Introduction and Overview

CS425: Computer Graphics I

Fabio Miranda

https://fmiranda.me

Overview

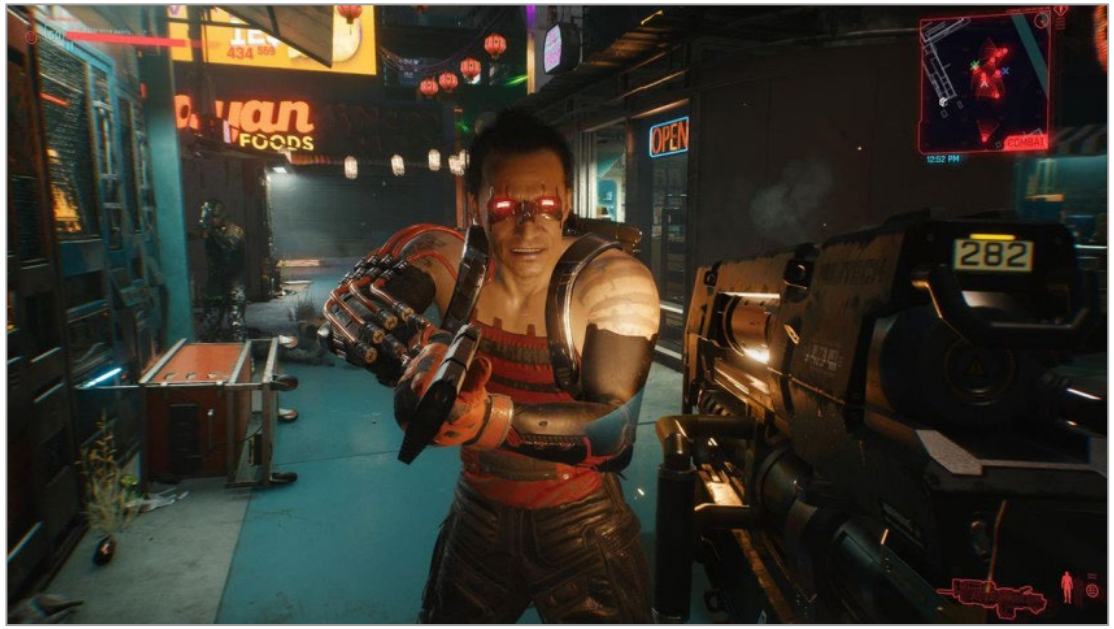
- Intro to computer graphics
- Course goals
- Logistics
- Requirements
- Content overview
- Grading
- Assignments
- Policy
- Workflow pattern
- Resources
- Communication

What is Computer Graphics?

- Broad sense: use of computer to create and manipulate images.
- Combination of hardware (input, processing, output) and software.
- 2D or 3D.

Example

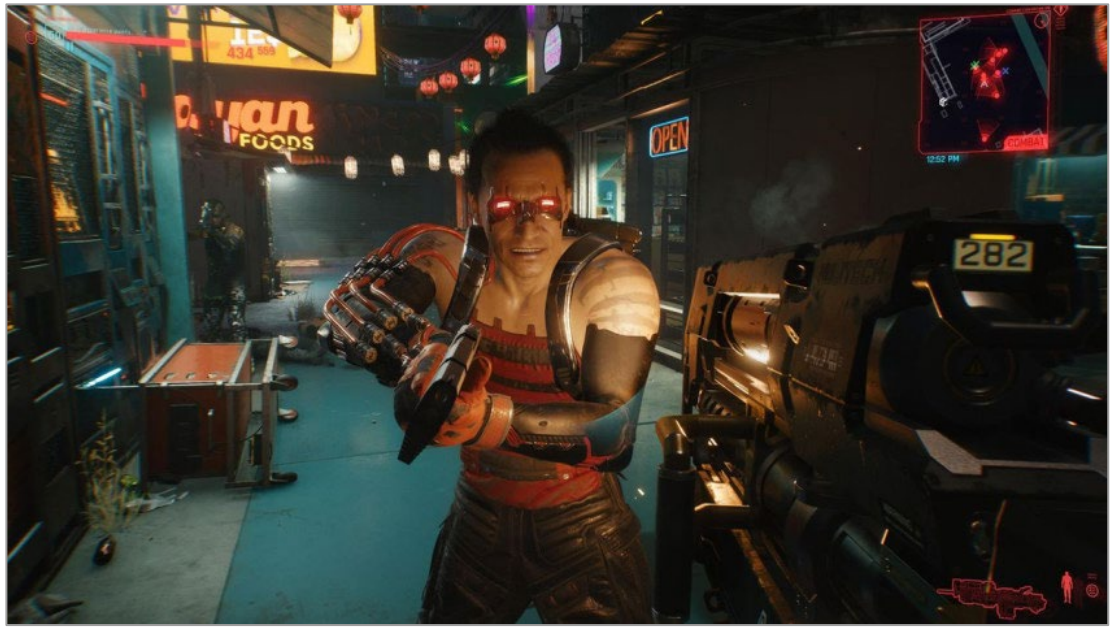
Cyberpunk 2077



Google Earth

Example

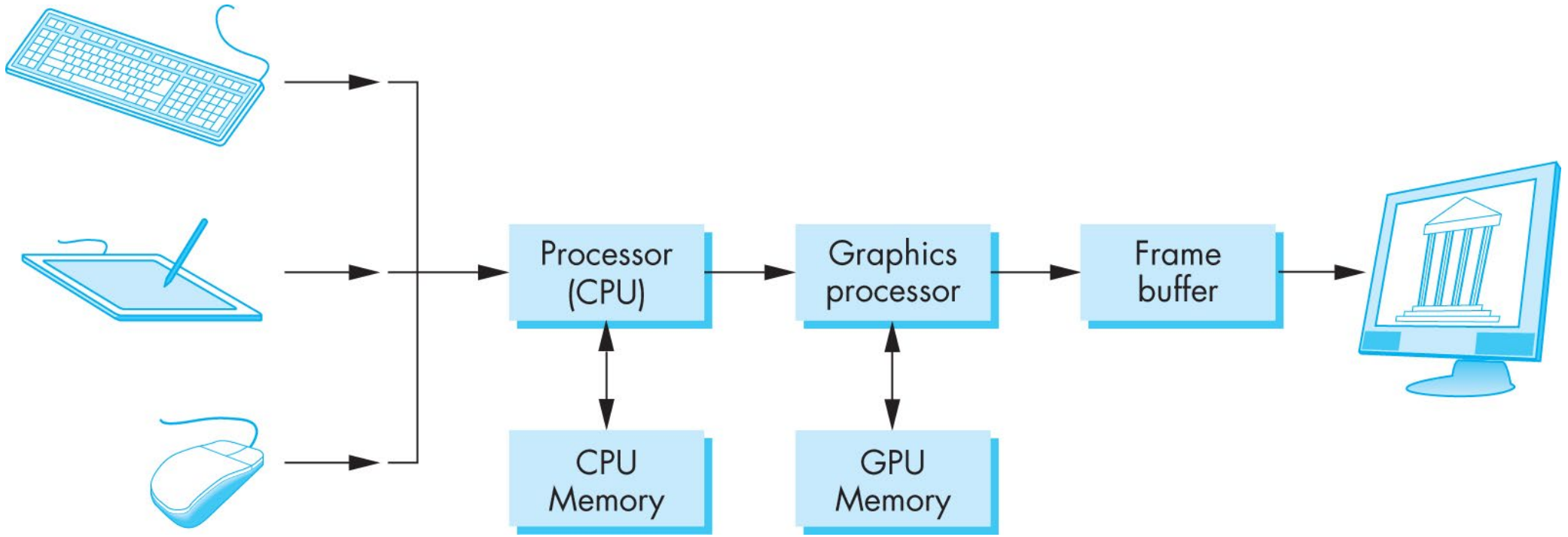
How was this image created?



Graphics system

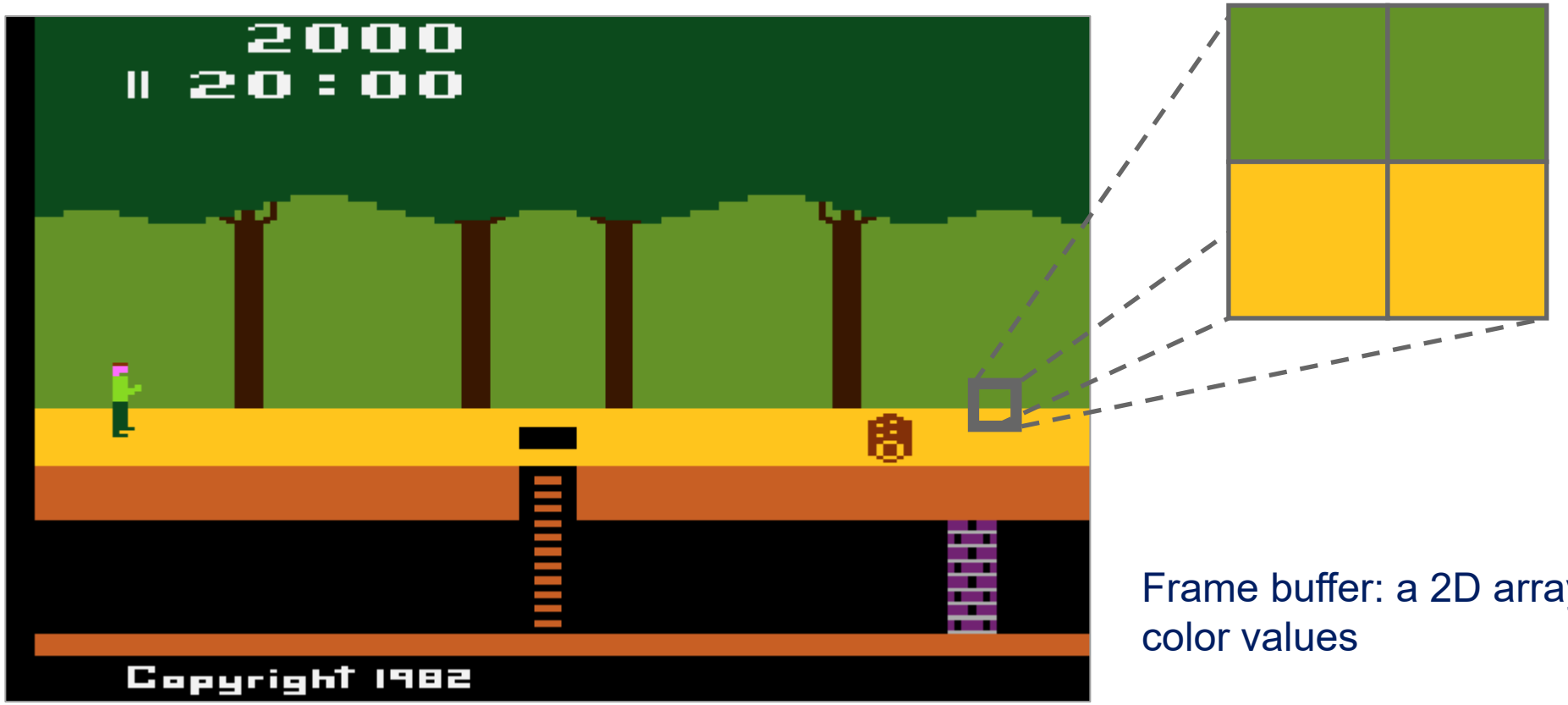
Urbane, OpenSpace, ArcGIS, Google Earth, …	Cyberpunk, Doom, FIFA, …
	Unreal, Unity, idTech, Frostbite, REDengine, …
OpenGL, DirectX, Vulkan, Metal, Glide, …	
Windows, Linux, iOS, …	
CPU, RAM, GPU, VRAM, …	

Basic graphics system



From: Interactive Computer Graphics 7th Ed by Professor Ed Angel and Dave Shreiner

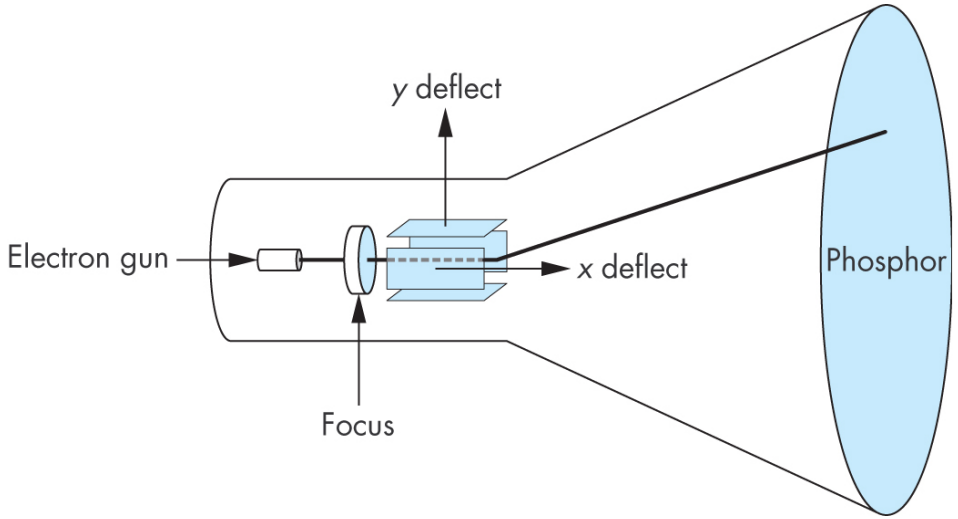
Basic graphics system



Frame buffer: a 2D array with color values

Computer Graphics: 1950s

- Introduction of cathode-ray tube (CRT) as a viable display.
- Light pen as input.



Computer Graphics: 1960s

- The phrase “computer graphics” is coined by Verne L. Hudson and William Fetter from Boeing.
- Wireframe graphics.
- Sutherland introduces Sketchpad, the first computer graphical user interface:
  - Precise drawing
  - Erase, move
  - Zoom in and out
- First ray casting algorithm by Arthur Appel.

Computer Graphics: 1960s

"The Sketchpad system uses drawing as a novel communication medium for a computer. The system contains input, output, and computation programs which enable it to interpret information drawn directly on a computer display. It has been used to draw electrical, mechanical, scientific, mathematical, and animated drawings; it is a general purpose system. Sketchpad has shown the most usefulness as an aid to the understanding of processes, such as the notion of linkages, which can be described with pictures. Sketchpad also makes it easy to draw highly repetitive or highly accurate drawings and to change drawings previously drawn with it."

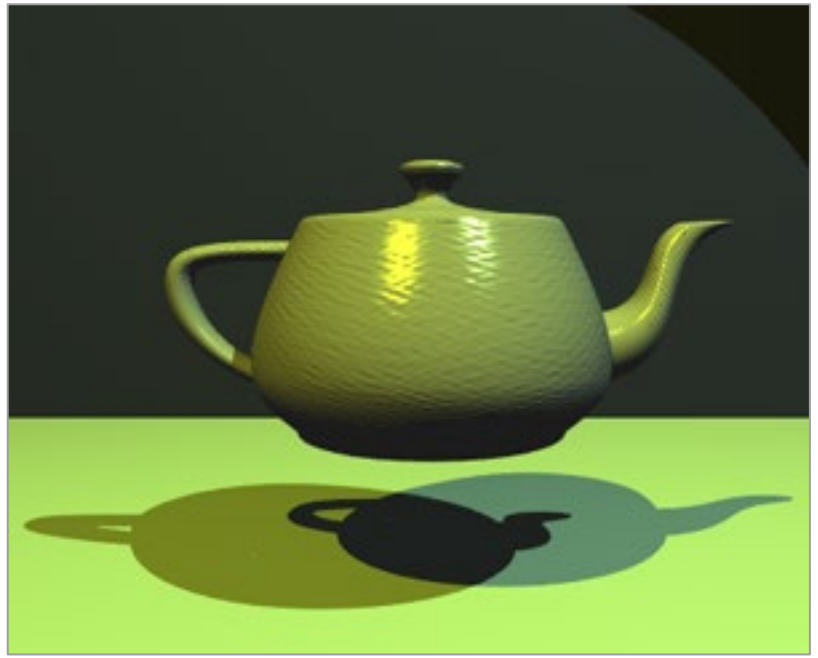
Sketchpad: A man-machine graphical communication system

By Ivan Sutherland

1963

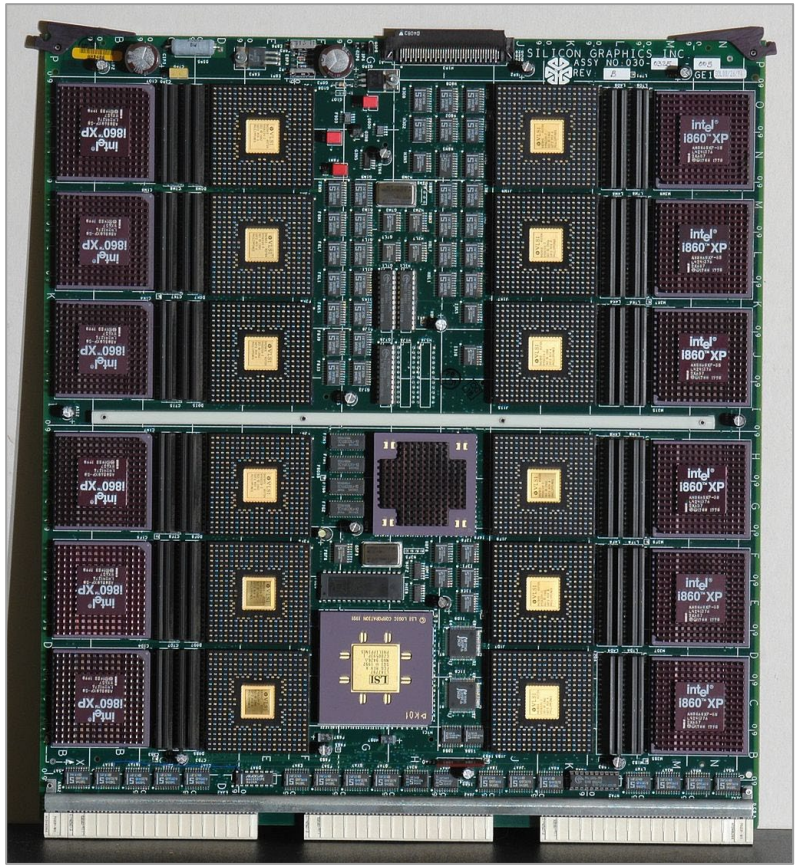
Computer Graphics: 1970s

- Beginning of graphics standards:
  - GKS: ISO 2D standard.
  - Core: 3D, not ISO standard.
- Pong, the first commercially successful video game.
- First commercial framebuffer.
- Utah teapot.
- Gouraud and Blinn-Phong shading models.
- Workstations and PCs.



Computer Graphics: 1980s

- Special purpose hardware:
  - Silicon Graphics geometry engine
  - SGI: 3D raster graphics hardware
- Shaded solids, no textures.



Computer Graphics: 1990s

- OpenGL API.
- Toy Story: First computer-generated feature-length movie .
- GeForce 256: first consumer-level with hardware-accelerated transforming and lighting.
- Texture mapping.
- Doom, Quake.

Computer Graphics: 2000s

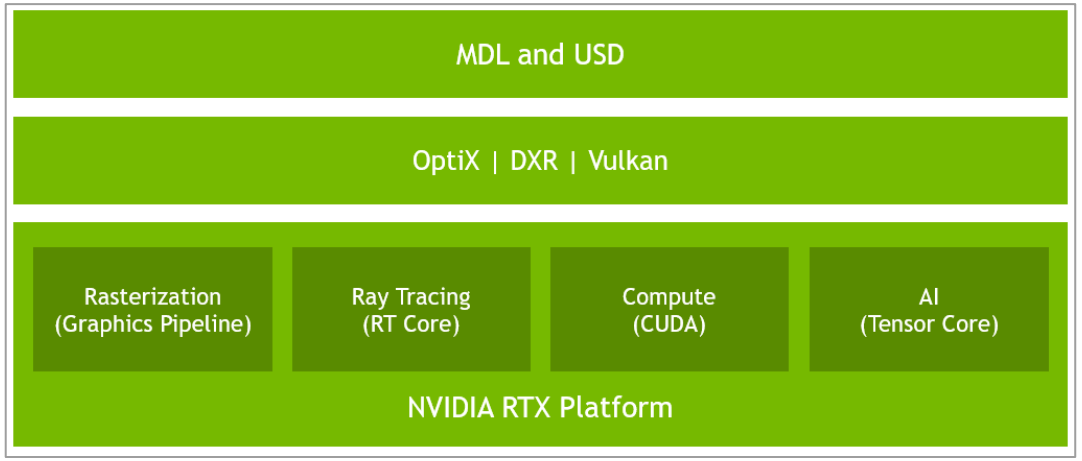
- GeForce 3: first to support programmable shaders.
- Proliferation of CG movies.
- GPU being used in other area: computer vision, machine learning, bioinformatics, etc.
- CUDA, OpenCL.

Computer Graphics: 2010s

- Graphics is now ubiquitous:
  - Cell phones.
  - Embedded.
- OpenGL ES and WebGL.
- Virtual Reality.
- 3D movies and TV.

Computer Graphics: 2020s

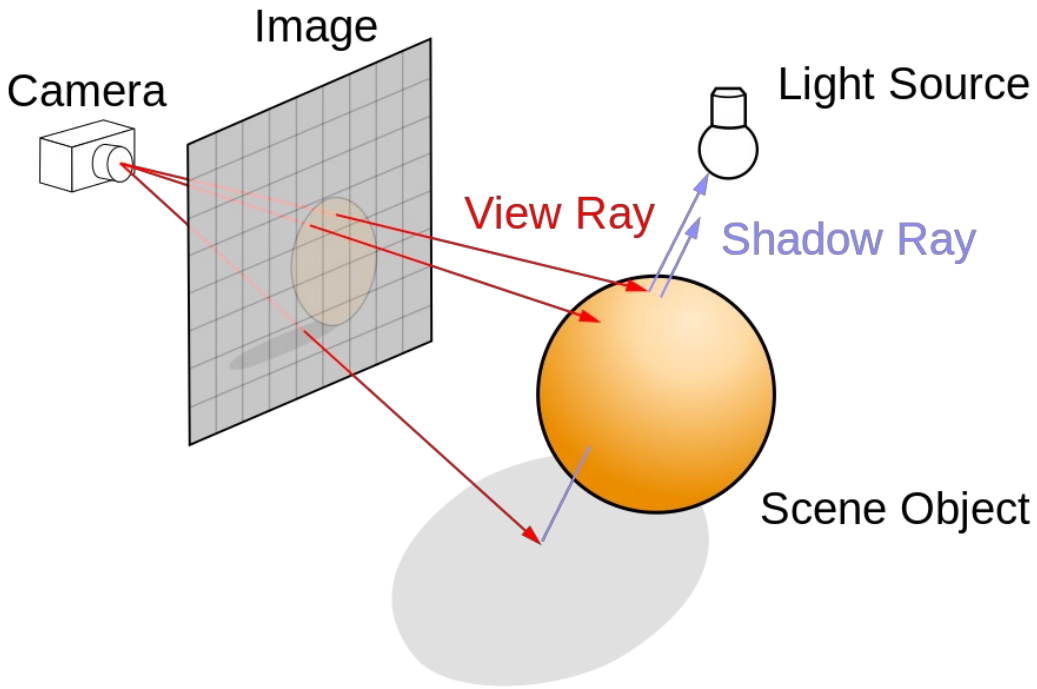
- Real-time ray tracing.
- 4K resolution.
- AI-based anti-aliasing.



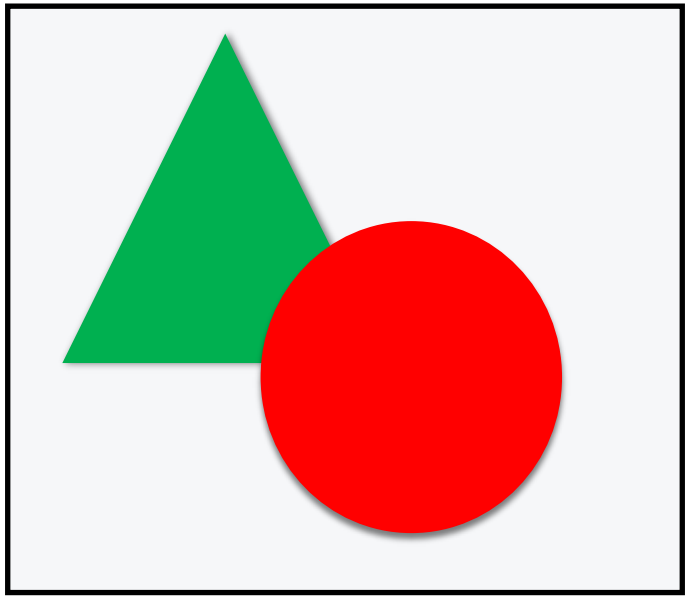
Nvidia - Reflections RTX Tech Demo

Creating images

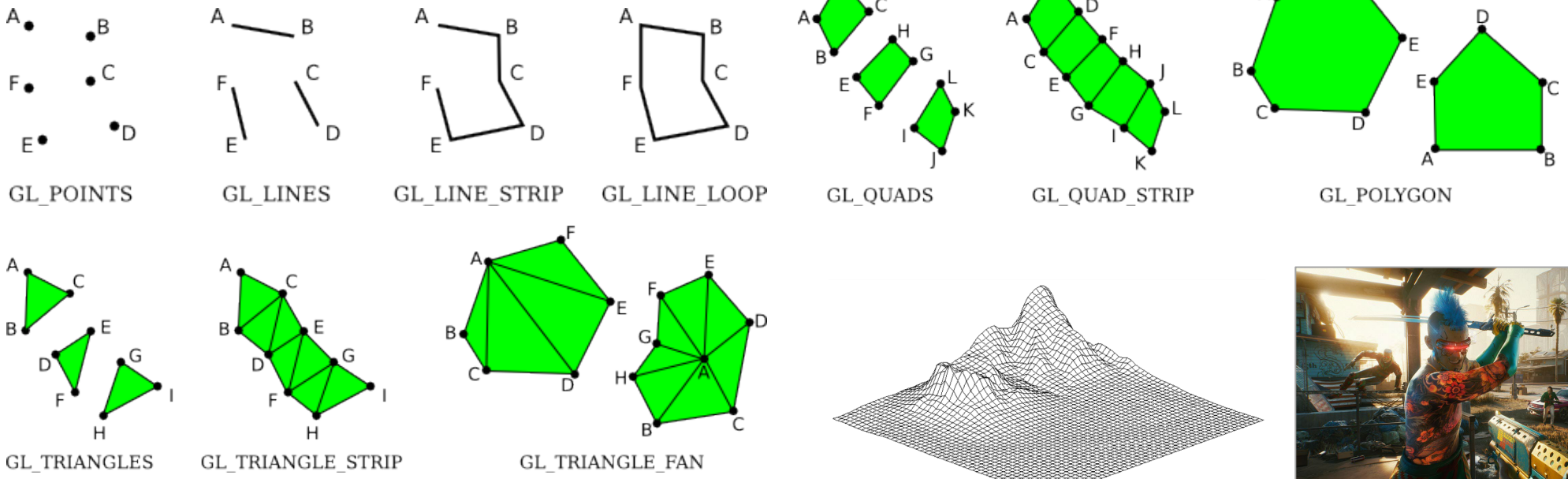
Per pixel: ray tracing



Per object: rasterization

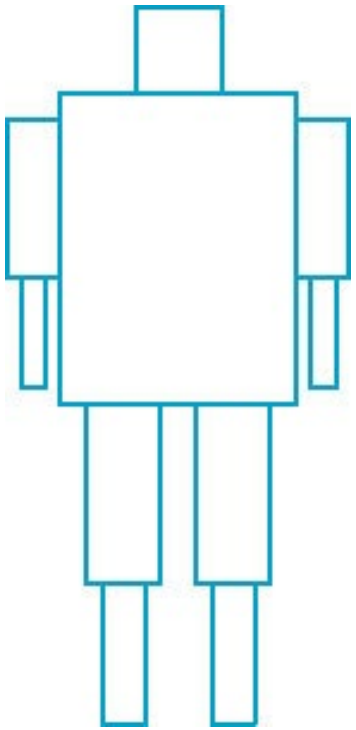


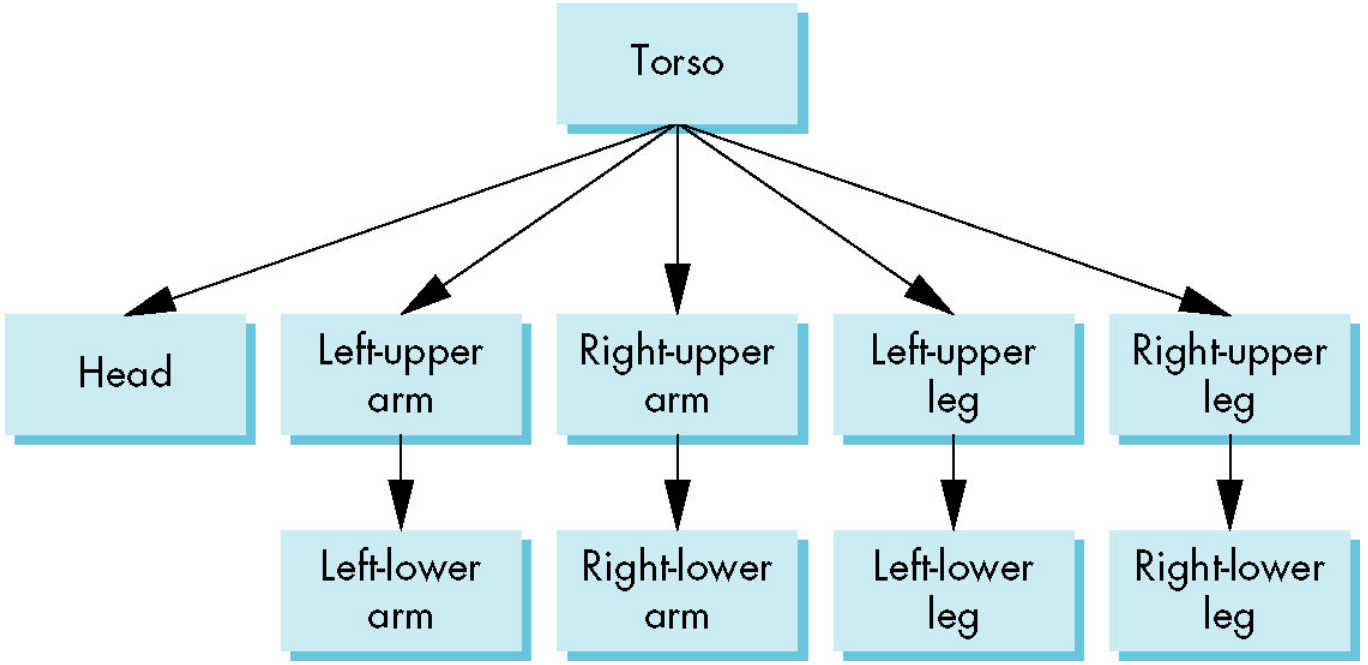
Creating images: Objects description



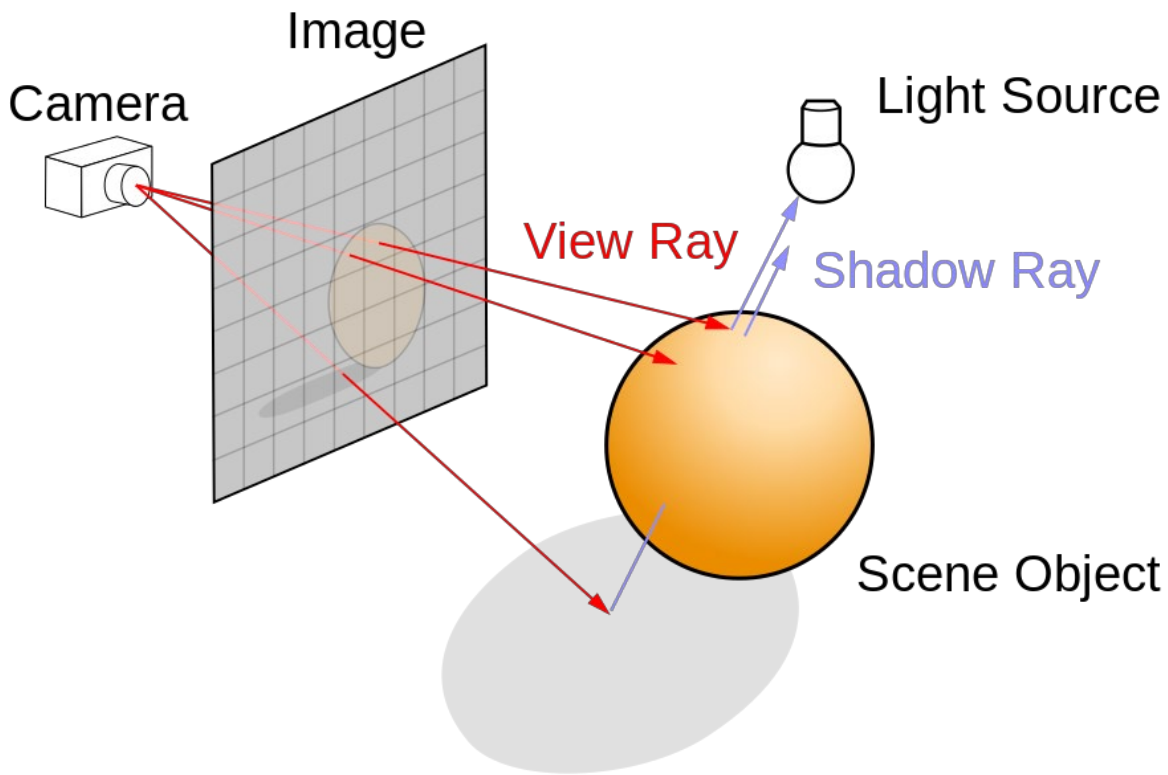
From: Introduction to Computer Graphics, David J. Eck

Creating images: Scene description



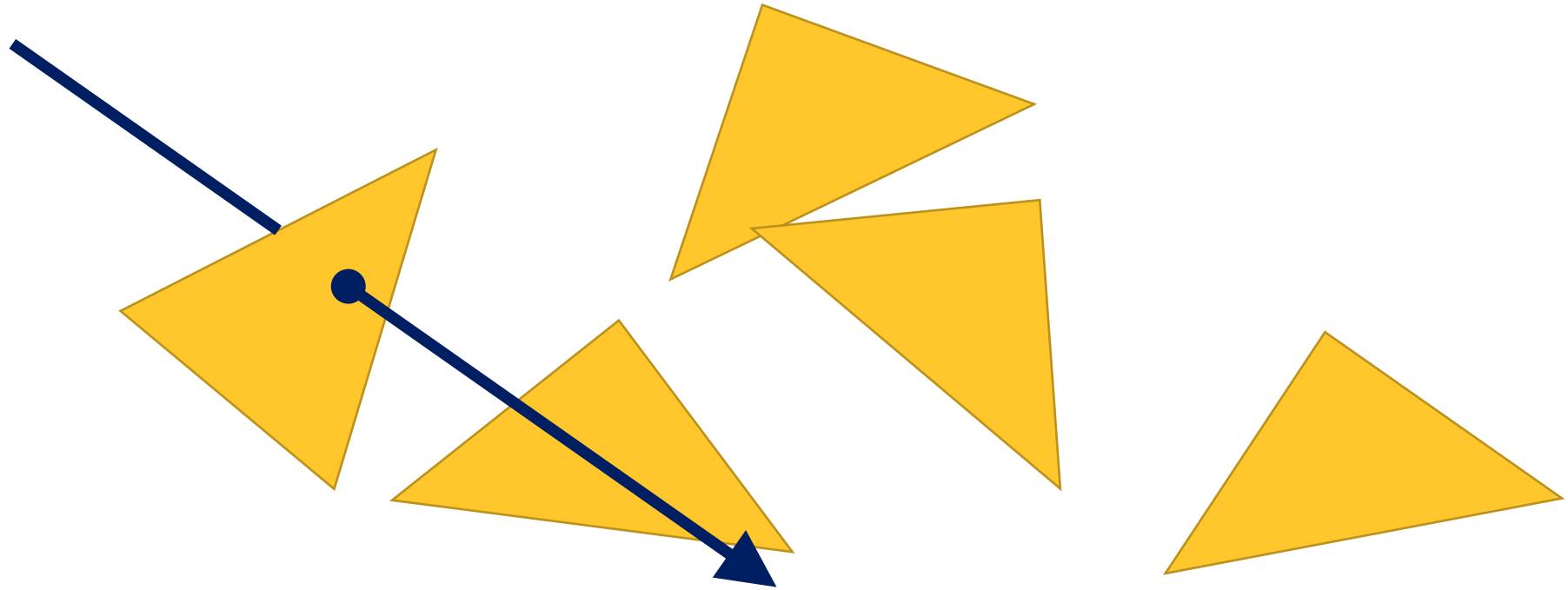


Creating images: Ray tracing

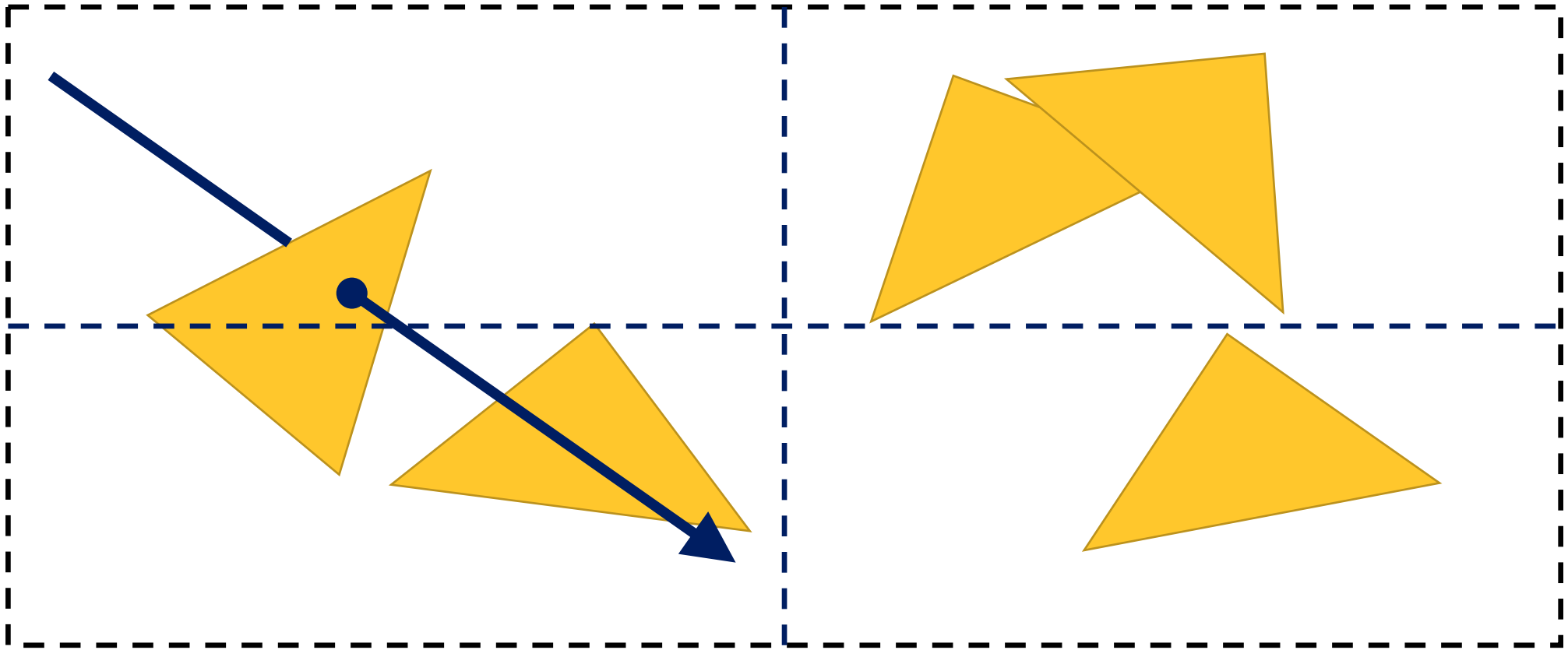


- Easy to parallelize but hard to map to hardware (up until recently)
- Expensive!
- It can be extended to model many physical phenomena (internal scattering, diffraction, reflections, etc)
- Used to obtain high-quality images

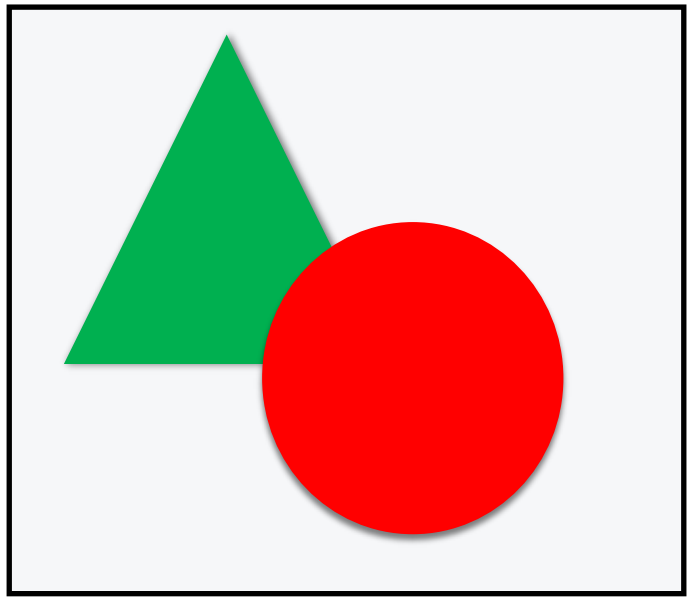
Creating images: Ray tracing



Creating images: Ray tracing

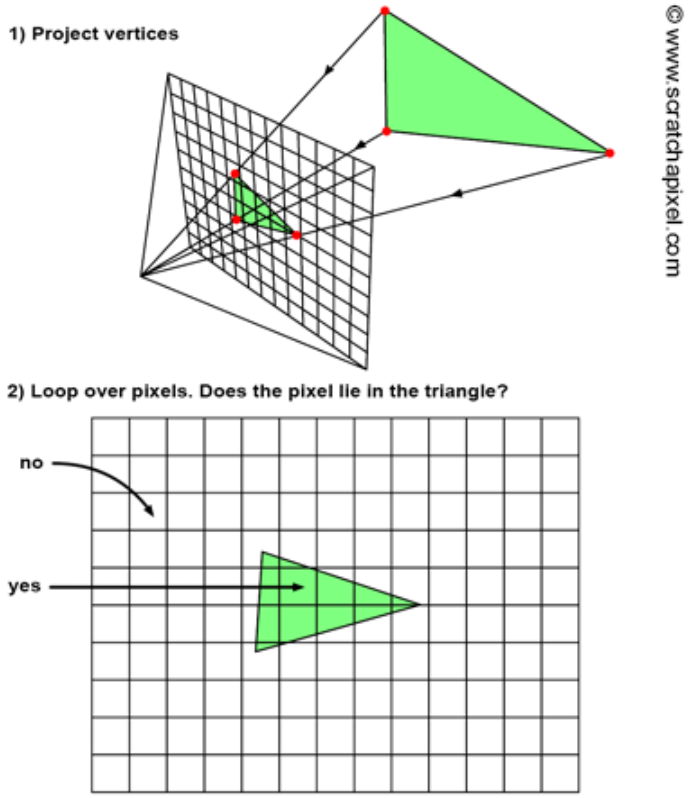


Creating images: Rasterization



- Easy to map to hardware
- While it cannot model directly complex effects, we can approximate them
- Used in interactive applications (mostly)

Creating images: Rasterization



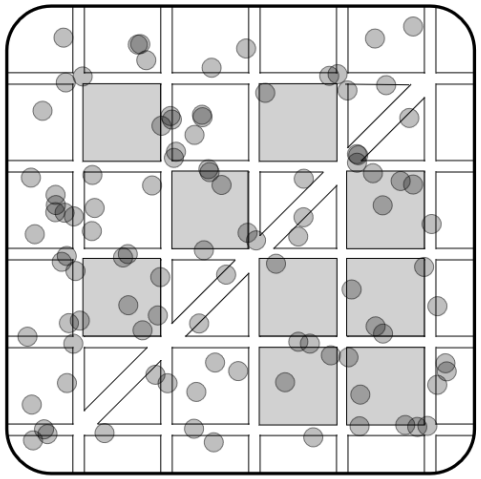
1. Project 3D vertices onto the screen.
2. Loop through pixels in the image and test if they lie within the resulting 2D triangles.

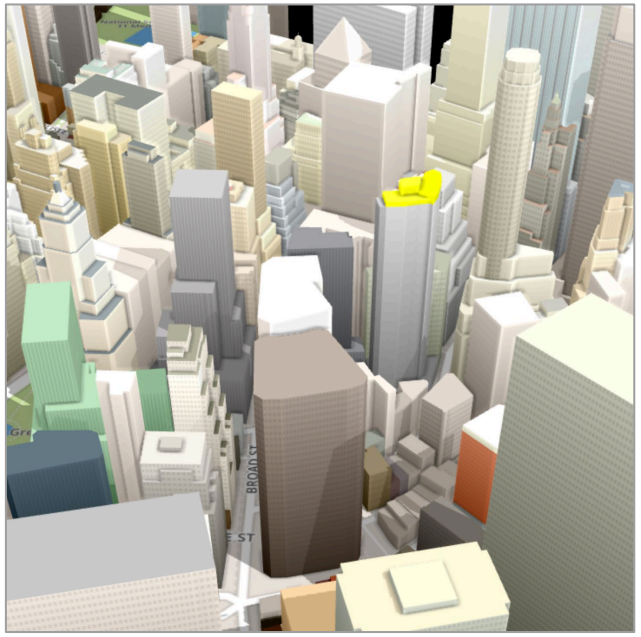
Real-time rendering vs off-line rendering

Doom (2016)

Soul (2020)

Computer Graphics & Visualization

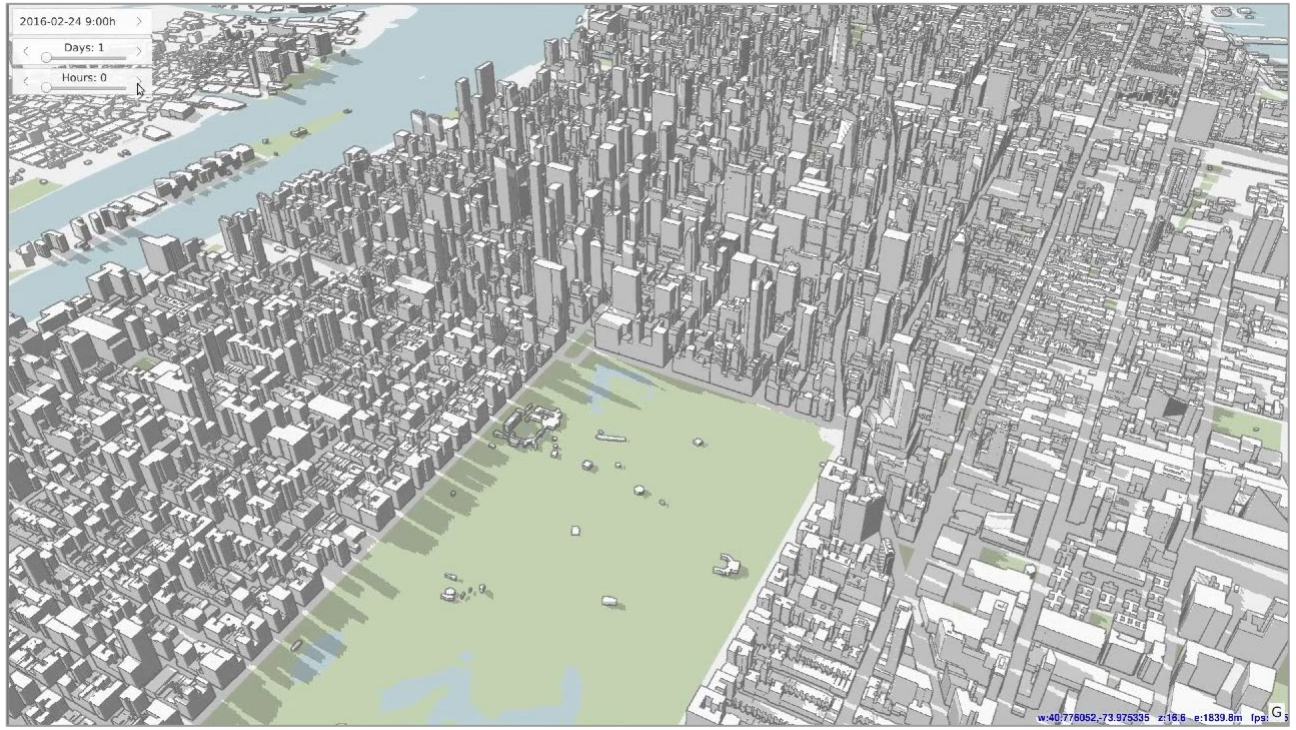




Open Street Maps

DoITT

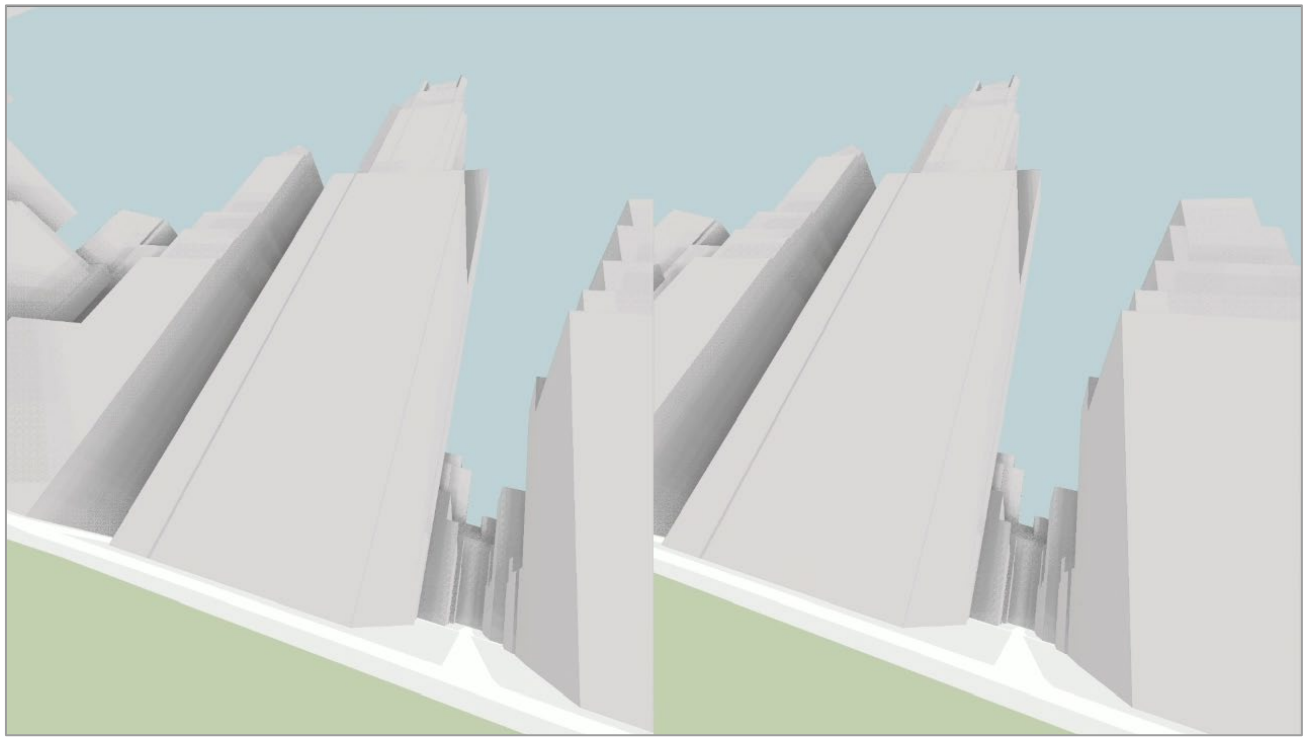
Computer Graphics & Visualization



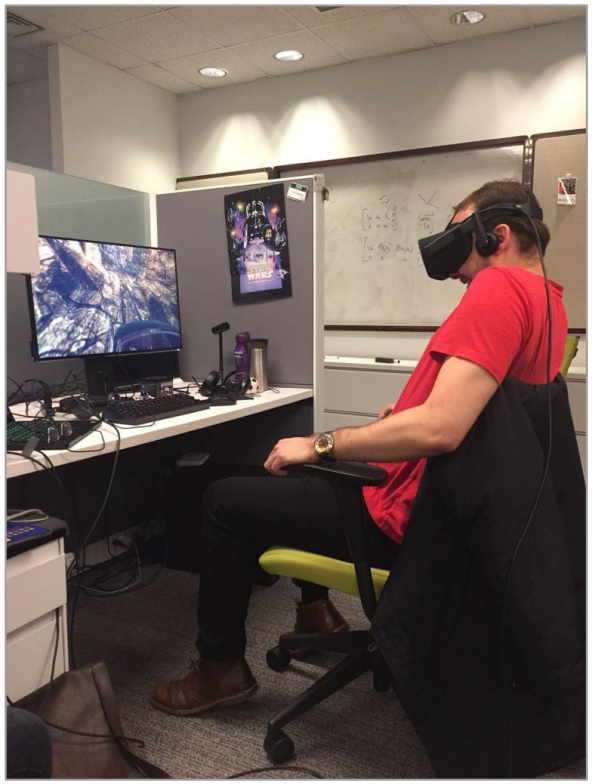
Shadow Accrual Maps: Efficient Accumulation of City-Scale Shadows Over Time

https://nyti.ms/2k0bF0G

Computer Graphics & Virtual Reality



Urbanrama



Computer Graphics & Database

Interactive Visual Exploration of Spatio-Temporal Urban Data Sets using Urbane

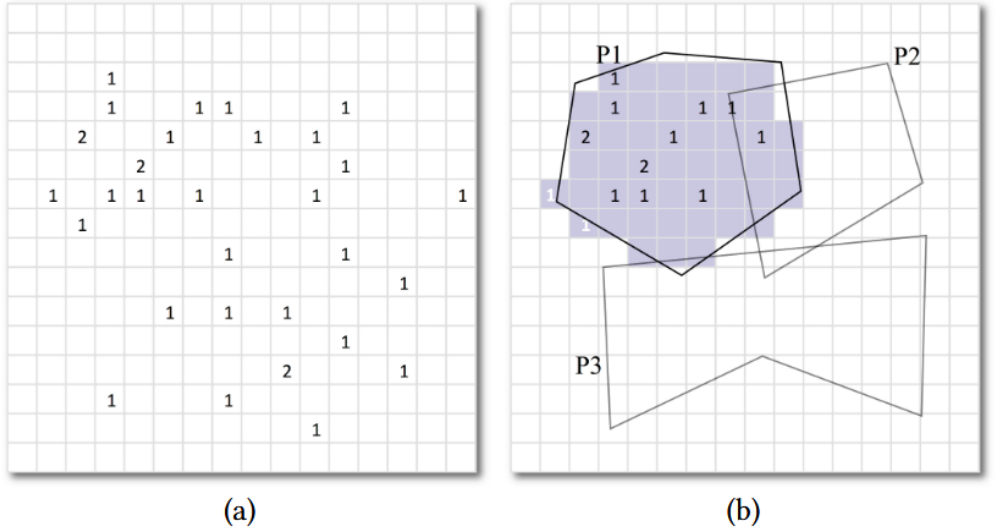
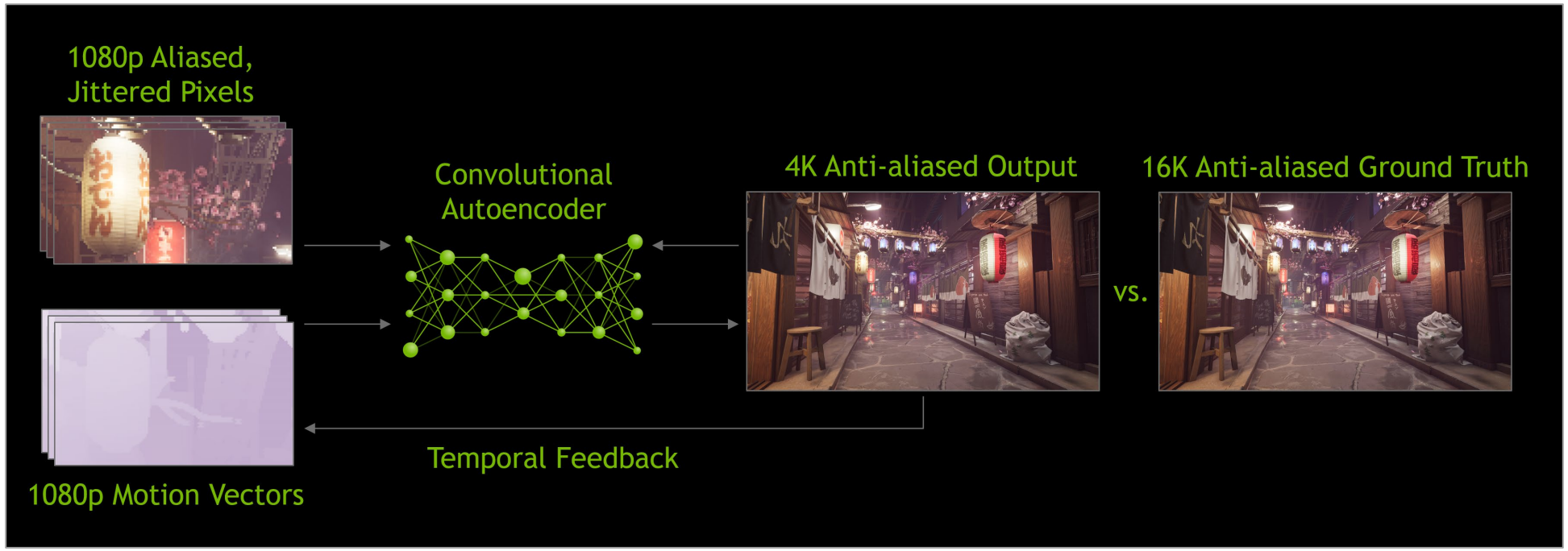


Figure 2: Raster Join first renders all points onto an FBO storing the count of points in each pixel (a). It then aggregates the pixel values corresponding to polygon fragments (b).

Computer Graphics & Machine Learning



NVIDIA: Deep learning super sampling

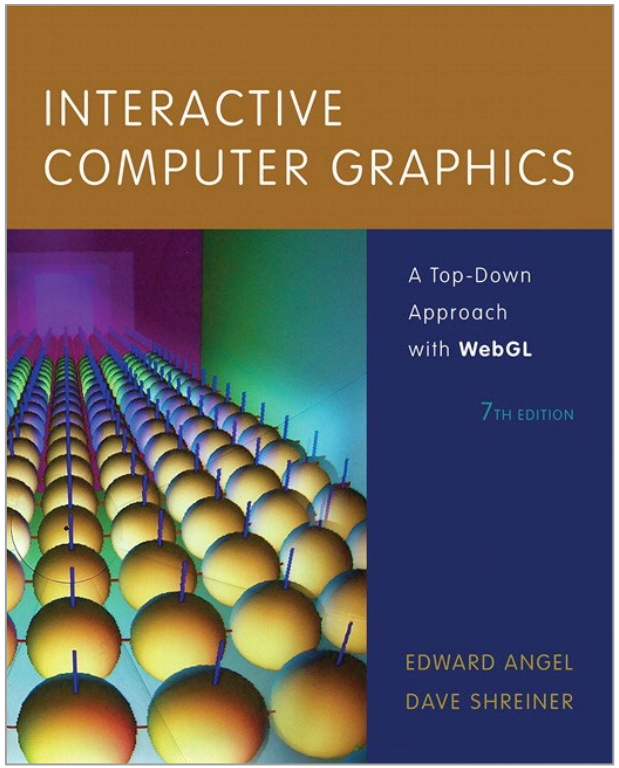
CS425: Course goals

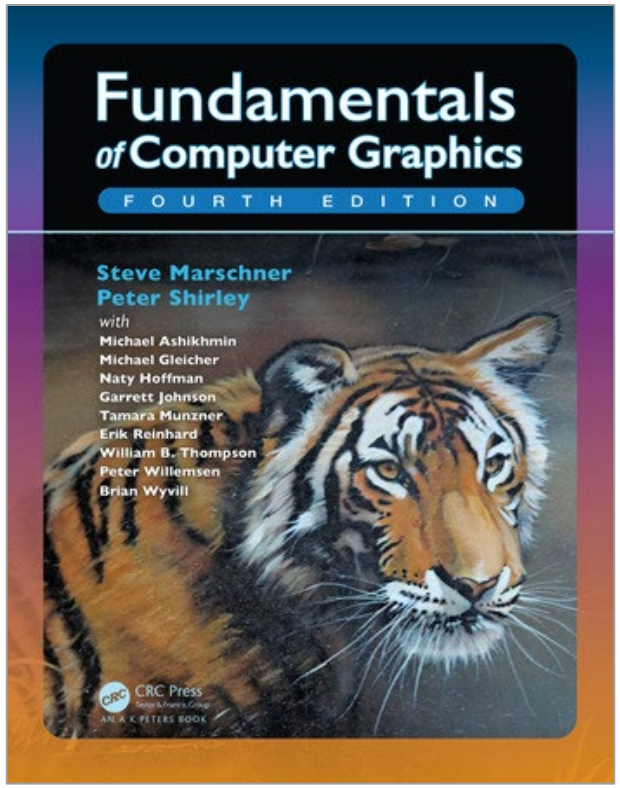
- Explain and apply the core concepts of computer graphics.
- Understand and use the different components of a programmable graphics pipeline.
- Understand and use different spatial data structures.
- Implement visual effects such as shadows.
- Implement interactive computer graphics programs using WebGL.

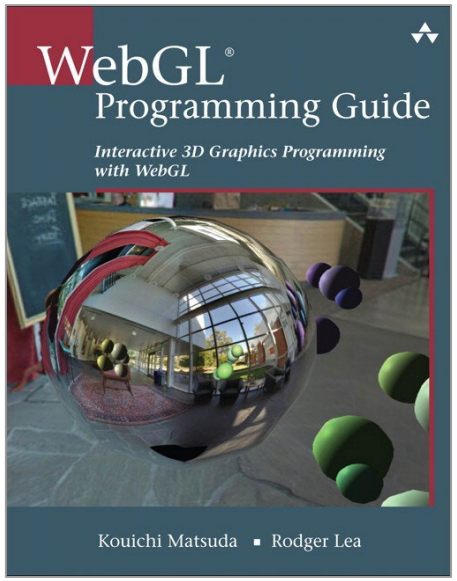
CS425: Course goals

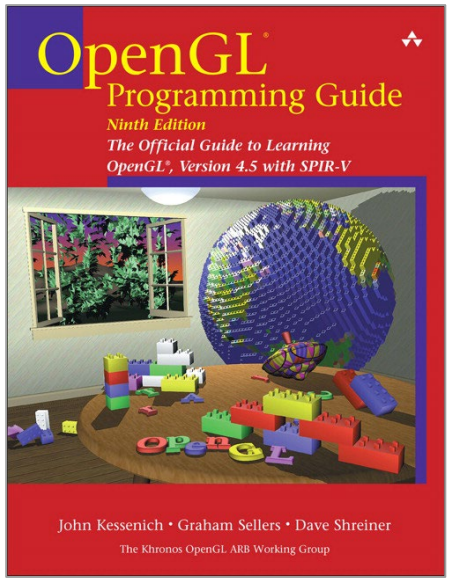
- Theory and systems behind applications
- Mathematics:
  - Physics of light, color, …
  - Geometry, perspective, …
- Systems:
  - Graphics APIs
  - Interaction devices

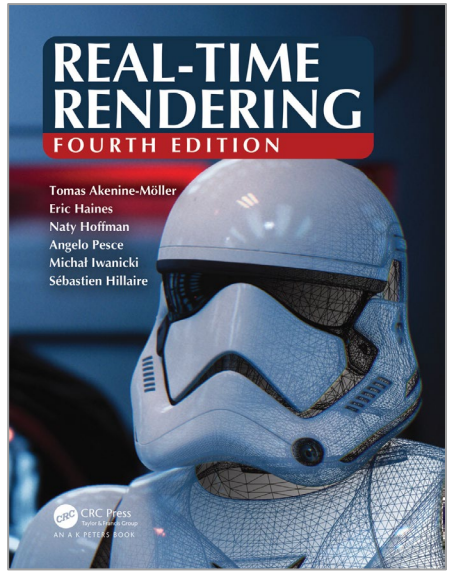
Material


INTERACTIVE
COMPUTER GRAPHICS
A Top-Down
Approach
with WebGL
7TH EDITION
EDWARD ANGEL
DAVE SHREINER


Fundamentals
of Computer Graphics
FOURTH EDITION
Steve Marschner
Peter Shirley
with
Michael Ashikhmin
Michael Gleicher
Naty Hoffman
Garrett Johnson
Tamara Munzner
Erik Reinhard
William B. Thompson
Peter Willemsen
Brian Wyvill
CRC Press


WebGL®
Programming Guide
Interactive 3D Graphics Programming
with WebGL
Kouichi Matsuda ▪ Rodger Lea


OpenGL®
Programming Guide
Ninth Edition
The Official Guide to Learning
OpenGL®, Version 4.5 with SPIR-V
John Kessenich • Graham Sellers • Dave Shreiner
The Khronos OpenGL ARB Working Group


REAL-TIME
RENDERING
FOURTH EDITION
Tomas Akenine-Möller
Eric Haines
Naty Hoffman
Angelo Pesce
Michał Iwanicki
Sébastien Hillaire
CRC Press

Other resources

https://open.gl

https://webgl2fundamentals.org/

https://songho.ca/opengl/

https://learnopengl.com/

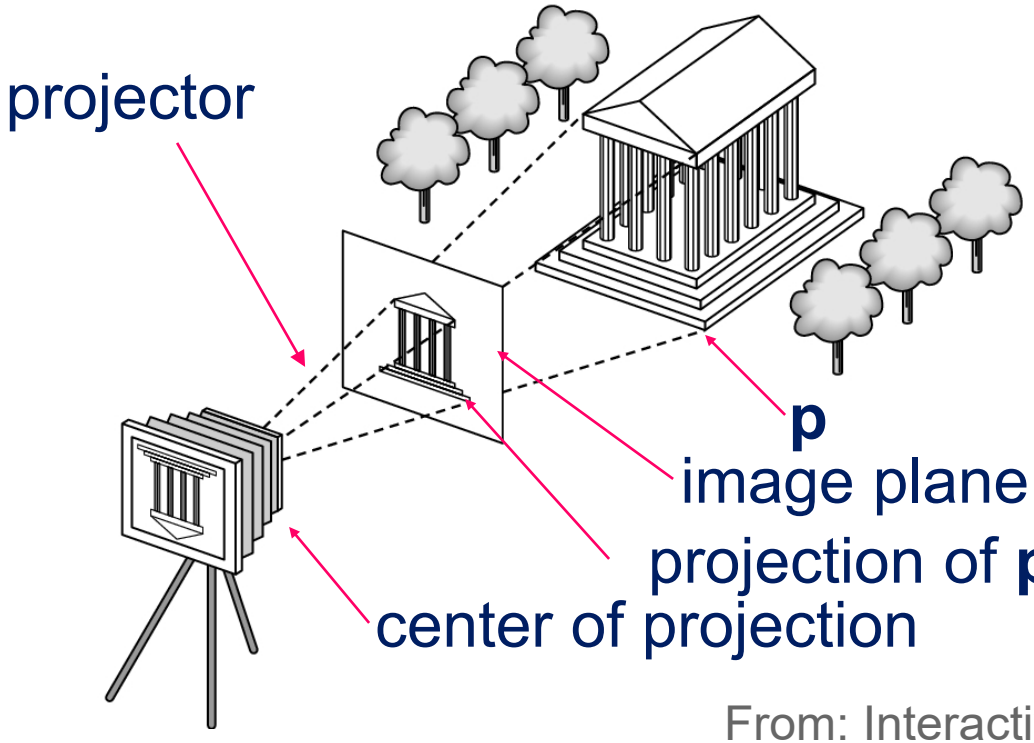
Requirements

- CS251 Data structures.
- We will use WebGL and JavaScript.
  - Portability
  - No need to install dependencies or plugins to run code: just open a browser.
  - Polyglot programming: JavaScript, GLSL, HTML, CSS, …
  - Easy to produce interactive examples.

Content overview

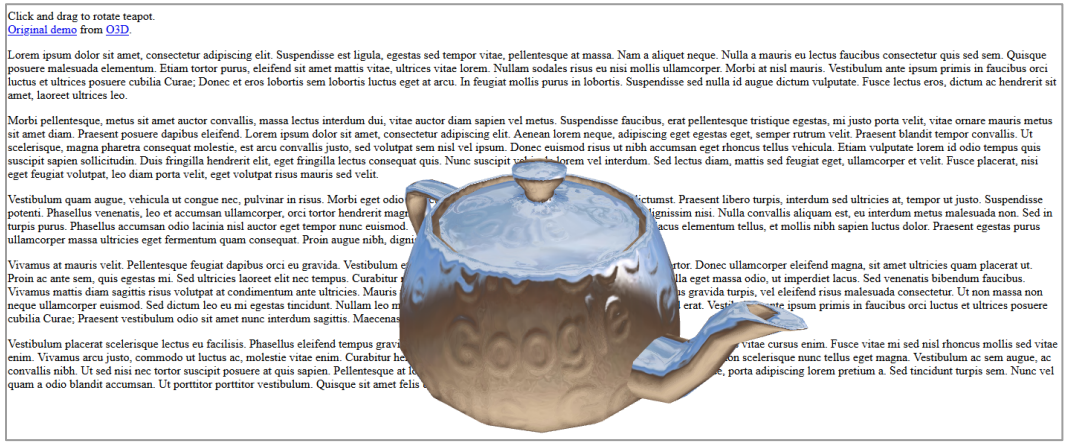
- Images and color
- WebGL
- Linear algebra and transformation
- Viewer transformations and rasterization
- Graphics pipeline
- Lighting and shading
- Texture mapping
- Shadows
- Ray tracing
- Antialiasing
- Curves and surfaces
- Spatial data structures
- Modern rendering techniques

Images and color

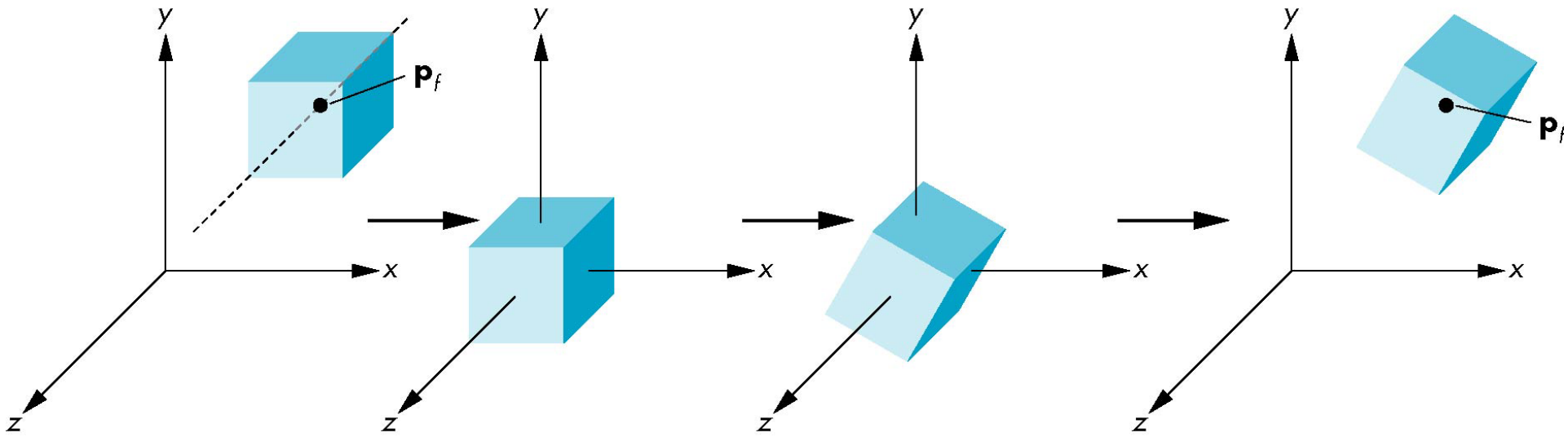


From: Interactive Computer Graphics 7th Ed by Professor Ed Angel and Dave Shreiner

WebGL & web programming

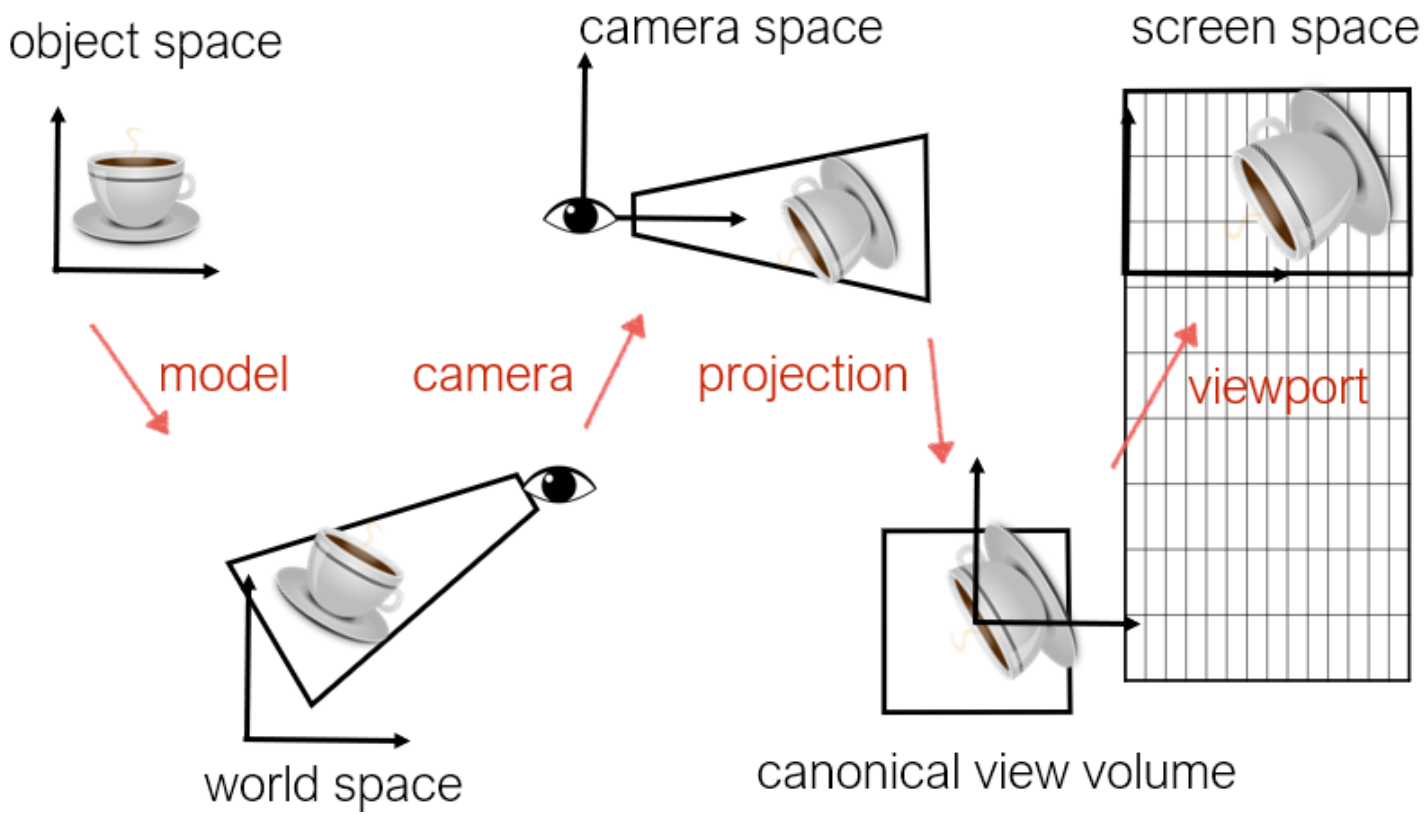


Linear algebra and transformations



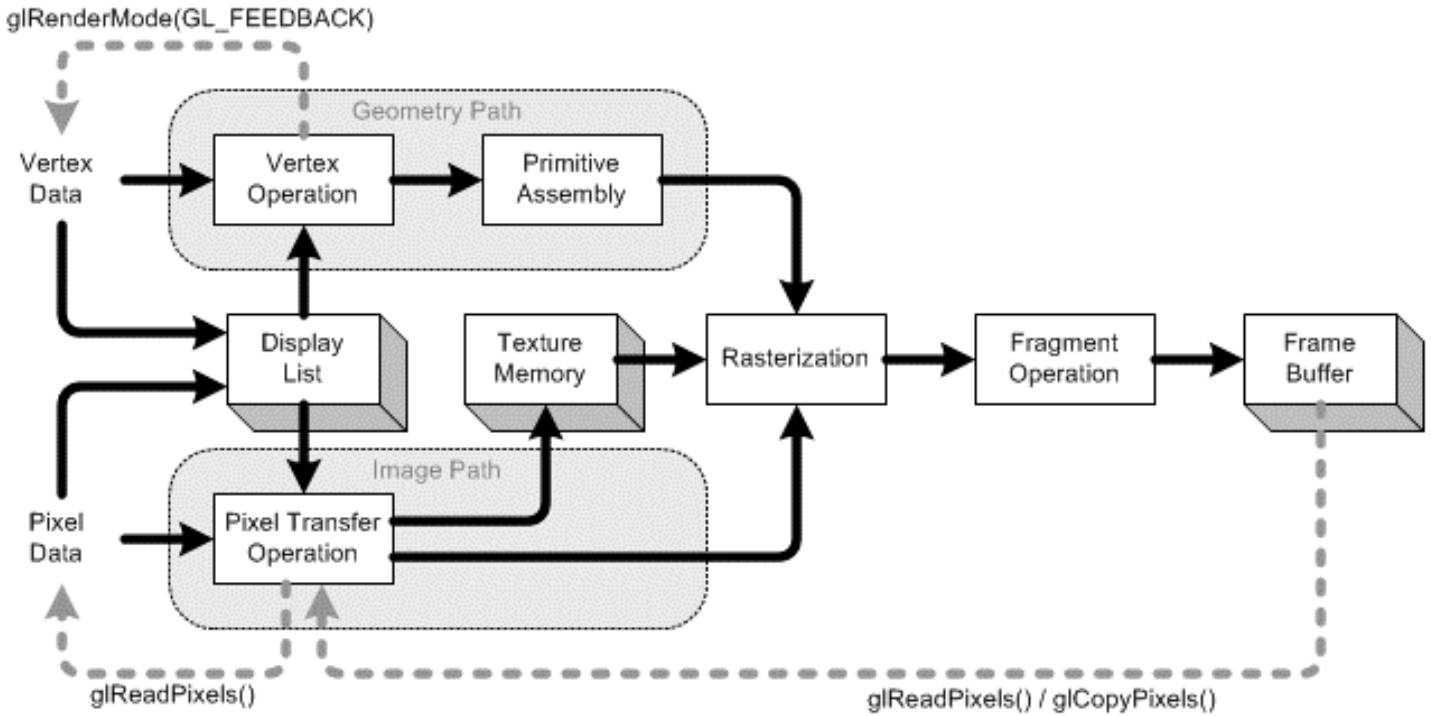
From: Computer Graphics by Professor Daniele Panozzo - NYU

Viewer transformations and rasterization



From: Computer Graphics by Professor Daniele Panozzo - NYU

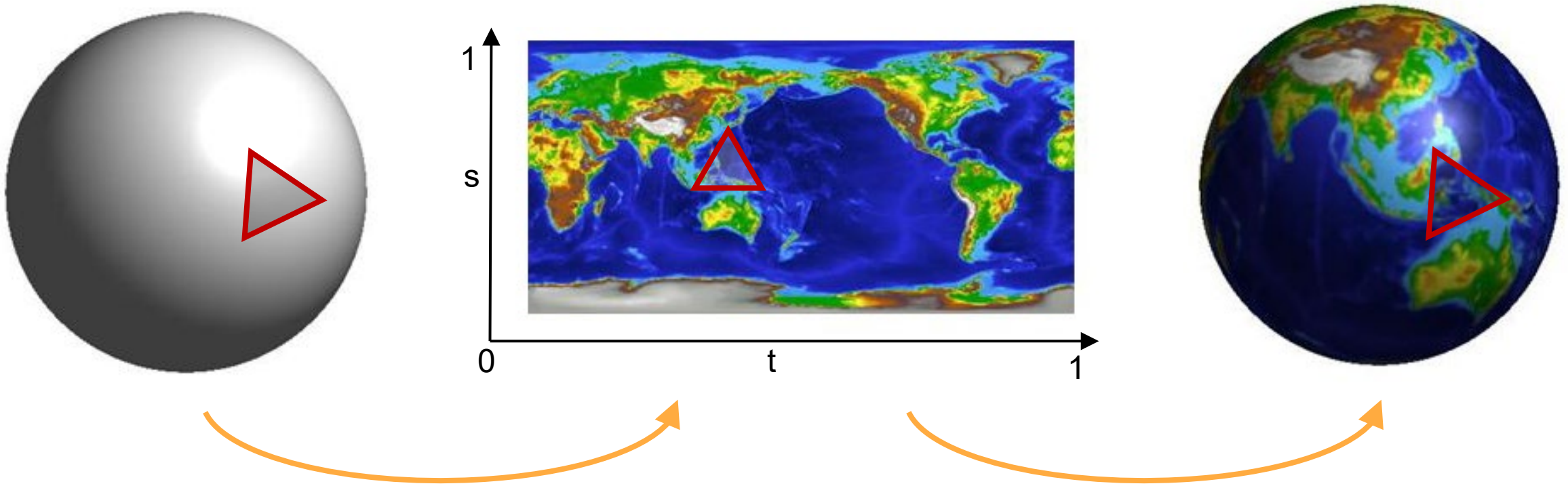
Graphics pipeline



From: songho.ca

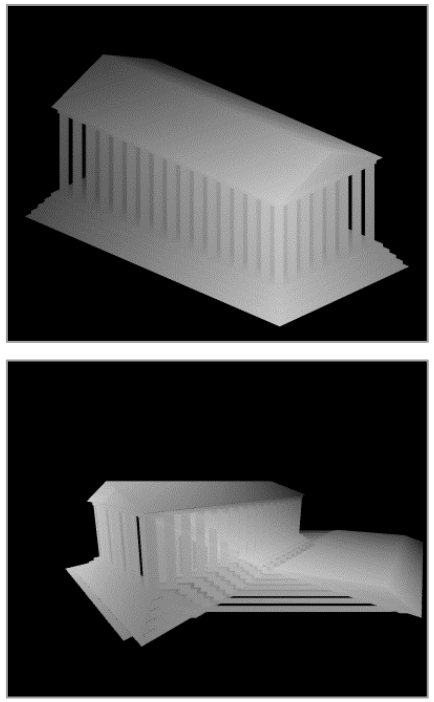
Lighting and shading

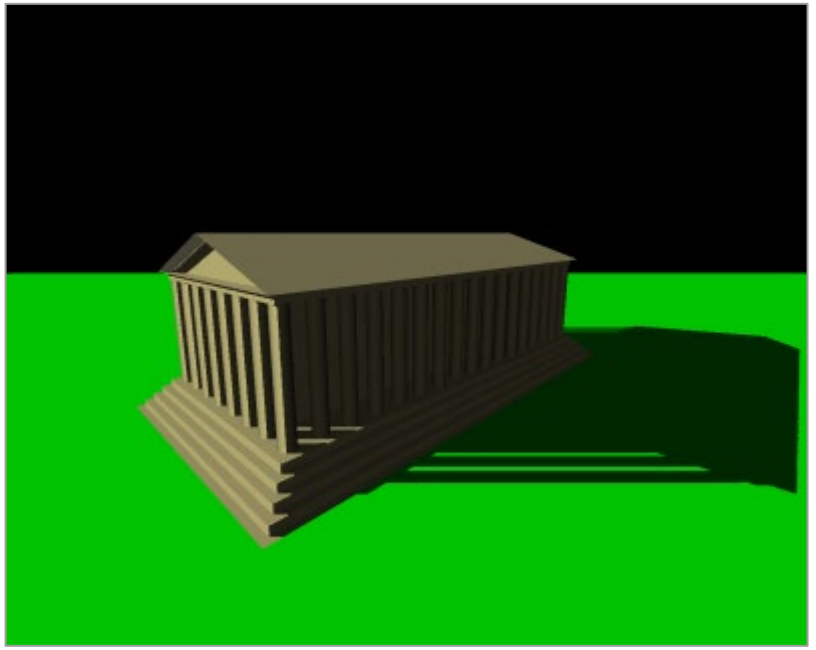
Texture mapping



Build a mapping between the texture and the object

Shadows





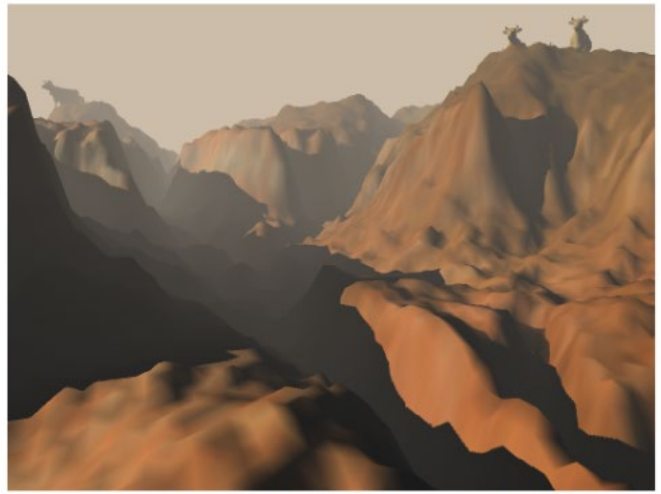


Figure 3-1. Large scale terrain rendering with 4-splits CSM

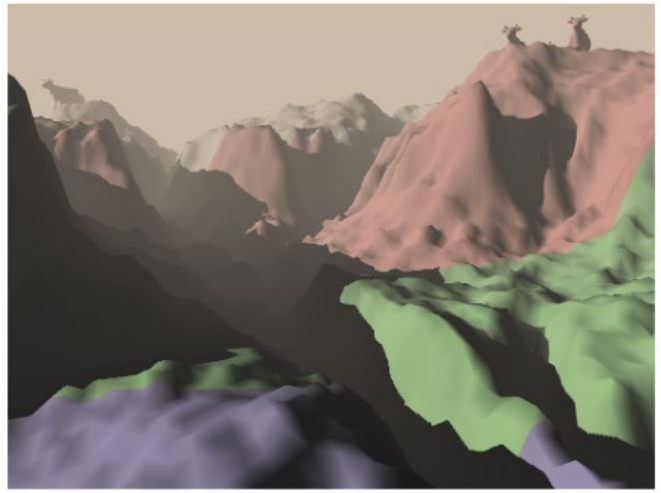
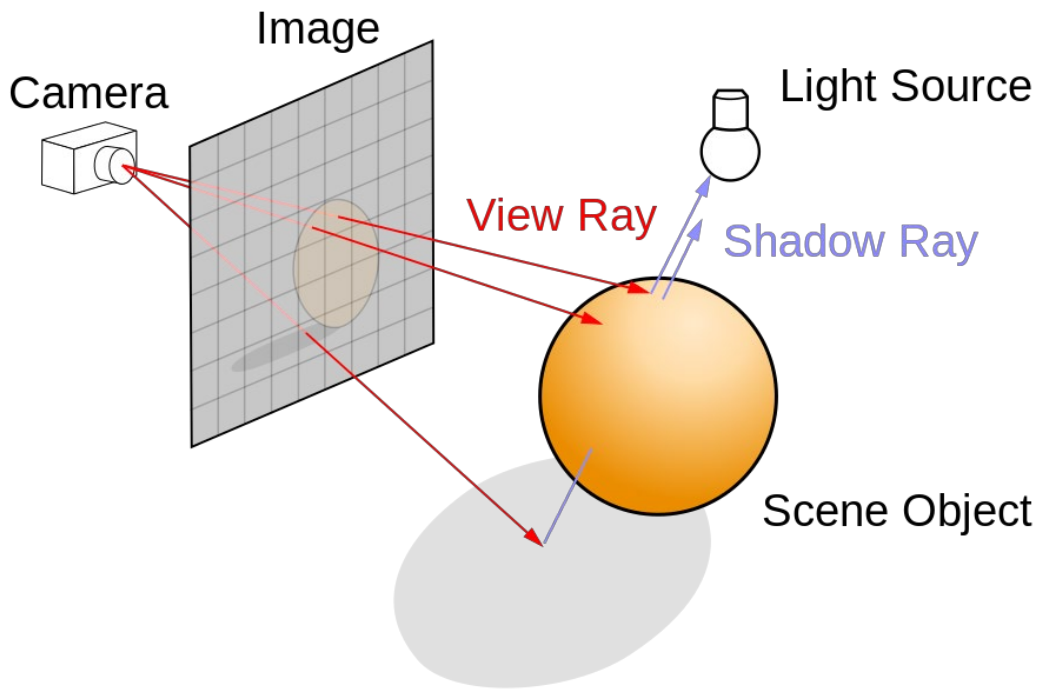
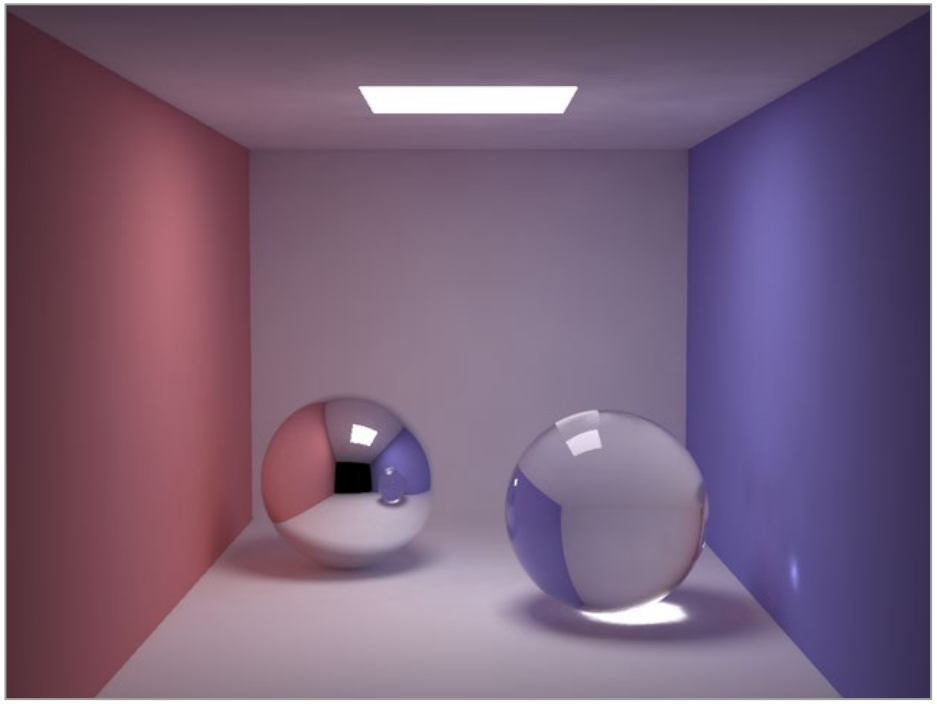


Figure 3-2. Texture look ups from different shadow maps are highlighted

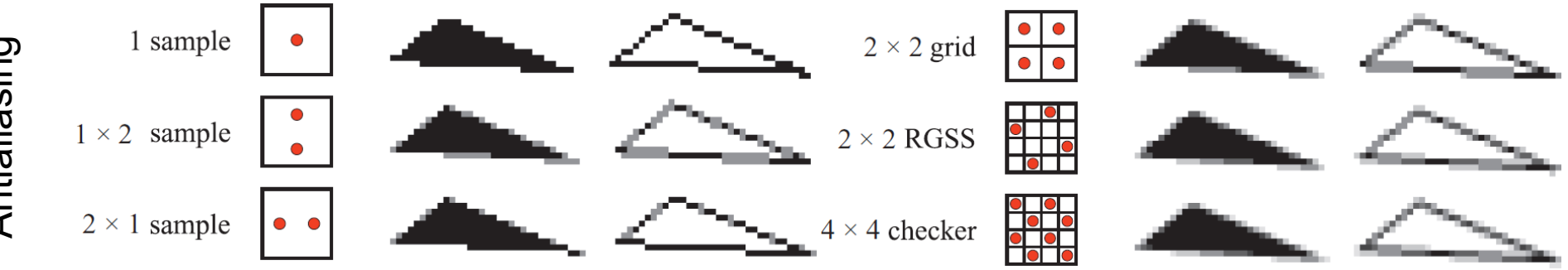
Ray tracing



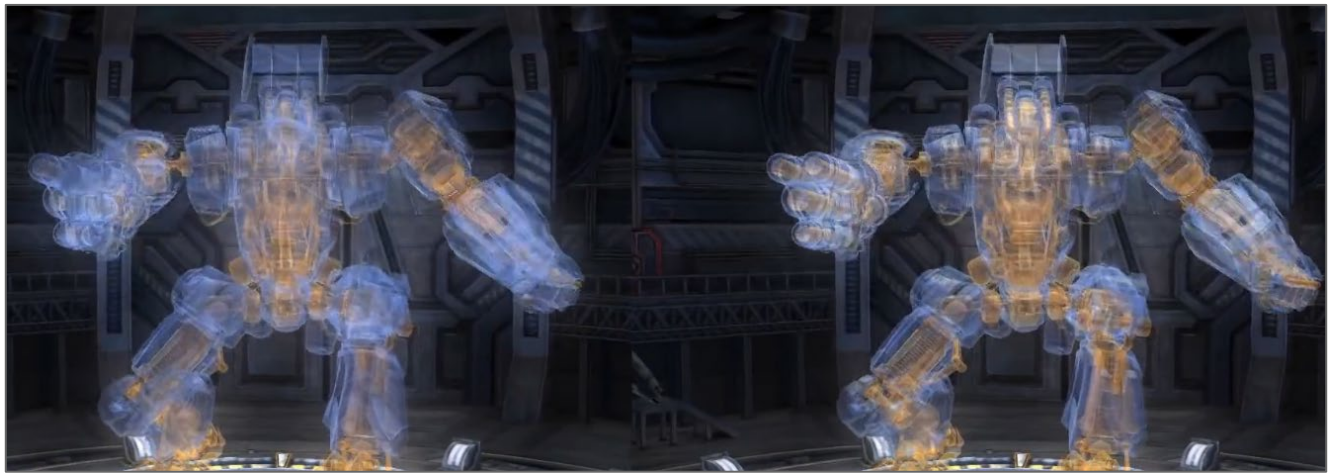


Visual appearance

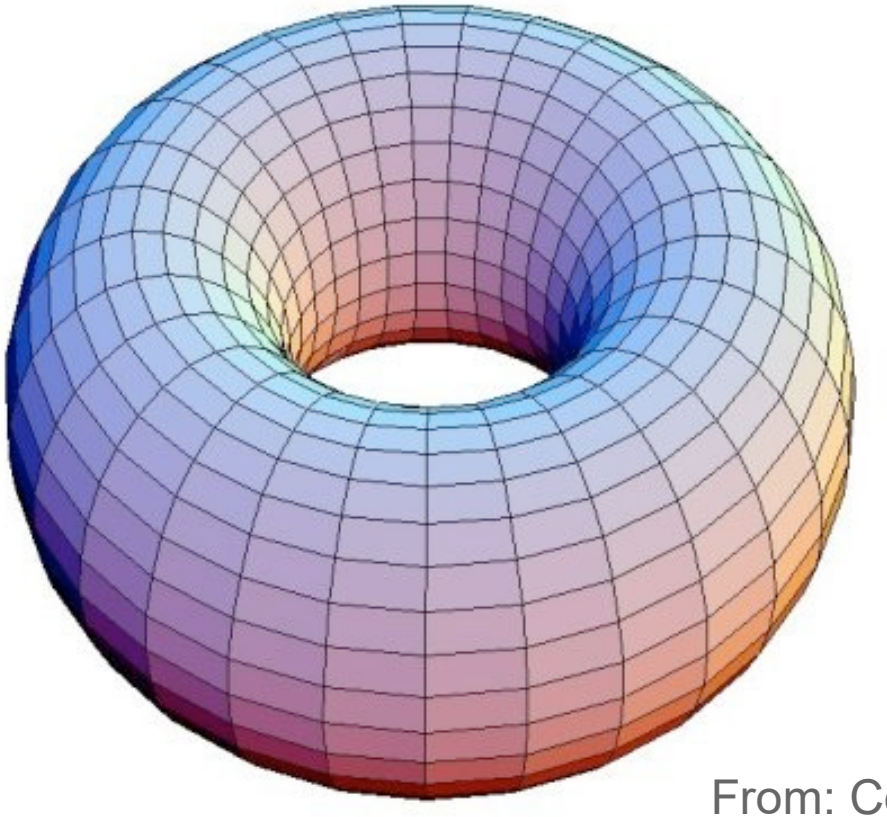
Antialiasing

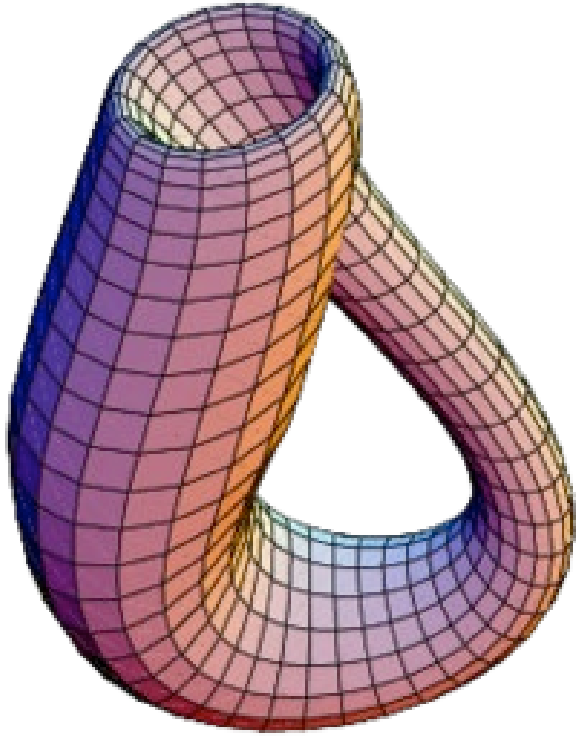


Transparency



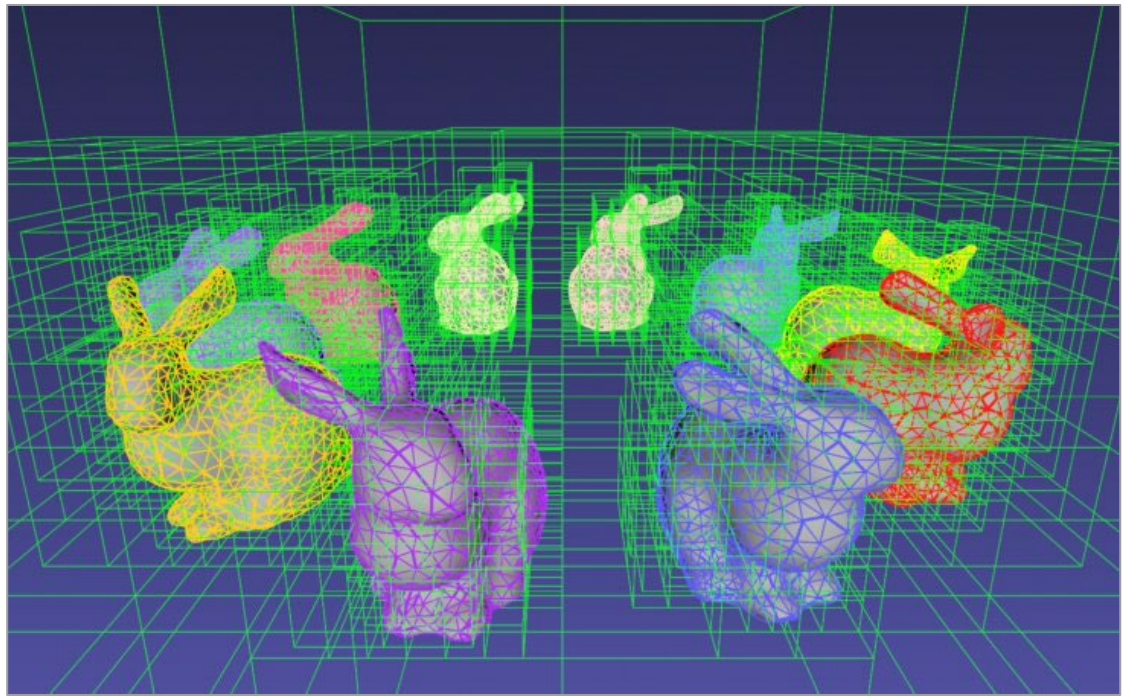
Curves and surfaces

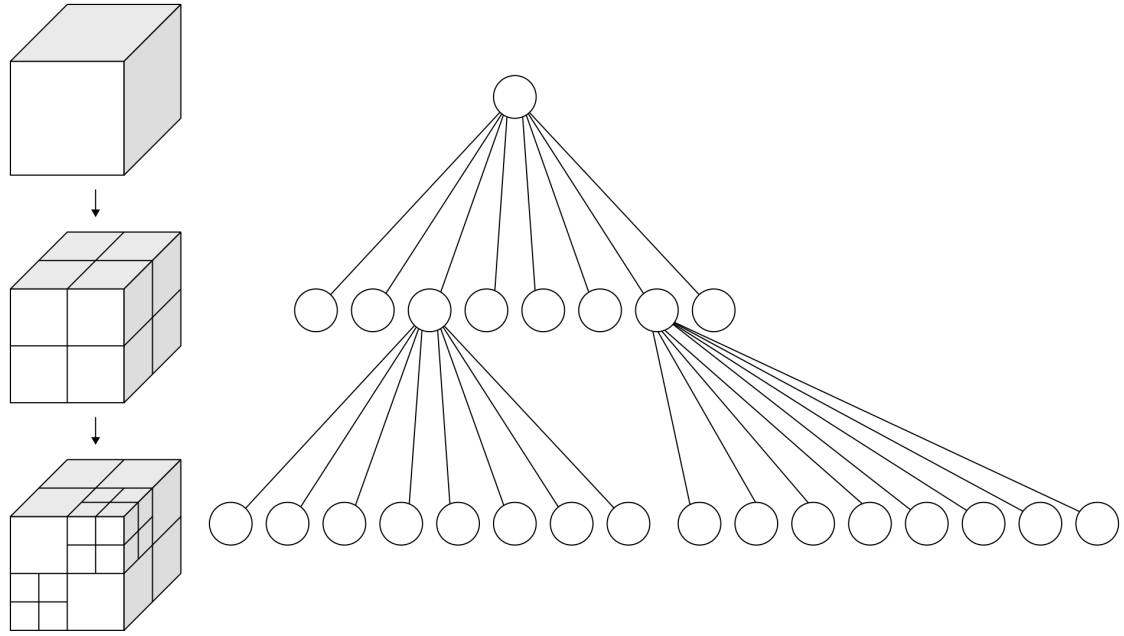




From: Computer Graphics by Professor Daniele Panozzo - NYU

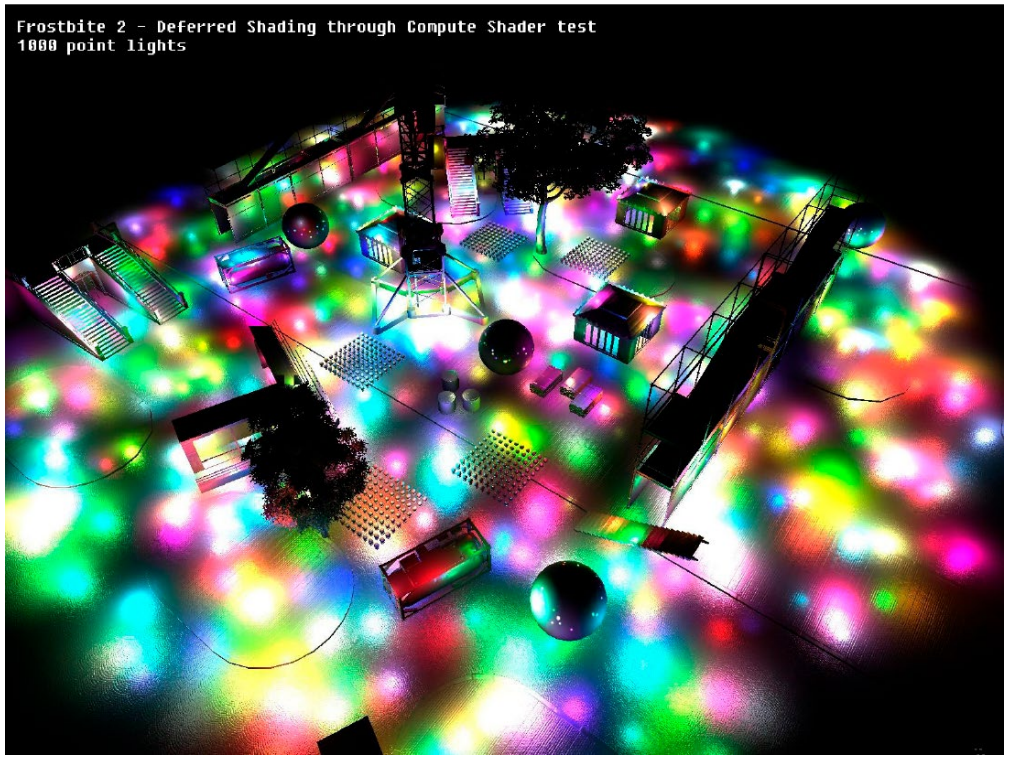
Spatial data structures





Modern rendering techniques

Ambient occlusion

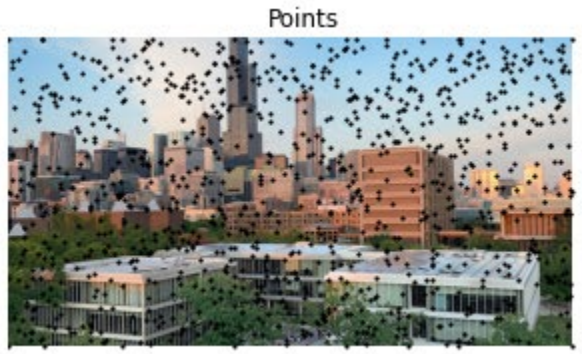


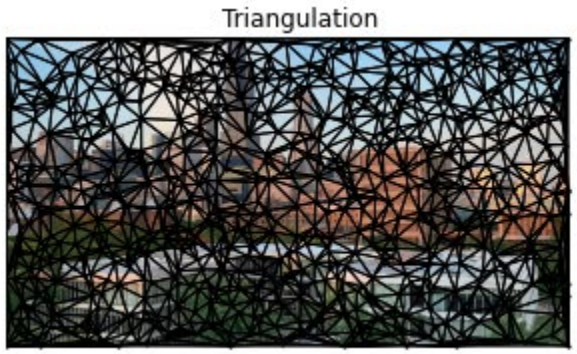
Deferred shading

Assignments

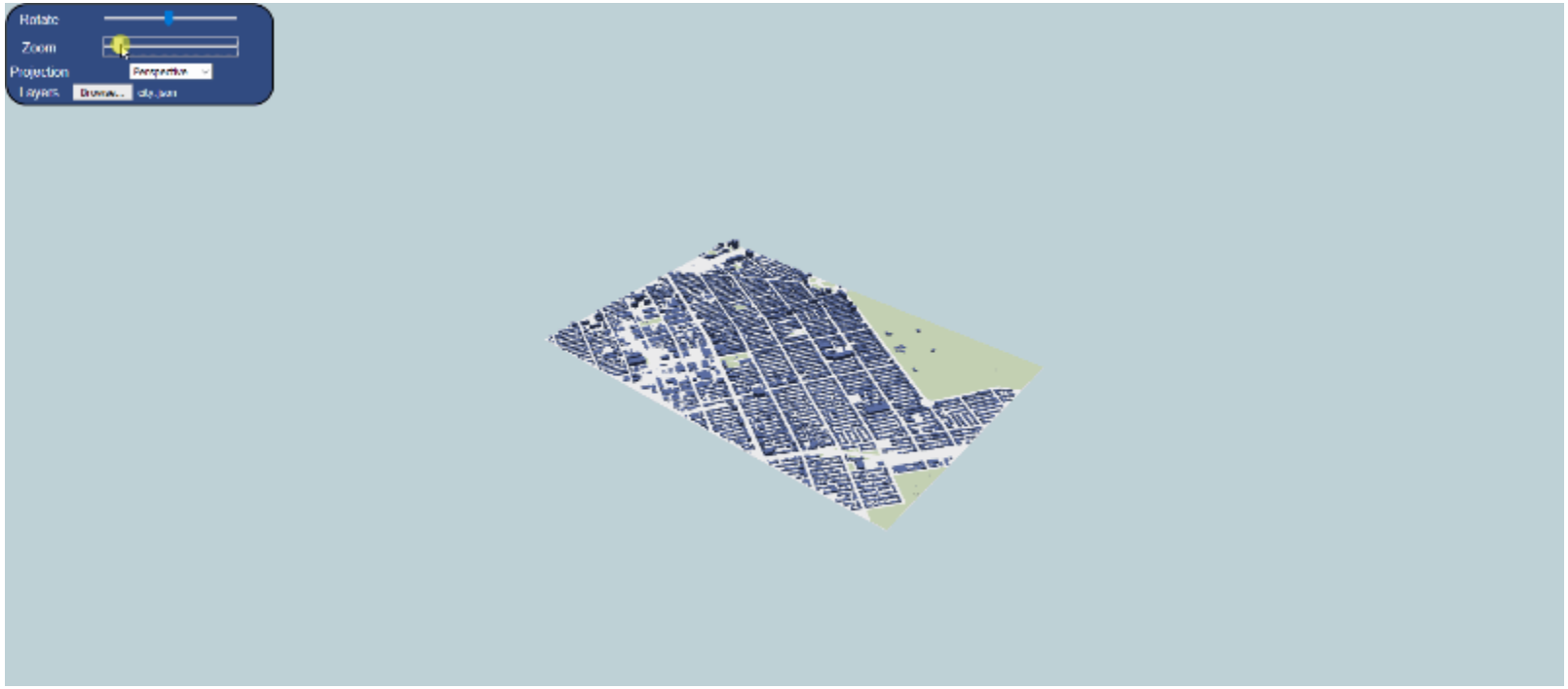
- Assignment 0: WebGL + Web environment
- Assignment 1: Triangle meshes rendering
- Assignment 2: Shading, texture and shadows
- Assignment 3: Ray tracing
- Assignment 4: Procedural meshes

Assignment 0: Intro to JavaScript and WebGL

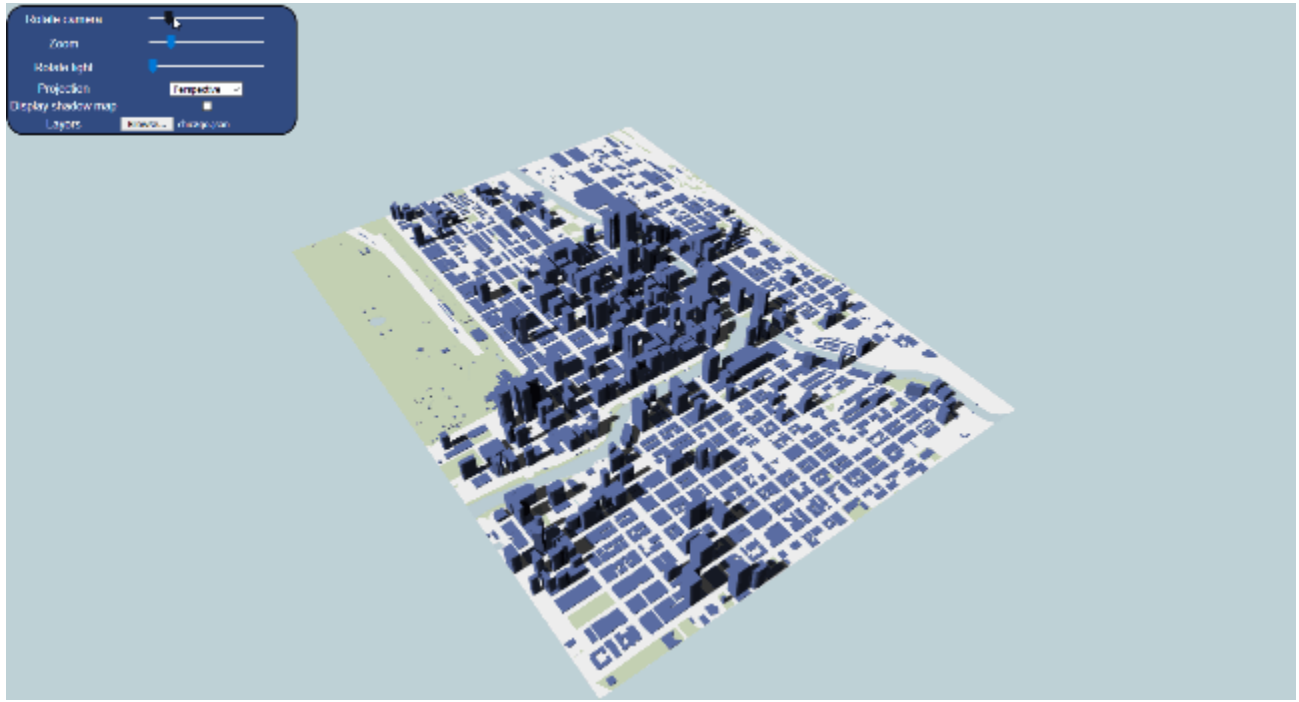




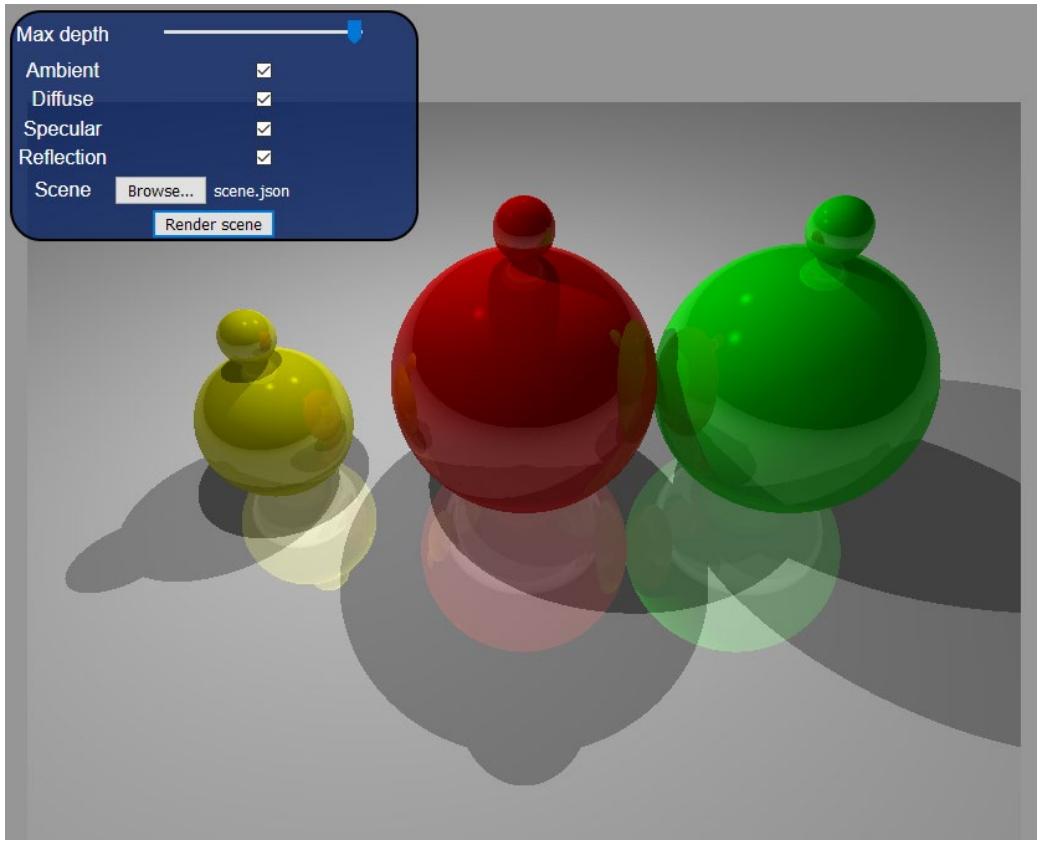
Assignment 1: Triangle meshes rendering



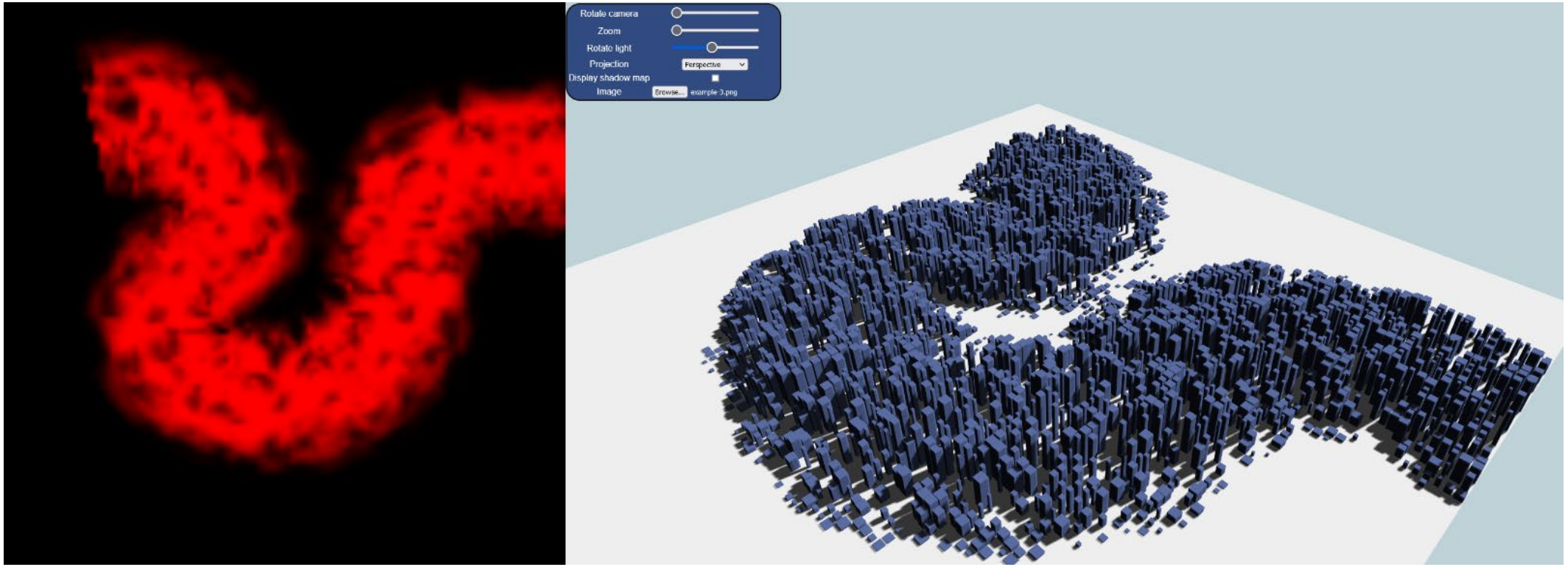
Assignment 2: Shadow maps



Assignment 3: Ray tracing



Assignment 4: Procedural meshes



Assignment considerations

- Create a GitHub project named **cs425-[term]-[year]**
- Inside this project create a folder named **assignment[X]** for each assignment.
- For each assignment you will hand in the following files:
  - index.html: main html file.
  - assignment[x].js: assignment main source code.

Grading

- Check syllabus.

Recommended workflow

Day 0: Read the assignment

Day 1-2: Familiarize yourself with the main topics of the assignment

Day 3-10: Code the different components of the assignment

Day 8-10: Start writing README.md file, make sure code runs on different computers

Day 11-12: Fix problems, double check README.md

Day 13: Submit

Assignment grading

- Example:

Grading

The code will be evaluated on Firefox. Your submission will be graded according to the quality of the image results, interactions, and correctness of the implemented algorithms. Your README.me file will also be graded.

To get a D on the assignment, your application should be able to load a JSON file in the format specified above, and visualize all layers using a perspective projection. To get a C on the assignment, you should implement the shadow map technique for a given light direction. To get a B, you must implement all interactions specified in the configuration panel (camera rotation, light rotation, perspective and orthographic projections). To get an A on the assignment, the application must be able to render the shadow map depth, and have a detailed readme file.

Assignment quizzes

- Assignments will be followed by short in-class quizzes; These quizzes will provide an opportunity for you to demonstrate your understanding of the basic concepts covered in the assignments.
- Assignment grades will be weighted by the scores of these short quizzes.

Assignment policies

- You are encouraged to discuss the assignments with your classmates, but collaboration in the assignment is not allowed.
- You are not allowed to copy code from online sources or use external libraries for any of the assignments (unless clearly specified in the assignment). Do not share implementation details or anything solution-oriented.

Final exam policies

- In-person exam.
- You can bring a one-page two-sided **handwritten** sheet, summarizing the content of the course.