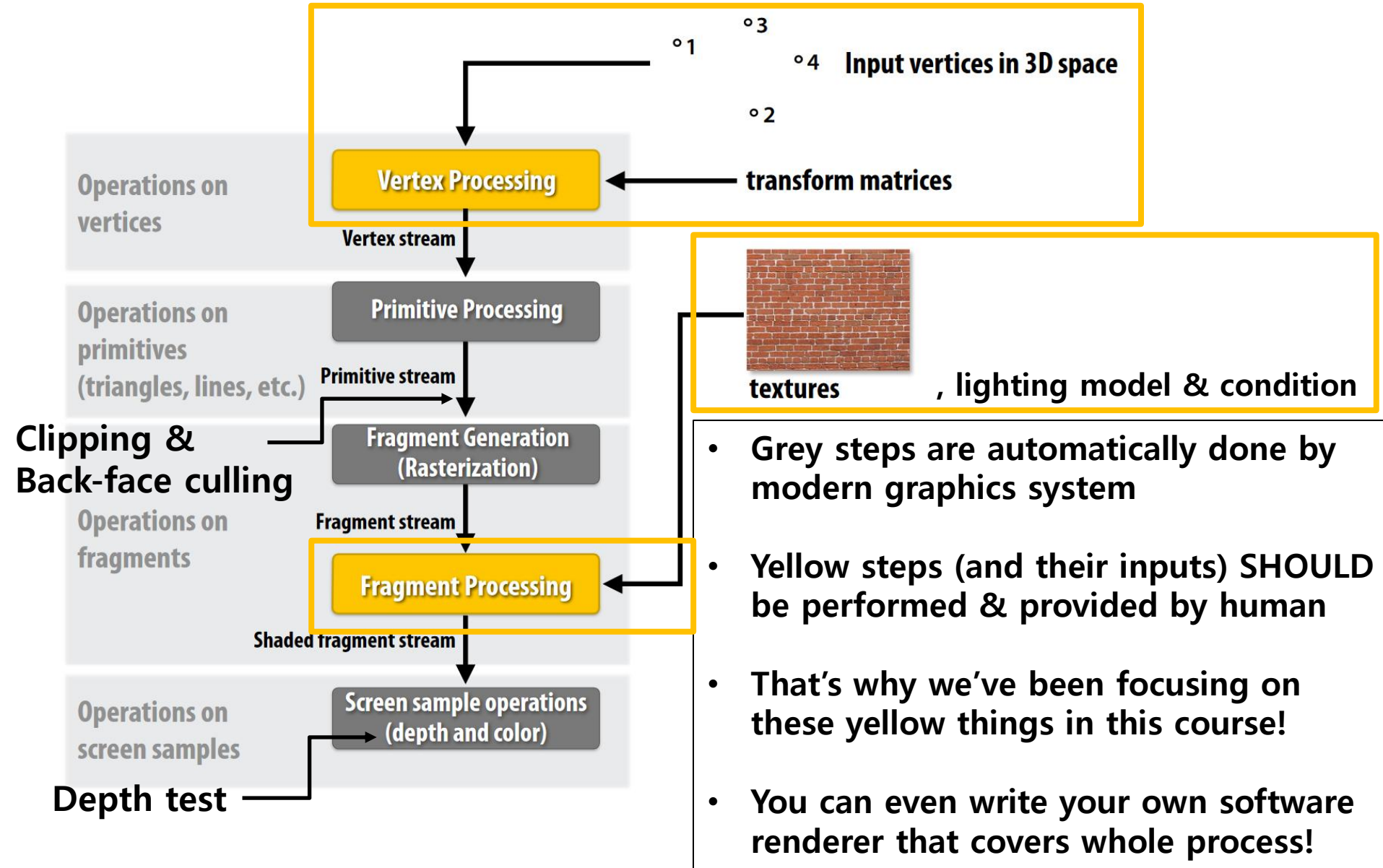


# OpenGL/Direct3D graphics pipeline \*



\* several stages of the modern OpenGL pipeline are omitted

# OpenGL/Direct3D graphics pipeline \*



\* several stages of the modern OpenGL pipeline are omitted

# Acknowledgement

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- Acknowledgement: Some materials come from the lecture slides of
  - Prof. Sung-eui Yoon, KAIST, <https://sglab.kaist.ac.kr/~sungeui/CG/>
  - Prof. JungHyun Han, Korea Univ., <http://media.korea.ac.kr/book/>
  - Prof. Taesoo Kwon, Hanyang Univ., <http://calab.hanyang.ac.kr/cgi-bin/cg.cgi>
  - Prof. Steve Marschner, Cornell Univ., <http://www.cs.cornell.edu/courses/cs4620/2014fa/index.shtml>
  - Prof. Kayvon Fatahalian and Prof. Keenan Crane, CMU, <http://15462.courses.cs.cmu.edu/fall2015/>

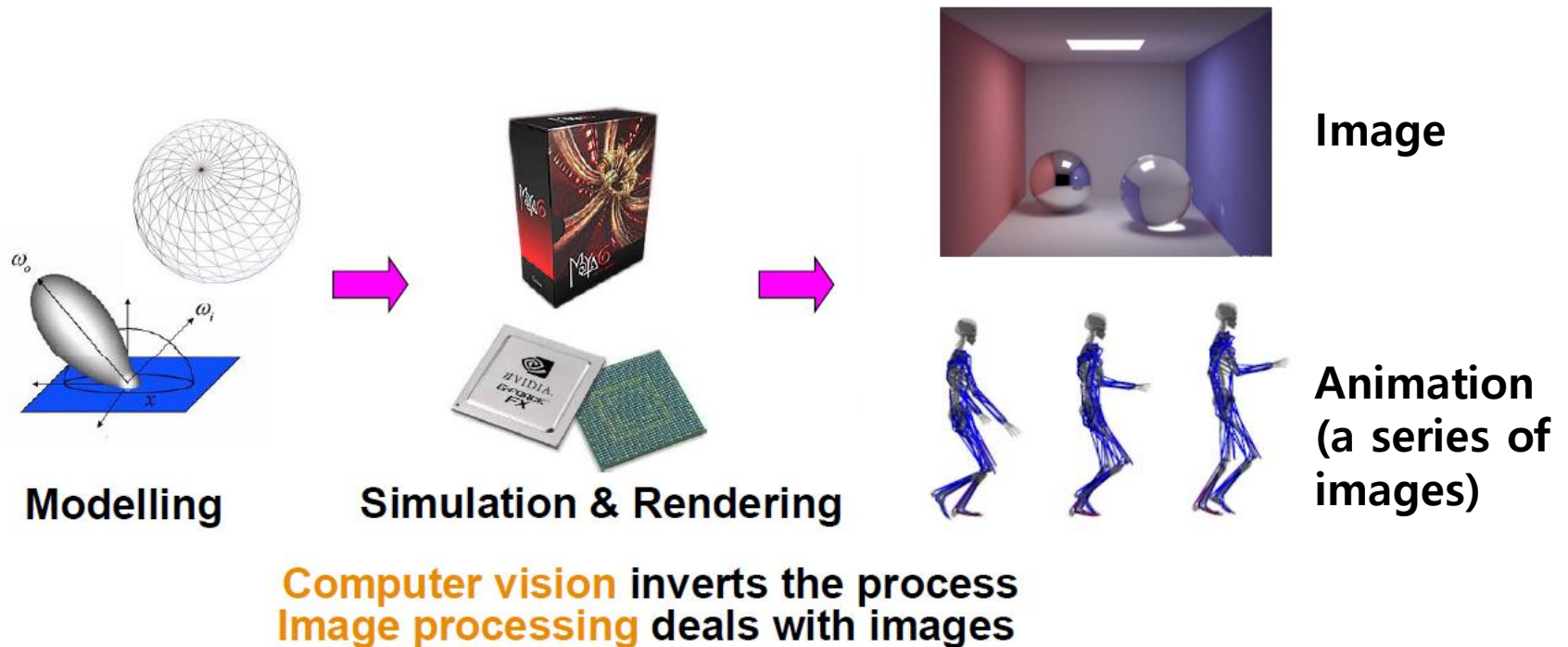


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# **Course Wrap-up**

# Do you remember?

- Computer graphics: The study of creating, manipulating, and using visual images in the computer.



# Questions about Computer Graphics

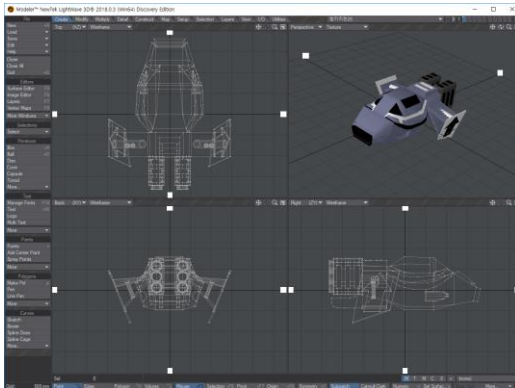
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- To do this, we should be able to answer:
- How to express movement, placement, shape, and appearance of objects
- How to map 3D objects into 2D screen
- How the whole rendering process is performed

<b>Movement &amp; placement</b>	3 - Transformation 1 4 - Transformation 2 5 - Rendering Pipeline, Viewing & Projection 1 8 - Hierarchical Modeling 9 - Orientation & Rotation 10 - Kinematics & Animation 11 - Curves
<b>Mapping to 2D screen</b>	5 - Rendering Pipeline, Viewing & Projection 1 6 - Viewing & Projection 2, Mesh
<b>Shape</b>	6 - Viewing & Projection 2, Mesh 11 - Curves
<b>Appearance</b>	7 - Lighting & Shading 12 - More Lighting, Texture
<b>Rendering Pipeline</b>	5 - Rendering Pipeline, Viewing & Projection 1 13 - Rasterization & Visibility

# How do you feel?

- If you've **had more fun** in this course than other courses, you already have **the potential** to do interesting research in computer graphics!
- I think, **passion** is the most important thing in computer graphics.
  - That was the starting point for me on this path.



# If you think "that's me!" and "I want to study more!",

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- 캐릭터 애니메이션 관련 프로젝트를 해보고 싶다:
  - (4학년이 되면) 졸업프로젝트를 함께 해봅시다.
- 캐릭터 애니메이션을 더 공부하고 실컷 프로그래밍해보고 싶다 :
  - (4학년 1학기) "COMPUTER SCIENCE Capstone PBL (Character Motion Synthesis and Character Control)" 수강을 추천
    - Software Design Principles
    - Understanding Motion Data, Software Design for Motion Viewer
    - Forward Kinematics, Inverse Kinematics
    - Motion Warping, Stitching, Blending
    - Particle Dynamics
    - Rigid Body Dynamics, Character Simulation & Control
- 4학년이 되기 전부터 뭔가 해보고 싶다!:
  - 저한테 이메일을 보내주세요: [yoonsanglee@hanyang.ac.kr](mailto:yoonsanglee@hanyang.ac.kr)

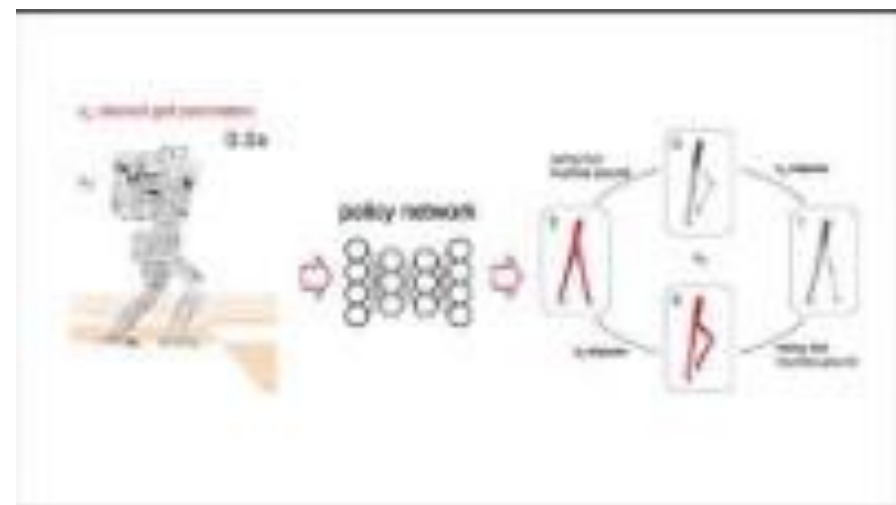
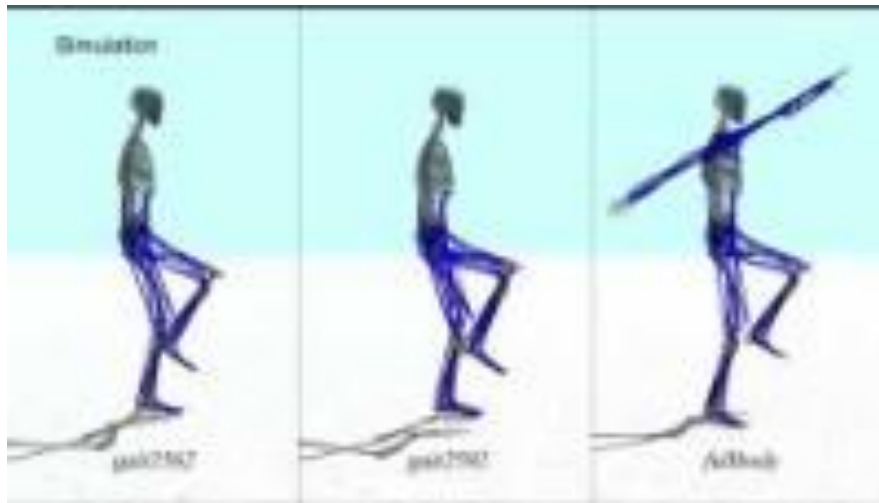
# Computer Graphics 연구의 특성

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- 구현을 많이 한다 (프로그래밍을 좋아하고, 자신이 있으면 잘 할 가능성이 크다).
- 모든 연구 결과는 눈으로 확인할 수 있는 형태로 나오기 때문에, **재미있다**.
  - Computer graphics 분야에서는 논문을 submit 할 때 비디오를 첨부하는 것이 기본

# Computer Graphics and Robotics Lab.

- <https://cgrhyu.github.io/>





**Thanks for  
being a great  
class!**

