Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

Introduction to Computer Graphics

(Wikipedia)

Beatriz Sousa Santos, Joaquim Madeira **University of Aveiro, 2024**

Topics

- What is Computer Graphics (CG)
- Brief history
- Main applications
- Computer Graphics main tasks
- Simple Graphics system
- CG APIs
- 2D and 3D visualization
- Geometric transformations
- Projections
- Illumination and shading

Computer Graphics

- The technology with which pictures, in the broadest sense of the word, are
  - Captured or generated, and presented
  - Manipulated and / or processed
  - Merged with other, non-graphical application data

- It includes:
  - Integration with other kinds of data – Multimedia
  - Advanced interactive technologies

Computer Graphics

- Computer Graphics deals with all aspects of creating images with a computer
  - Hardware
  - Software
  - Applications

(Angel, 2012)

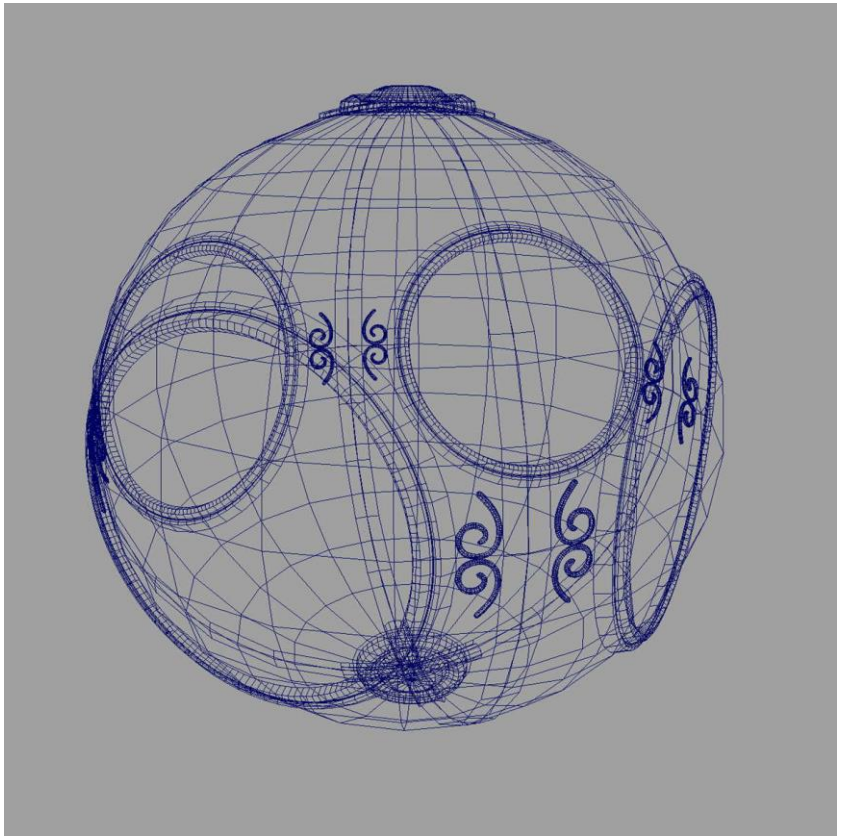
Computer Graphics: 1950 – 1960

- Earliest days of computing
  - Pen plotters
  - Simple calligraphic displays

- Issues
  - Cost of display refresh
  - Slow, unreliable, expensive computers

Computer Graphics: 1960 – 1970

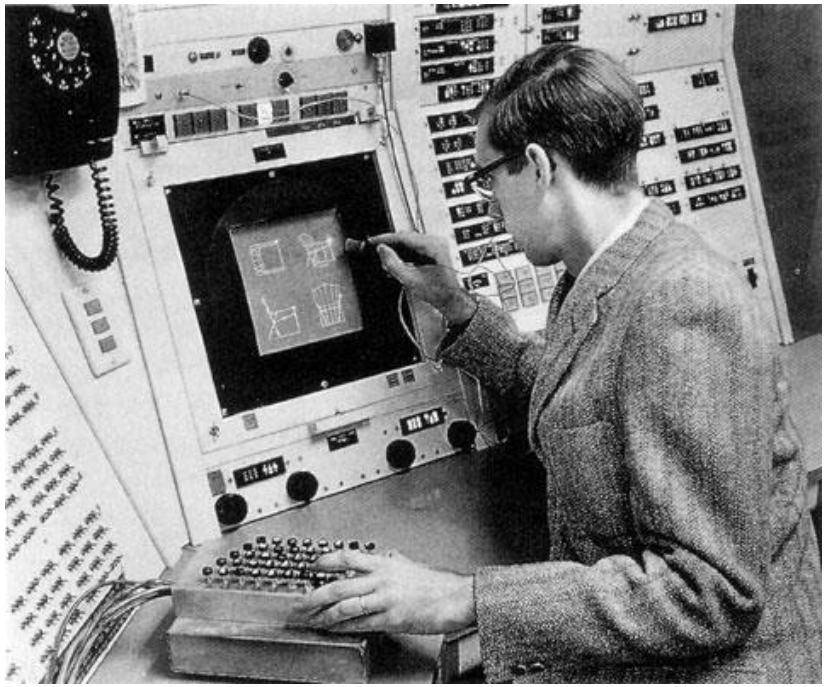
- Wireframe graphics
  - Draw only lines !



(Angel, 2012)

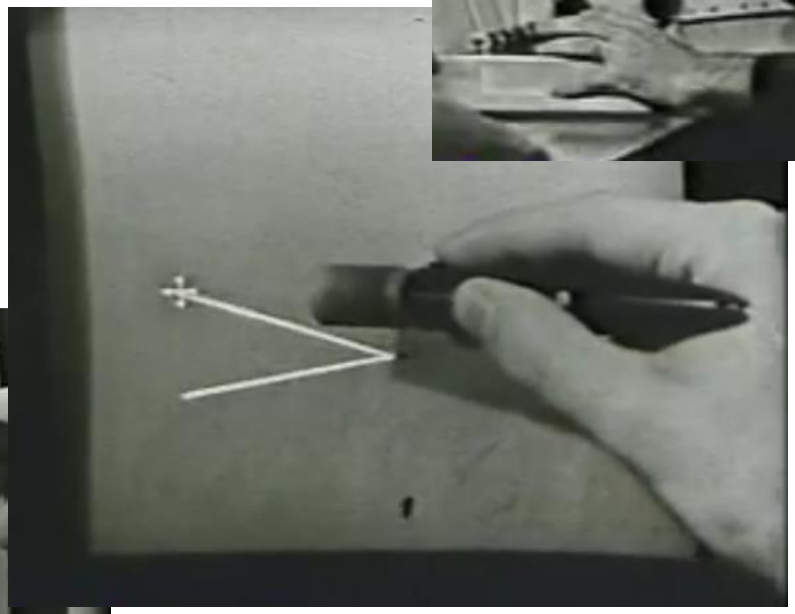
Computer Graphics: 1960 – 1970

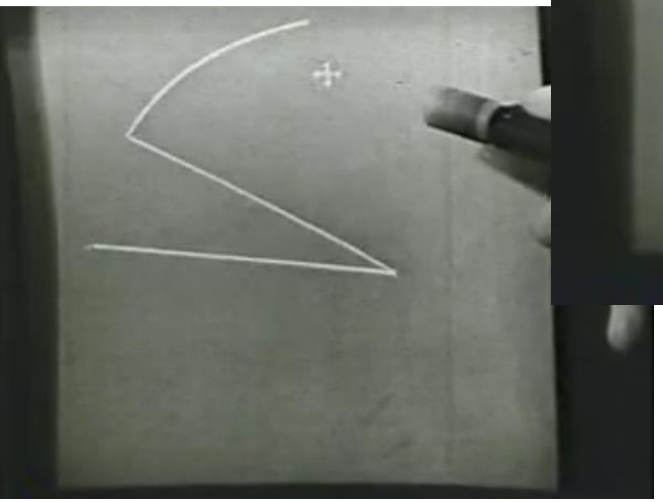
- Ivan Sutherland's Sketchpad
  - PhD thesis at MIT (1963)
  - Man-machine interaction
  - Processing loop
    - Display something
    - Wait for user input
    - Generate new display



https://computerhistory.org/profile/ivan-sutherland/

Sketchpad
(Ivan Sutherland, 1963)





https://www.youtube.com/watch?v=6orsmFndx_

Computer Graphics: 1970 – 1980

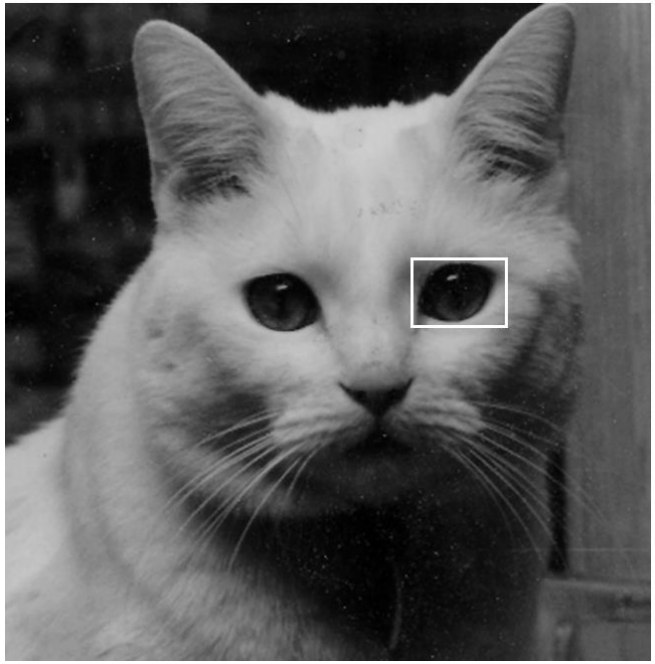
- Raster graphics
  - Allows drawing polygons
- First graphics standards
- Workstations and PCs

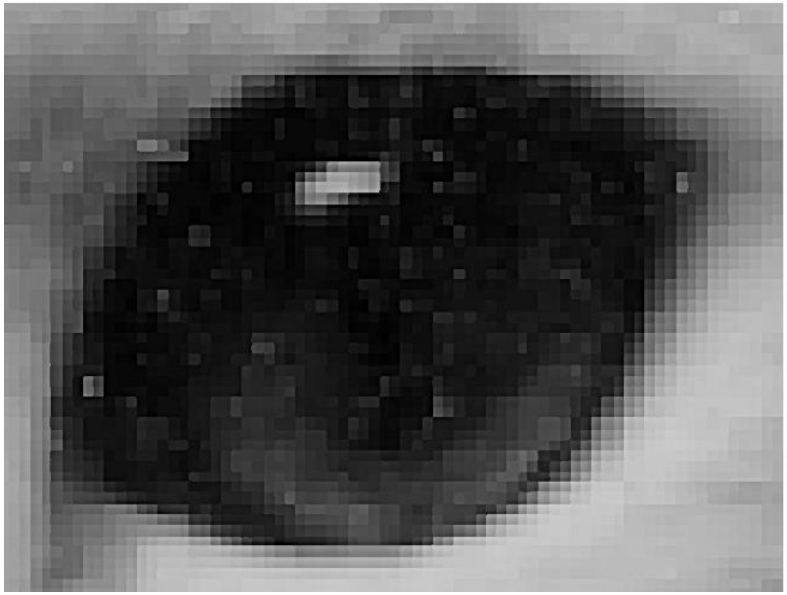
Vector graphics terminal

https://terminals-wiki.org/wiki/index.php/Tektronix_4010

Raster graphics

- Image produced as an array (the raster) of picture elements (pixels) in the frame buffer

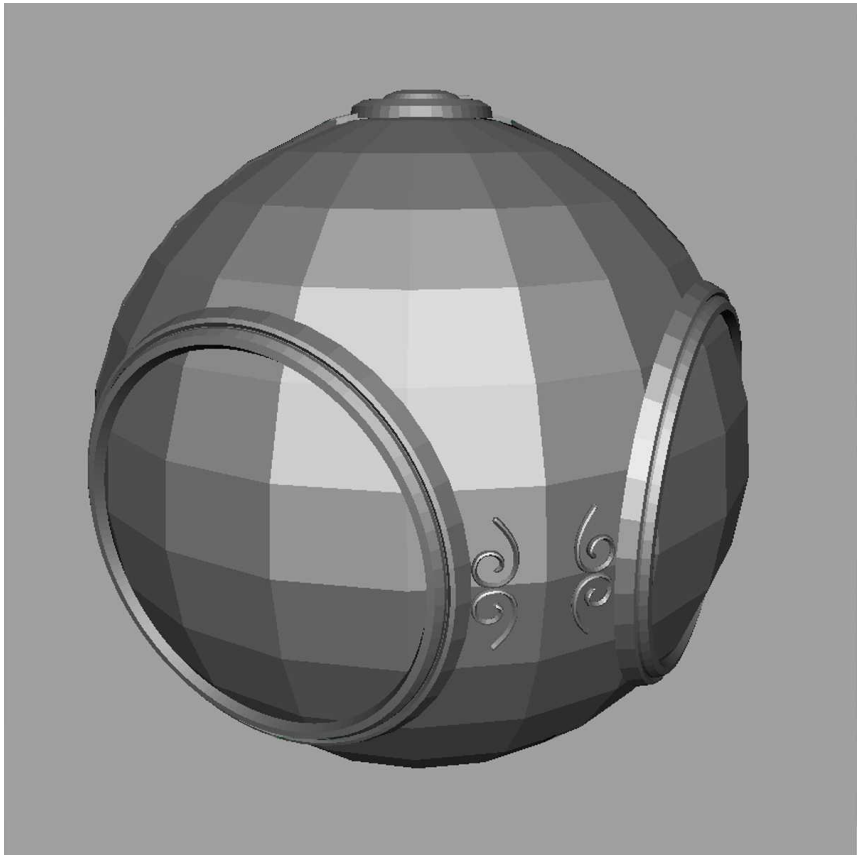




(Angel, 2012)

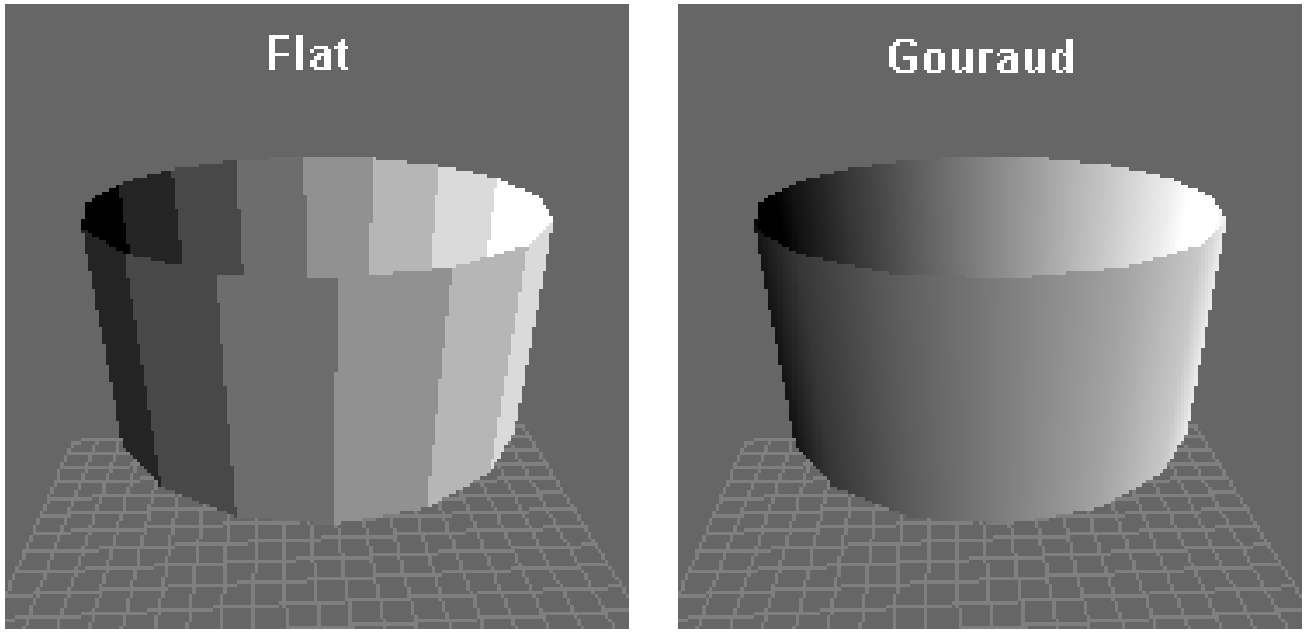
Raster graphics

- Allow higher realism:
- Drawing polygons
- Illumination models
- Shading methods



(Angel, 2012)

Gouraud shading – 1971

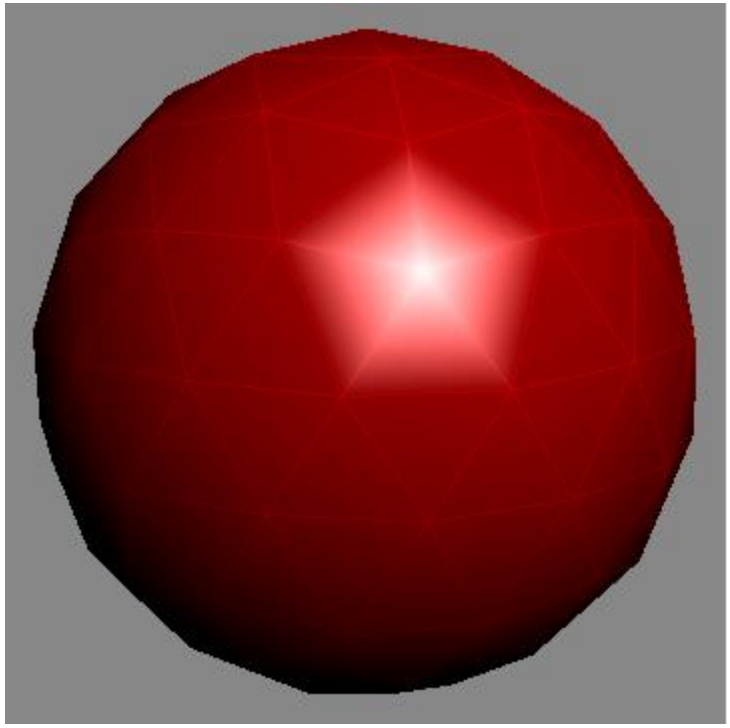


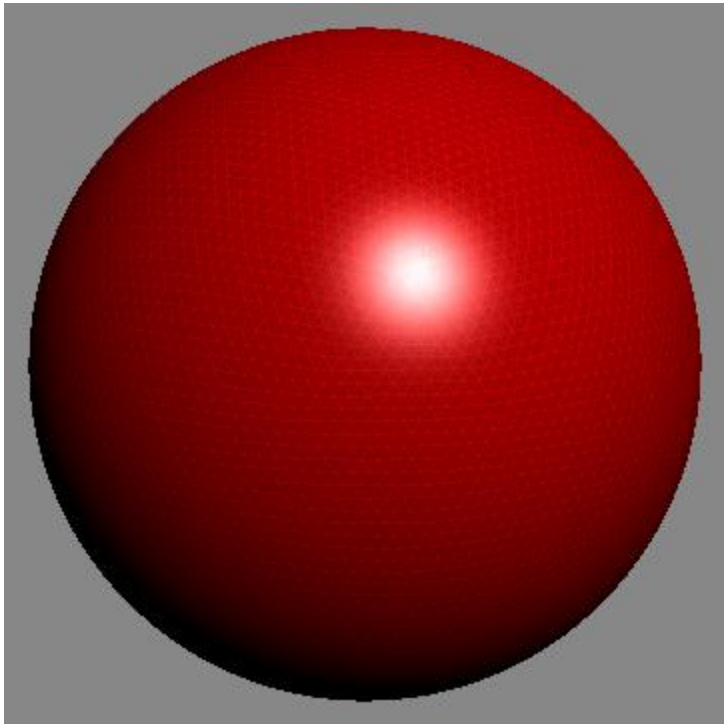
(Wikepedia)

Flat shading – all pixels of a face have the same color (according to the geometry of the polygonal mesh and characteristics of the material and lights)

Gouraud shading – the geometry of neighboring faces is also considered to produce a more continuous representation of surfaces approximated by polygonal meshes

Gouraud shading



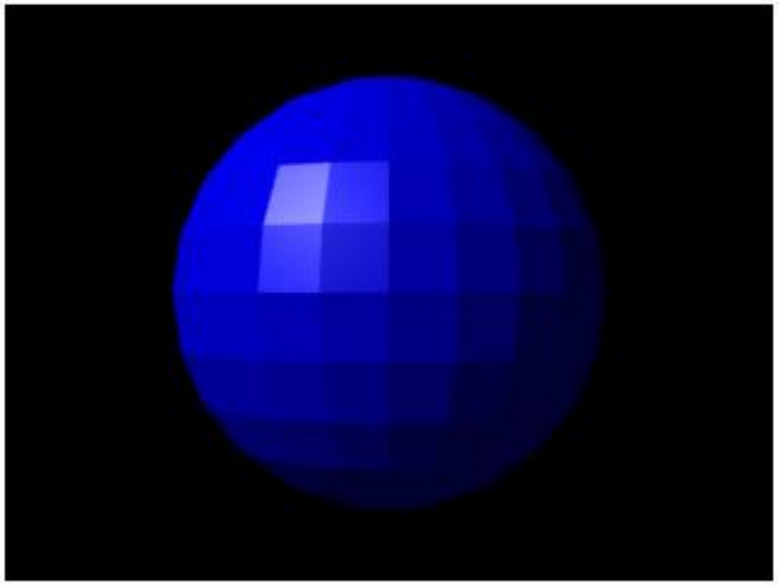


Poor highlight (Wikipedia) Very high polygon count

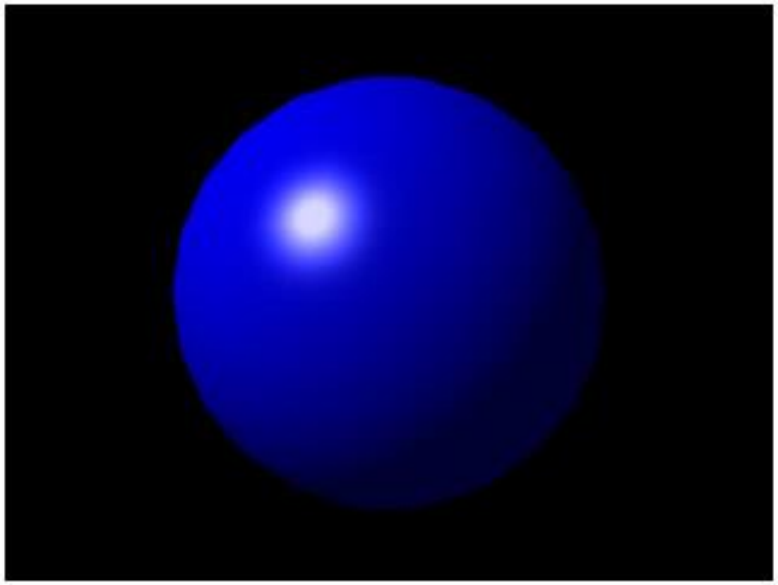
Gouraud shading produces poor quality highlights (specular reflections)

Very high polygon count improves the result, but is not an interesting solution …

Phong shading– 1973



FLAT SHADING



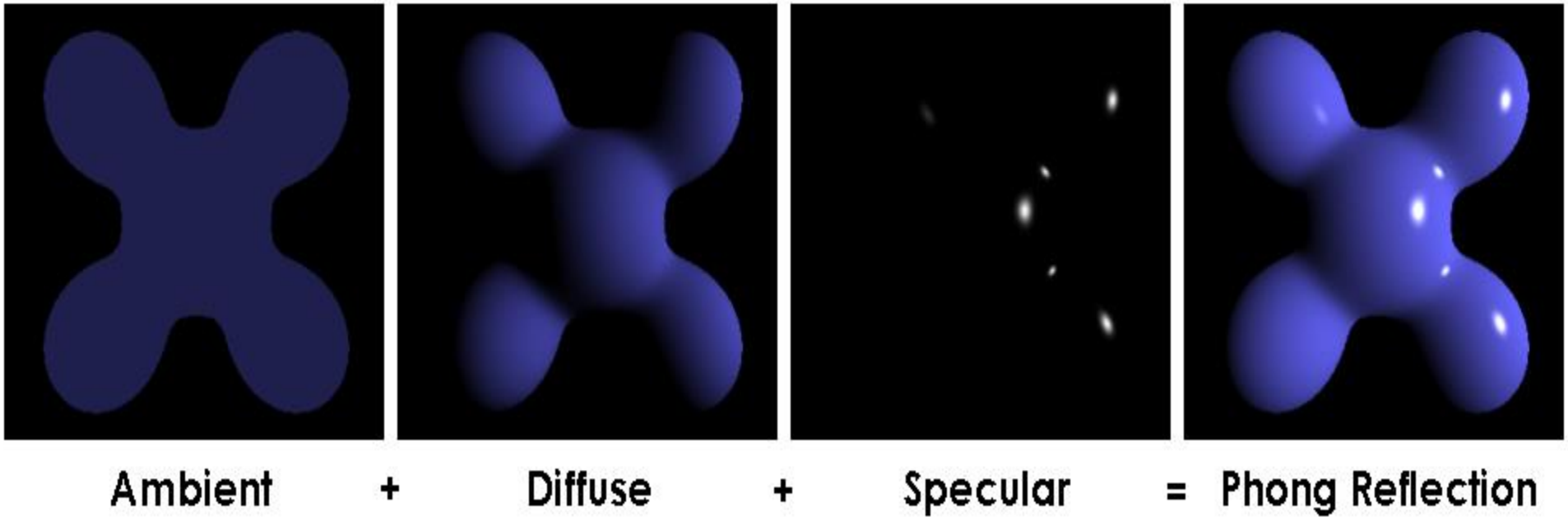
PHONG SHADING

(Wikipedia)

Phong shading produces higher quality highlights (specular reflections)

But is more computing-intensive…

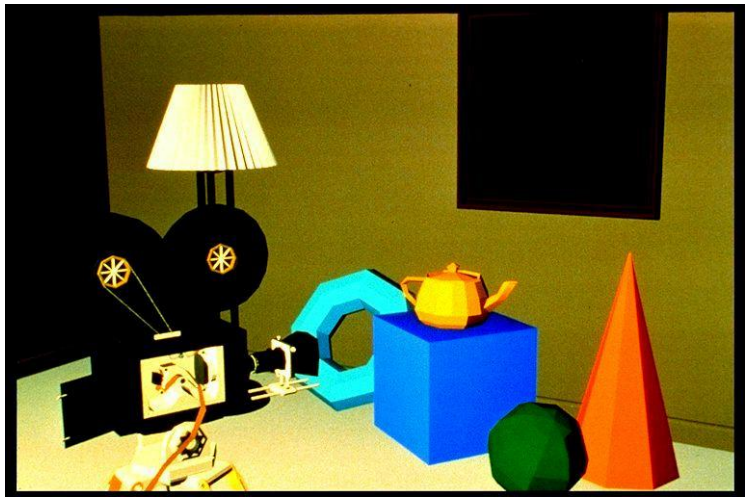
Phong reflection model – 1973

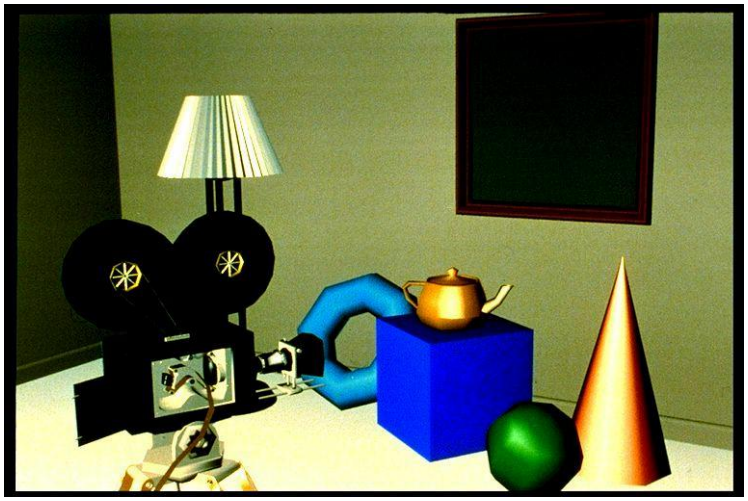


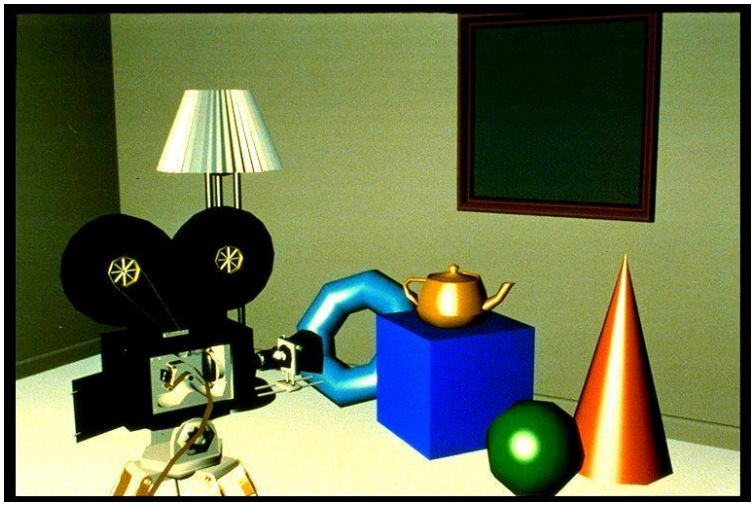
(Wikipedia)

Empirical model of local illumination - describes the way a surface reflects light as a combination of the diffuse reflection of rough surfaces with the specular reflection of shiny surfaces

Can you see the differences ?



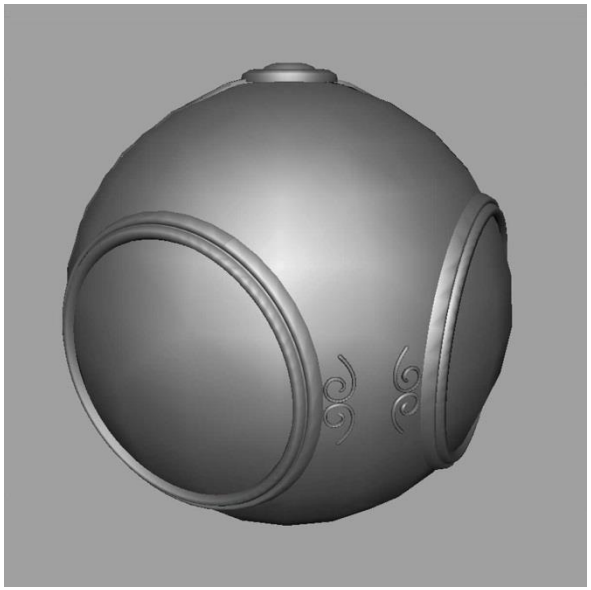




(Foley , Van Dam 1993)

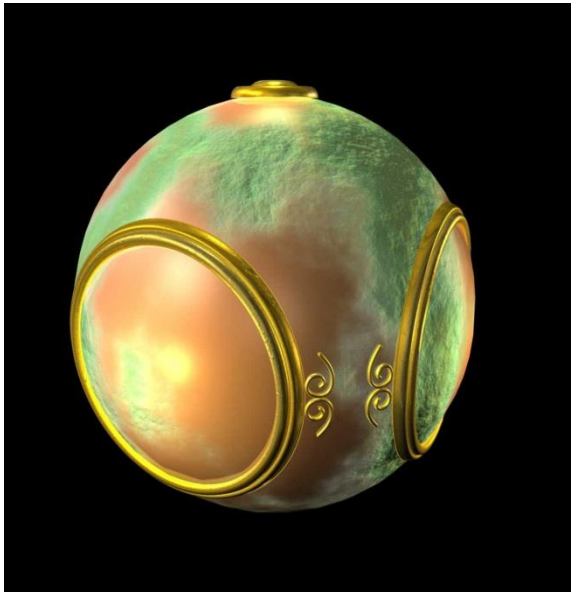
Computer Graphics: 1980 – 1990

- The quest for realism



Smooth shading

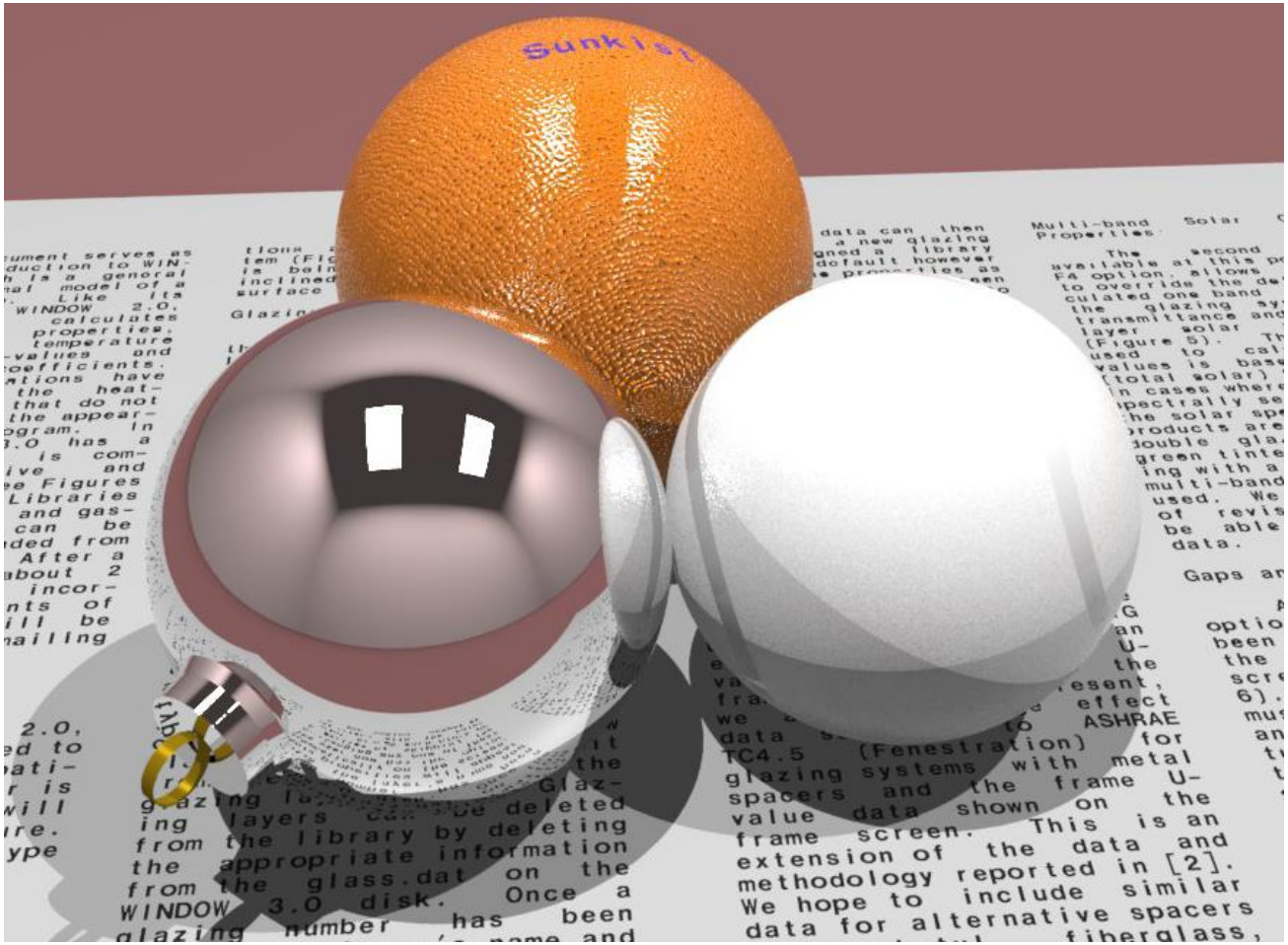
Environment mapping



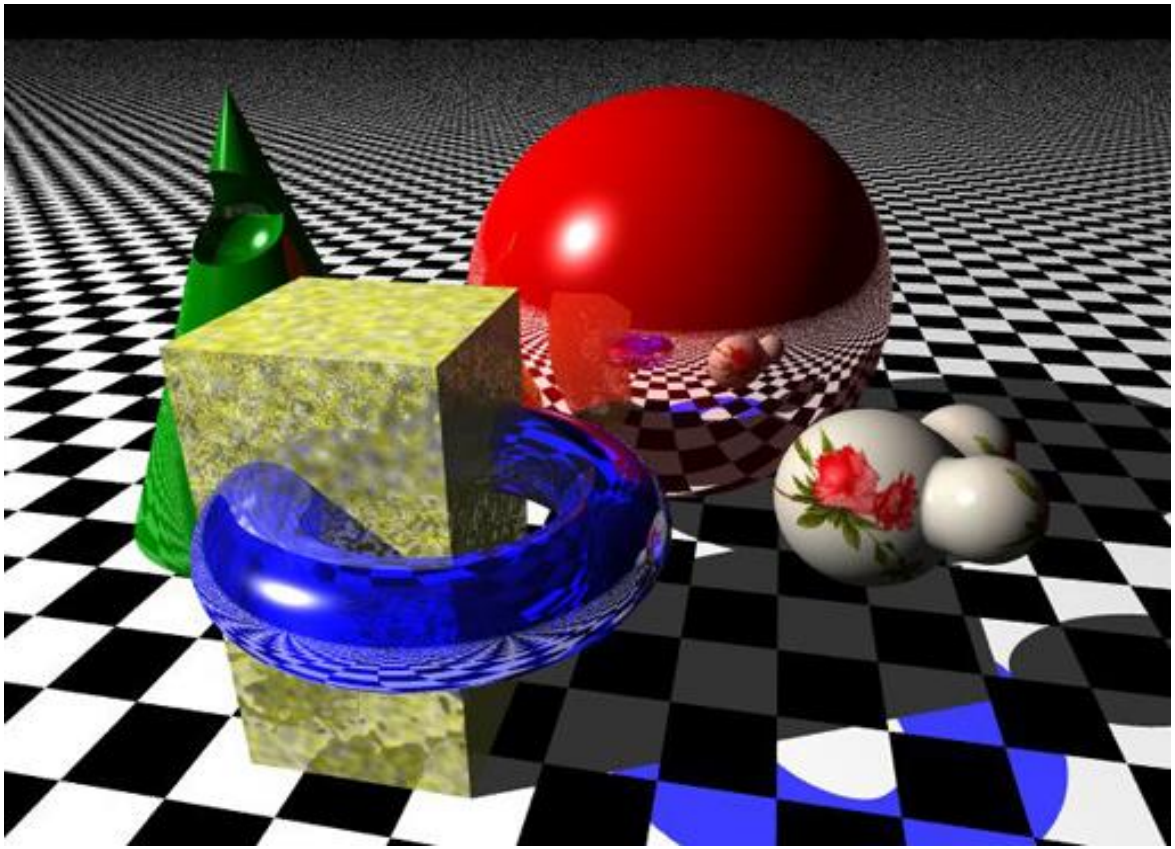
Bump mapping

(Angel, 2012)

Ray-Tracing examples



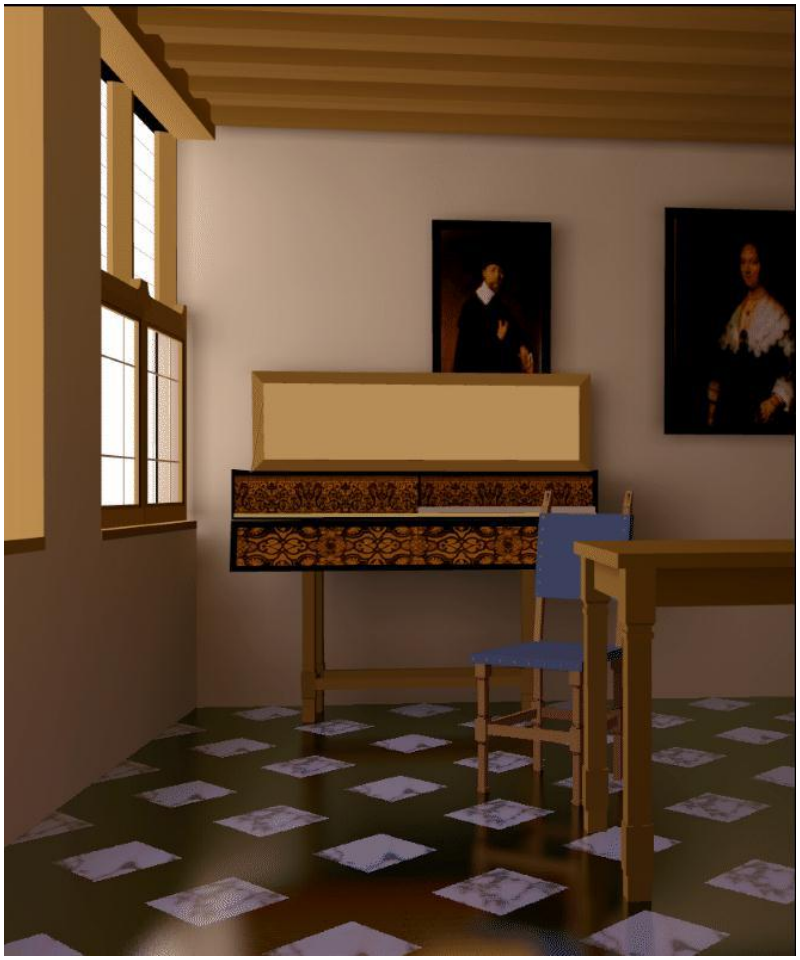
http://radsite.lbl.gov/radiance/book/img/plate10.jpg



http://www.tjhsst.edu/~dhyatt/superap/samplex.jpg

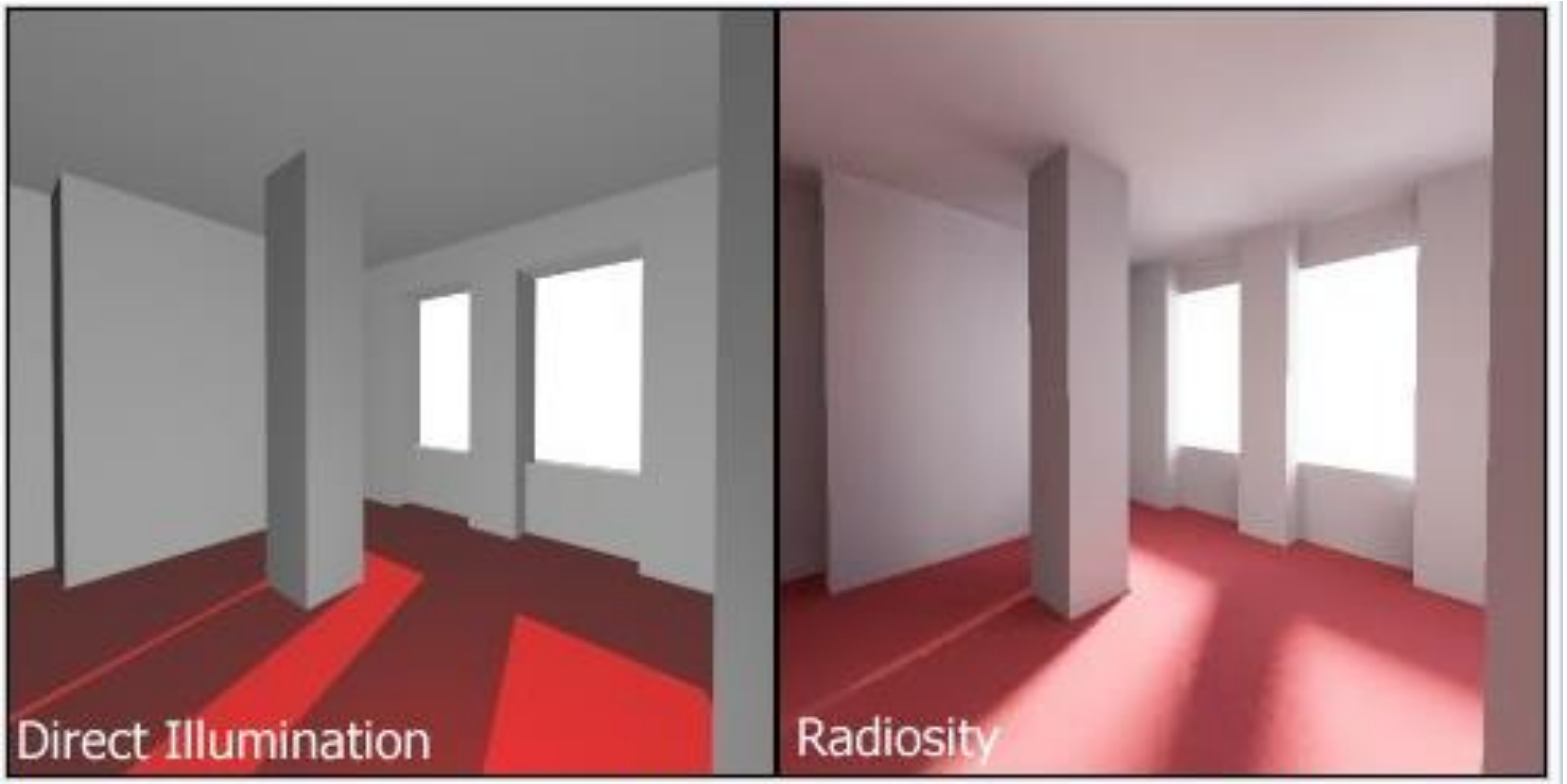
https://en.wikipedia.org/wiki/Ray_tracing_(graphics)

“Vermeer’s Studio”



Wallace & Cohen, 1987: Radiosity and Ray-Tracing

Radiosity



Difference between standard direct illumination without shadow umbra, and radiosity with shadow umbra

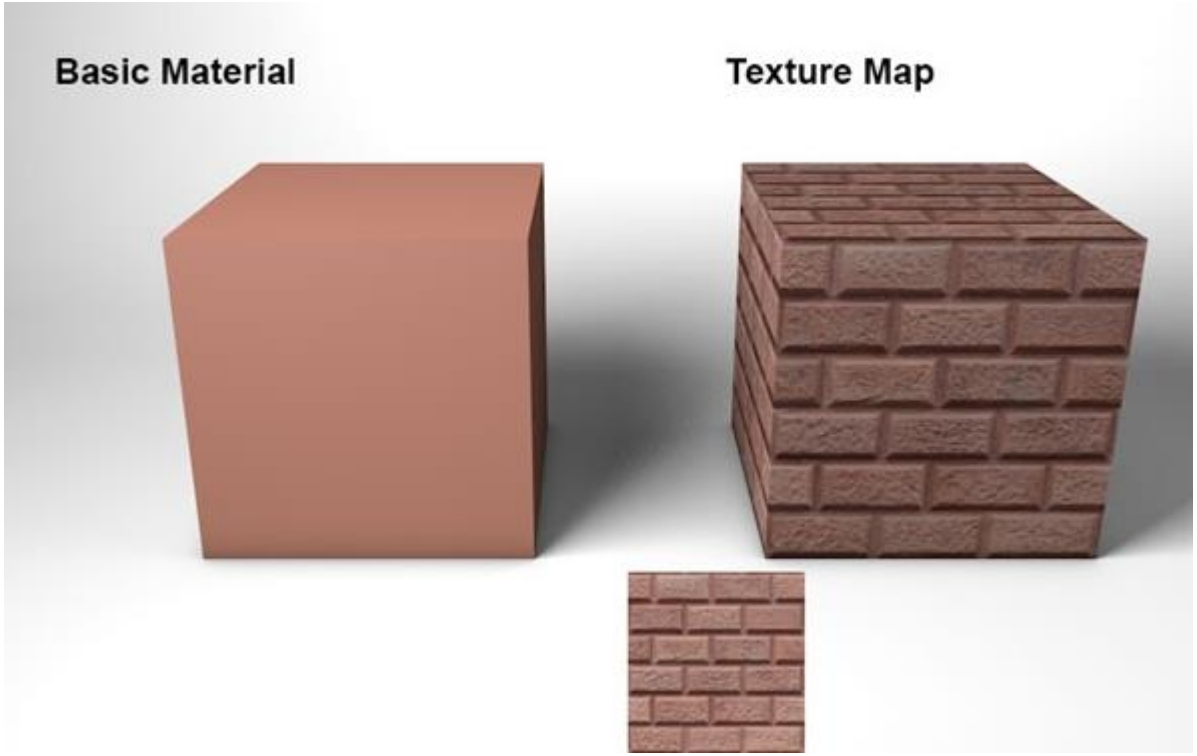
https://en.wikipedia.org/wiki/Radiosity_(computer_graphics)

Radiosity

Without radiosity

With radiosity

Texture mapping



(Angel, 2012)

Computer Graphics: 1980 – 1990

- Special purpose hardware
- Industry-based standards
  - PHIGS
  - RenderMan (https://renderman.pixar.com/)
- Human-Computer Interaction

Luxo Jr. - 1986

https://www.youtube.com/watch?v=6G3O60o5U7w

(Wikipedia)

Computer Graphics: 1990 – 2000

- OpenGL - cross-language, multi-platform API

- Typically used to interact with a graphics processing unit (GPU)

- Managed by the Khronos Group

- First successful computer-generated feature
  - length animation film: Toy Story

https://www.khronos.org/opengl/

Original author(s)	Silicon Graphics
Developer(s)	formerly: ARB now: Khronos Group
Initial release	January 1992
Stable release	4.6 / 2017
Written in	C[1]
Operating system	Cross-platform
Platform	Cross-platform
Type	API
License	Various[2]
Website	www.opengl.org

Computer Graphics: 2000 – …

- Photorealism
- Graphics cards for PCs dominate the market
  - Nvidia
  - AMD
- Game boxes / players determine the market
- CG is routine in the film industry (XFs and animation)

Oscar winner 2017- Piper

https://renderman.pixar.com/stories
https://www.youtube.com/watch?v=3MxxvMUnsY4

To know interesting new developments in CG:

- Conferences:

  SIGGRAPH, Eurographics, Pacific Graphics

and other smaller conferences

- Journals:

  ACM Transactions on Graphics

  Computer Graphics Forum

  Computers and Graphics

  IEEE Computer Graphics and Applications

  IEEE Transactions on Visualization and Computer Graphics

  The Visual Computer

  …

CG – Application areas

- Entertainment
  - Computer games
  - Animation films
  - Special effects
- Engineering / Architecture
  - Computer-Aided Design (CAD)
  - Data and Information Visualization
  - Simulators (XR)
- Medicine
  - Visualization
  - Simulators
- …

Games – *Lara Croft*

1996

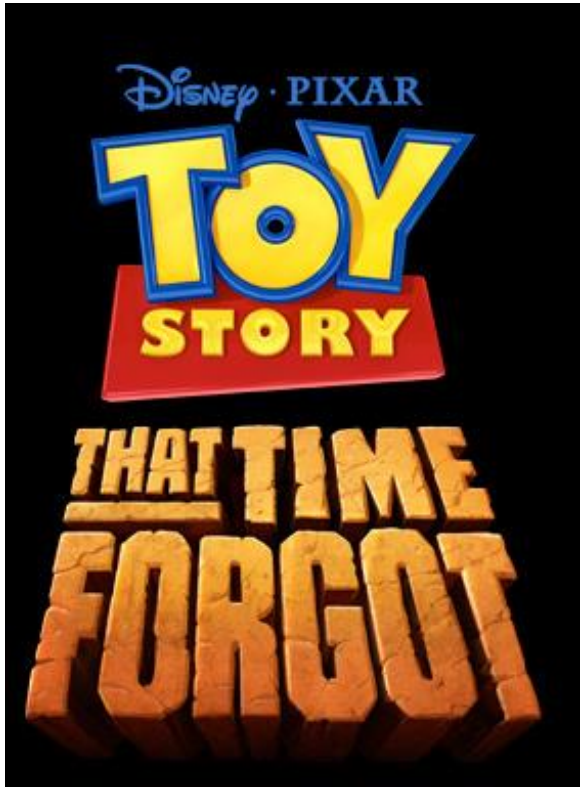
2013

2018

(Wikipedia)

Animation films – *Pixar*

Toy Story – 1995



Toy Story – 2014

Lightyear – 2022

www.pixar.com

Special effects – *ILM*

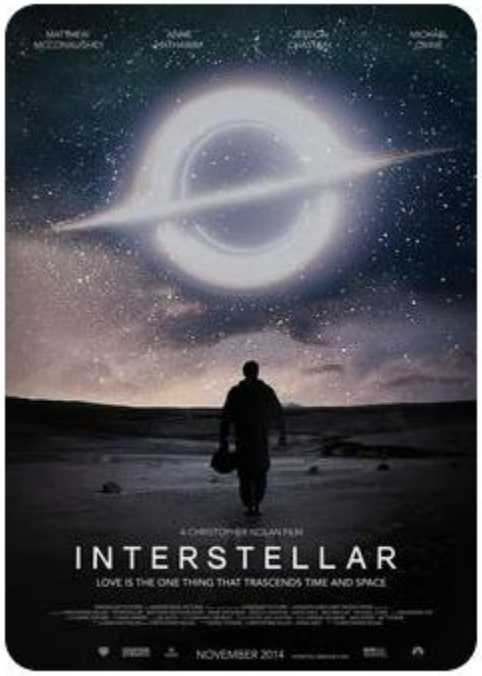
2005

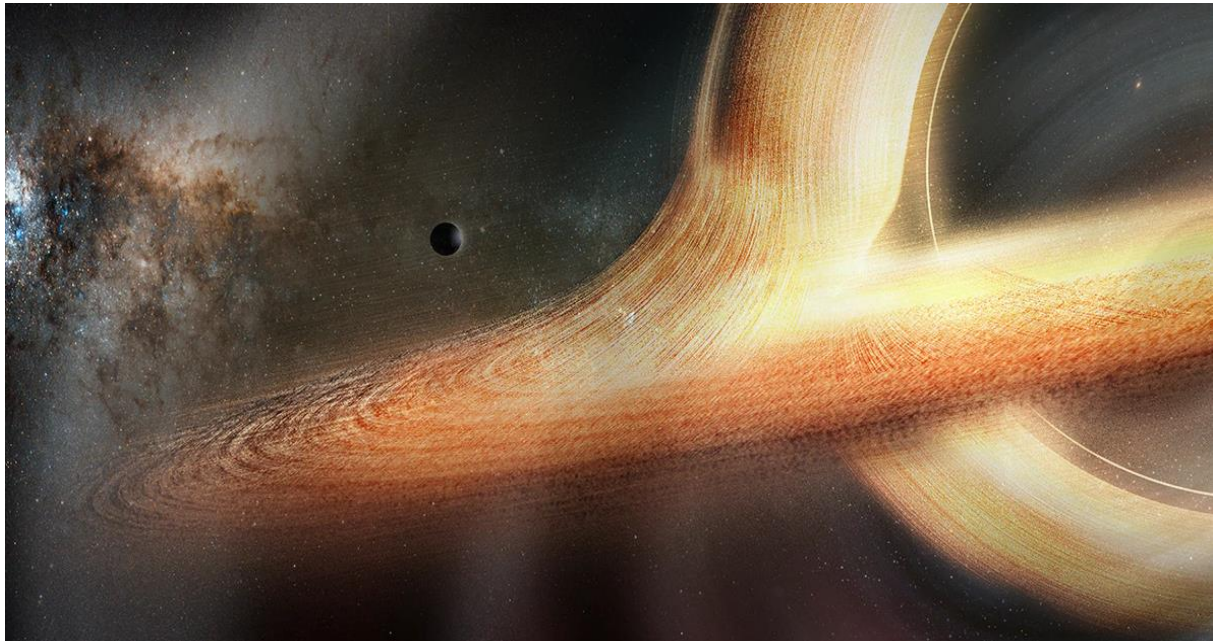
2009

[Wikipedia]

2015

Bridging art and science





Best visual effects 2015

https://www.siggraph.org/news/the-visual-effects-of-interstellar-bridging-art-and-science/
https://www.screendaily.com/awards/the-vfx-of-interstellar/5082127.article

Improving the method to higher performance:

A. Verbraeck and E. Eisemann, "Interactive Black-Hole Visualization“, *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, no. 2, pp. 796-805, Feb. 2021, doi: 10.1109/TVCG.2020.3030452.

CAD – Simulation

https://www.autodesk.com/solutions/cad-design

Augmented Reality

http://www.youtube.com/watch?v=Ag7H4YScqZs

Virtual Reality – examples
Industry

VR at McLaren

https://www.youtube.com/watch?v=mWaQfjEJIMQ

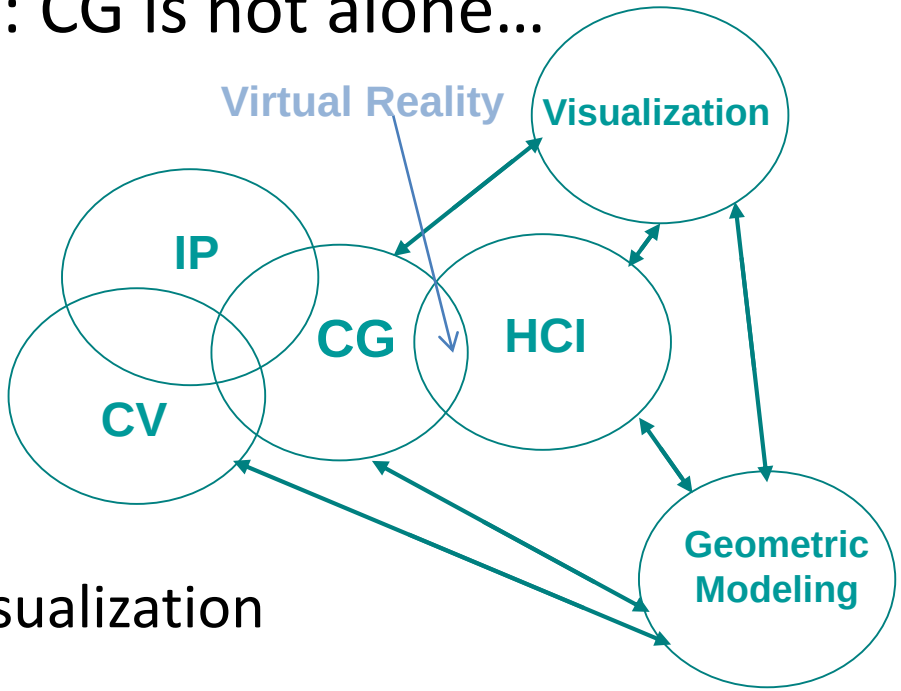
Entertainment- Virtual reality

Oculus Rift
2014; ~300 USD
Oculus Quest 3
2024 ~ 500 USD

http://www.oculusvr.com/

http://www.youtube.com/watch?v=N8uuDT5AYts

Visual Computing: CG is not alone…



- Core areas:
  - CG, IP, CV and HCI
- Satellite areas:
  - Geometric Modeling
  - Data and Information Visualization
  - Extended Reality

- What is common?
  - CG, IP : image file formats, color models, …
  - CG, CV : 3D model representations, …
  - IP, CV : noise removal, filters, …

Example – Medical Imaging

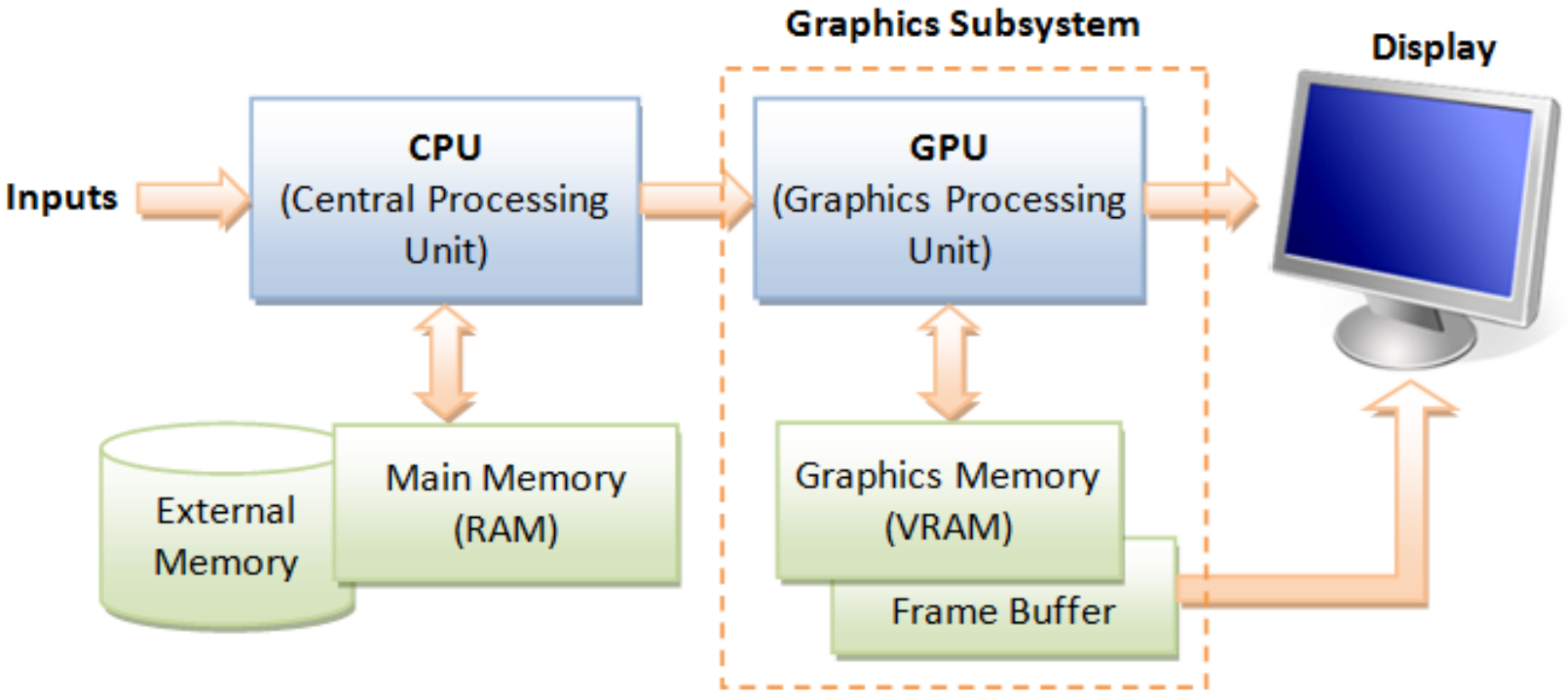
- Processing pipeline
  - Noise removal
  - Segmentation
  - Generating 2D / 3D models
  - Data visualization
  - User interaction
  - …

https://www.mevislab.de/]

CG Main Tasks

- Modeling
  - Construct individual models / objects
  - Assemble them into a 2D or 3D scene
- Rendering
  - Generate final images
  - Where is the observer?
  - How is he / she looking at the scene?
- Animation
  - Static vs. dynamic scenes
  - Movement and / or deformation

Basic Graphics System



Computer Graphics APIs

- Create 2D / 3D scenes from simple primitives
- OpenGL and variants …
  - Rendering
  - No modeling or interaction facilities
- Direct 3D – Microsoft
- VTK
  - 3D CG + Image processing + Visualization
- Three.js
- Vulkan …

OpenGL

- Multi-platform API for rendering
  2D and 3D computer graphics

- Interaction with the GPU to achieve hardware-accelerated rendering

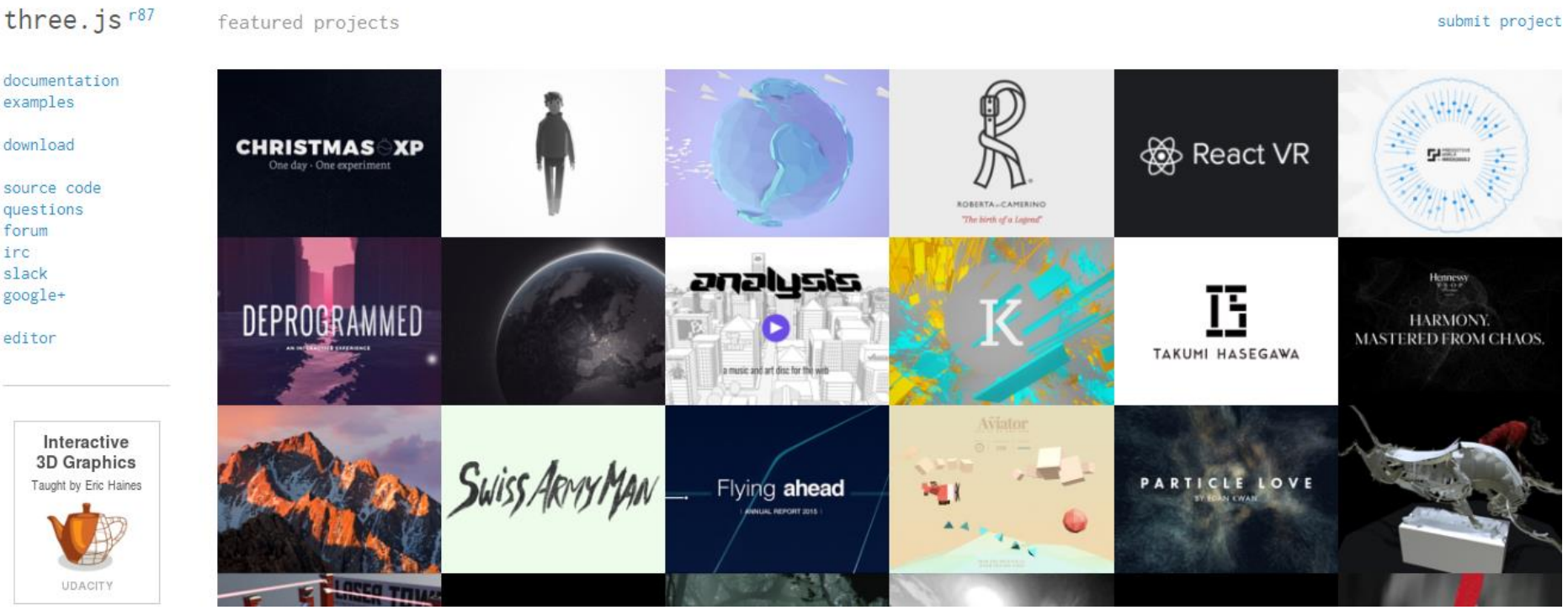
- Application areas
  - CAD
  - Virtual reality
  - Scientific and Information Visualization
  - …

- OpenGL ES
  - Subset for use in embedded systems and portable devices

- WebGL
  - JavaScript API based on OpenGL ES 2.0
  - Rendering interactive 2D and 3D graphics on any compatible browser, without the use of plug-ins

Three.js

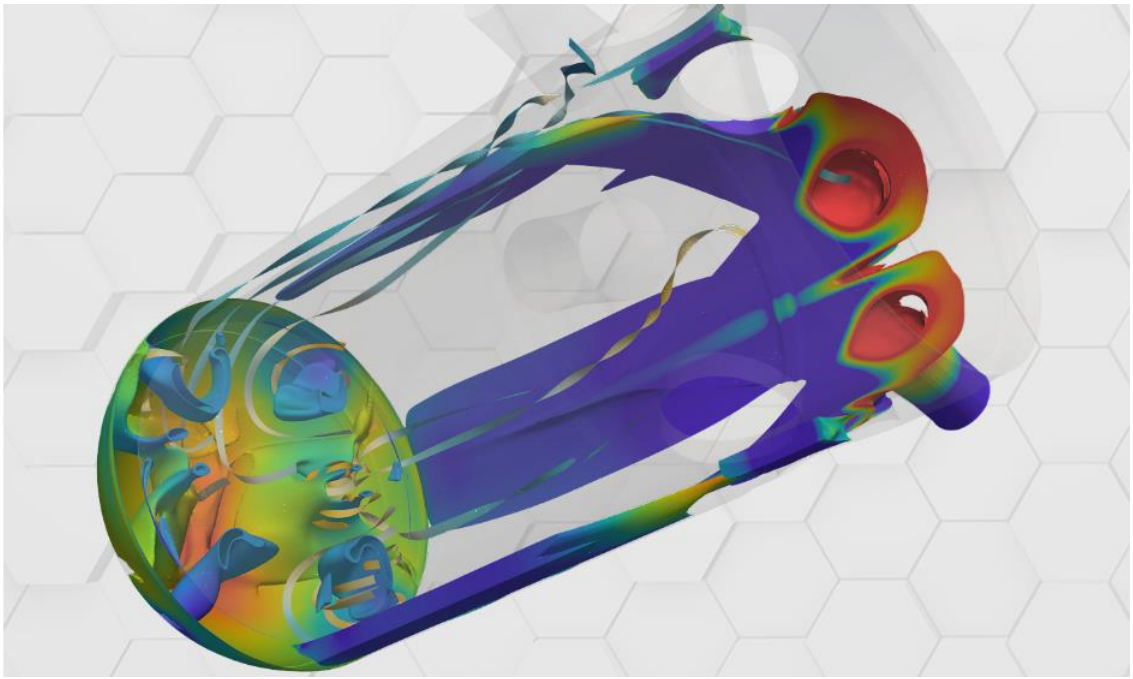
- Cross-browser JavaScript library/API used to create and display animated 3D computer graphics in a web browser.
- Uses WebGL



https://threejs.org/

VTK

- open-source, freely available software system for 3D computer graphics, modeling, image processing, volume rendering, scientific visualization.
- Is designed to be platform agnostic



https://vtk.org/

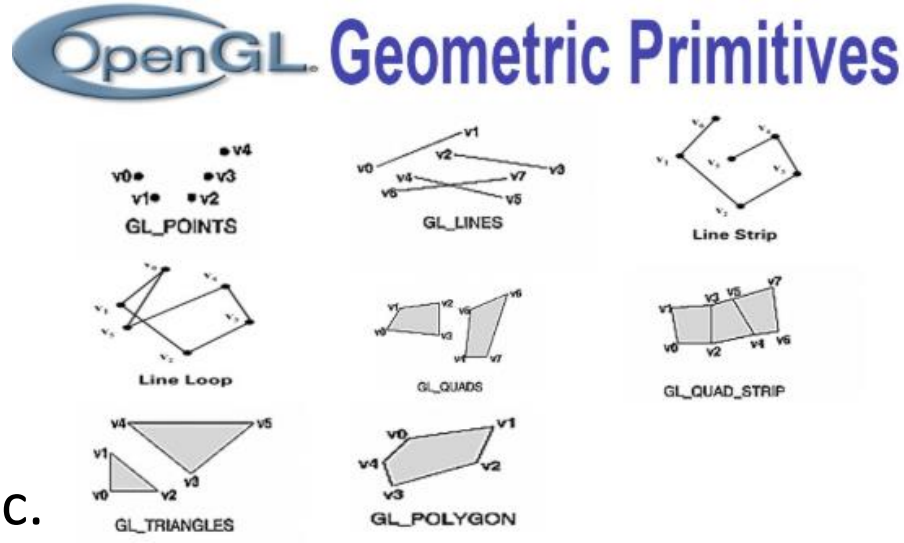
API contents

- Functions for specifying / instantiating
  - Geometric primitives
  - Materials
  - Light sources
  - Viewer / Camera
  - …
- Functions for simple user interaction
  - Input from devices: mouse, keyboard, etc.

Geometric Primitives

- Simple primitives
  - Points
  - Line segments
  - Polygons
- Geometric primitives
  - Parametric curves / surfaces
  - Cubes, spheres, cylinders, etc.

Examples:



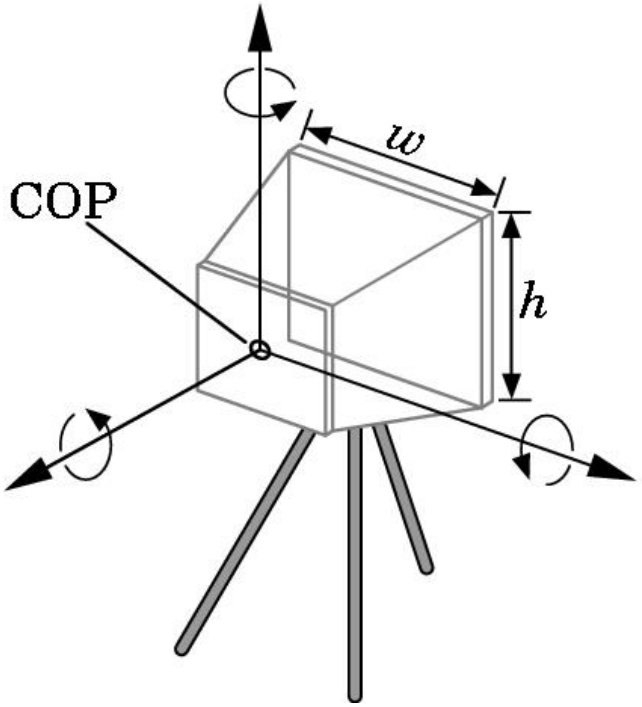
https://threejs.org/manual/#en/primitives

Lights and materials

- Types of light sources
  - Point vs distributed light sources
  - Spot lights
  - Near and far sources
  - Color properties
- Material properties
  - Absorption: color properties
  - Scattering: diffuse and specular
  - Transparency

Camera specification

- Position and orientation
- Lens
- Image size
- Orientation of image plane



(Angel, 2012)

Some reference books

- S. Marschner, P. Shirley, *Fundamentals of Computer Graphics*, 5th ed., A K Peters/CRC Press, 2021

  Fundamentals of Computer Graphics, 5th Edition (oreilly.com)

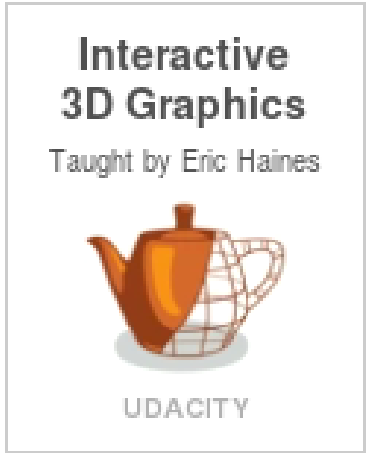
- D. Hearn and M. P. Baker, *Computer Graphics with OpenGL*, 3rd Ed., Addison-Wesley, 2004

- E. Angel and D. Shreiner, *Introduction to Computer Graphics,* 6th Ed., Pearson Education, 2012

- Hughes, J., A. Van Dam, et al., *Computer Graphics, Principles and Practice*, 3rd Ed., Addison Wesley, 2013

  Hughes/Computer Graphics, 3/E (oreilly.com)

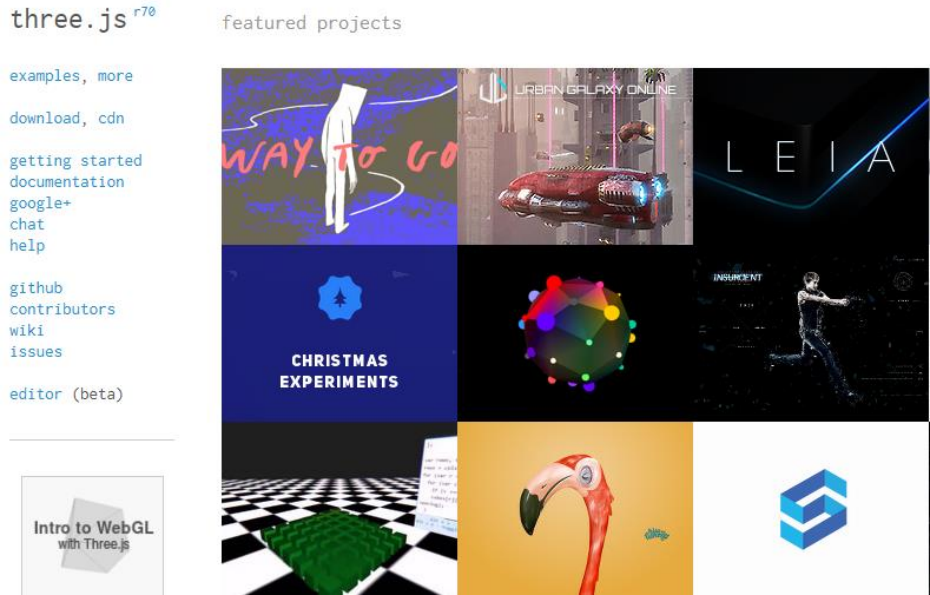
On-line courses



Interactive 3D Graphics, by Eric Haines

https://www.udacity.com/course/interactive-3d-graphics--cs291

https://threejs.org/



Pixar founders and recipients of Turing Award 2019

Ed Catmull work in CG:
texture mapping and bicubic patches

algorithms for spatial anti-aliasing and refining subdivision surfaces

Z-buffering

Pixar received ~30 Oscars

https://cacm.acm.org/magazines/2020/6/245148-attaining-the-third-dimension/fulltext