An Introduction to Computer Graphics

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October 2020

Overview

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

PIXAR'S COMPUTER-ANIMATED FILMS

Onward (2020)

Trailer at YouTube

- Pixar's latest computer-animated film

Toy Story 4 (2019)

Trailer at YouTube

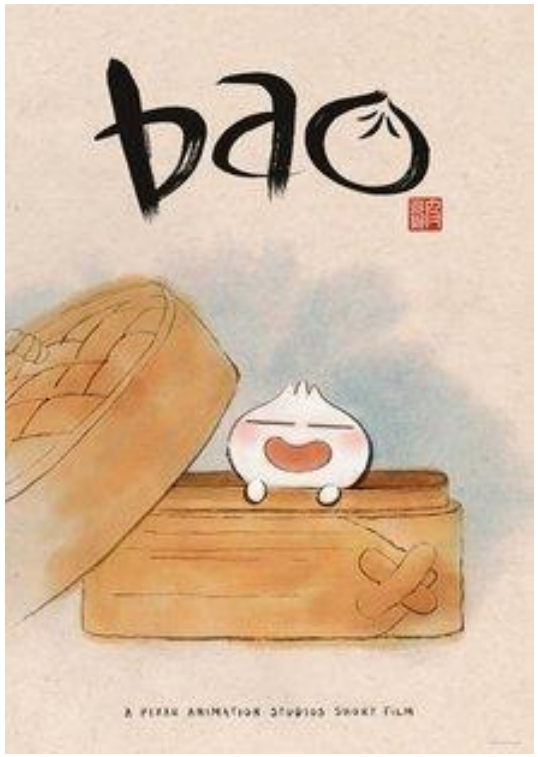
- Pixar's 2019 computer-animated film

Incredibles 2 (2018)

Trailer at YouTube

- Pixar's 2018 computer-animated film

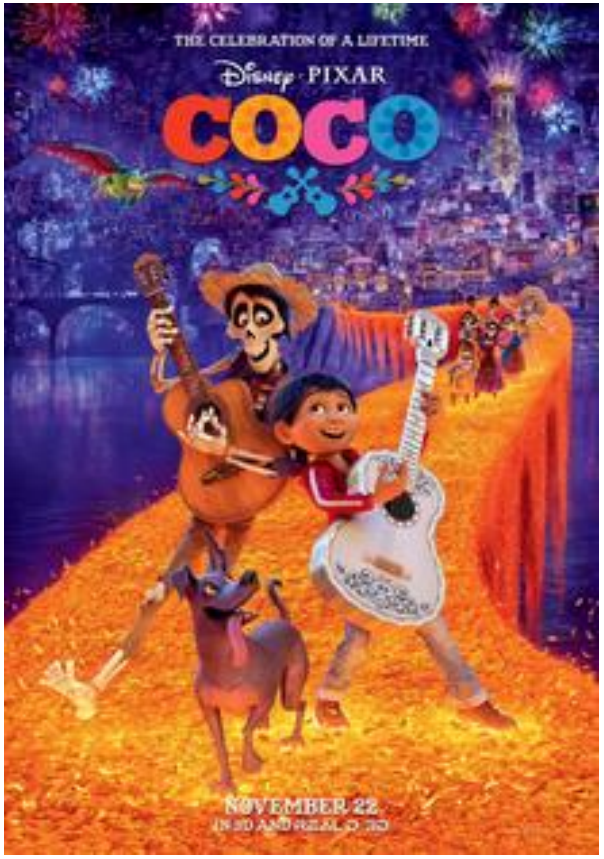
Bao (2018)



Clip at YouTube

- Pixar's 2018 computer-animated short-film

Coco (2017)



Teaser Trailer at YouTube

- Pixar's 2017 computer-animated film

Lou (2017)

Clip at YouTube

- Pixar's 2017 computer-animated short-film

Piper (2016)

Clip at YouTube

- Pixar's 2016 computer-animated short-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

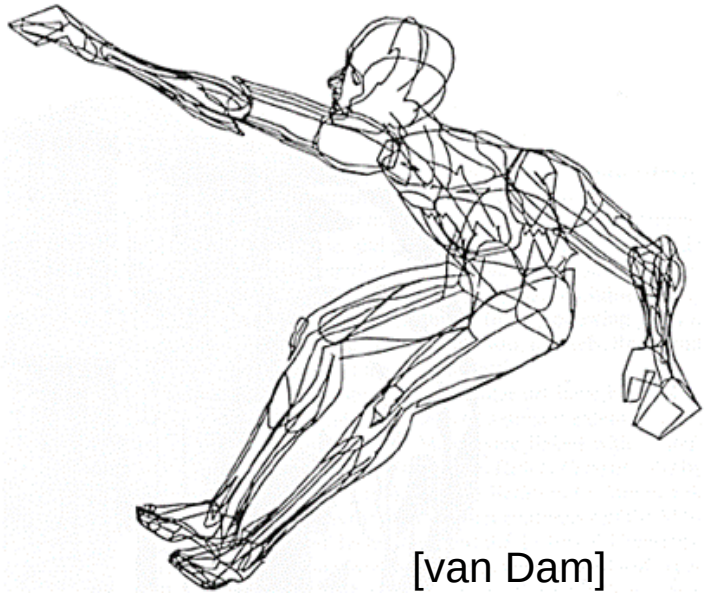
- How was this image produced?

[Angel]

EVOLUTION

Computer Graphics: 1950 – 1960

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

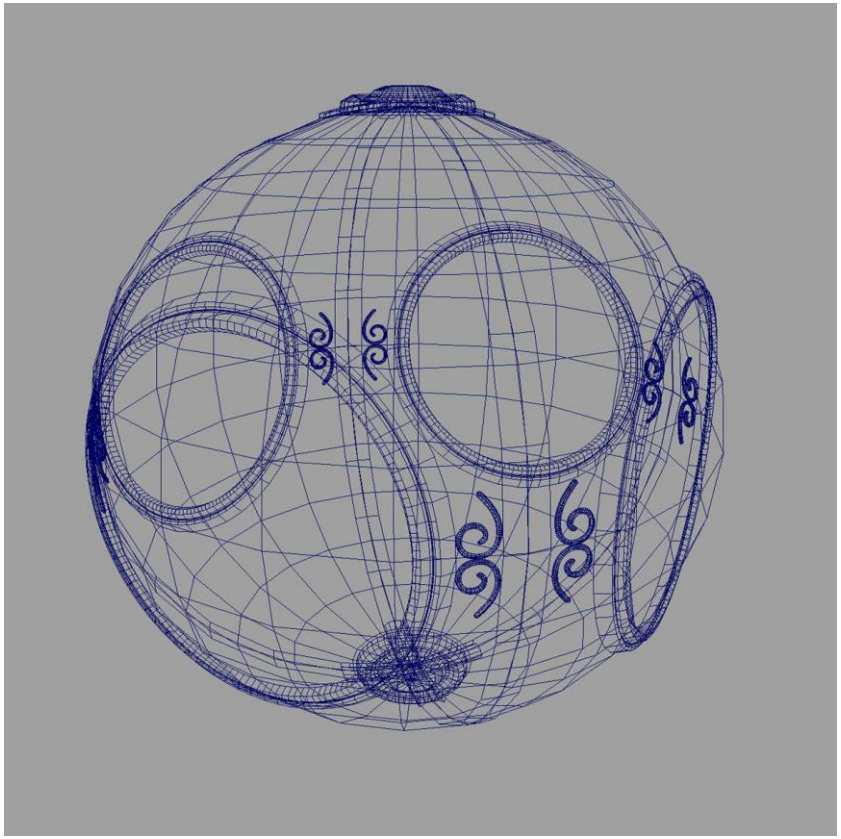


[van Dam]

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

Computer Graphics: 1960 – 1970

- Wireframe graphics
  - Draw only lines !

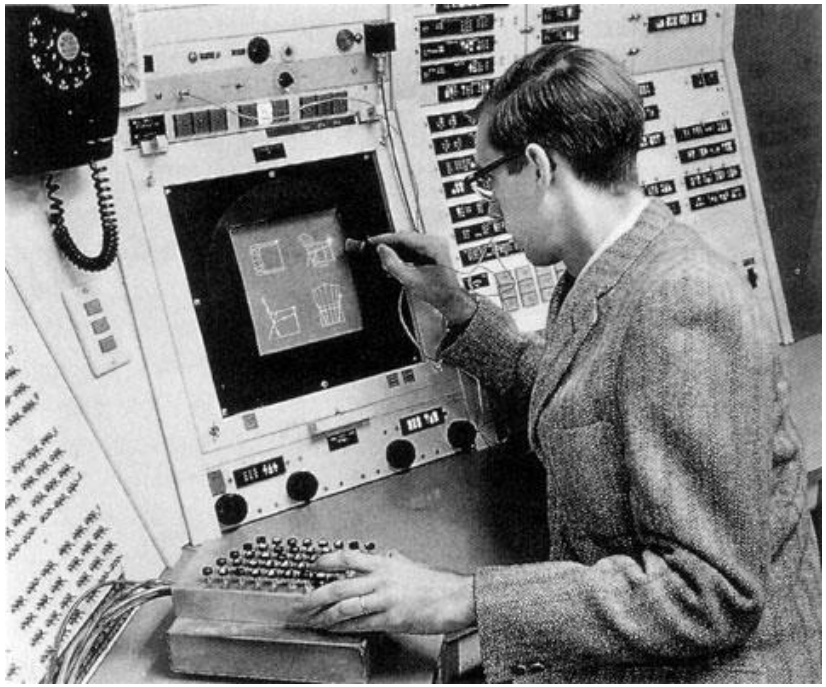


[Angel]

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



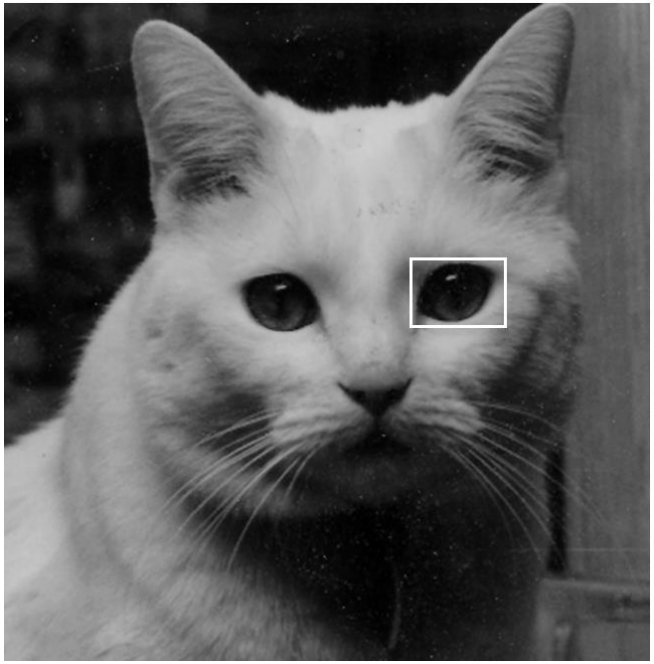
[http://history-computer.com]

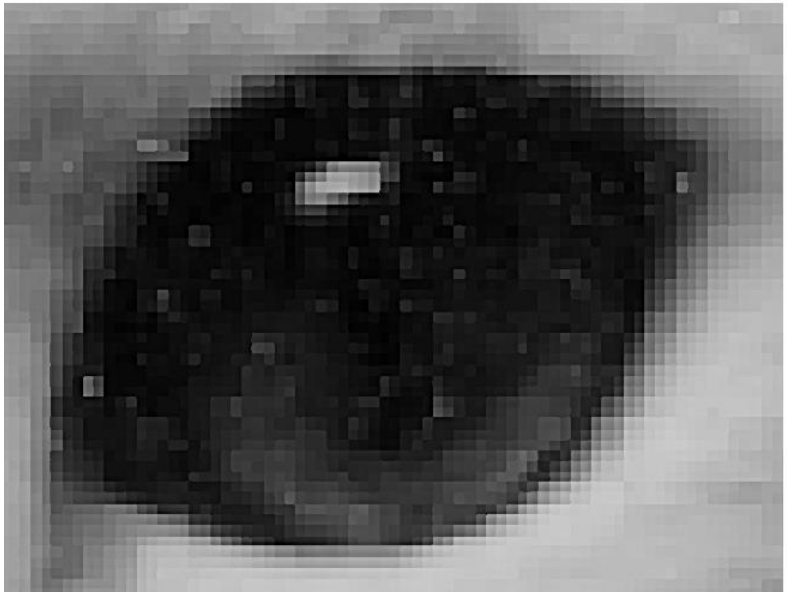
Computer Graphics: 1970 – 1980

- 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

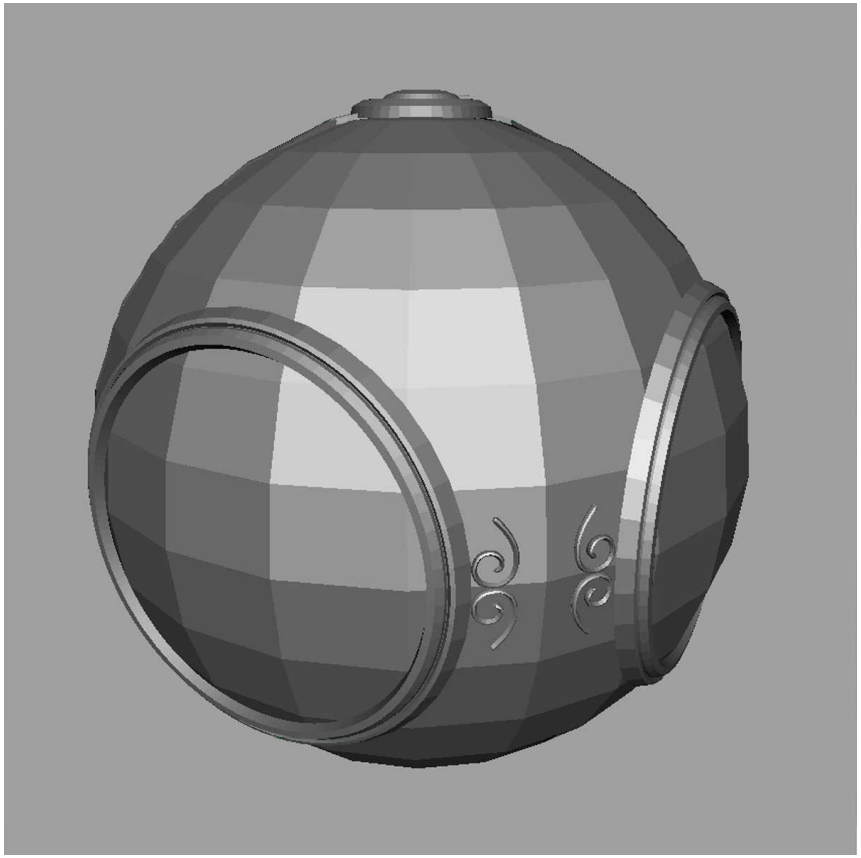




[Angel]

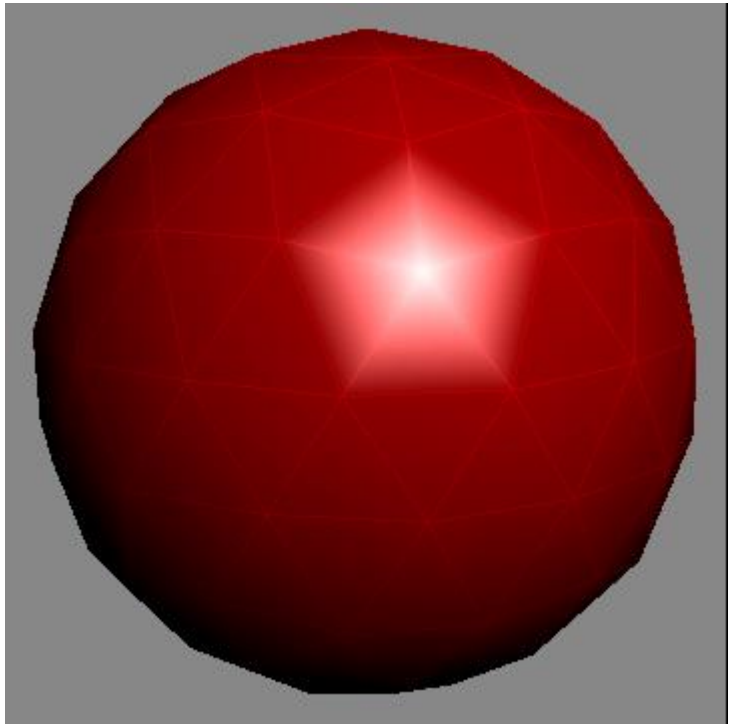
Raster graphics

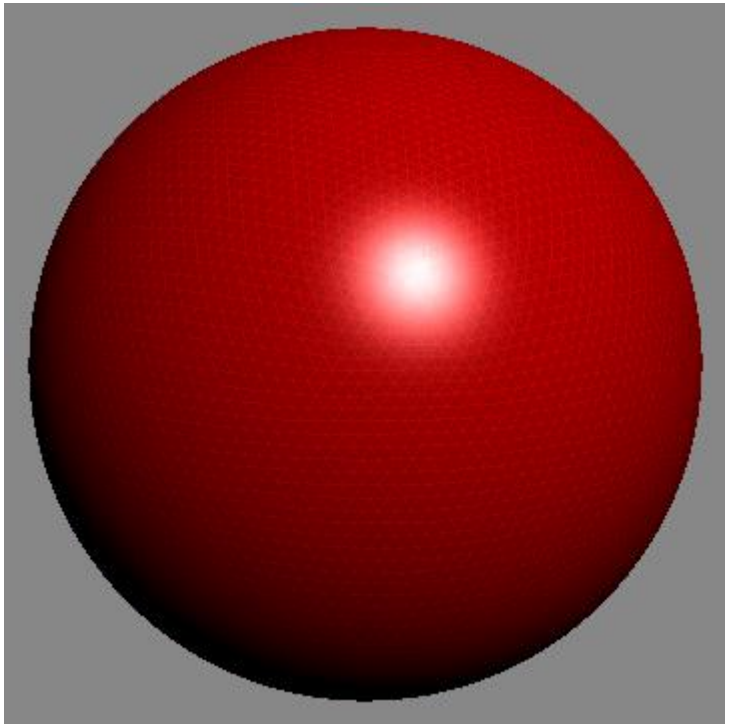
- Drawing polygons
- Illumination models
- Shading methods



[Angel]

Gouraud shading

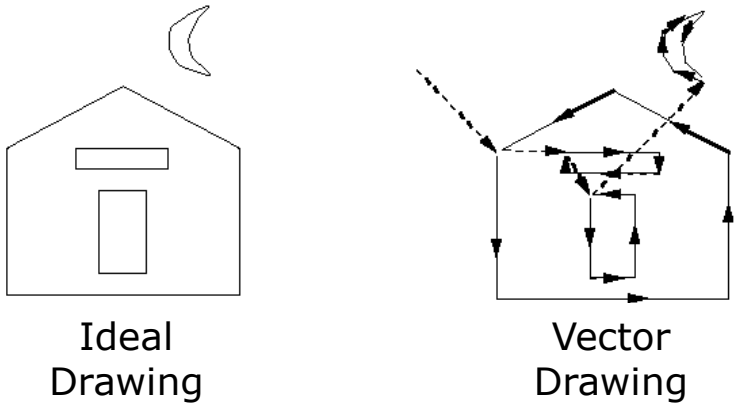




[Wikipedia]

Vector graphics vs Raster graphics

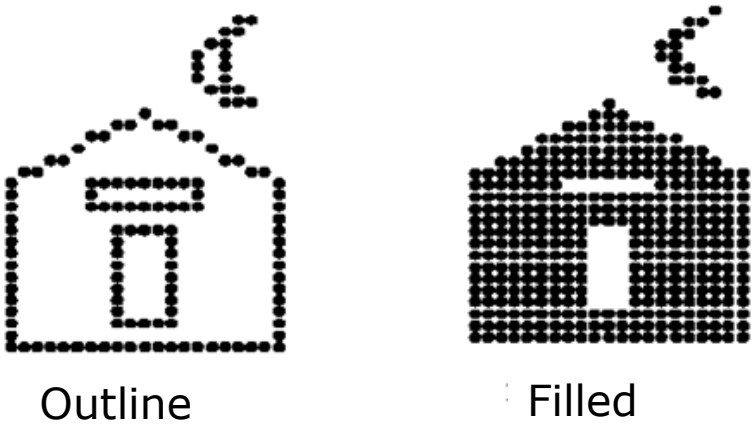
- Vector graphics is driven by display commands
  - move(x,y); line(x,y); …
  - Survives as SVG – Scalable Vector Graphics



[van Dam]

Vector graphics vs Raster graphics

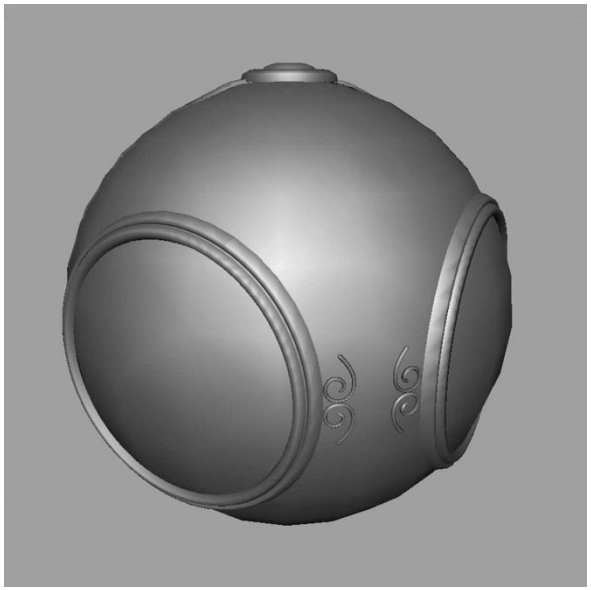
- Raster graphics is used in TV displays and laser printers
  - Lowest level of representation
  - No semantics
  - BUT aliasing errors



[van Dam]

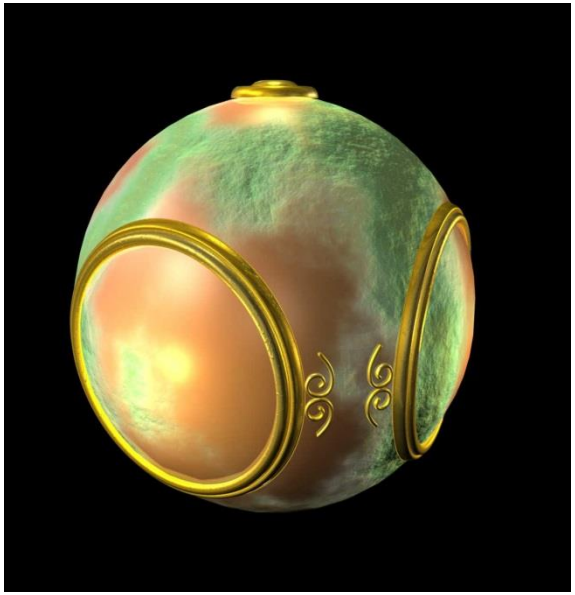
Computer Graphics: 1980 – 1990

- The quest for realism



Smooth shading

Environment mapping

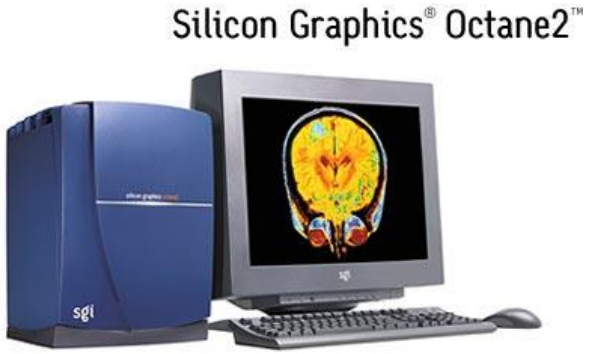


Bump mapping

[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
  - ATI
- Game boxes / players determine the market
- CG is routine in the film industry

2015 – Important trends !

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

2015 – Important trends !

- Science and Maths are cool !
  - Modeling / Simulation / Animation
- Gamification
  - Unreal Engine / Unity / Cryengine

- https://teamscarlet.wordpress.com/2015/09/01/5-take-aways-from-siggraph-2015/

BATCH VS INTERACTIVE CG

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]

TECHNOLOGIES & TRENDS

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

- 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

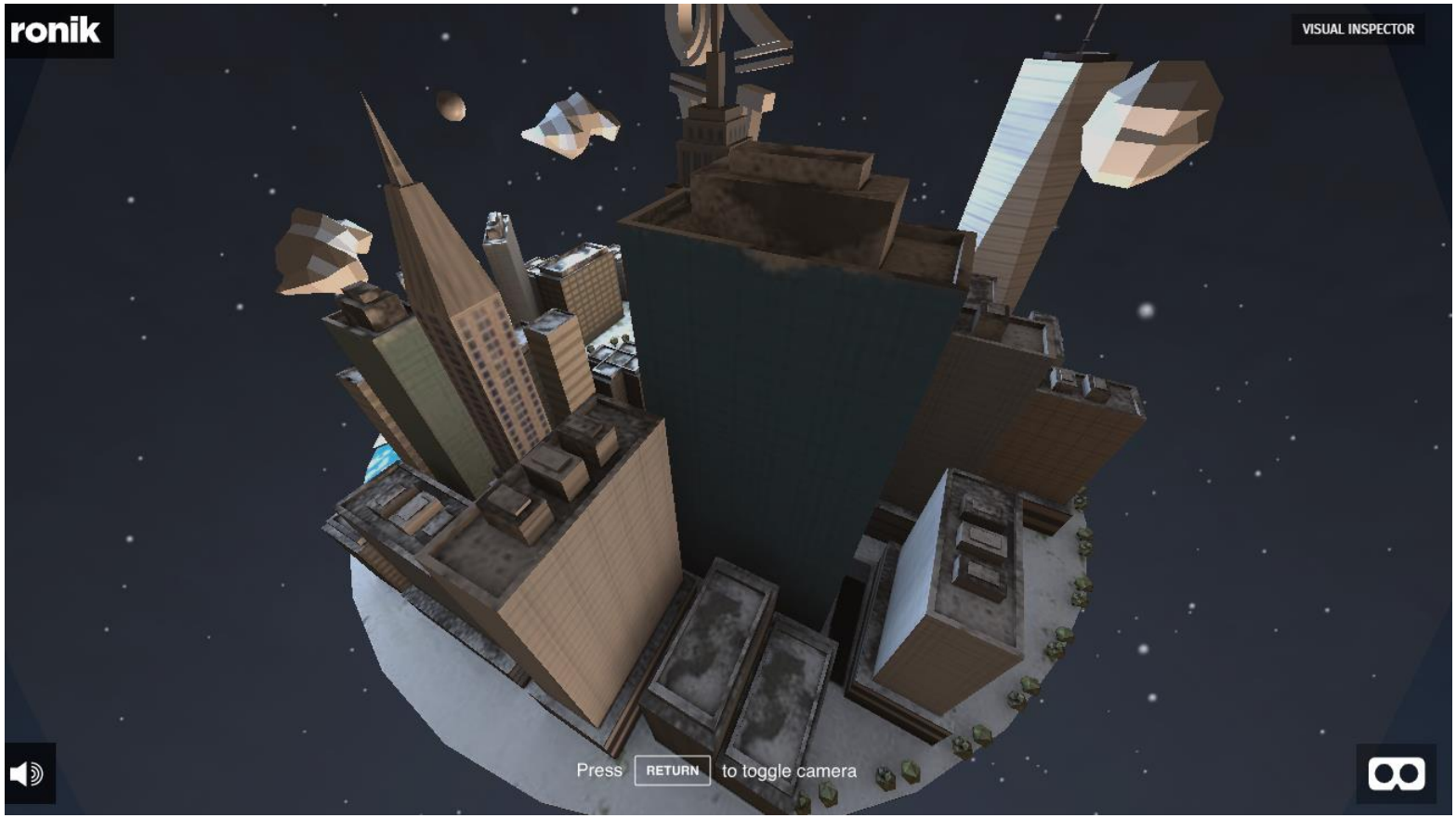
Enabling technologies for modern CG

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

Mobile Graphics

[SIGGRAPH Asia 2017 Course Notes]

Web-based VR



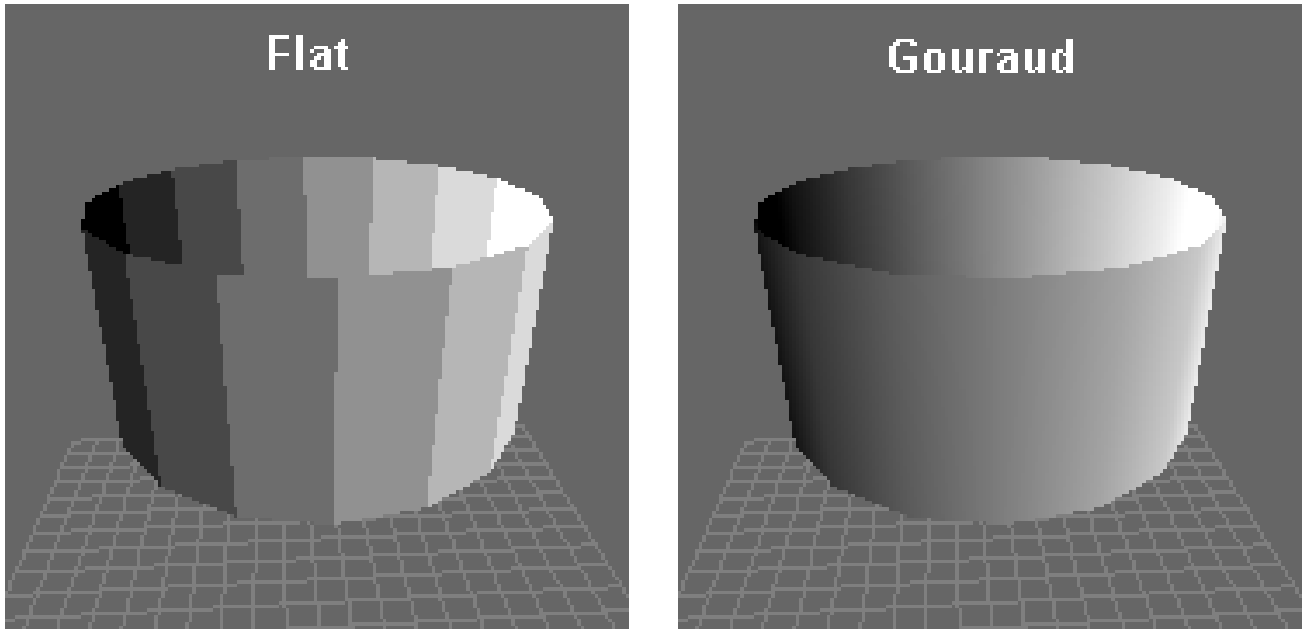
[https://aframe.io/examples/showcase/snowglobe/]

Web-based CG and VR

- PlayCanvas - The Web-first game engine
- WebVR
- React 360
- Sketchfab
- Vizor

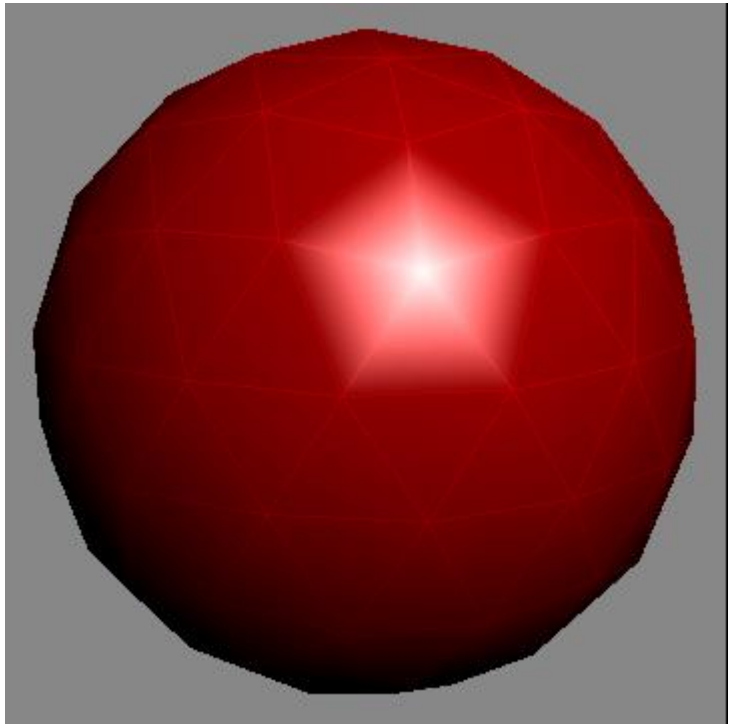
MILESTONES

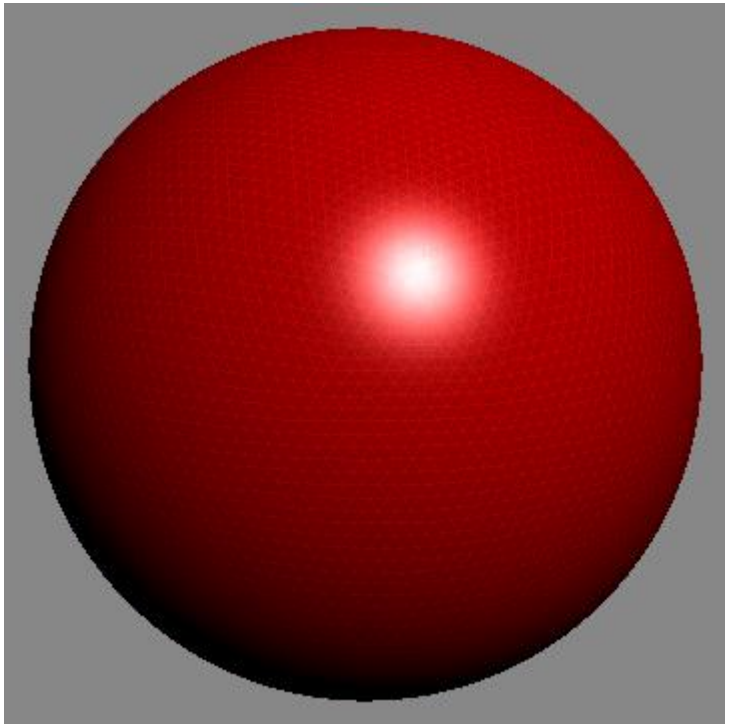
Gouraud shading – 1971



[Wikipedia]

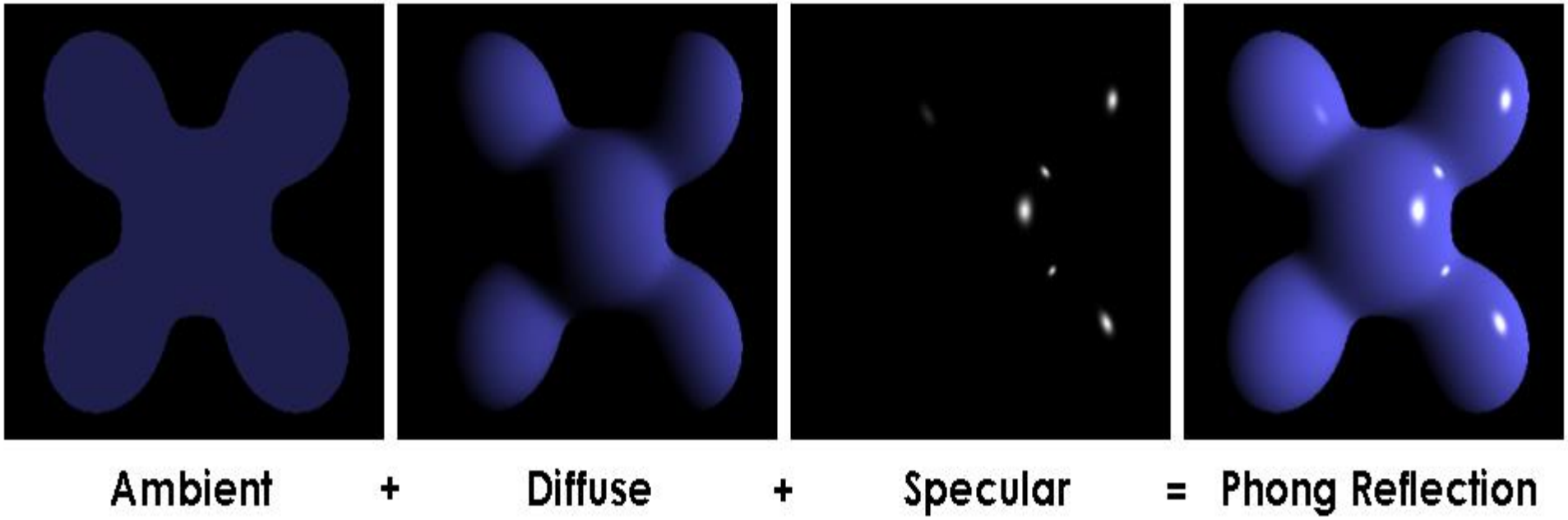
Gouraud shading





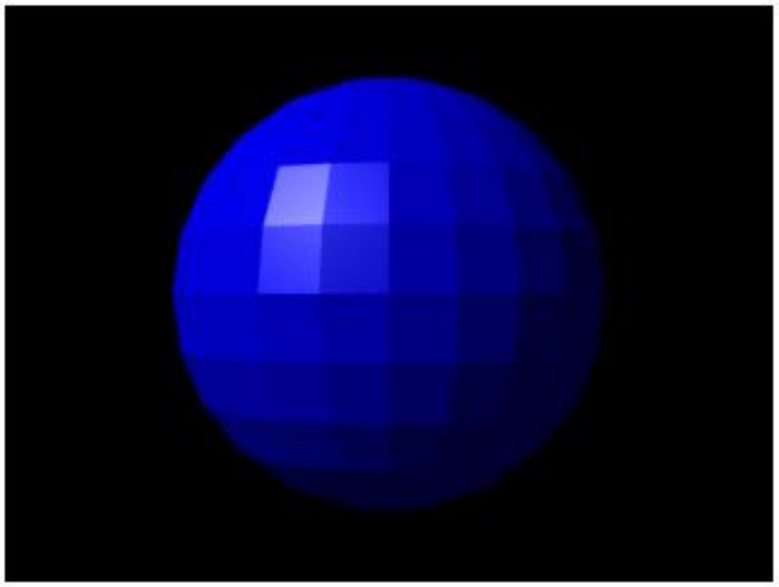
[Wikipedia]

Phong reflection model – 1973

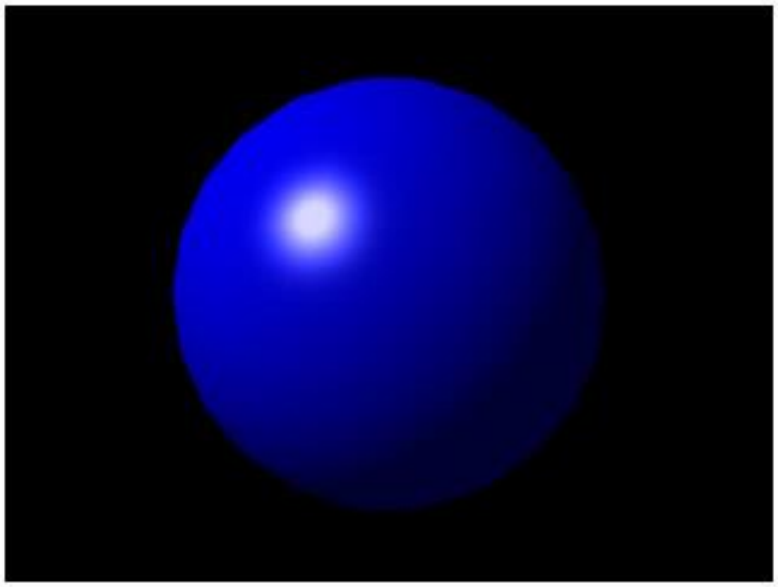


[Wikipedia]

Phong shading – 1973



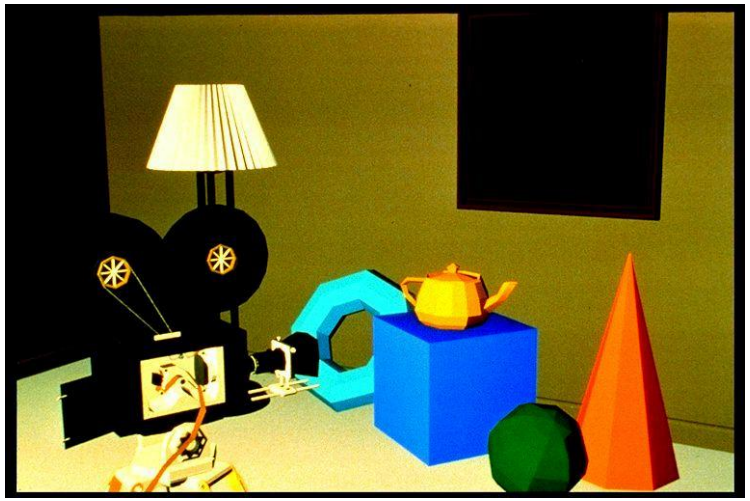
FLAT SHADING

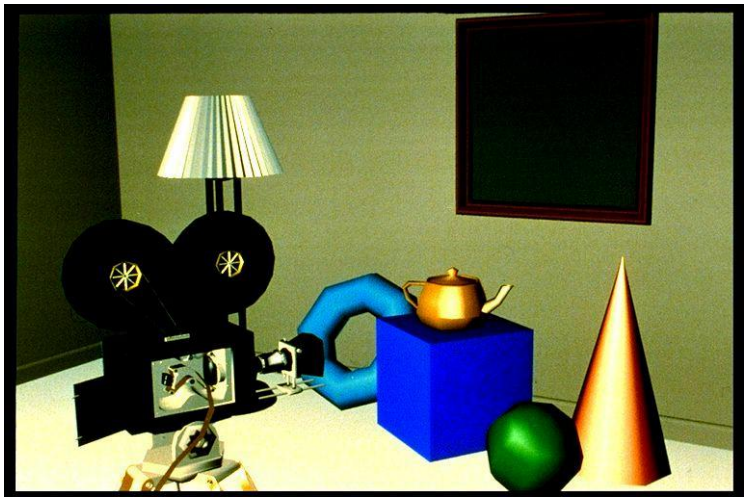


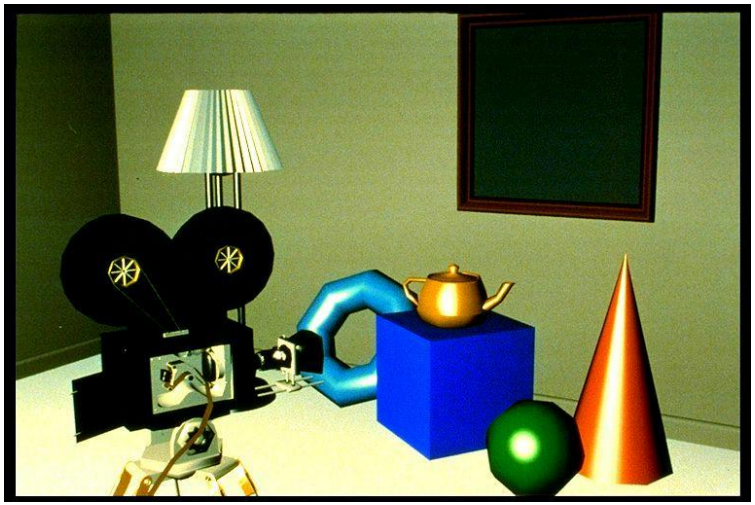
PHONG SHADING

[Wikipedia]

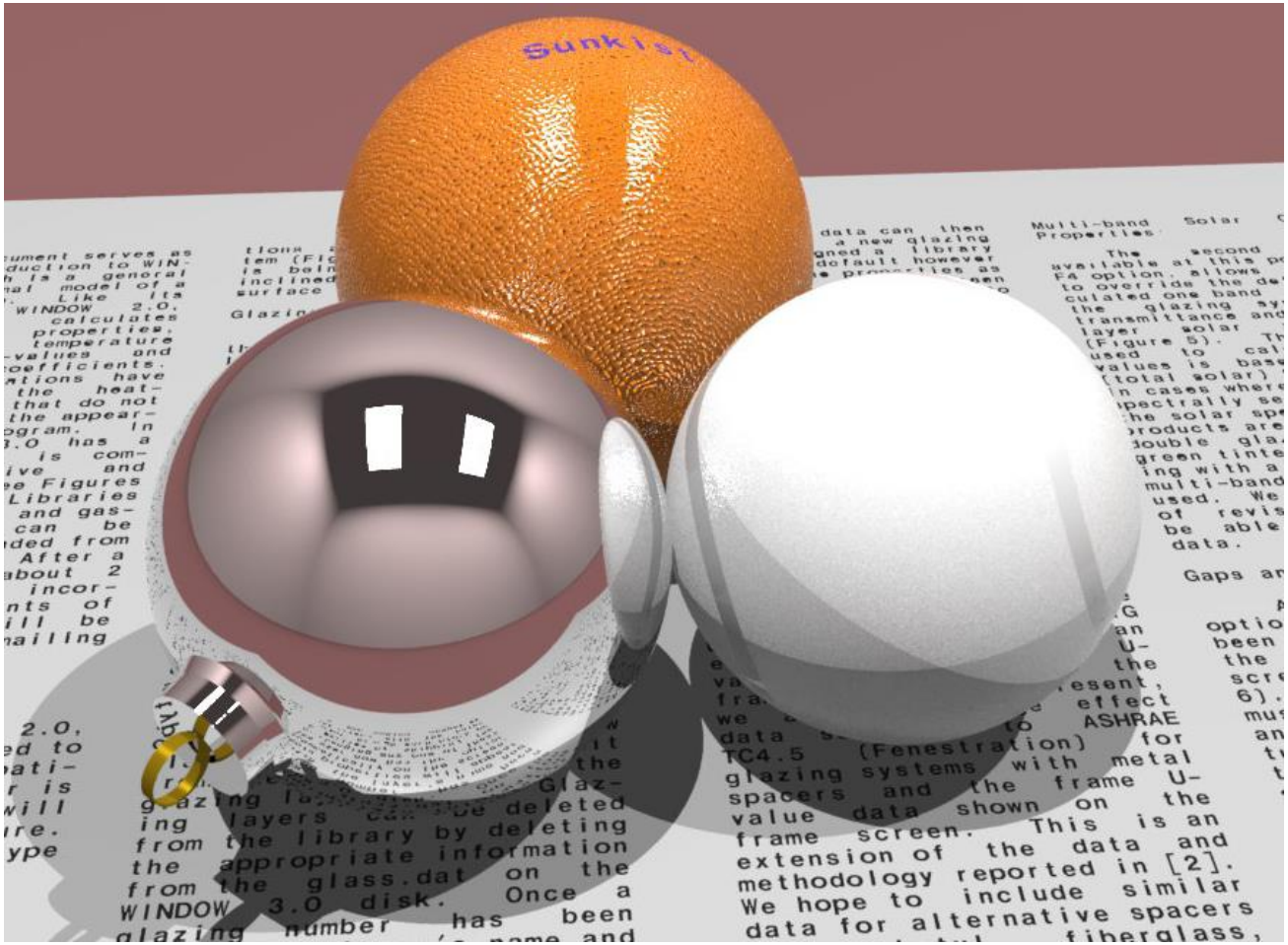
Can you see the differences ?







Ray-Tracing example

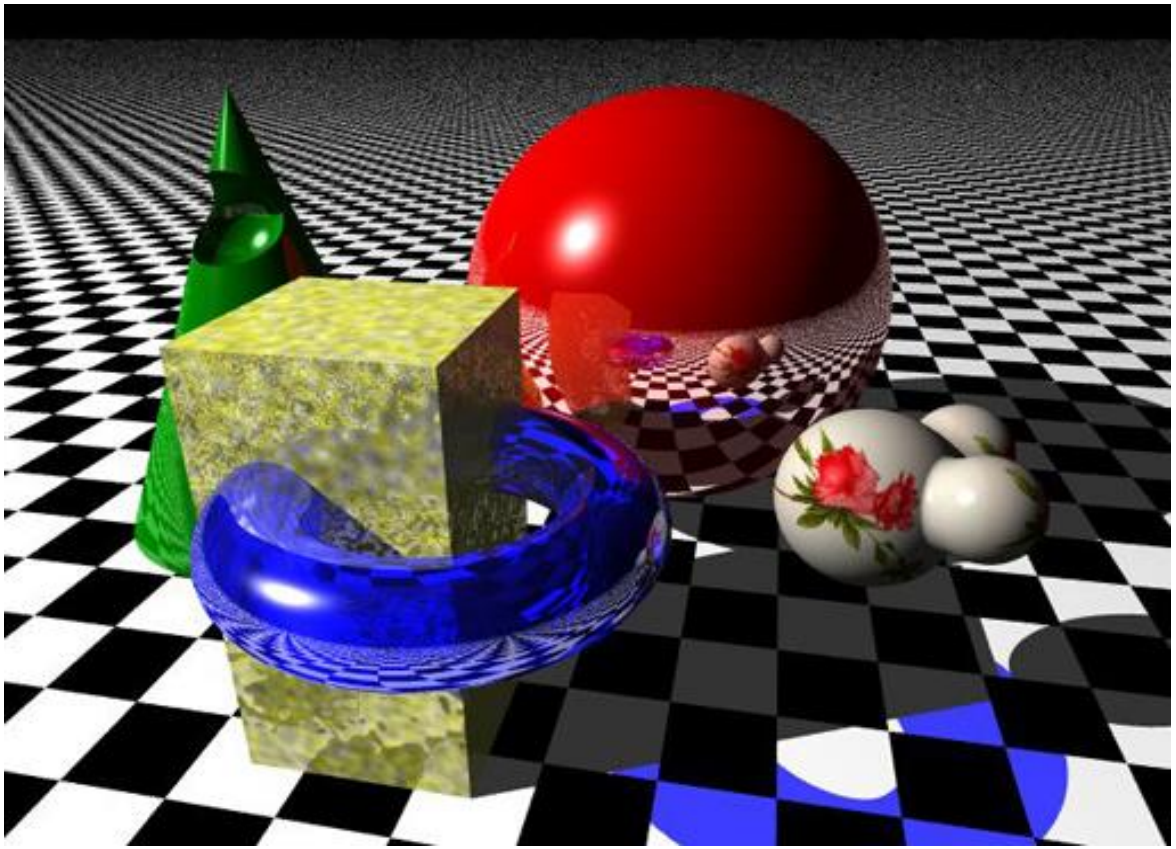


http://radsite.lbl.gov/radiance/book/img/plate10.jpg

"Vermeer's Studio"

Wallace & Cohen, 1987: Radiosity and Ray-Tracing

Another Ray-Tracing example

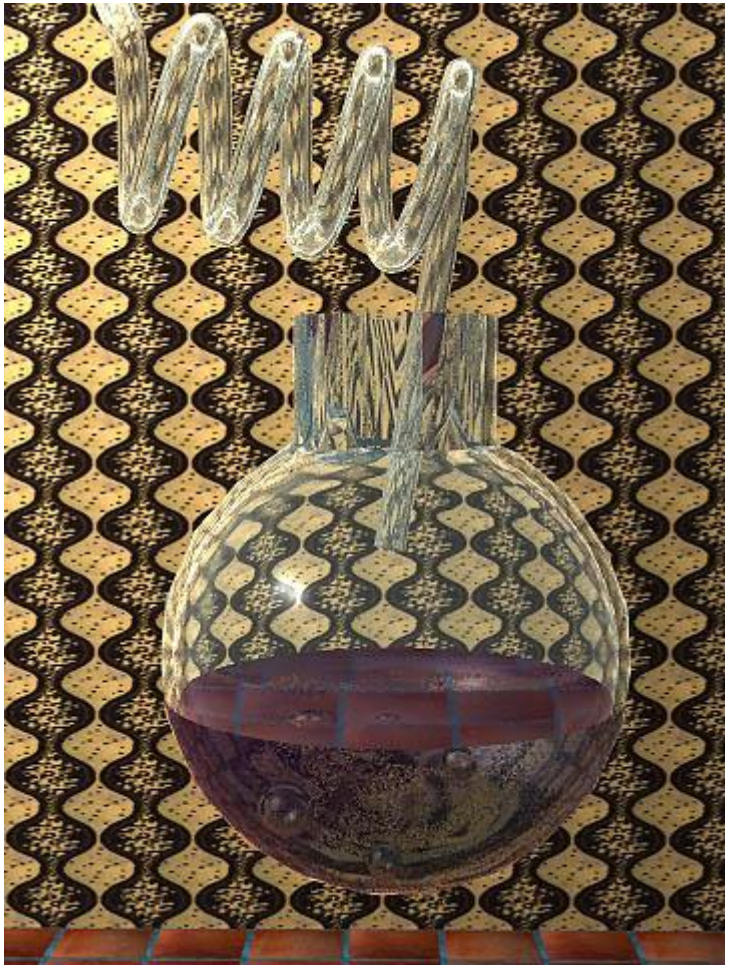


http://www.tjhsst.edu/~dhyatt/superap/samplex.jpg

Ray-Tracing – Diamond ring

[http://www.okino.com]

Ray-Tracing – Chemist's flask

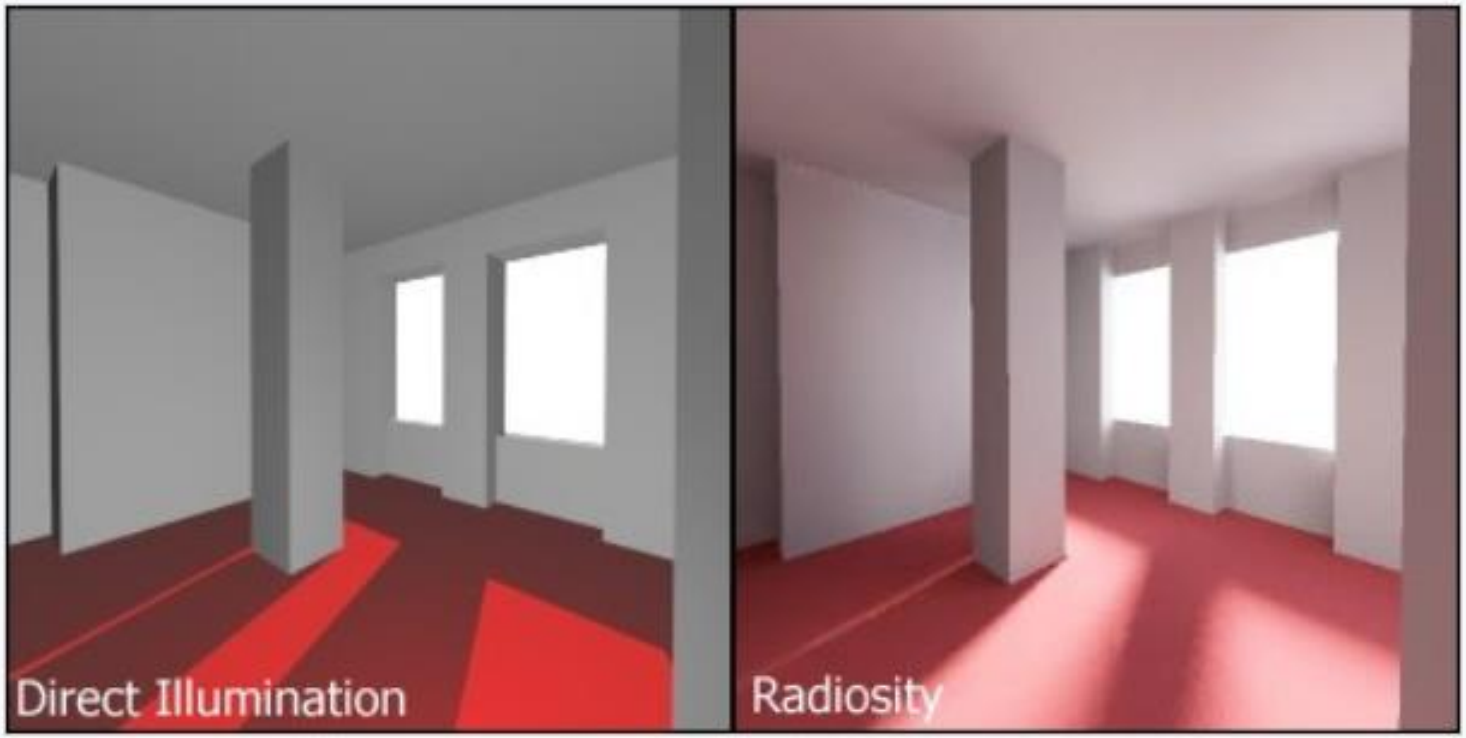


[http://www.okino.com]

Ray-Tracing + Radiosity

[Wikipedia]

Radiosity



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

[Wikipedia]

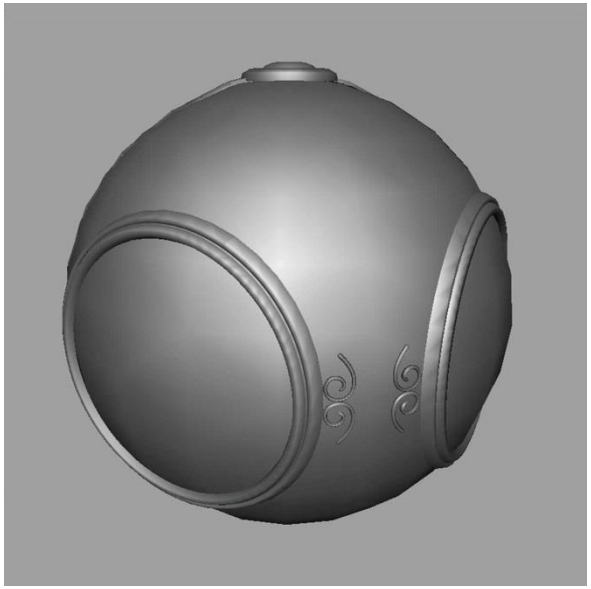
Radiosity

Without radiosity

With radiosity

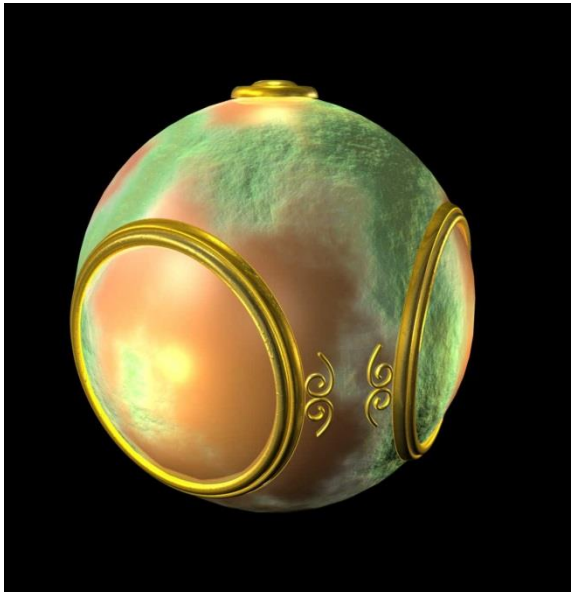
[Burdea]

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

APPLICATION AREAS

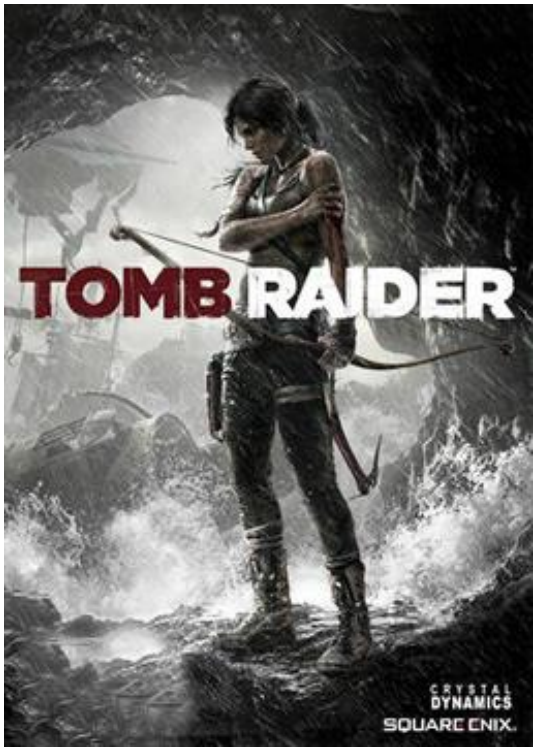
CG – Application areas

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

Games – *Lara Croft*

1996

2007



2013

[Wikipedia]

Animation films – *Pixar*

Toy Story – 1995

Ratatouille – 2007

[www.pixar.com]

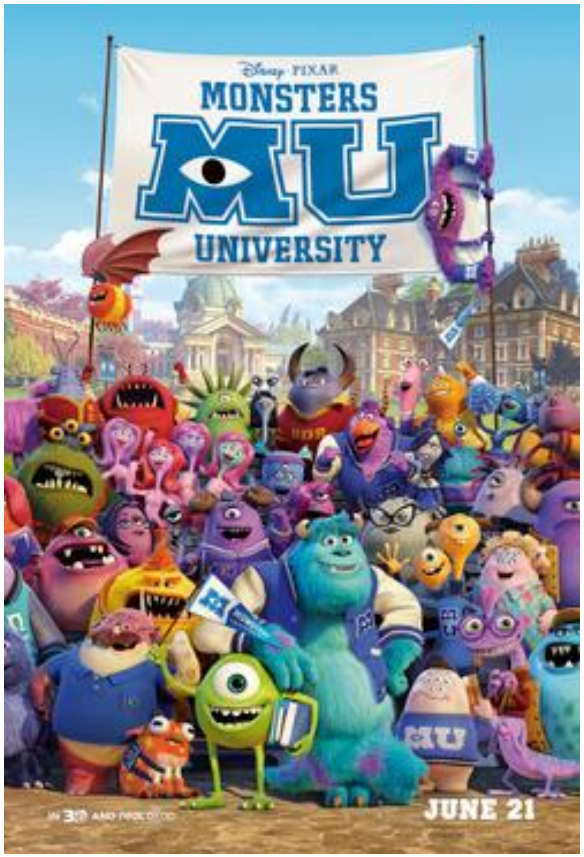
Animation films – *Pixar*

Toy Story 3 – 2010

Brave – 2012

[www.pixar.com]

Animation films – *Pixar*



Monster's University – 2013

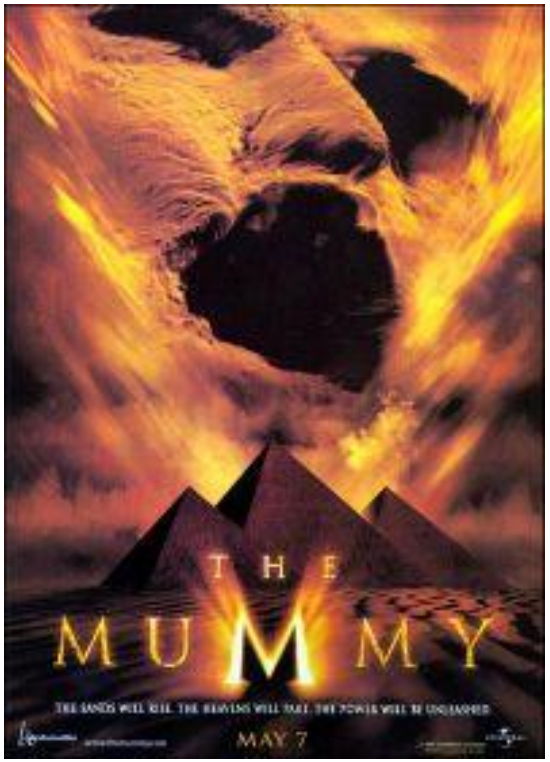
Finding Dory – 2016

[www.pixar.com]

Special effects – *ILM*

1991

1994



1999

[Wikipedia]

Special effects – *ILM*

2005

2009

[Wikipedia]

2013

Special effects – *ILM*

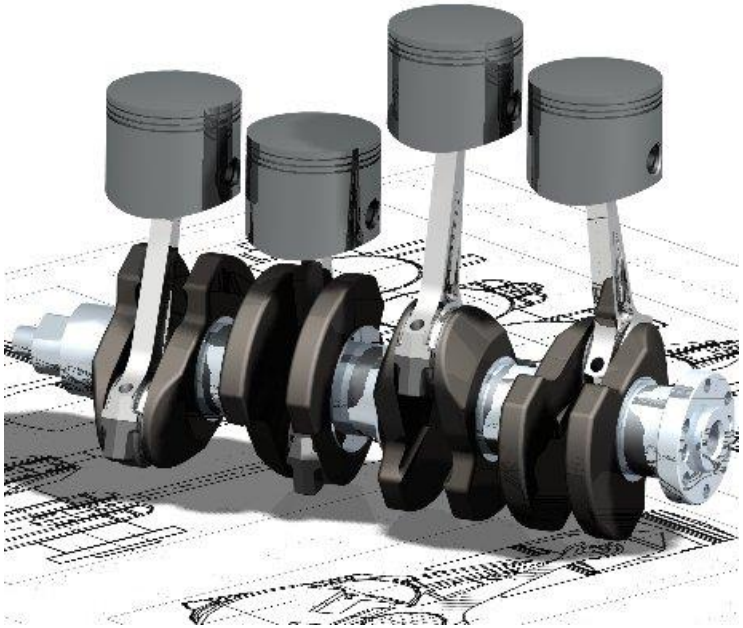
2015

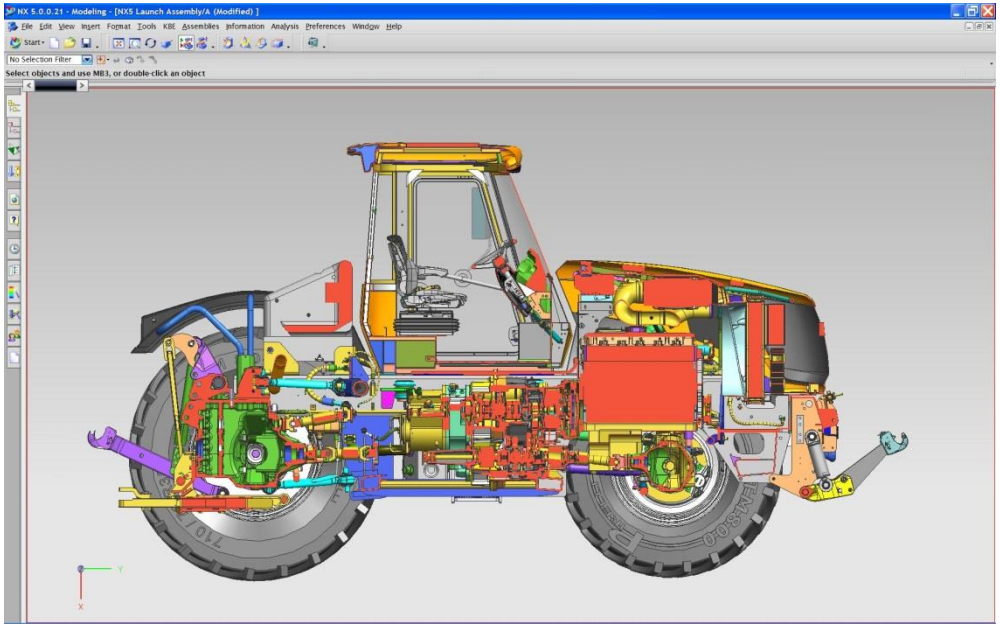
2016

[Wikipedia]

2017

Computer-Aided Design

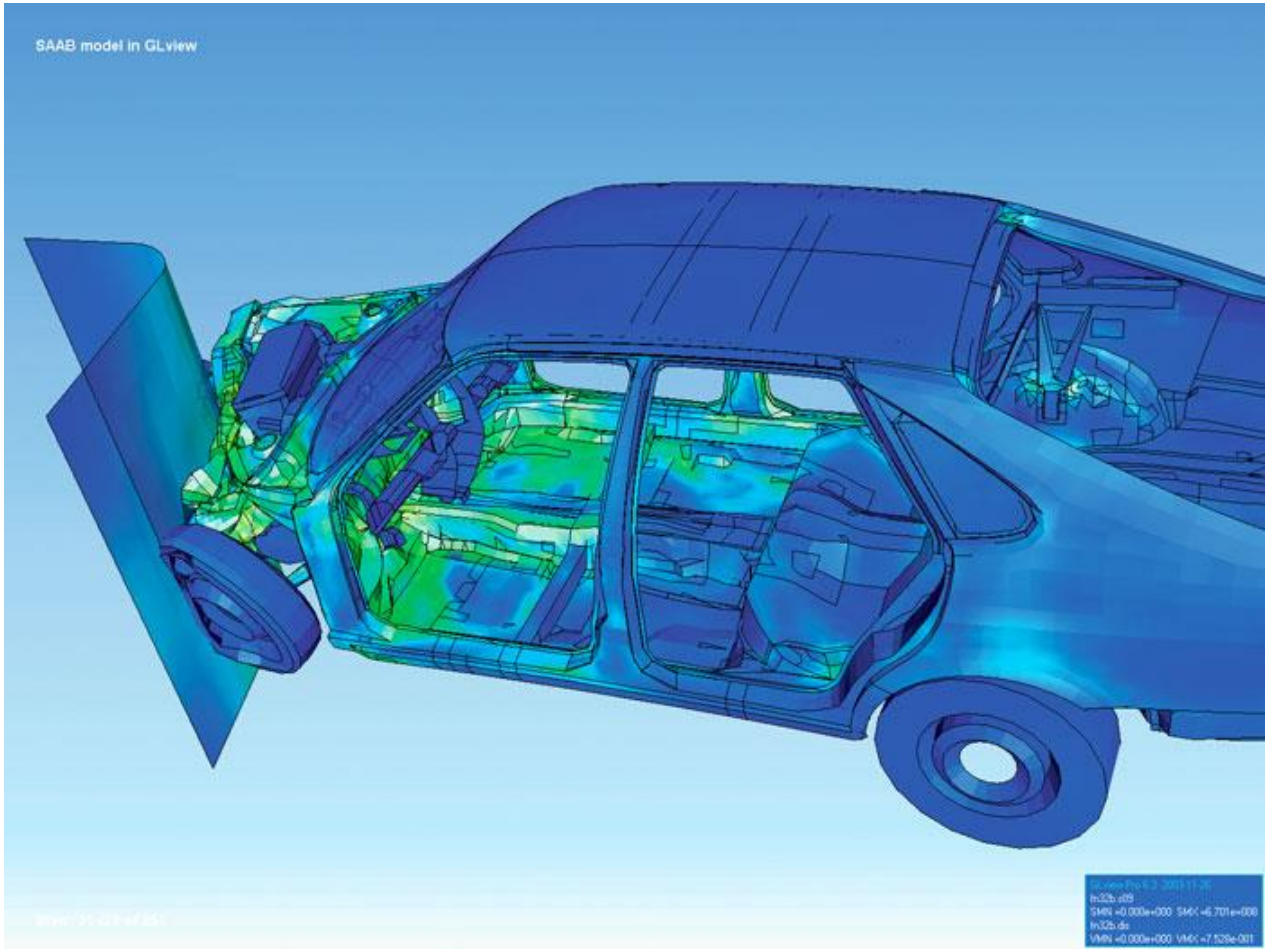




CAD mockup

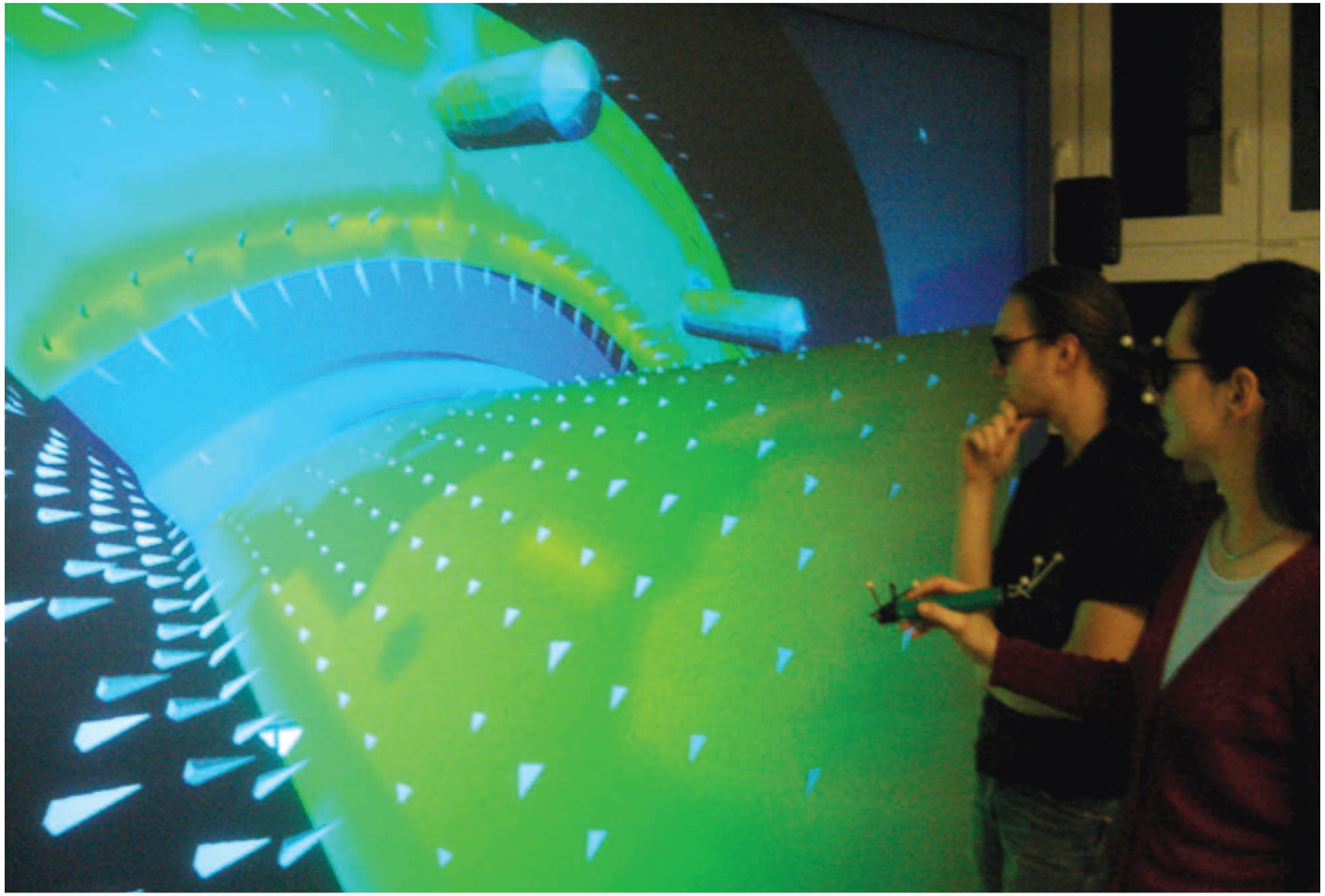
[Wikipedia]

CAD – Simulation



[Wikipedia]

VR / AR Visualization



[Weidlich et al, 2008]

Visualization

- Techniques / tools for creating
  - Images
  - Diagrams
  - Animations
  - …
- Aims
  - Convey a message – Static Visualization !
  - Allow interactive exploration / analysis

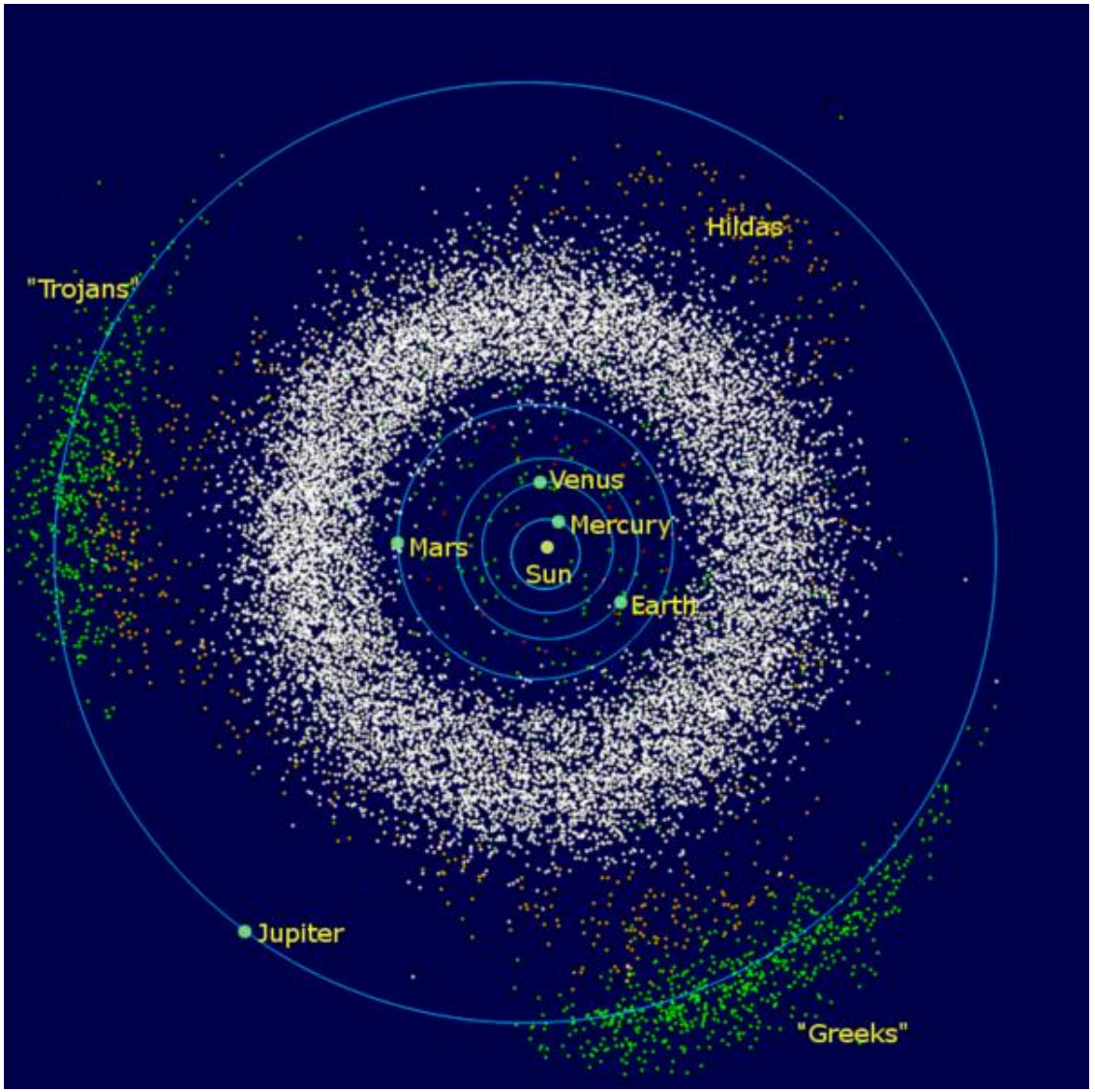
Scientific Data Visualization

- Transformation, selection and / or representation of data with an underlying geometric structure

- Data ?
  - Real data
  - Experimental data
  - Simulation data

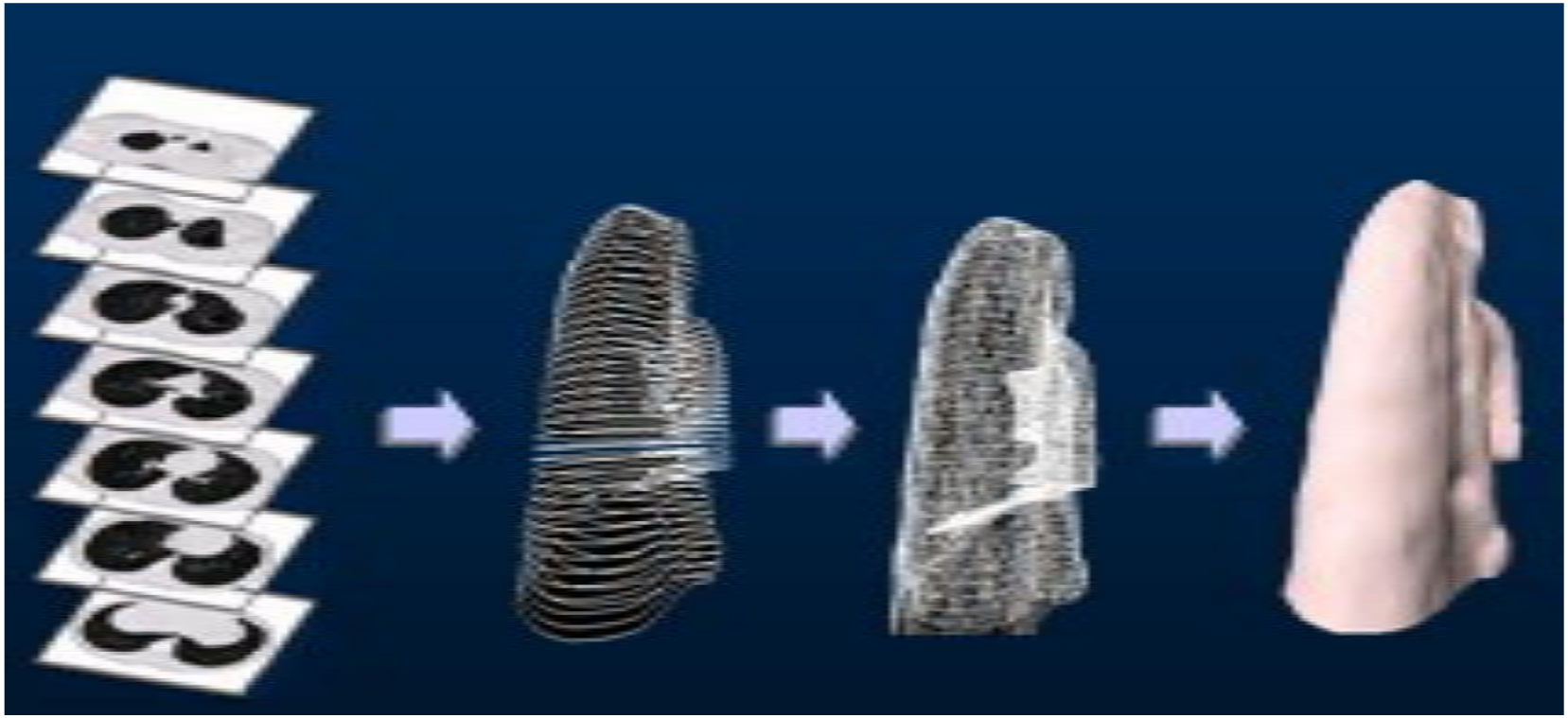
Astronomy

- The asteroid belt



[Wikipedia]

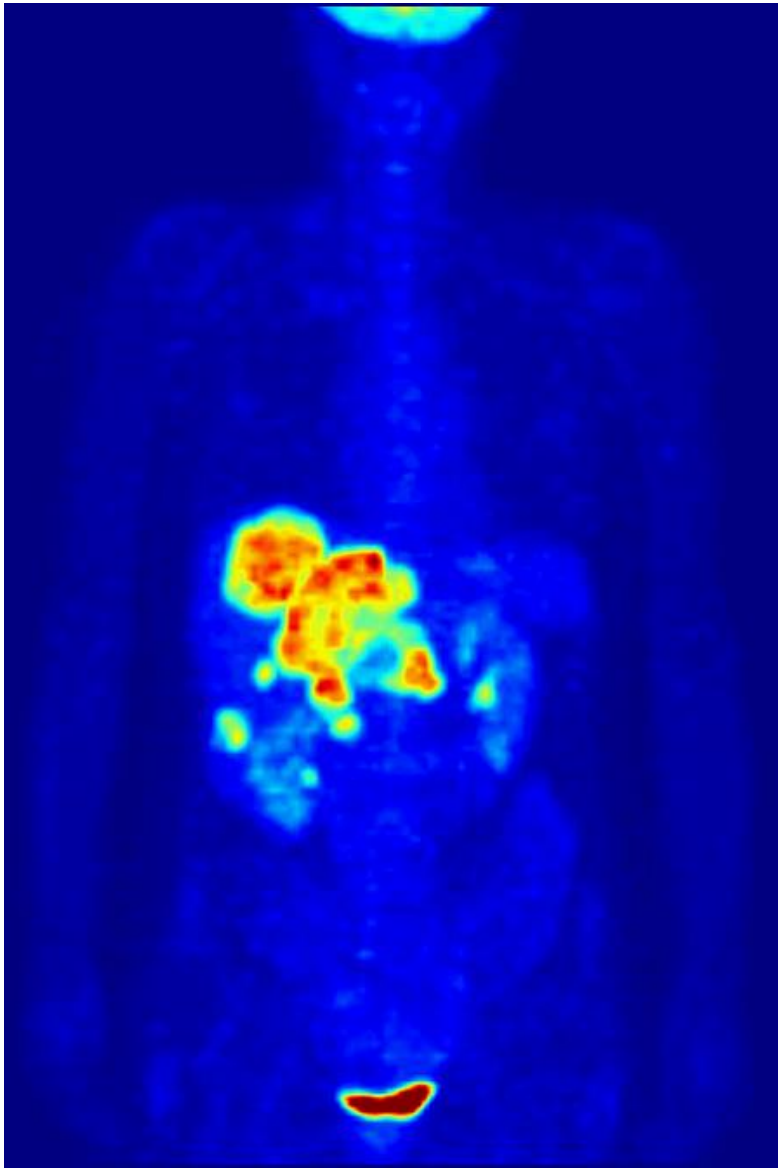
Medical Data Visualization



From CT data to lung models
U.Aveiro, 2004

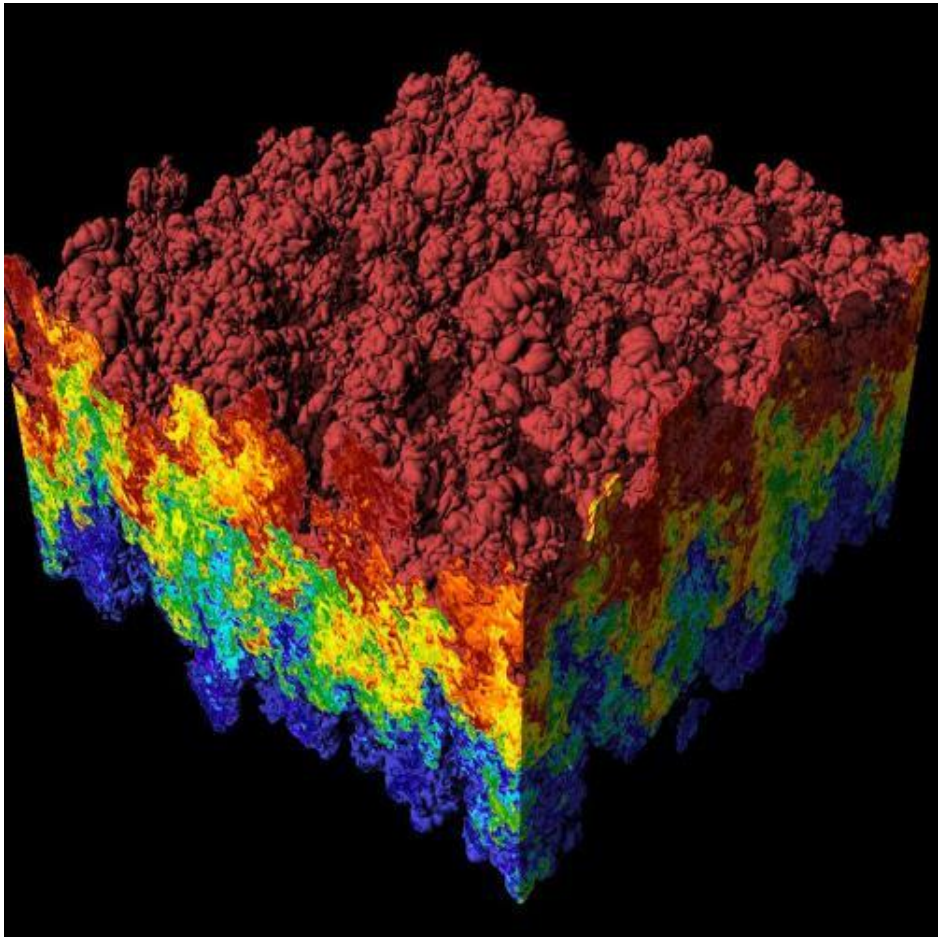
Medical Data Visualization

- PET scan for tumor diagnosis



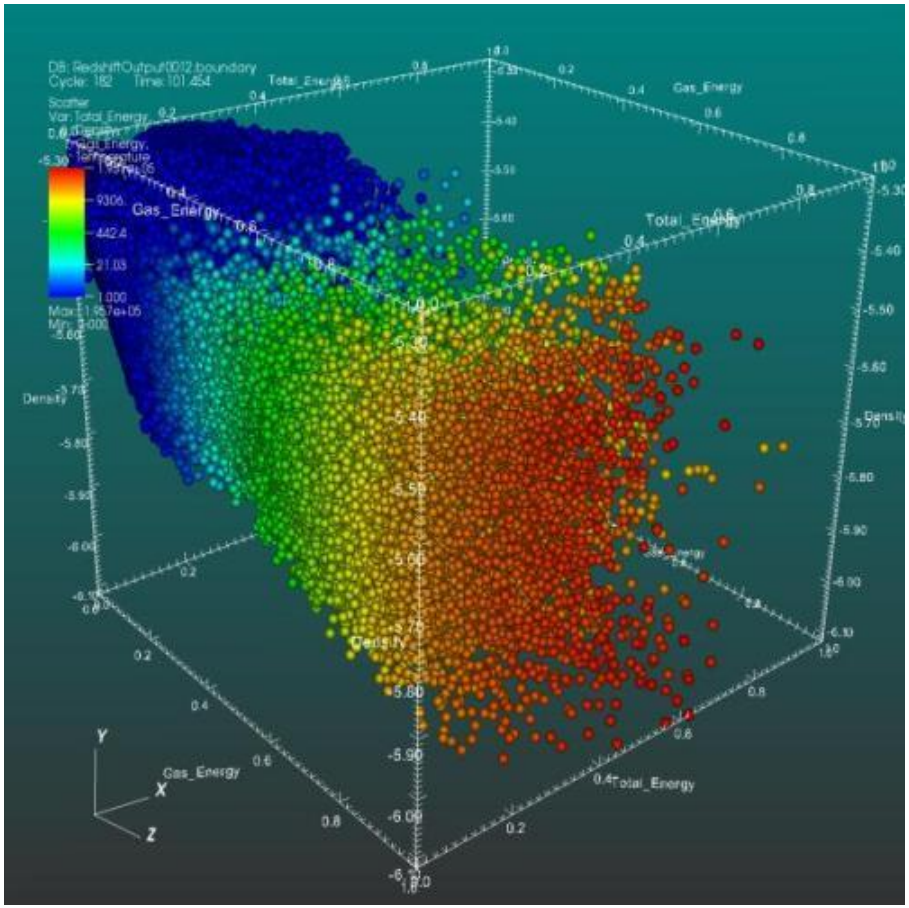
[Wikipedia]

Data Visualization



[Wikipedia]

Data Visualization



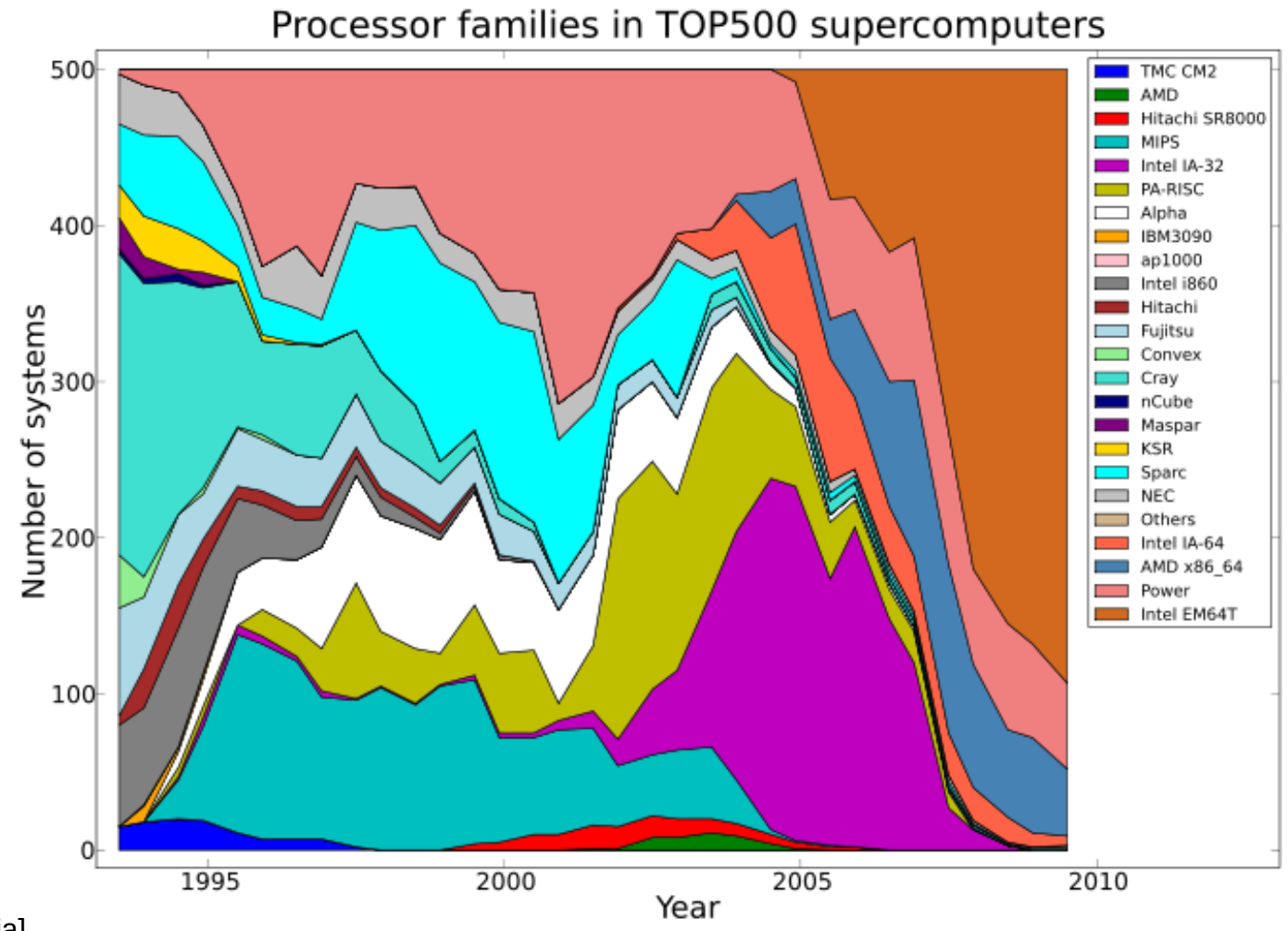
[Wikipedia]

Information Visualization

- Transformation, selection and / or representation of abstract data

- Data ?
  - Numerical data
  - Text
  - Geographical information
  - …

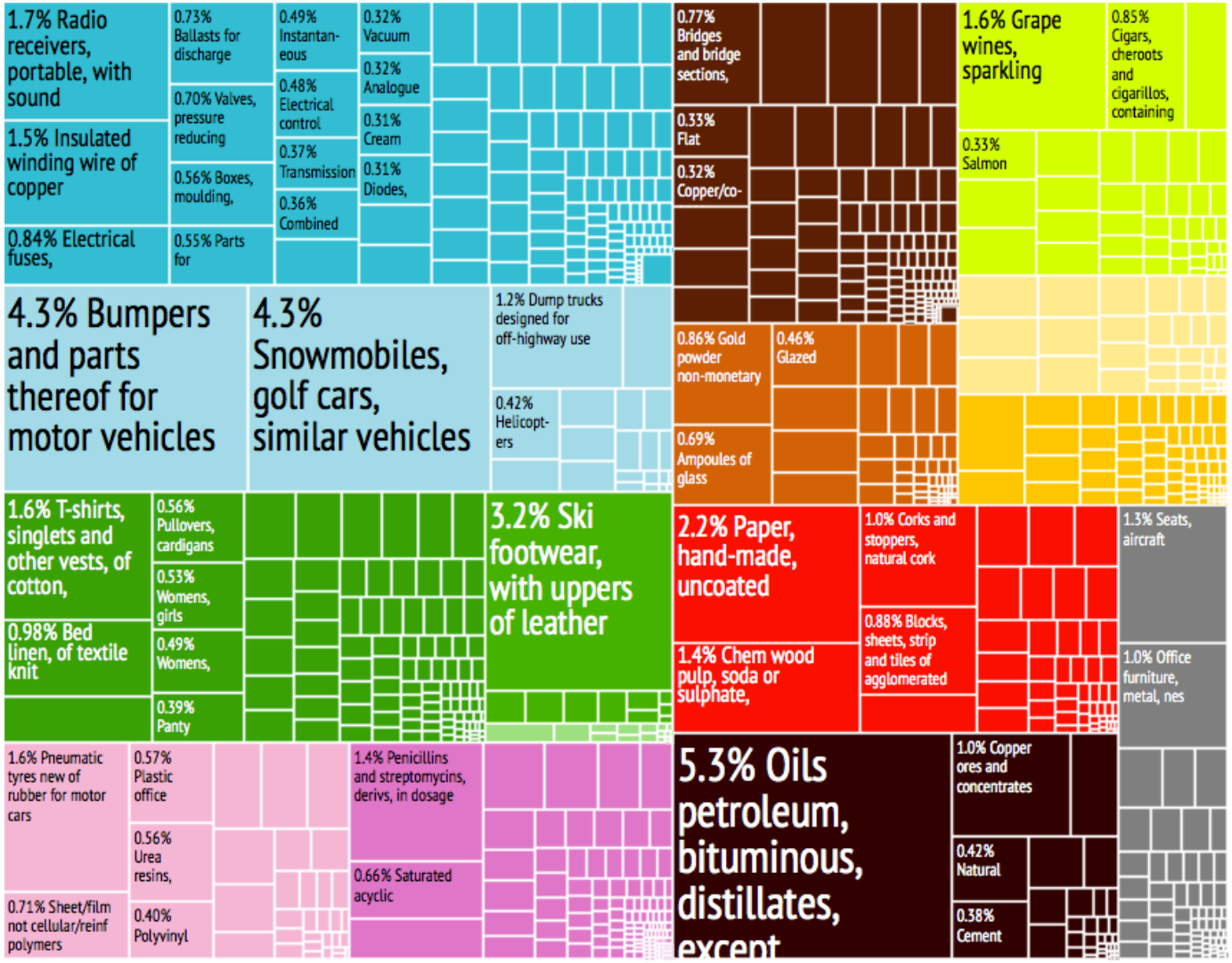
Stacked Graph



[Wikipedia]

Treemap

Portugal Exports



[Wikipedia]

CG – Some YouTube videos

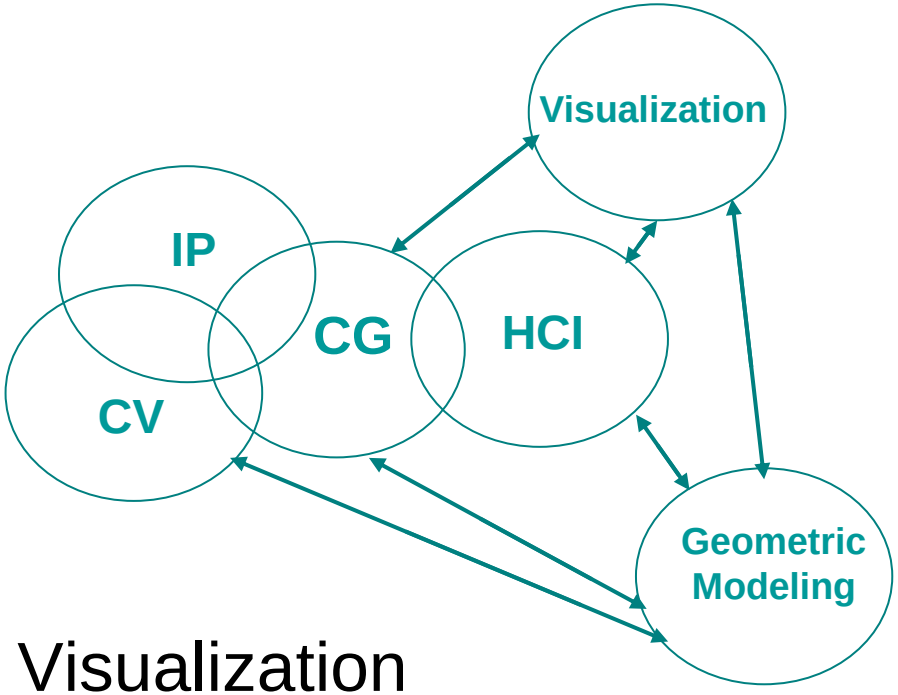
- SIGGRAPH 2020
  - Technical Papers Trailer
  - Production & Animation
  - VR Theater
  - Gaming & Interactive
  - Computer Animation Festival Electronic Theater

CG IS NOT ALONE

Computer Graphics vs …

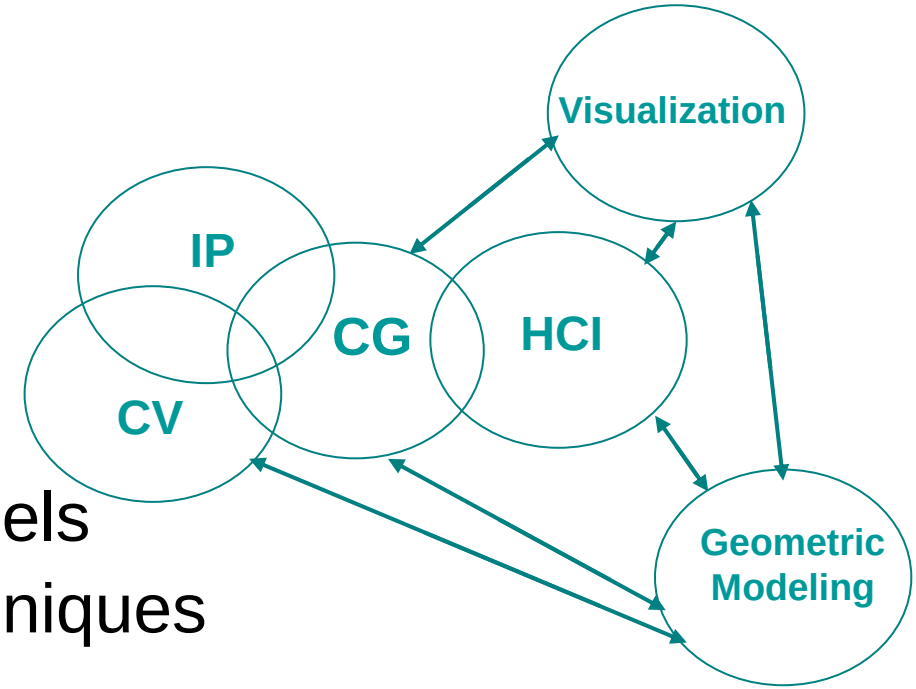
		Output	
		Model	Image
Input	Model	Geometric Modeling	Computer Graphics
	Image	Computer Vision	Image Processing

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, …

CG is not alone…



- Geometric Modeling
  - CV : 3D scanning
  - CG : 2D and 3D models
  - HCI : interaction techniques
- Visualization
  - HCI : interaction techniques
  - GeoM : 2D and 3D models
  - CG : rendering

Example – Medical Imaging

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

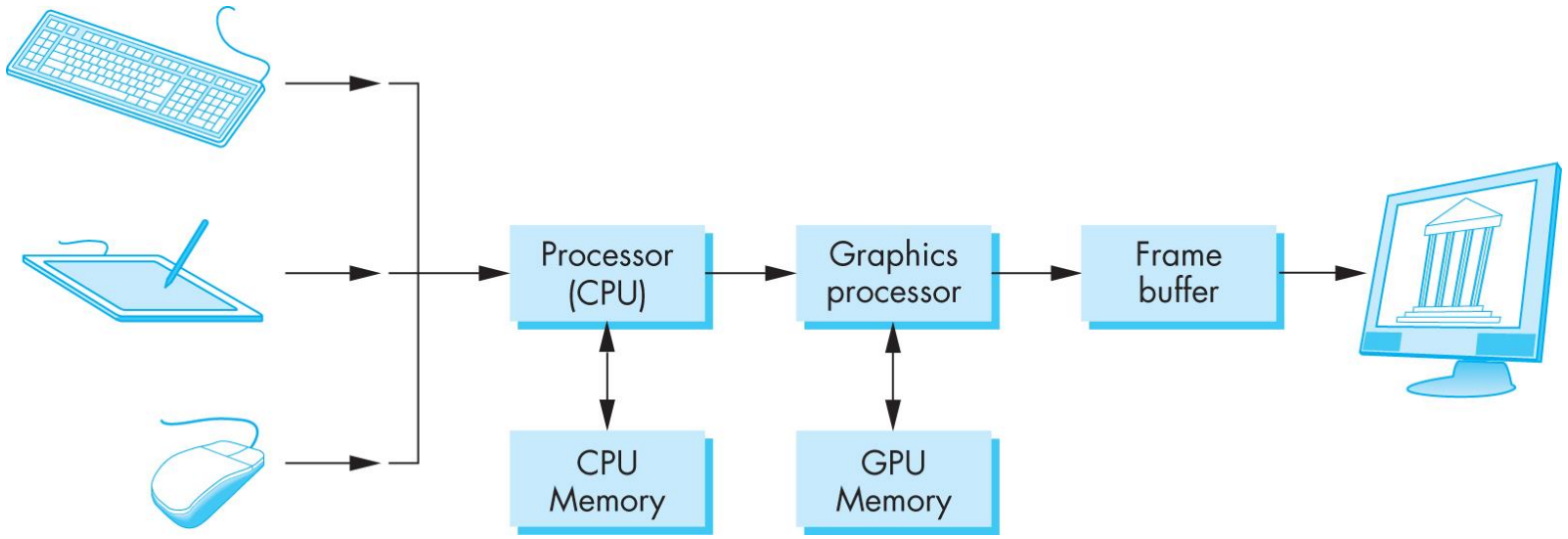
[www.mevislab.de]

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?

Basic Graphics System

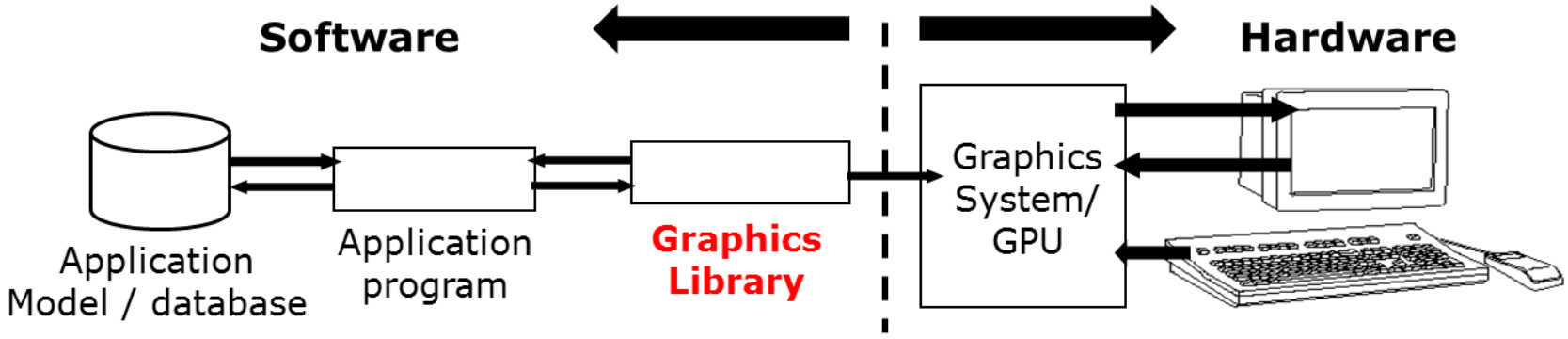


[Angel]

- Image formed in the frame buffer

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 APIS / LIBRARIES

Graphics Libraries / APIs

- OpenGL, RenderMan, DirectX, Windows Presentation Foundation (WPF), HTML5 + WebGL, three.js, …

- Primitives : characters, points, lines, triangles, …
- Attributes : color, line /polygon style, …
- Transformations : rotation, scaling, …
- Light sources
- Viewing
- …

Computer Graphics APIs

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

API contents

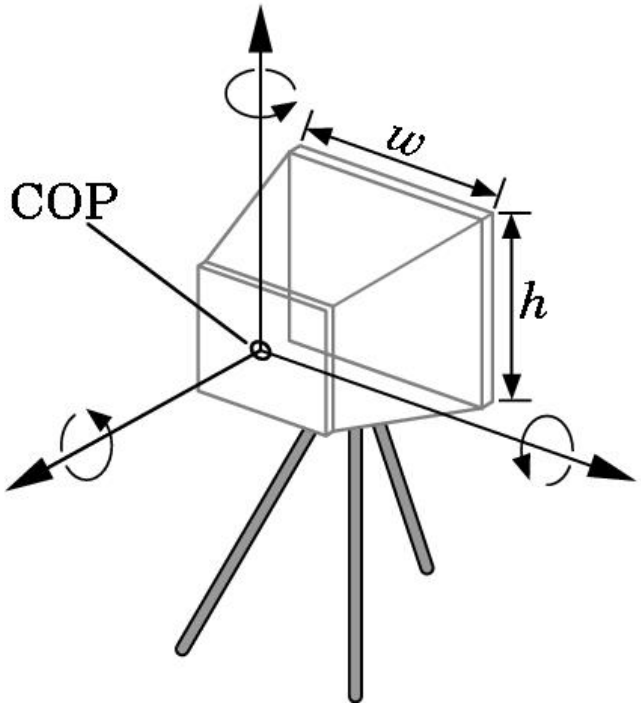
- Functions for specifying / instantiating
  - Geometric primitives
  - Viewer / Camera
  - Light sources
  - Materials
  - …
- Functions for simple user interaction
  - Input from devices: mouse, keyboard, etc.

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
  - Spot lights
  - Near and far sources
  - Color properties
- Material properties
  - Absorption: color properties
  - Scattering: diffuse and specular
  - Transparency

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

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

three.js r97

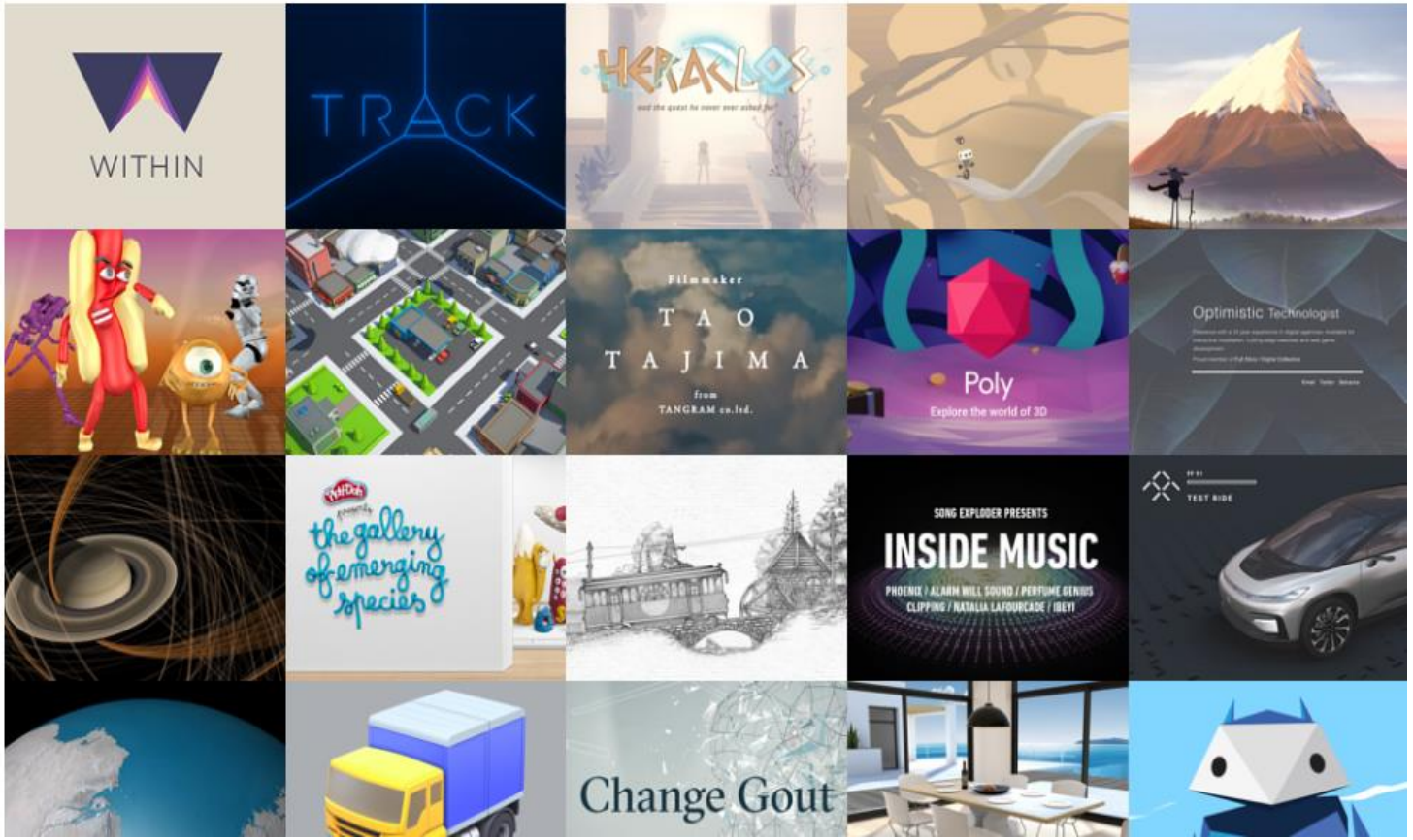
featured projects

documentation
examples

download

source code
questions
forum
irc
slack
google+

Interactive 3D Graphics
Taught by Eric Haines
UDACITY



GEOMETRIC MODELING

Geometric Modeling

- A geometric model describes the shape of an (real or virtual) object
  - Geometry, attributes, appearance, …
- How?
  - Different representations?
  - Data structures?
  - Possible operations?
  - Compactness ? Robustness ?
  - Interpolation vs Approximation ?
  - …

Geometric Modeling

- What for?
  - Distinguish between inside, outside and border of a model
  - Compute properties
    - Centroid
    - Area / Volume
    - …
  - Detect interferences / collisions
  - Compute light reflections and / or transparencies
  - …

Modeling vs Rendering

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

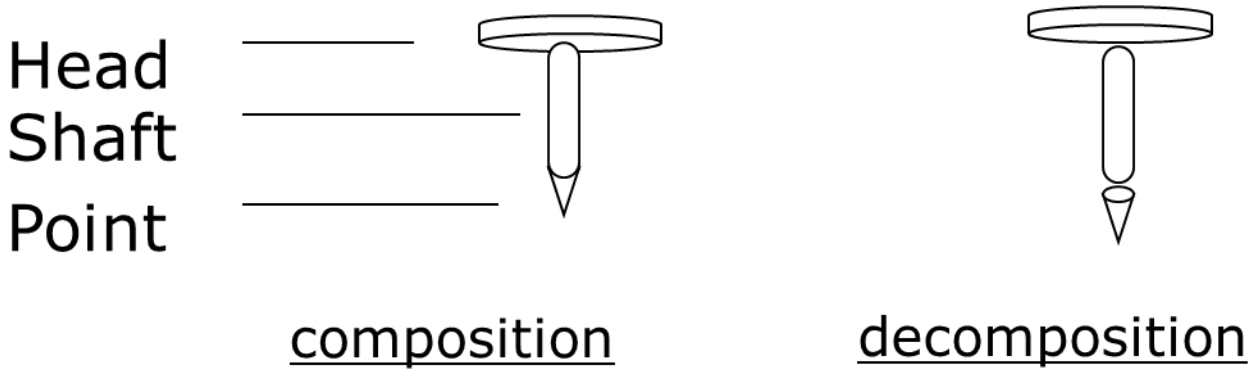
YouTube Demo

- Rendering
  - Take picture with the camera

[van Dam]

Decomposition of a geometric model

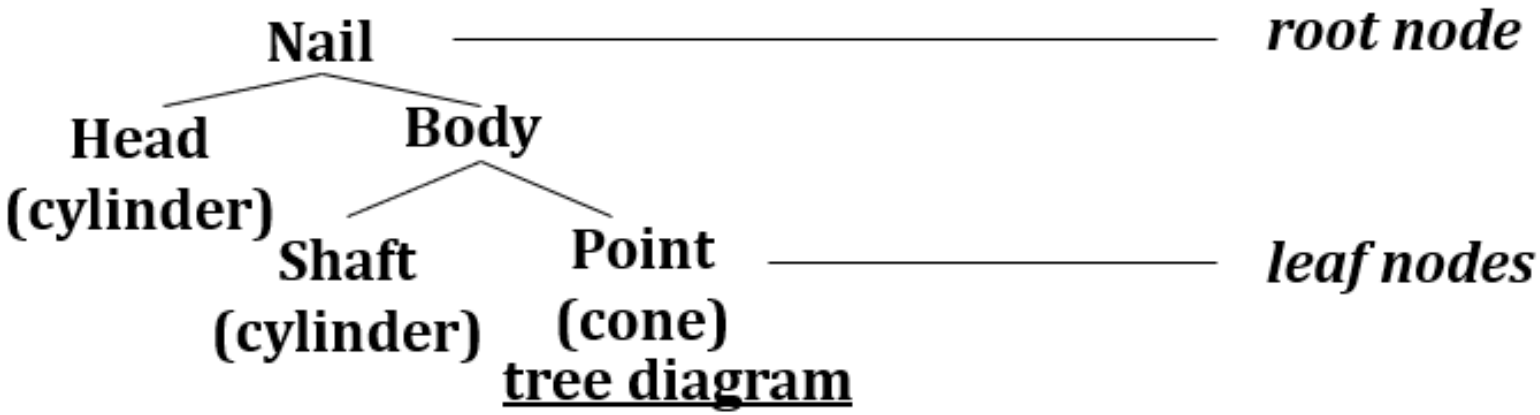
- Hierarchy of geometrical componentes
- Reduction to primitives
  - Spheres, cubes, etc.
- Simple vs not-so-simple elements



[van Dam]

Hierarchical representation

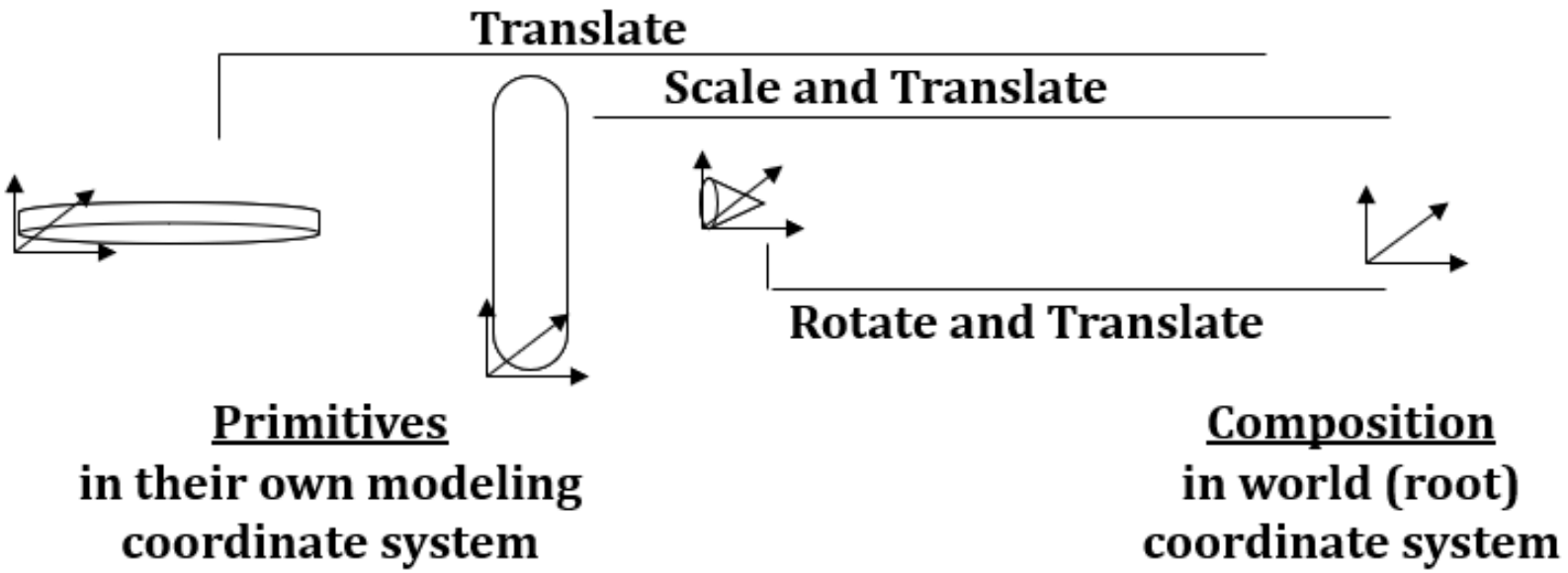
- Decomposition into collections of primitive shapes
  - Tree diagram
- Scene-graph : data structure to be rendered



[van Dam]

Composition of a geometric model

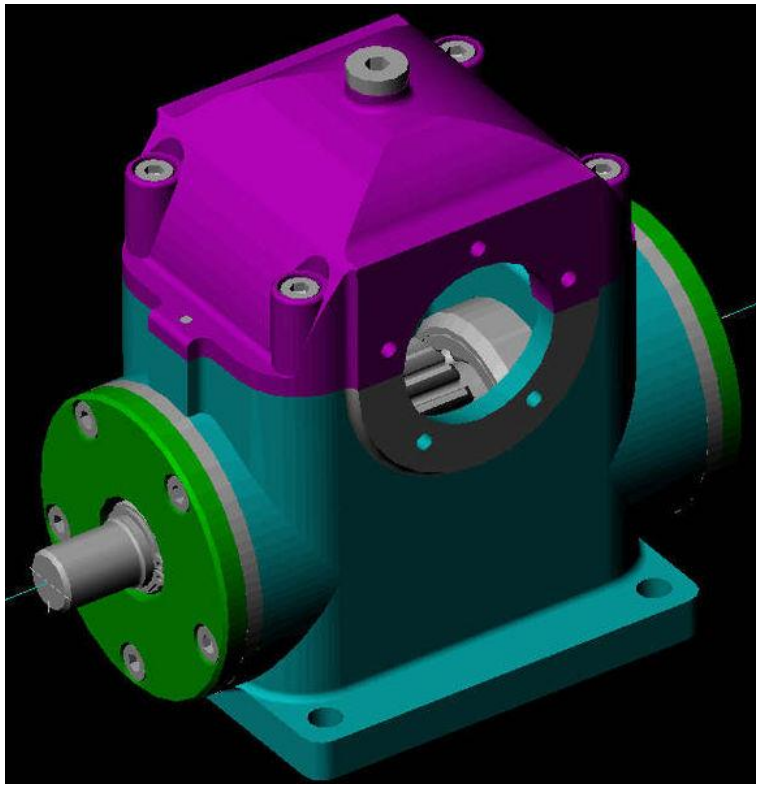
- Assemble primitives to create final object
  - Apply affine transformations

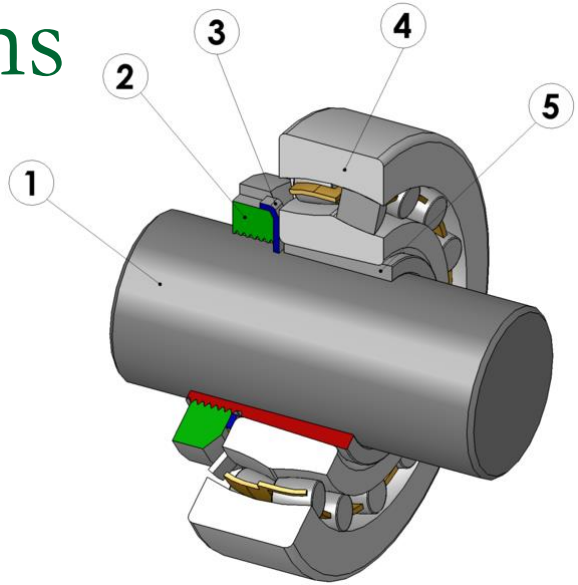


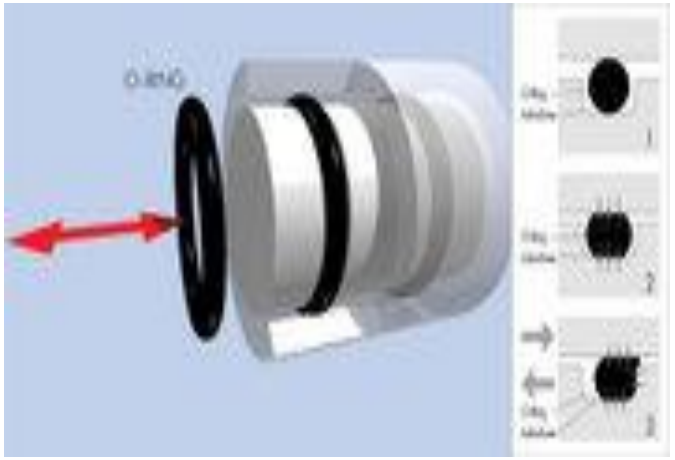
[van Dam]

3D models – Applications

- CAD / CAM



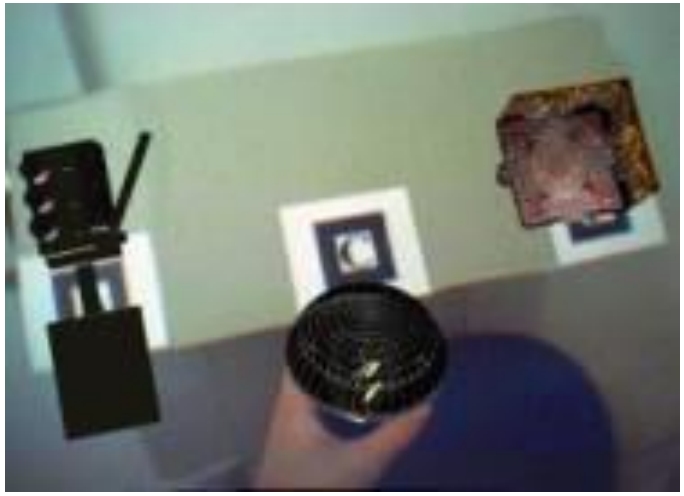




[Wikipedia]

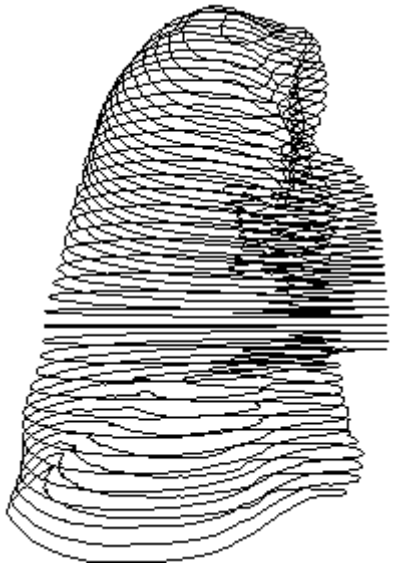
3D models – Applications

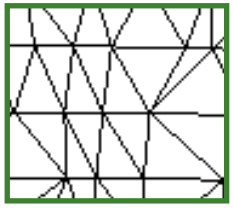
- Virtual / Augmented reality



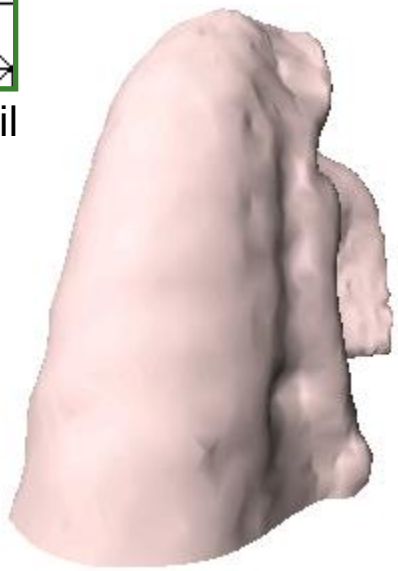
3D models – Applications

- Medical Data Processing





Mesh detail



Mesh

3D models – Applications

- Other application areas
  - Computer games
  - Geographical information systems (GIS)
  - Engineering analysis
  - Rapid prototyping
  - Medical solid modeling
  - …

3D models – Shape

- Define from scratch using VRML / X3D, OpenGL, VTK, …
  - Tedious; requires skill
- Obtain from CAD files or model databases
  - Convert to compatible VR formats
  - Use of existing models in manufacturing applications
- Create using a 3D digitizer or a 3D scanner
  - 3D digitizer : stylus
  - 3D scanner : tracker, cameras and laser

3D modeling tools

- Spatial Corp.'s ACIS; 3D modeling engine
  - http://www.spatial.com
- Siemens's Parasolid; 3D modeling engine
  - https://www.plm.automation.siemens.com/en_us/products/open/parasolid/

- Dassault Systemes's CATIA; CAD / CAM / CAE
  - http://www.3ds.com
- PTC's Creo Parametric; 3D feature modeling
  - http://www.ptc.com
- SolidWorks; 3D feature modeling
  - http://www.solidworks.com

3D modeling tools

- Autodesk's 3ds Max and Maya
  - http://www.autodesk.com
- Blender: Free open source 3D content creation suite
  - http://www.blender.org
- Rhino: Uninhibited free-form 3-D modeling
  - http://www.rhino3d.com
- Trimble SketchUp: Intuitive 3D modeler
  - http://www.sketchup.com

- POV-Ray: Persistence of Vision Ray-Tracer
  - http://www.povray.org

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

Acknowledgments

- Some ideas and figures have been taken from slides of other CG courses.
- In particular, from the slides made available by Ed Angel and Andy van Dam.
- Thanks!