



Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

Introduction to Computer Graphics



(Wikipedia)

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



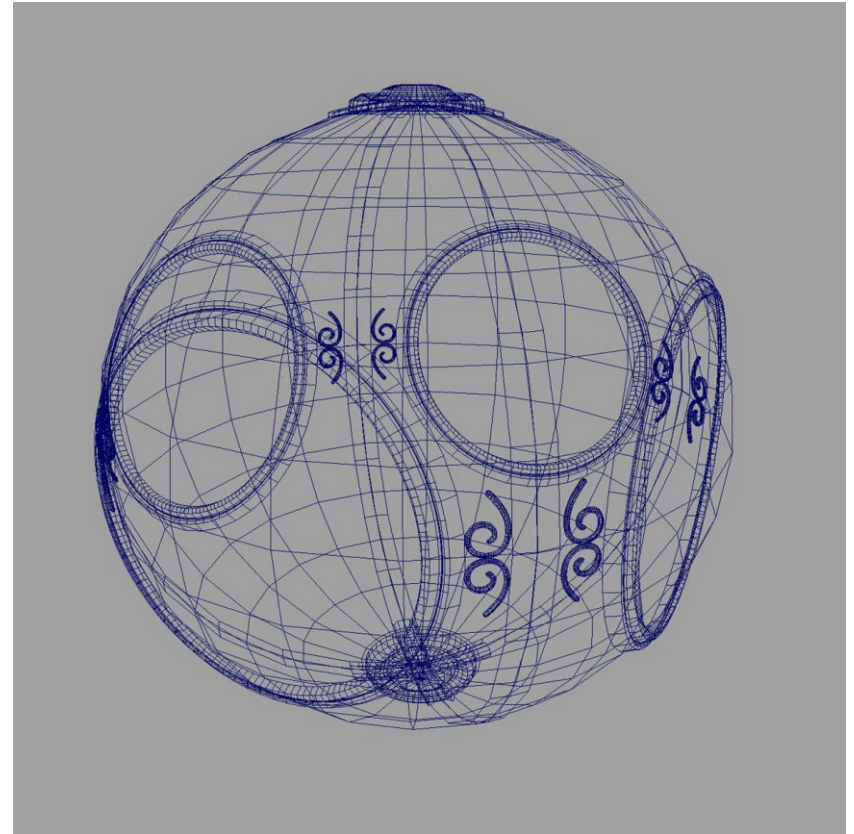
(Angel, 2012)

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)

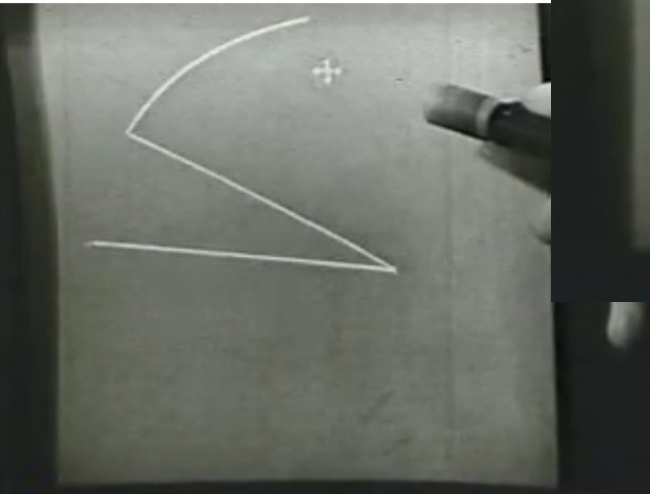
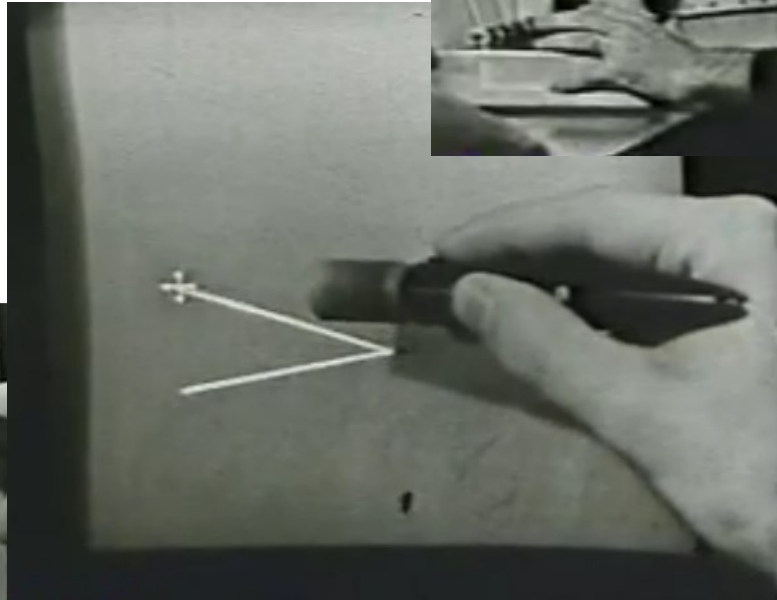
Computer Graphics: 1960 – 1970

- 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)



Computer Graphics: 1970 – 1980

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

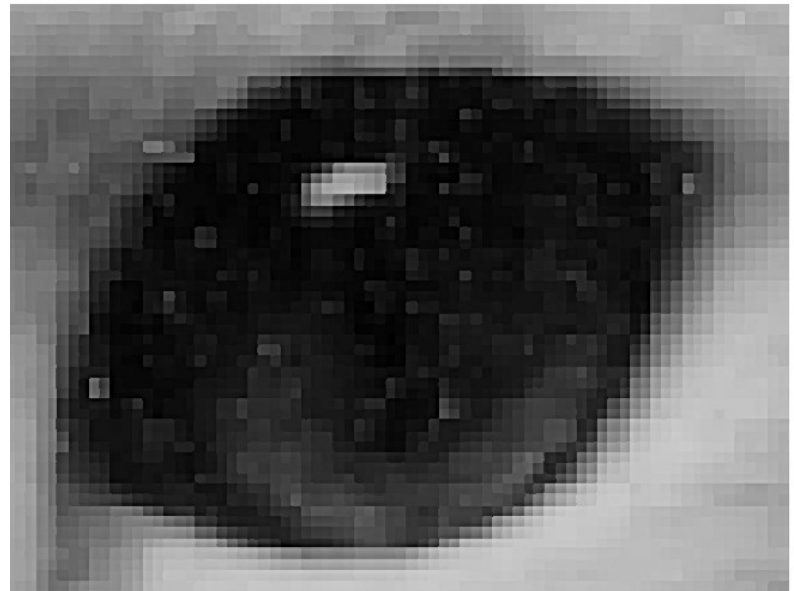
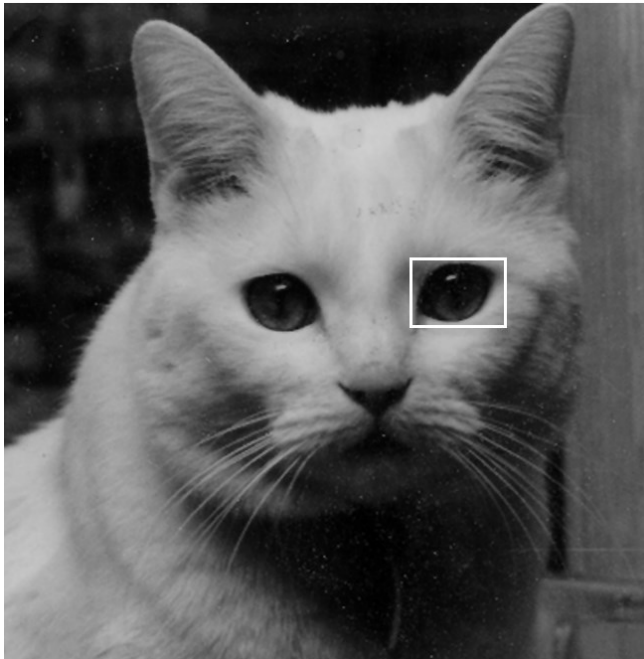
Vector graphics terminal

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



Raster graphics

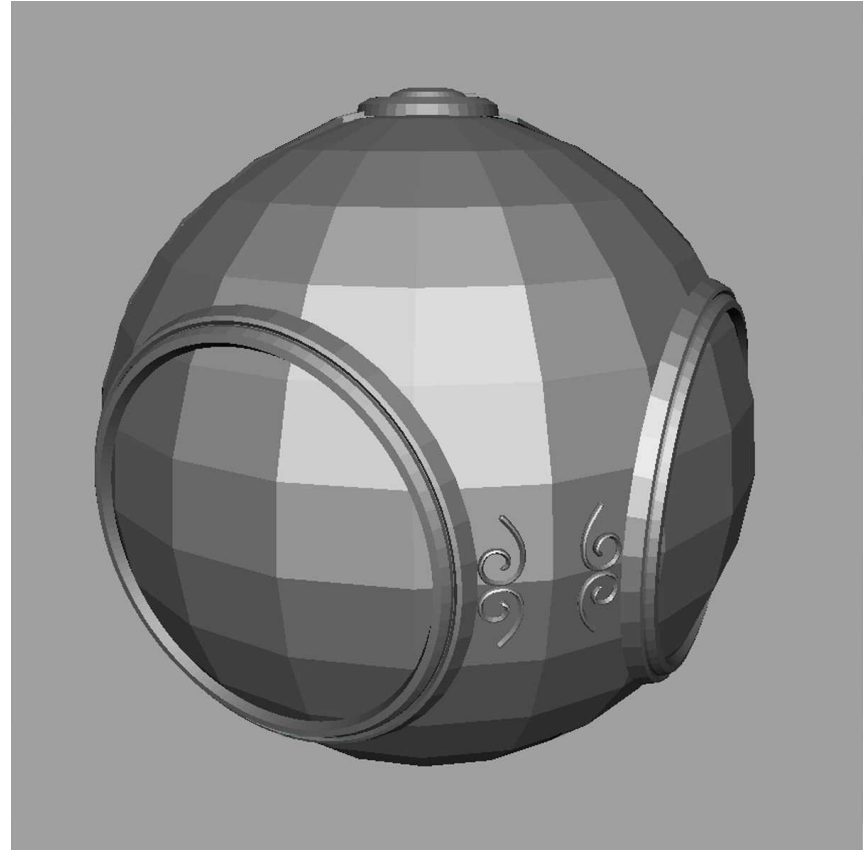
- Image produced as an array (the **raster**) of picture elements (**pixels**) in the **frame buffer**



(Angel, 2012)

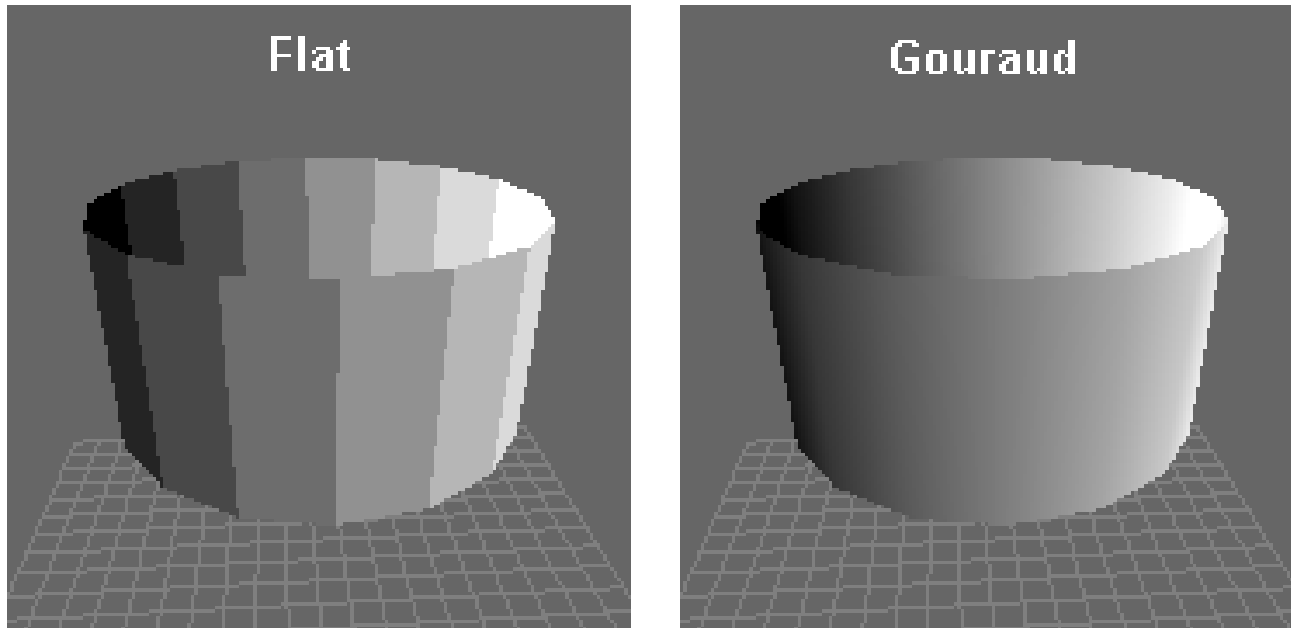
Raster graphics

- Drawing **polygons**
- **Illumination** models
- **Shading** methods



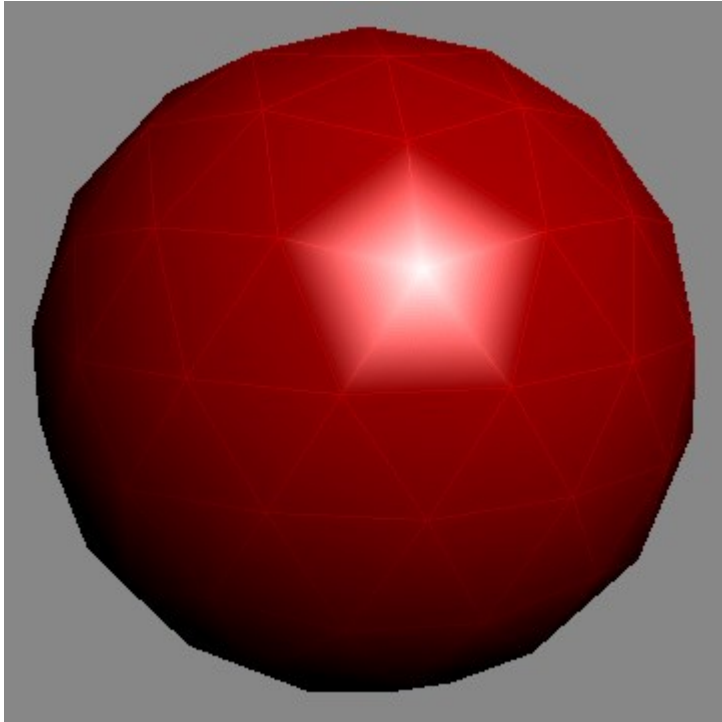
(Angel, 2012)

Gouraud shading – 1971

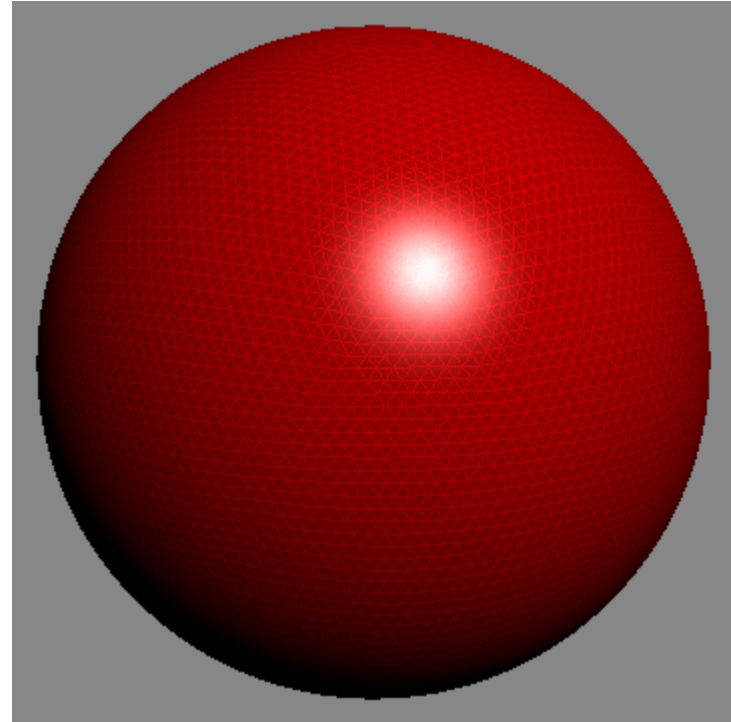


(Wikipedia)

Gouraud shading



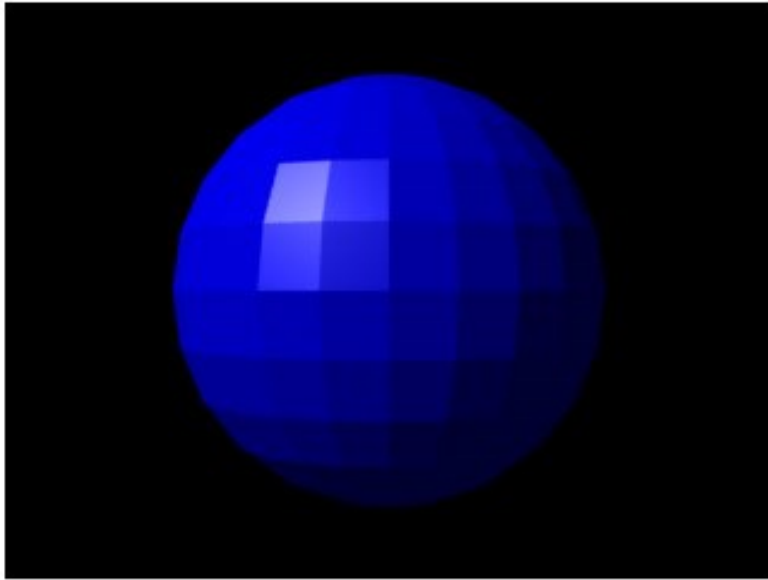
Poor highlight



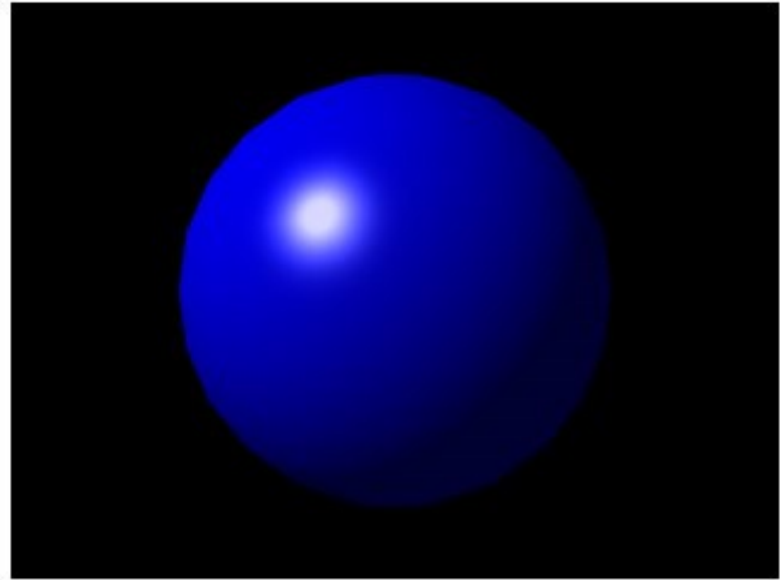
Very high polygon count

(Wikipedia)

Phong shading– 1973



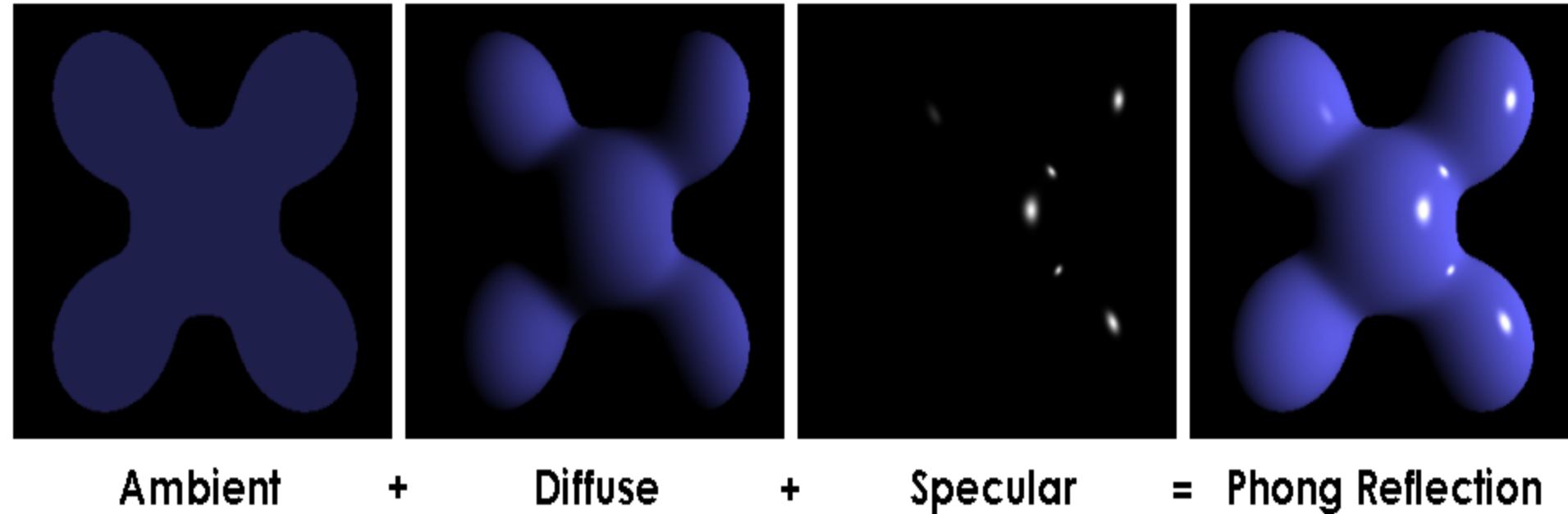
FLAT SHADING



PHONG SHADING

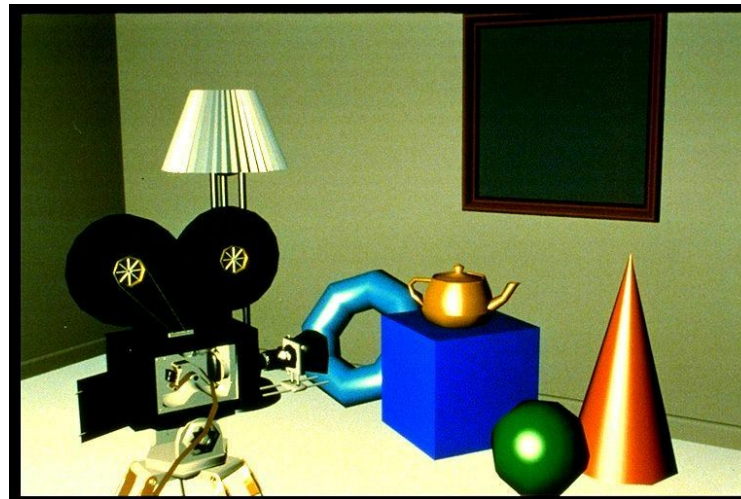
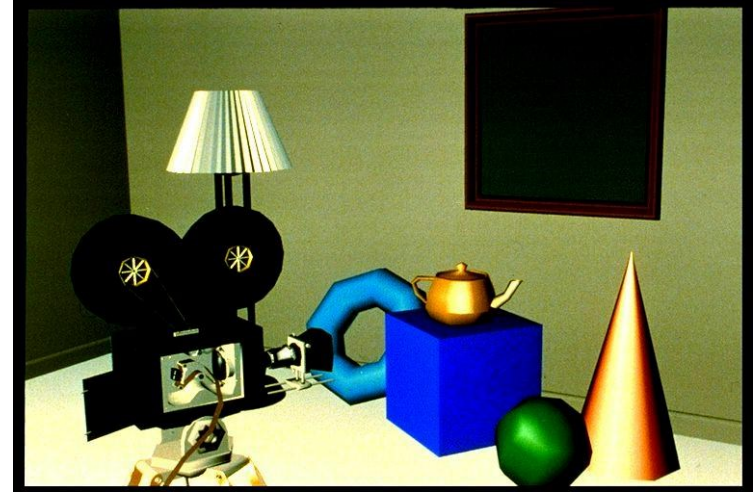
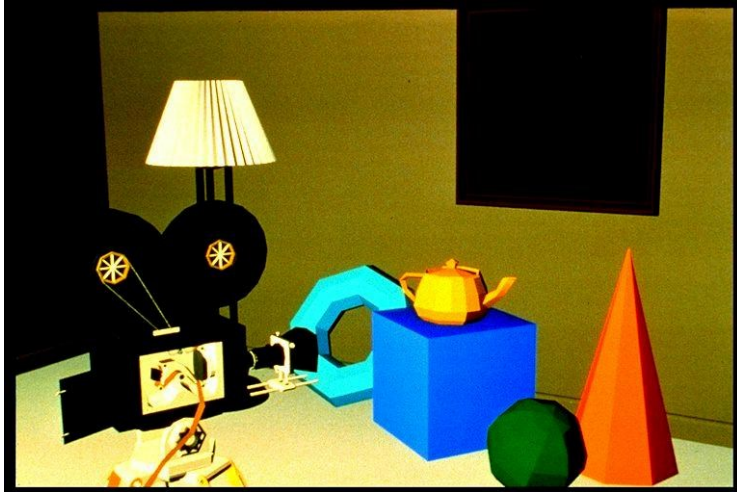
(Wikipedia)

Phong reflection model – 1973



(Wikipedia)

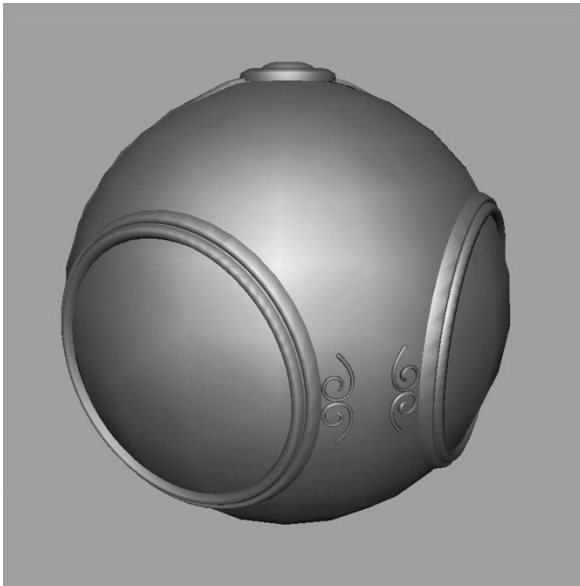
Can you see the differences ?



(Foley , Van Dam 1993)

Computer Graphics: 1980 – 1990

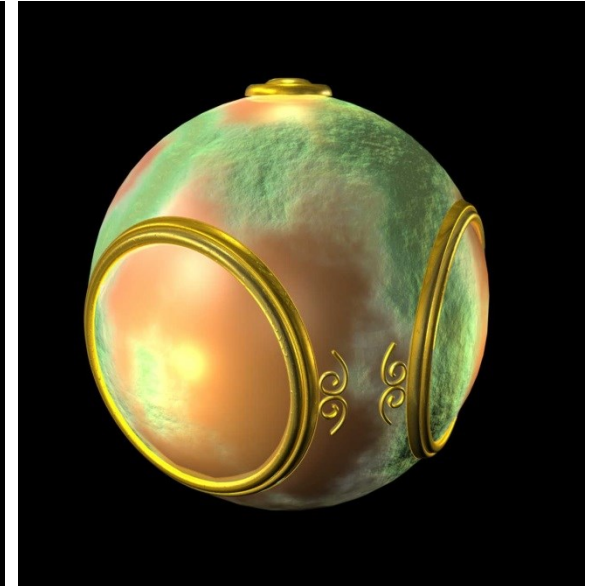
- The quest for **realism**



Smooth shading



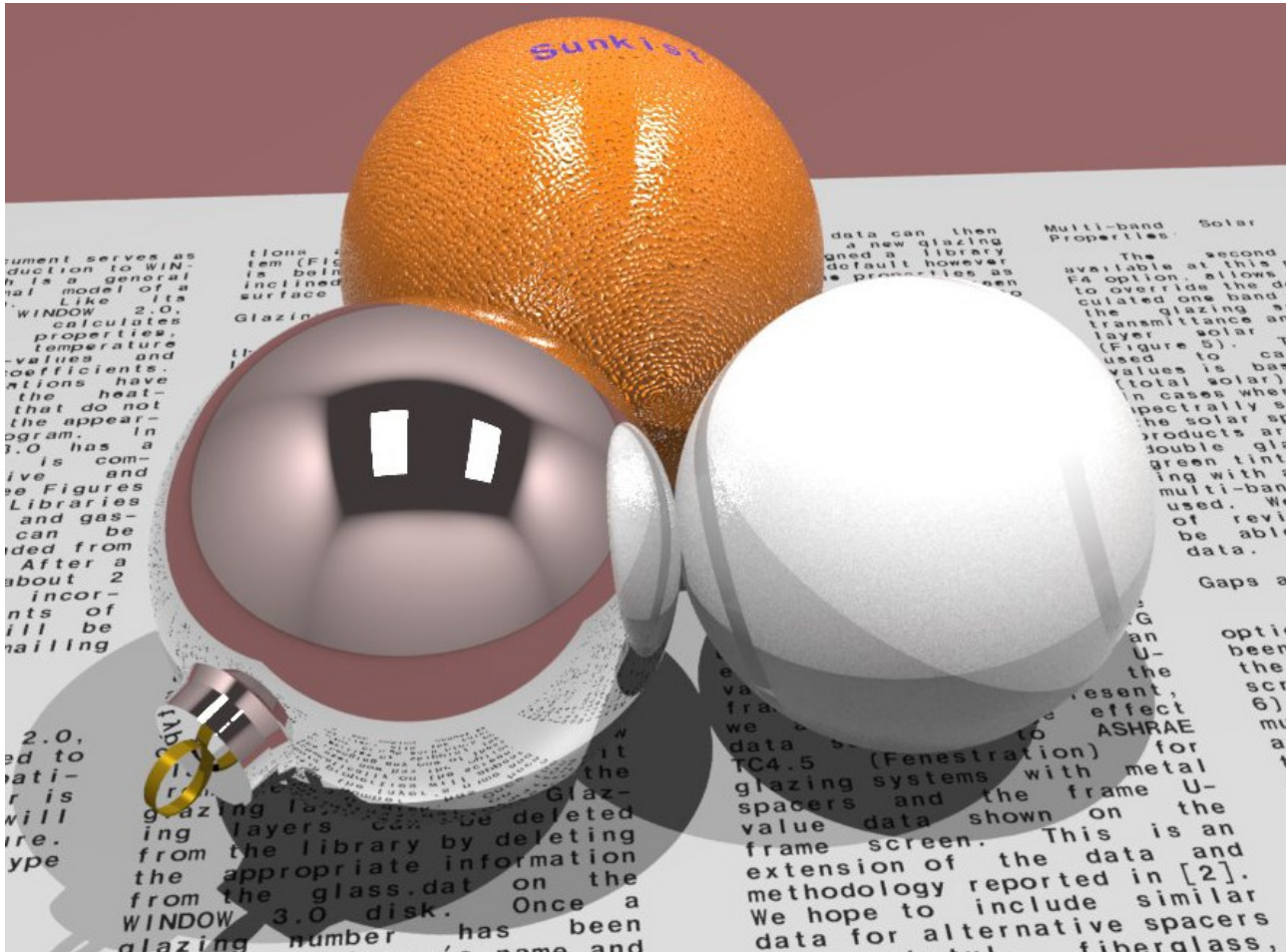
Environment mapping



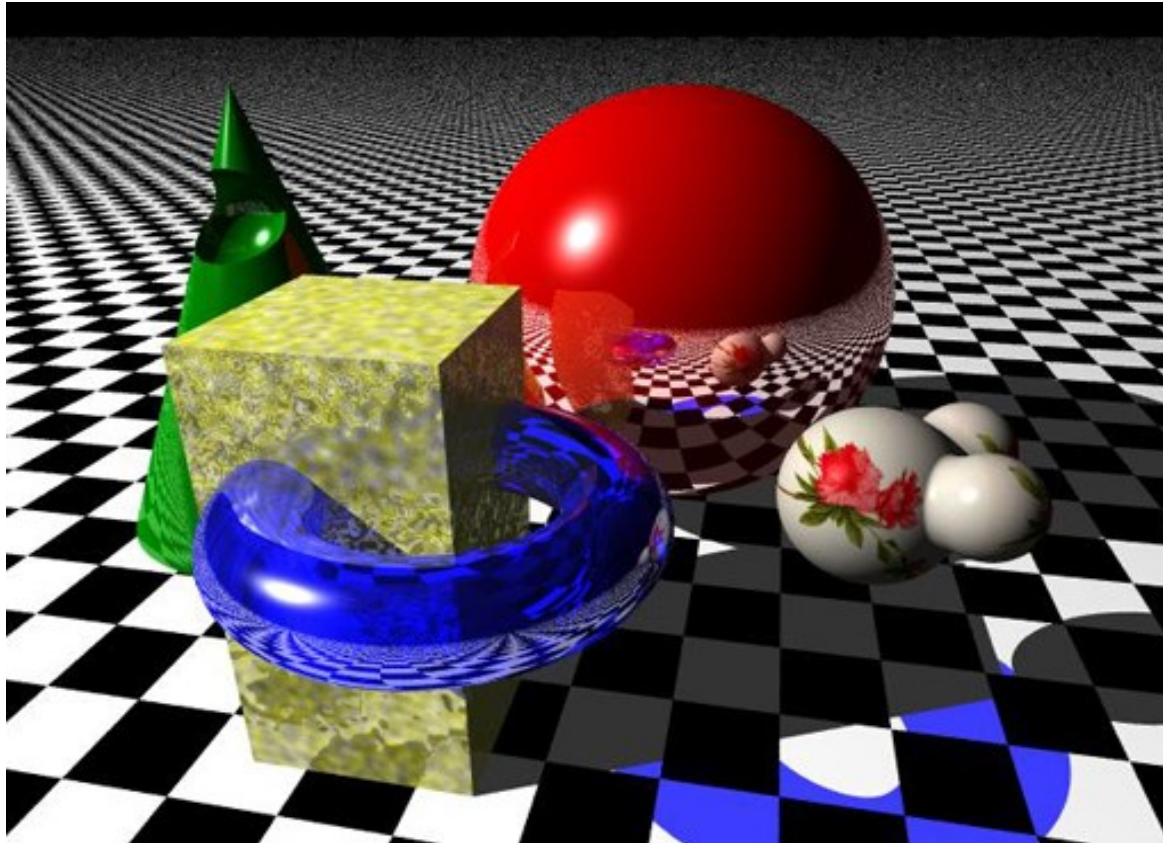
Bump mapping

(Angel, 2012)

Ray-Tracing examples



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



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



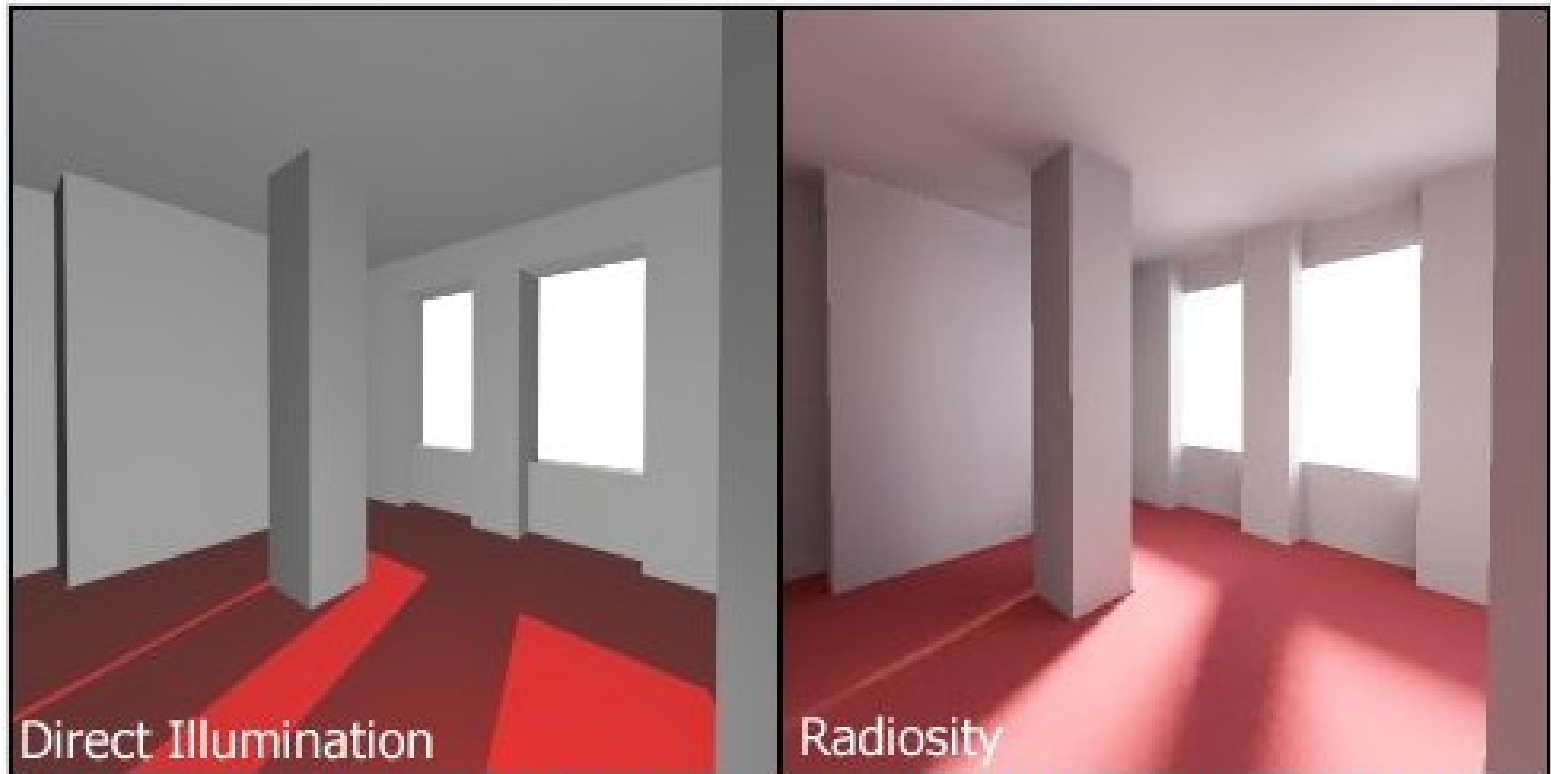
[https://en.wikipedia.org/wiki/Ray_tracing_\(graphics\)](https://en.wikipedia.org/wiki/Ray_tracing_(graphics))

“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_\(computer_graphics\)](https://en.wikipedia.org/wiki/Radiosity_(computer_graphics))

Radiosity

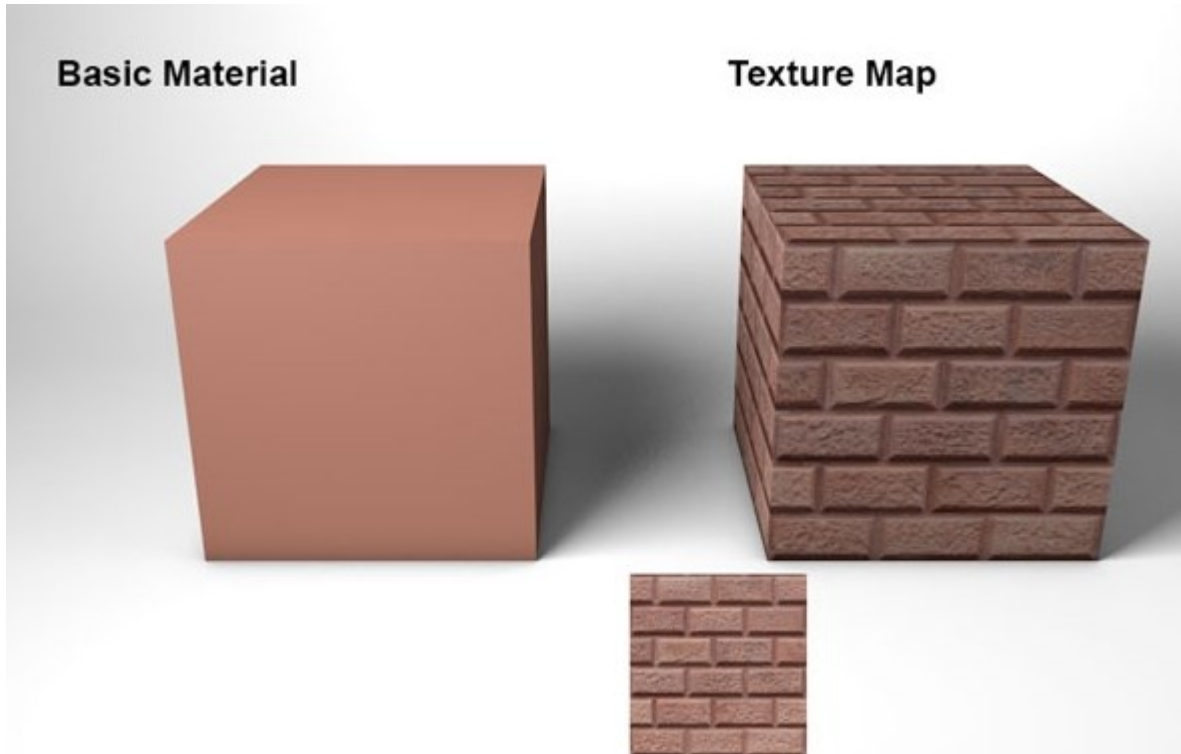


Without radiosity



With radiosity

Texture mapping



(Angel, 2012)

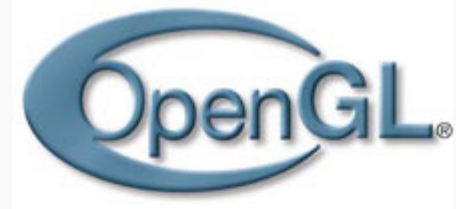
Computer Graphics: 1980 – 1990

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



Computer Graphics: 1990 – 2000

- **OpenGL** API
- First successful computer-generated feature-length animation film: Toy Story
- New hardware capabilities



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 

Oscar winner 2017- Piper ^{The} OSCARS.



<https://renderman.pixar.com/stories>

<https://www.youtube.com/watch?v=3MxxvMUnsY4>

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

Keynote speakers at Eurographics 2020

- *Understanding Visual Appearance from Micron to Global Scale*
Kavita Bala
- *Perception Driven Computational Shape Design*
Alla Sheffer
- *AI+Computer Graphics: The Neural Revolution in Image Synthesis*
David Luebke
- *The Art of Intel's Advanced Ray Tracing*
James L. Jeffers

<https://conferences.eg.org/egev20/program/keynotes/>

CG – Application areas

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

Luxo Jr. - 1986



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

(Wikipedia)

Games – *Lara Croft*



1996



2013



2018

(Wikipedia)

Animation films – *Pixar*



Toy Story – 1995



Toy Story – 2014



Soul – 2020

www.pixar.com

Special effects – ILM

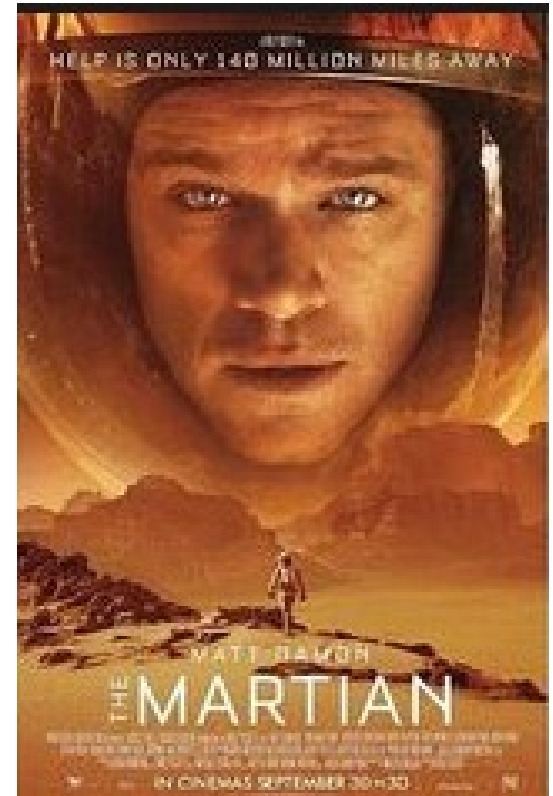


2005

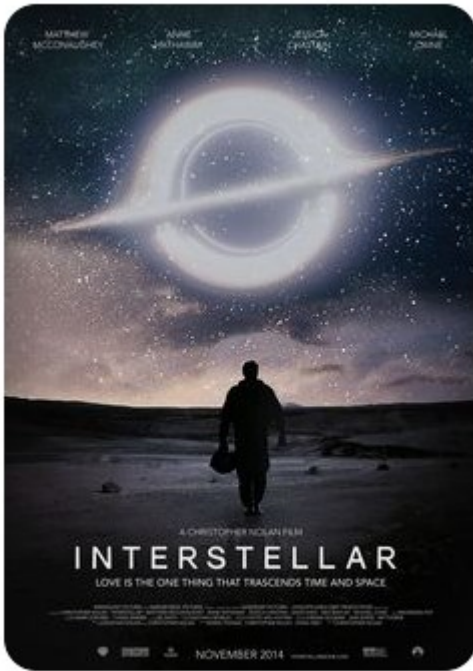


2009

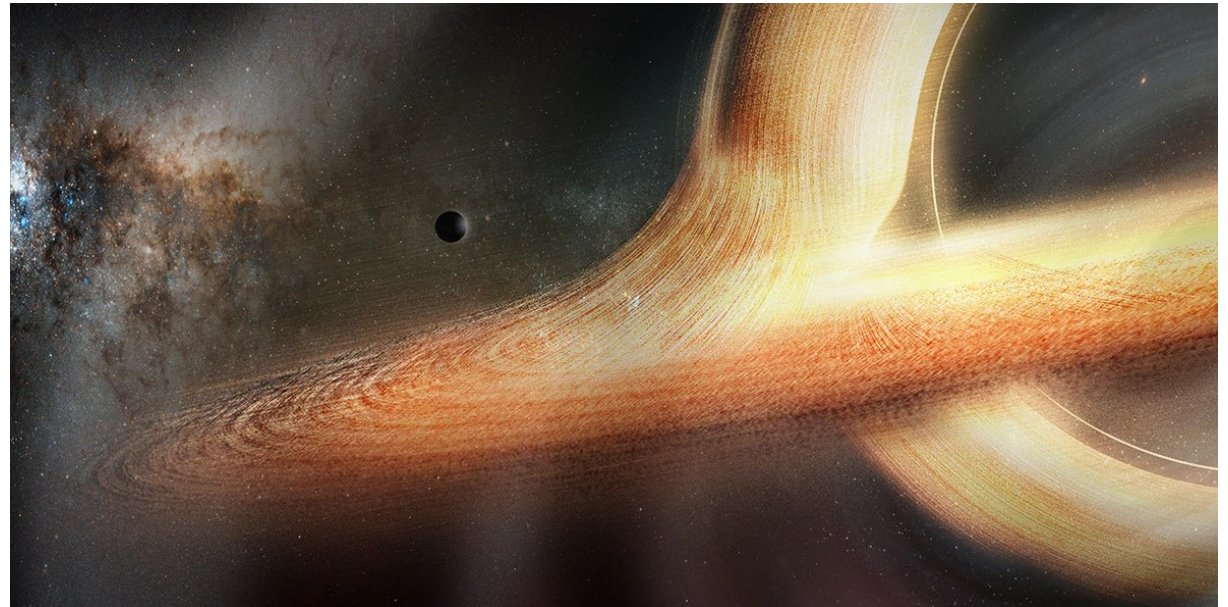
[Wikipedia]



2015



Best visual effects
2015



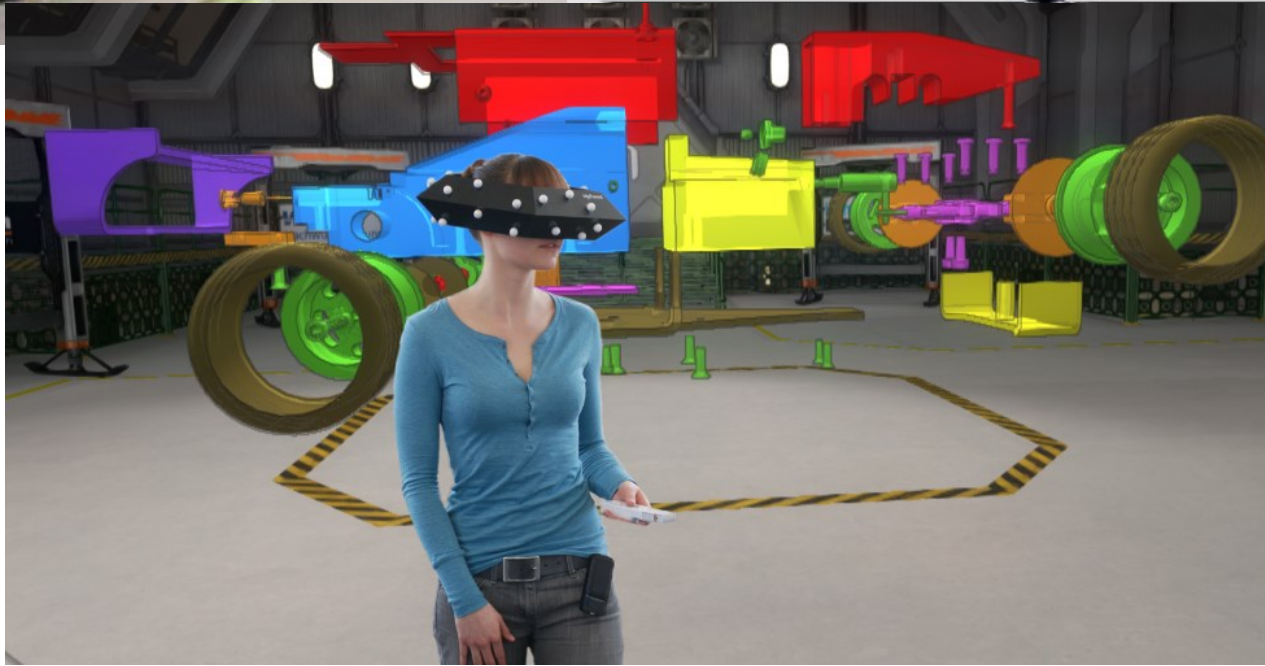
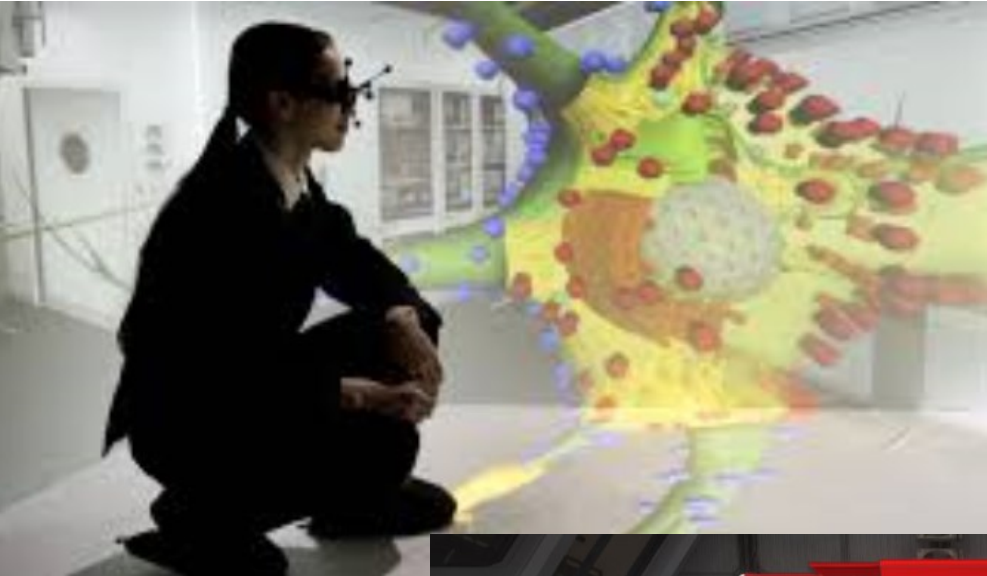
<https://www.siggraph.org/the-visual-effects-of-interstellar-bridging-art-and-science/>
<https://www.screendaily.com/awards/the-vfx-of-interstellar/5082127.article>

CAD – Simulation



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

Virtual and Augmented Reality



Virtual Reality – examples Industry

VR at McLaren

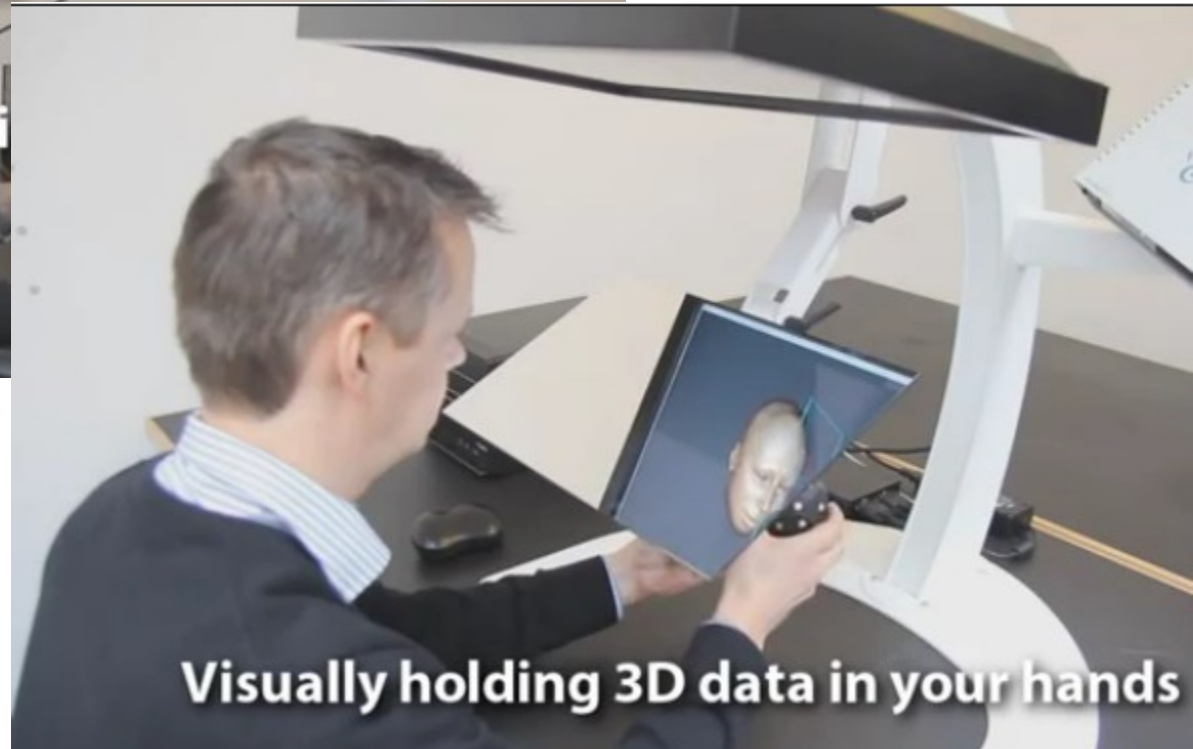


<https://www.youtube.com/watch?v=mWaQfjEJIMQ>

Medicine (data visualization)



<http://www.youtube.com/watch?v=zJmrcEM-uvA>



Entertainment- Virtual reality

Oculus Rift
2014; ~300 USD
Oculus Quest 2
2020 ~ 400 USD

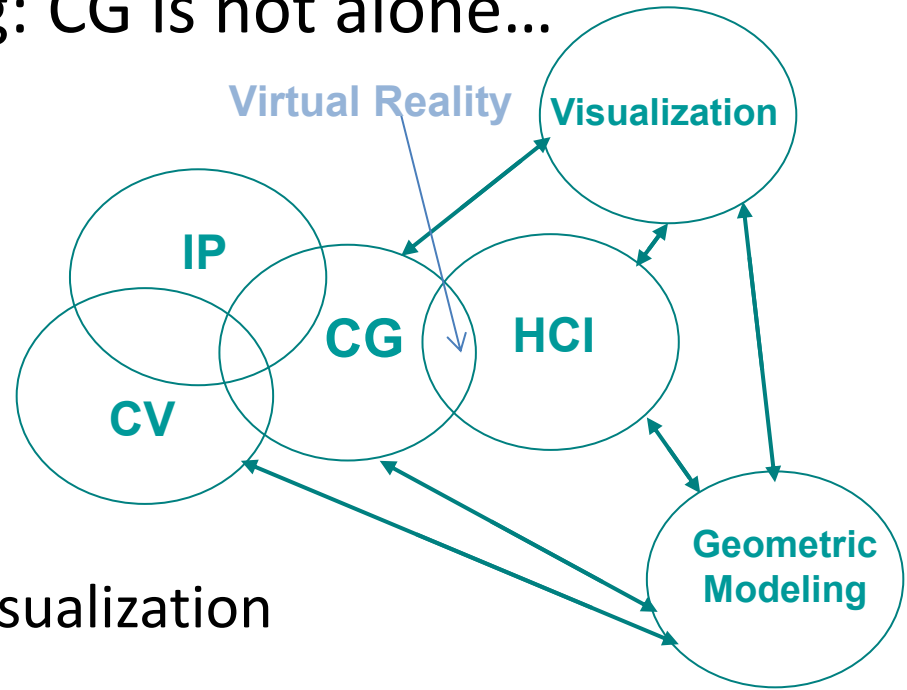
<http://www.oculusvr.com/>



<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
 - Mixed 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
 - ...

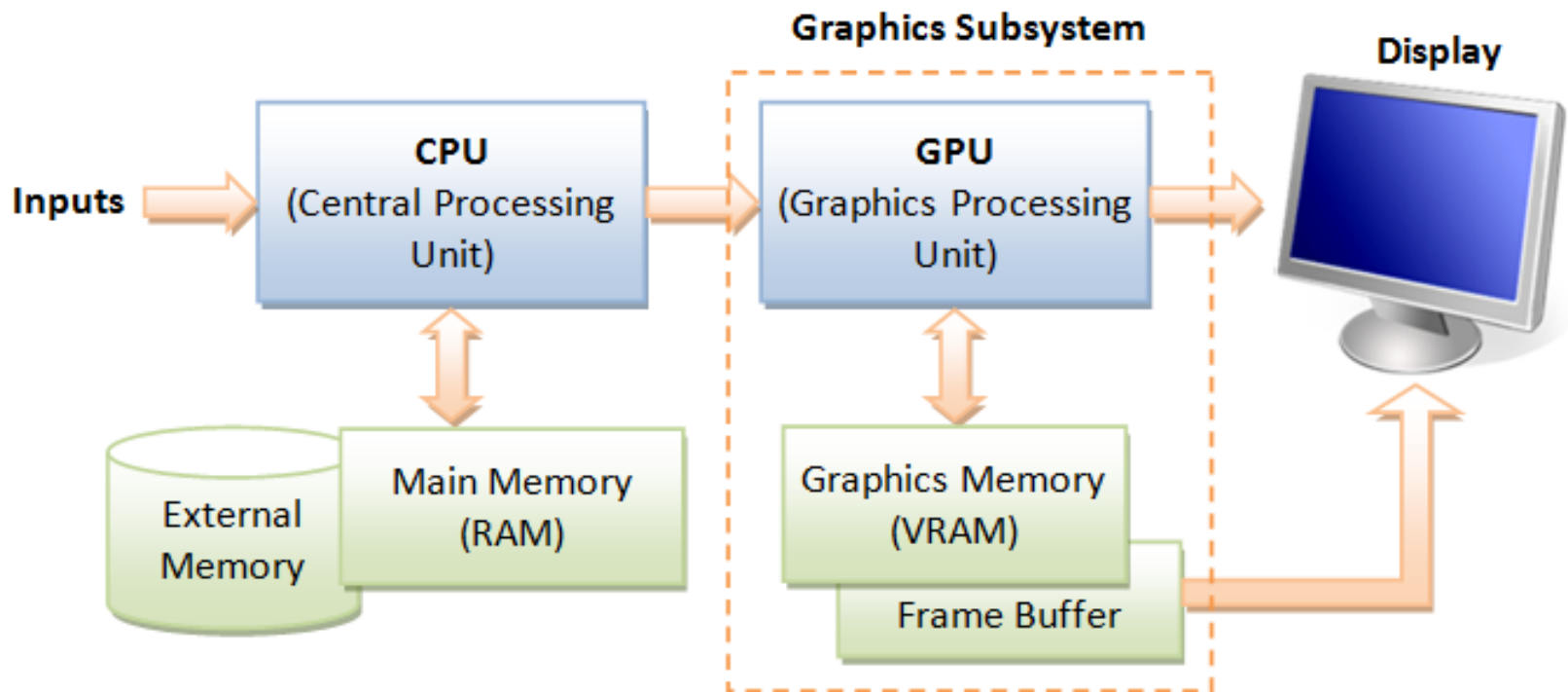


<https://www.mevislab.de/>

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

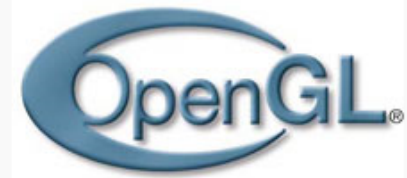
- Three.js



- Vulkan ...



OpenGL



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

Original author(s)	Silicon Graphics
Developer(s)	formerly: ARB now: Khronos Group
Initial release	January 1992
Stable release	4.5 / August 11, 2014
Written in	C ^[1]
Operating system	Cross-platform
Platform	Cross-platform
Type	API
License	Various ^[2]
Website	www.opengl.org

- 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

three.js ^{r87}

featured projects

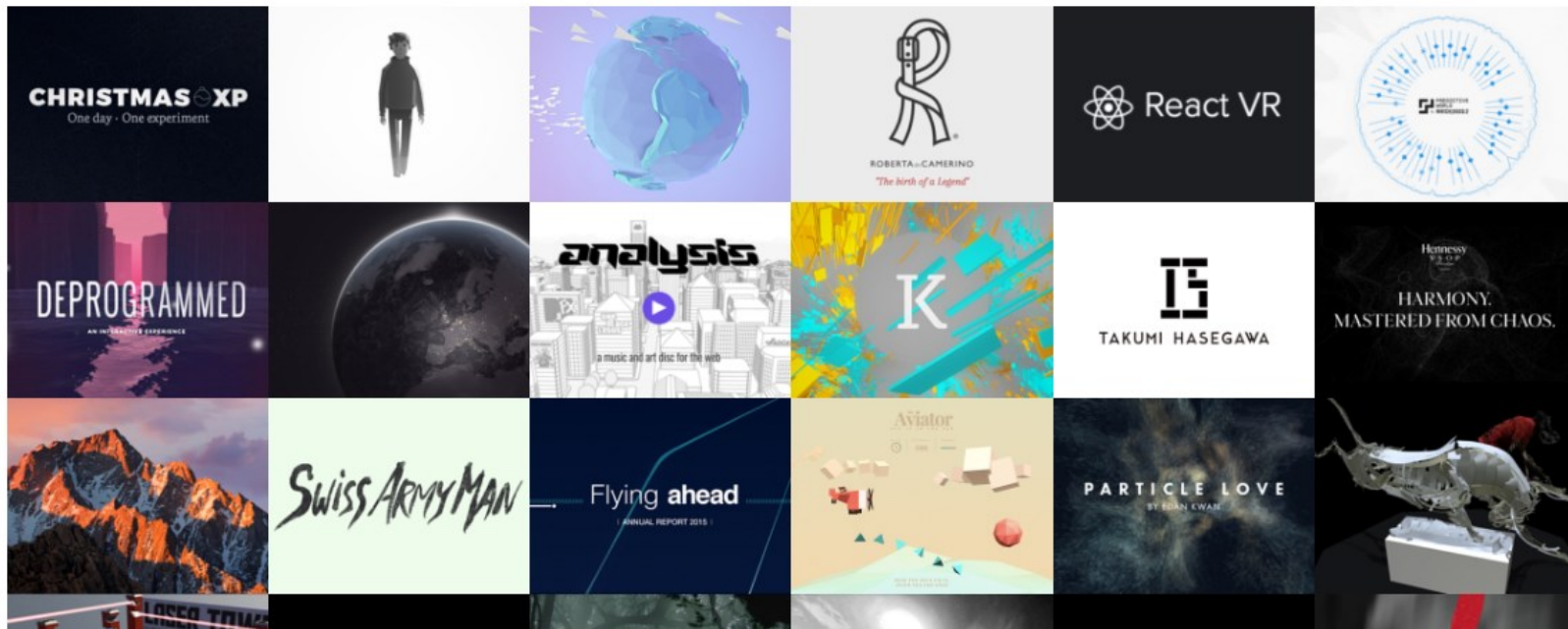
[submit project](#)

[documentation](#)
[examples](#)

[download](#)

[source code](#)
[questions](#)
[forum](#)
[irc](#)
[slack](#)
[google+](#)

[editor](#)



<https://threejs.org/>

API contents

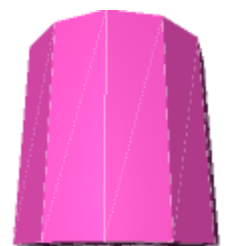
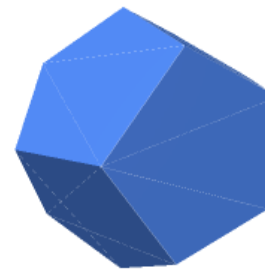
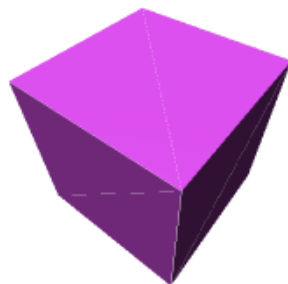
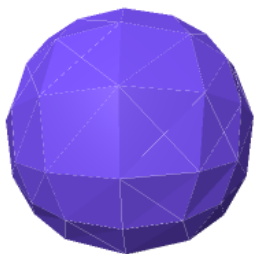
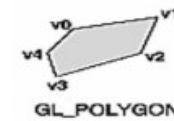
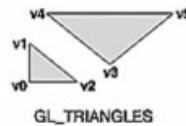
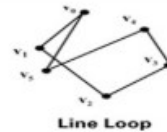
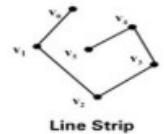
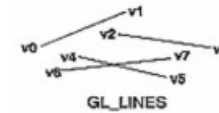
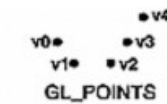
- Functions for specifying / instantiating
 - Geometric primitives
 - Materials
 - Light sources
 - Viewer / Camera
 - ...
- Functions for simple user interaction
 - Input from devices: mouse, keyboard, etc.

Geometric Primitives

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

Examples:

OpenGL Geometric Primitives



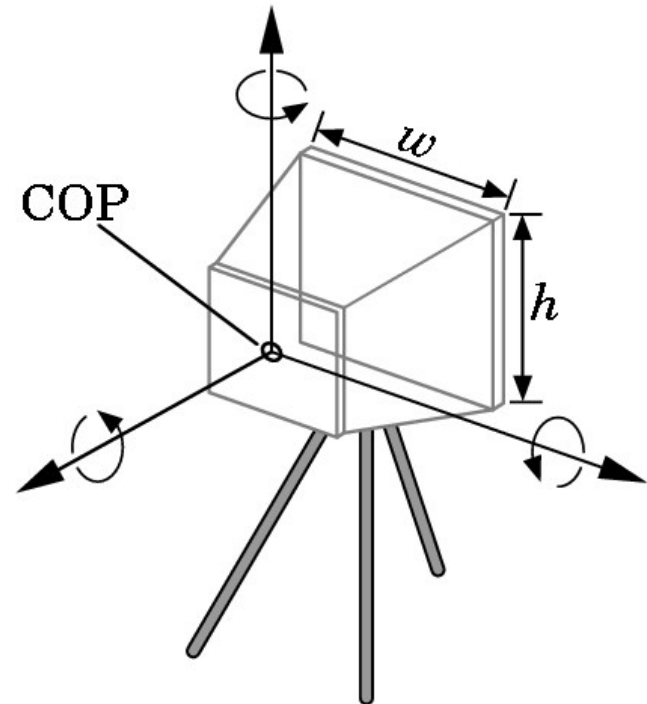
Lights and materials

- 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)

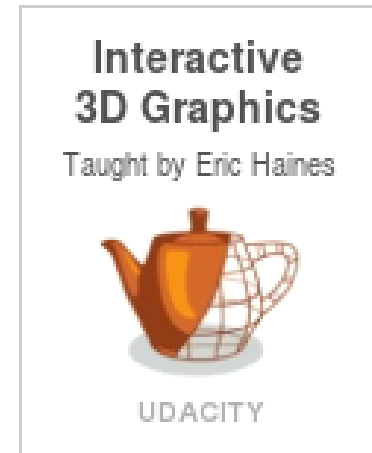
Some reference books

- 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
- J. Foley et al., *Introduction to Computer Graphics*, Addison-Wesley, 1993

On-line courses

Interactive 3D Graphics, by Eric Haines

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



<https://threejs.org/>

three.js^{r70}

examples, more

download, cdn

getting started

documentation

google+

chat

help

github

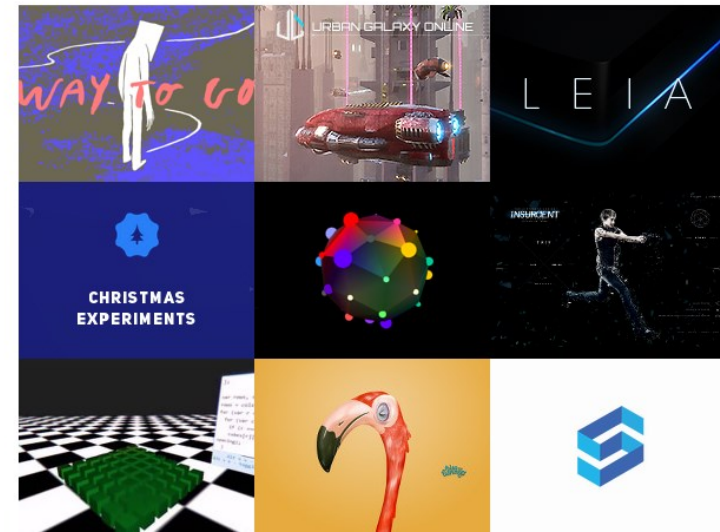
contributors

wiki

issues

editor (beta)

featured projects



Intro to WebGL
with Three.js

Pixar founders and recipients of Turing Award 2019

Ed Catmull work in CG:

[texture mapping](#) and [bicubic patches](#)

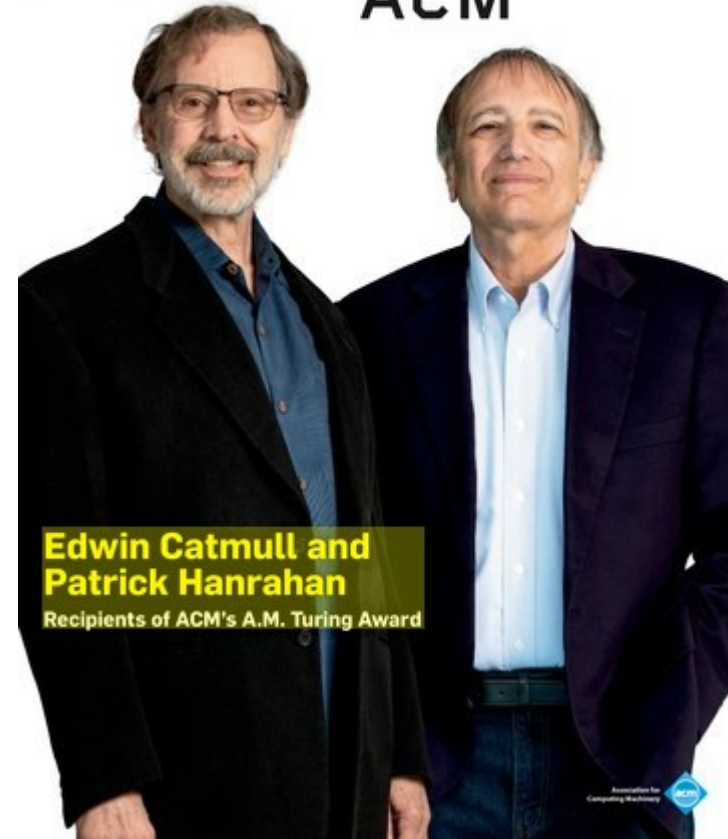
algorithms for [spatial anti-aliasing](#) and refining [subdivision surfaces](#)

[Z-buffering](#)

Pixar received 27 Oscars

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

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Interesting example of CG/animation application



David Attenborough's Natural History Museum Alive

<https://www.vision3.tv/VR-3D-projects/post.php?permalink=david-attenboroughs-natural-history-museum-alive-3d>