An Introduction to Computer Graphics

Joaquim Madeira

February 2024

Overview

- What is CG ?
- Application areas
- Evolution and trends
- Main tasks
- CG APIs

PIXAR'S COMPUTER-ANIMATED FILMS

Turning Red (2022)

Trailer at YouTube

- Pixar's 2022 computer-animated film

Luca (2021)

Trailer at YouTube

- Pixar's 2021 computer-animated film

Soul (2020)

Trailer at YouTube

- Pixar's 2020 computer-animated film

Onward (2020)

Trailer at YouTube

- Pixar's 2020 computer-animated film

Toy Story 4 (2019)

Trailer at YouTube

- Pixar's 2019 computer-animated film

Incredibles 2 (2018)

Trailer at YouTube

- Pixar's 2018 computer-animated film

Toy Story (1995)

Trailer at YouTube

- Pixar's first entirely computer-animated feature film

Pixar's Luxo Jr. (1986)

Trailer at YouTube

- Pixar's second computer-animated short-film

WHAT IS COMPUTER GRAPHICS?

What is 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 dialogue and interactive technologies

[CG Topics – Darmstadt]

What is Computer Graphics?

- Computer graphics generally means creation, storage and manipulation of models and images

- Such models come from a diverse and expanding set of fields
  - Physical, biological, mathematical, artistic, and conceptual / abstract structures

[Andy van Dam]

What is Computer Graphics?

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

- How was this image produced?

[Angel]

APPLICATION AREAS

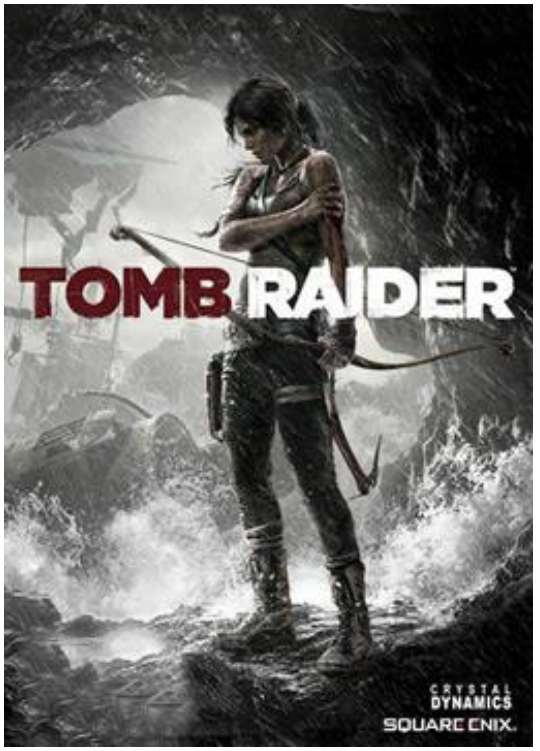
CG – Application areas

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

Games – *Lara Croft*

1996

2007



2013

[Wikipedia]

The Games With The Most Impressive Graphics, Ranked

Graphics can make a good game look great. Regardless of the actual gameplay, here are the games with the most undeniably impressive graphics

BY JAMES CARR
UPDATED FEB 05, 2022

https://gamerant.com/video-games-best-graphics/

10 Older Video Games That Still Boast Amazing Graphics

Despite how old some of these classic games are, their graphics still stand the test of time and were amazing in their day. These are the standouts.

BY DEREK DRAVEN
PUBLISHED APR 22, 2021

https://screenrant.com/classic-older-video-games-that-best-graphics/

10 Games With The Best Graphics Ever (At Their Time Of Release)

Gorgeous graphics tend to make an average game ten times better, and these games in particular wowed players with incredible visuals.

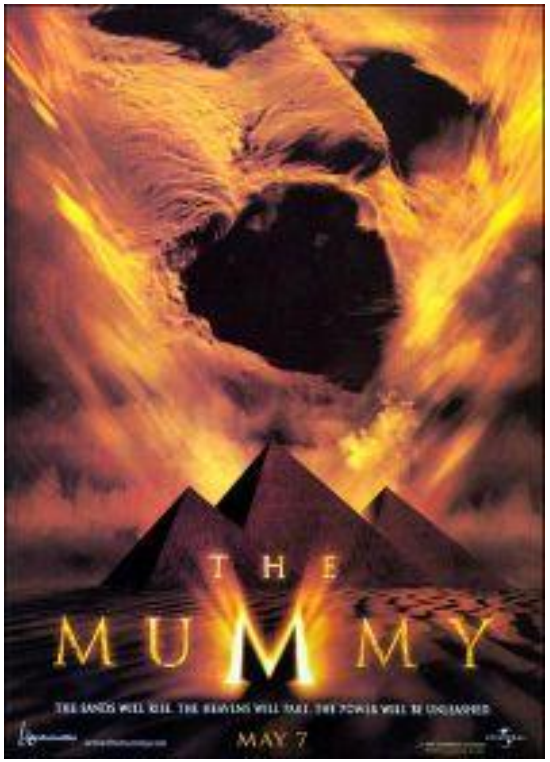
BY GAVIN FRASER MACKENZIE
PUBLISHED SEP 07, 2021

https://gamerant.com/best-game-graphics-at-release/

Special effects – *ILM*

1991

1994



1999

[Wikipedia]

Special effects – *ILM*

2005

2009

[Wikipedia]

2013

Special effects – *ILM*

2015

2016

[Wikipedia]

2017

Special effects – *ILM*

2018

2019

[Wikipedia]

2019

HOME > ENTERTAINMENT

14 groundbreaking movies that took special effects to new levels

Lucien Formichella Jan 11, 2020, 6:30 PM

https://www.insider.com/most-groundbreaking-cgi-movies-ever-created-2020-1

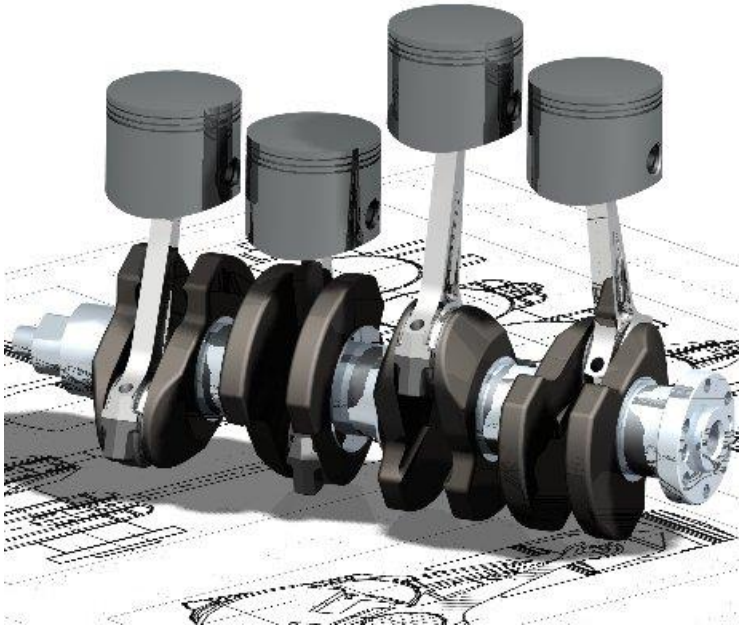
35 greatest CGI movie moments of all time

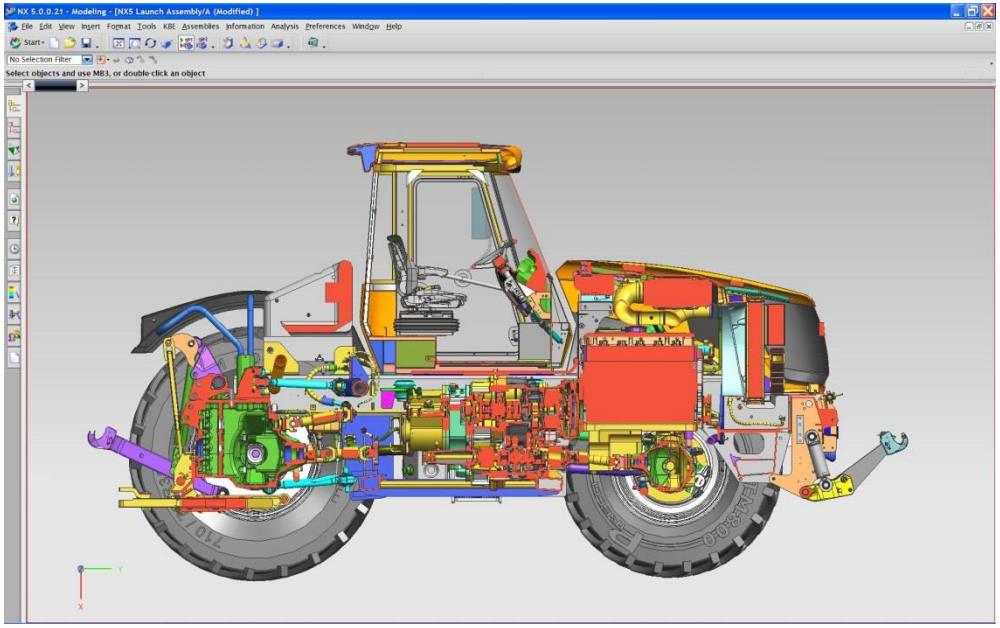
By Creative Bloq Staff published August 01, 2019

Our pick of the best CGI movie moments in live action films.

https://www.creativebloq.com/3d-tips/cgi-movie-moments-1234014

Computer-Aided Design

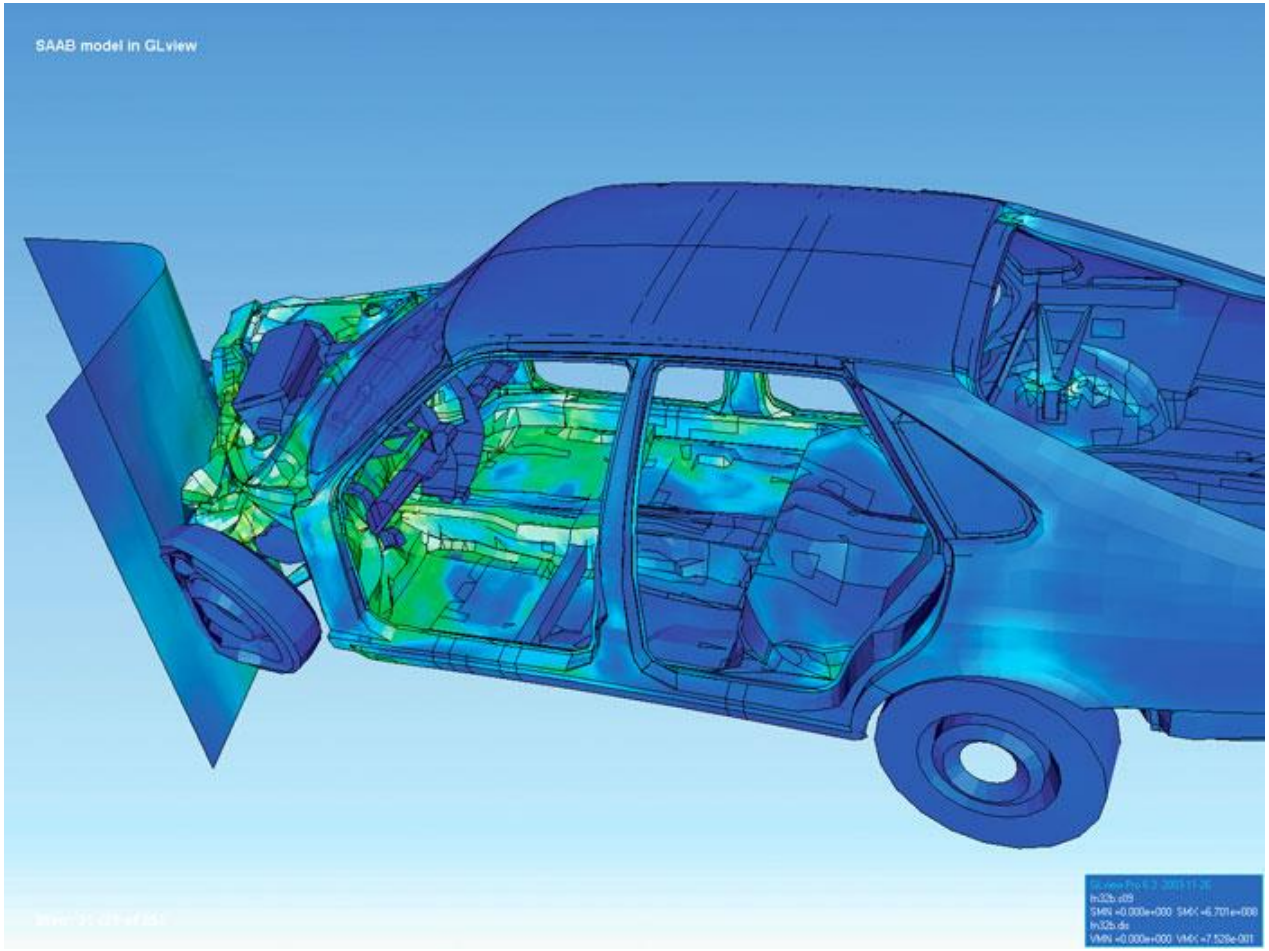




CAD mockup

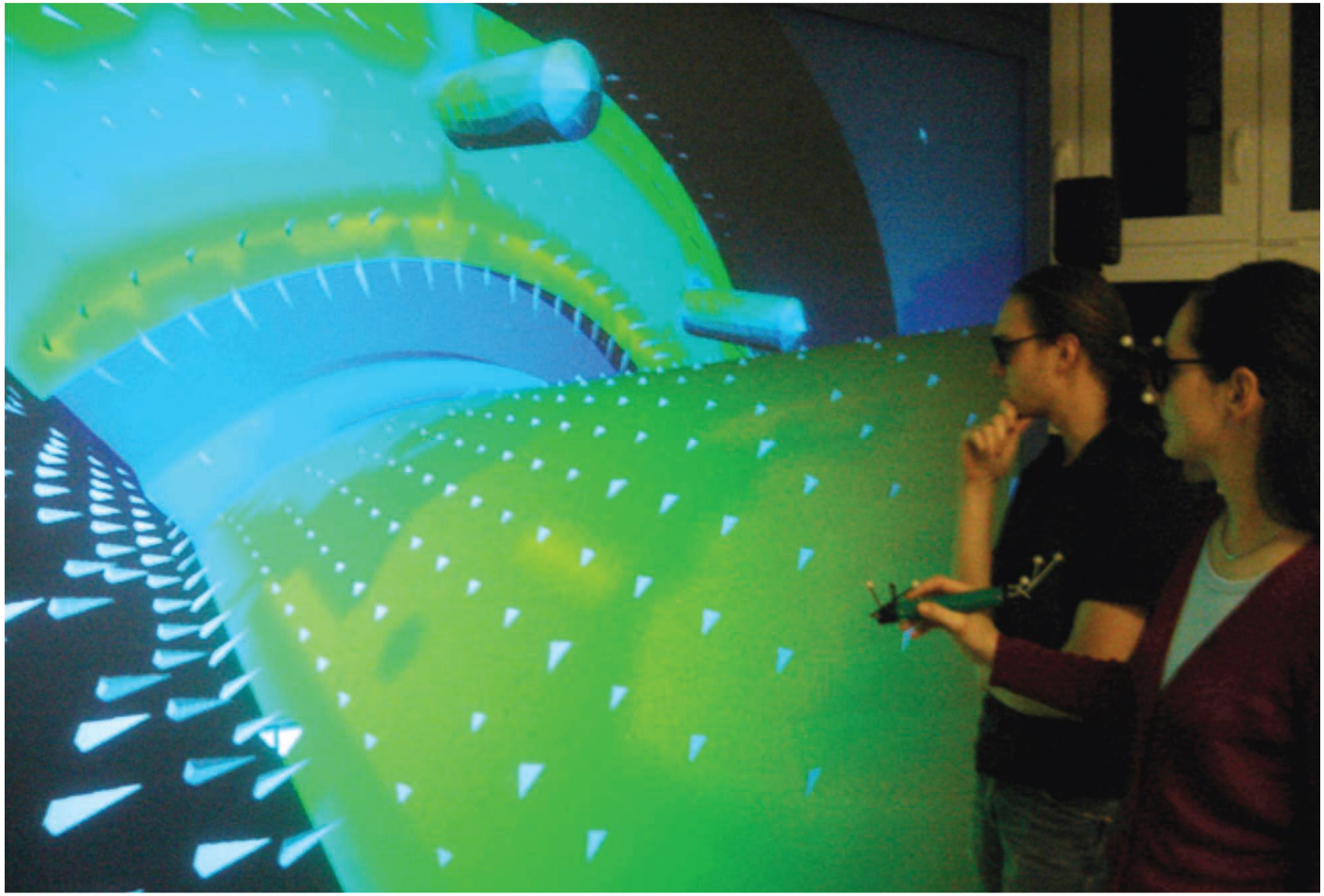
[Wikipedia]

CAD – Simulation



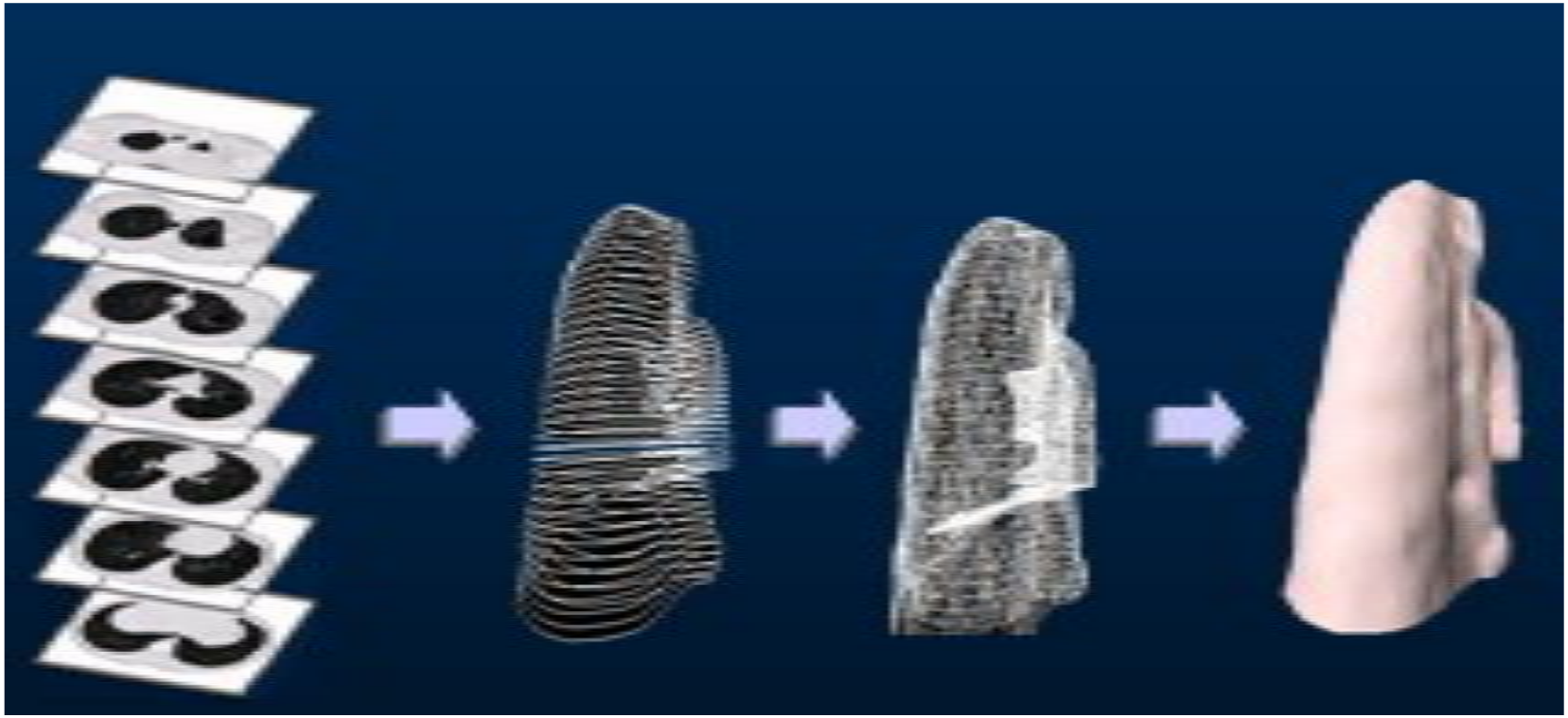
[Wikipedia]

VR / AR Visualization



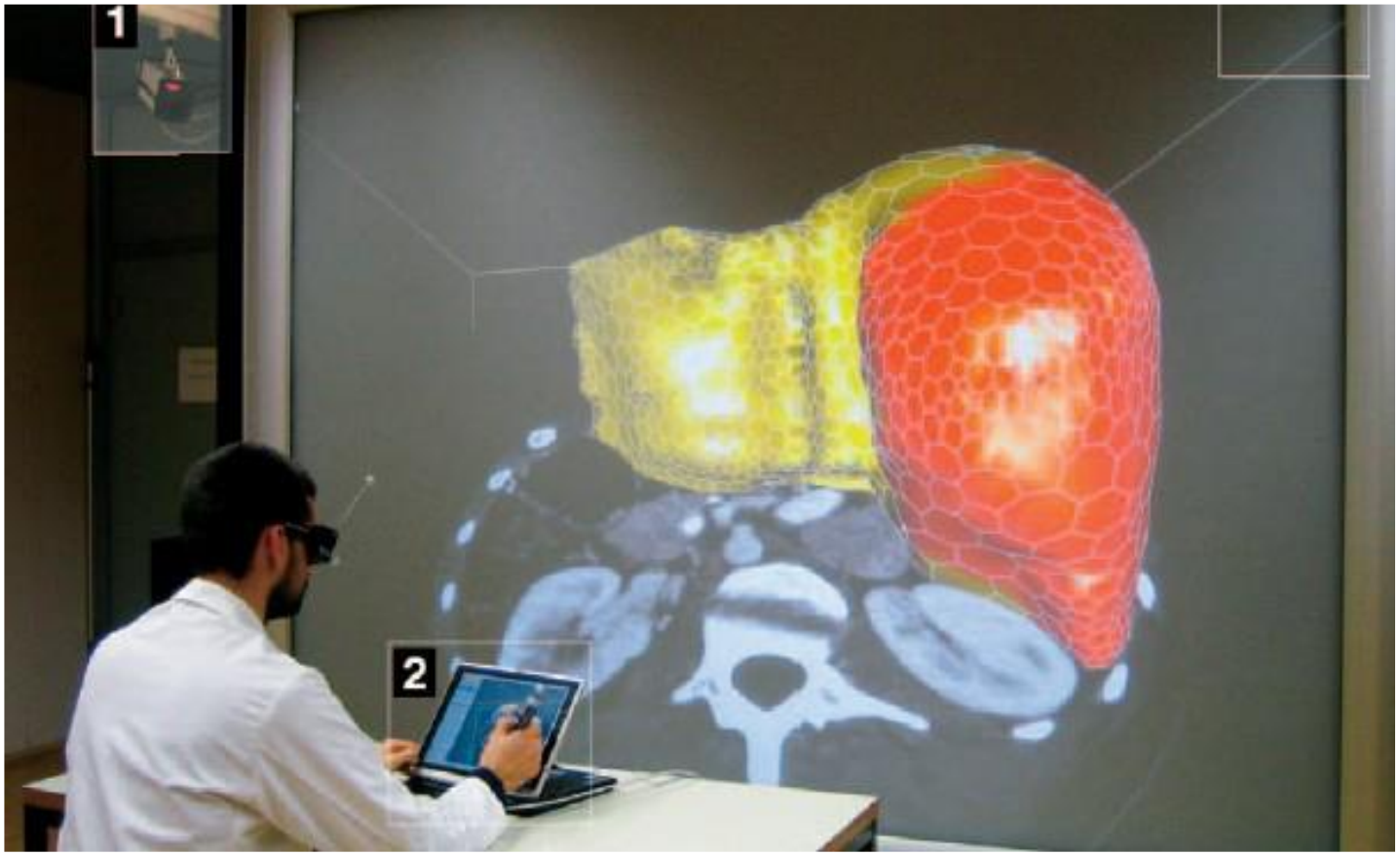
[Weidlich et al, 2008]

Medical Data Visualization

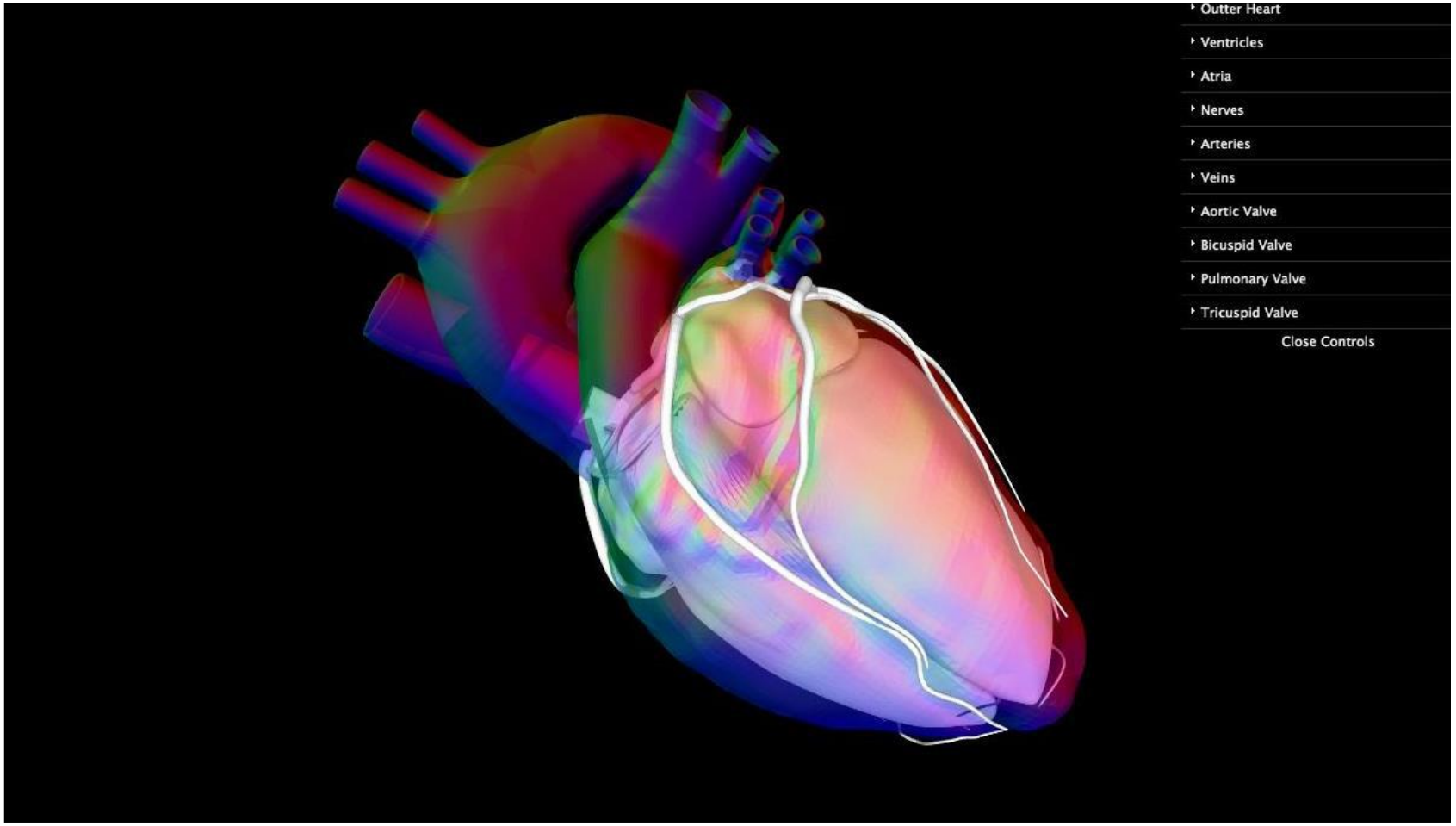


From CT data to lung models
U.Aveiro, 2004

Medical Data Visualization

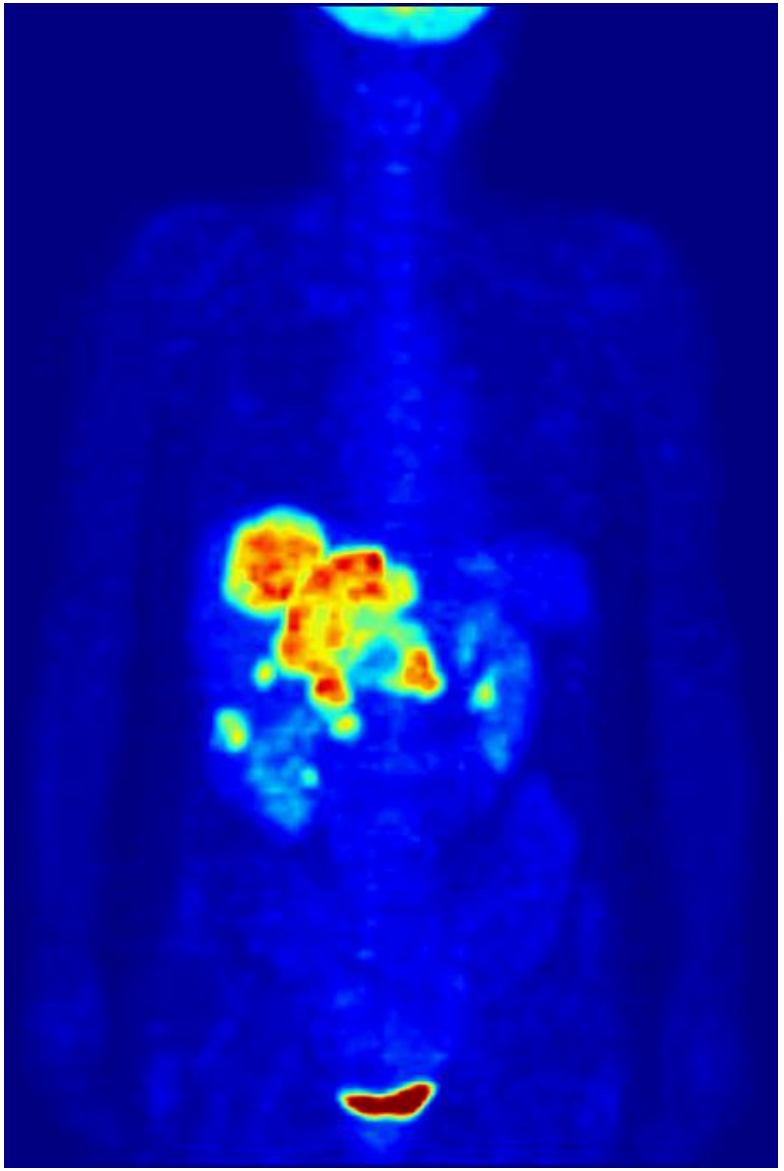


Medical Data Visualization



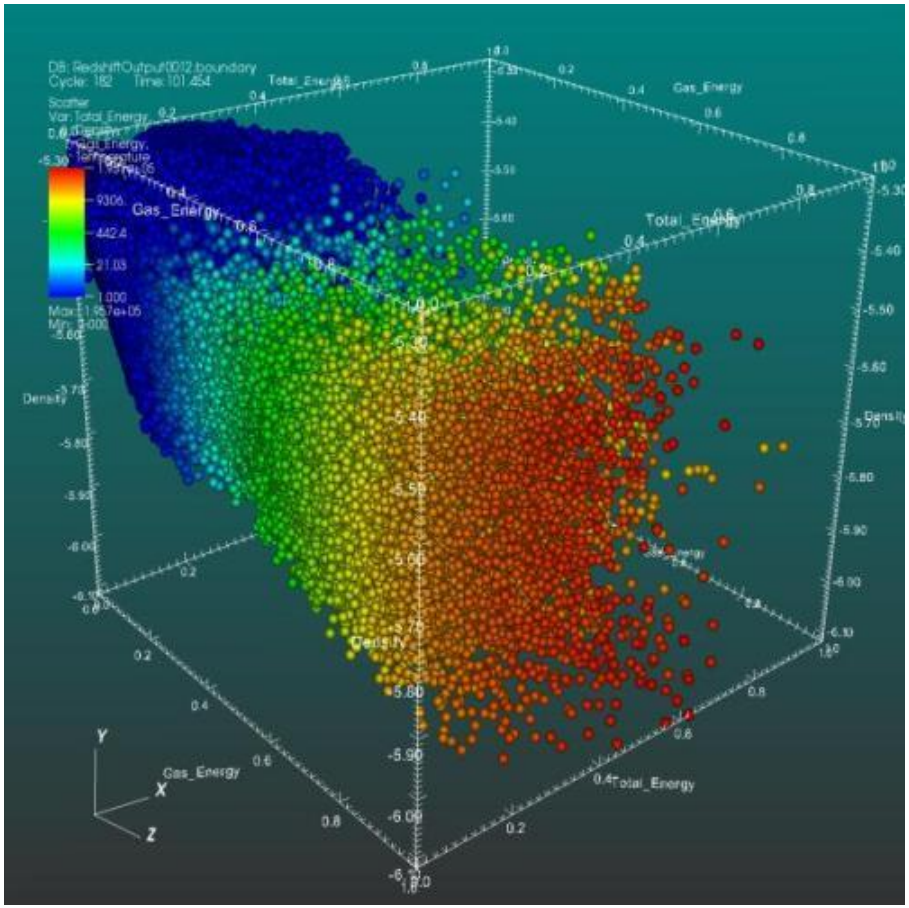
Medical Data Visualization

- PET scan for tumor diagnosis



[Wikipedia]

Data Visualization

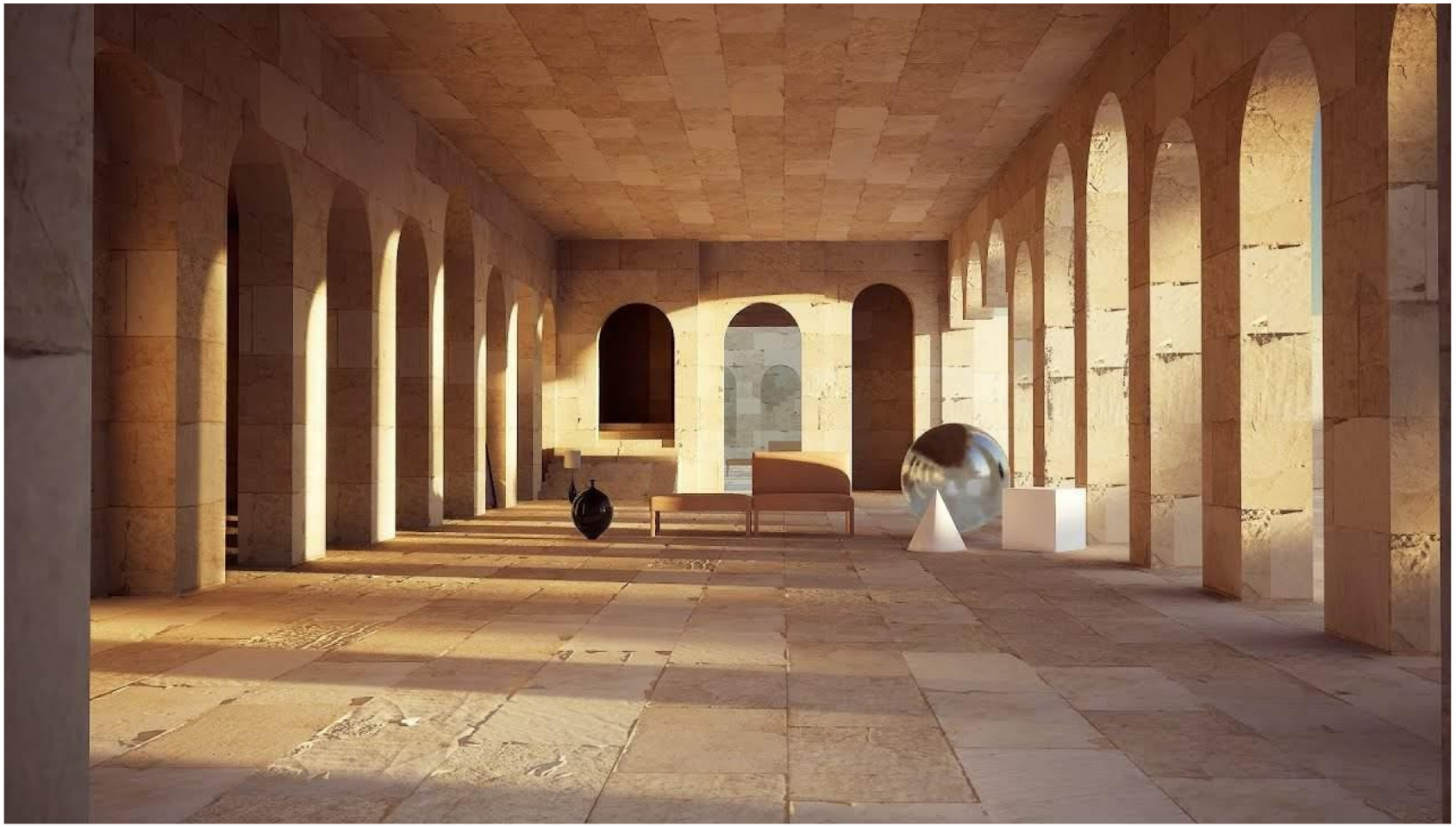


[Wikipedia]

Visualizing Population Density

Realistic Image Synthesis – dezeen

Global Illumination



immersivelearning.news

CG – Some YouTube videos

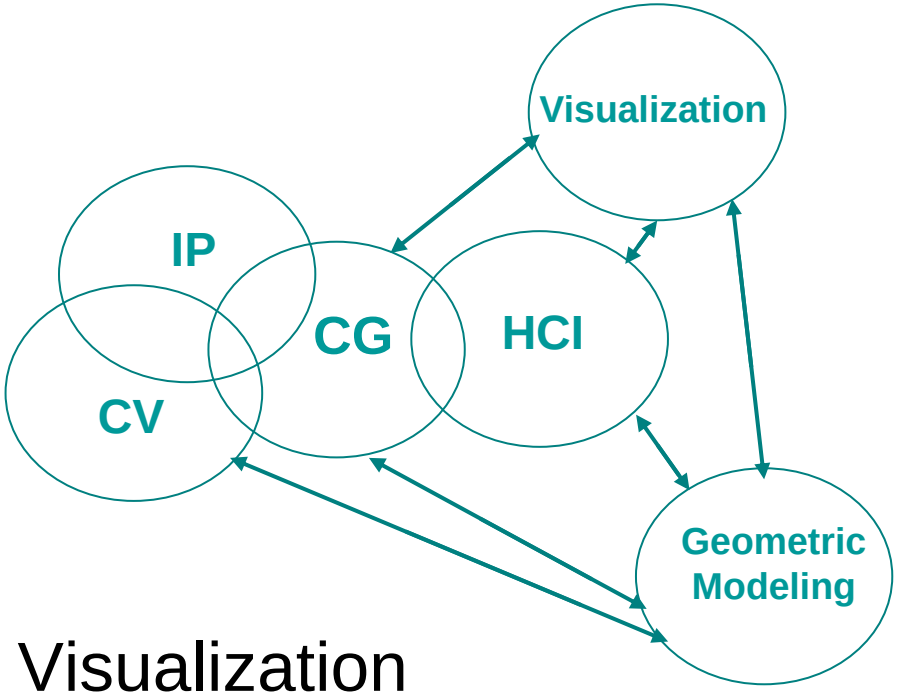
- SIGGRAPH 2021
  - Technical Papers Trailer
  - VR Theater
  - Computer Animation Festival Electronic Theater

CG IS NOT ALONE

Computer Graphics vs …

		Output	
		Model	Image
Input	Model	Geometric Modeling	Computer Graphics
	Image	Computer Vision	Image Processing

CG is not alone…



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

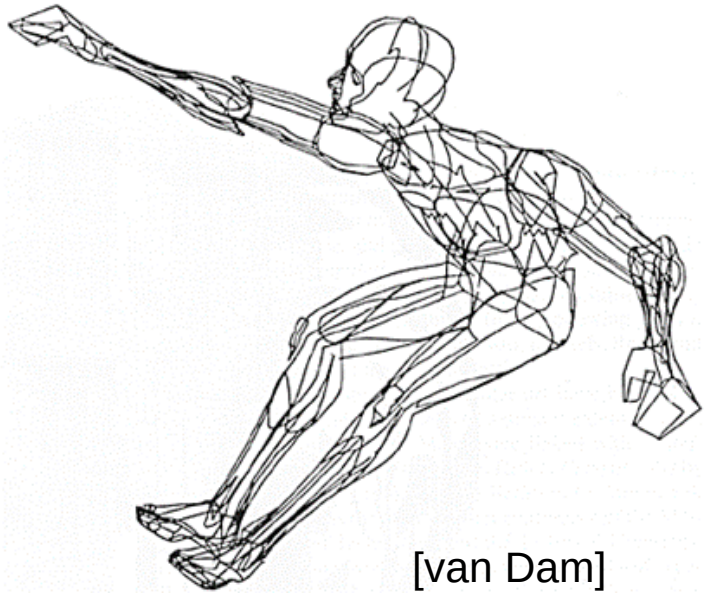
[www.mevislab.de]

EVOLUTION

Lara Croft

Computer Graphics: 1950 – 1960

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

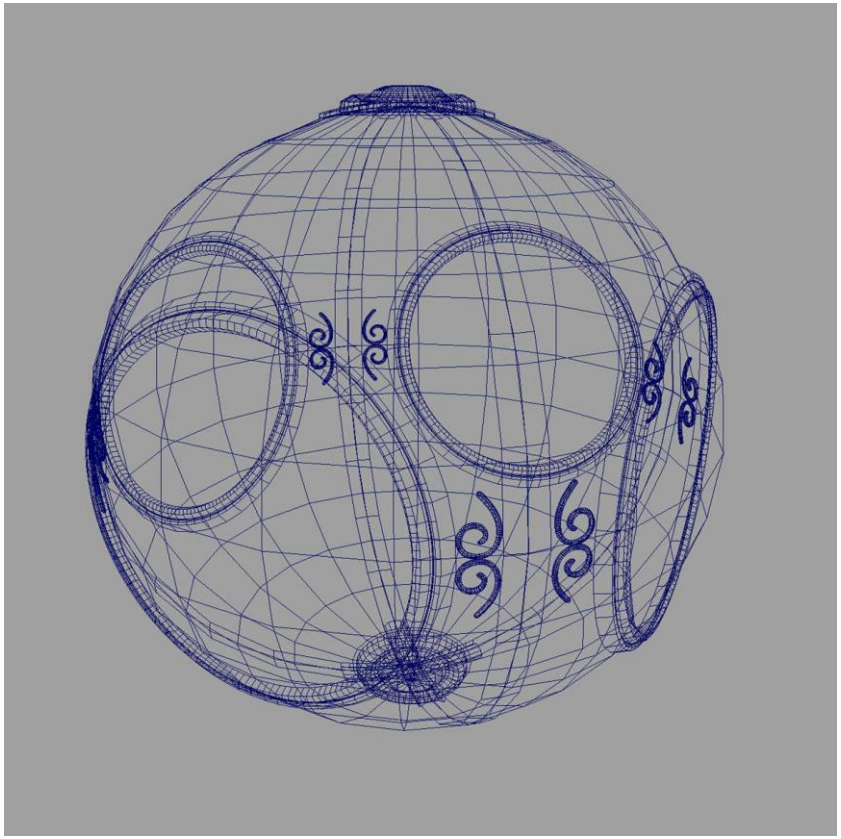


[van Dam]

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

Computer Graphics: 1960 – 1970

- Wireframe graphics
  - Draw only lines !

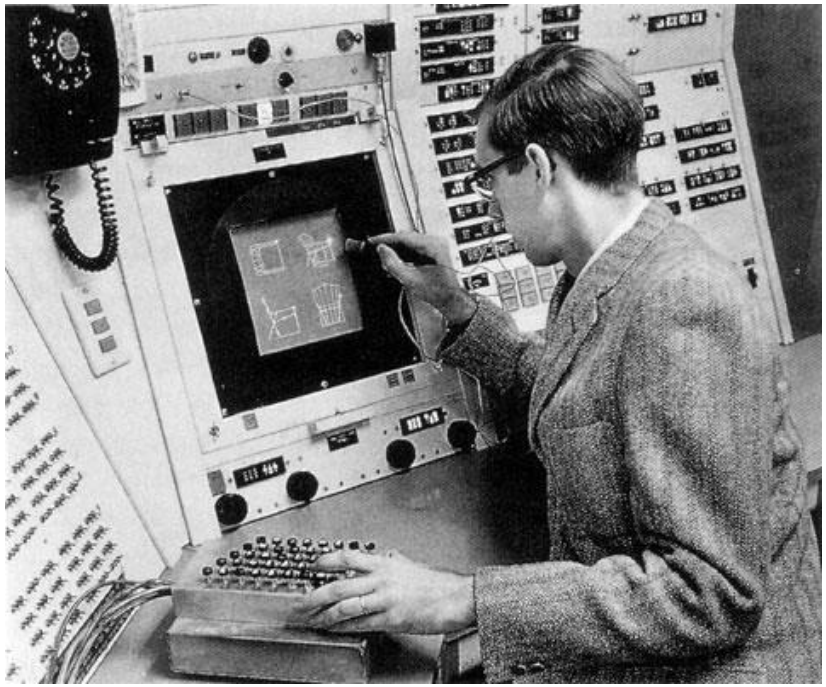


[Angel]

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

Demo at YouTube



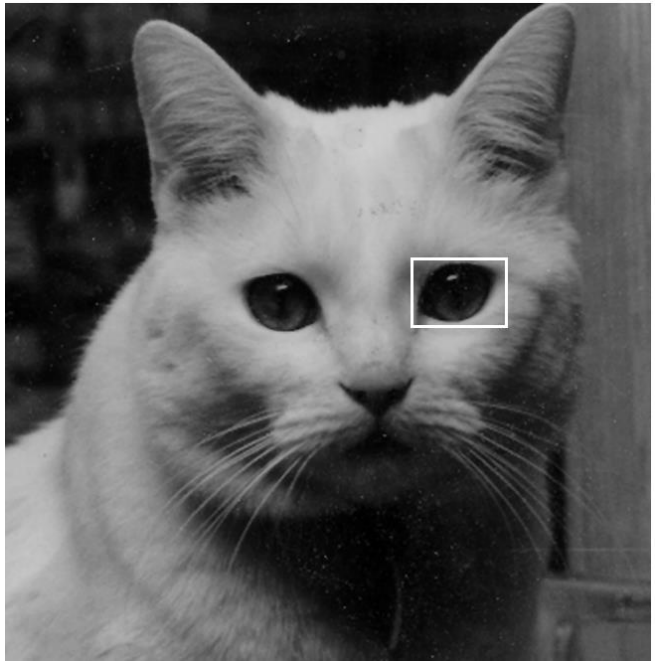
[http://history-computer.com]

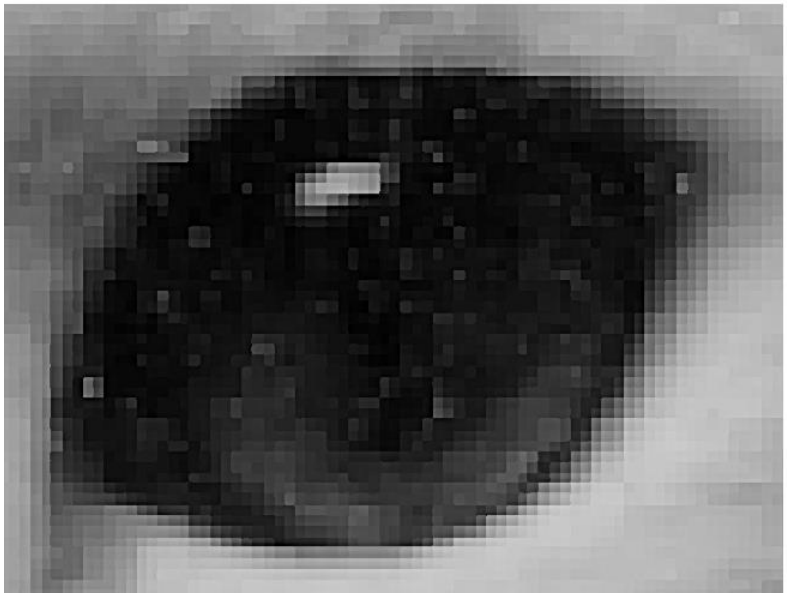
Computer Graphics: 1970 – 1980

- Raster graphics
  - Allows drawing polygons
- First graphics standards
- Workstations and PCs
- WIMP GUI + WYSIAWYG
  - Desktop metaphor
  - Selection and direct manipulation

Raster graphics

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

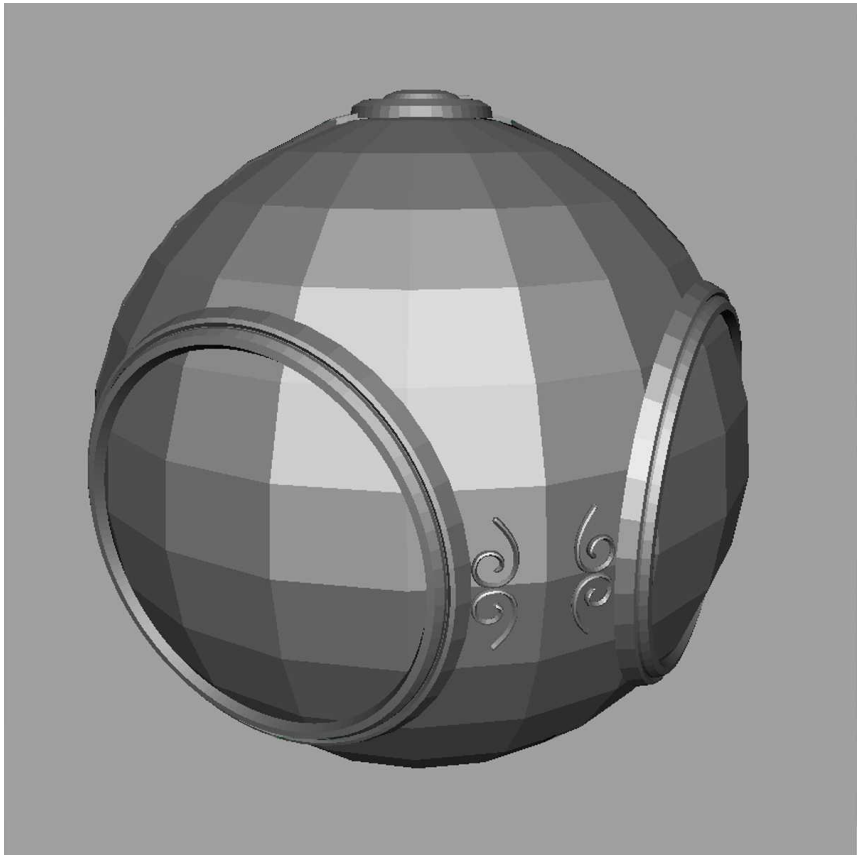




[Angel]

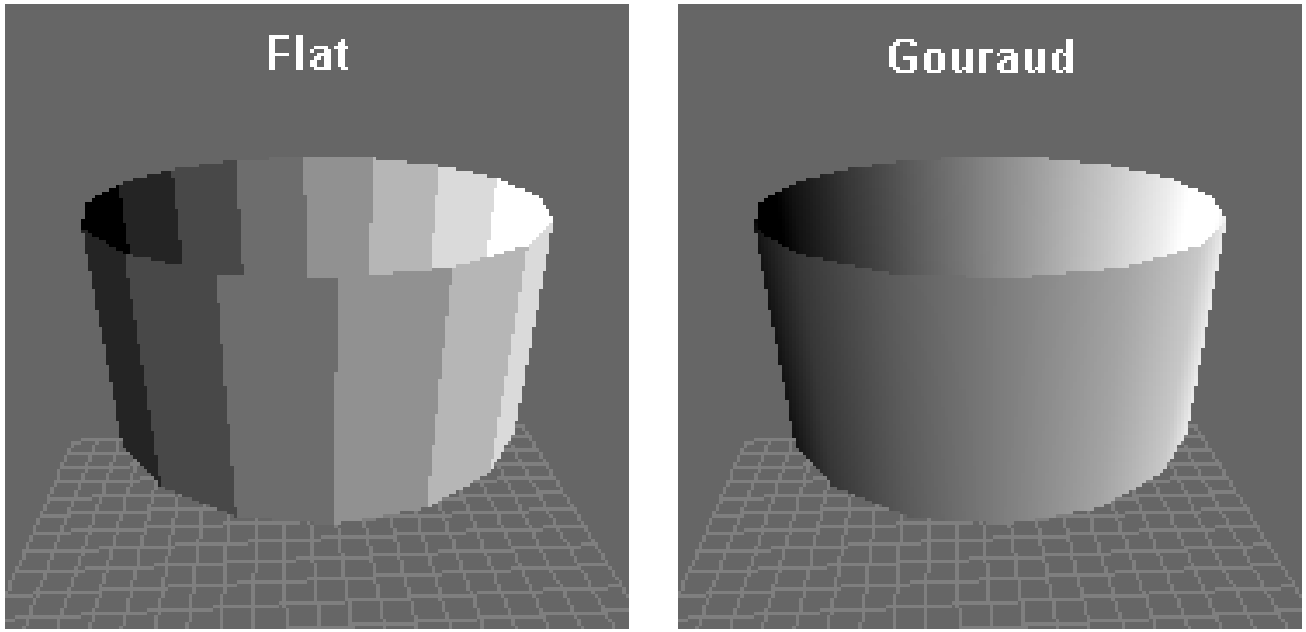
Raster graphics

- Drawing polygons
- Illumination models
- Shading methods



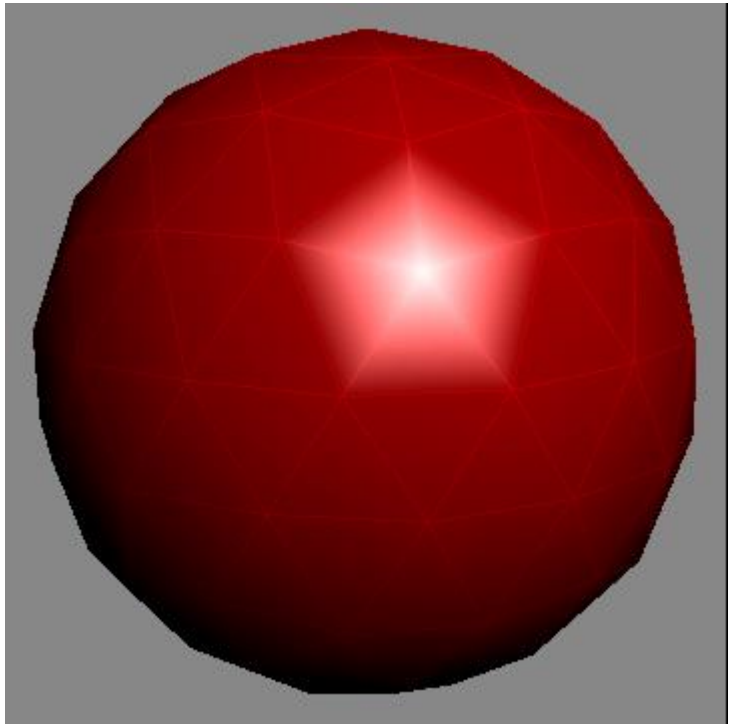
[Angel]

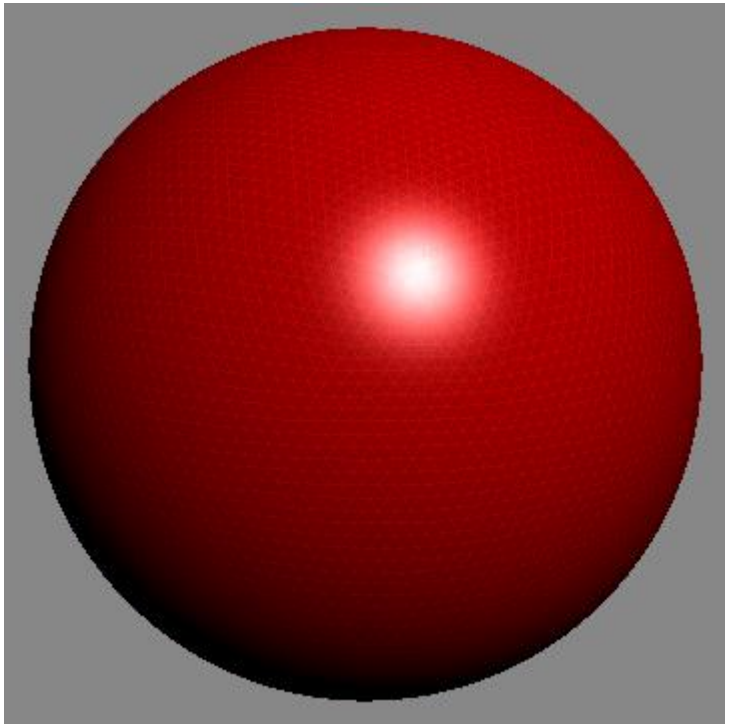
Gouraud shading – 1971



[Wikipedia]

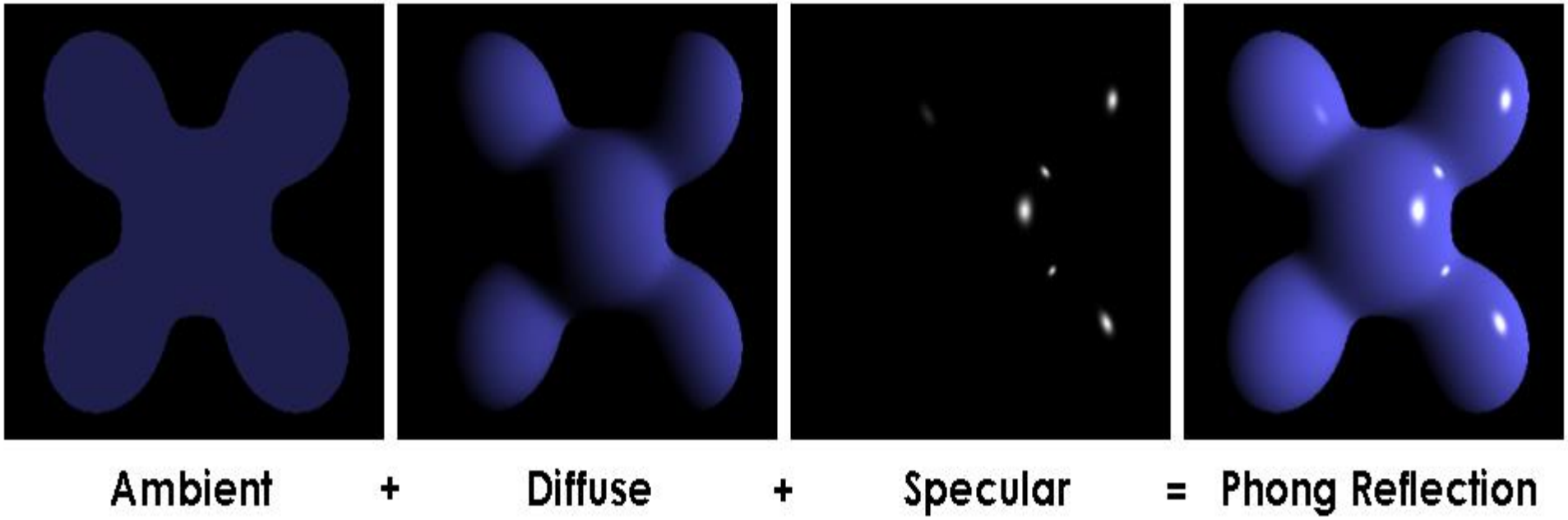
Gouraud shading





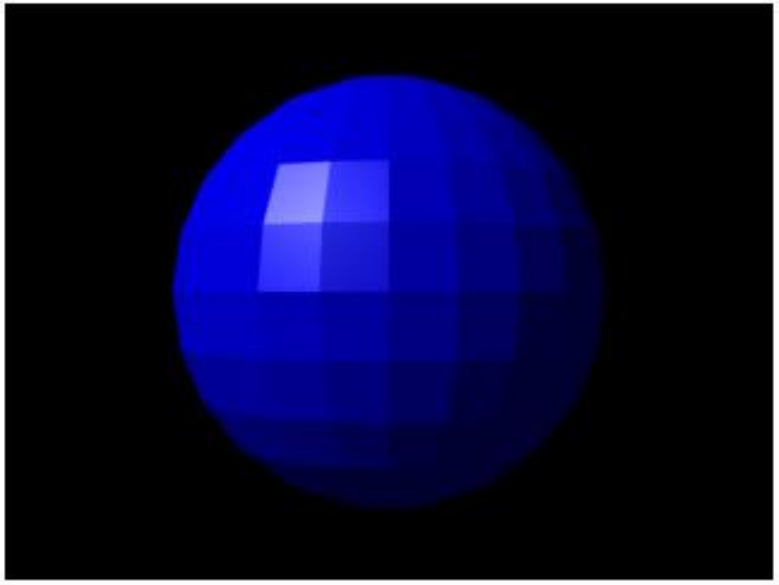
[Wikipedia]

Phong reflection model – 1973

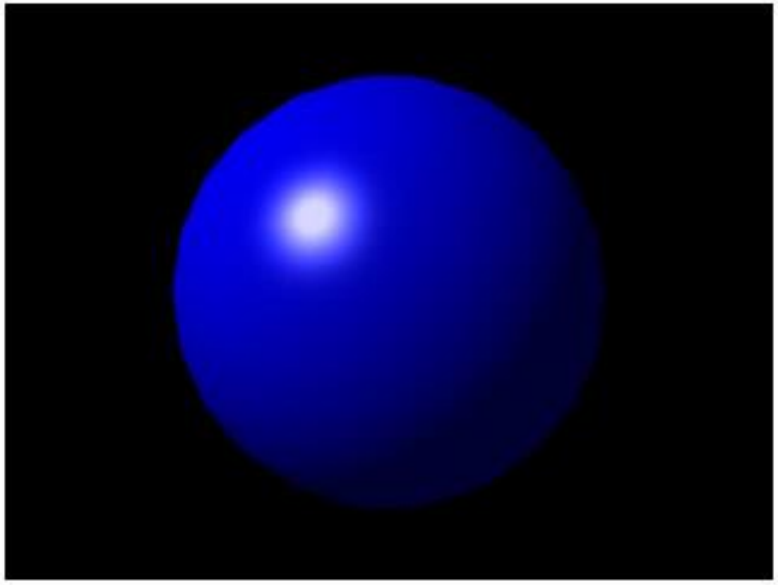


[Wikipedia]

Phong shading – 1973



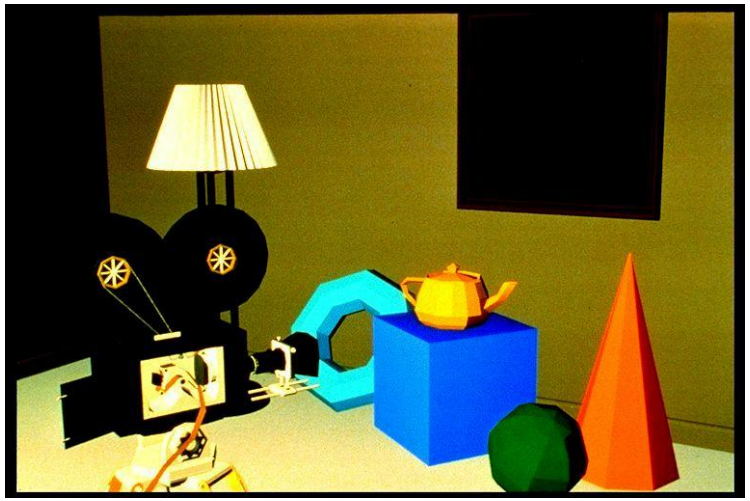
FLAT SHADING

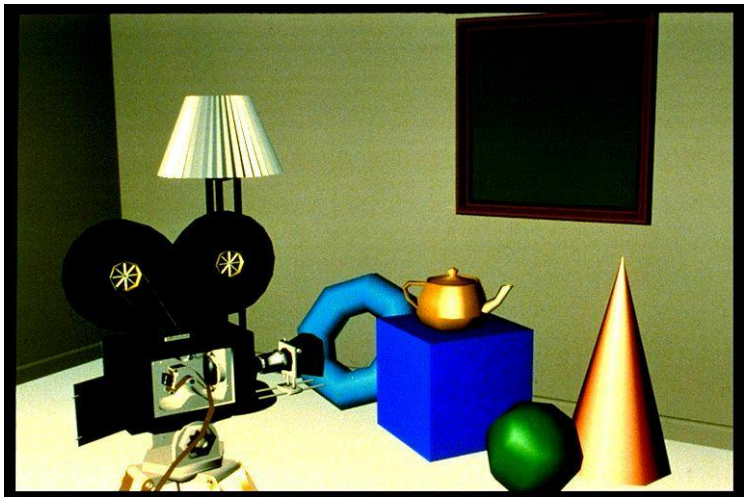


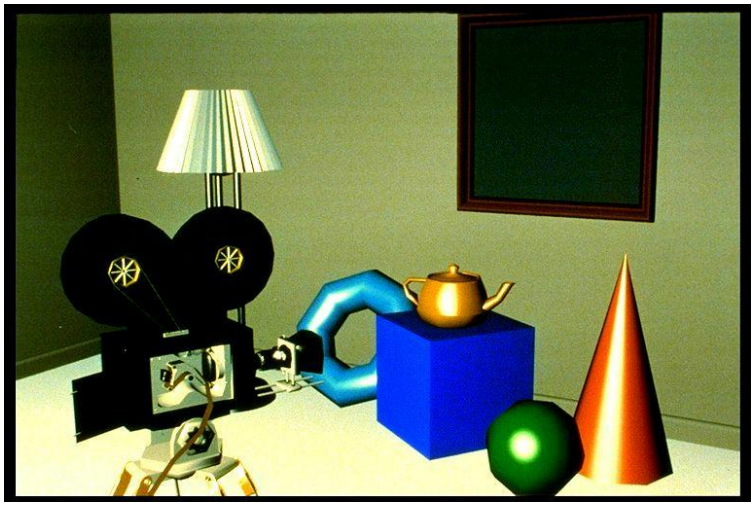
PHONG SHADING

[Wikipedia]

Can you spot the differences ?

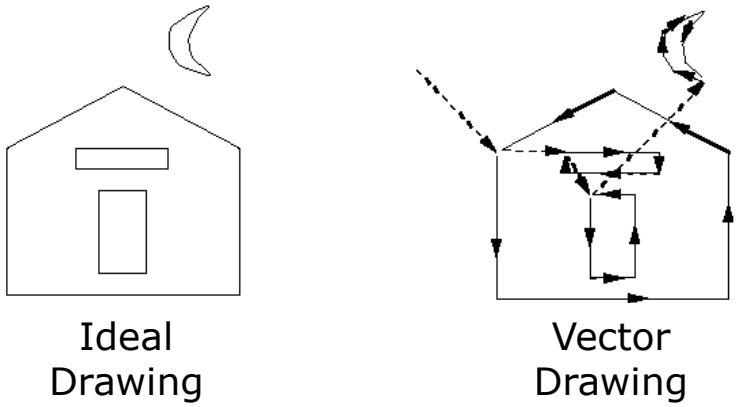






Vector graphics vs Raster graphics

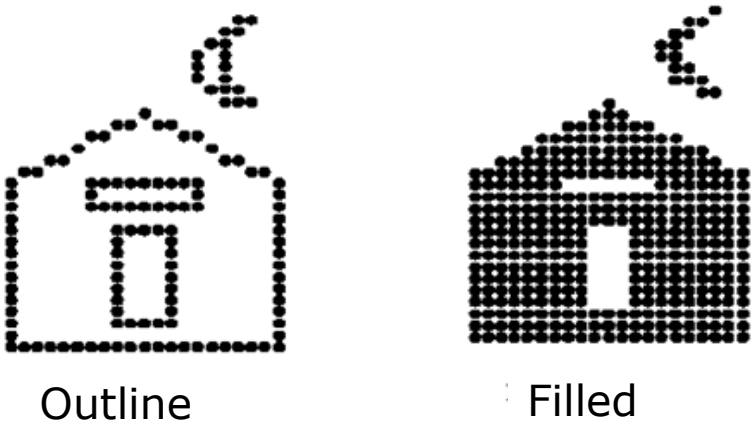
- Vector graphics is driven by display commands
  - move(x,y); line(x,y); …
  - Survives as SVG – Scalable Vector Graphics



[van Dam]

Vector graphics vs Raster graphics

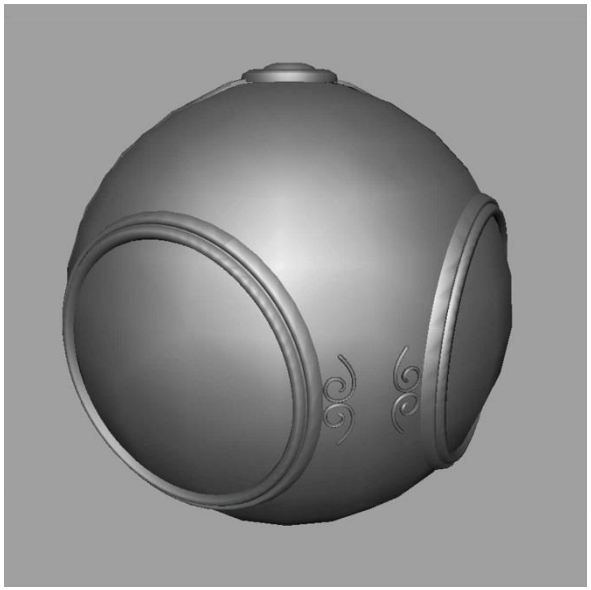
- Raster graphics is used in TV displays and laser printers
  - Lowest level of representation
  - No semantics
  - BUT aliasing errors



[van Dam]

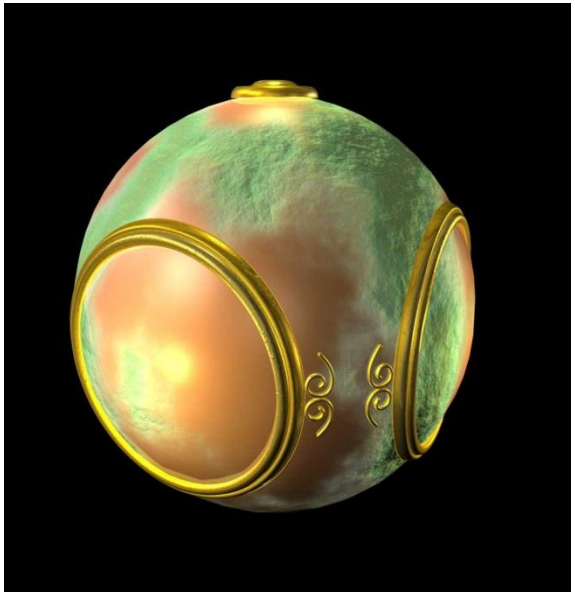
Computer Graphics: 1980 – 1990

- The quest for realism



Smooth shading

Environment mapping

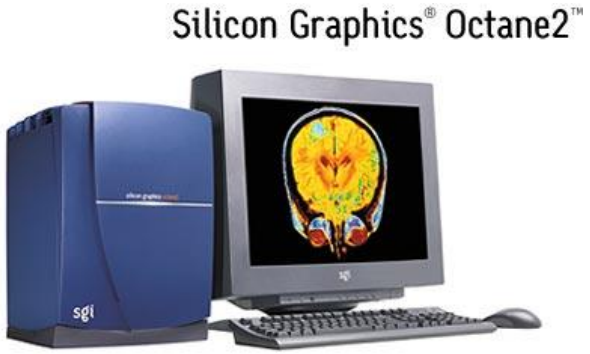


Bump mapping

[Angel]

Computer Graphics: 1980 – 1990

- Special purpose hardware
  - Graphics workstations
- Industry-based standards
  - PHIGS
  - RenderMan
- Human-Computer Interaction



Graphics workstations such as these have been replaced with commodity hardware (CPU + GPU),

[van Dam]

Computer Graphics: 1990 – 2000

- OpenGL API

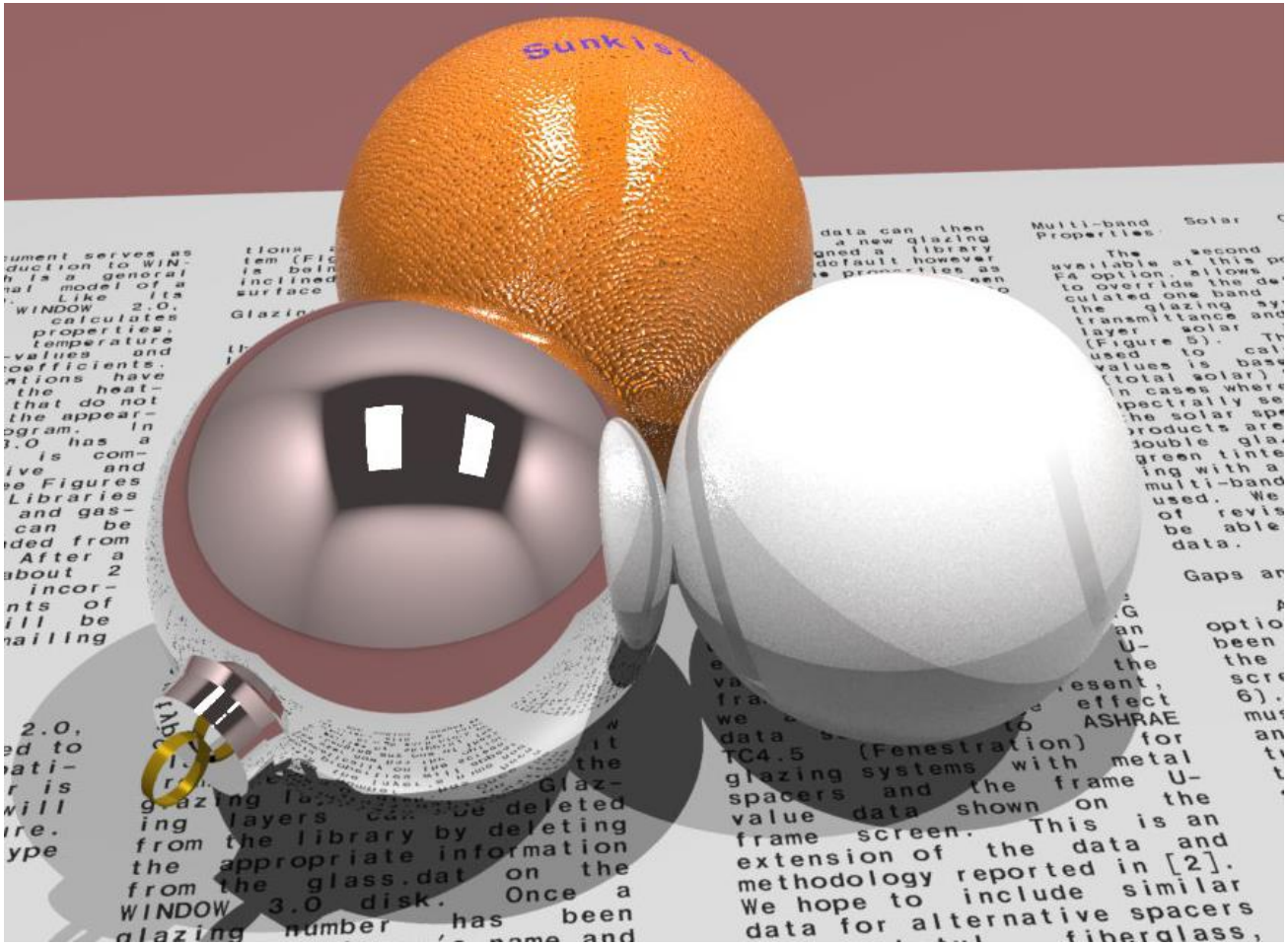
- First successful computer-generated feature-length animation film: Toy Story

- New hardware capabilities

Computer Graphics: 2000 – …

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

Ray-Tracing example

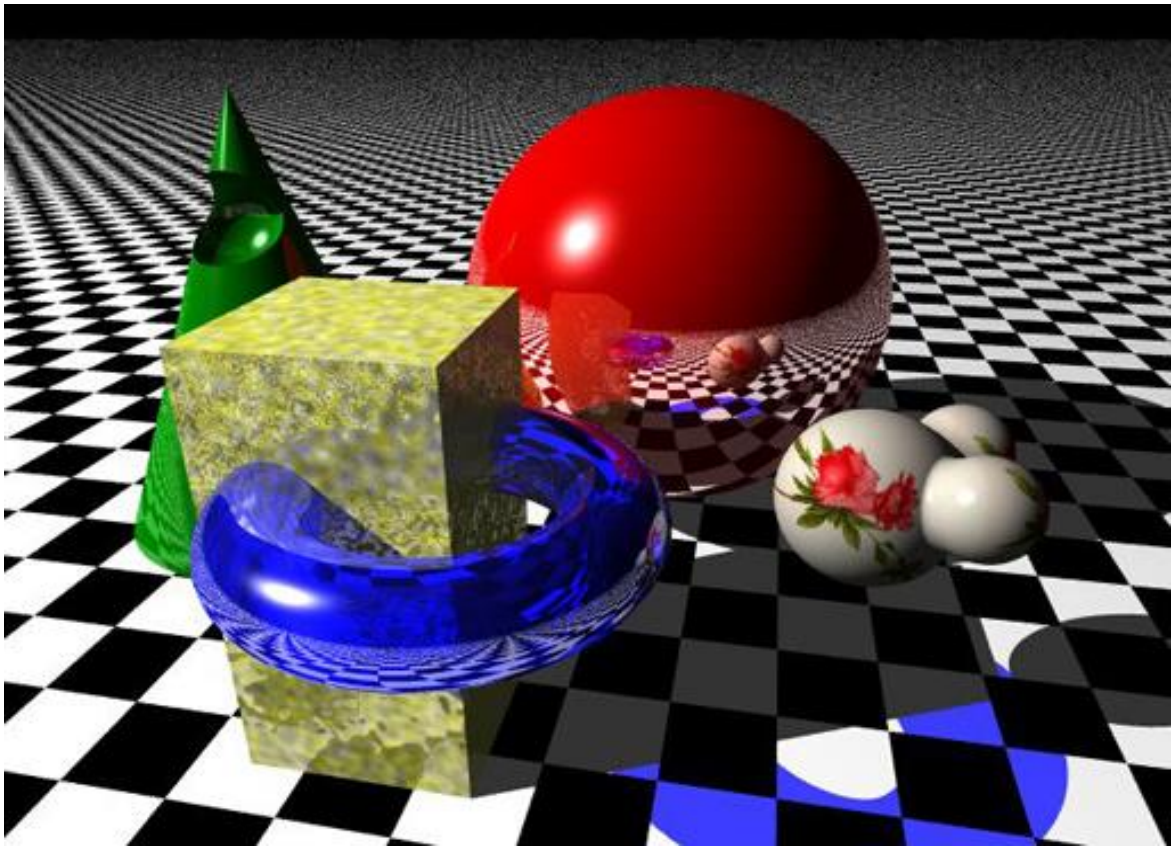


http://radsite.lbl.gov/radiance/book/img/plate10.jpg

"Vermeer's Studio"

Wallace & Cohen, 1987: Radiosity and Ray-Tracing

Another Ray-Tracing example

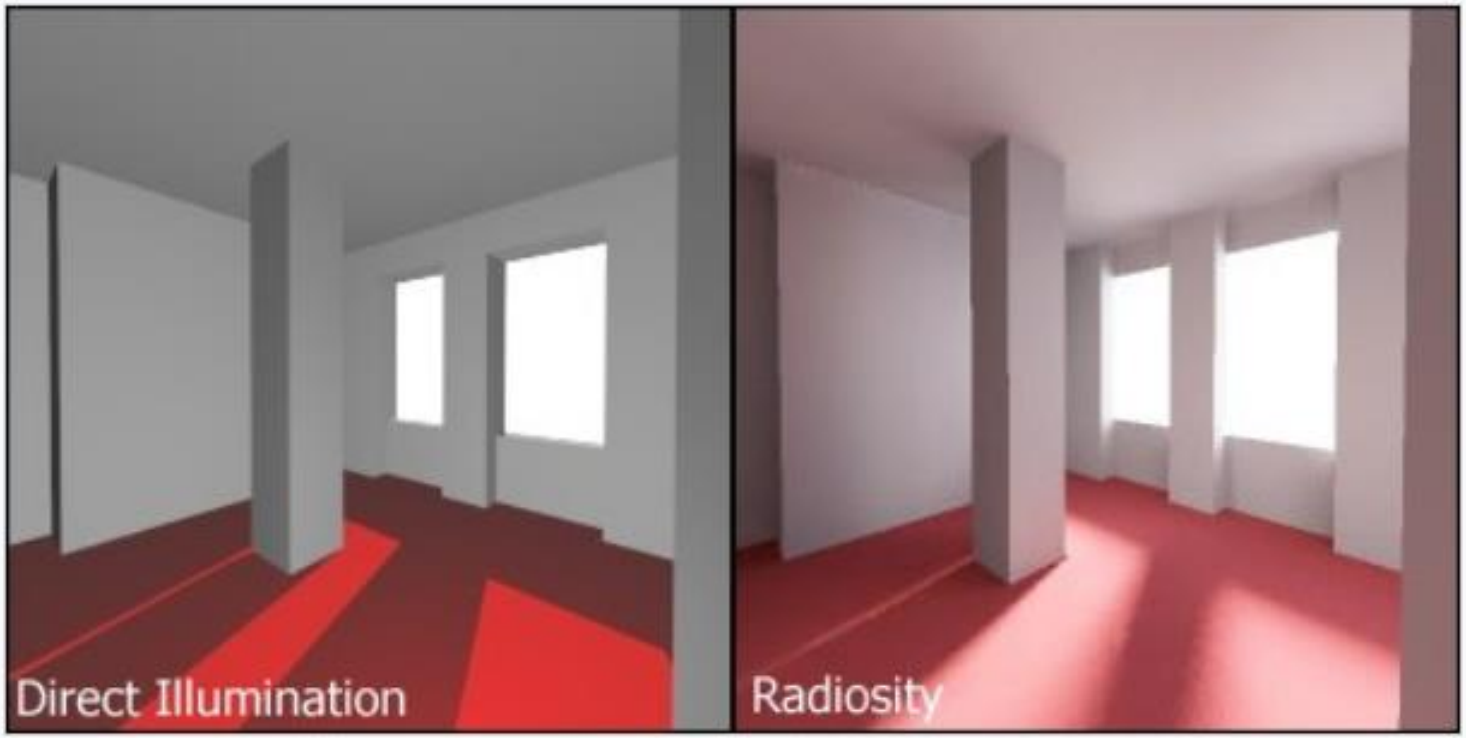


http://www.tjhsst.edu/~dhyatt/superap/samplex.jpg

Ray-Tracing + Radiosity

[Wikipedia]

Radiosity



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

[Wikipedia]

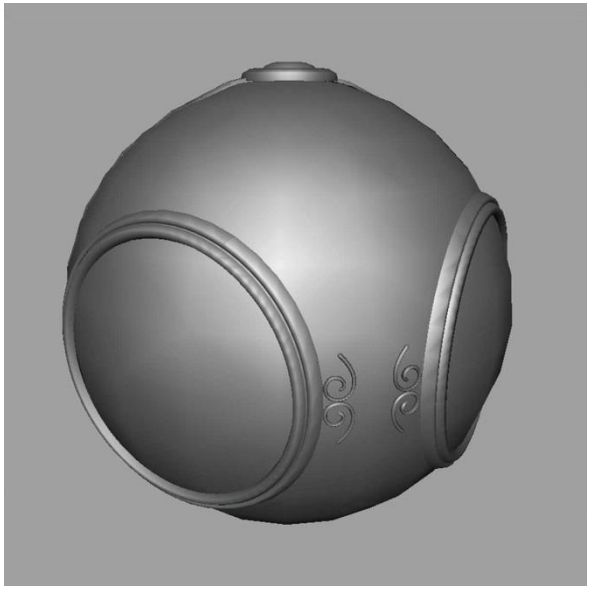
Radiosity

Without radiosity

With radiosity

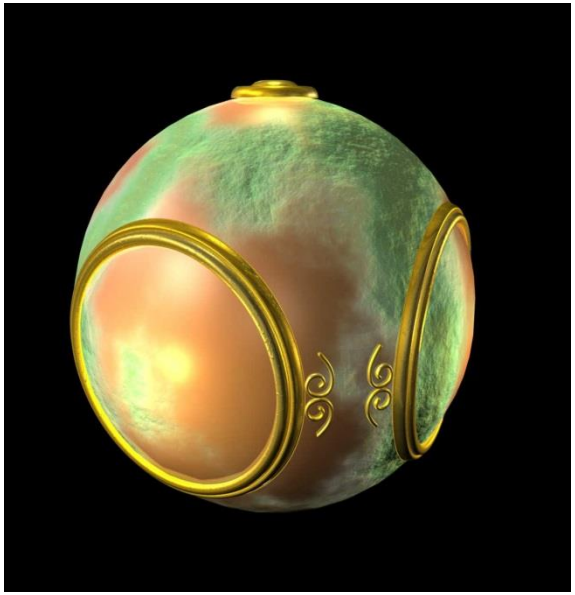
[Burdea]

Texture mapping



Smooth shading

Environment mapping



Bump mapping

[Angel]

Textures – Simulating Ray-Tracing

[http://www.okino.com]

- Increased realism !!
  - 11 light sources + 25 texture maps

TRENDS & TECHNOLOGIES

Current Panorama

- Augmented Reality used in Hollywood film making
- Virtual Reality WILL be massive !
  - Crash test dummies
  - New car design / development
- Pixar is here !
  - RenderMan is free !!

Current Panorama

- Science and Maths enabling and profiting from advances
  - Modeling / Simulation / Animation
- Gamification
  - Unreal Engine / Unity / Cryengine

Enabling technologies for modern CG

- Graphics subsystems
  - Offload processing from CPU to GPU, for doing graphics operations much quicker
- Hardware constant "revolution"
  - Moore's Law
  - Multi-core 64-bit CPUs
  - Advances in commodity GPUs every 6 months vs. some years for general purpose CPUs

Enabling technologies for modern CG

- Software improvements
- Algorithms and data structures
  - Modeling of materials
  - Rendering of natural phenomena
  - “Acceleration” data structures for rendering
- Parallelization
  - GPUs

Enabling technologies for modern CG

- Input devices
  - Mouse / tablet & stylus / multi-touch
  - Force feedback / game controllers
  - Scanners / digitizers / digital cameras
  - Body as interaction device

Xbox Kinect


Leap Motion


Nimble UX

[Andy van Dam]

Enabling technologies for modern CG

- Many form factors
  - Laptops / desktops
  - Smartphones / tablets
  - Smartwatches
  - HMDs
  - Augmented Reality
  - Virtual Reality


Apple iPhone


Android Phones


Tablets


Microsoft's first Surface


Apple Watch


Android Wear

[Andy van Dam]


Microsoft Hololens


Vive

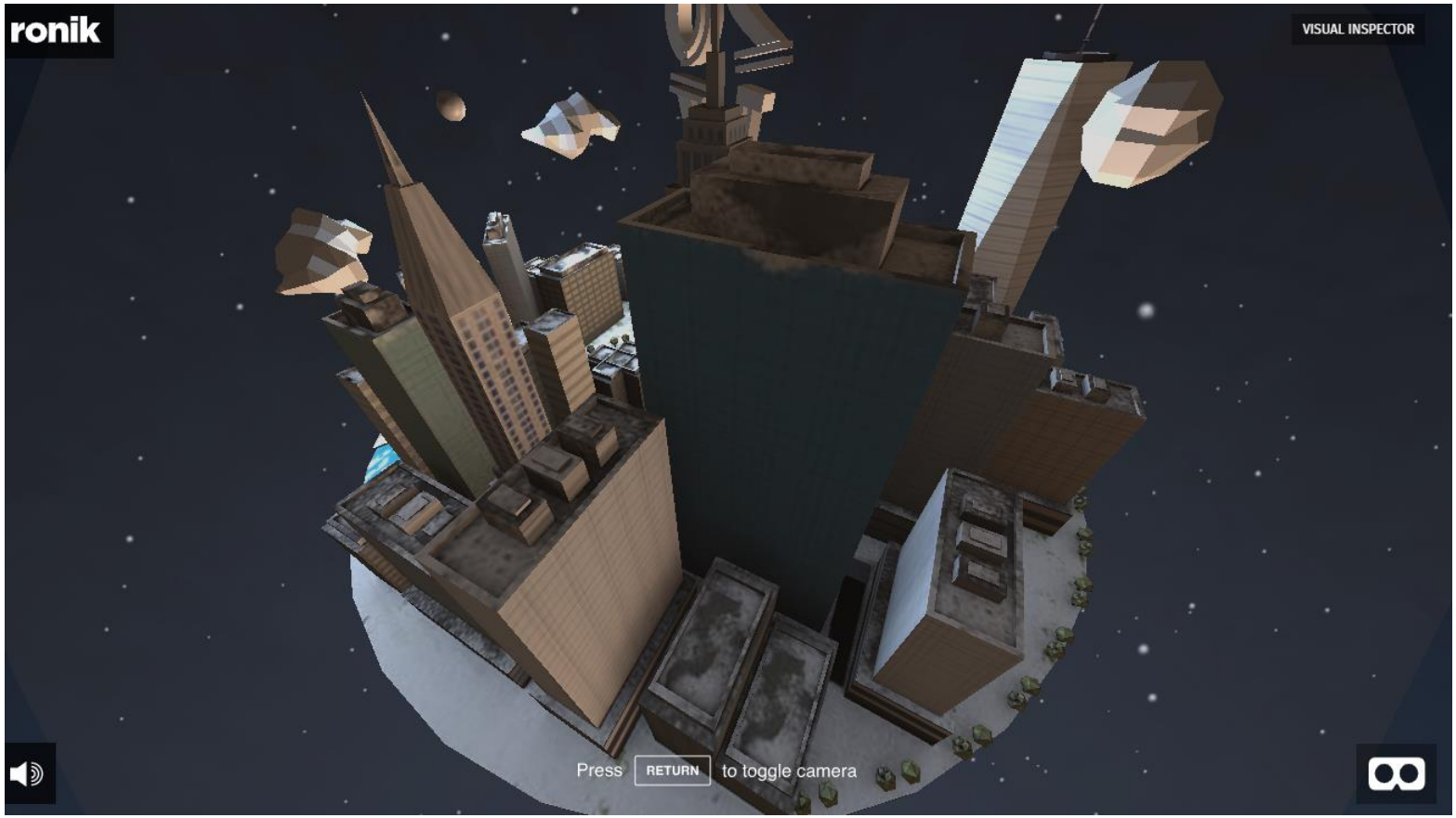

Oculus Rift


Google Cardboard

Mobile Graphics

[SIGGRAPH Asia 2017 Course Notes]

Web-based VR



[https://aframe.io/examples/showcase/snowglobe/]

Web-based CG and VR

- PlayCanvas - The Web-first game engine
- WebXR
- Sketchfab

INTERACTIVE VS BATCH CG

CG Main Tasks

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

Interactive Computer Graphics

- User controls content, structure, and appearance of objects and their displayed images, via rapid visual feedback
  - Also called real-time computer graphics or, in certain contexts, real-time rendering
- Remember Sutherland's Sketchpad (1963)
  - Monitor + light pen + function-key panels
  - Bimanual operation

Interactive CG – Basic components

- Input
  - Mouse / stylus / multi-touch / in-air fingers / …
- Processing and storing of the underlying models
- Display / Output
  - Screen / paper printer / 3D printer / video / …

Batch Computer Graphics

- Non-interactive, off-line rendering
- Final production-quality video and film
  - Animation / Special effects – FX
- Rendering a single frame of *The Good Dinosaur* (a 24 fps movie) averaged 48 hours on a 30,000-core render farm!
  - See statistics at fxguide article

Batch Computer Graphics

Still from *The Good Dinosaur*

Pixar's Render Farm

[Andy van Dam]

MAIN TASKS

CG Main Tasks

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

Modeling vs Rendering

- Modeling
  - Create models
  - Apply materials to models
  - Place models around scene
  - Place lights in the scene
  - Place the camera

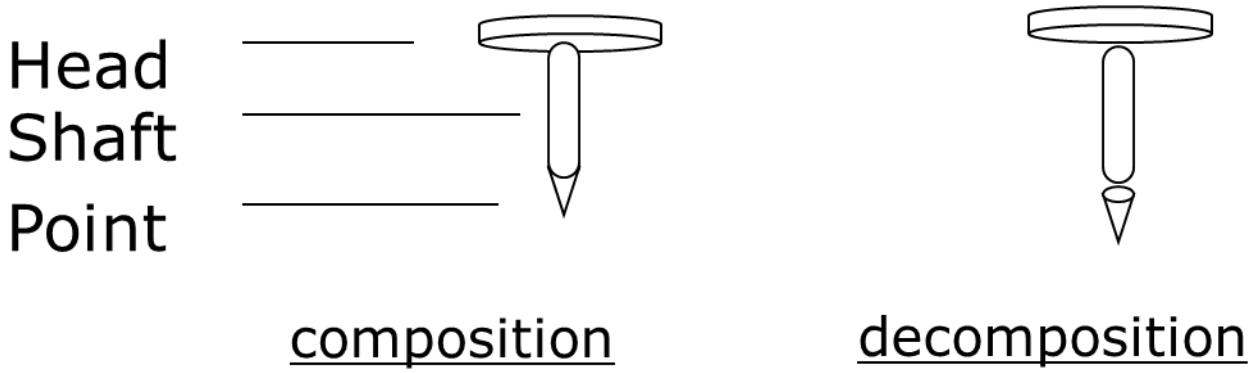
YouTube Demo

- Rendering
  - Take picture with the camera

[van Dam]

Decomposition of a geometric model

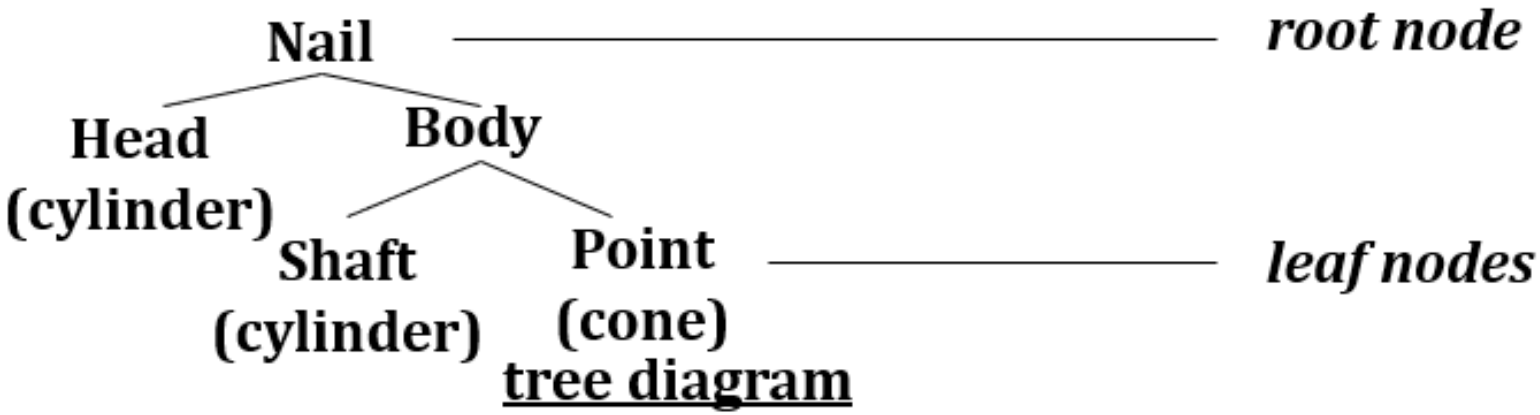
- Hierarchy of geometrical componentes
- Reduction to primitives
  - Spheres, cubes, etc.
- Simple vs not-so-simple elements



[van Dam]

Hierarchical representation

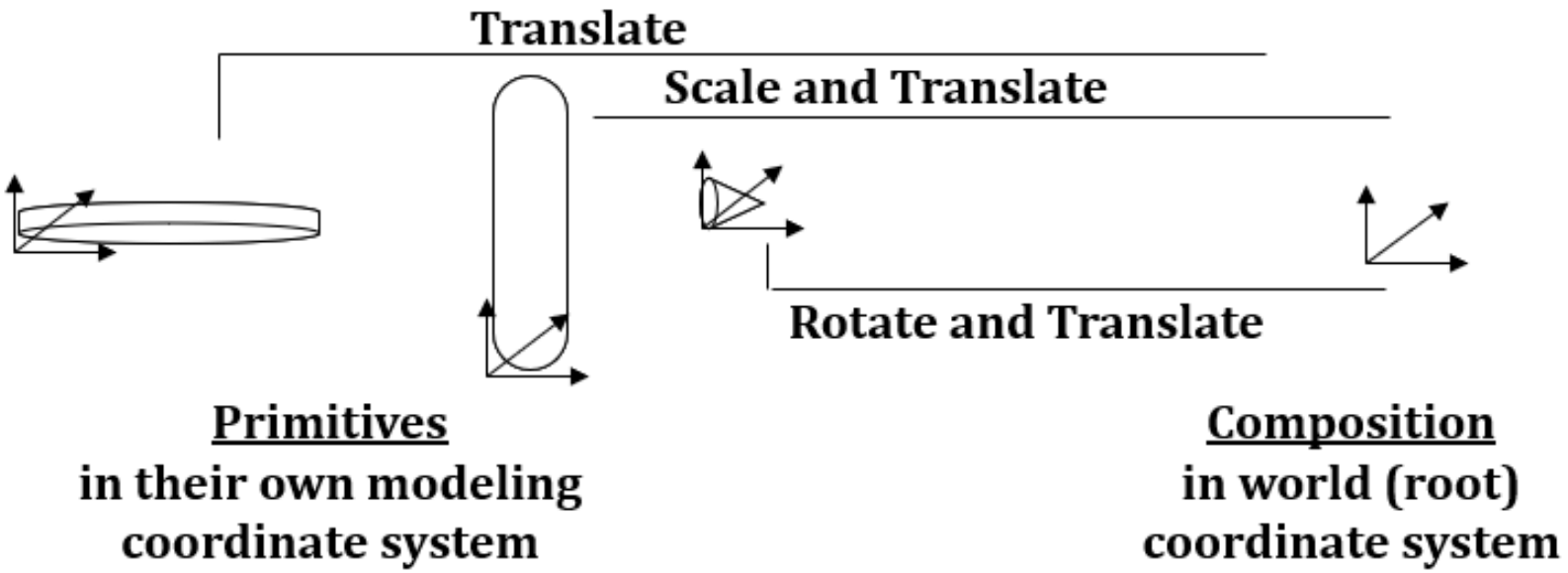
- Decomposition into collections of primitive shapes
  - Tree diagram
- Scene-graph : data structure to be rendered



[van Dam]

Composition of a geometric model

- Assemble primitives to create final object
  - Apply affine transformations

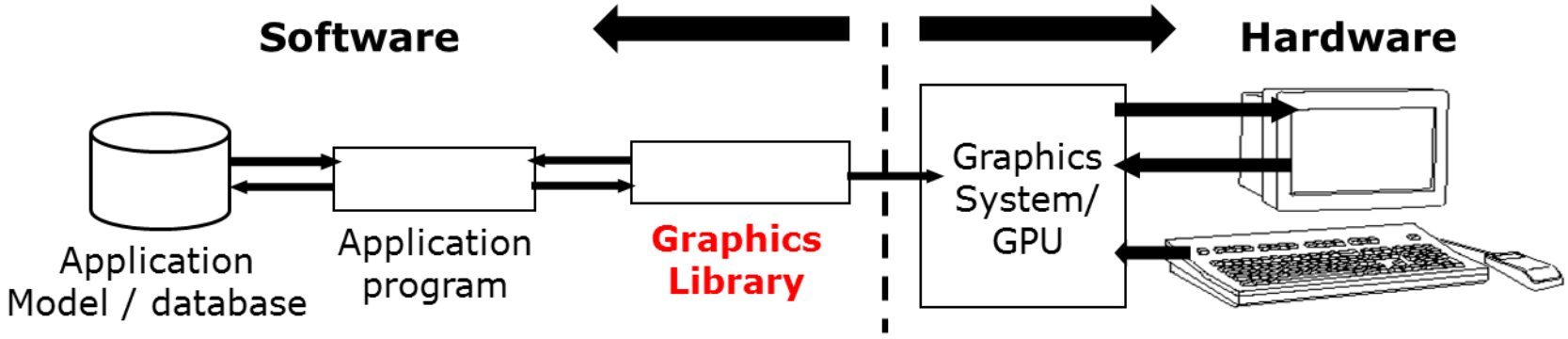


[van Dam]

GRAPHICS APIS / LIBRARIES

Interactive Computer Graphics

- Graphics library / package is intermediary between application and display hardware
- Application program maps / renders objects / models to images by calling on the graphics library
- User interaction allows image and / or model modification



[van Dam]

Graphics Libraries / APIs

- OpenGL, RenderMan, DirectX, Windows Presentation Foundation (WPF), HTML5 + WebGL, three.js, Vulkan, …
- Primitives : characters, points, lines, triangles, …
- Attributes : color, line /polygon style, …
- Transformations : rotation, scaling, …
- Light sources
- Viewing
- …

API contents

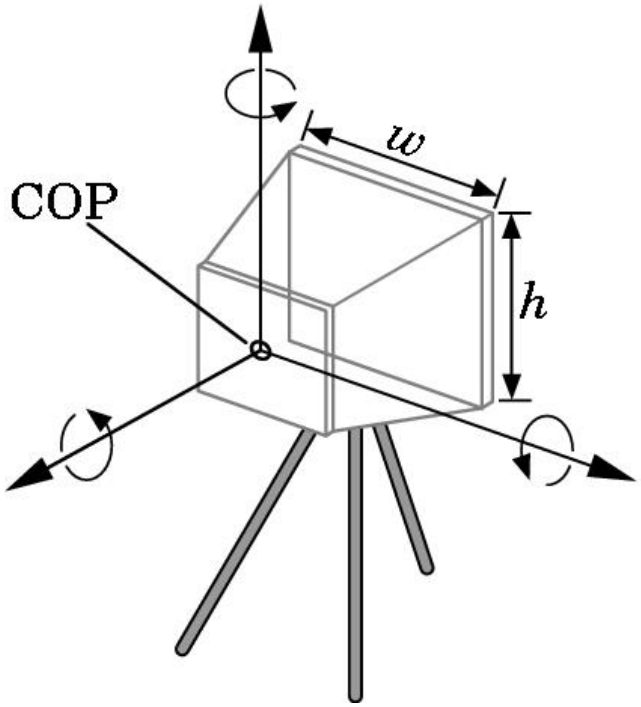
- Functions for specifying / instantiating
  - Geometric primitives
  - Viewer / Camera
  - Light sources
  - Materials
  - …
- Functions for simple user interaction
  - Input from devices: mouse, keyboard, etc.

Geometric Primitives

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

Camera specification

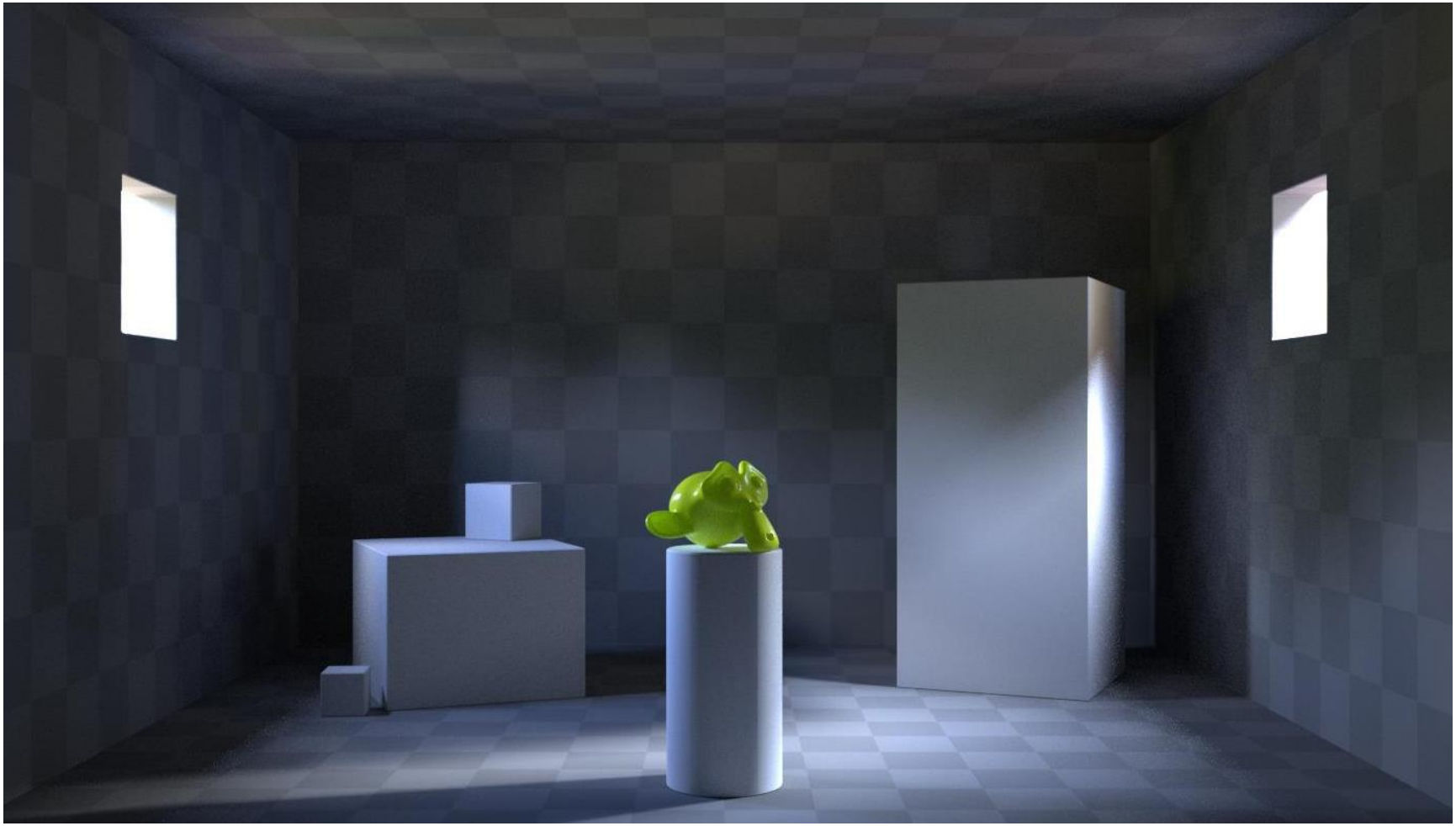
- Six degrees of freedom
  - Position of lens center
- Lens
- Film size
- Orientation of film plane



[Angel]

Lights and materials

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



https://blenderartists.org/t/what-if-i-want-a-low-light-in-door-scene/685160

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

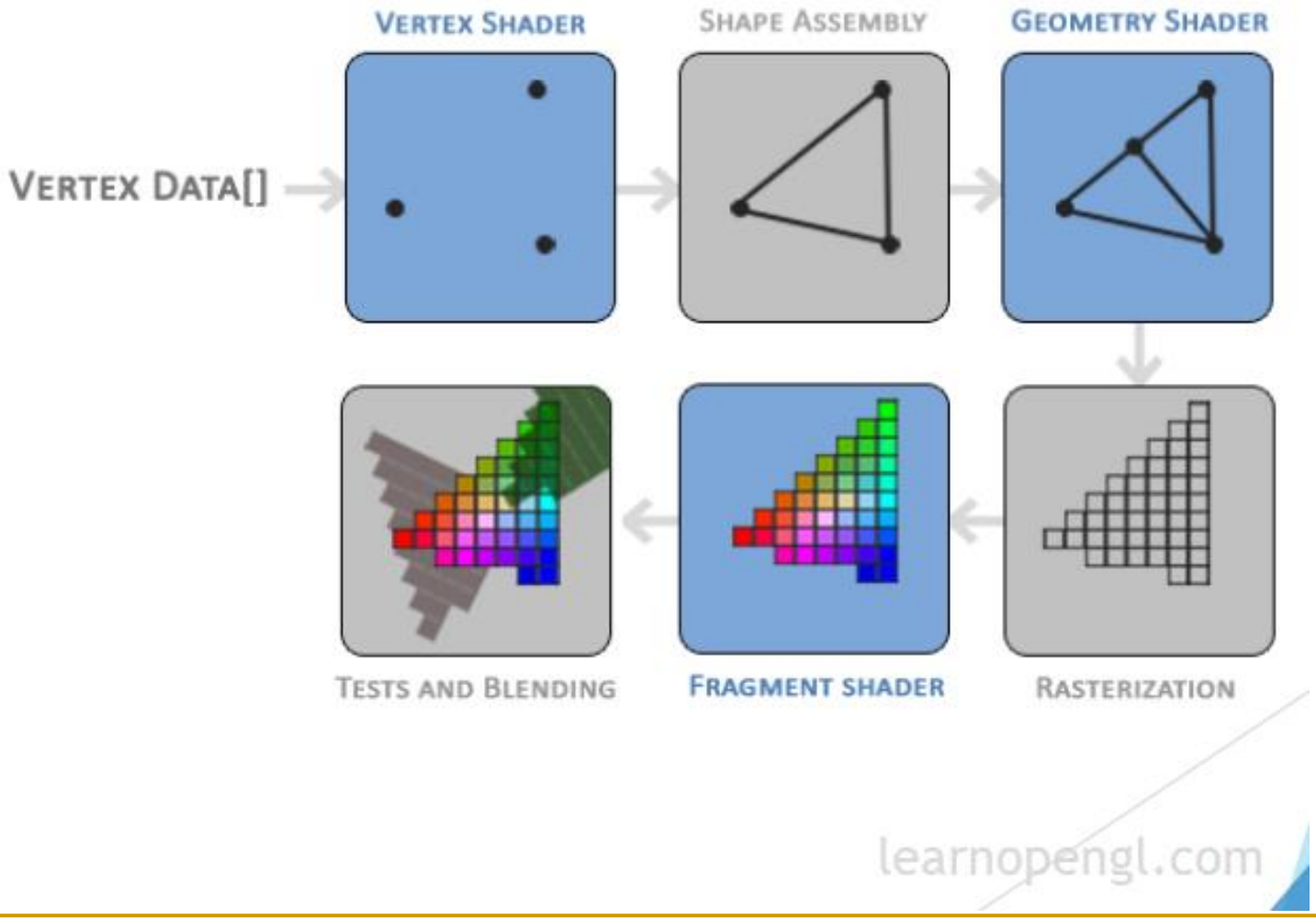
- OpenGL ES
  - Subset for use in embedded systems and portable devices

- 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

GPUs

- Large collection of highly parallel high-speed arithmetic units; several thousand cores !
- GPUs run simple programs ("shaders")
  - Take in vertices and other data
  - Output a color value for an individual pixel
- GLSL, (O)GL Shader Language, is a C-like language; controls arithmetic pipelines

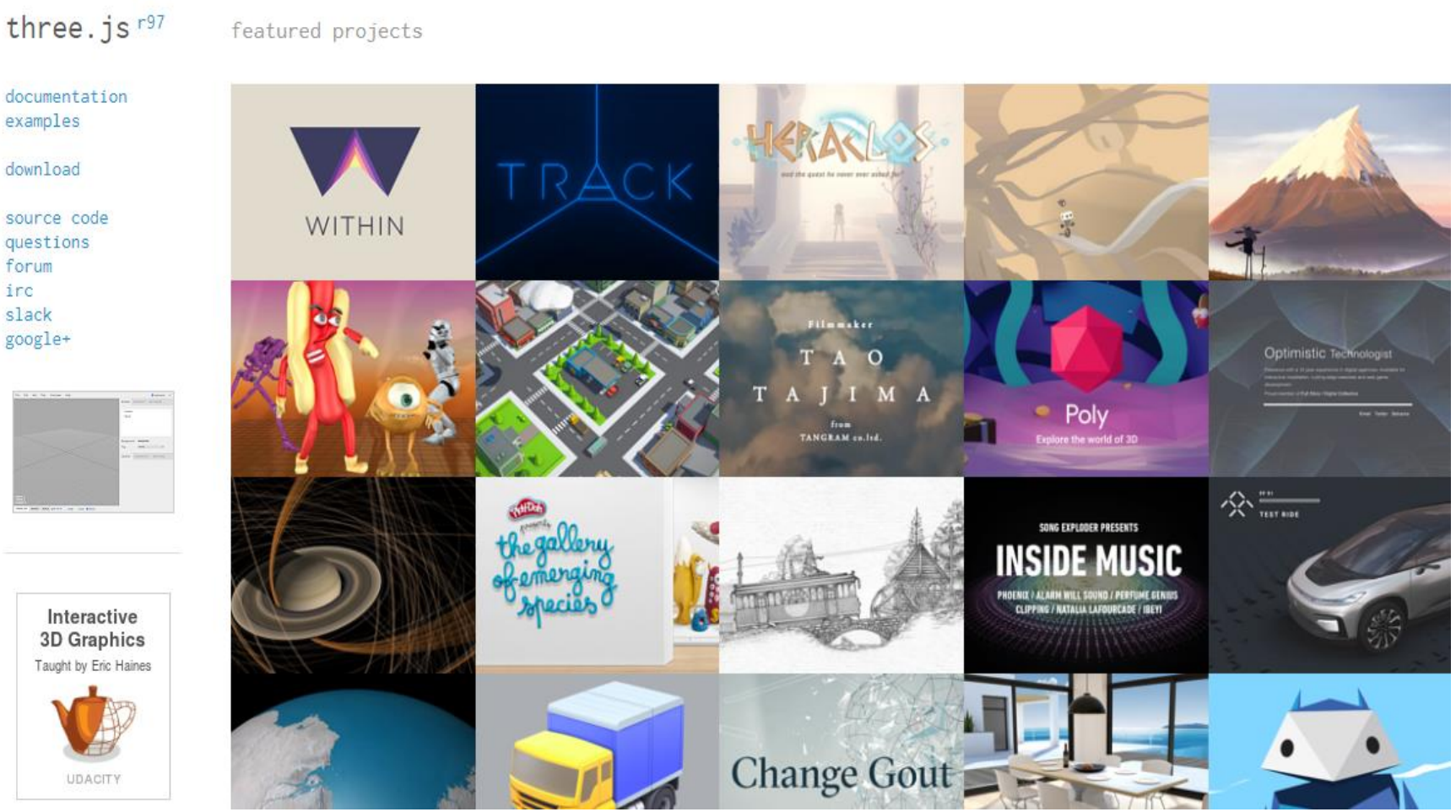
Shaders


VERTEX SHADER
SHAPE ASSEMBLY
GEOMETRY SHADER
VERTEX DATA[]
TESTS AND BLENDING
FRAGMENT SHADER
RASTERIZATION
learnopengl.com

Three.js

- Create and display 3D CG in Web-browsers
  - Cross-browser Javascript API
  - No need for browser plug-ins !
- No need to develop stand-alone apps !
- Uses WebGL !
- threejs.org

Three.js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Optimistic Technologist
the gallery of emerging species
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INSIDE MUSIC
PHOENIX / ALARM WILL SOUND / PERFUME GENIUS
CLIPPING / NATALIA LAFOURCADE / IBEYI
TEST RIDE
Change Gout
Interactive
3D Graphics
Taught by Eric Haines
UDACITY

RECAP

In Summary

- Computer graphics involves both real-time / interactive and batch / offline applications
  - Both equally important, but different use cases
- Photo-realism has really advanced !!
  - But it still takes dozens of hours on fastest computers to mimic physical behavior

In Summary

- Hardware evolution from vector to raster graphics
  - But we still have SVG
- Geometry-based vs Image-based graphics
  - Mathematical definition vs pixel manipulation

In Summary

- Complex geometric models typically constructed hierarchically
  - Scene-graph data structure
- Pixels are discrete samples of continuous functions
  - Causes artifacts (“jaggies”/ “aliases”) to appear
  - Need fixing through “anti-aliasing”

In Summary

- Geometric models allow representing objects or characters
  - Geometry / Detail / …
  - Material / Appearance
  - Static vs Animated / Deformable models
- Scene modeling
  - Place models / light sources
  - Place the camera

REFERENCES

References

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- J. F. Hughes, A. van Dam, et al., “Computer Graphics: Principles and Practice”, 3rd ed, Addison-Wesley, 2013
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  - https://learning.oreilly.com/library/view/hughes-computer-graphics-3-e/9780133373721/

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