Introduction

Computer Graphics

Yu-Ting Wu

Outline

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

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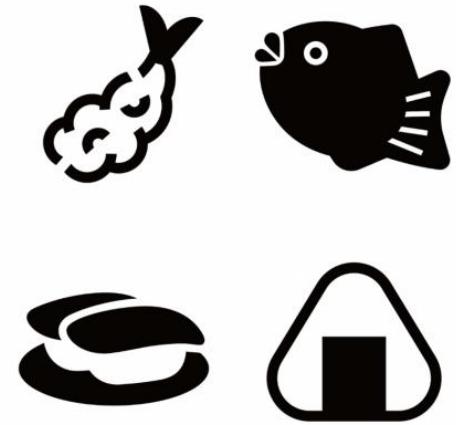
- **Introduction to computer graphics**
- Introduction to graphics programming
- Homework assignments and rendering competition

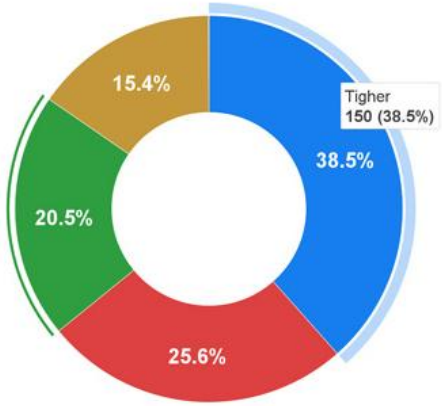
Overview

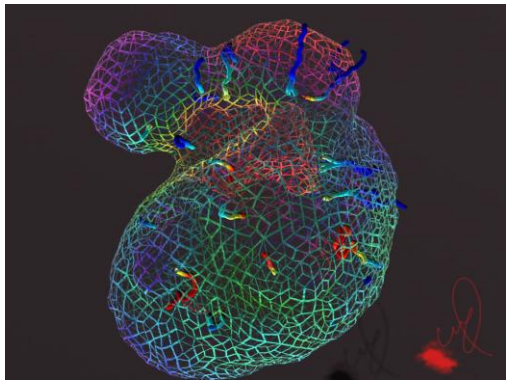
What is Computer Graphics

- 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

Applications of Computer Graphics

Digital Visual Effects (VFX)

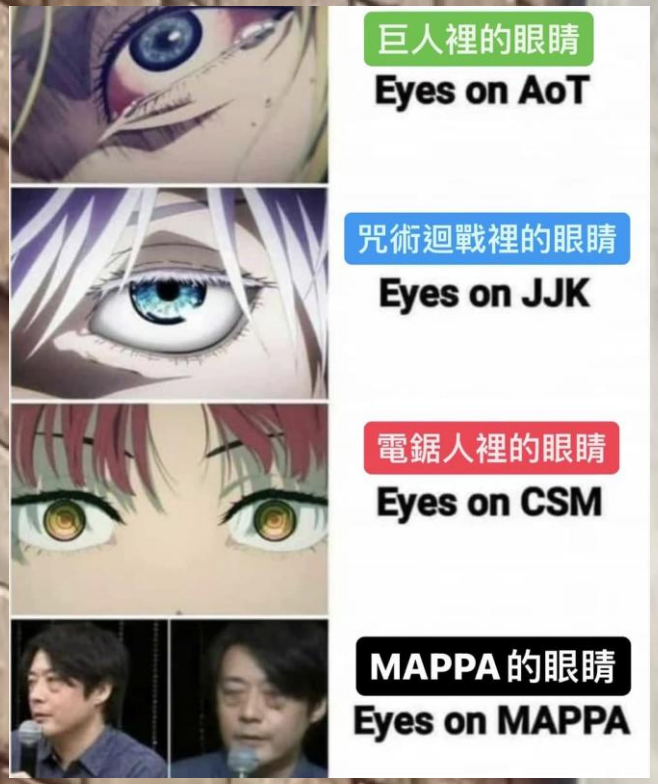
Digital Visual Effects (VFX) (cont.)

Digital Visual Effects (VFX) (cont.)

Digital Visual Effects (VFX) (cont.)

Featured Animations

Anime



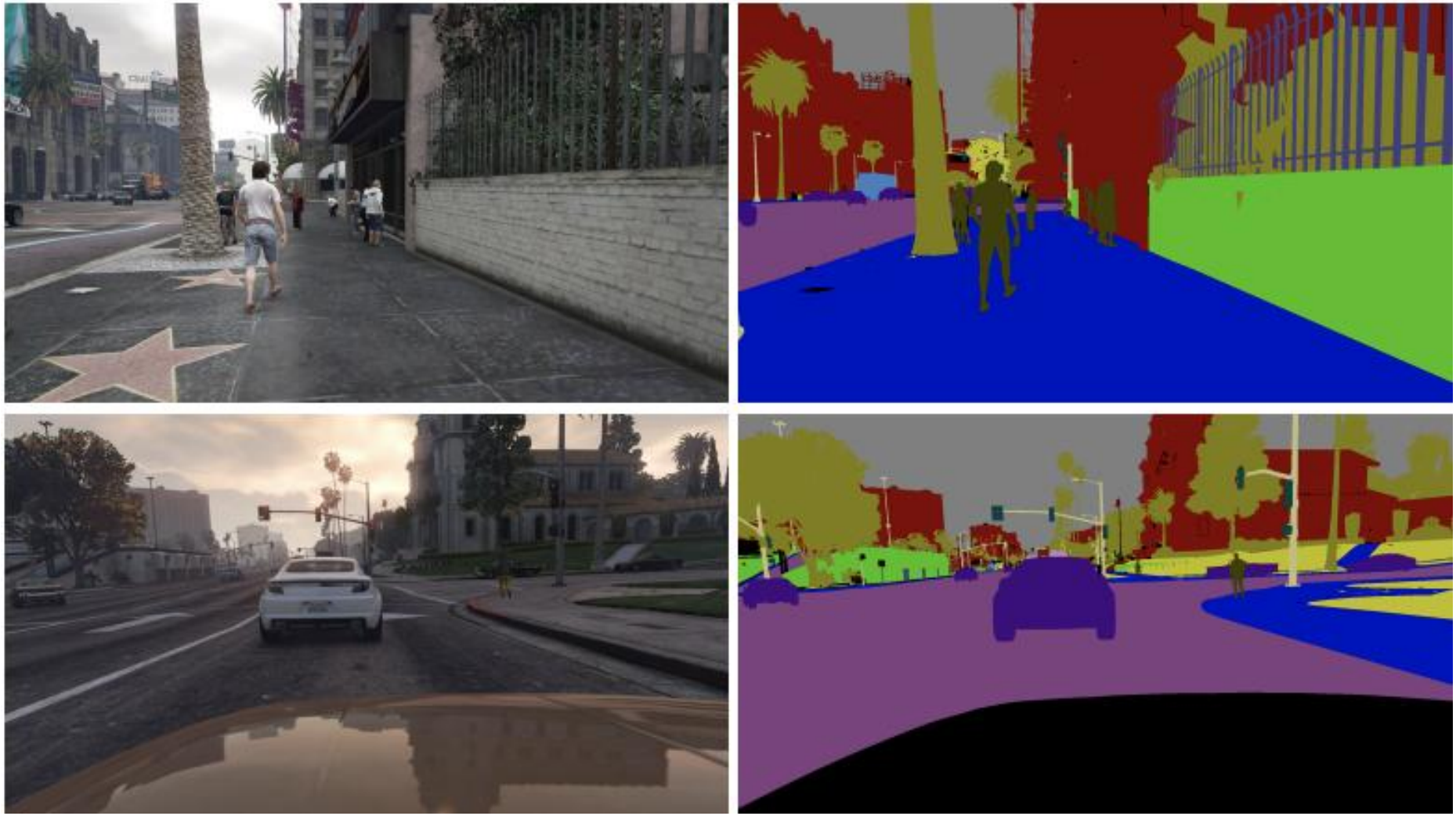
Video Games

Extended Reality (XR: VR/AR/MR)

Computer-Aided Design

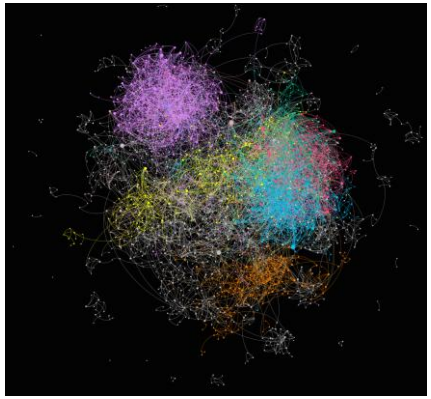
Machine (Deep) Learning

GTA5 Database

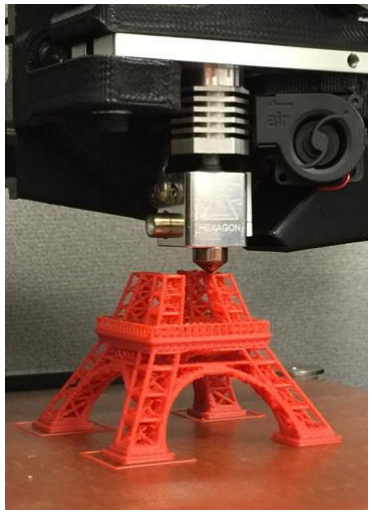


More Applications

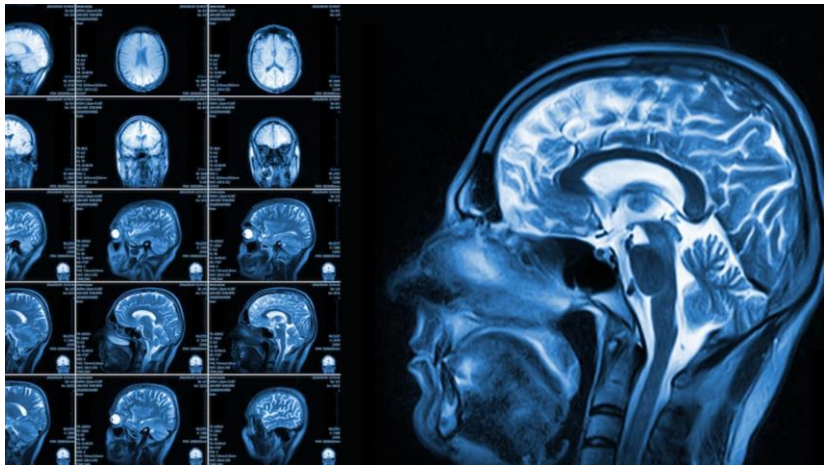
Simulation



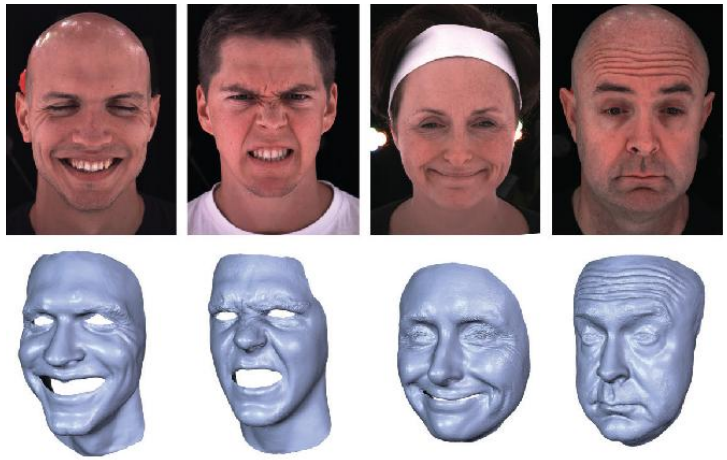
Data Vis



Fabrication



Medical Imaging

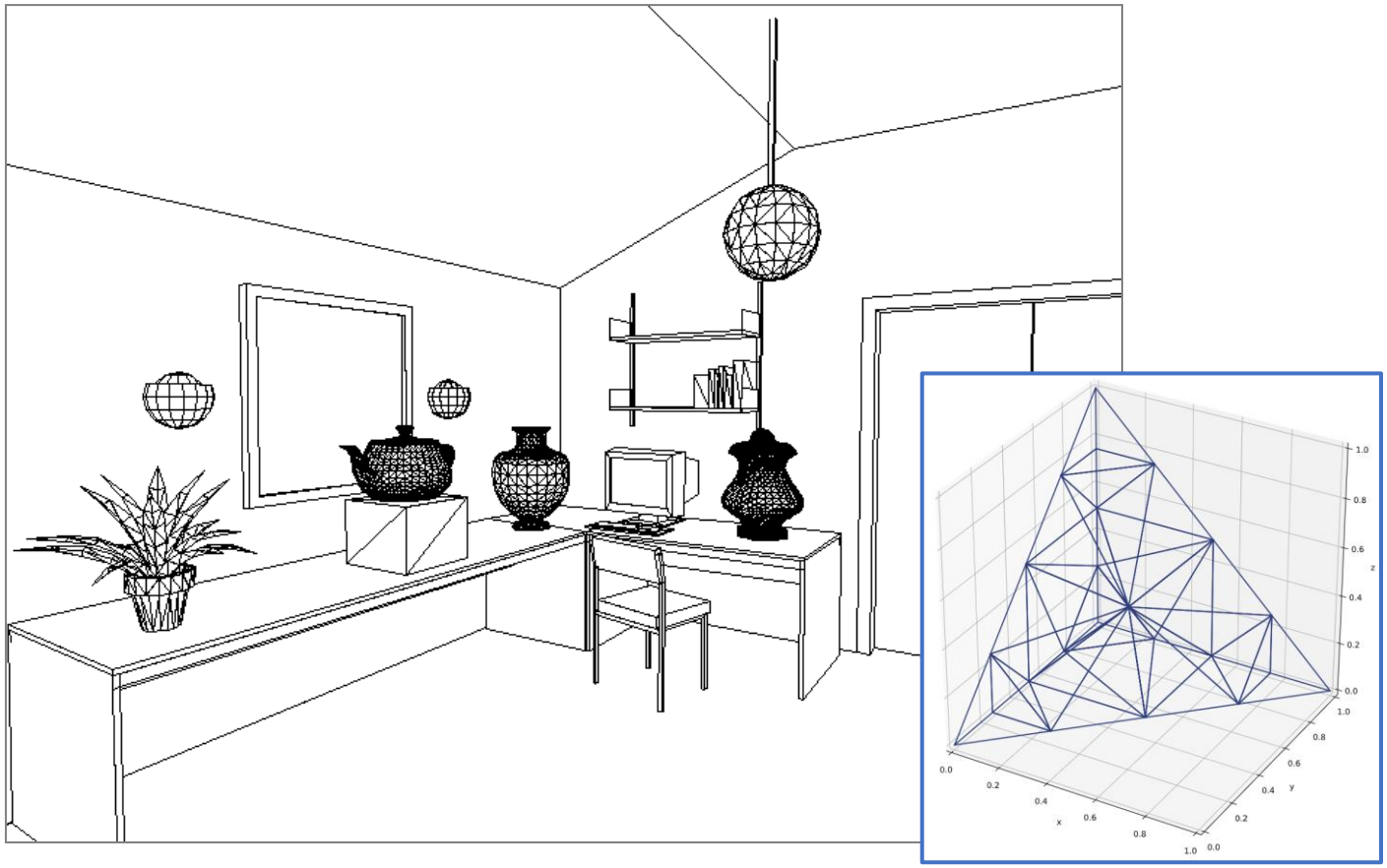


3D Reconstruction

A Quick Overview for How to Synthesize an Image

How to Synthesize an Image

- Model geometry of the 3D objects (scene)

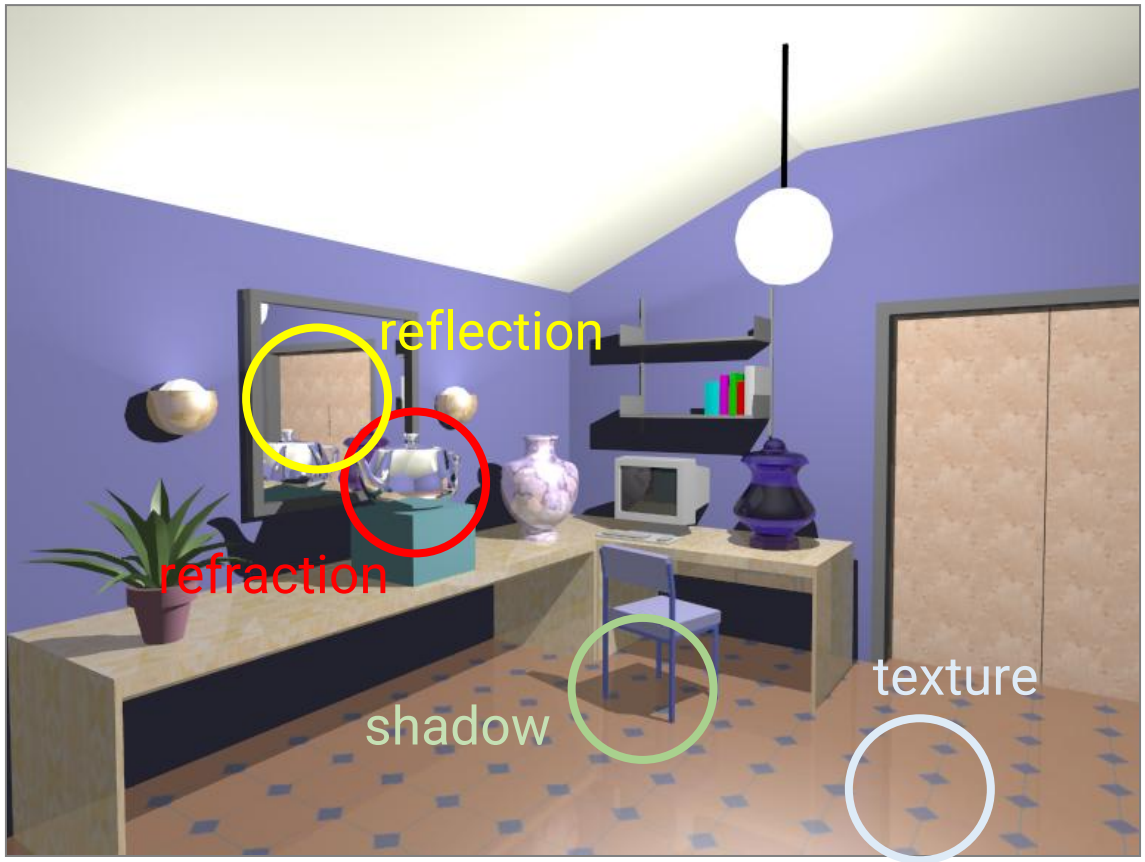


How to Synthesize an Image (cont.)

- Model materials of the 3D objects and simulate lighting

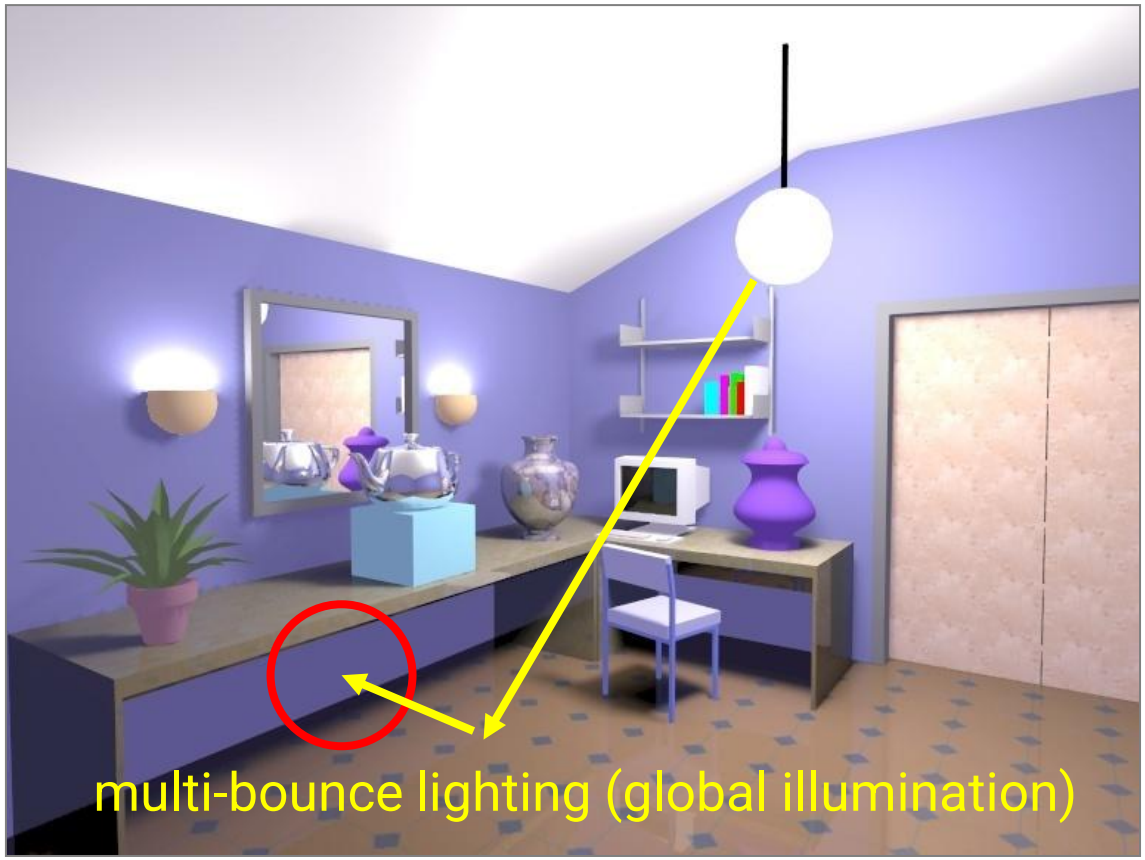
How to Synthesize an Image (cont.)

- Simulate more realistic materials and lighting phenomena



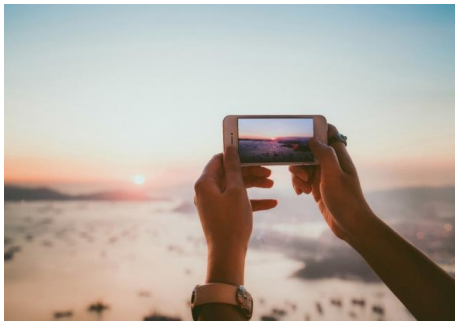
How to Synthesize an Image (cont.)

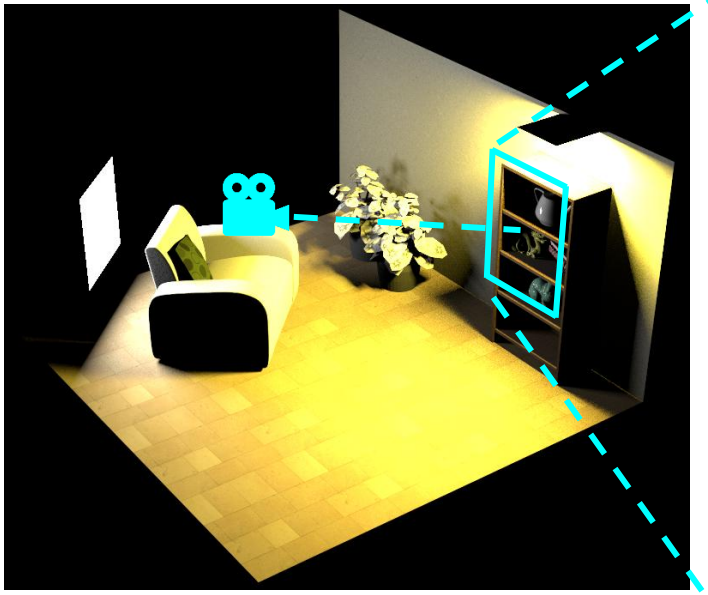
- Simulate more complex light paths



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**

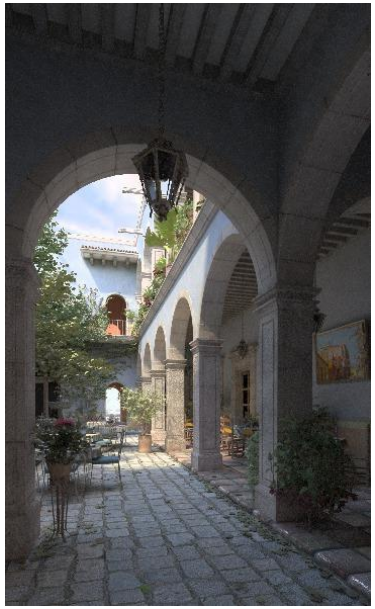




3D virtual world

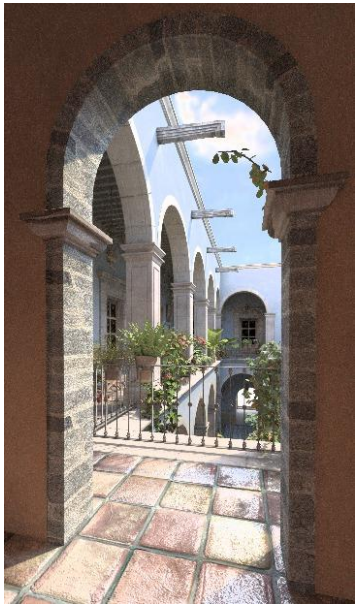
rendered image

How to Synthesize an Image (cont.)









Relevant Fields

- Traditionally, we will categorize ***computer graphics***, ***computer vision***, and ***image processing*** by their inputs and outputs:

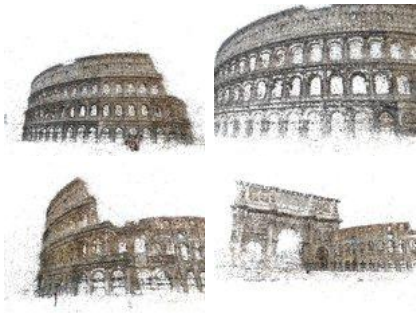
outputs

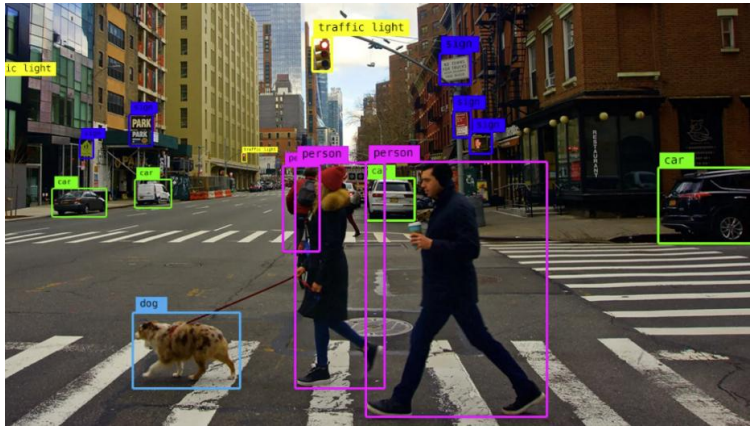
inputs	**descriptions**	**images**
descriptions		***computer graphics***
images	***computer vision***	***Image processing***

- However, the gaps are much vaguer now!

Relevant Fields (cont.)

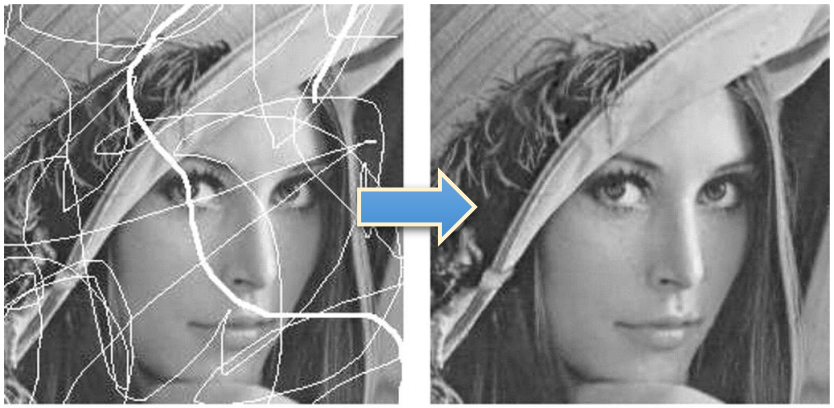
- **Computer vision**
  - From images to scene descriptions





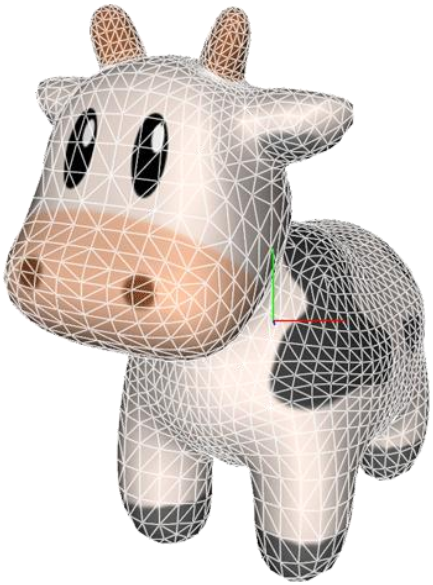
Relevant Fields (cont.)

- **Image processing**
  - From an image to a better image



Major Topics of Computer Graphics

Three Pillars of Computer Graphics



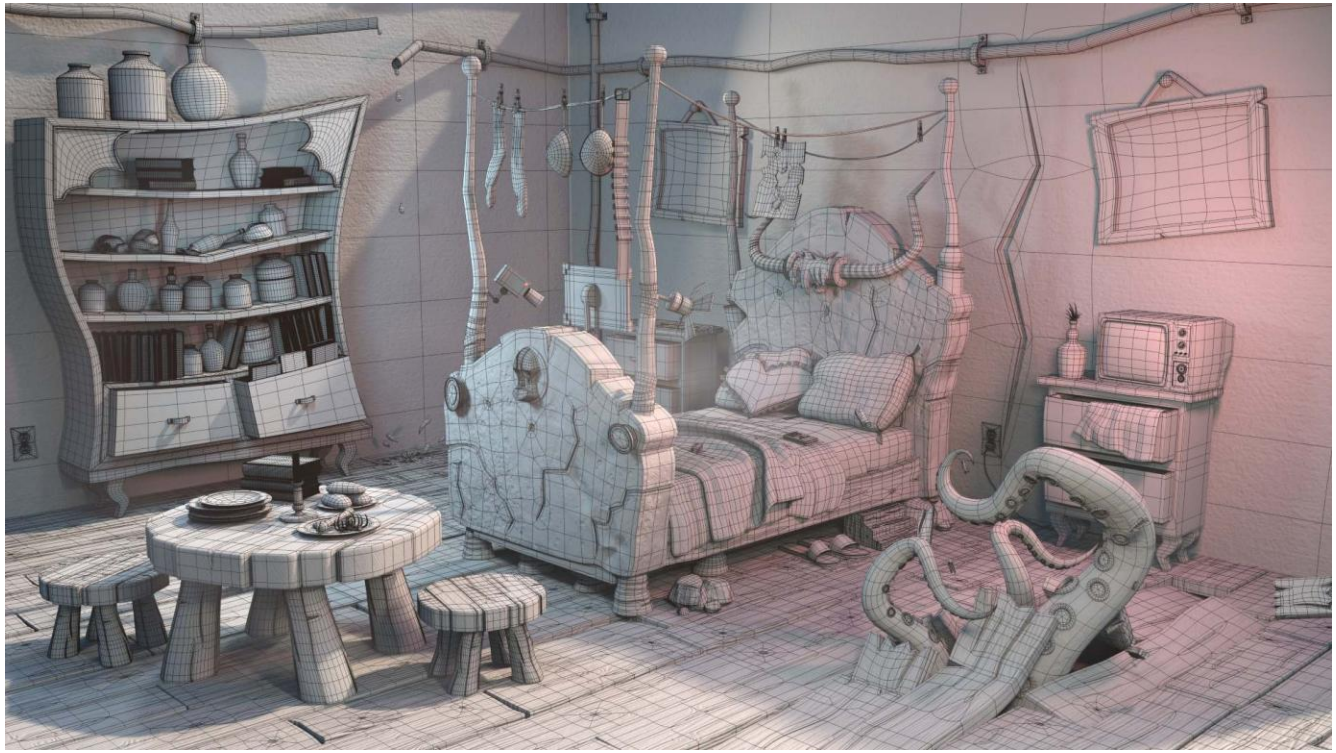
Modeling

Rendering

Animation

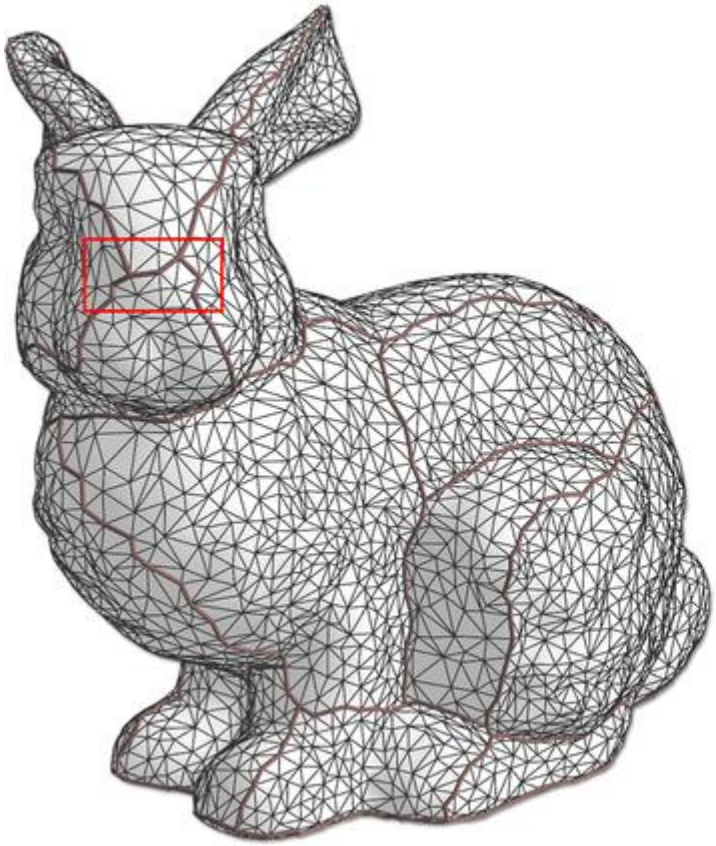
Modeling

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

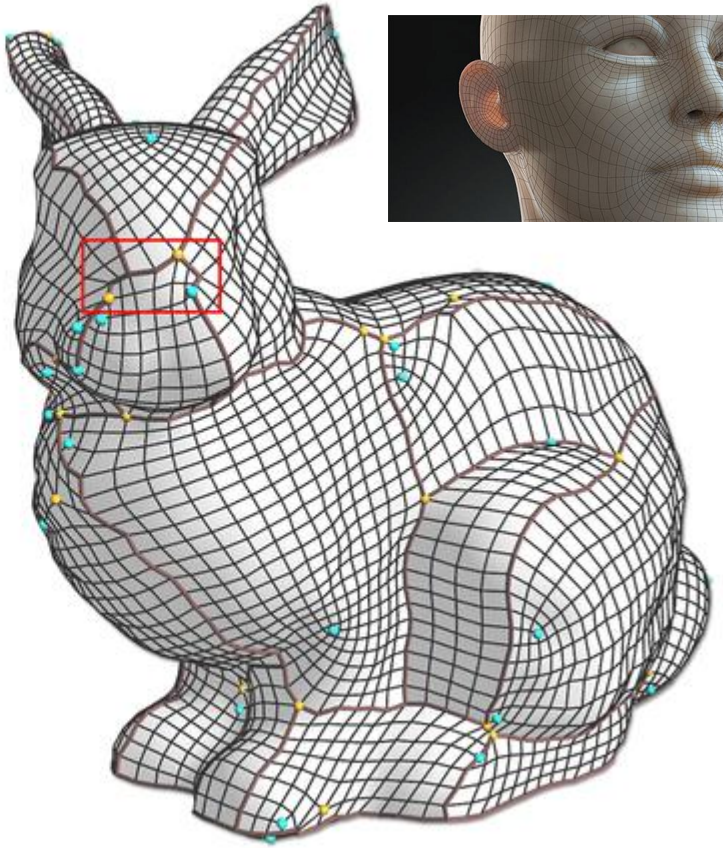


Modeling (cont.)

- Meshes



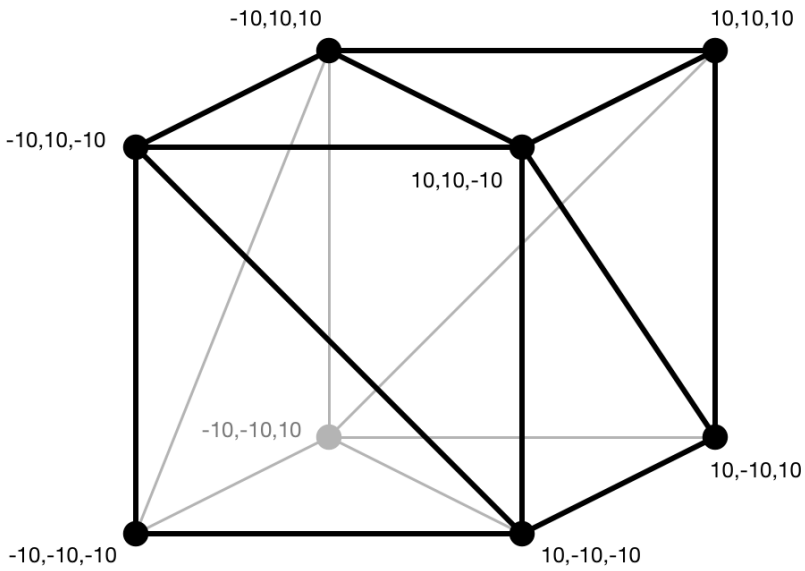
triangle mesh



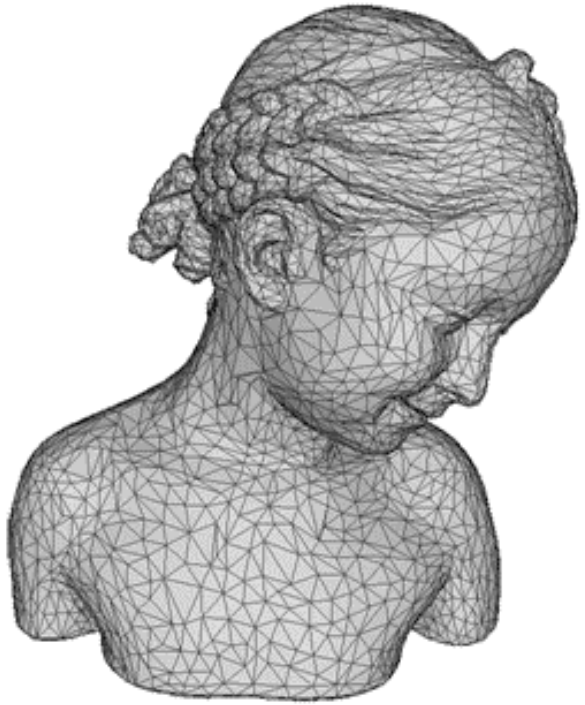
quad mesh

Modeling (cont.)

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



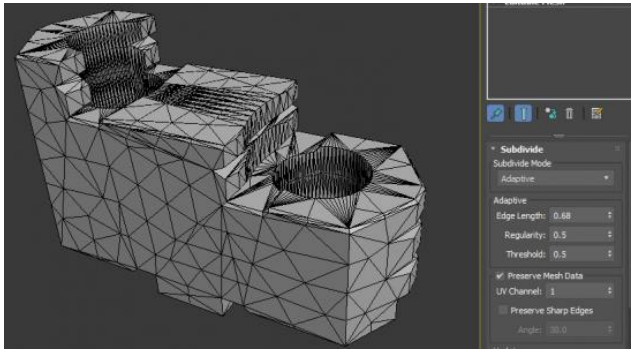
12 triangles



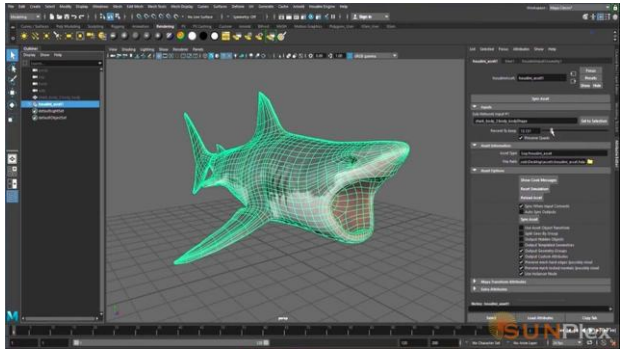
10K triangles

Modeling (cont.)

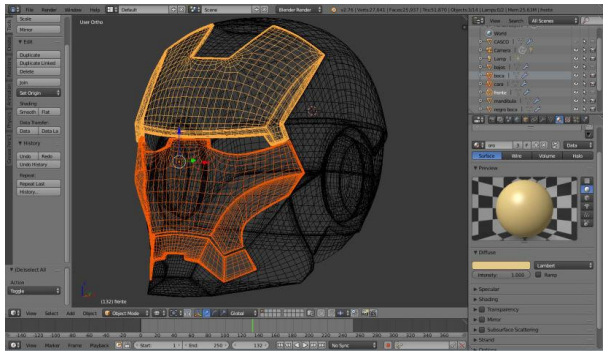
- 3D models are usually obtained by professional manipulations in 3D modeling tools



Blender



Maya

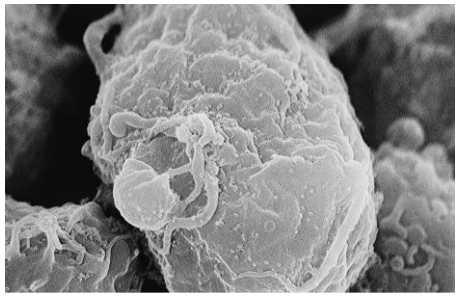


AUTODESK 3DS MAX

Modeling (cont.)

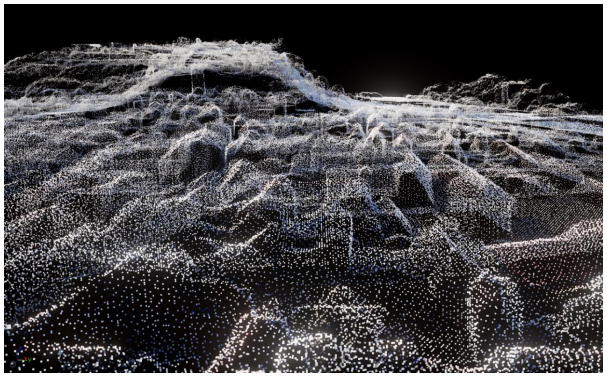
- World geometries are diverse!

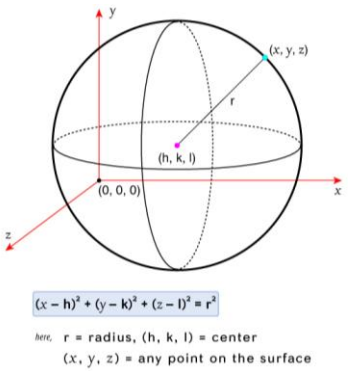




- There are alternative geometry representations


volume data

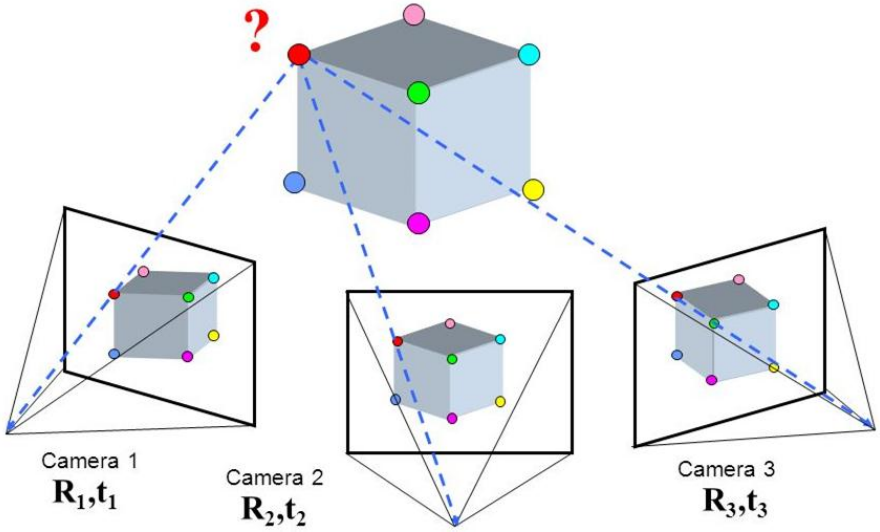

point cloud

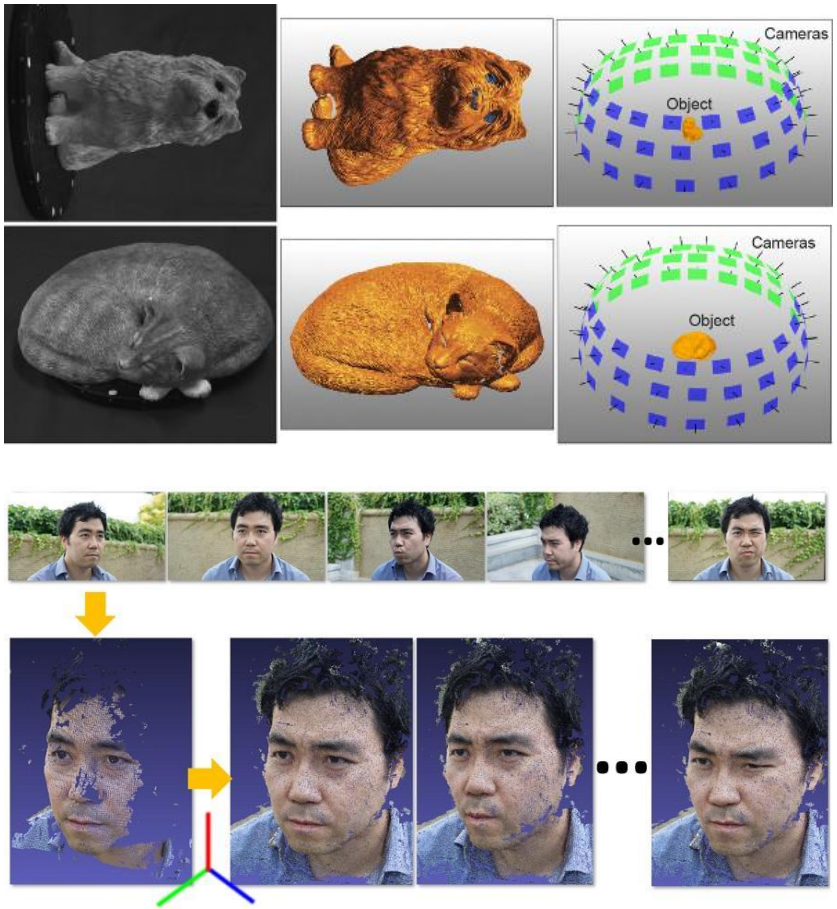


functions

Modeling (cont.)

- Multi-view reconstruction



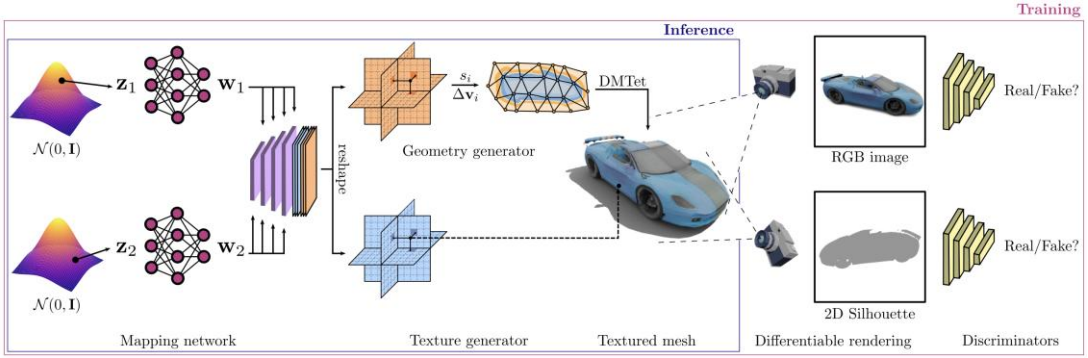


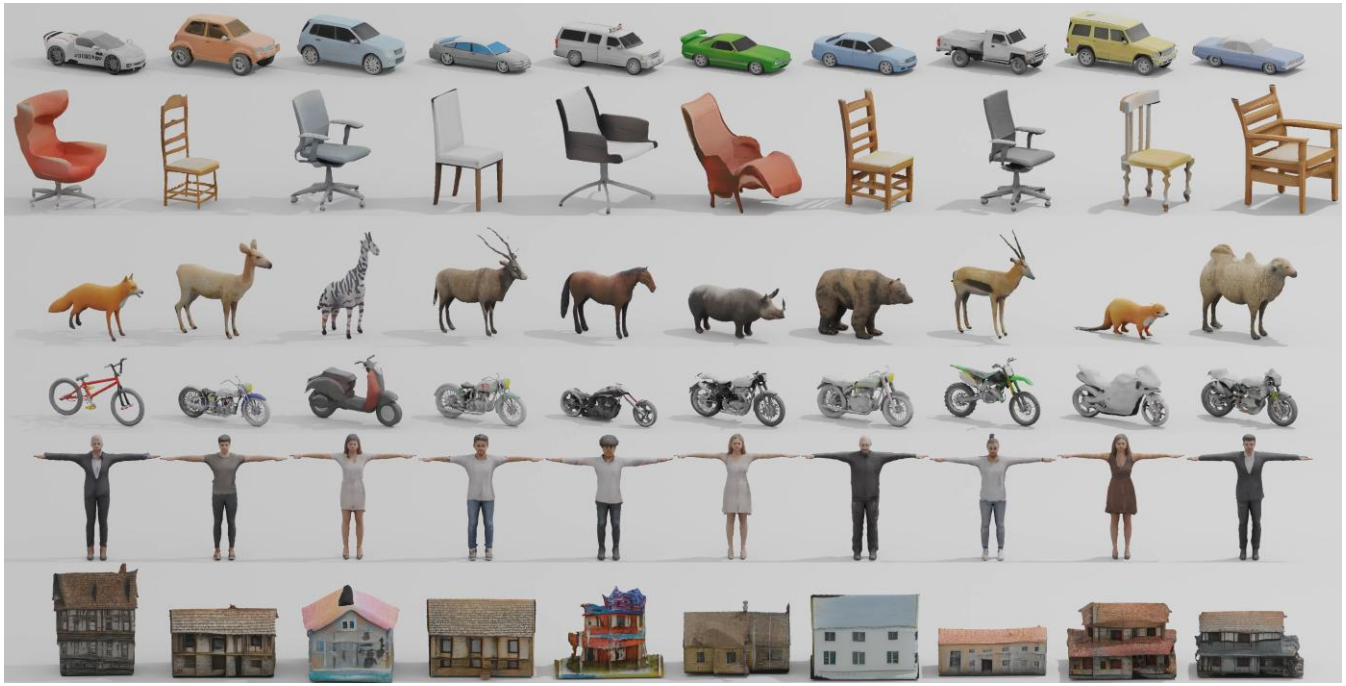
Modeling (cont.)

- 3D scanning

Modeling (cont.)

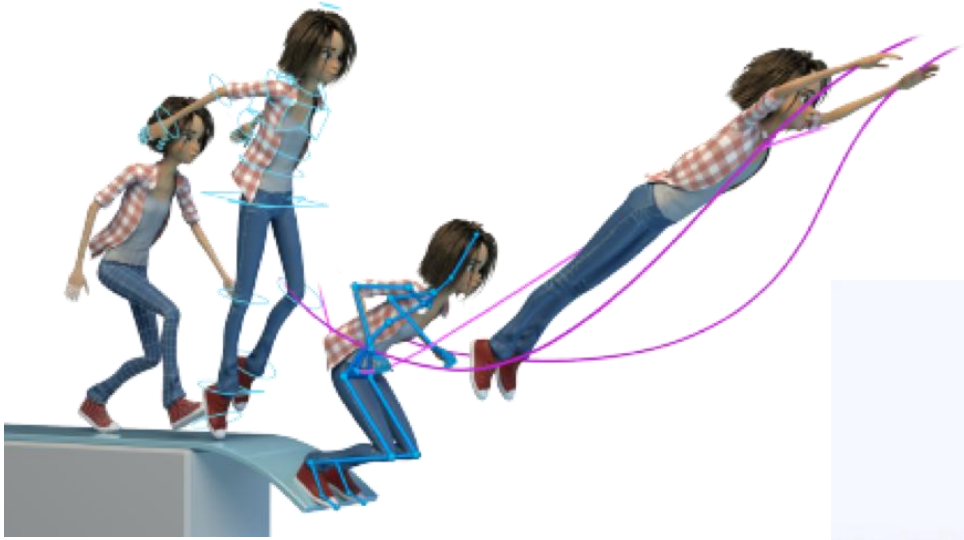
- AI generated

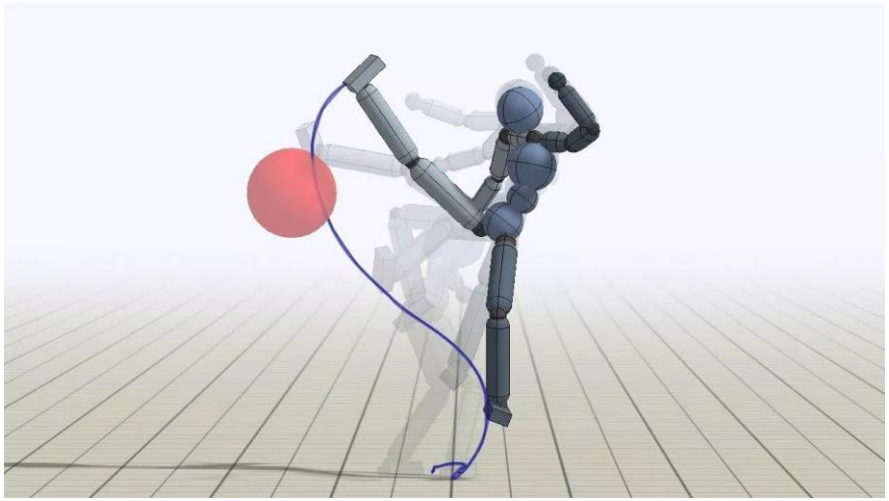




Animation

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



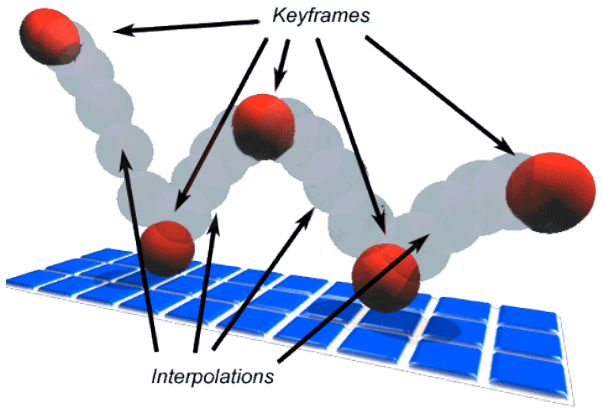


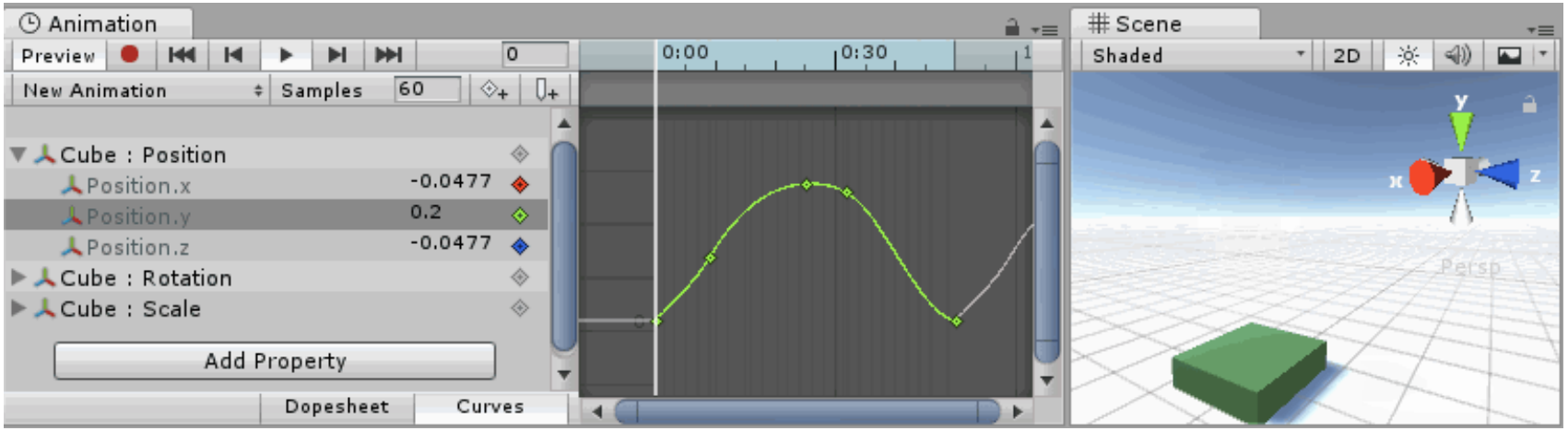
Animation (cont.)

- Animations are usually expected to be physically-based

Animation (cont.)

- Keyframe-based animations





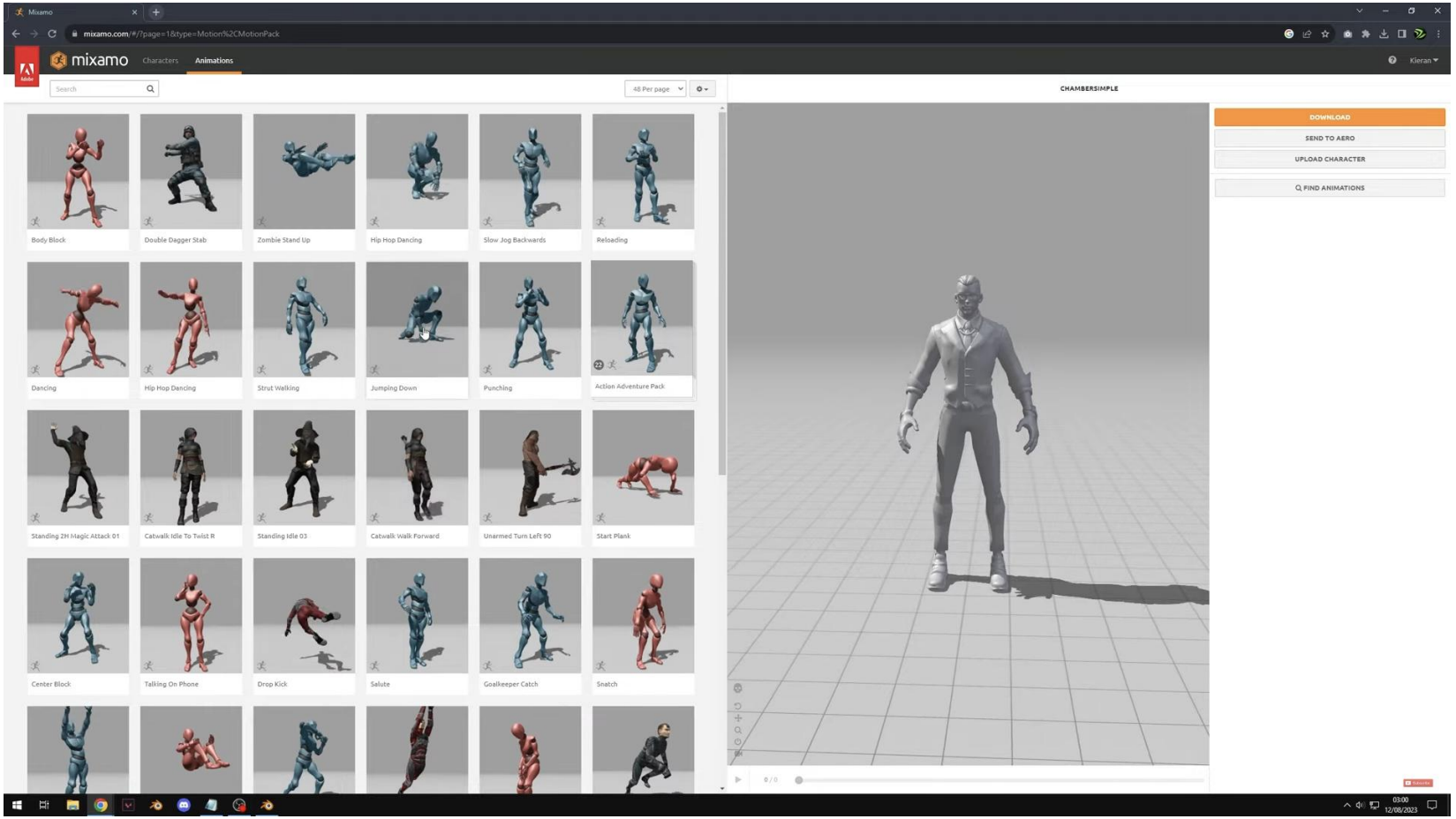
Animation (cont.)

- Motion capture

Dawn of the Planet of the Apes, 2014

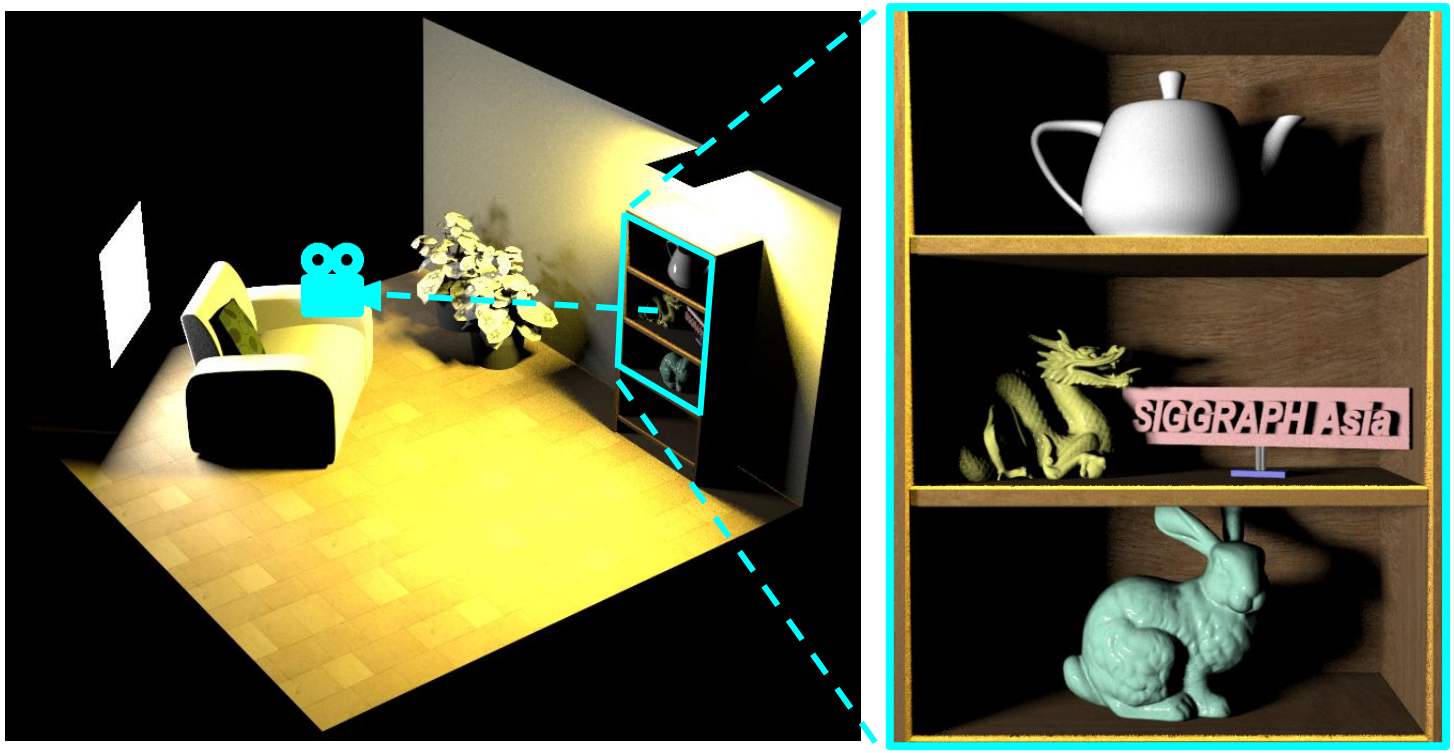
Animation (cont.)

- AI generated



Rendering

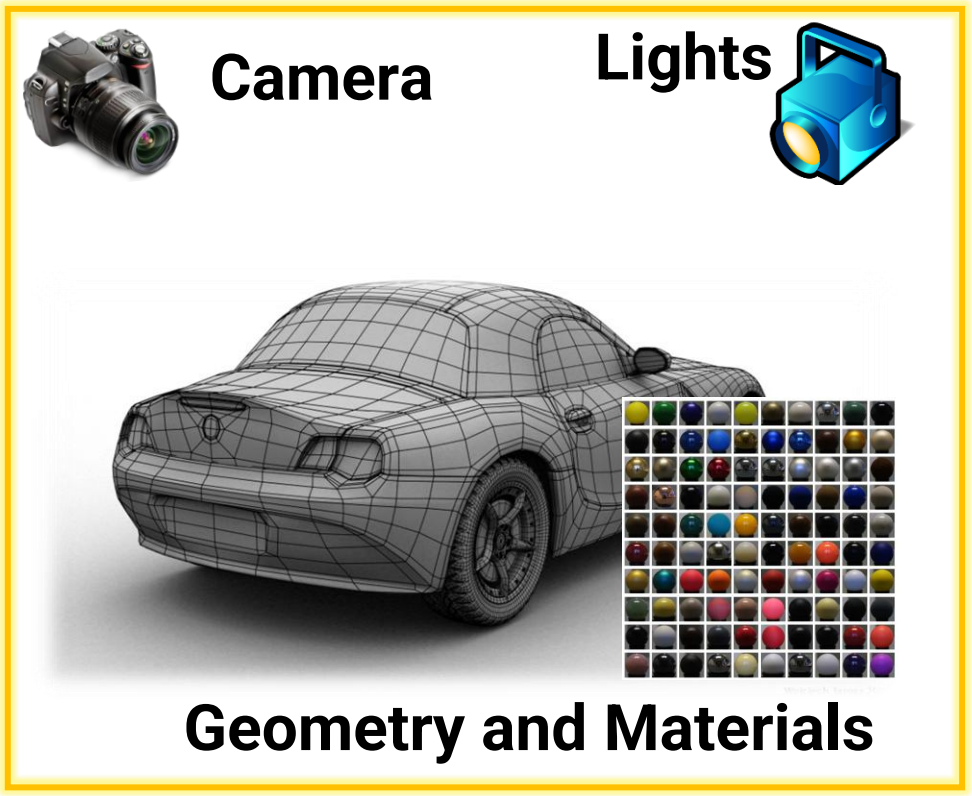
- Simulate the appearance of virtual objects and synthesize the final image



3D virtual world rendered image

Rendering (cont.)

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

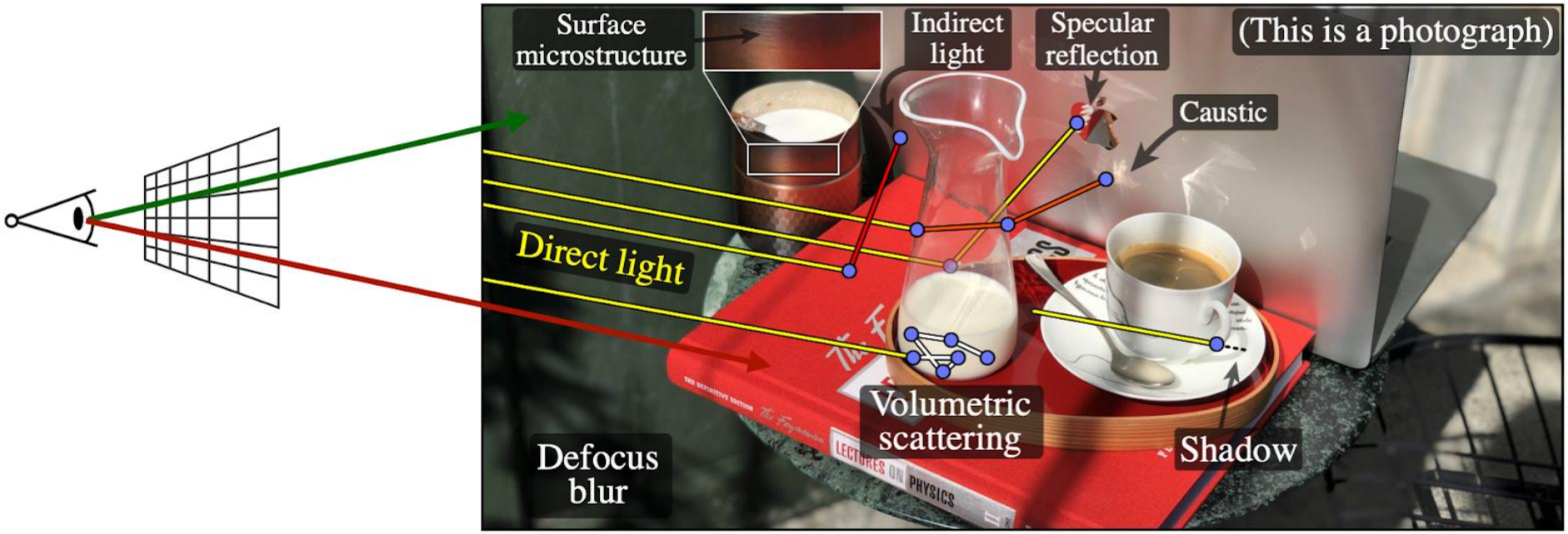


input: 3D description of a scene

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



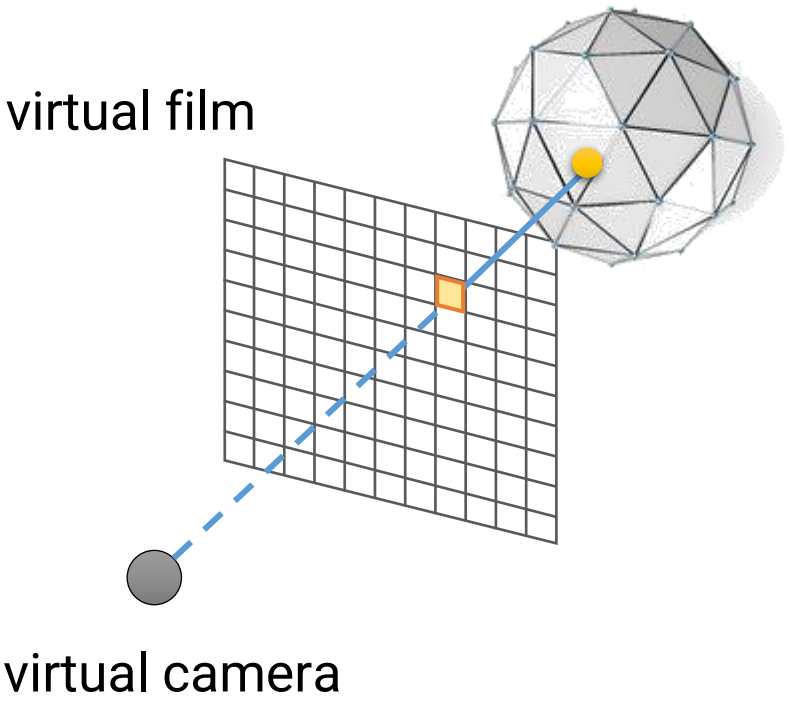
Rendering (cont.)

- Non-photo-realistic rendering

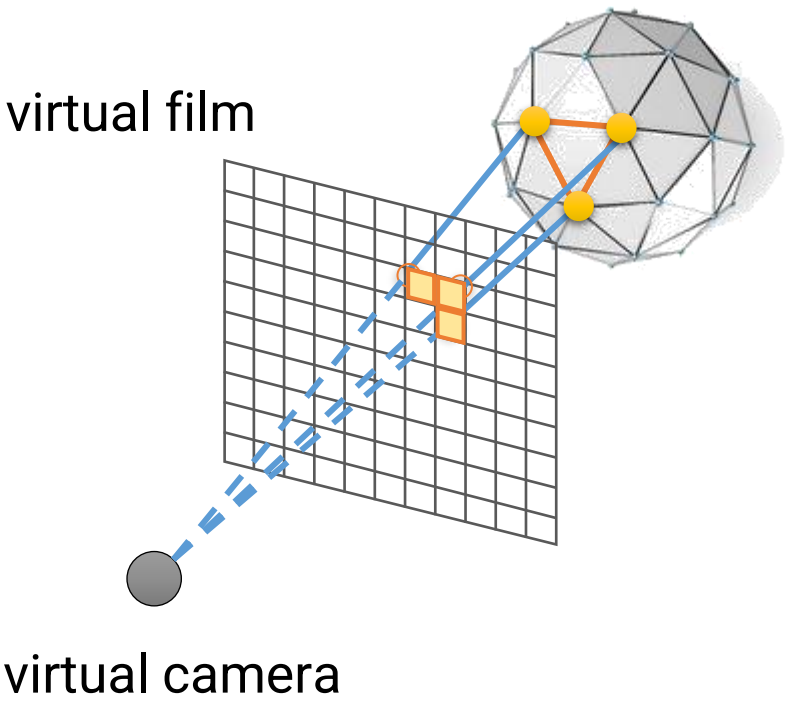
Rendering (cont.)

- Two ways for generating synthetic images

Ray tracing



Rasterization



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

text treatment

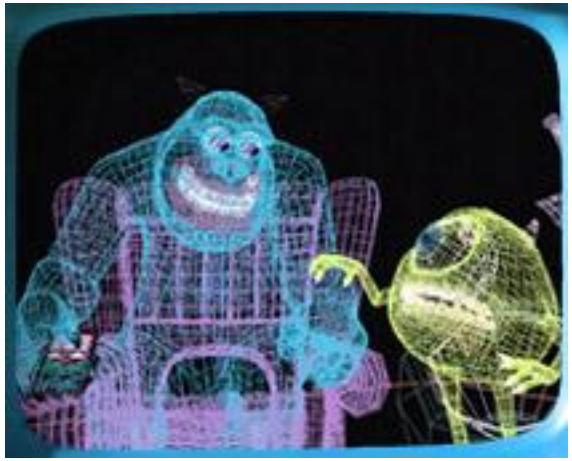
storyboard

voice

storyreel

look and feel

Animation Production Pipeline (cont.)



modeling / articulation

layout

animation

shading / lighting

rendering

final touch

Computer Graphics vs Generative AI

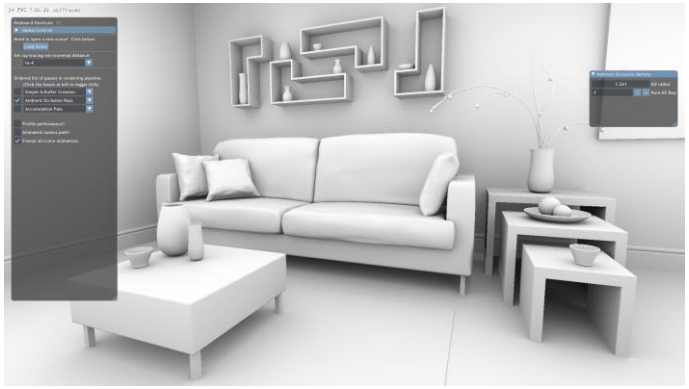
Computer Graphics vs Generative AI

- You have likely tried generating images using AI tools like Midjourney or Stable Diffusion:
  - No 3D models or high-end GPUs required
  - No background in physics or math needed
  - No coding required: just a prompt

Why do we still need to learn computer graphics?

Computer Graphics vs Generative AI (cont.)

Computer Graphics (Rasterization / Ray Tracing)



Generative AI (Diffusion / GANs / Autoregressive)

Computer Graphics vs Generative AI (cont.)

Generative AI
(Diffusion / GANs / Autoregressive)

A modern, minimalist living room interior captured from a front-facing, eye-level perspective. The room is anchored by a sleek white sofa placed centrally against a plain off-white wall, accented with soft, pale pink throw pillows. In front of the sofa sits a simple square white coffee table, adorned with a glossy red vase and smaller dark vessels. Above the sofa, a geometric, multi-tiered white shelving unit displays several decorative red and black vases. To the right, a side table holds a dark vase with slender, curved branches, and a square art piece featuring abstract, vibrant red glossy spheres hangs on the wall. The floor is made of warm, polished wooden planks, partially covered by a vibrant, solid red rectangular rug centered under the coffee table. The lighting is soft and diffused, creating a clean, airy, and sophisticated atmosphere with a high-contrast color palette of white, red, and wood tones. The style is contemporary, emphasizing clean lines, balanced composition, and a serene, uncluttered aesthetic.

Computer Graphics vs Generative AI (cont.)

- **Paradigms of Image Creation: Computer Graphics**

From 3D models to 2D pixels, based on math and physics simulation (light transport)

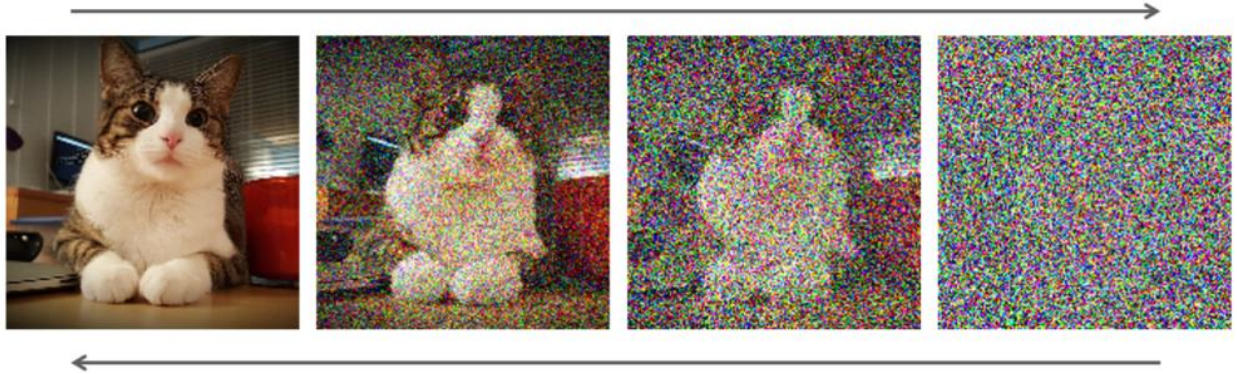
Fully controllable illumination, materials, shape, and camera

Deterministic

Real-time performance

Computer Graphics vs Generative AI (cont.)

- **Paradigms of Image Creation: Generative AI**



Start with **random Gaussian noise** and progressively strips away noise step-by-step using a neural network until a coherent image emerges (predict **pixel likelihoods**)

Non-deterministic and more difficult to control

No real-time performance (at least now)

Need massive CG images for training

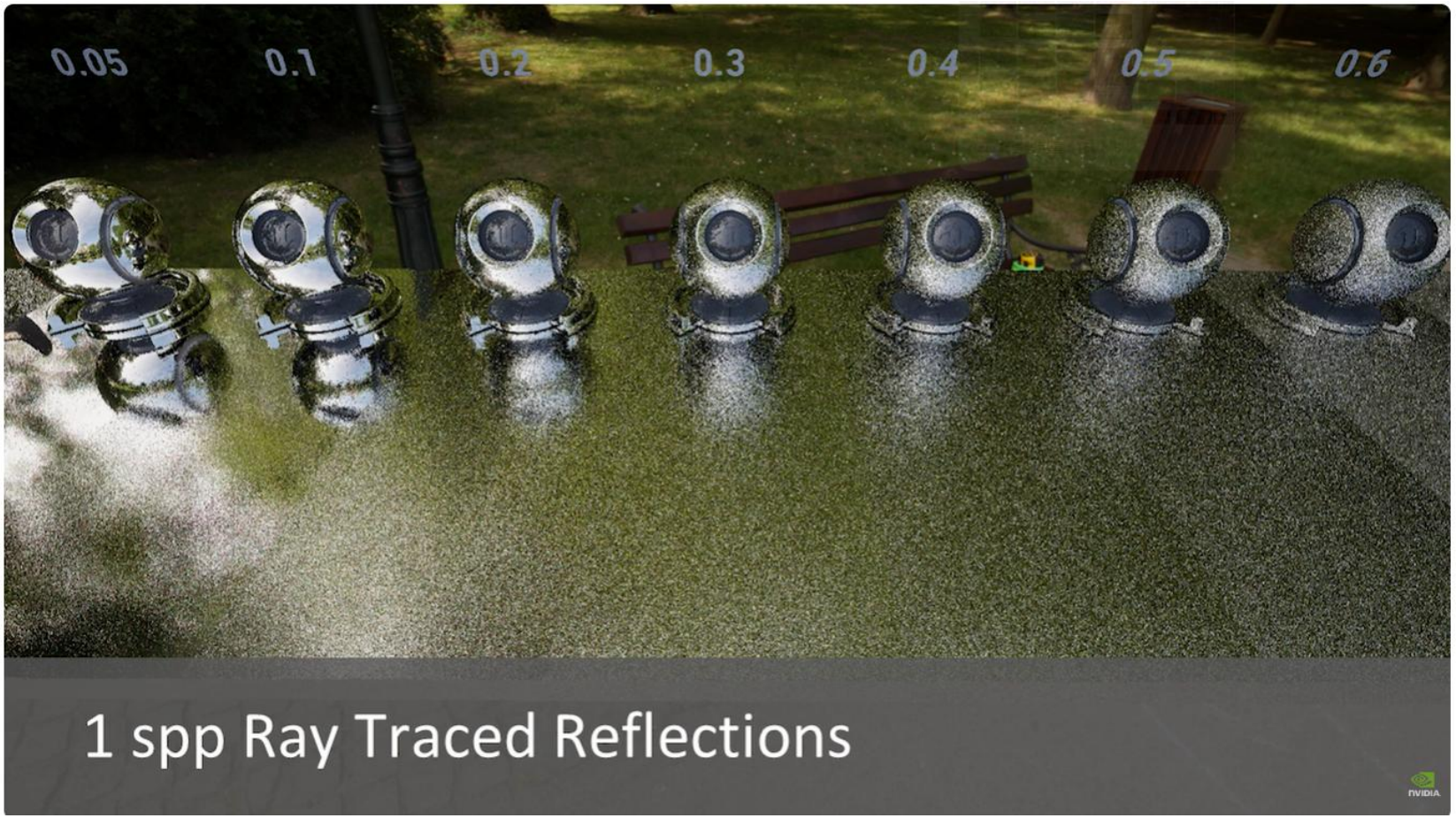
Computer Graphics vs Generative AI (cont.)

- **Paradigms of Image Creation: comparisons**

Computer Graphics (Rasterization / Ray Tracing)	**Generative AI (Diffusion / GANs / Autoregressive)**
• Builds explicit 3D worlds from first-principles physics and geometry	• Synthesizes 2D pixel patterns based on statistical distributions learned from millions of training images
• Control by scene data and rendering configurations	• Control by prompts, random noises
• Used for real-time interactions, games, CAD, VFX	• Used for concept design, fast material generation artistic creation

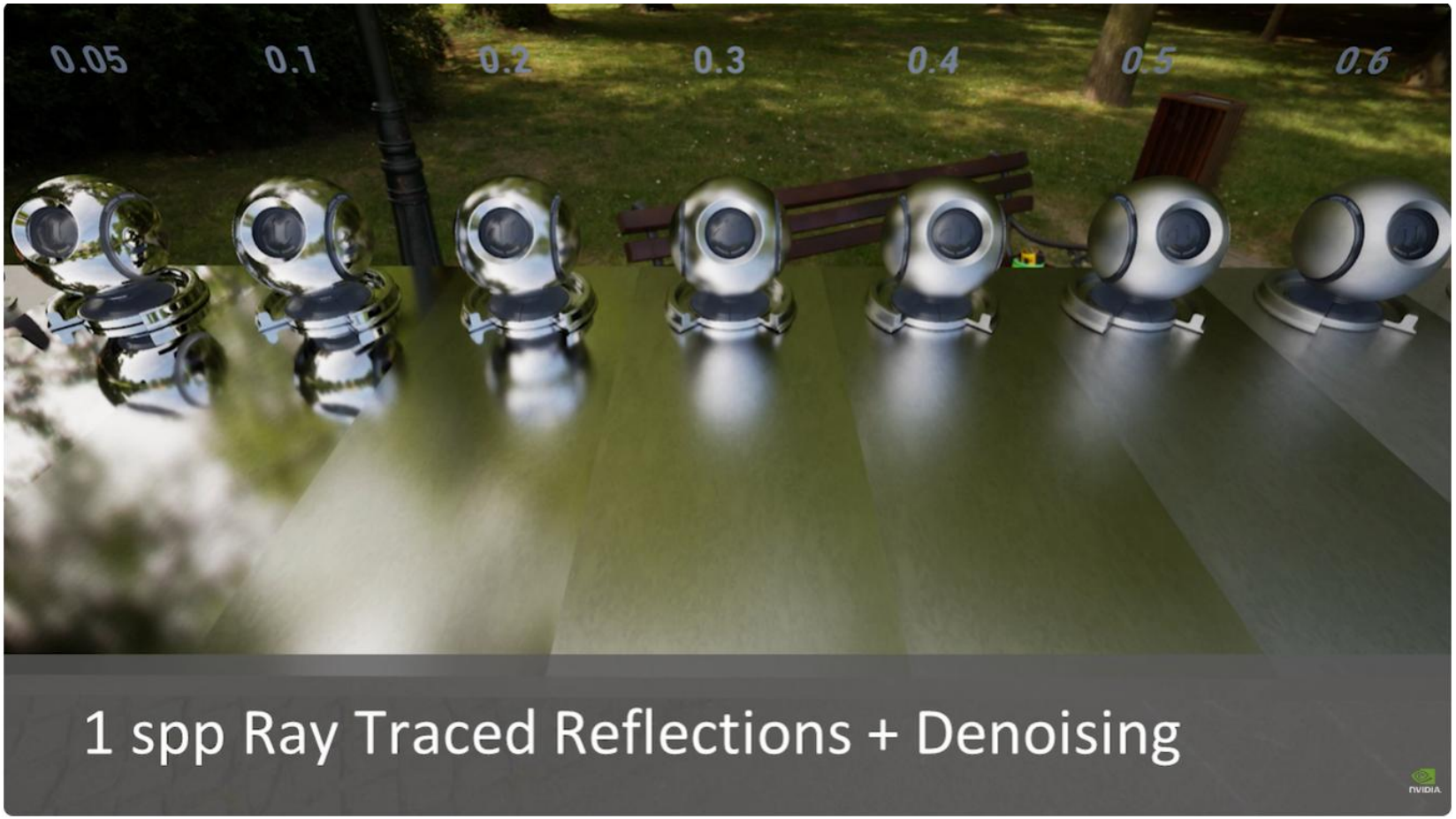
Combination of CG and AI

- **Denoising**



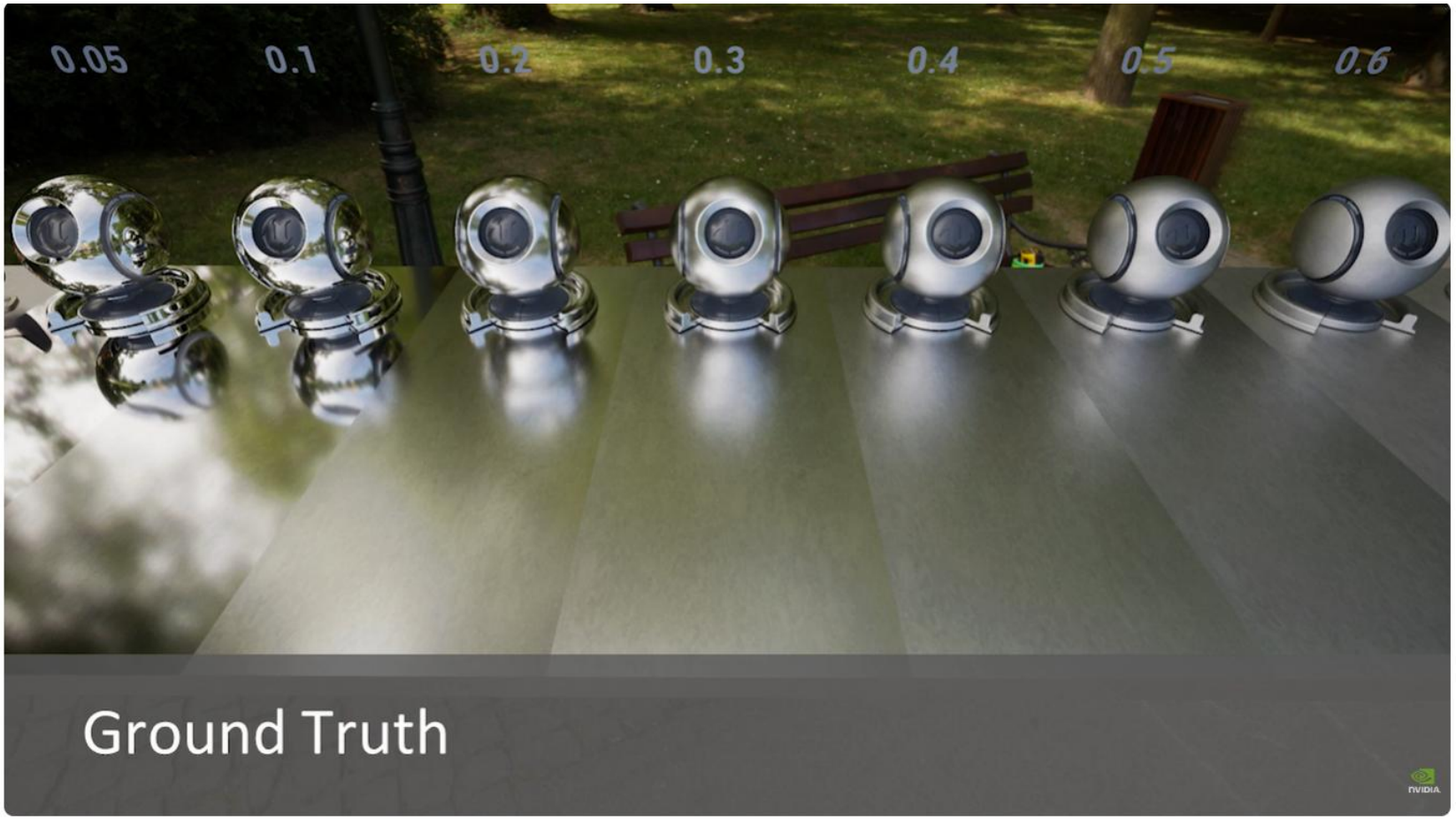
Combination of CG and AI (cont.)

- **Denoising**



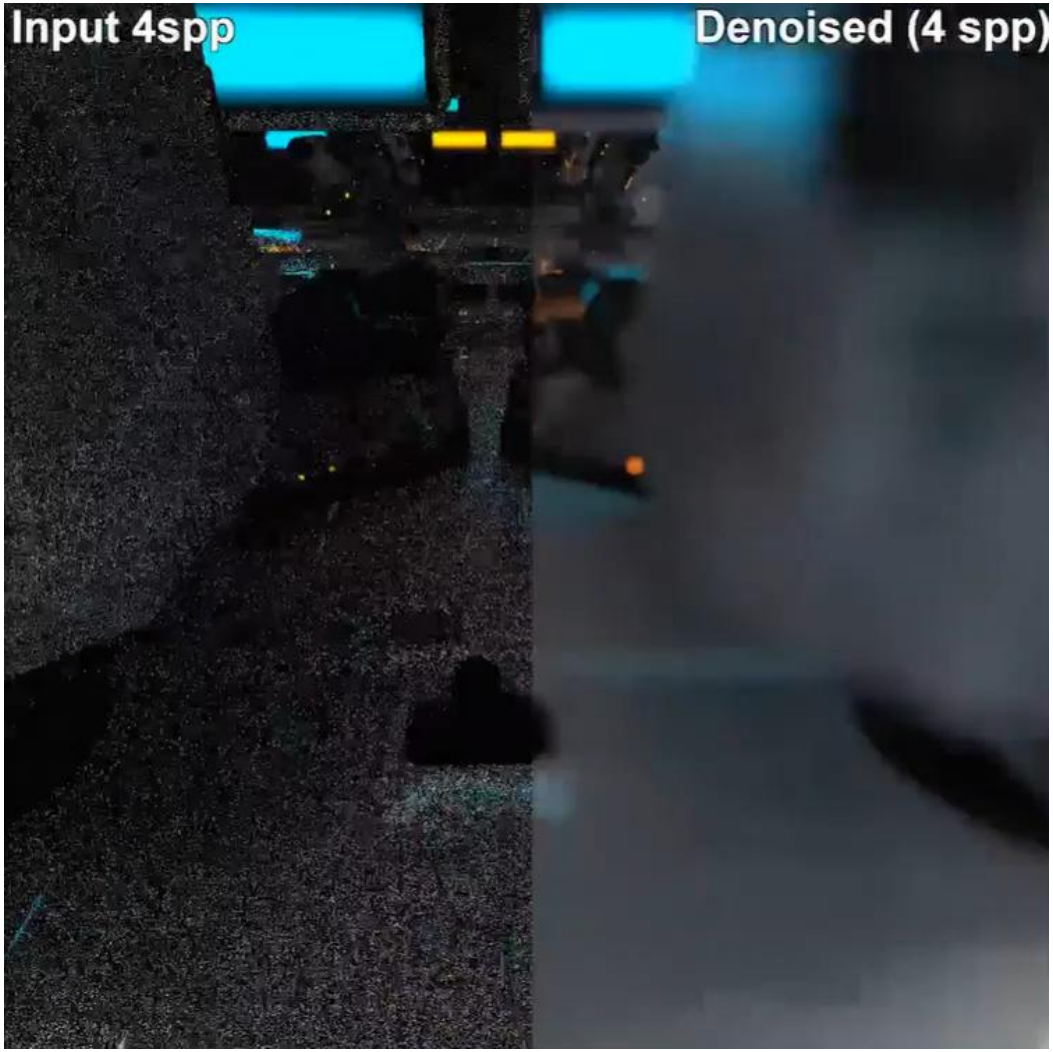
Combination of CG and AI (cont.)

- **Denoising**



Combination of CG and AI (cont.)

- **Denoising**



Combination of CG and AI (cont.)

- **Deep Learning Super Sampling (DLSS)**
  - Super resolution
  - Frame generation
  - Ray reconstruction

Combination of CG and AI (cont.)

- DLSS 5?

Combination of CG and AI (cont.)

- DLSS 5?

Outline

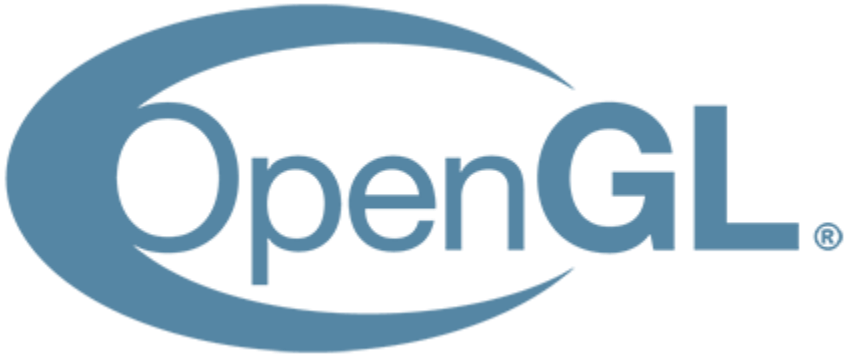
- Introduction to computer graphics
- **Introduction to graphics programming**
- Homework assignments and rendering competition

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

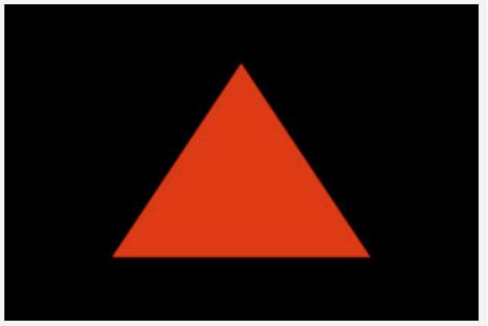
OpenGL

- 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



```
32  static void RenderSceneCB()
33  {
34      glClear(GL_COLOR_BUFFER_BIT);
35
36      glBindBuffer(GL_ARRAY_BUFFER, VBO);
37
38      glEnableVertexAttribArray(0);
39
40      glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0, 0);
41
42      glDrawArrays(GL_TRIANGLES, 0, 3);
43
44      glDisableVertexAttribArray(0);
45
46      glutSwapBuffers();
47  }
48
49
50  static void CreateVertexBuffer()
51  {
52      Vector3f Vertices[3];
53      Vertices[0] = Vector3f(-1.0f, -1.0f, 0.0f);    // bottom left
54      Vertices[1] = Vector3f(1.0f, -1.0f, 0.0f);     // bottom right
55      Vertices[2] = Vector3f(0.0f, 1.0f, 0.0f);      // top
56
```

```
#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?

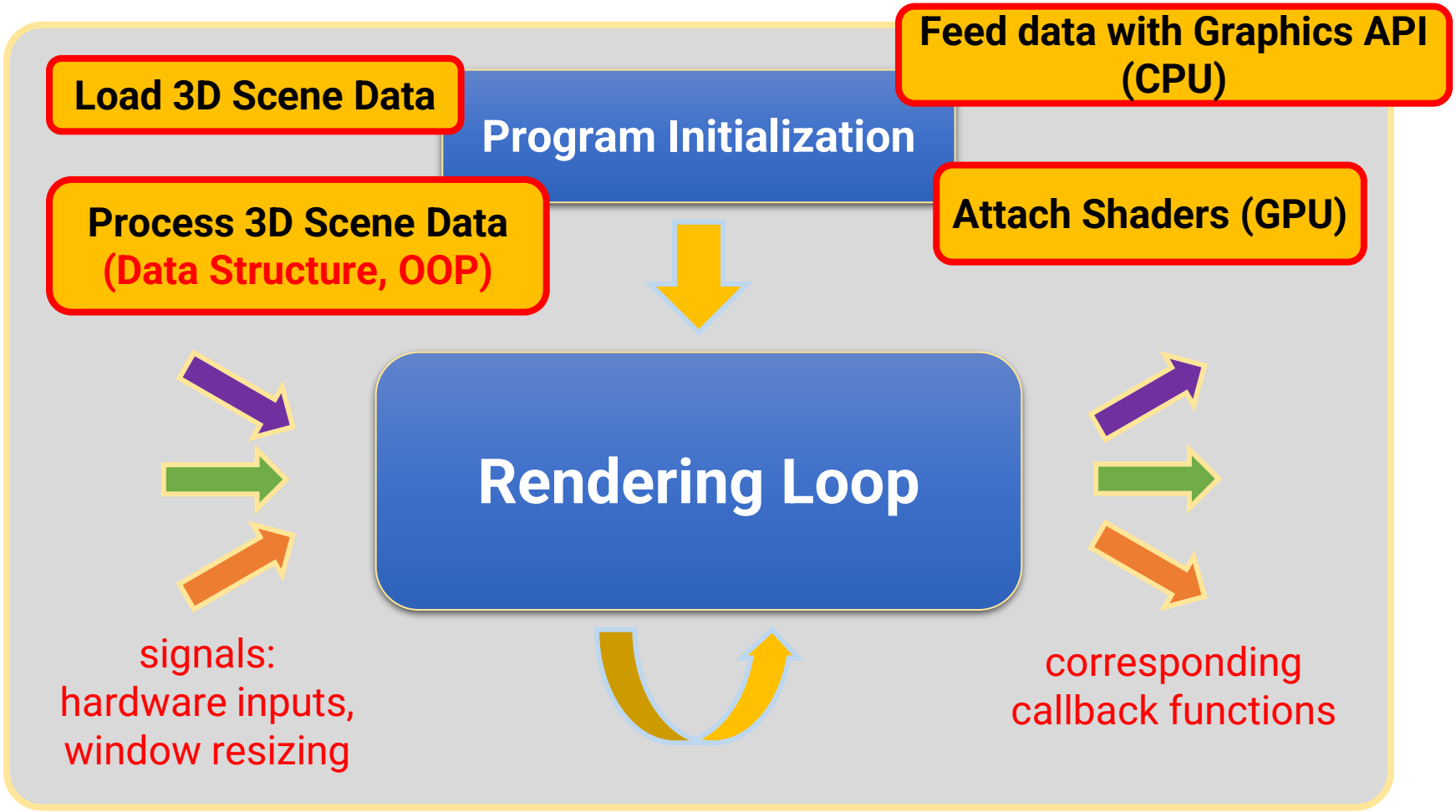
- A simple program to draw a triangle on the screen
  - **457** lines of C++ code

```
    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;
};
```

...

```
    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;
```

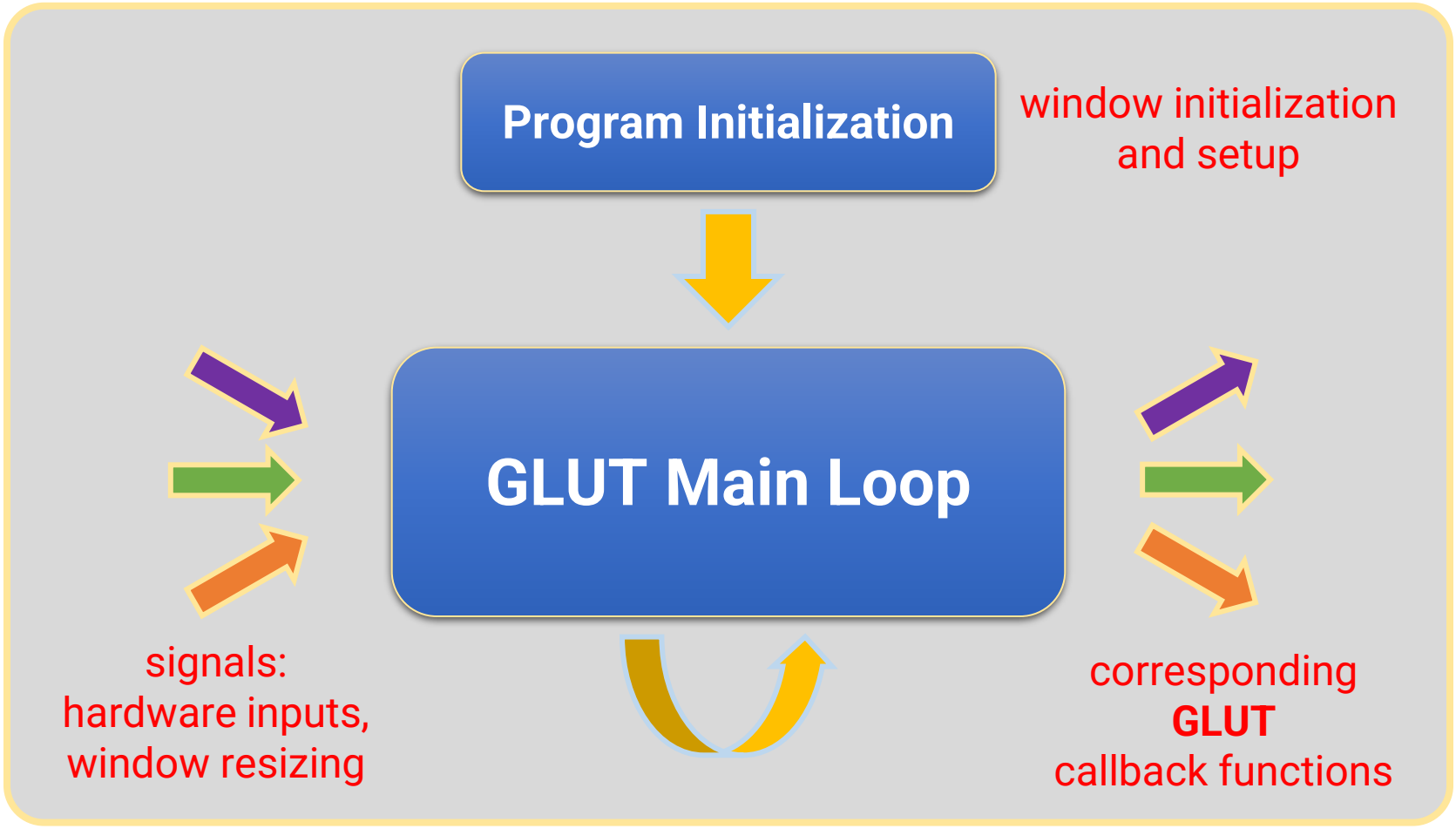
Life Cycle of a Rendering Engine



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 a 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



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

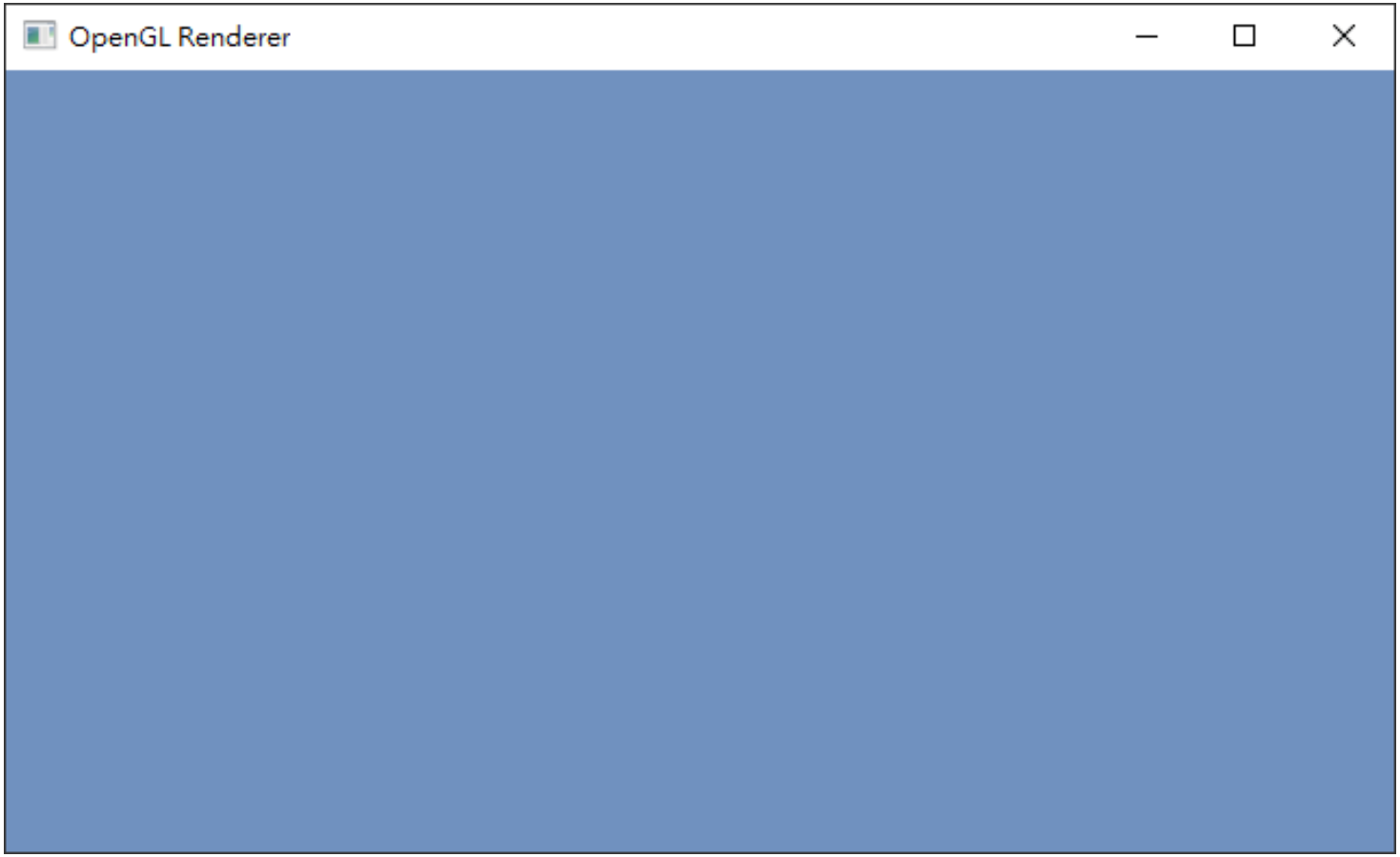
do initialization jobs

register callback functions

start the main loop

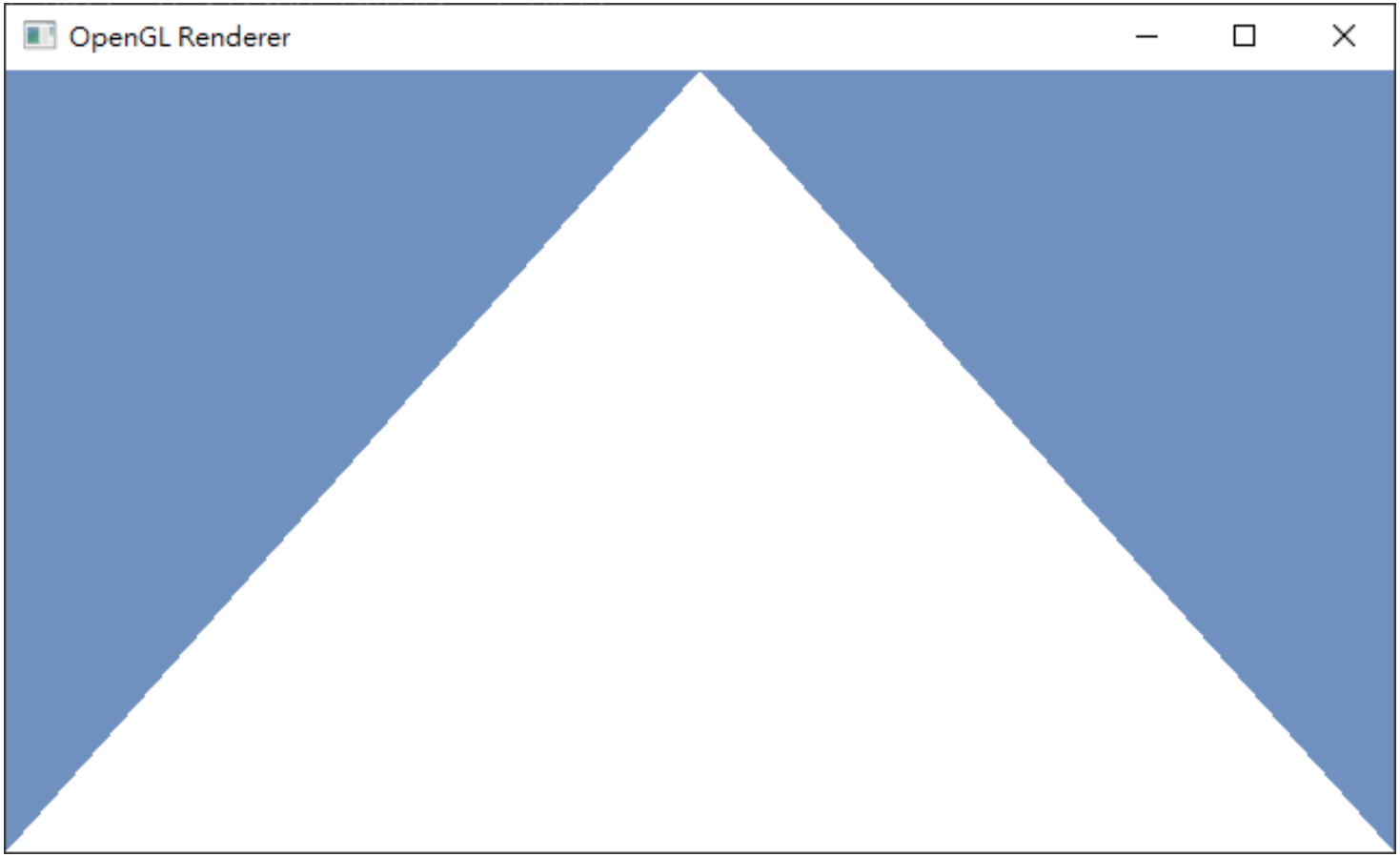
FreeGLUT Window

- 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

HW1
- Geometry Representation
- Transformations
- Camera

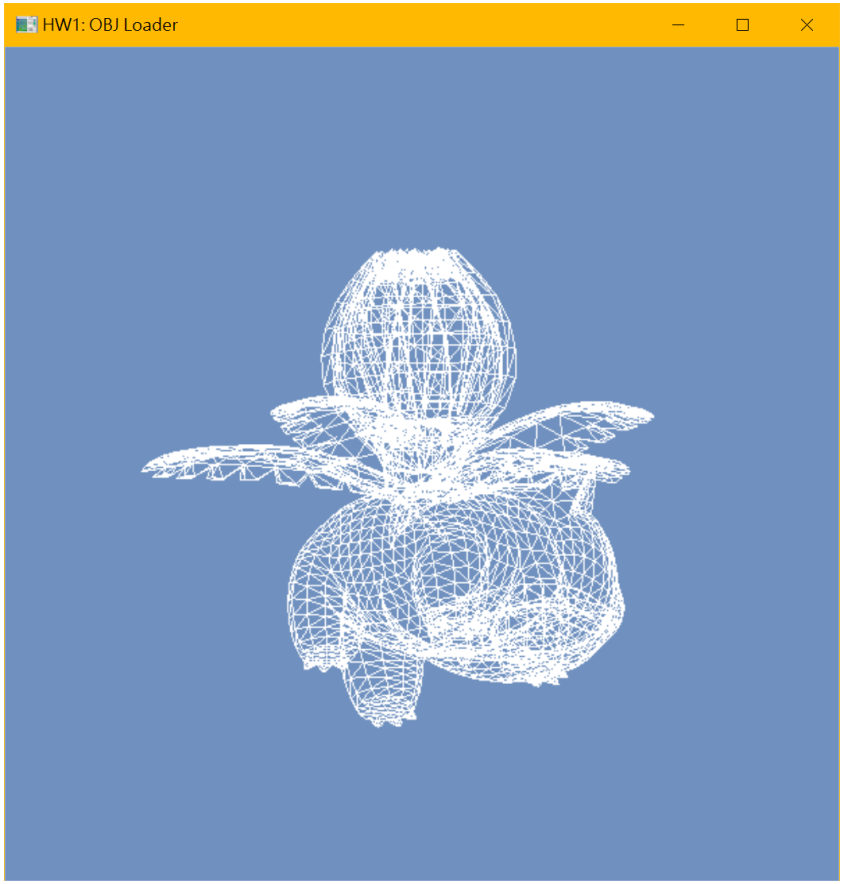
HW2
- GPU Graphics Pipeline

HW3
- Shading
- Textures

Advanced

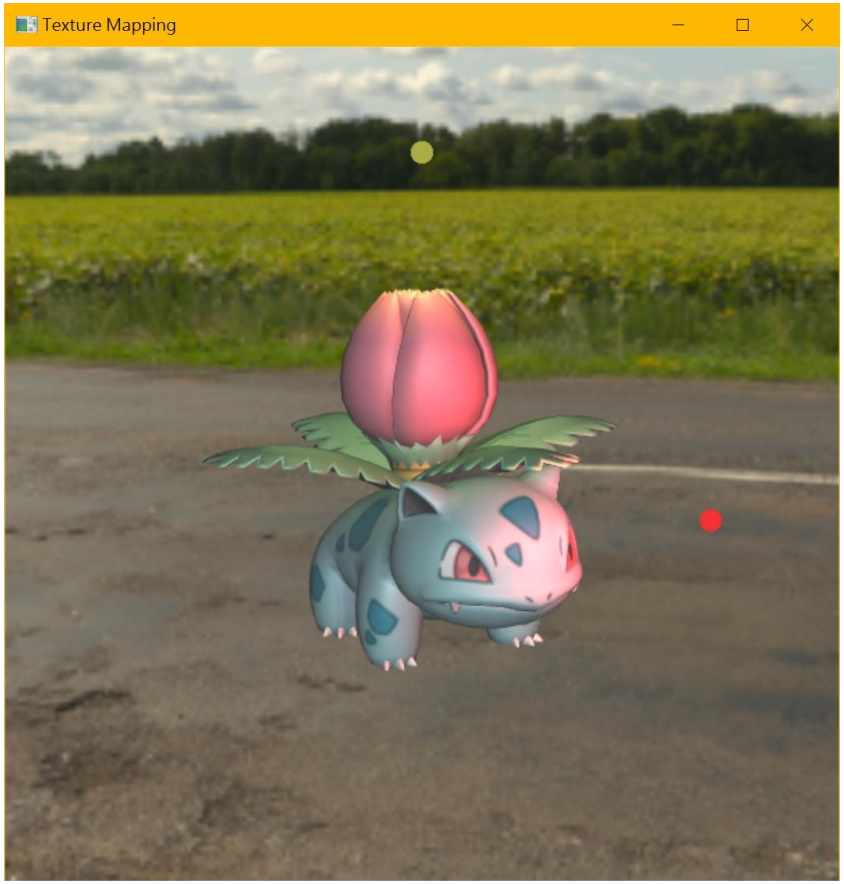
- Transparency
- Shadows
- Deferred Shading
- Terrain
- Ray Tracing
- Advanced Shaders
- Unity Case Study

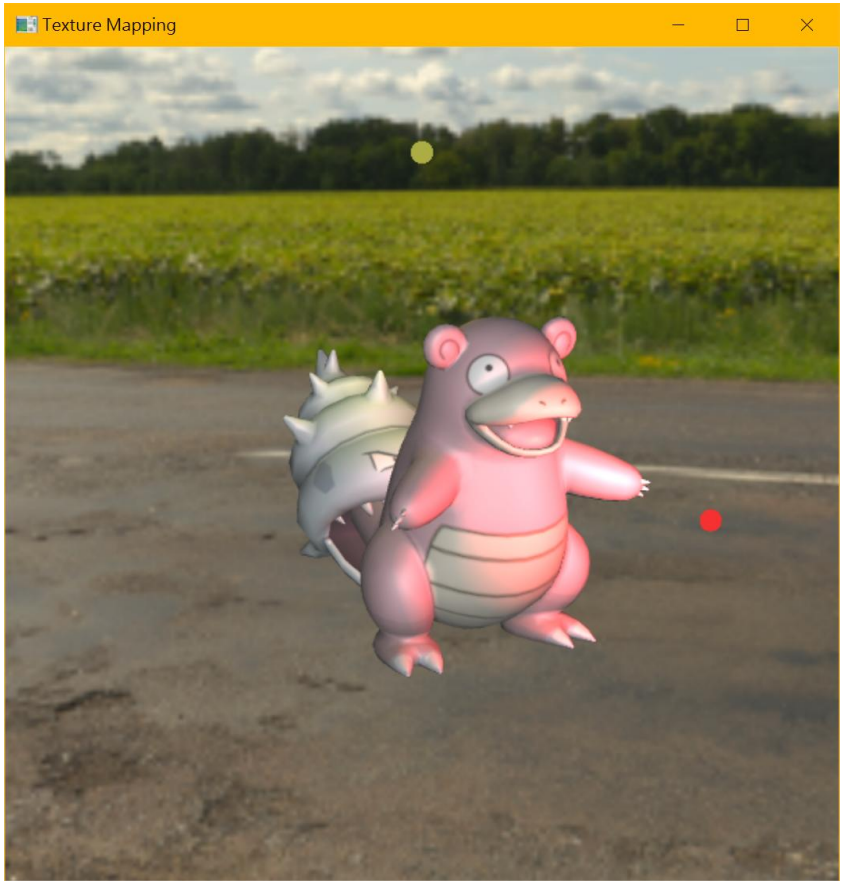
HW1: Geometry Representation (15%)



HW2: GPU Pipeline and Materials (15%)

HW3: Lighting and Texturing (15%)





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.

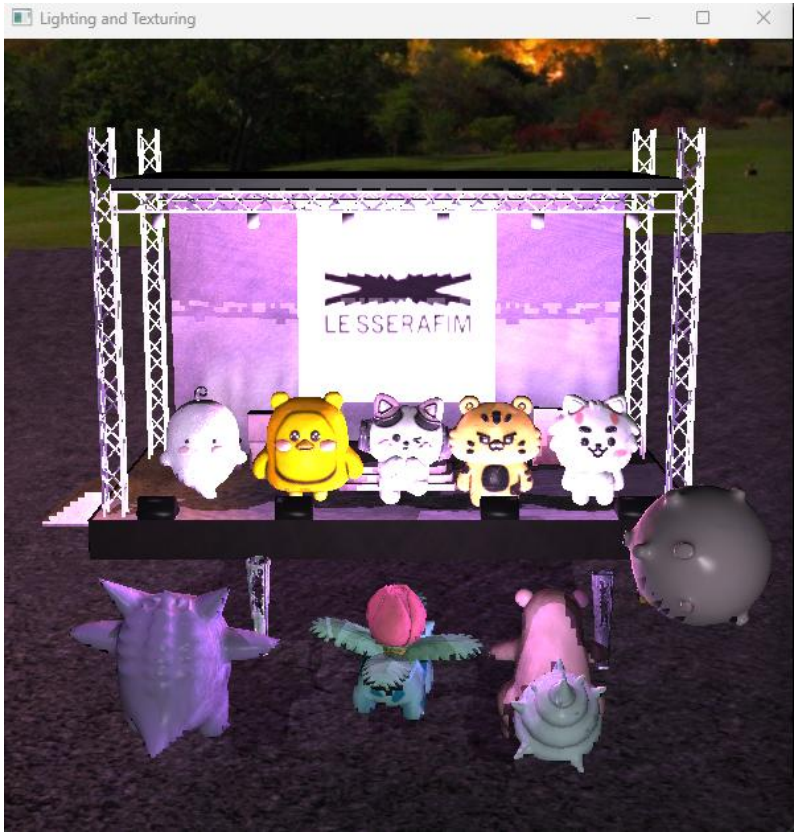
Rendering Competition (5%)

Rendering Competition (5%)

- Amazing works from previous courses

劉睿寬

陳映瑋



廖宣


END OF PRESENTATION
ANY QUESTIONS?