Introduction

Computer Graphics

Yu-Ting Wu

Outline

- Introduction to computer graphics
- Introduction to graphics programming
- Homework assignments and rendering competition

Outline

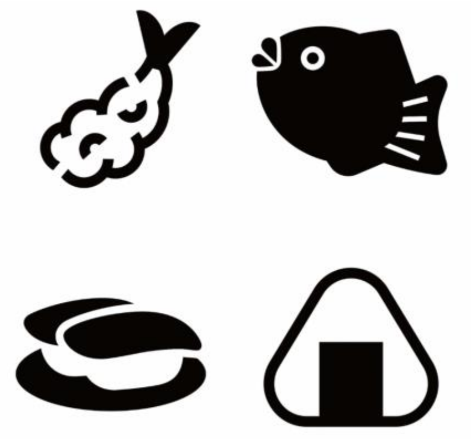
- **Introduction to computer graphics**
- Introduction to graphics programming
- Homework assignments and rendering competition

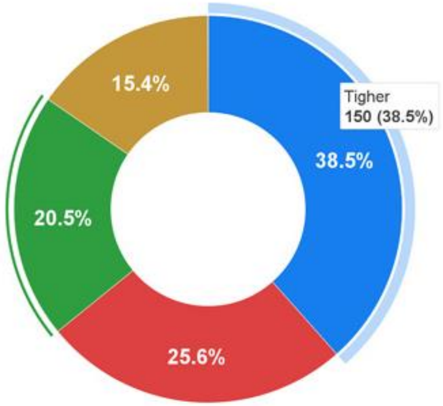
Overview

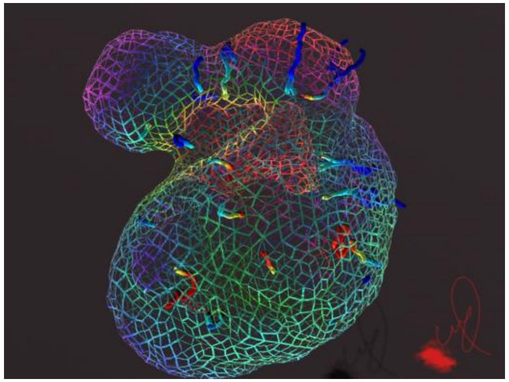
What is Computer Graphics

- A sub-field of computer science that studies methods for **digitally synthesizing** and **manipulating** visual content (from *wiki*)
- Is concerned with all aspects of **producing pictures or images using a computer** (from our *textbook*)

These are All Computer Graphics







What we will focus on in this course

Goals of 3D Computer Graphics

- **Digitally synthesize** and **manipulate** a virtual world

Goals of 3D Computer Graphics (cont.)

- **Digitally synthesize** and **manipulate** a virtual world

Copyright © Ralph Breaks the Internet: Wreck-It Ralph 2, 2018, Disney Inc.

Goals of 3D Computer Graphics (cont.)

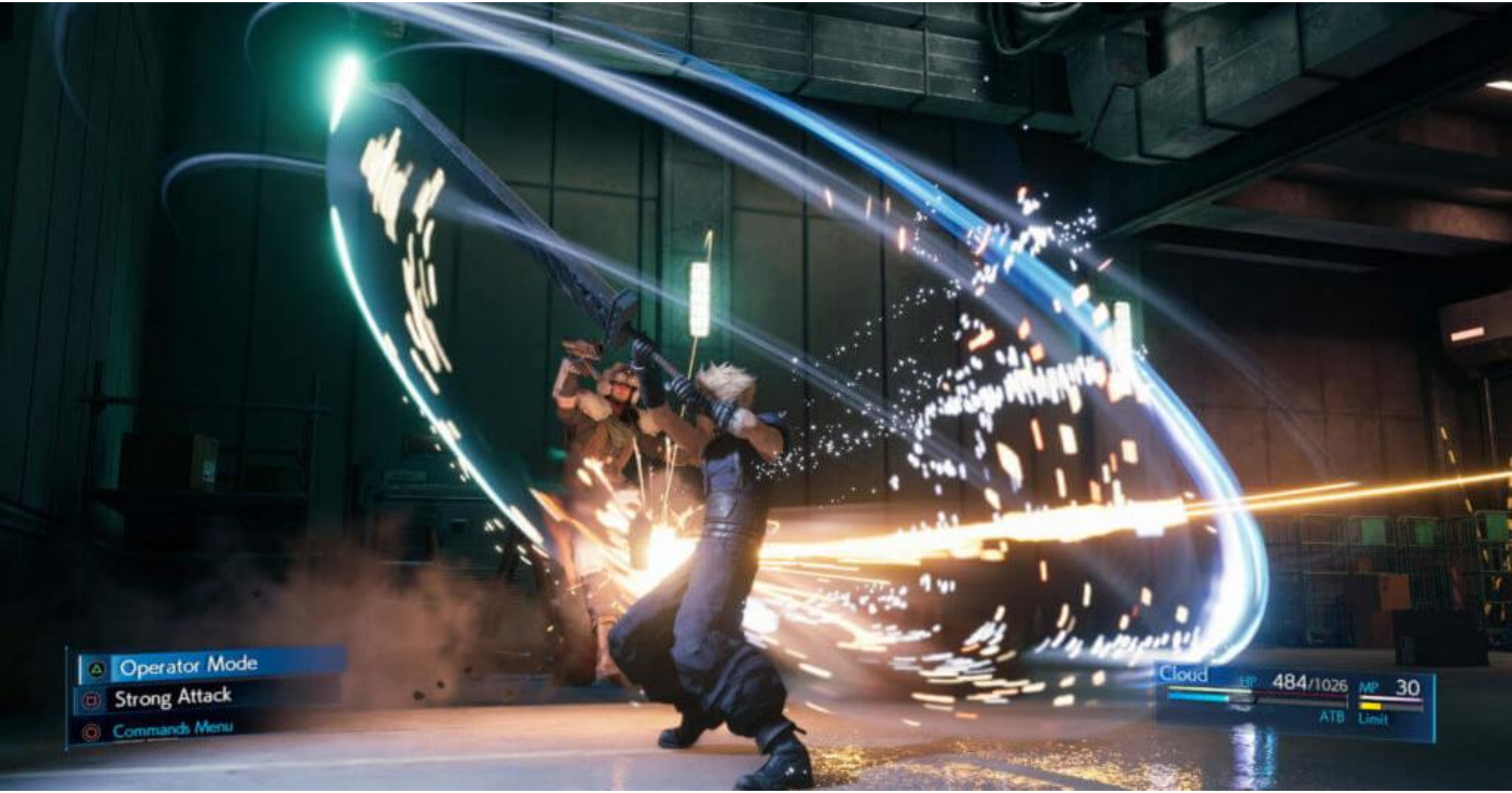
Copyright © Kingdom of the Planet of the Apes, 2024, 20th Century Studios Inc.

Goals of 3D Computer Graphics (cont.)

Copyright © Godzilla Minus One, 2023, TOHO, Inc.

Applications of Computer Graphics

Video Games

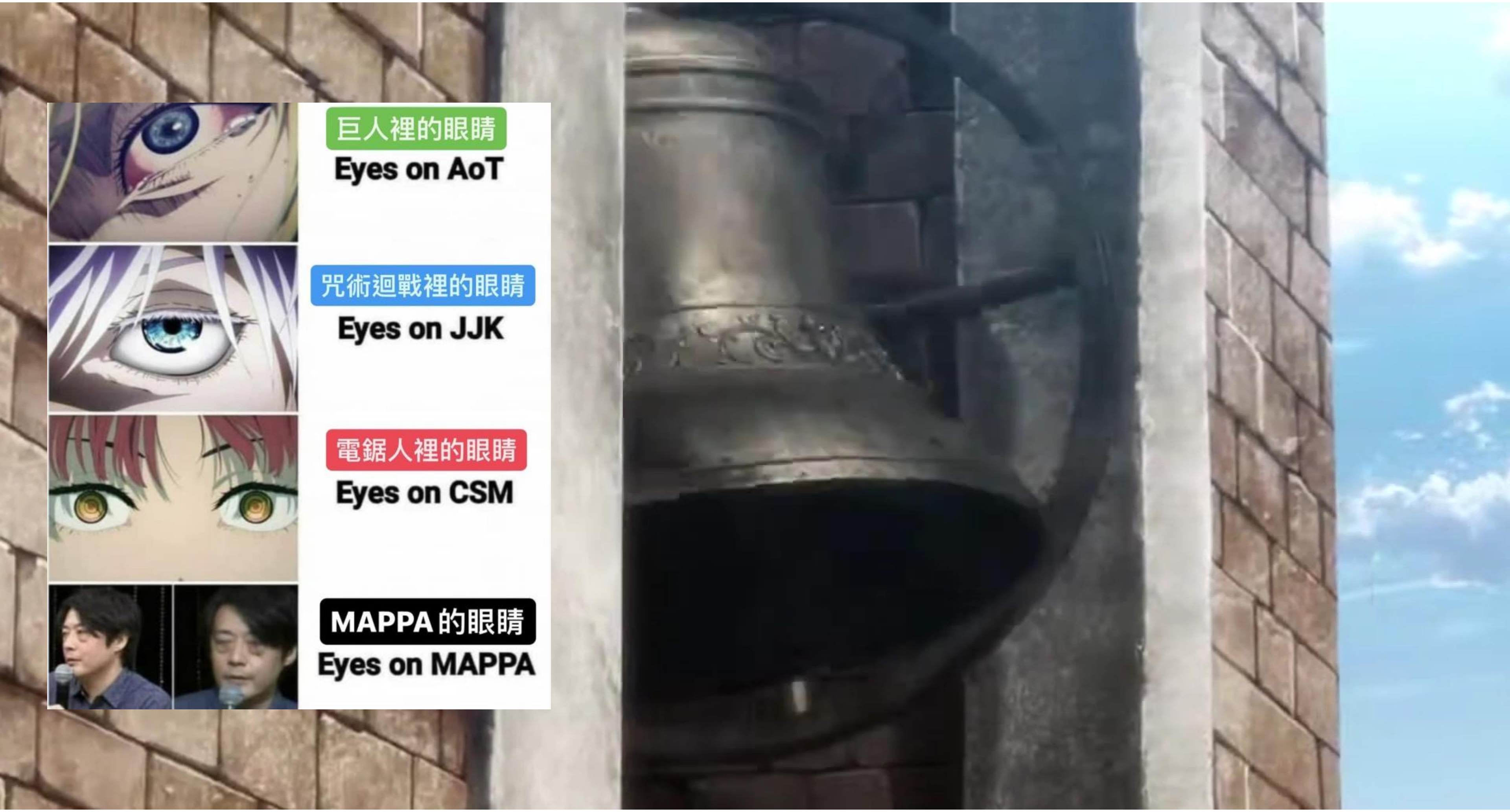


Copyright © Final Fantasy VII Rebirth, 2024, SQUARE ENIX Inc.

Digital Visual Effects (VFX)

Featured Animations

Animes

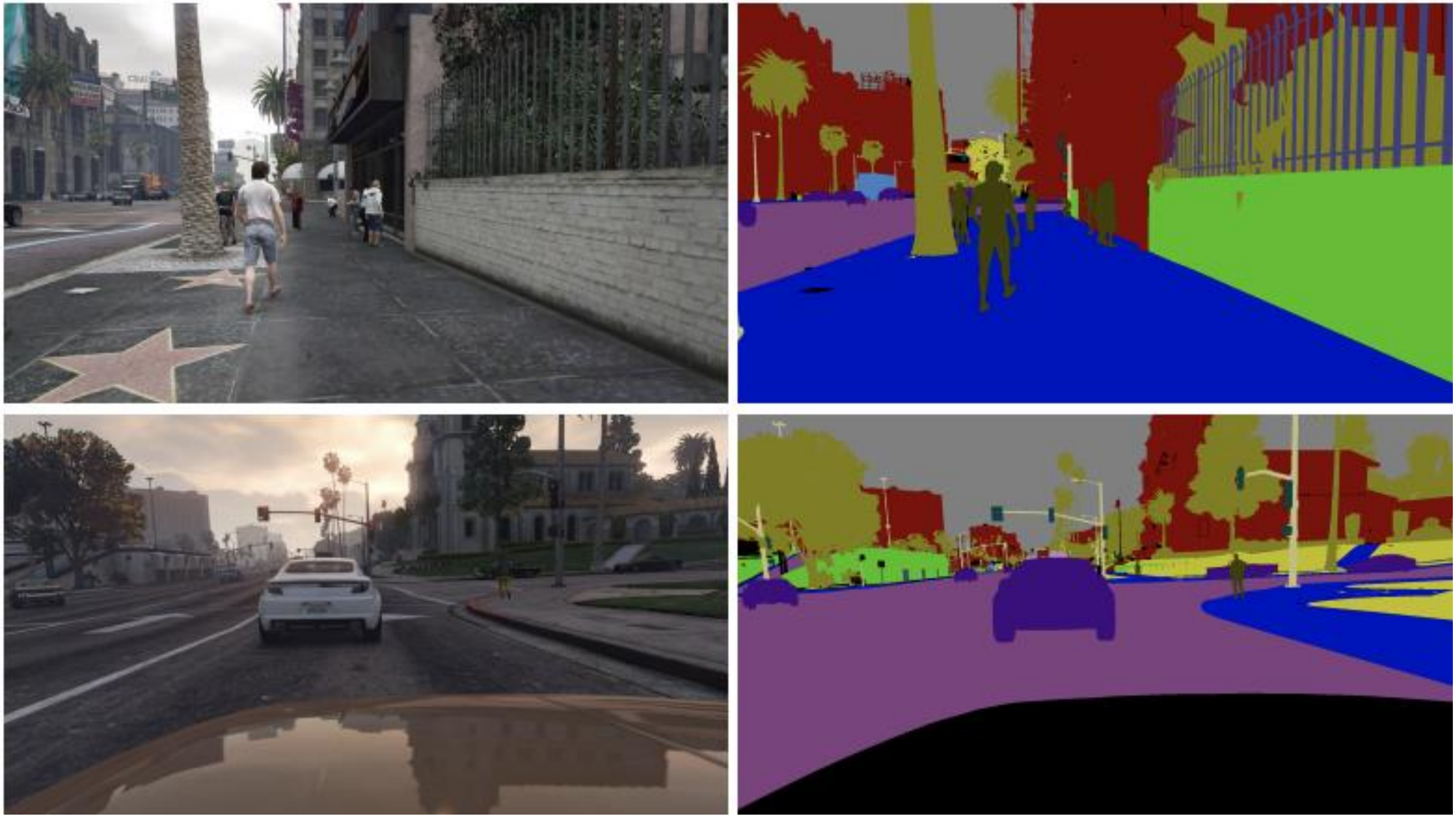

巨人裡的眼睛
Eyes on AoT
咒術迴戰裡的眼睛
Eyes on JJK
電鋸人裡的眼睛
Eyes on CSM
MAPPA 的眼睛
Eyes on MAPPA

Extended Reality (XR: VR/AR/MR)

Computer-Aided Design

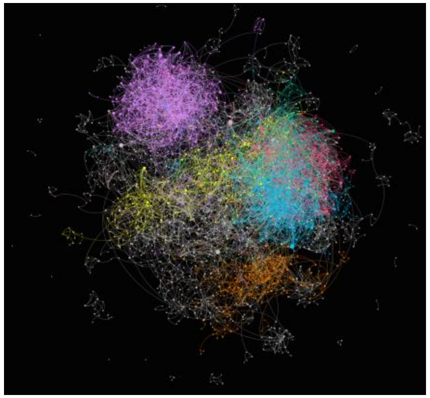
Machine (Deep) Learning

GTA5 Database

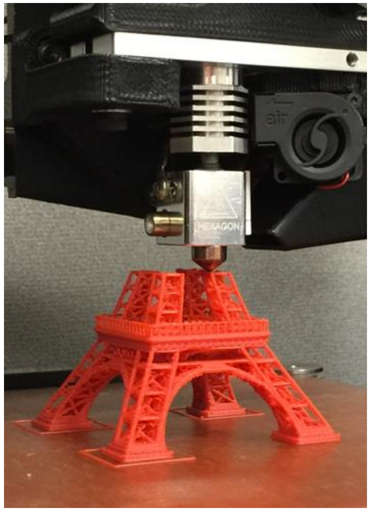


More Applications

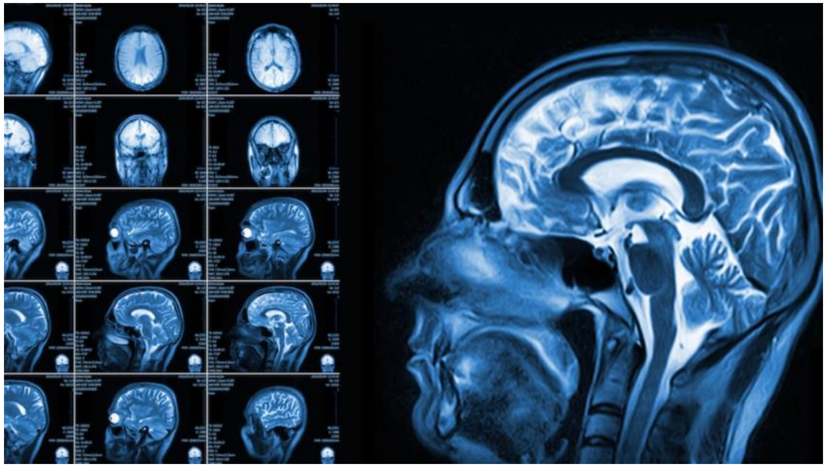
Simulation



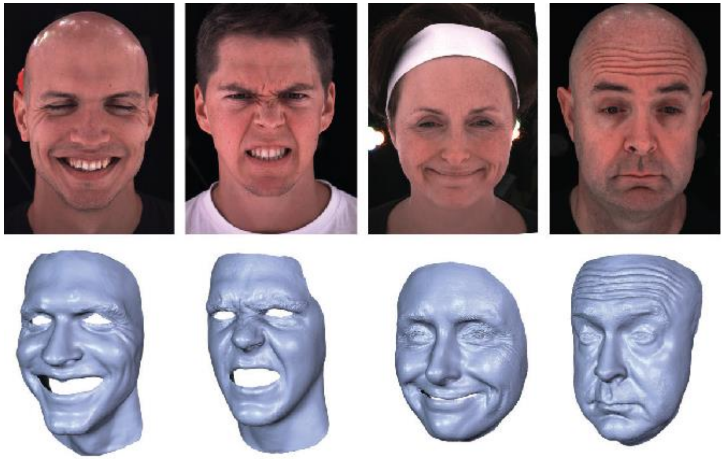
Data Vis



Fabrication



Medical Imaging

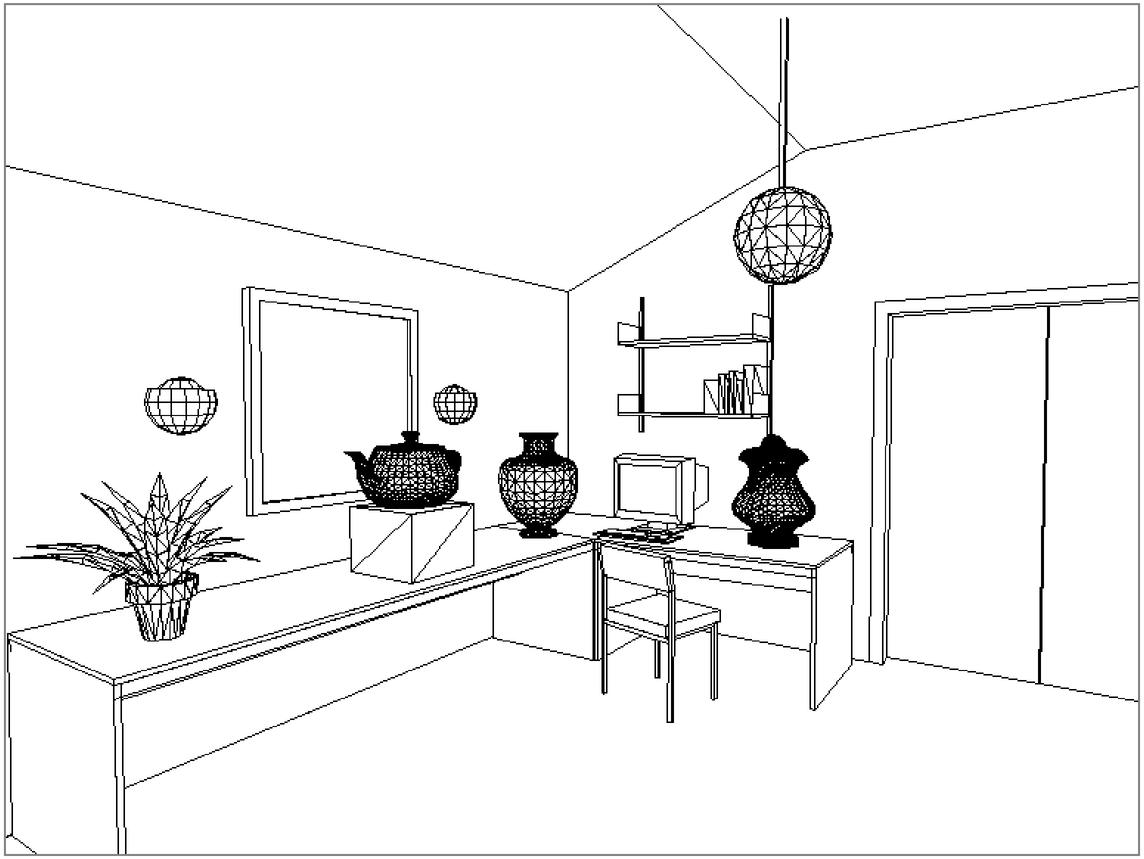


3D Reconstruction

A Quick Overview for How to Synthesize an Image

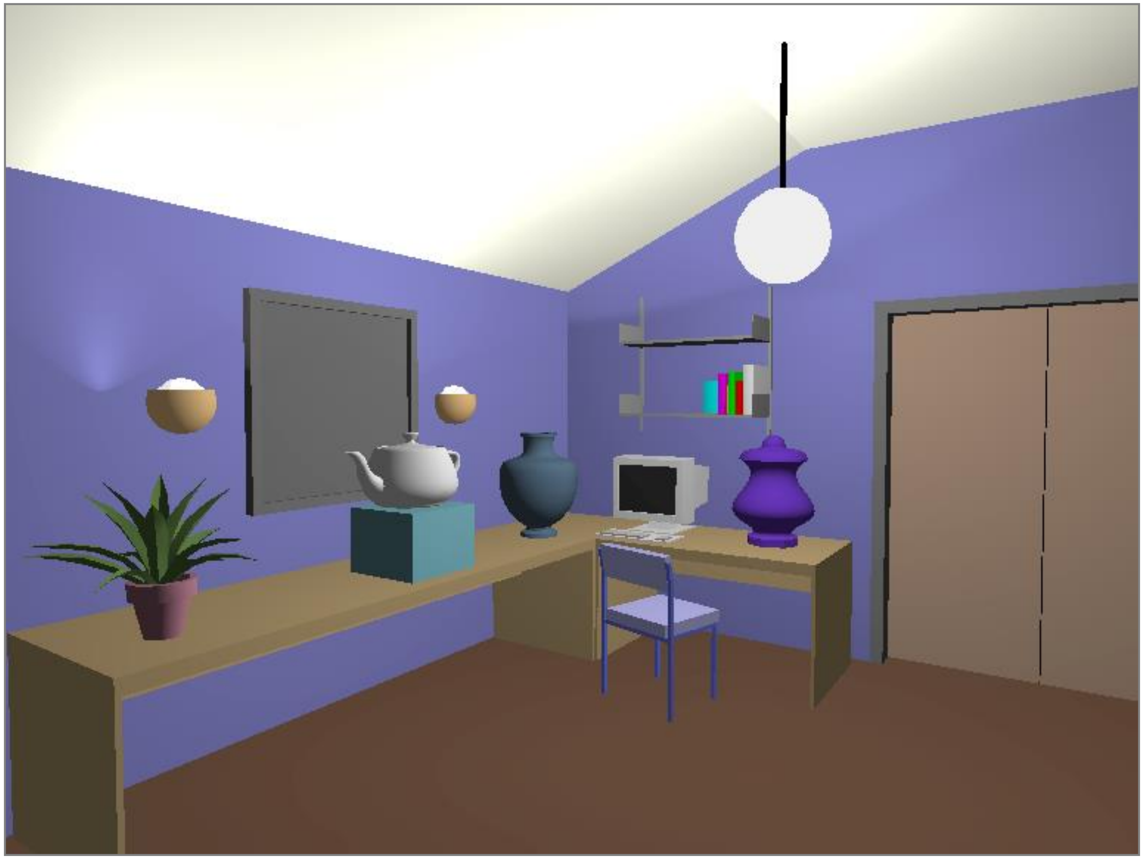
How to Synthesize an Image

- Model geometry of the 3D objects (scene)



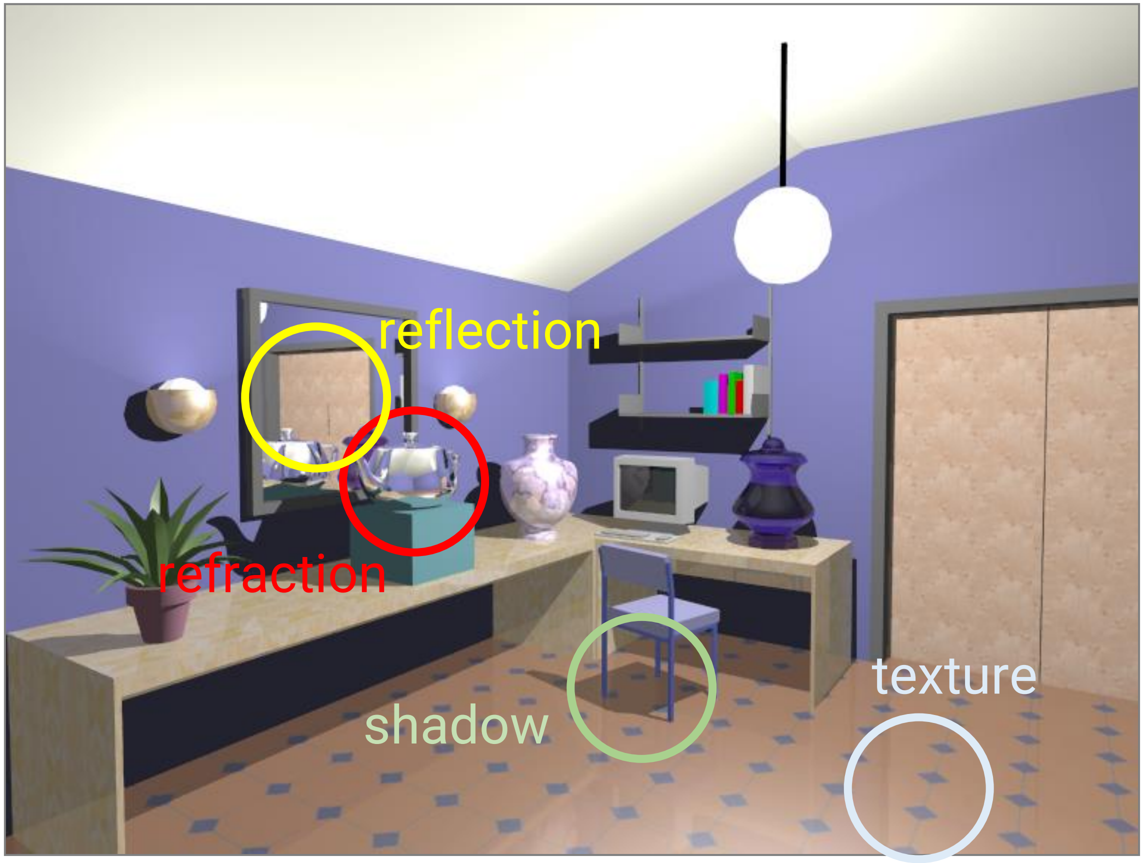
How to Synthesize an Image (cont.)

- Model materials of the 3D objects and simulate lighting



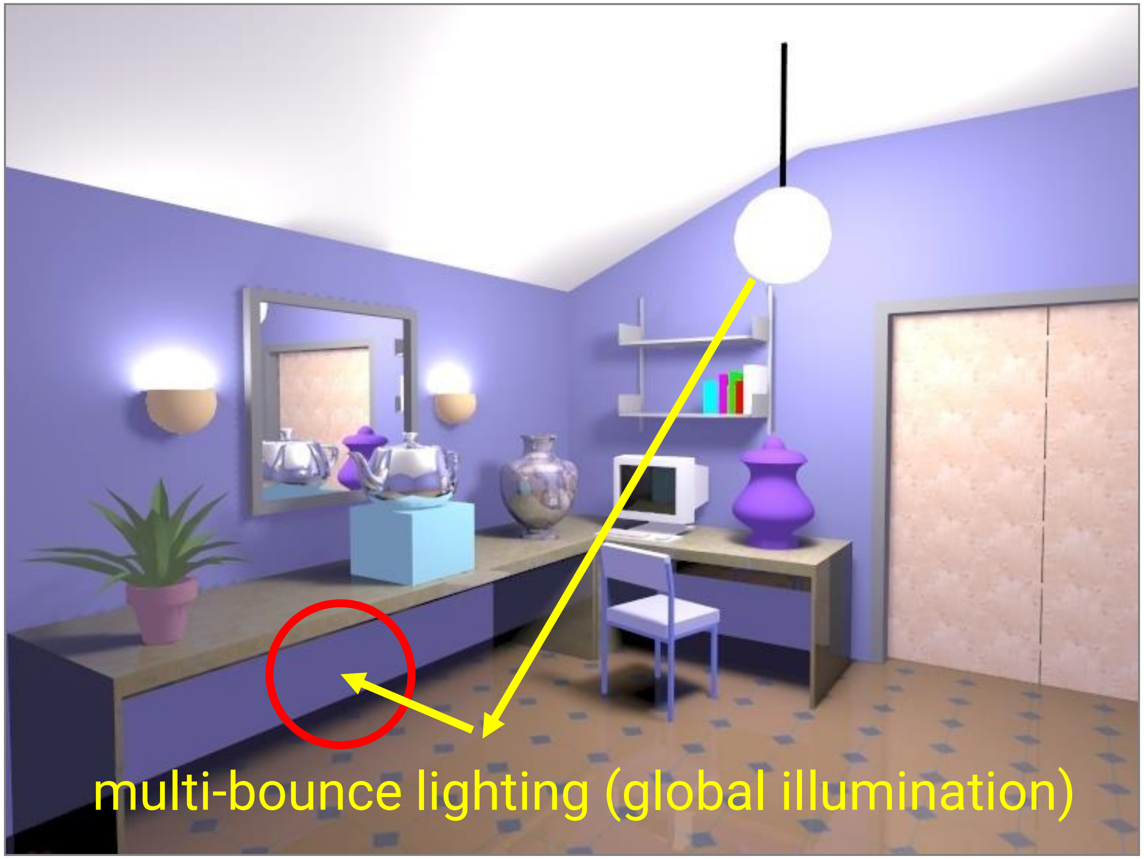
How to Synthesize an Image (cont.)

- Simulate more realistic materials and lighting phenomena



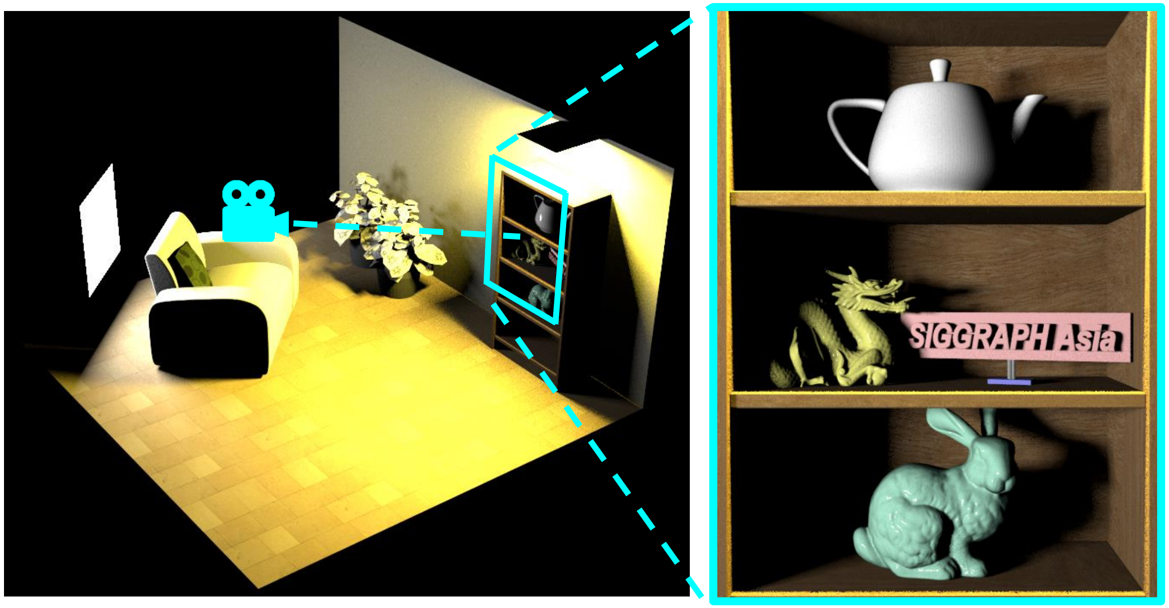
How to Synthesize an Image (cont.)

- Simulate more complex light paths



How to Synthesize an Image (cont.)

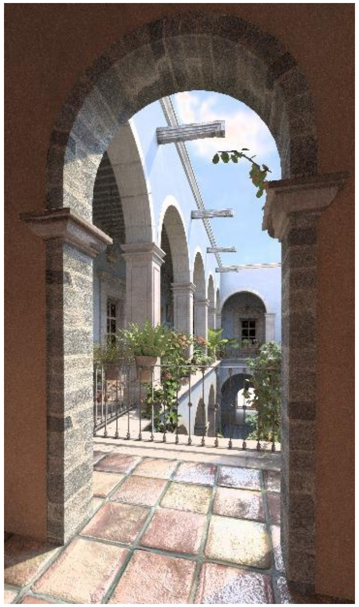
- Most displays are 2D, so we need to generate images from the 3D world
- Just like taking a picture with a camera in our daily lives
  - But with a **virtual camera** and a **virtual film**



3D virtual world

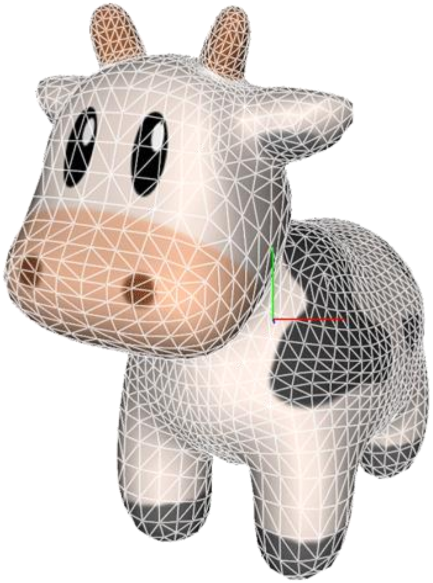
rendered image

How to Synthesize an Image (cont.)



Major Topics of Computer Graphics

Three Pillars of Computer Graphics



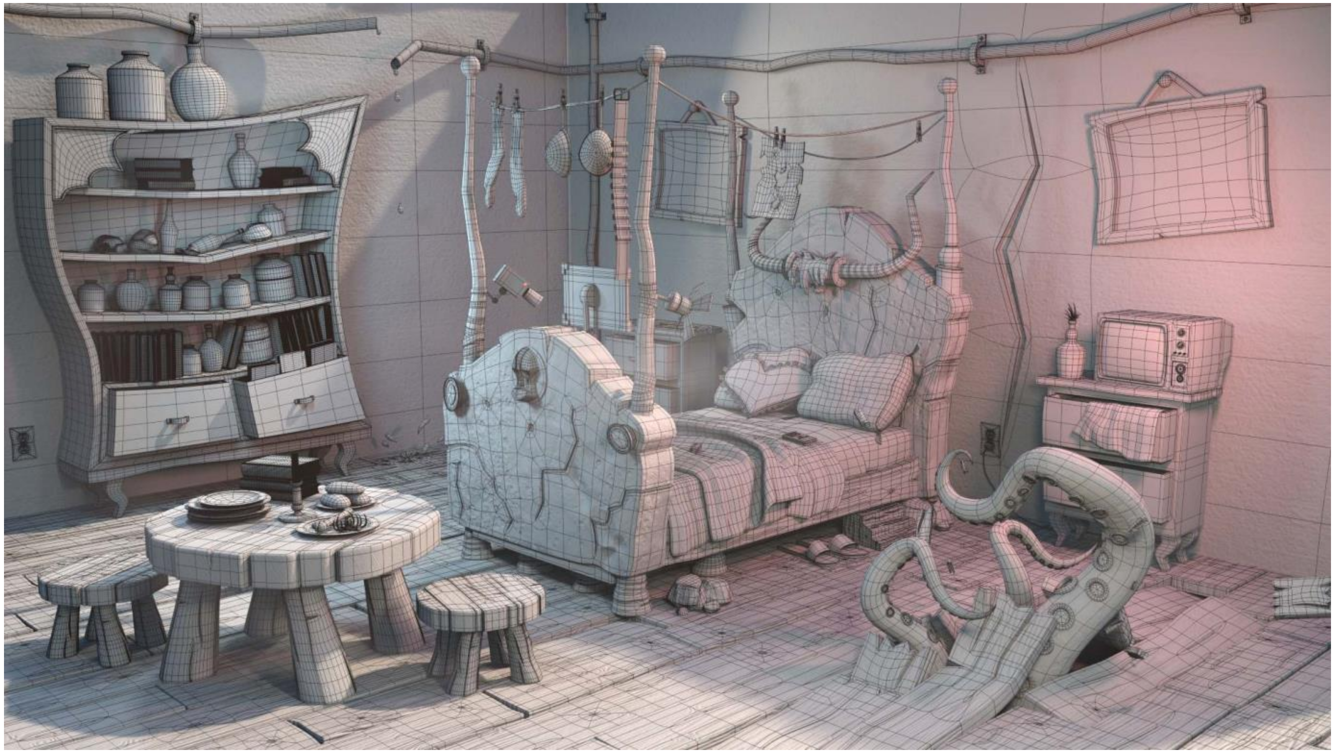
Modeling

Rendering

Animation

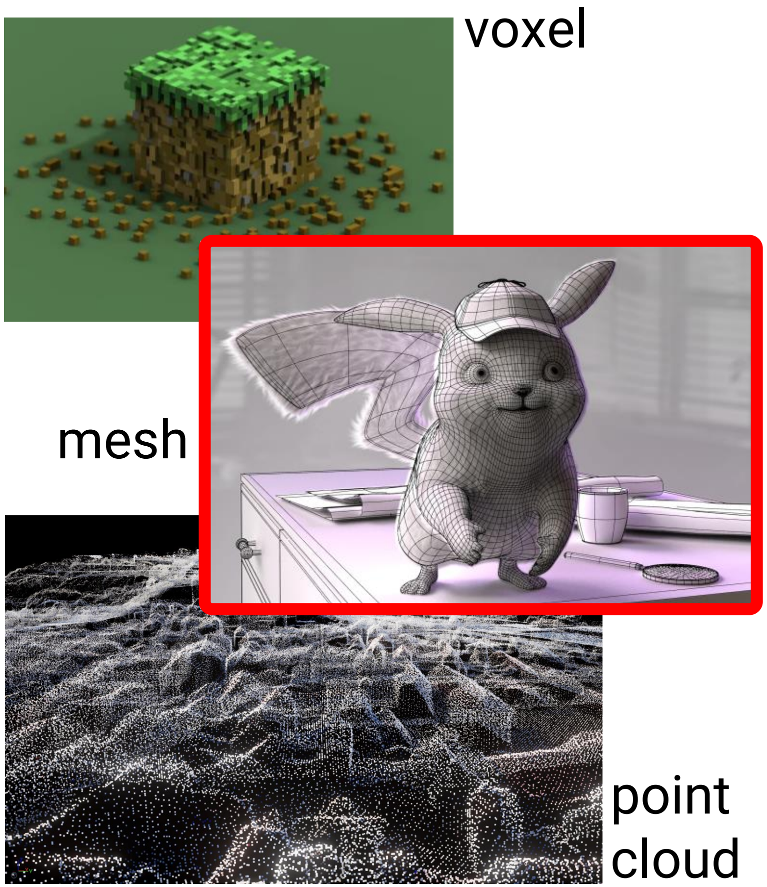
Modeling

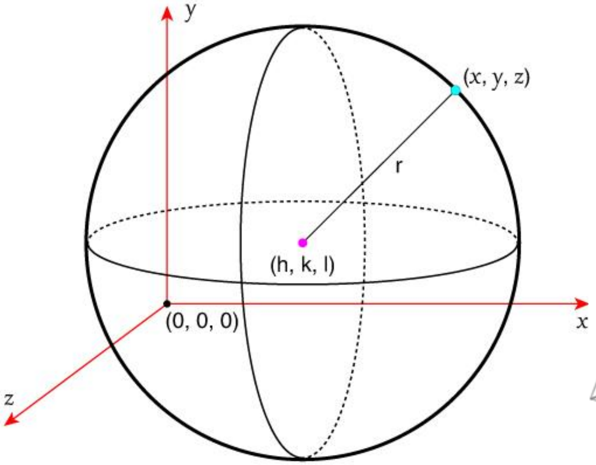
- Build 3D representation of the virtual world
- The process of generating “data” in computer graphics



Modeling (cont.)

- **Explicit** representation v.s. **implicit** representation

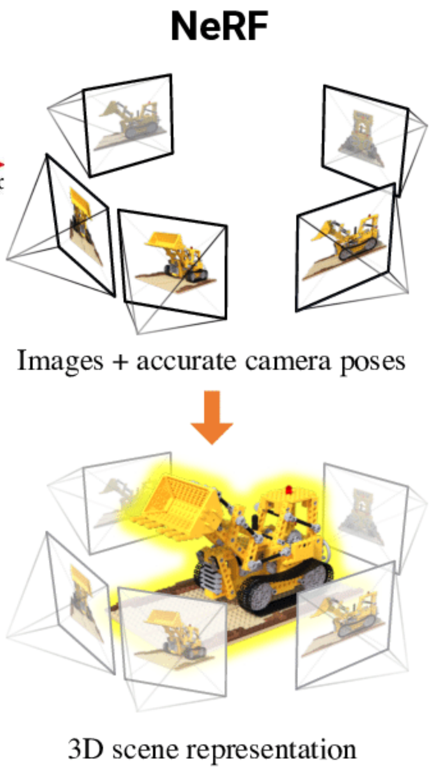




$$(x-h)^2 + (y-k)^2 + (z-l)^2 = r^2$$

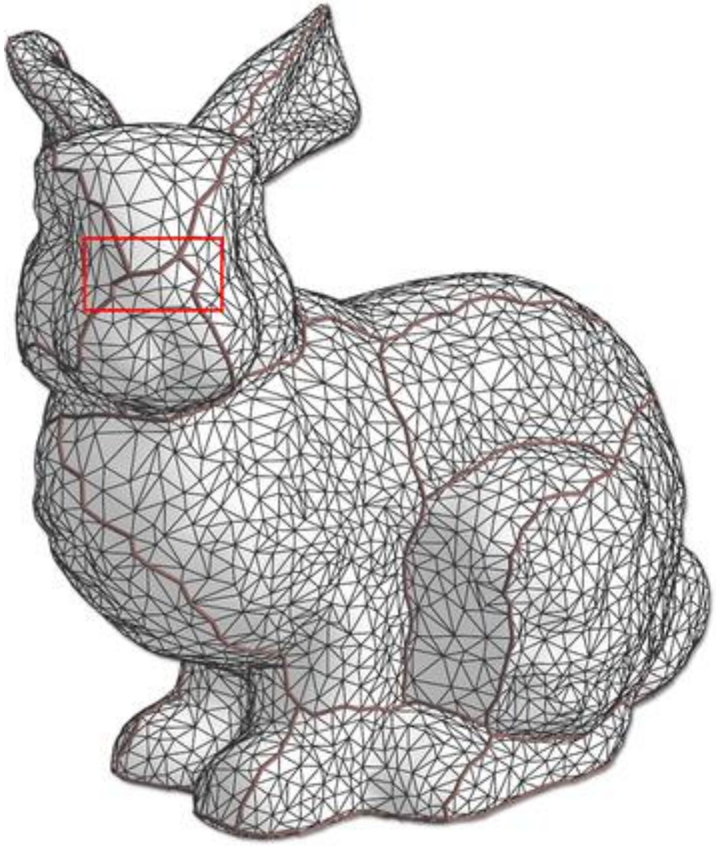
here, r = radius, (h, k, l) = center

(x, y, z) = any point on the surface

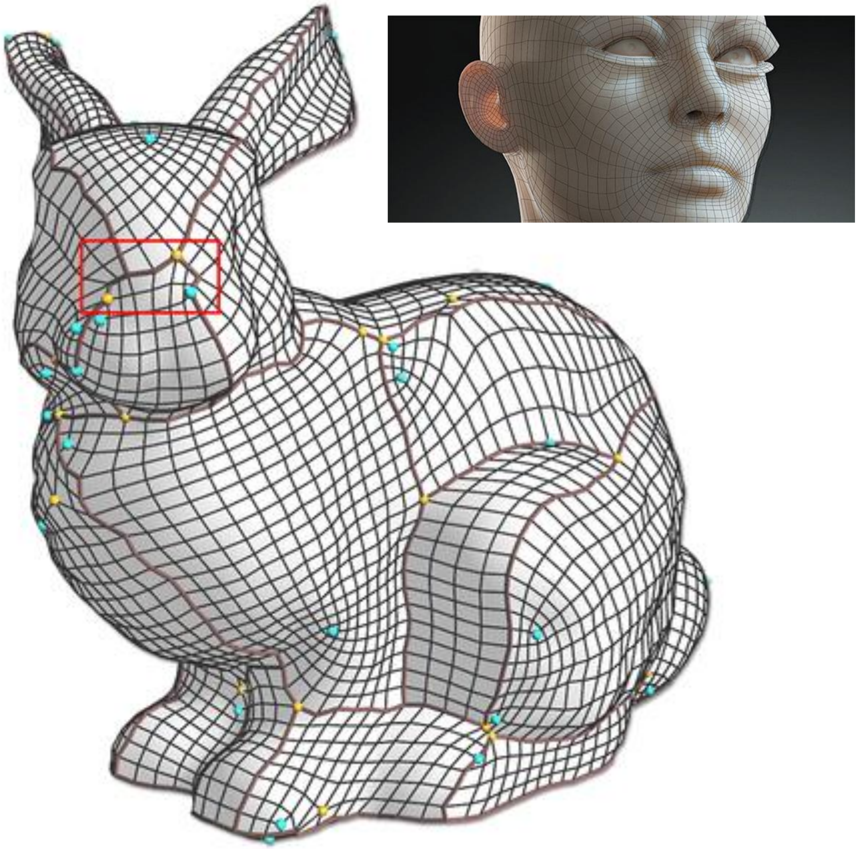


Modeling (cont.)

- Meshes



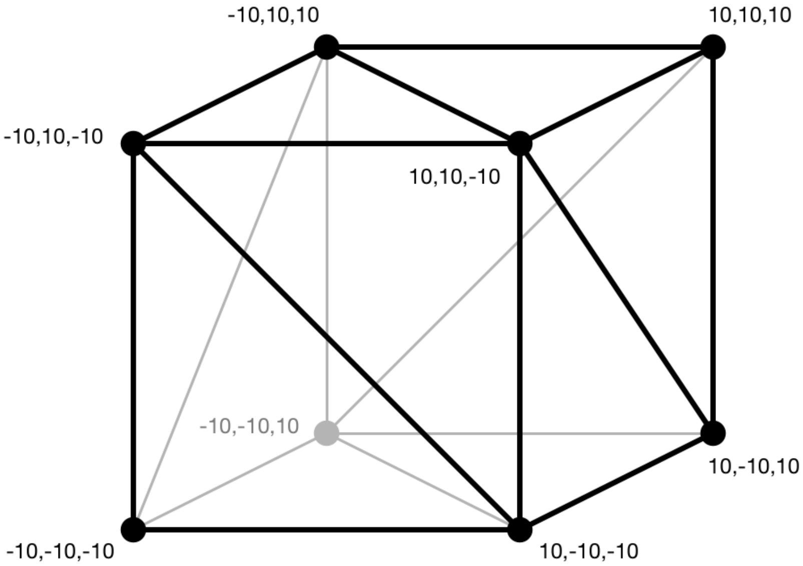
triangle mesh



quad mesh

Modeling (cont.)

- **Triangle mesh** is the most popular representation
- Define the **positions** and **adjacencies** of **vertices**

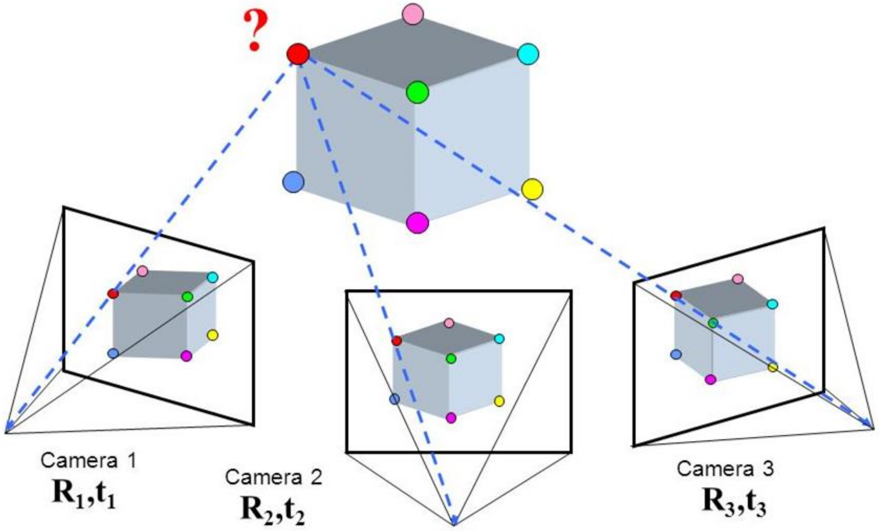


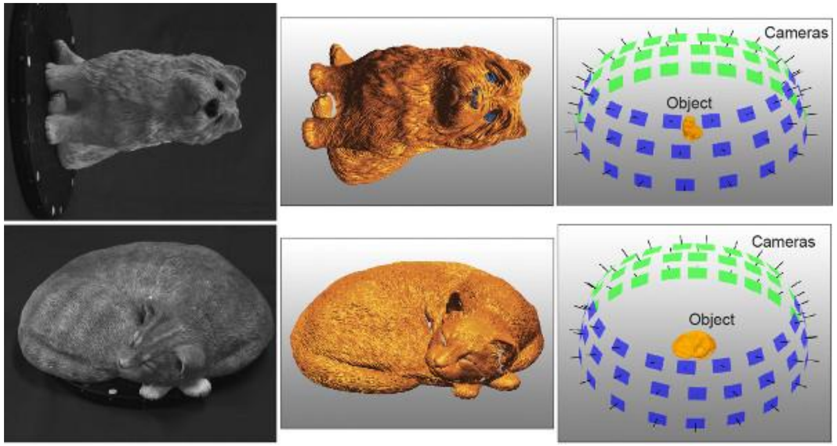
12 triangles

10K triangles

Modeling (cont.)

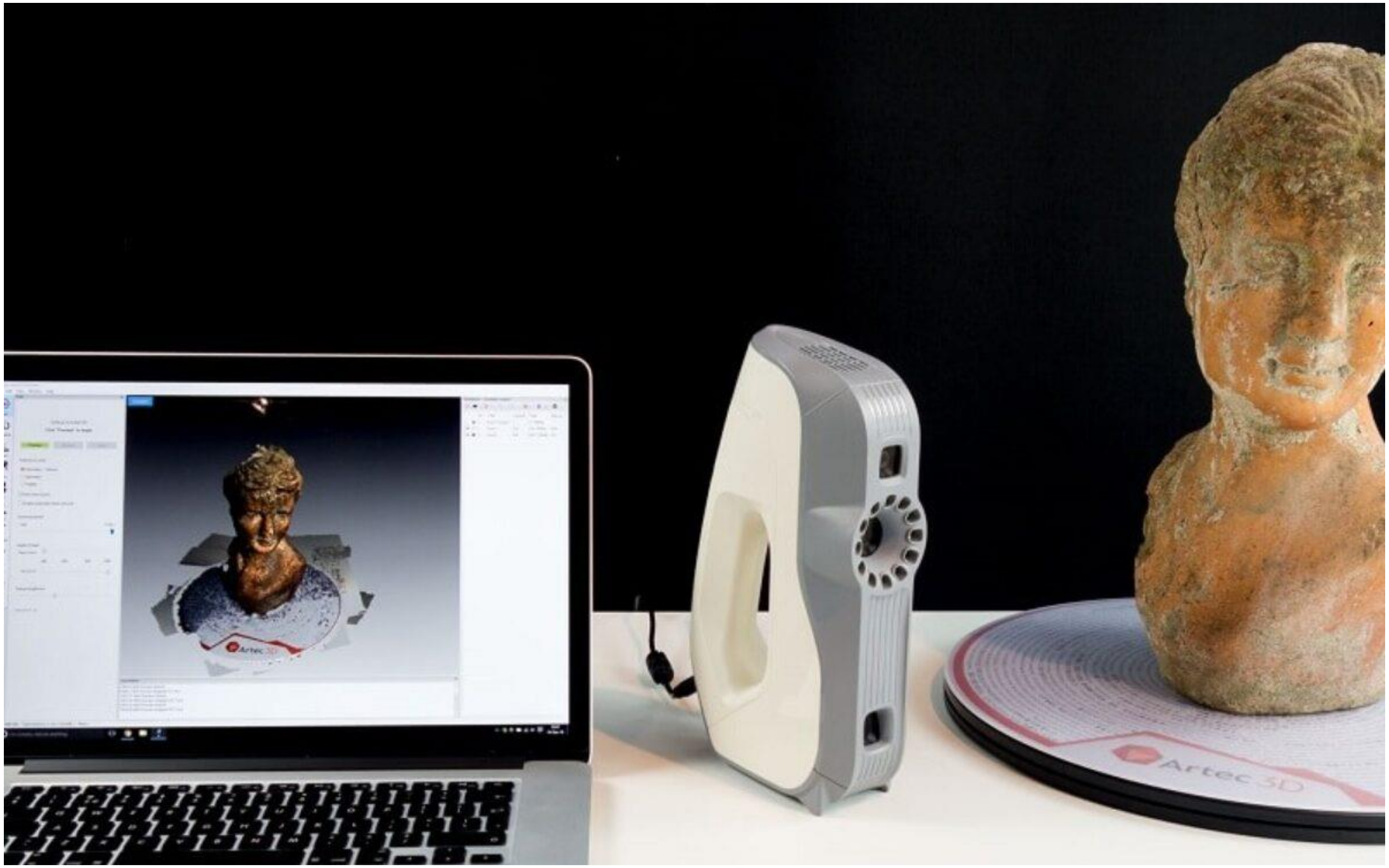
- Multi-view reconstruction


?
Camera 1
$\mathbf{R}_1,\mathbf{t}_1$
Camera 2
$\mathbf{R}_2,\mathbf{t}_2$
Camera 3
$\mathbf{R}_3,\mathbf{t}_3$



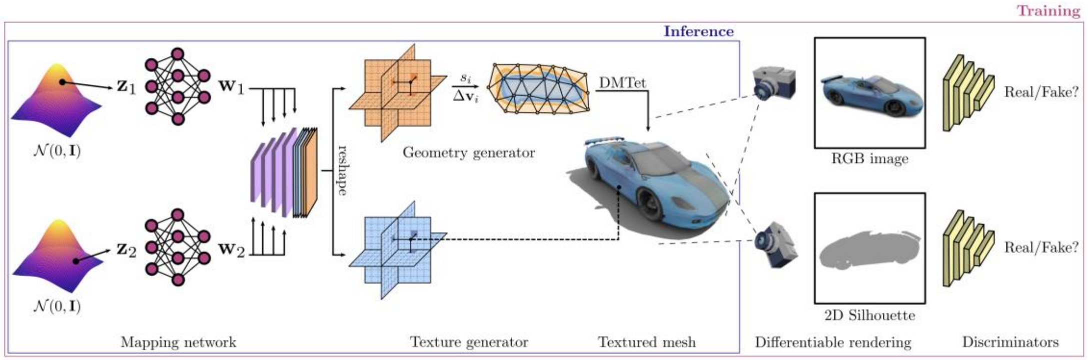
Modeling (cont.)

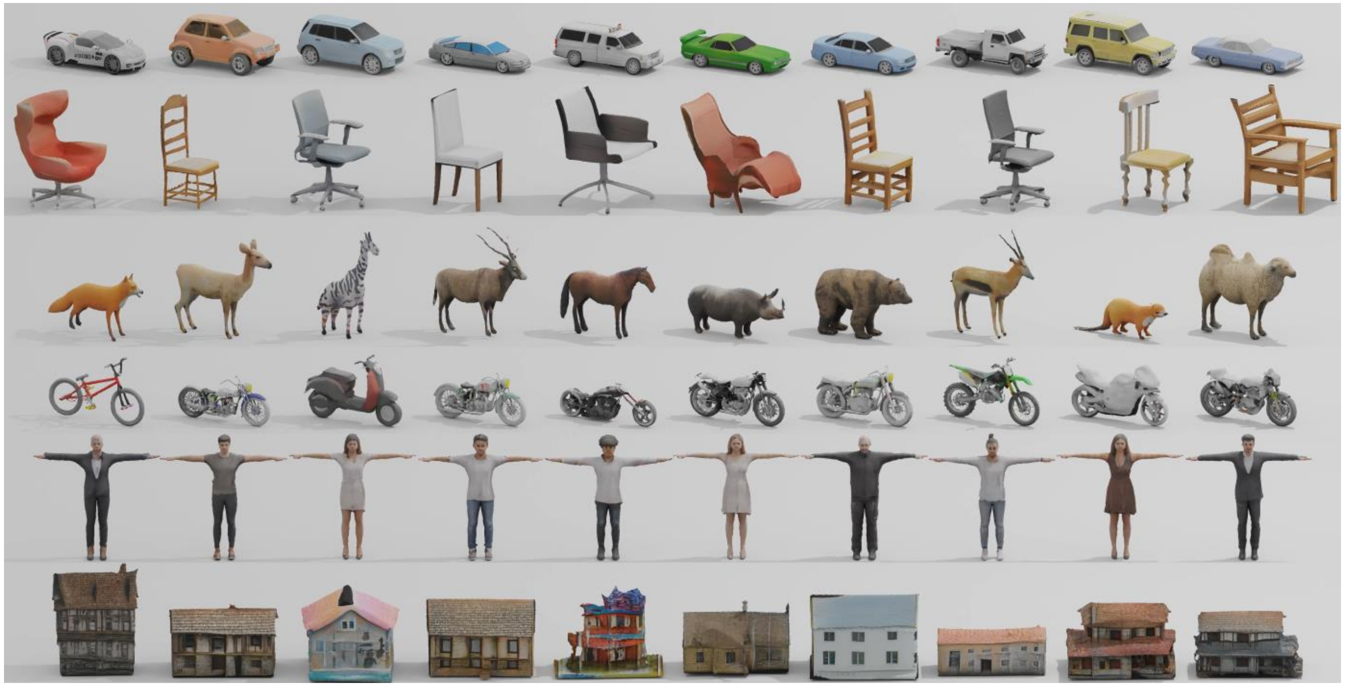
- 3D scanning



Modeling (cont.)

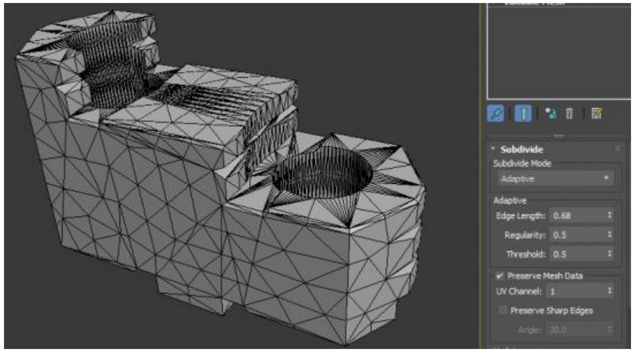
- AI generated



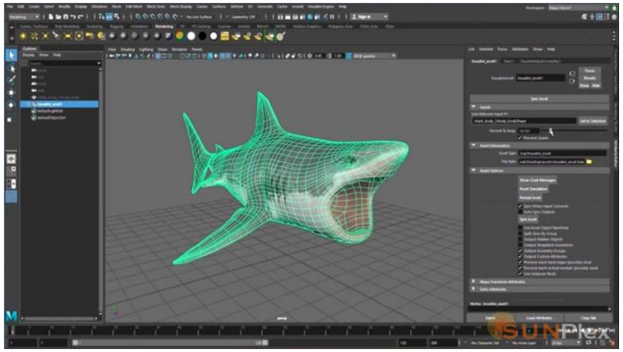


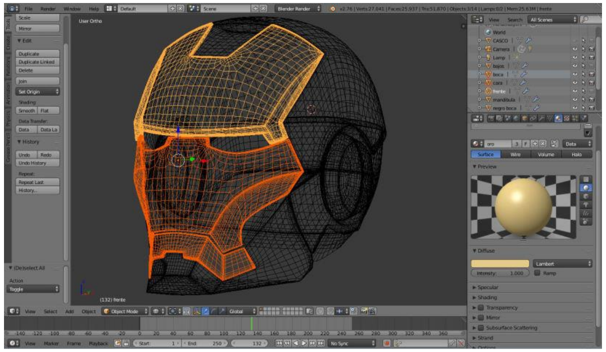
Modeling (cont.)

- 3D models are usually obtained by professional manipulations in 3D modeling tools



Subdivide
Subdivide Mode
Adaptive
Adaptive
Edge Length: 0.68
Regularity: 0.5
Threshold: 0.5
☑ Preserve Mesh Data
UV Channel: 1
□ Preserve Sharp Edges
Angle: 30.0





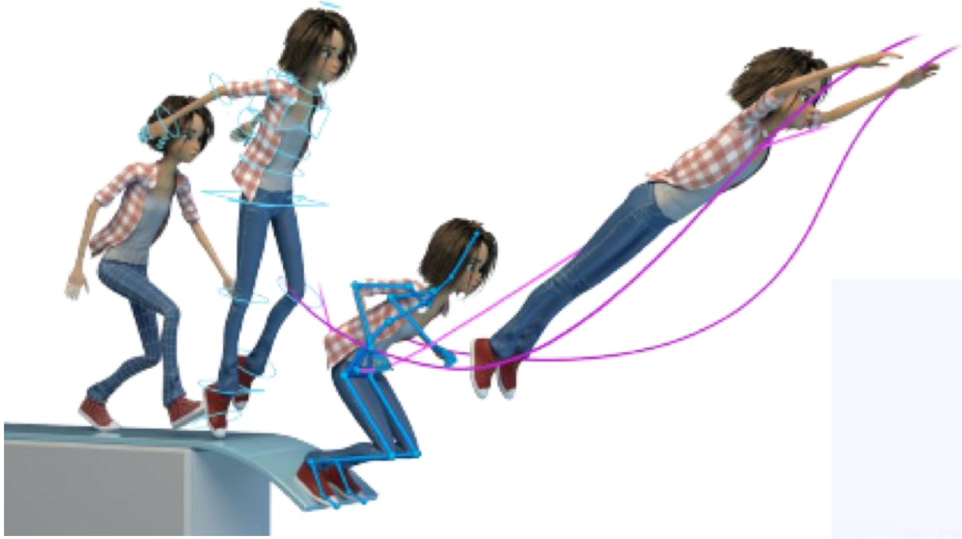
Blender

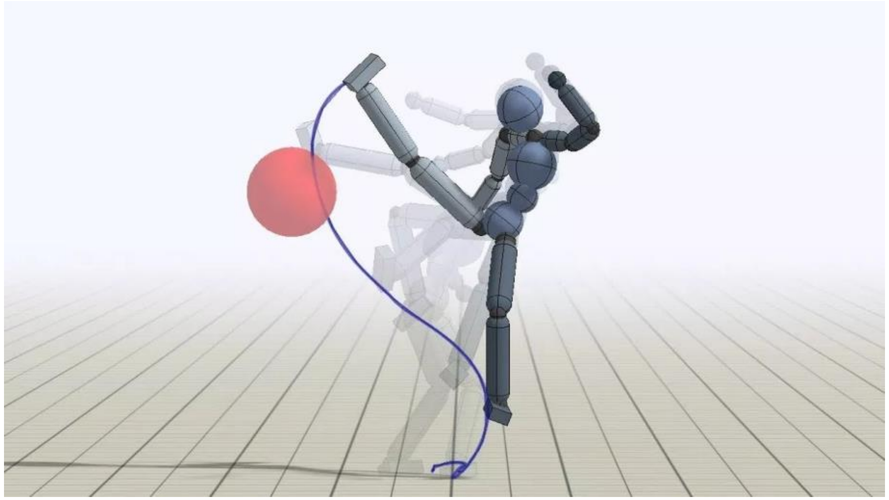
Maya

AUTODESK
3DS MAX

Animation

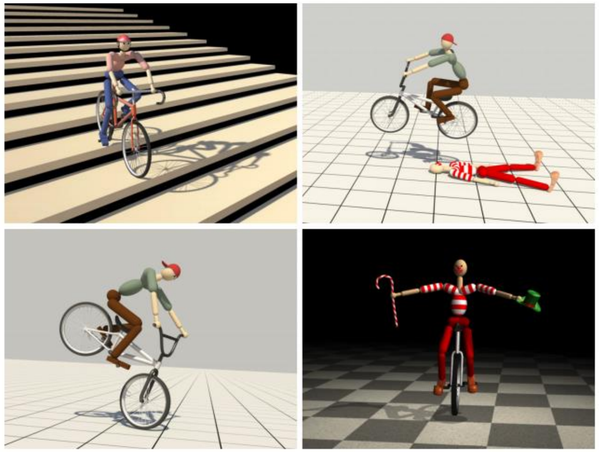
- Describe (or simulate) how the geometry changes / moves over time





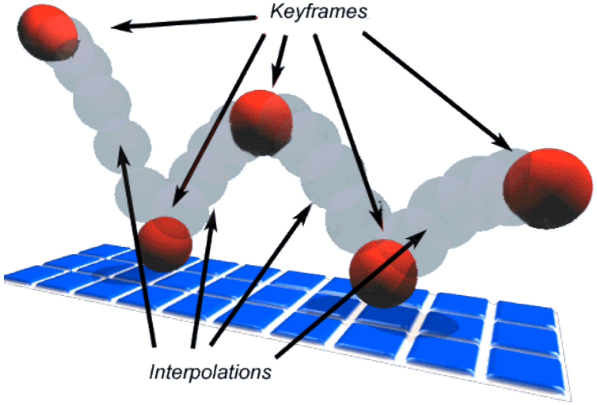
Animation (cont.)

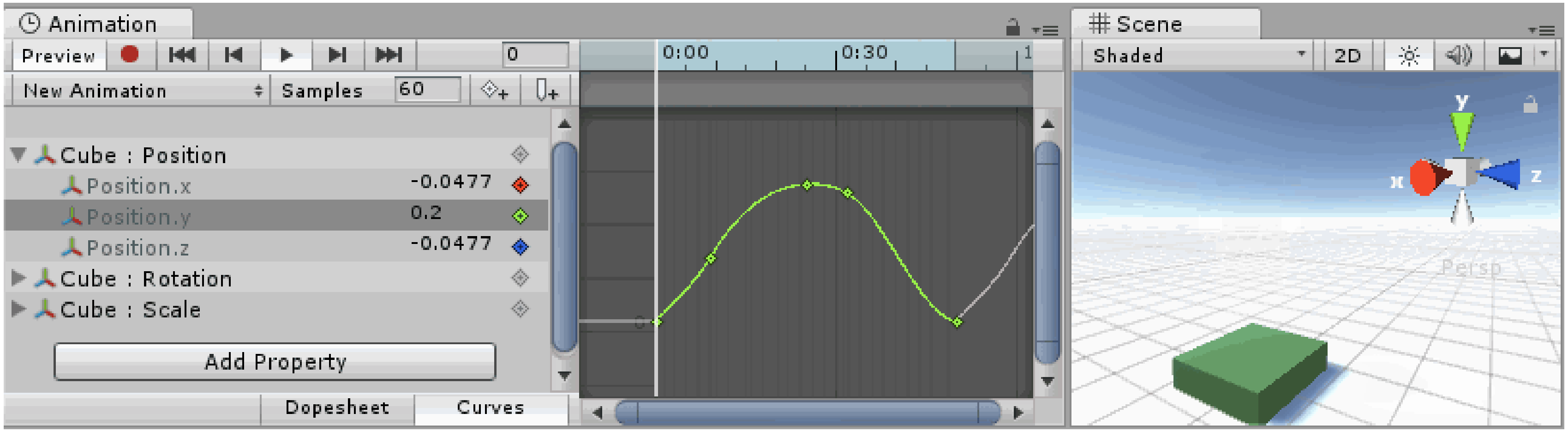
- Animations are usually expected to be physically-based



Animation (cont.)

- Keyframe-based animations





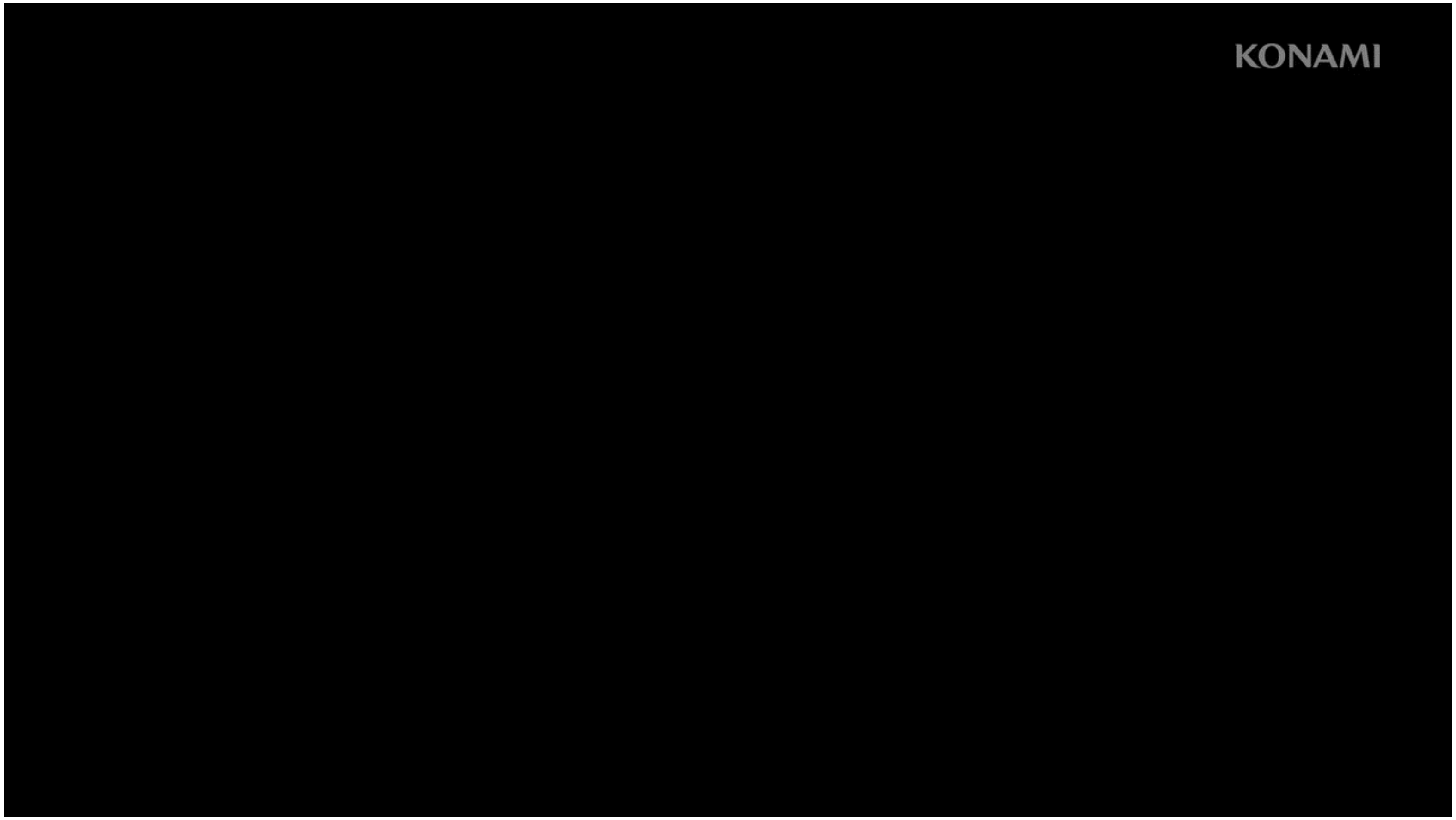
Animation (cont.)

- Motion capture

Dawn of the Planet of the Apes, 2014

Animation (cont.)

- Motion capture + 3D scanning



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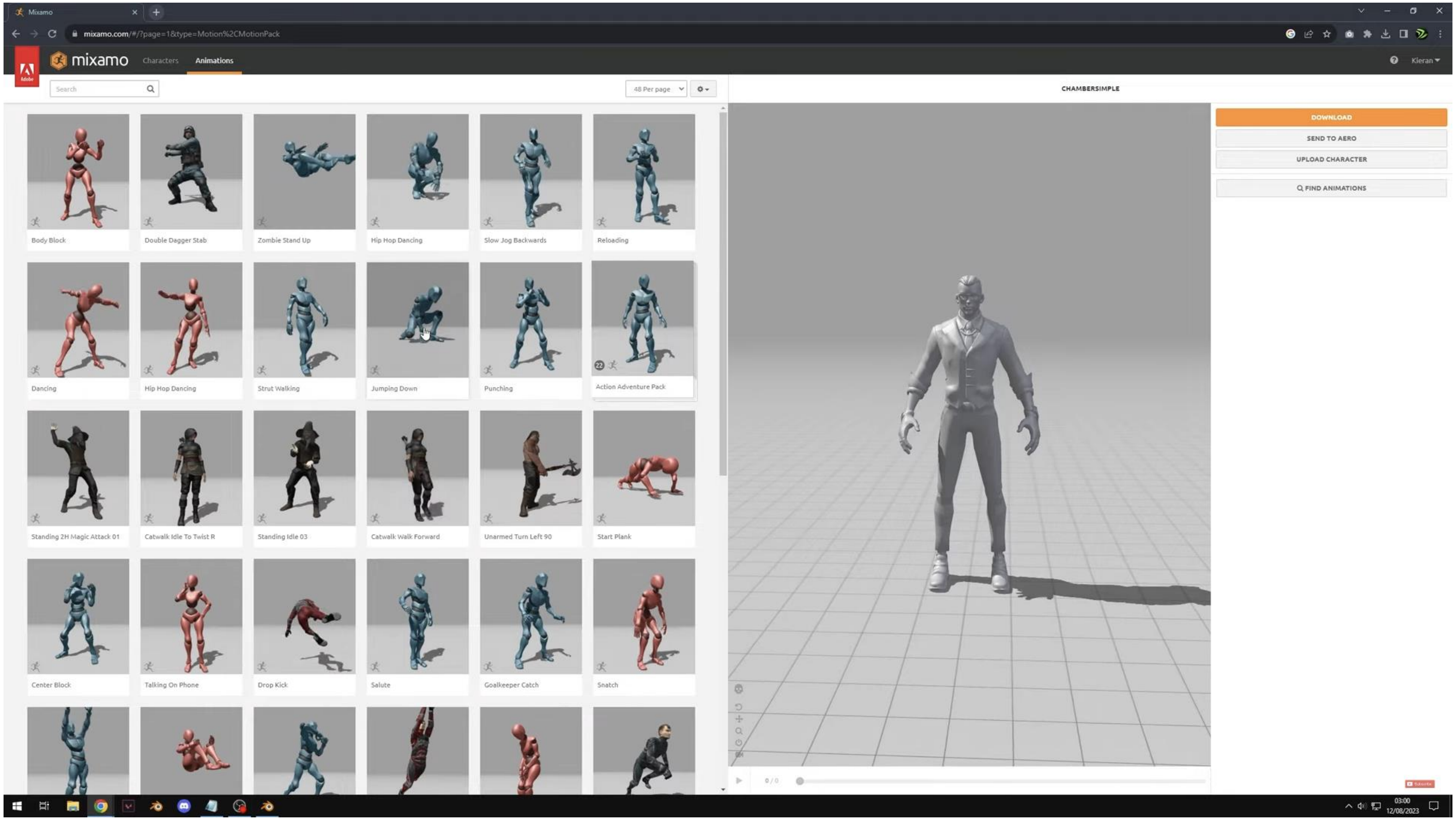
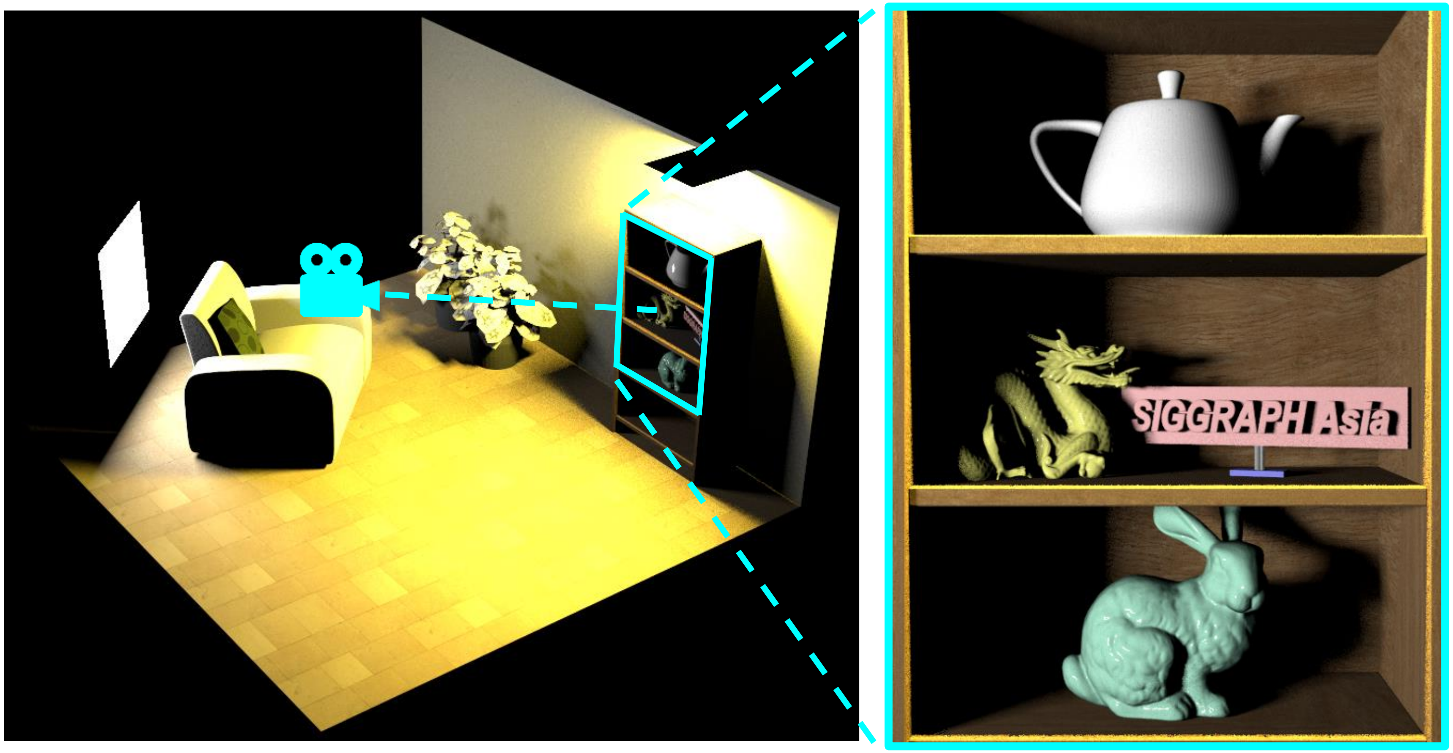
Animation (cont.)

- AI generated



Rendering

- Simulate the appearance of virtual objects and synthesize the final image

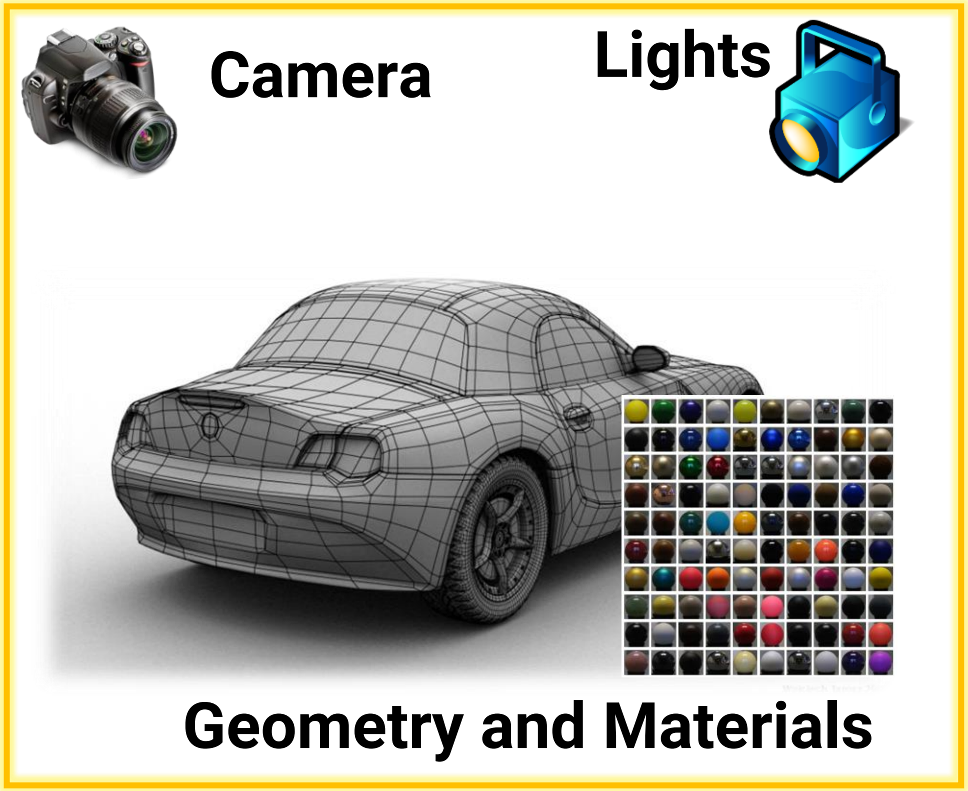


3D virtual world

rendered image

Rendering (cont.)

- Simulate the appearance of virtual objects and synthesize the final image



Camera

Lights

Geometry and Materials

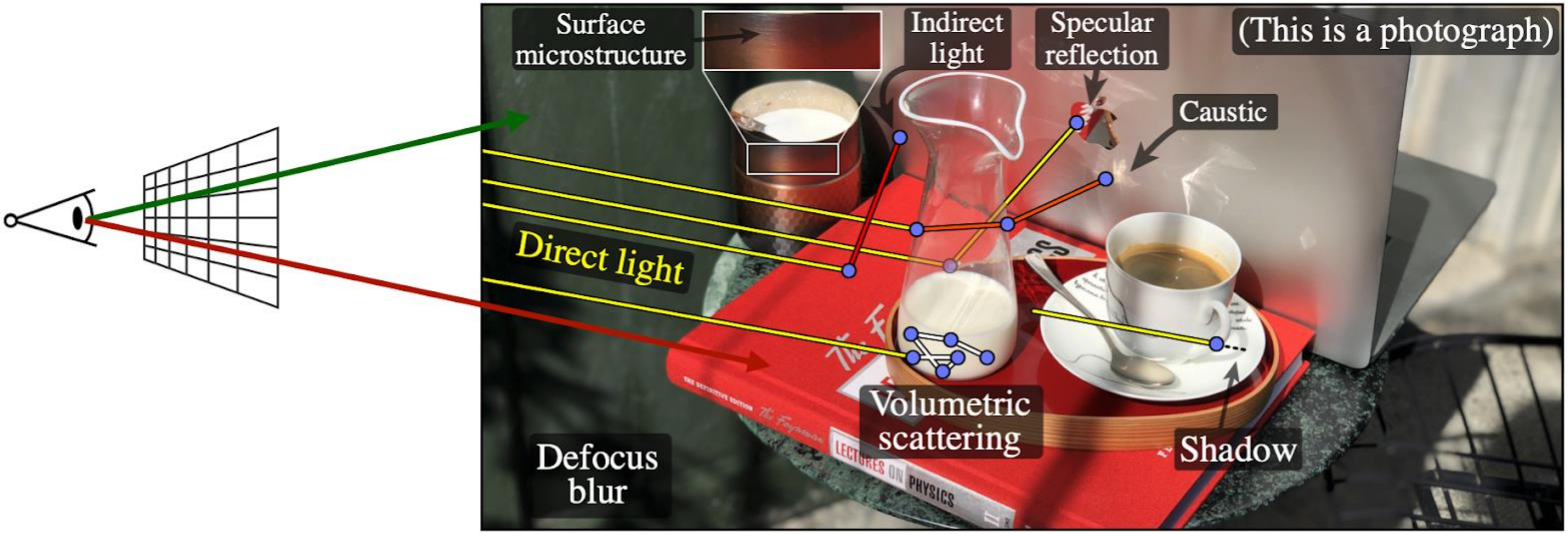
input: 3D description of a scene

Wojciech Jarosz 2005

output: 2D synthetic image

Rendering (cont.)

- **Physically-based rendering**
  - Uses **physics** and **math** to simulate the interaction between matter and light, **realism** is the primary goal



Rendering (cont.)

- Non-photo-realistic rendering

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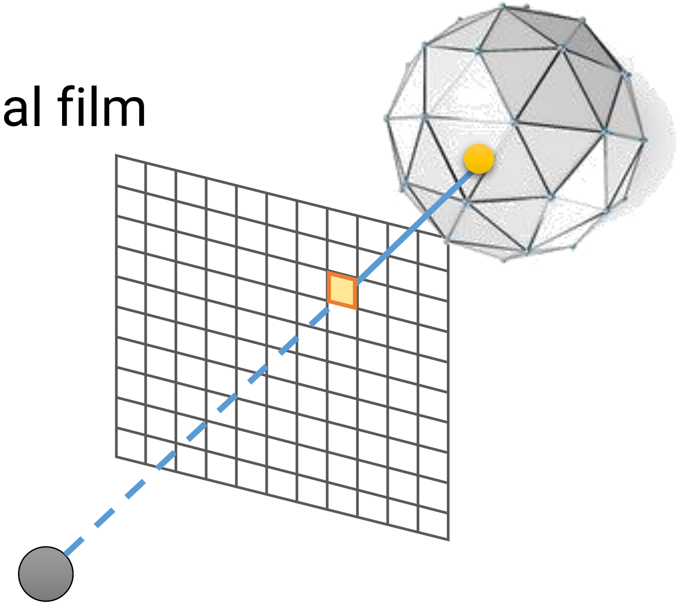
Rendering (cont.)

- Two ways for generating synthetic images

Ray tracing

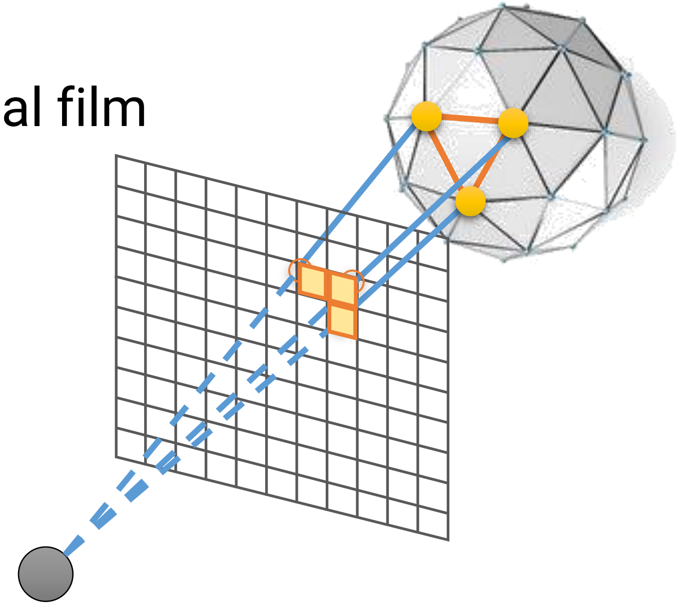
virtual film



virtual camera

Rasterization

virtual film



virtual camera

Rendering (cont.)

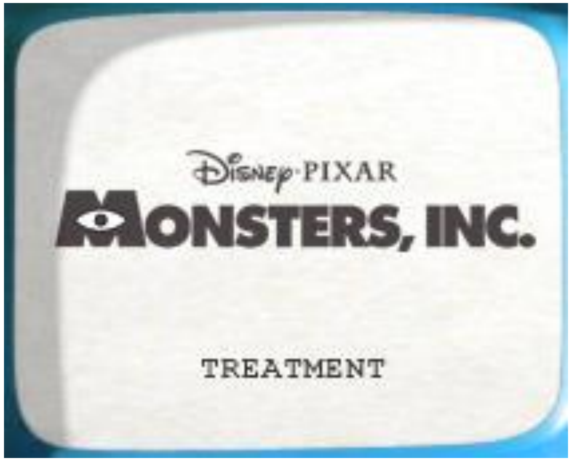
- We will focus on the **rasterization-based** rendering because
    - It is widely used in **interactive computer graphics** and has more applications in our daily lives
    - It is more commonly used in Taiwan’s industry
        - Thus, can be a great help to your future jobs
    - It takes less time to generate an image

- However, the knowledge is the same and we will also give an overview of ray tracing at the end of this course

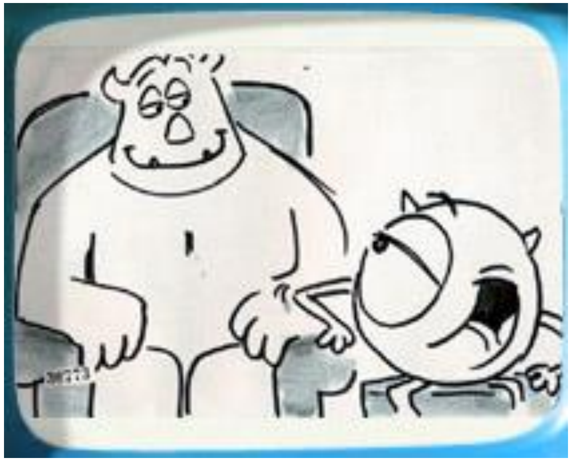
Case Study: Animation Production Pipeline

Animation Production Pipeline

story


Disney·PIXAR
MONSTERS, INC.
TREATMENT

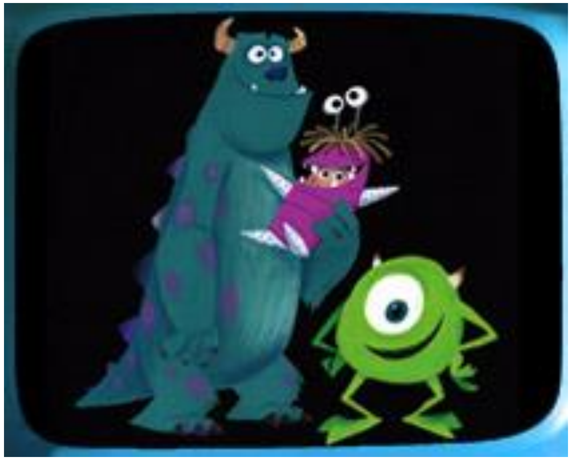
text treatment



storyboard

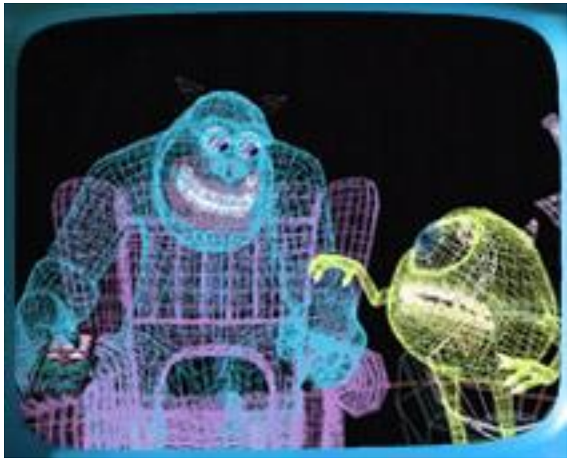
voice

storyreel



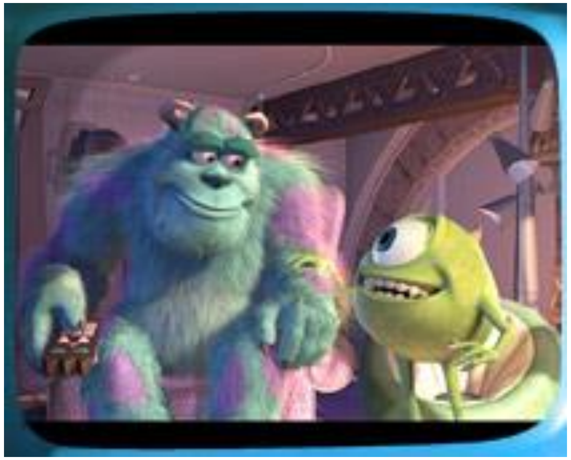
look and feel

Animation Production Pipeline (cont.)


modeling / articulation

layout

animation


shading / lighting

rendering

final touch

Outline

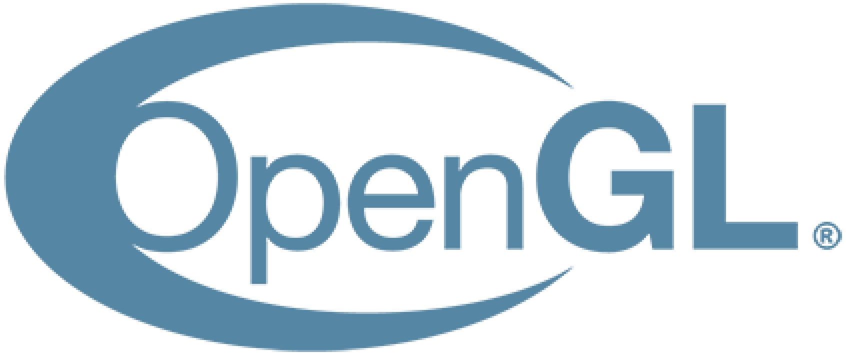
- Introduction to computer graphics
- **Introduction to graphics programming**
- Homework assignments and rendering competition

Graphics Programming

- For rasterization-based graphics, programs are usually implemented with graphics **application programming interface (API)** and **shader programs**
- Common choices are
  - OpenGL + GLSL (OpenGL shading language)
    - OpenGL ES
    - WebGL
  - DirectX + HLSL (High-level shading language)
  - Vulkan + GLSL/HLSL

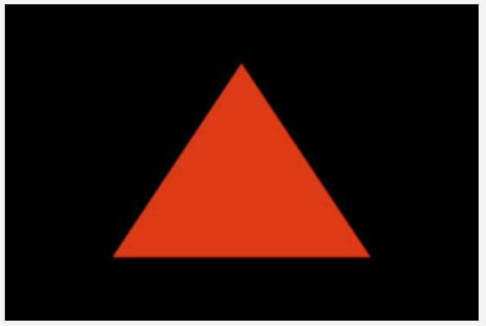
OpenGL

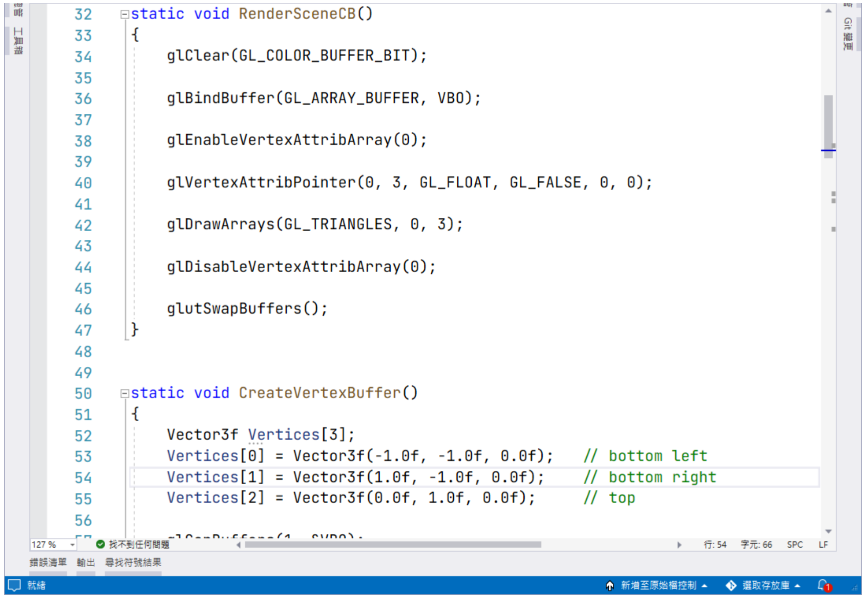
- A **cross-platform** API for rendering 2D and 3D vector graphics, typically used to interact with a graphics processing unit (GPU)
- Developed by Silicon Graphics Inc. (SGI) in 1991
- Managed by a non-profit technology consortium **Khronos Group** after 2006



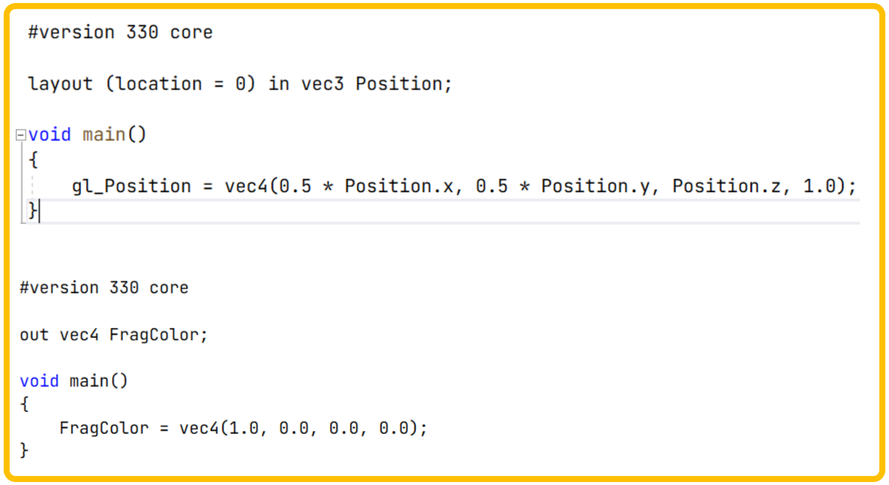
OpenGL + GLSL

- A simple program to draw a triangle on the screen
    - 176 lines of C++ code and 16 lines of shader code





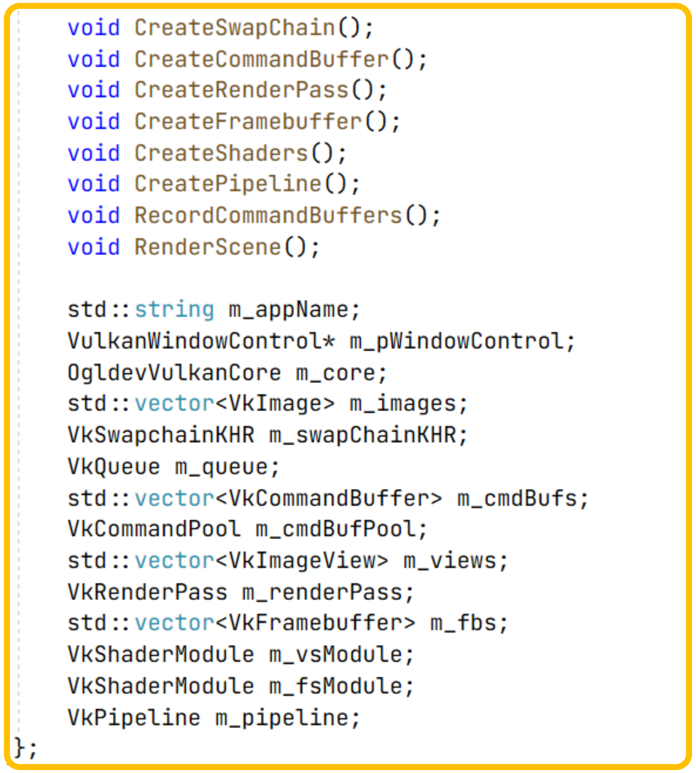
```
static void RenderSceneCB()
{
    glClear(GL_COLOR_BUFFER_BIT);

    glBindBuffer(GL_ARRAY_BUFFER, VBO);

    glEnableVertexAttribArray(0);

    glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0, 0);

    glDrawArrays(GL_TRIANGLES, 0, 3);

    glDisableVertexAttribArray(0);

    glutSwapBuffers();
}


static void CreateVertexBuffer()
{
    Vector3f Vertices[3];
    Vertices[0] = Vector3f(-1.0f, -1.0f, 0.0f);   // bottom left
    Vertices[1] = Vector3f(1.0f, -1.0f, 0.0f);    // bottom right
    Vertices[2] = Vector3f(0.0f, 1.0f, 0.0f);     // top

    glGenBuffers(1, &VBO);
```



```
#version 330 core

layout (location = 0) in vec3 Position;

void main()
{
    gl_Position = vec4(0.5 * Position.x, 0.5 * Position.y, Position.z, 1.0);
}


#version 330 core

out vec4 FragColor;

void main()
{
    FragColor = vec4(1.0, 0.0, 0.0, 0.0);
}
```

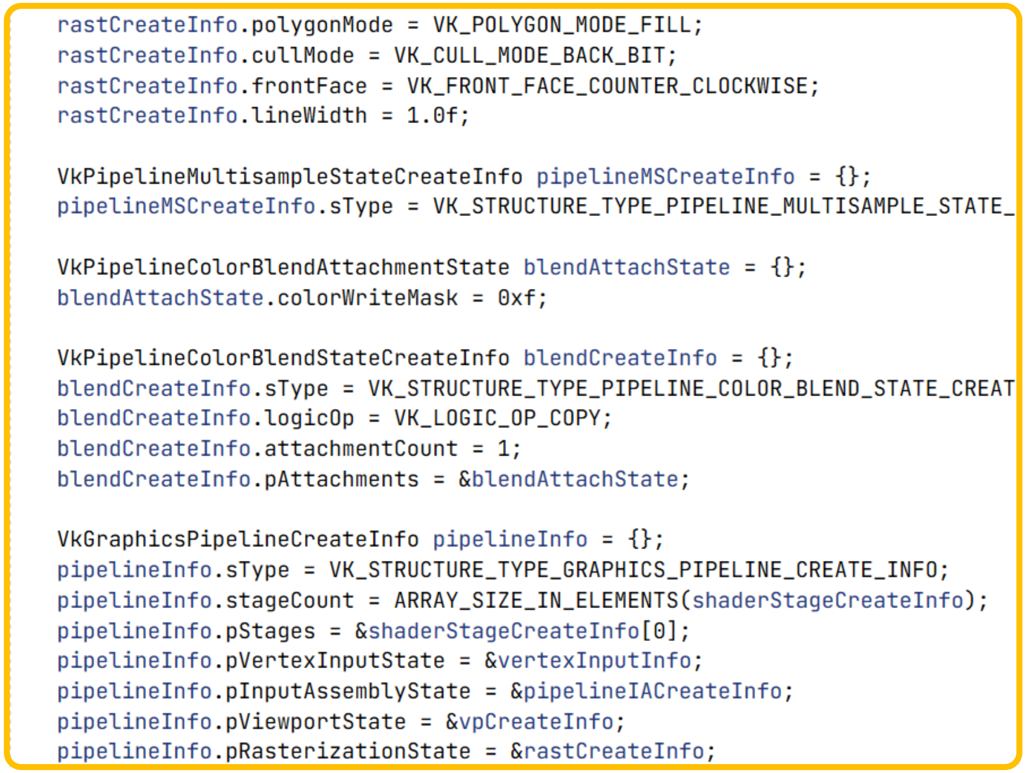
Why not Teaching Vulkan in this Course?

- A simple program to draw a triangle on the screen
    - **457** lines of C++ code



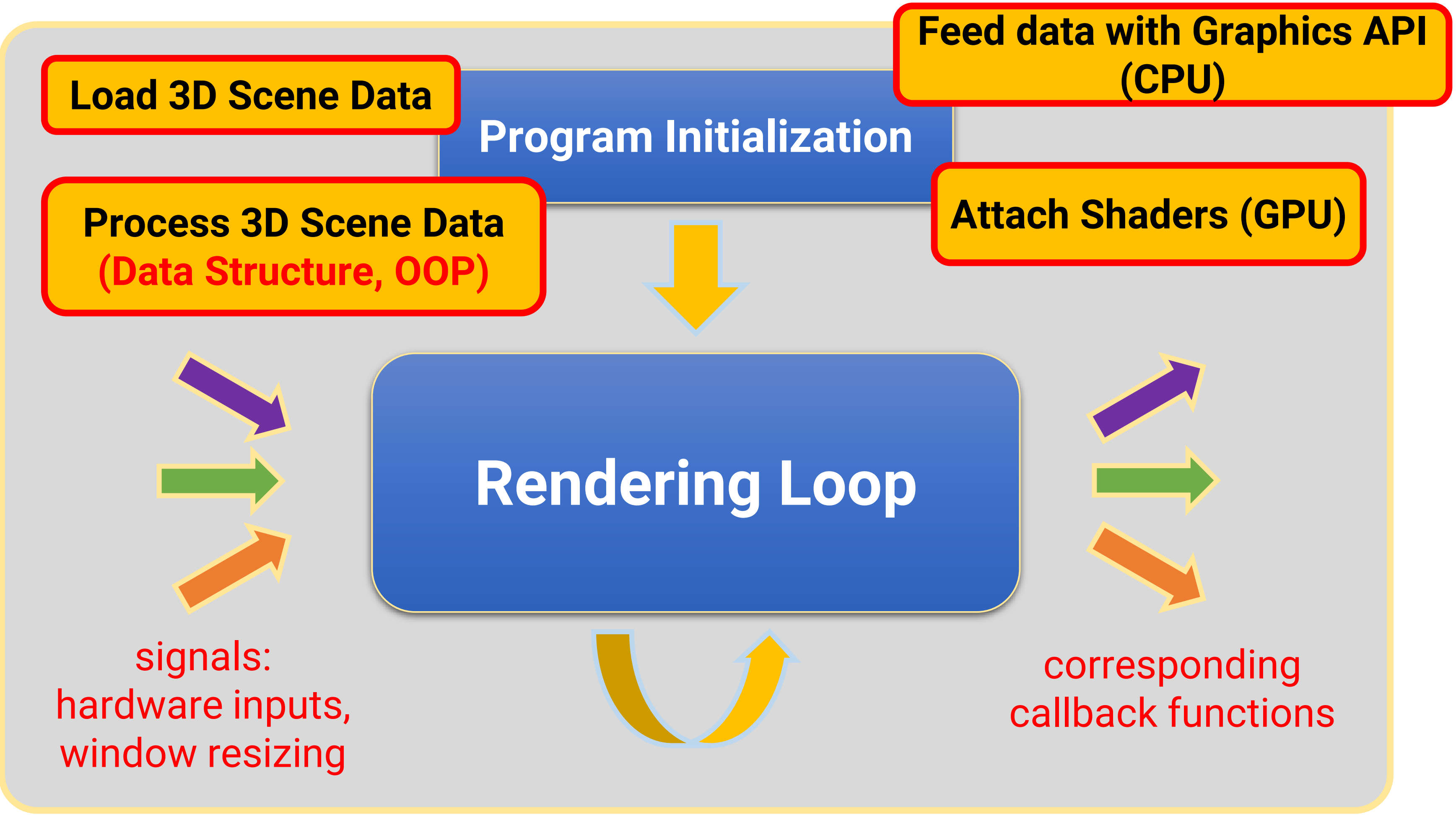
```cpp
    void CreateSwapChain();
    void CreateCommandBuffer();
    void CreateRenderPass();
    void CreateFramebuffer();
    void CreateShaders();
    void CreatePipeline();
    void RecordCommandBuffers();
    void RenderScene();

    std::string m_appName;
    VulkanWindowControl* m_pWindowControl;
    OgldevVulkanCore m_core;
    std::vector<VkImage> m_images;
    VkSwapchainKHR m_swapChainKHR;
    VkQueue m_queue;
    std::vector<VkCommandBuffer> m_cmdBufs;
    VkCommandPool m_cmdBufPool;
    std::vector<VkImageView> m_views;
    VkRenderPass m_renderPass;
    std::vector<VkFramebuffer> m_fbs;
    VkShaderModule m_vsModule;
    VkShaderModule m_fsModule;
    VkPipeline m_pipeline;
};
```

…



```cpp
rastCreateInfo.polygonMode = VK_POLYGON_MODE_FILL;
rastCreateInfo.cullMode = VK_CULL_MODE_BACK_BIT;
rastCreateInfo.frontFace = VK_FRONT_FACE_COUNTER_CLOCKWISE;
rastCreateInfo.lineWidth = 1.0f;

VkPipelineMultisampleStateCreateInfo pipelineMSCreateInfo = {};
pipelineMSCreateInfo.sType = VK_STRUCTURE_TYPE_PIPELINE_MULTISAMPLE_STATE_

VkPipelineColorBlendAttachmentState blendAttachState = {};
blendAttachState.colorWriteMask = 0xf;

VkPipelineColorBlendStateCreateInfo blendCreateInfo = {};
blendCreateInfo.sType = VK_STRUCTURE_TYPE_PIPELINE_COLOR_BLEND_STATE_CREAT
blendCreateInfo.logicOp = VK_LOGIC_OP_COPY;
blendCreateInfo.attachmentCount = 1;
blendCreateInfo.pAttachments = &blendAttachState;

VkGraphicsPipelineCreateInfo pipelineInfo = {};
pipelineInfo.sType = VK_STRUCTURE_TYPE_GRAPHICS_PIPELINE_CREATE_INFO;
pipelineInfo.stageCount = ARRAY_SIZE_IN_ELEMENTS(shaderStageCreateInfo);
pipelineInfo.pStages = &shaderStageCreateInfo[0];
pipelineInfo.pVertexInputState = &vertexInputInfo;
pipelineInfo.pInputAssemblyState = &pipelineIACreateInfo;
pipelineInfo.pViewportState = &vpCreateInfo;
pipelineInfo.pRasterizationState = &rastCreateInfo;
```

Life Cycle of a Rendering Engine



Load 3D Scene Data

Program Initialization

Feed data with Graphics API (CPU)

Process 3D Scene Data (Data Structure, OOP)

Attach Shaders (GPU)

Rendering Loop

signals:
hardware inputs,
window resizing

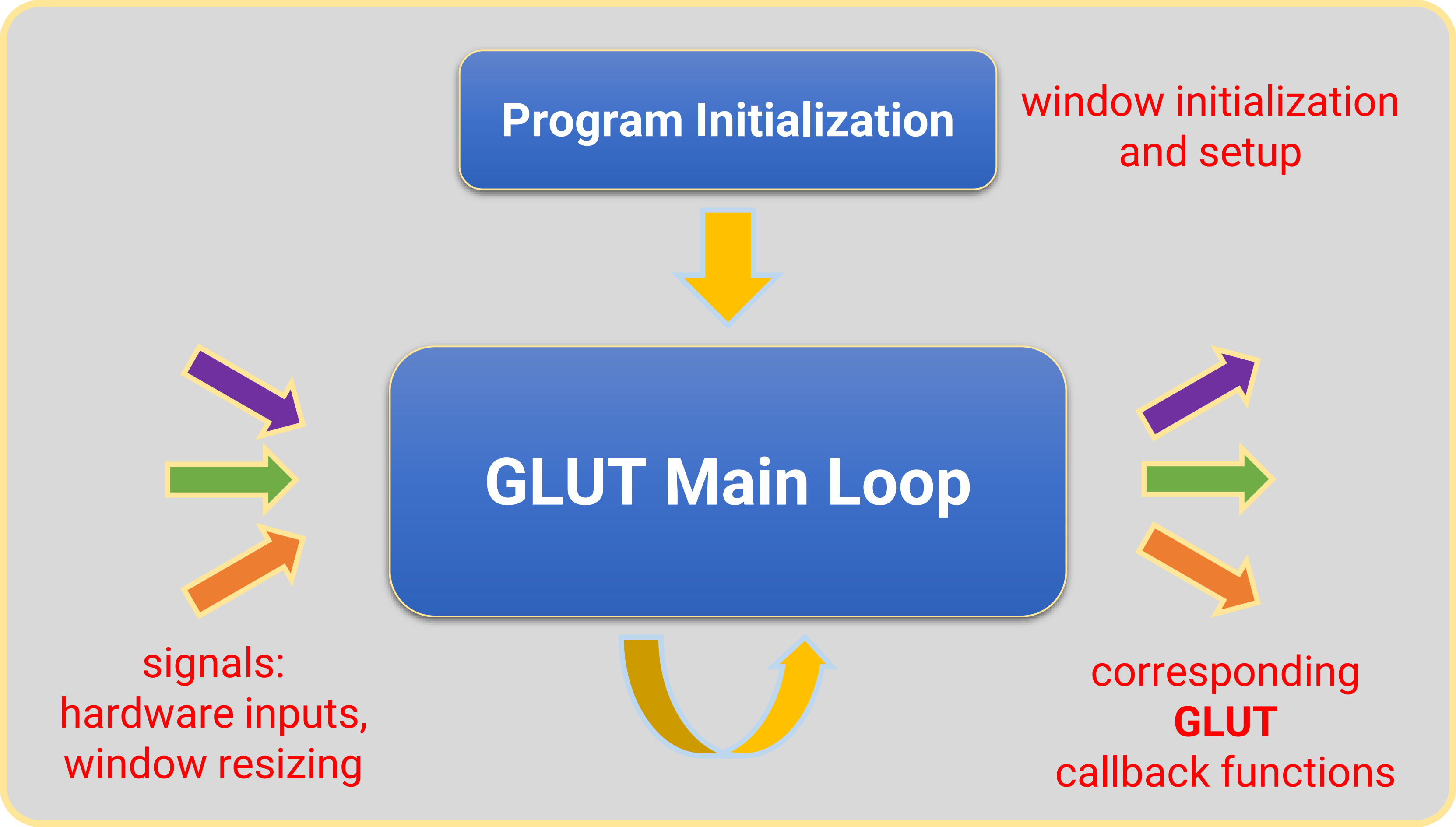
corresponding
callback functions

your program

Library for Handling Screen Rendering

- **GLUT: OpenGL Utility Toolkit (link)**
  - Window system independent
  - Implement a simple window application programming interface (API) for OpenGL
  - Designed for constructing small to medium-sized OpenGL programs
    - For large applications, it is suggested to use a native window system toolkit such as Qt for more sophisticated UI
- **FreeGLUT: Free OpenGL Utility Toolkit (link)**
  - GLUT has gone into stagnation and has some issues with licenses
  - FreeGLUT is intended to be a full replacement for GLUT

Life Cycle of a FreeGLUT Program



Program Initialization

window initialization and setup

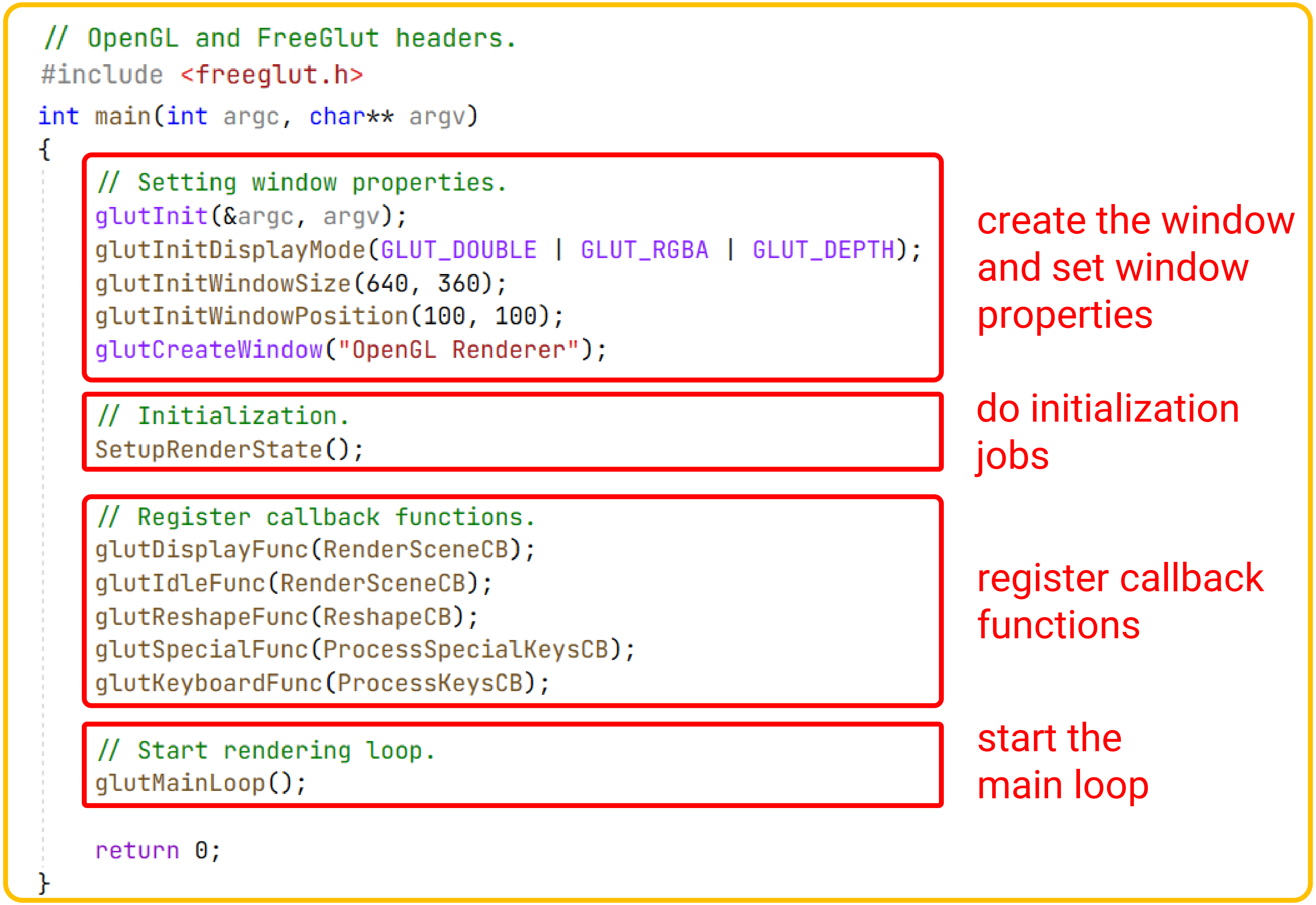
GLUT Main Loop

signals: hardware inputs, window resizing

corresponding **GLUT** callback functions

your program

Structure of a FreeGLUT Program



```
// OpenGL and FreeGlut headers.
#include <freeglut.h>
int main(int argc, char** argv)
{
    // Setting window properties.
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGBA | GLUT_DEPTH);
    glutInitWindowSize(640, 360);
    glutInitWindowPosition(100, 100);
    glutCreateWindow("OpenGL Renderer");

    // Initialization.
    SetupRenderState();

    // Register callback functions.
    glutDisplayFunc(RenderSceneCB);
    glutIdleFunc(RenderSceneCB);
    glutReshapeFunc(ReshapeCB);
    glutSpecialFunc(ProcessSpecialKeysCB);
    glutKeyboardFunc(ProcessKeysCB);

    // Start rendering loop.
    glutMainLoop();

    return 0;
}
```

create the window and set window properties

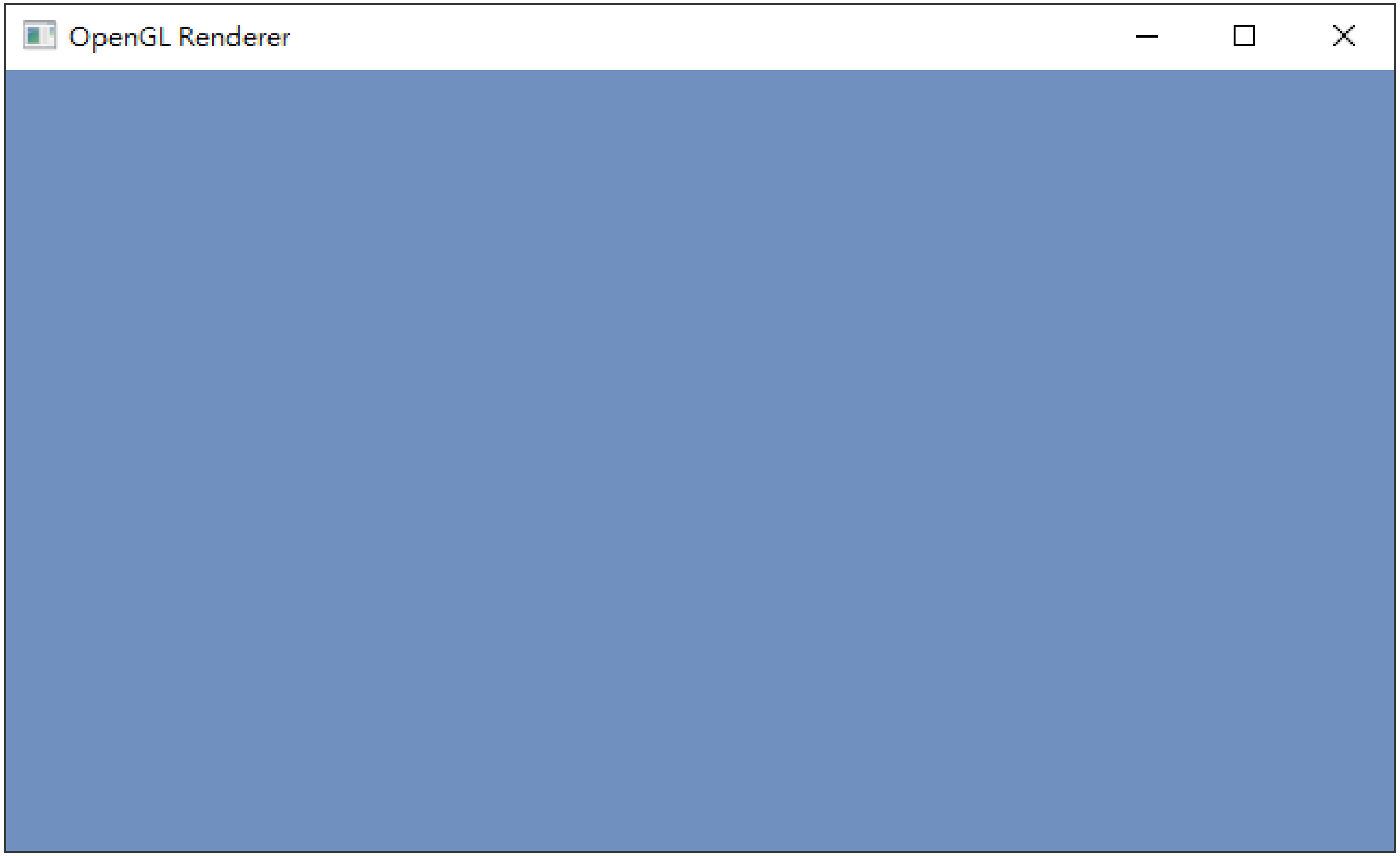
do initialization jobs

register callback functions

start the main loop

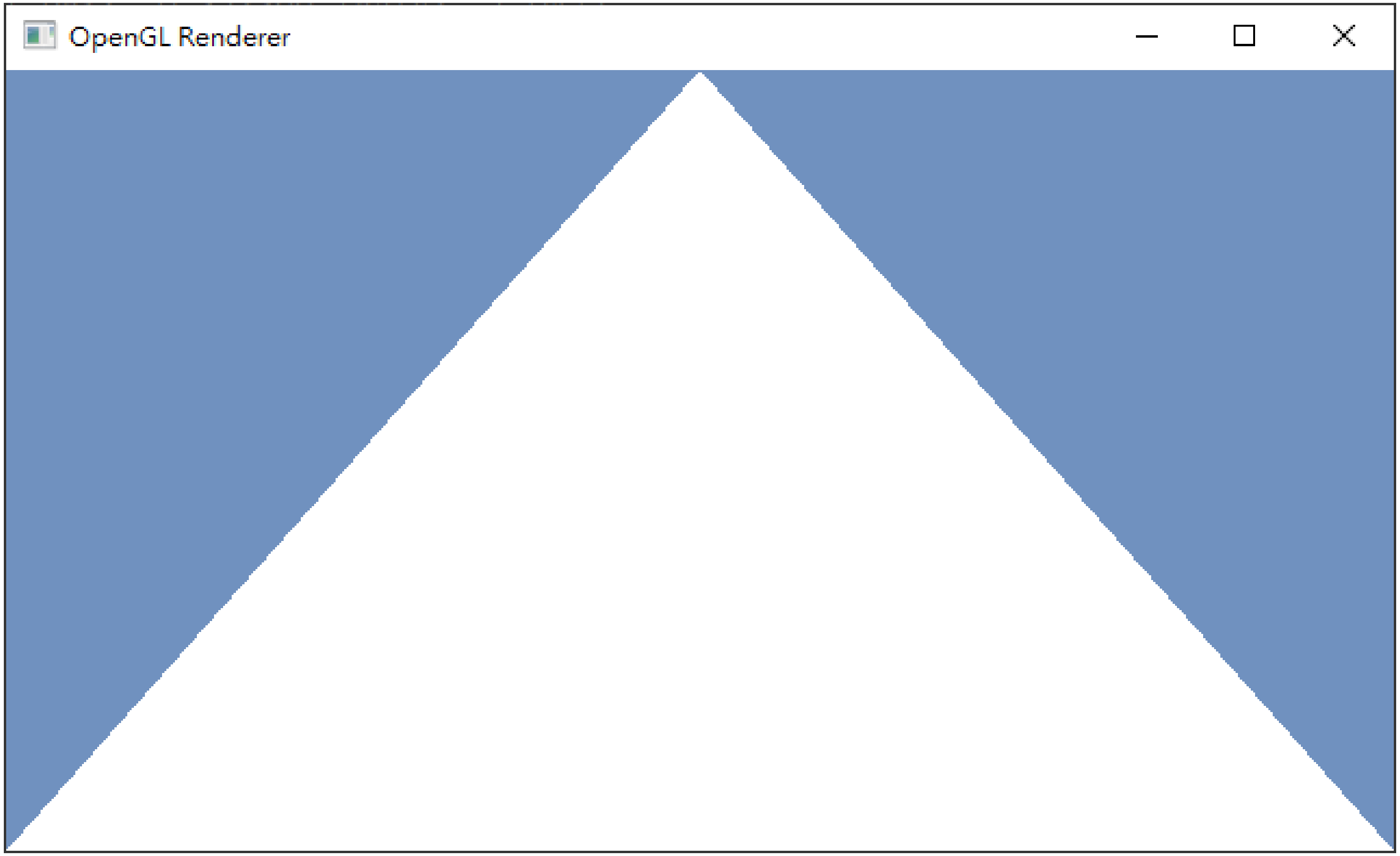
FreeGLUT Window

- FreeGLUT will create and maintain a window on screen



Next Two Weeks

- We will learn how to render a single triangle



Outline

- Introduction to computer graphics
- Introduction to graphics programming
- **Homework assignments and rendering competition**

Topics We Plan to Cover

Basic

- Geometry Representation

HW1

- Transformations
- Camera
- GPU Graphics Pipeline

HW2

- Shading
- Textures

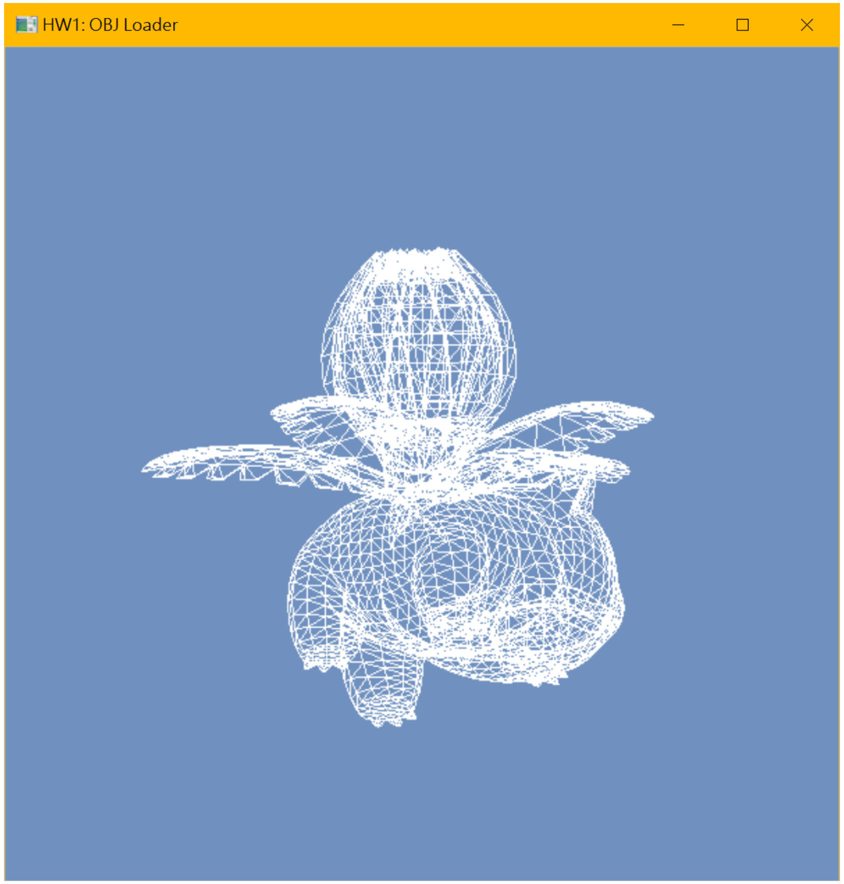
HW3

- Skybox

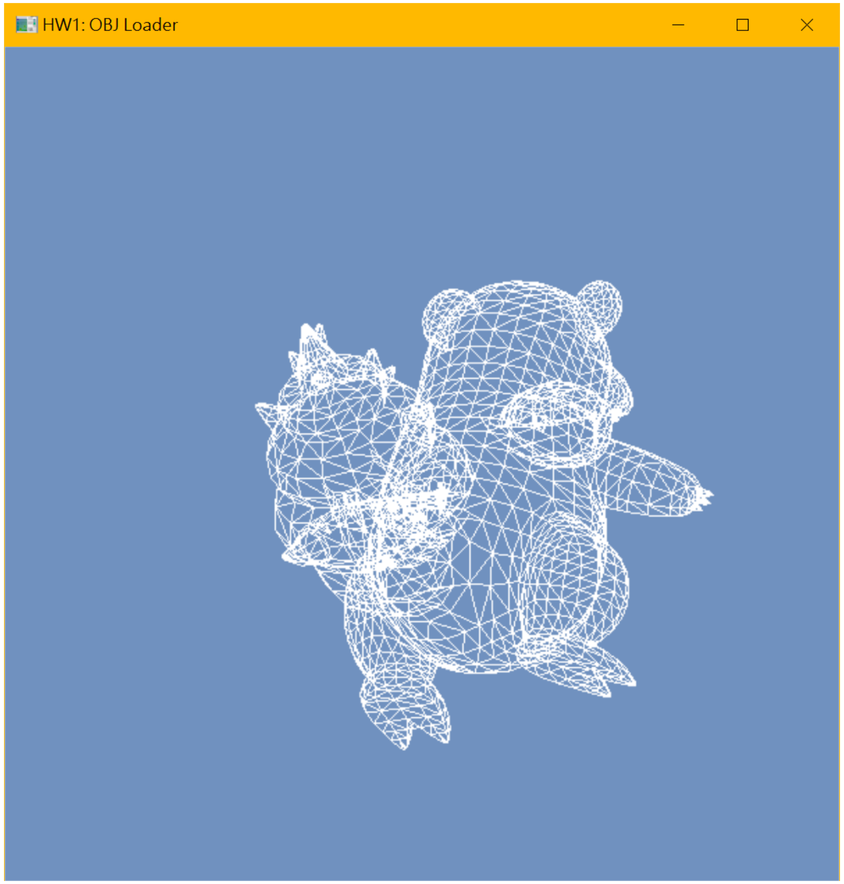
Advanced

- Transparency
- Shadows
- Deferred Shading
- Terrain
- Ray Tracing
- Advanced Shaders
- Unity Case Study

HW1: Geometry Representation (18%)

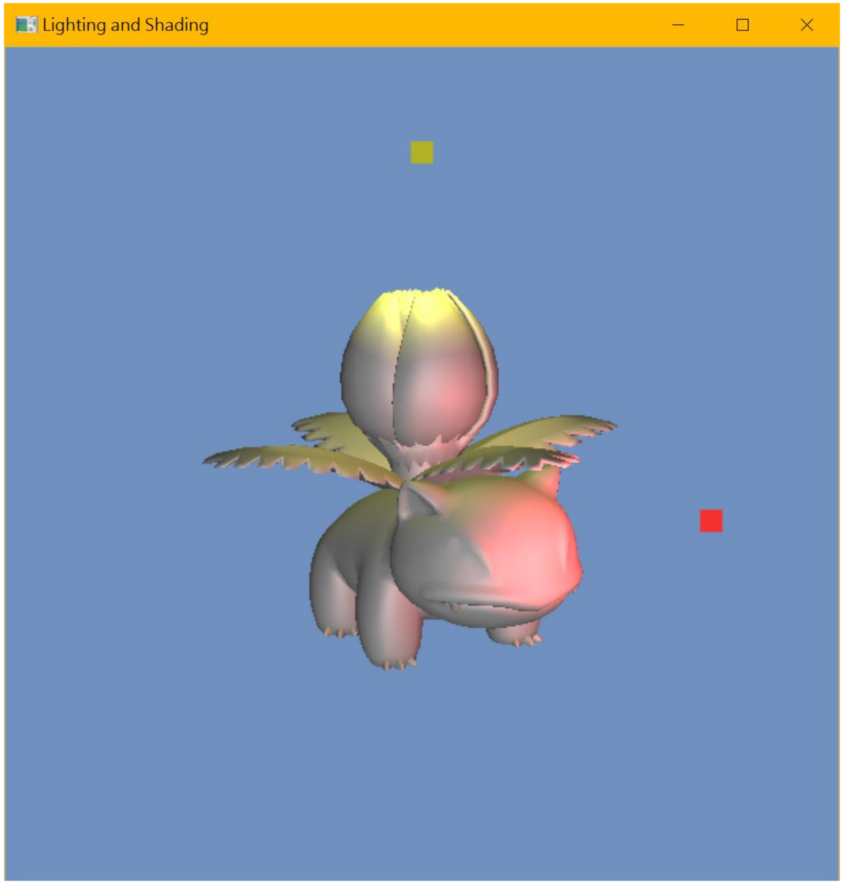


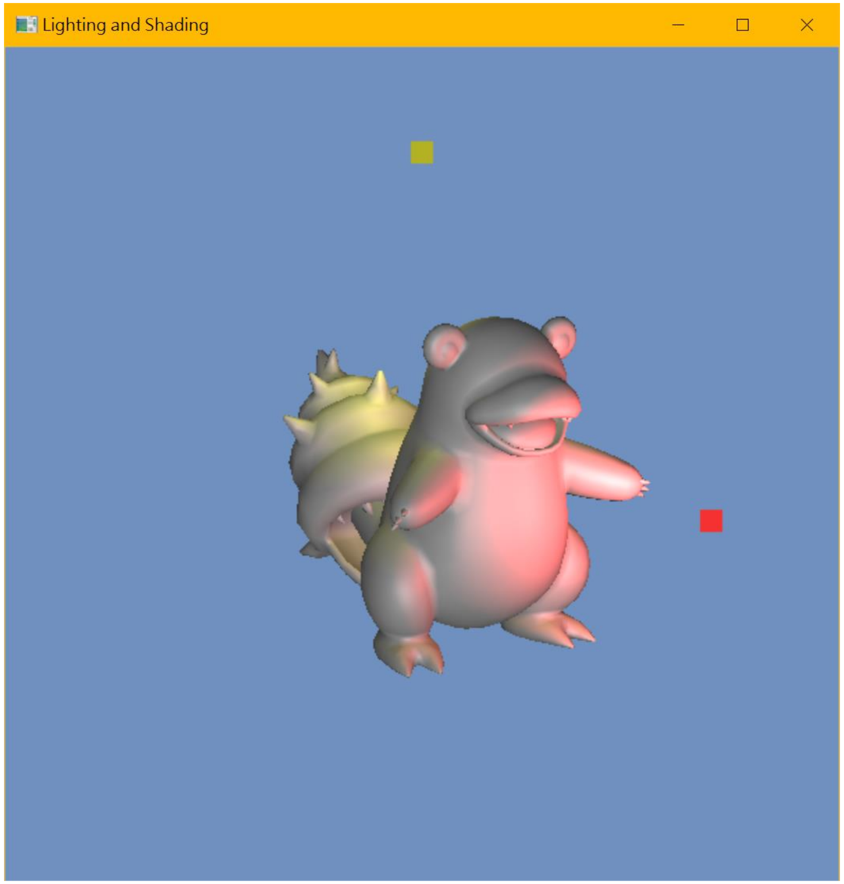
HW1: OBJ Loader



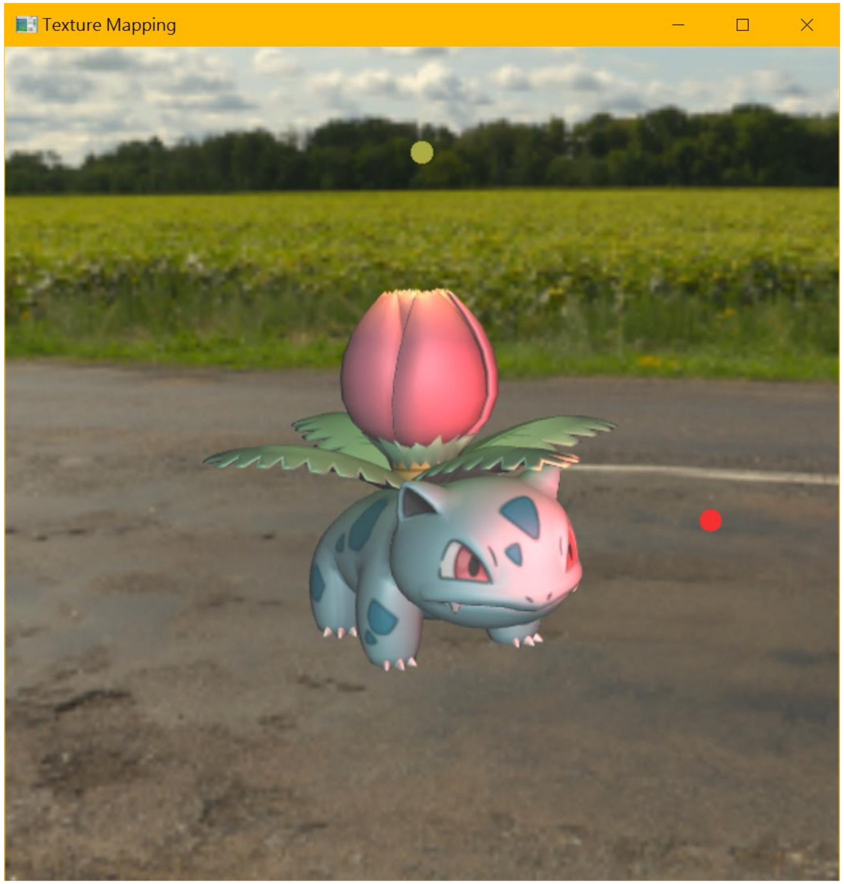
HW1: OBJ Loader

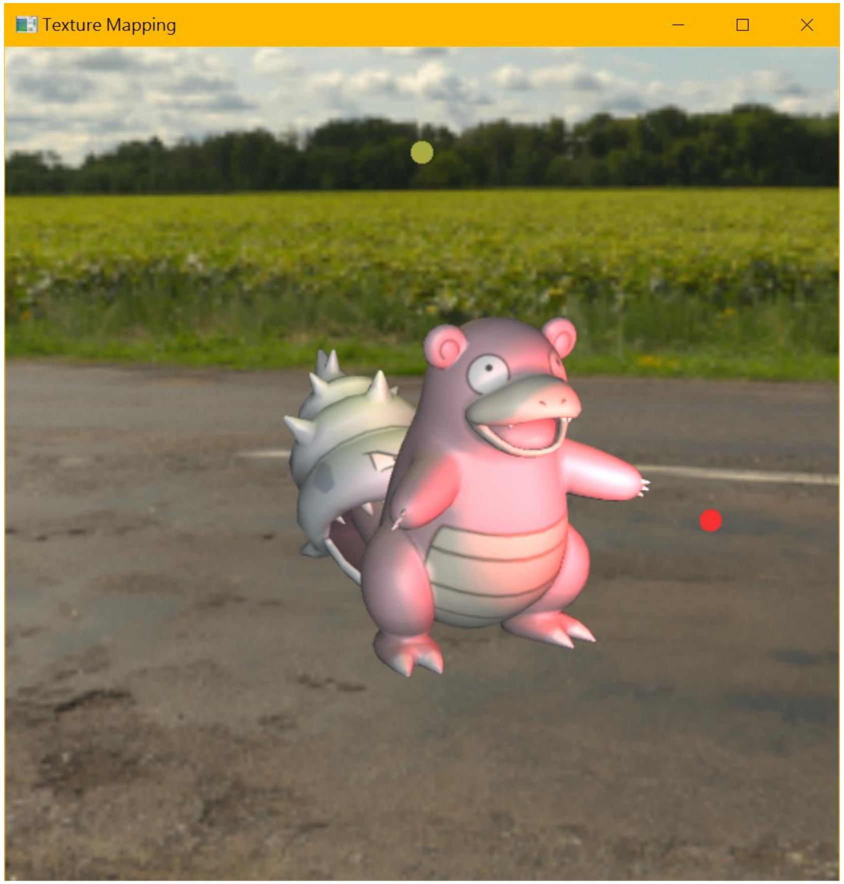
HW2: Lighting and Shading (18%)





HW3: Texturing and Skybox (9%)

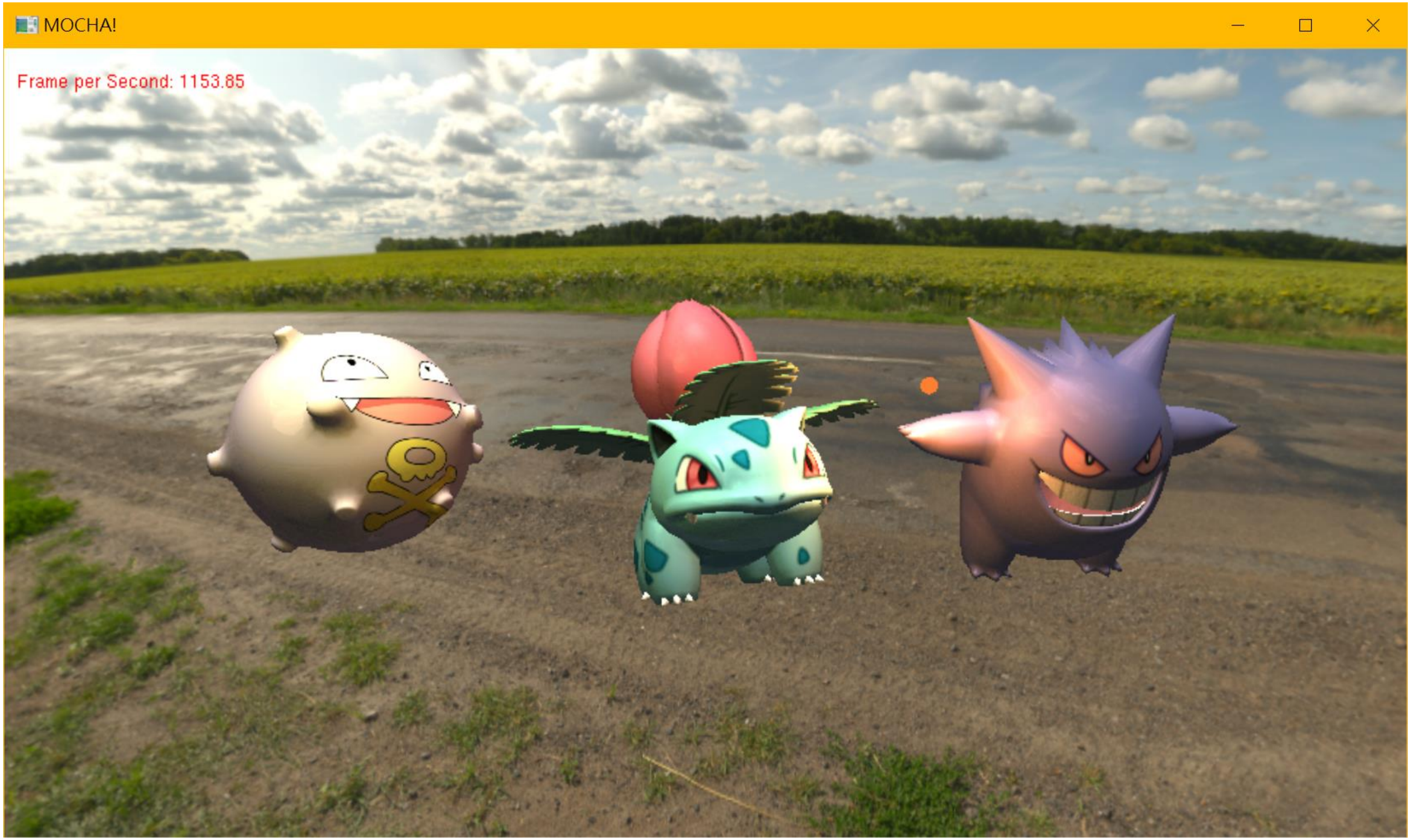




Rendering Competition (5%)

- **Submit a beautiful image rendered by your program**
- Your program is encouraged to support the following features
  - Advanced rendering algorithms
  - Multiple objects
  - New 3D models downloaded from the Internet
  - New skybox downloaded from the Internet
  - Nice lighting and material setting
  - … etc.

Rendering Competition (5%)



Rendering Competition (5%)

- Amazing works from last year’s course

彭東駿

陳怡茜

張智堯

END OF PRESENTATION
ANY QUESTIONS?