Grafica/Fondamenti di COMPUTER GRAPHICS

A.A.2018/2019

Pixar Animation Studios, 1986 John Lasseter

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Università di Bologna

course website:

http://www.dm.unibo.it/~morigi/homepage_file/courses_file/fcg1819.htm

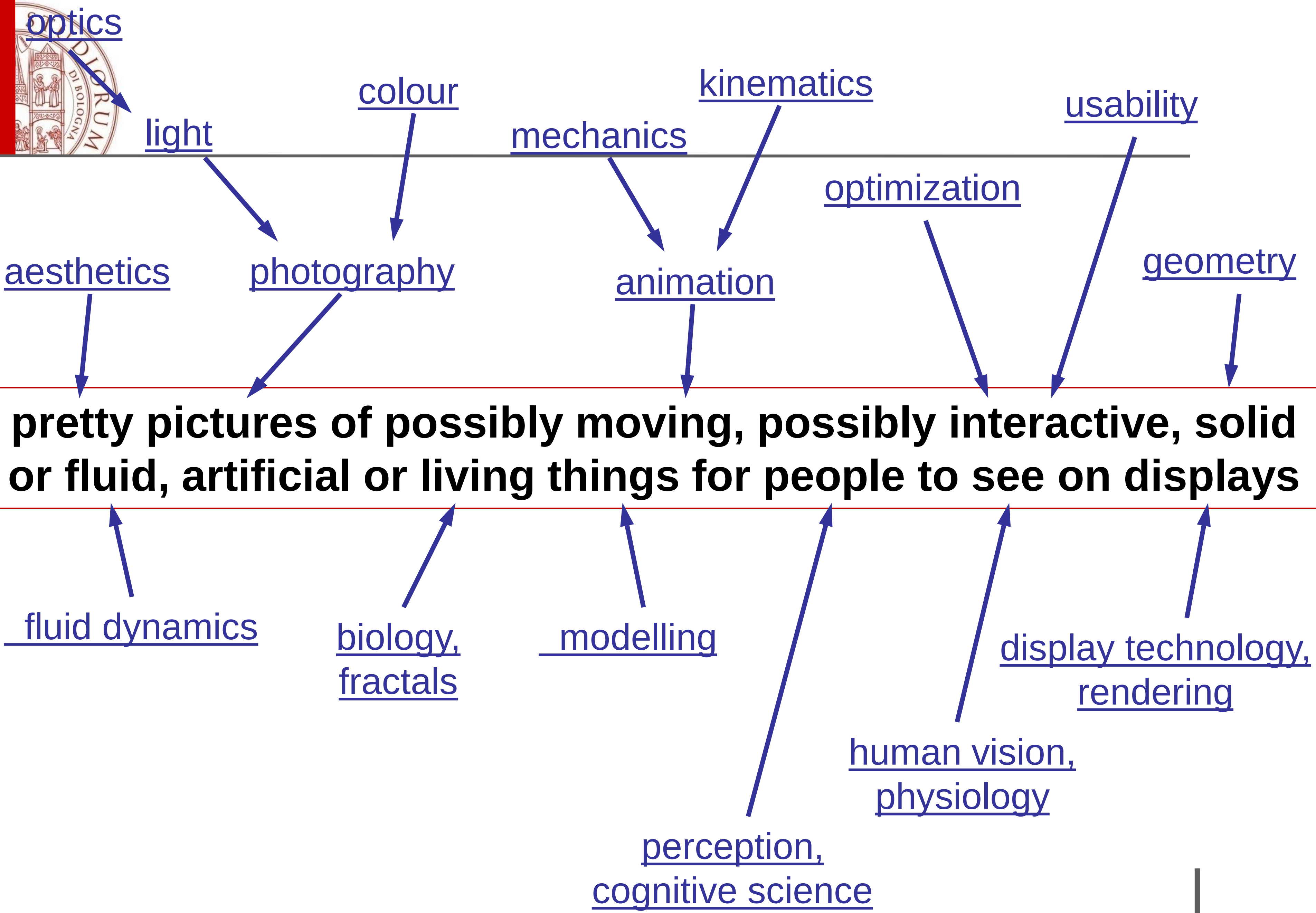
Insegnamenti On Line (IOL)

Computer Graphics is...

Computer Graphics =

pretty pictures

of possibly moving, possibly interactive, solid or fluid, artificial or living things for people to see on displays



optics

light

colour

mechanics

kinematics

usability

optimization

aesthetics

photography

animation

geometry

pretty pictures of possibly moving, possibly interactive, solid or fluid, artificial or living things for people to see on displays

fluid dynamics

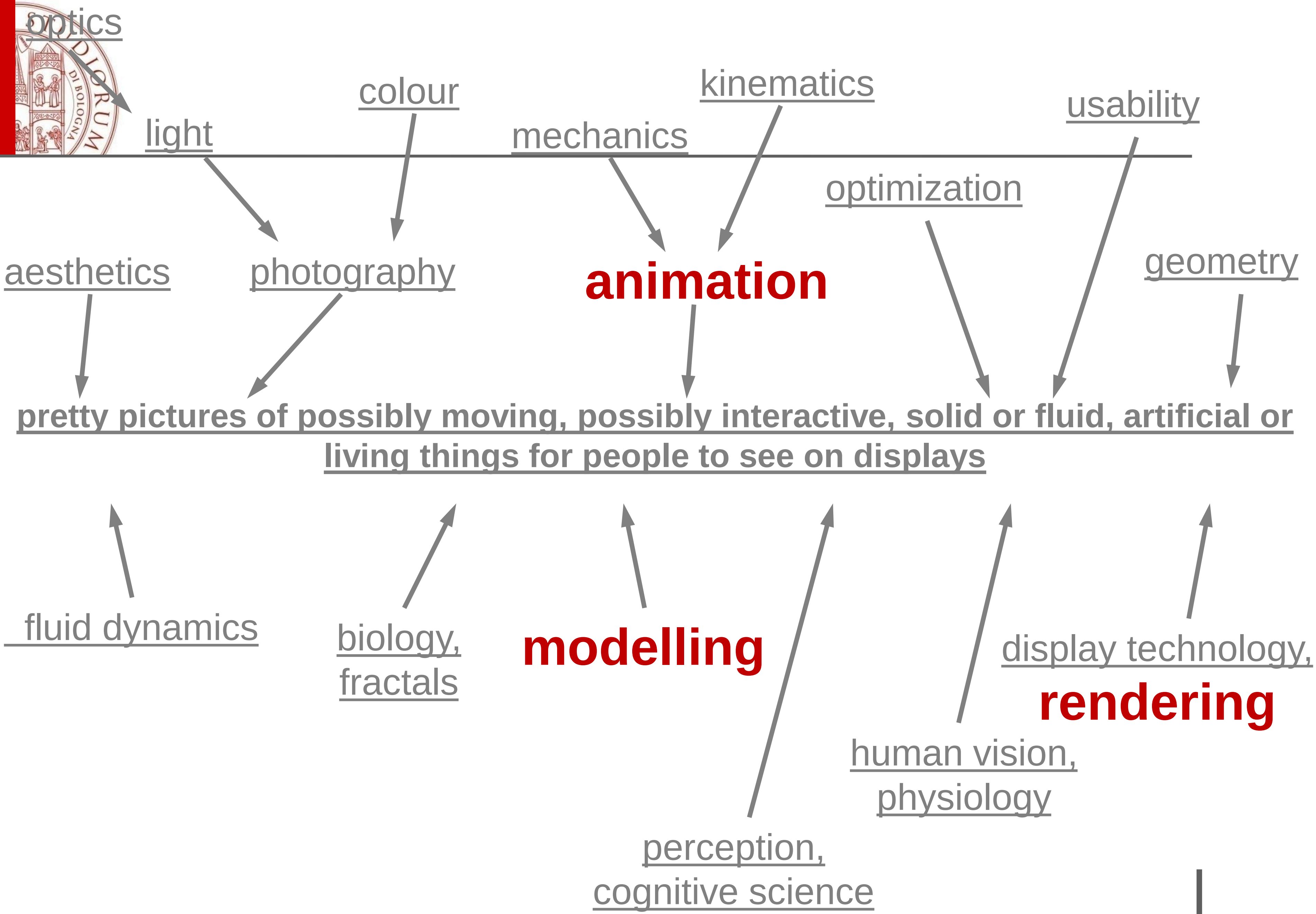
biology, fractals

modelling

display technology, rendering

human vision, physiology

perception, cognitive science



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rendering

human vision,
physiology

perception,
cognitive science

What you will learn

- Fundamentals of computer graphics algorithms
  - Modelling, Rendering Animation
- We will concentrate on 3D, not 2D illustration or image processing
- Theoretical background (math) for the technical aspects of drawing pictures
- Basics of real-time rendering and graphics hardware
- OpenGL / Basic GLSL

It’s not supposed to be a programming course or math course, except that programming and math are necessary enabling technologies

How much math?

- Lots of simple linear algebra/calculus
  - Vectors, matrices, basis, solving systems of equations
  - Basic computational geometry
  - Get it right, it will help you a lot!
- Always in a concrete and visual context
- Many of the mathematical and algorithmic tools are useful in other engineering and scientific context

Grading Policy

- Assignments: 45%

  6CFU:

  4 over 7 programming assignments (individually)

  alternatively:

  – individual project or seminar presentation

  8CFU:

  6 over 7 programming assignments (individually)

  4 can be replaced by :

  – individual project or seminar presentation

- Final Exam: 50% – oral
- Participation: 5%

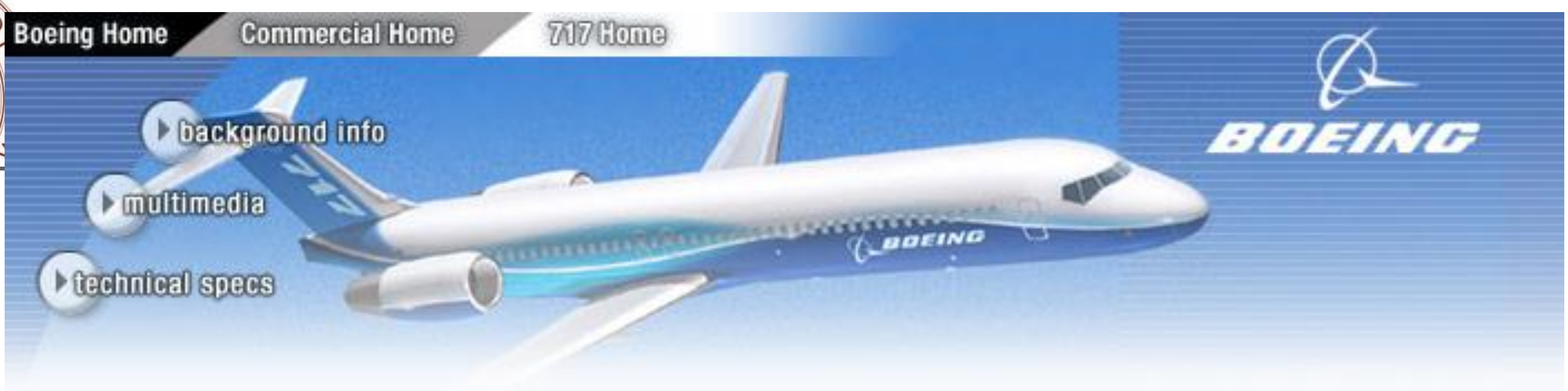
Who needs Computer Graphics?

- Computer-Aided Design/Manufacturing
- Medical Imaging
- Simulation
- Architecture
- Electronic publishing
- Computer Animation / Film Production
- Art
- Games
- …

Industrial Design

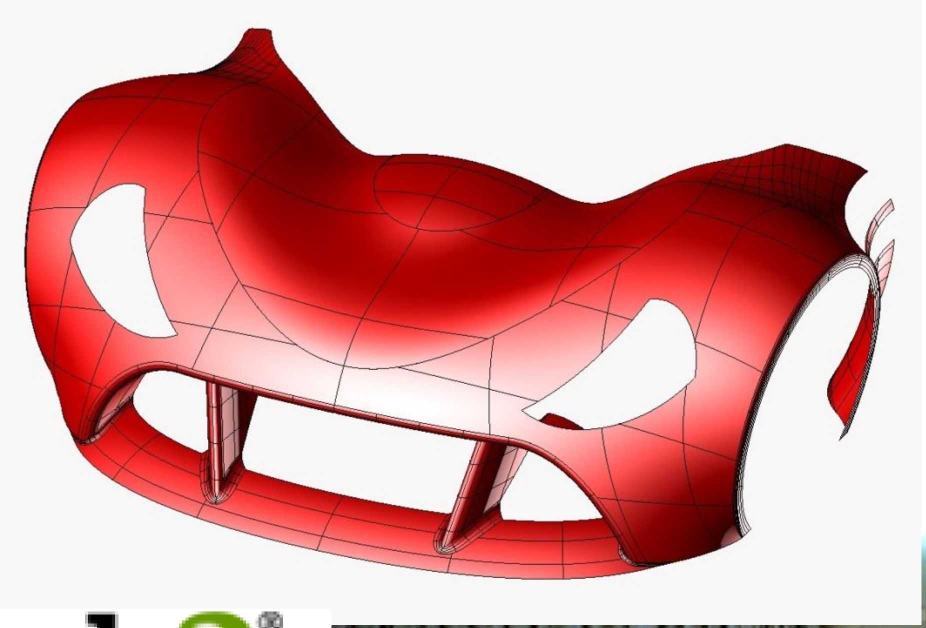
The final product is 3D

- Aeroplane
- Cars
- Boat
- Toys
- Tools
- ….

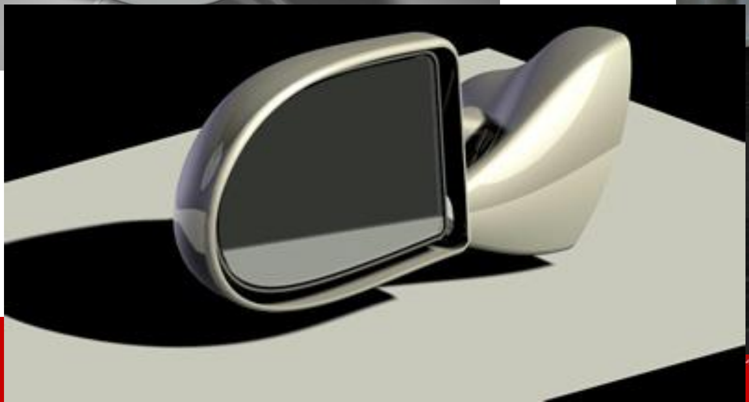


CAD Systems

William Fetter coined term "computer graphics" in 1960 to describe new design methods he was pursuing at Boeing



think3®



Higher Quality Models are achieved through thinkD’s extensive modeling, editing, and continuity analysis toolsets. The dynamic, real-time capabilities provide immediate feedback for making critical aesthetic, functional and engineering decisions

NEW
SPRING
CLEAN

think3®

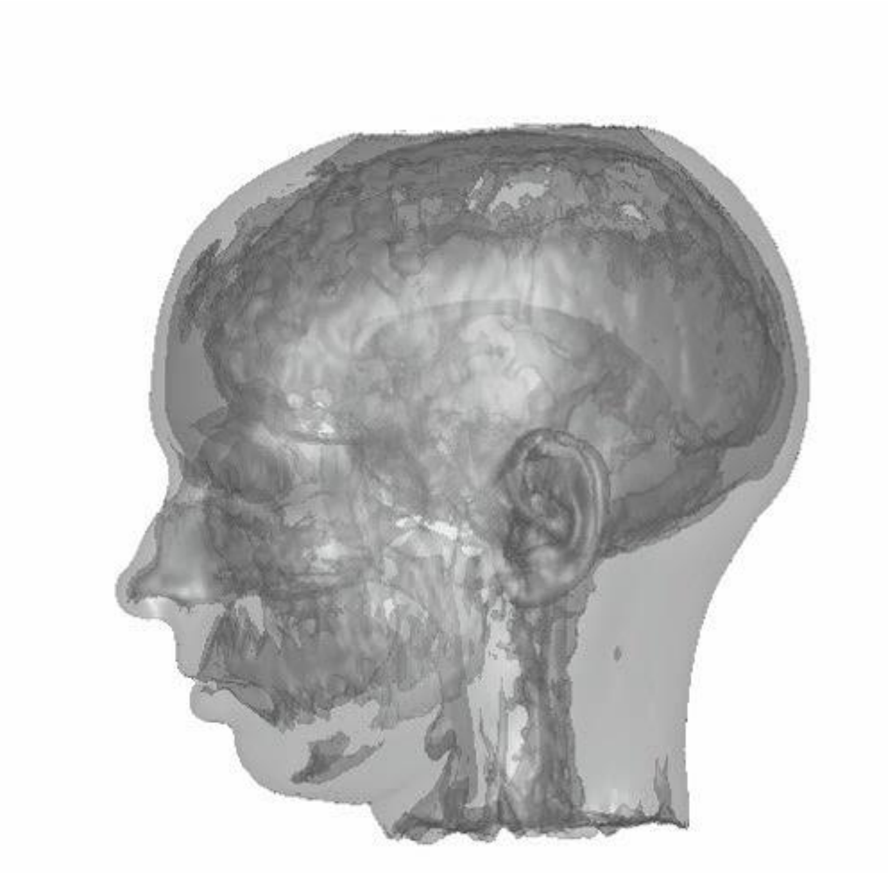
Medical Imaging

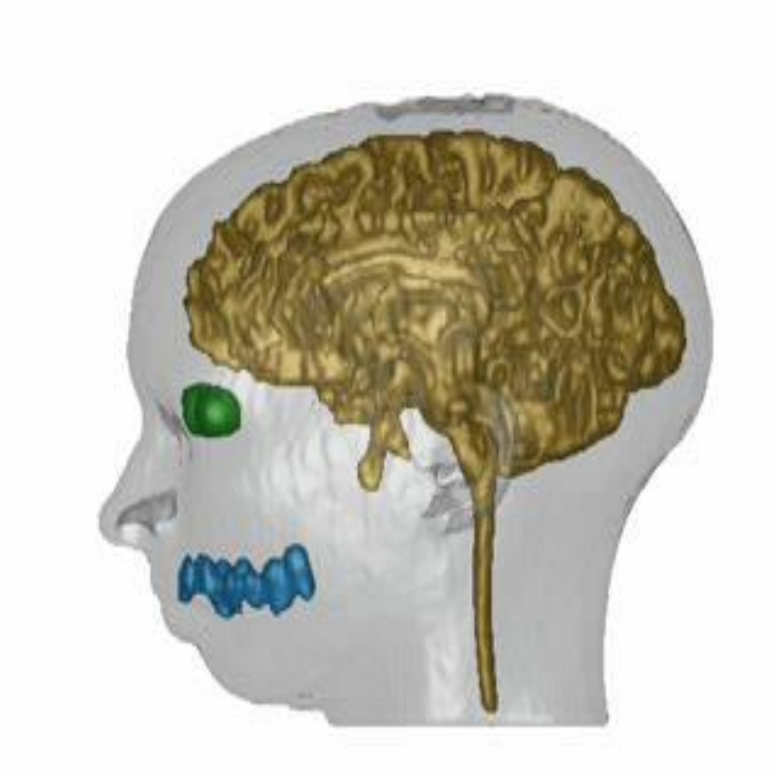
How to represent volume data?

-volume rendering

-isosurfacing

Magnetic resonance MRI (3D volume 257^3)

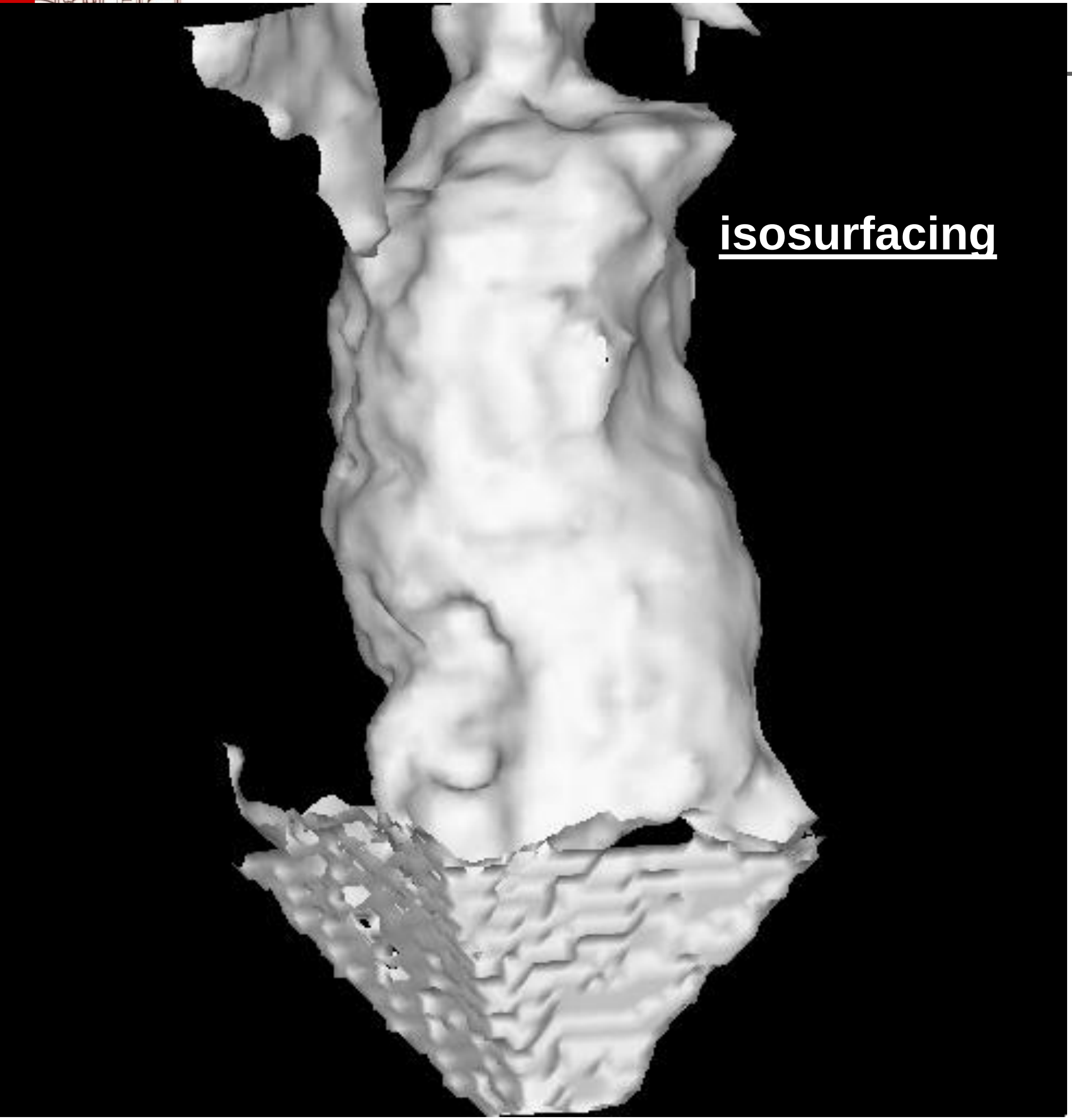




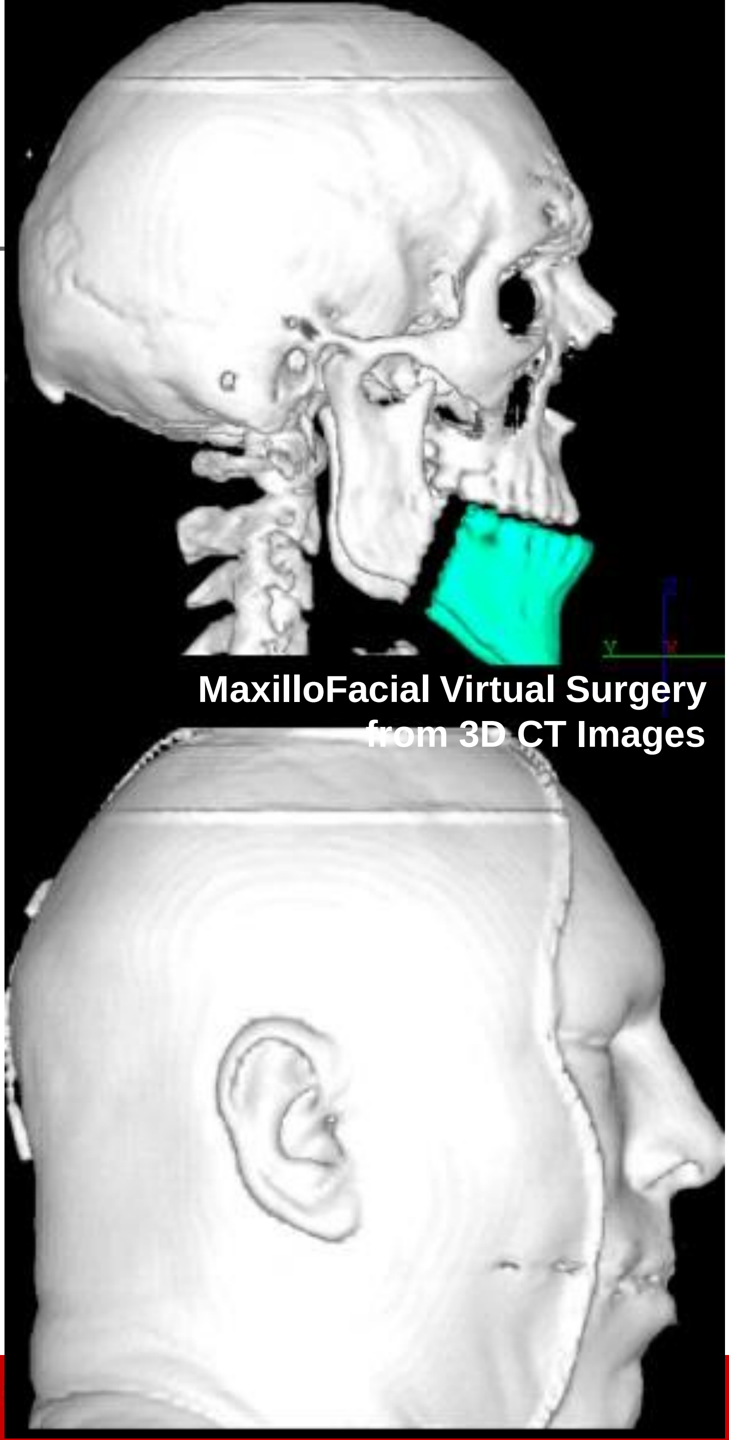
segmentation

Collaboration with Prof. Martin Rumpf – Bonn Germany

Medical Imaging



isosurfacing



MaxilloFacial Virtual Surgery from 3D CT Images

Collaboration Prof. Sgallari –ESAOTE

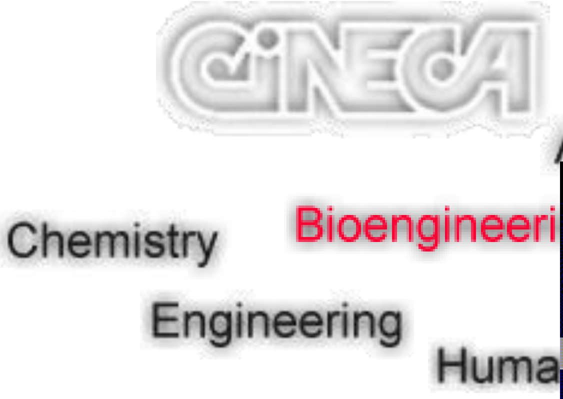
Scientific Visualization

“The merging of data with the display of geometric objects through computer graphics”

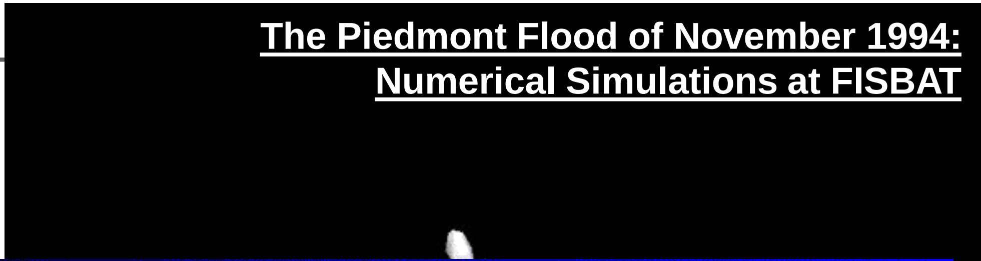
DATA + GEOMETRY:

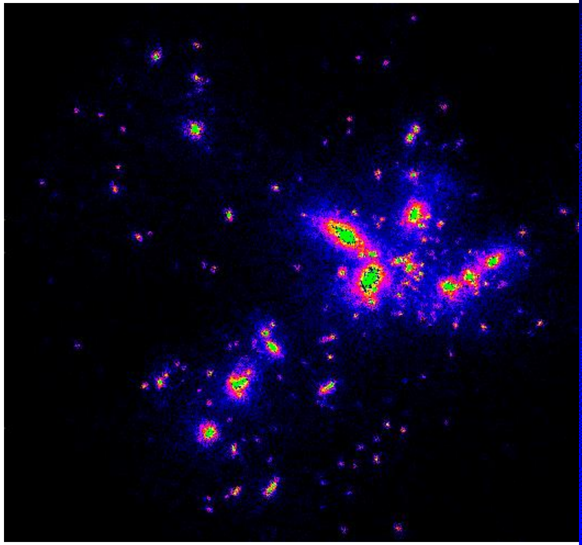
- Understanding of data
- Insight into information
- Presentation and sharing of insights.

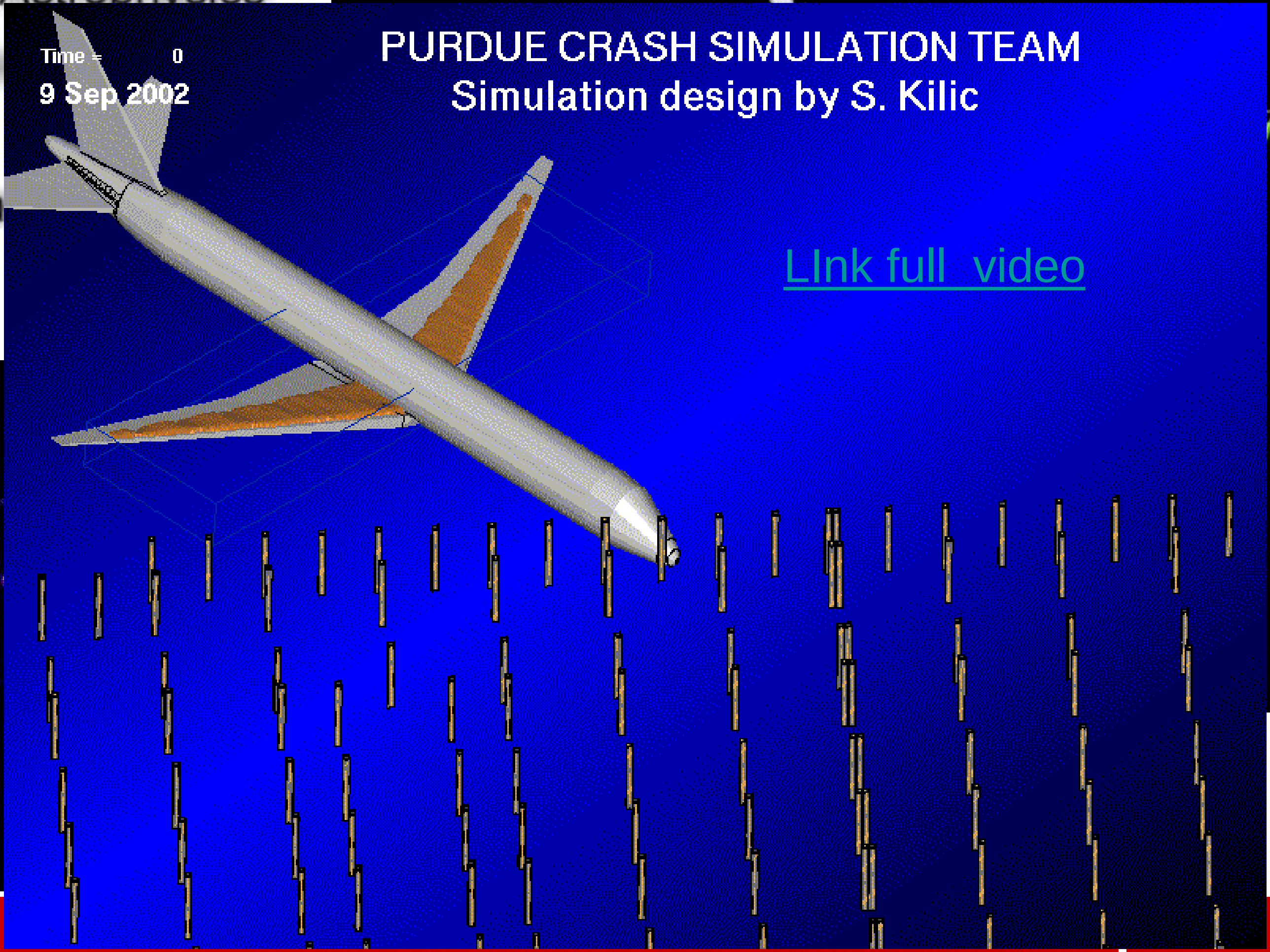
Scientific Visualization



The Piedmont Flood of November 1994: Numerical Simulations at FISBAT







LInk full video

Visual Simulation and Training

- Apollo spacecraft
- Flight simulators
- Driving simulators
- Surgical simulation

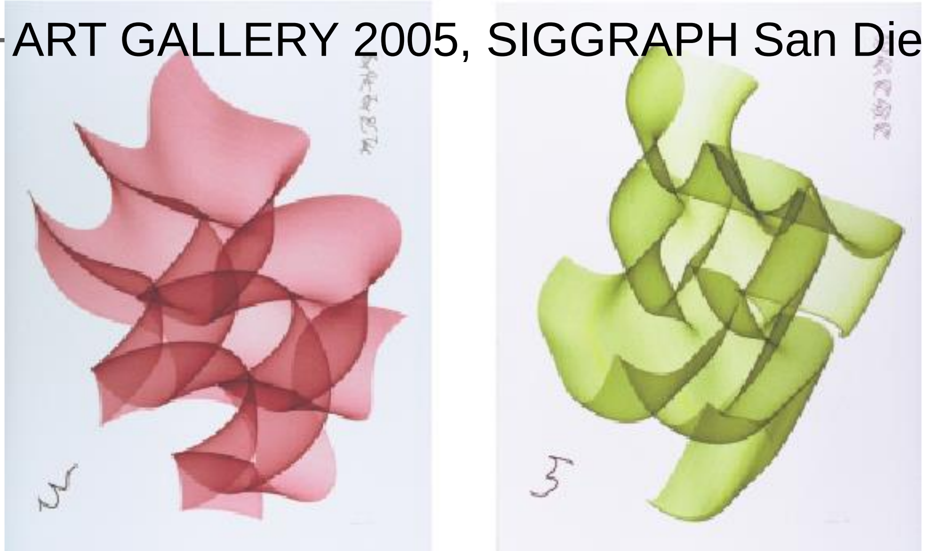
Davinci surgical robot
Intuitive Surgical

Driving simulator
Toyota Higashifuji Technical Center

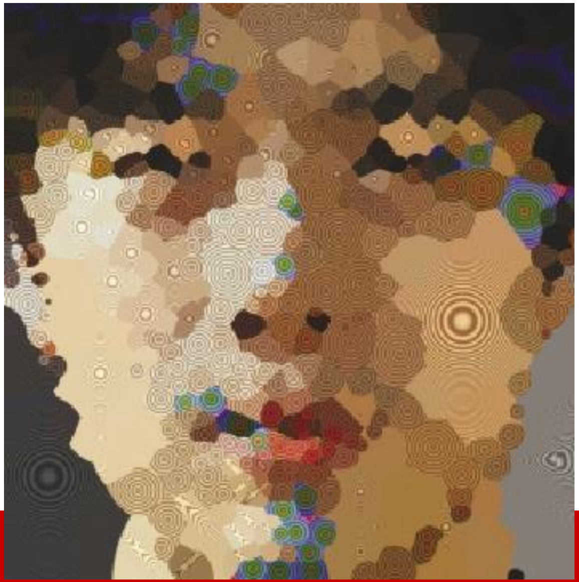
Art

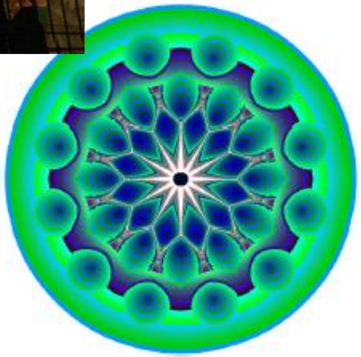
Video Mapping 3D

ART GALLERY 2005, SIGGRAPH San Diego

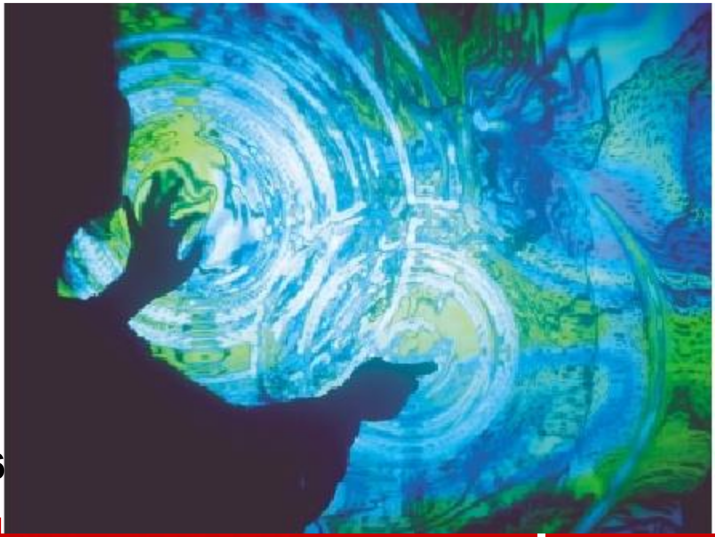


Cyberflower duet, red & green



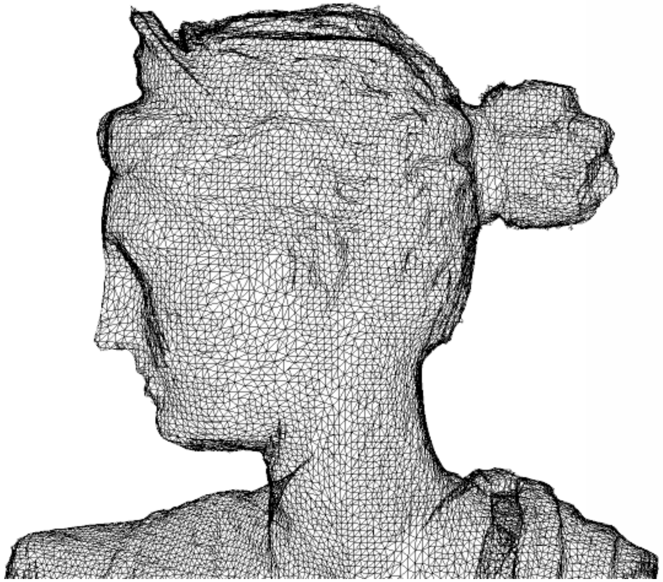


Polynomiography: visualizzazione
di approssimazioni di zeri
di polinomi. Fig: degree 36



Waves

Art

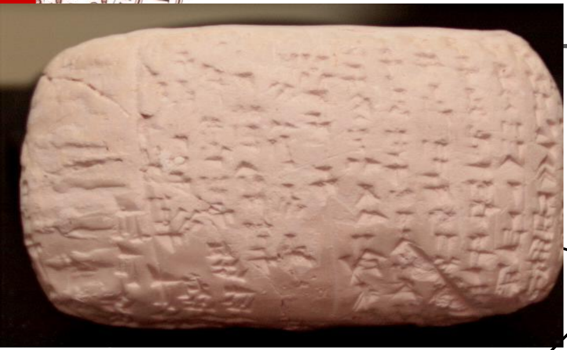


Surface fairing

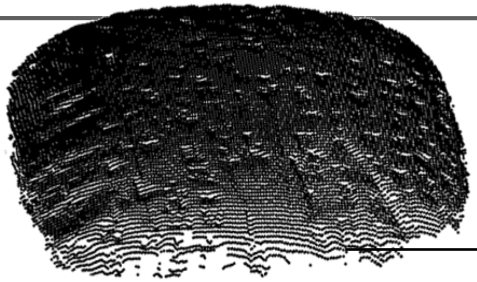
Reverse Engineering and …
…..Rapid Prototyping

La Tavoletta Cuneiforme

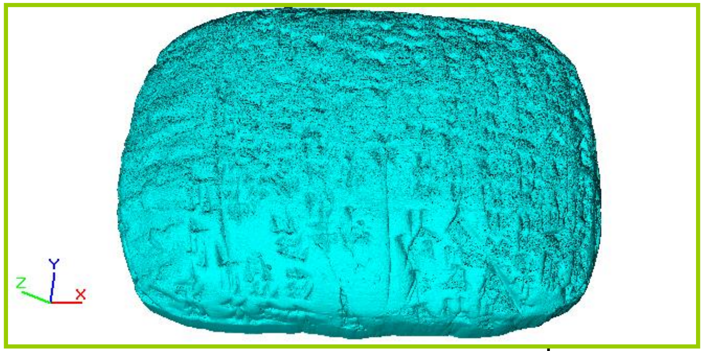
(tesi di S. Trerè - ENEA -Bologna)



Object

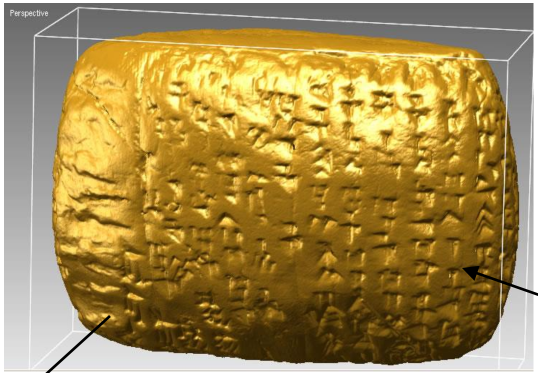


Cloud of points

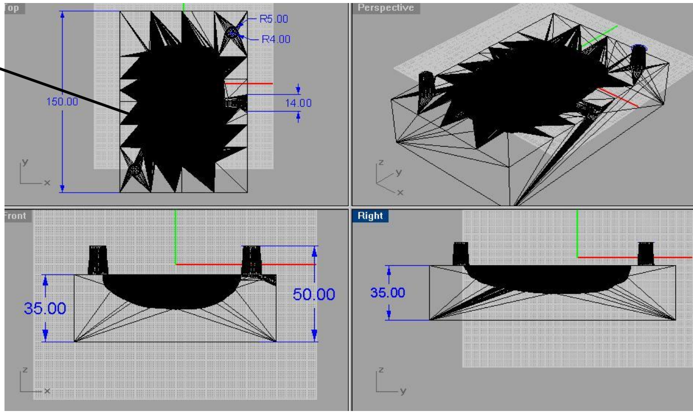


Virtual Model

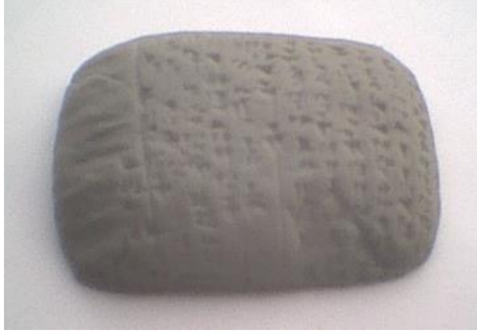
3D scanner Picza



Rendering



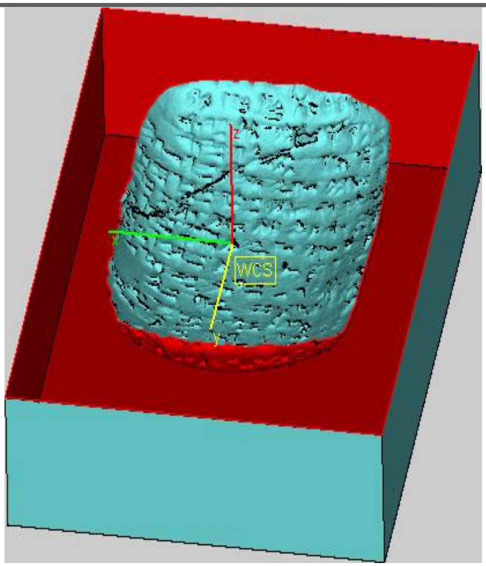
CAD

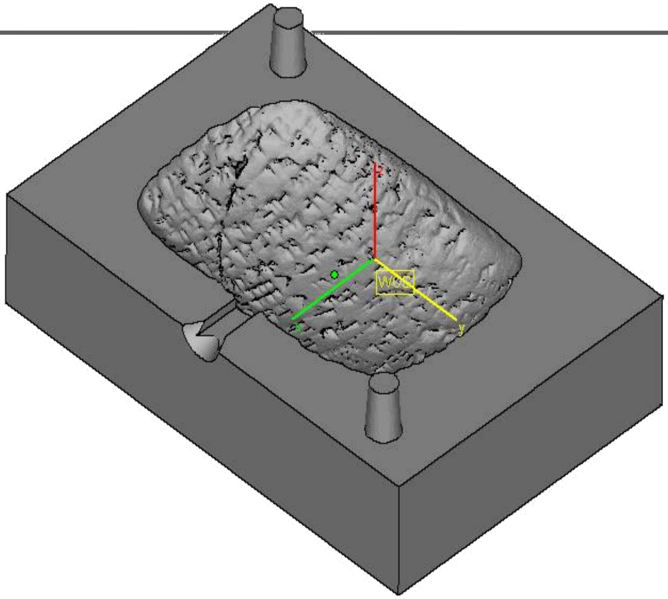


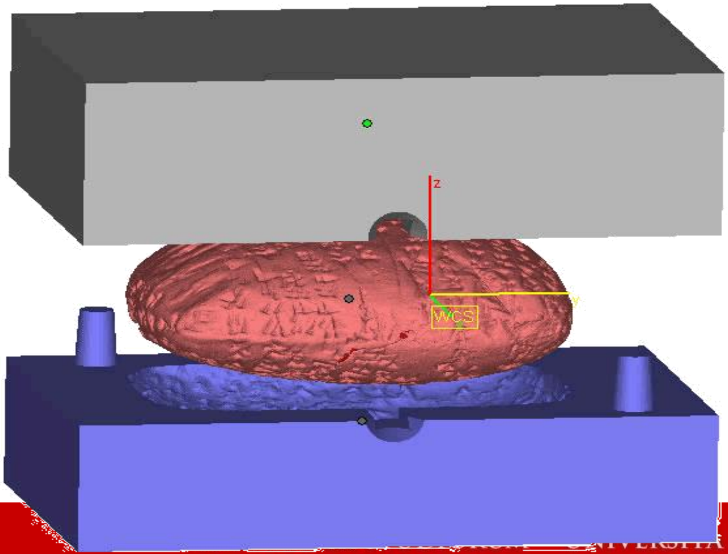
Prototype object

“Thermojet” -ENEA-

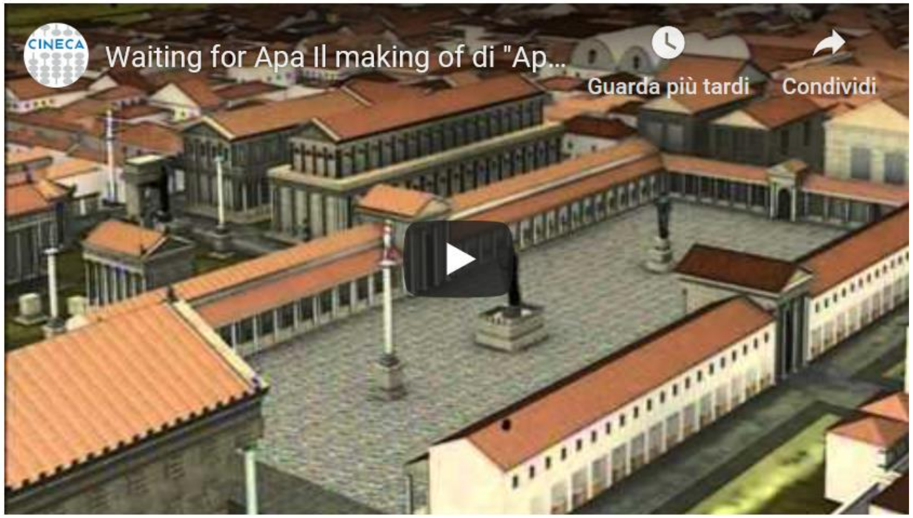
CAD PostProcessing







Architectural Walkthroughs
Virtual paths: Apa alla scoperta di Bologna

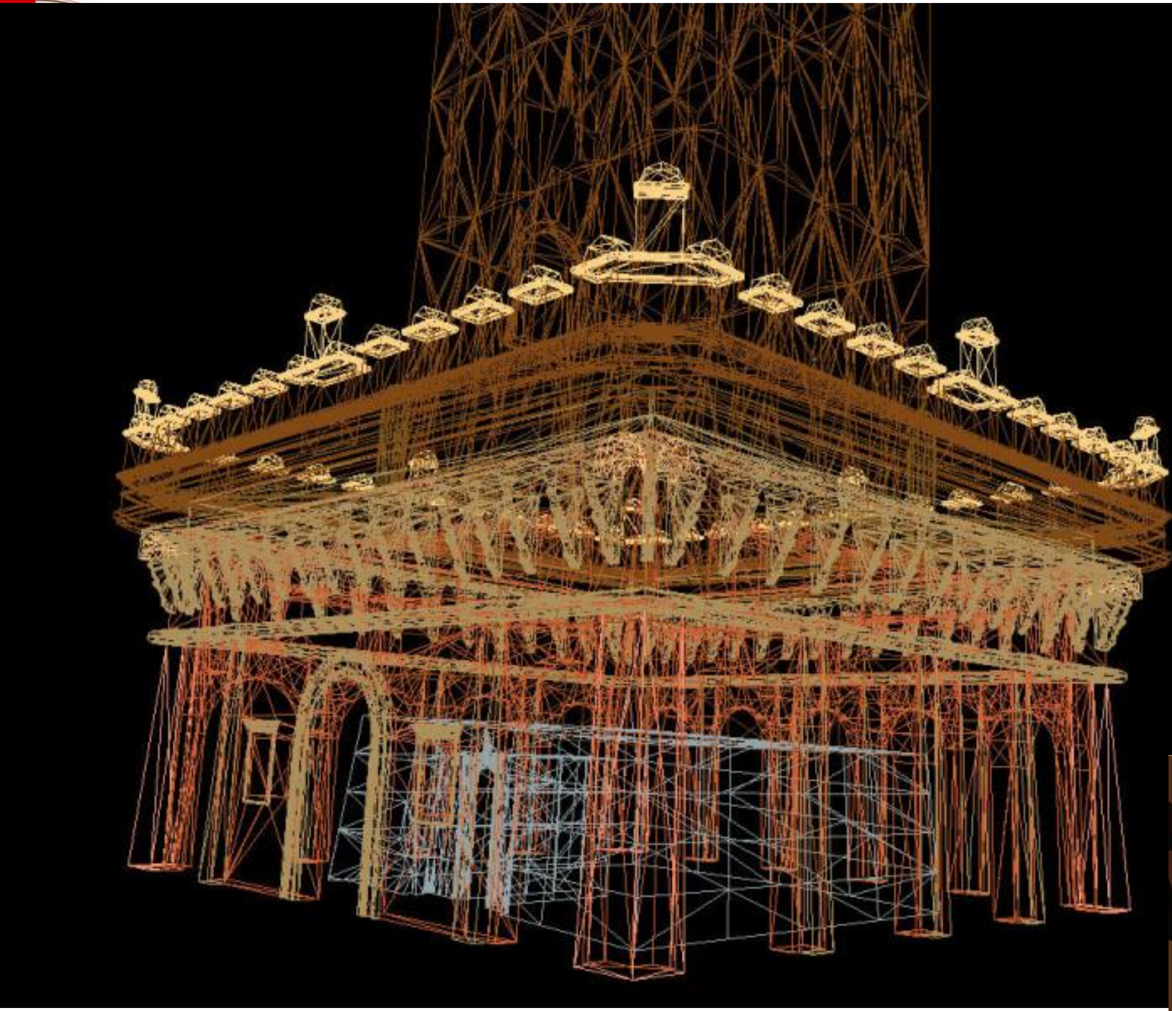


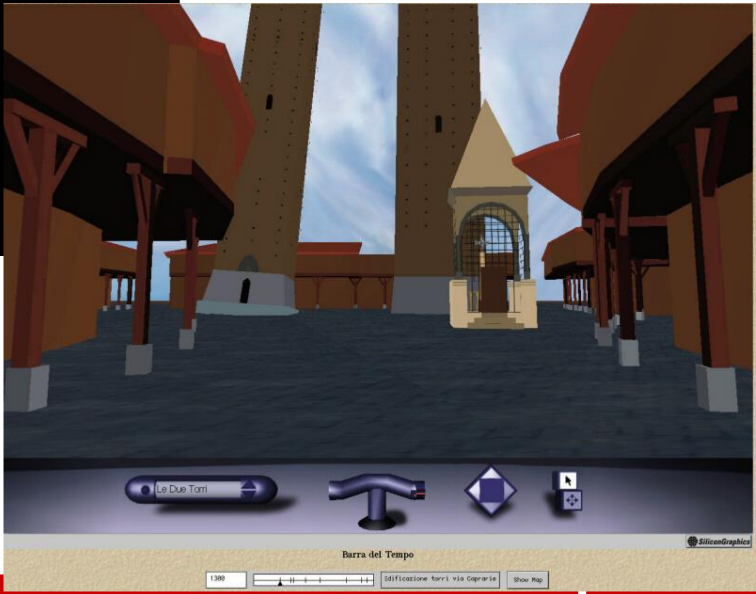
Making of del cartoon 3D visibile nella saletta imersiva del Museo della Storia di Bologna. Apa, il prota
del cartoon, è doppiato da Lucio Dalla

Cineca, Bologna

2012 Al centro del Museo della Storia di Bologna, in una sala immersiva, è possibile vedere il cartoon 3D che il Cineca ha realizzato per Genus Bononiae: un cartone animato stereoscopico sulla storia di Bologna che combina un grande rigore filologico e le più innovative tecnologie con l'intento di informare divertendo.

Computer applications of virtual reality are a valuable tool to provide new means of access to the history of a city.




Le Due Torri
SiliconGraphics
Barra del Tempo
1300
Edificazione torri via Caprarie
Show Map

E-business, E-commerce

Electronic publishing

digital publication of e-books, EPUBs (short for *electronic publication*) is a free and open e-book), digital magazines, and the development of digital libraries and catalogues

GATORADE: Gatorade “23 vs 39“ presented interesting challenges.
The spot involves present-day Michael Jordan playing one-on-one against 1986 Michael Jordan. The challenge was to keep the performances fresh, creating the illusion that two MJs are playing one-on-one.

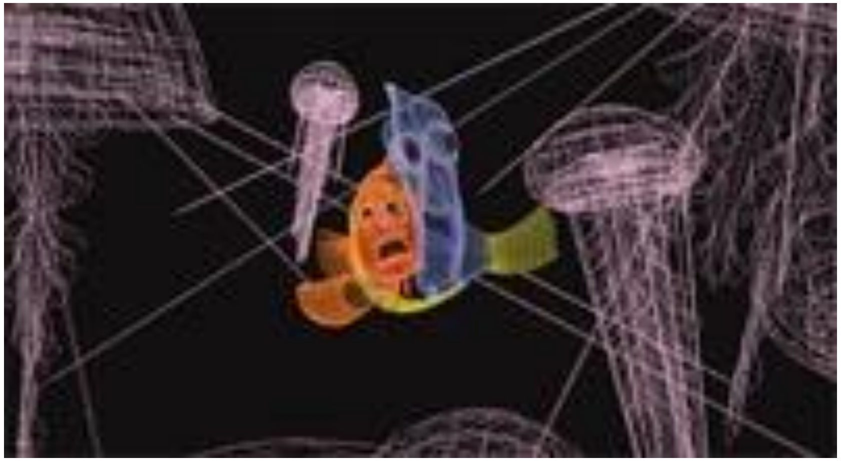
Entertainment

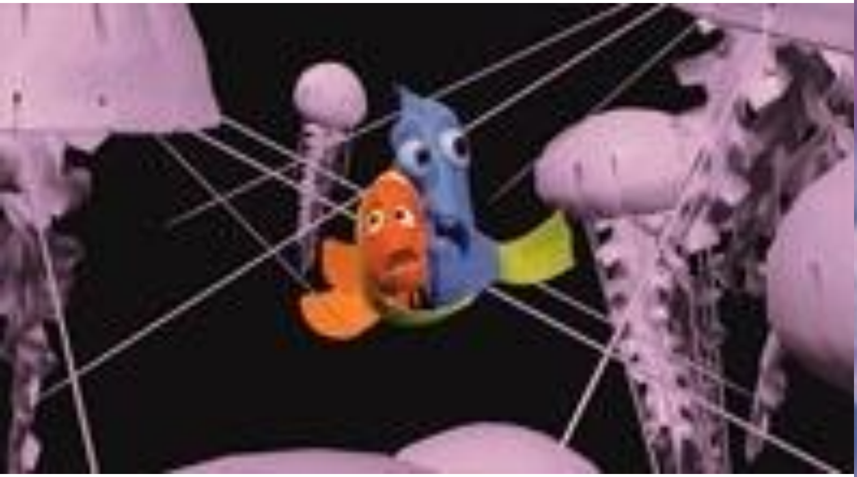
- Video Games
- Animated Film
- Visual Effects

PIXAR Animation Studios
Luxo Junior (1986)
Red’s Dream (1987)
Toy Story (1995)
A Bug’s Life (1998)
Toy Story 2 (1999)
Monster,Inc. (2001)
Finding Nemo (2003)
The Incredibles (2004)
Cars (2006)
Ratatouille (2007)…..
DREAMWORKS
Shrek/Shrek 2,3
(2003/2005/2007)
Madagascar (2005) ....

PIXAR Animation Studios

©Disney/Pixar





Film, Visual Effects

CG creature skin and muscles, skin rendering, motion capture, rigid and deformable dynamics, image-based modeling, digital doubles, fluid and smoke simulation, 3D compositing, cloth simulation, and new animation techniques.

(Industrial Light & Magic (ILM), Sony Pictures Imageworks, Inc.)

Walt Disney Pictures · Walden Media
NARNIA
Il Leone, la Strega e l'Armadio
Natale 2005
INDUSTRIAL LIGHT & MAGIC
LOTR-Demos_Mod
The

Harry Potter

(ESC Entertainment)

Facial capture in Avatar (2009)

Visual effects

The day after tomorrow

Liquids,
gases,
Solids

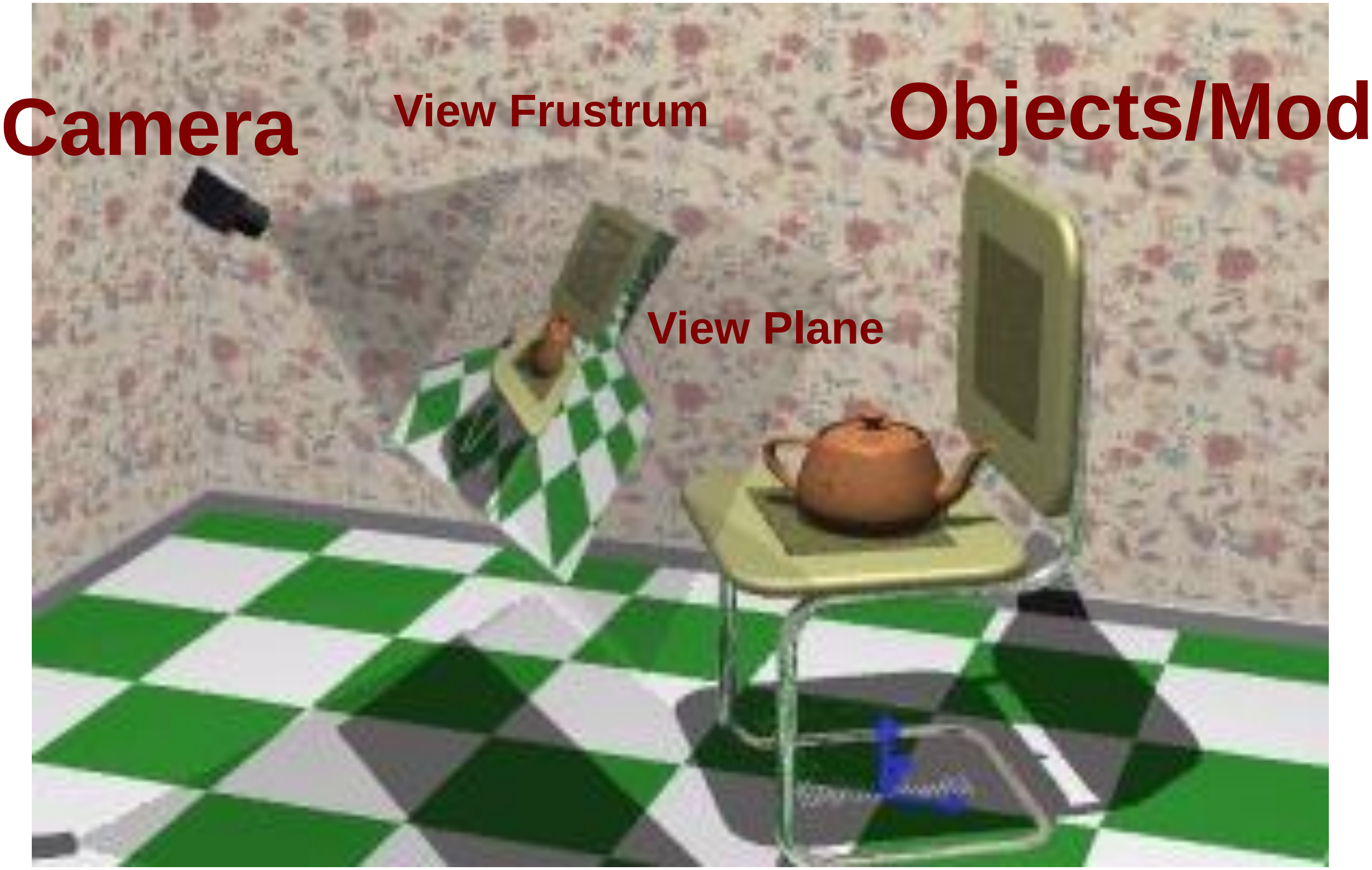
Star Wars Episode III

Destruction:
fracture, explosions, etc.

Videogames

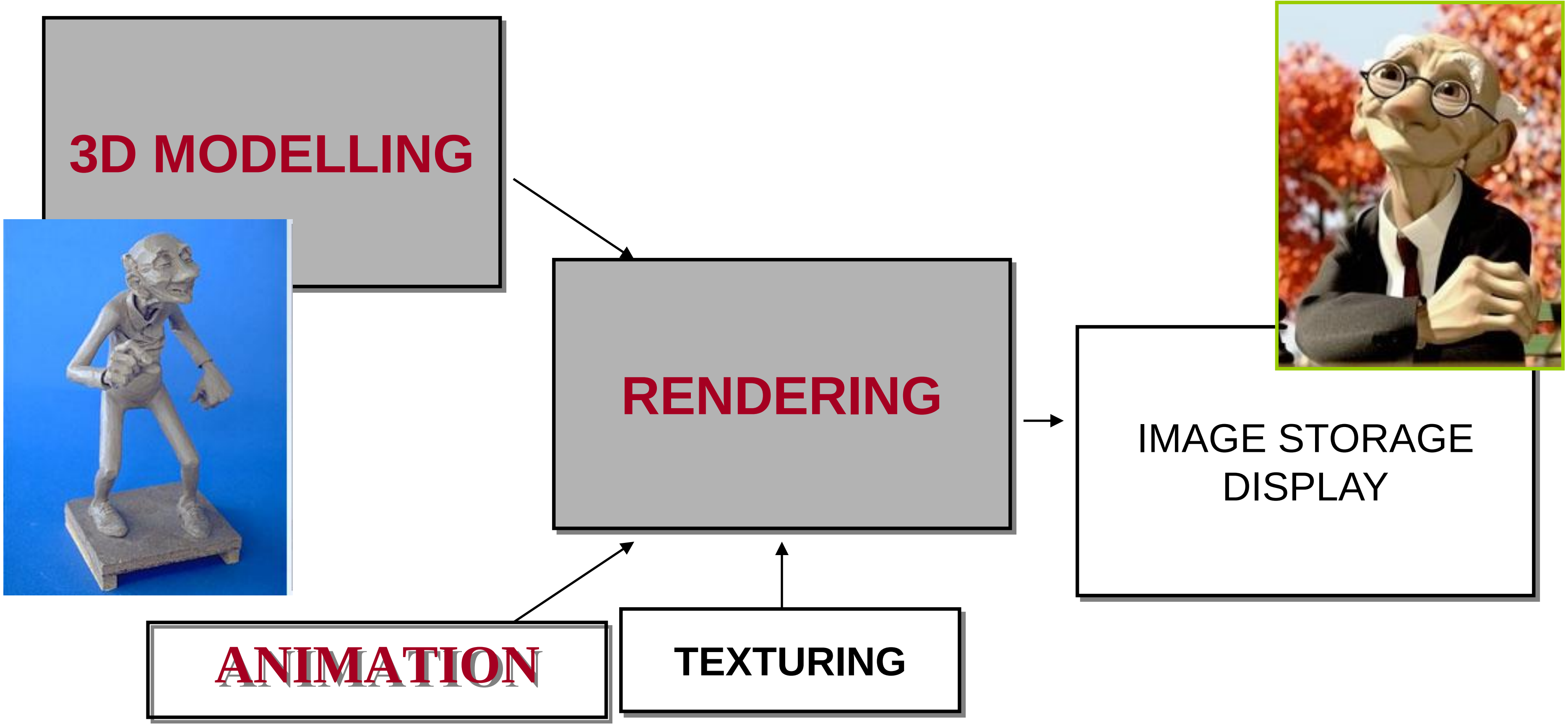
CG basic:

Virtual objects, scene,Viewer (camera)



The graphics process

Pixar, ‘Geri’s game’



3D MODELLING

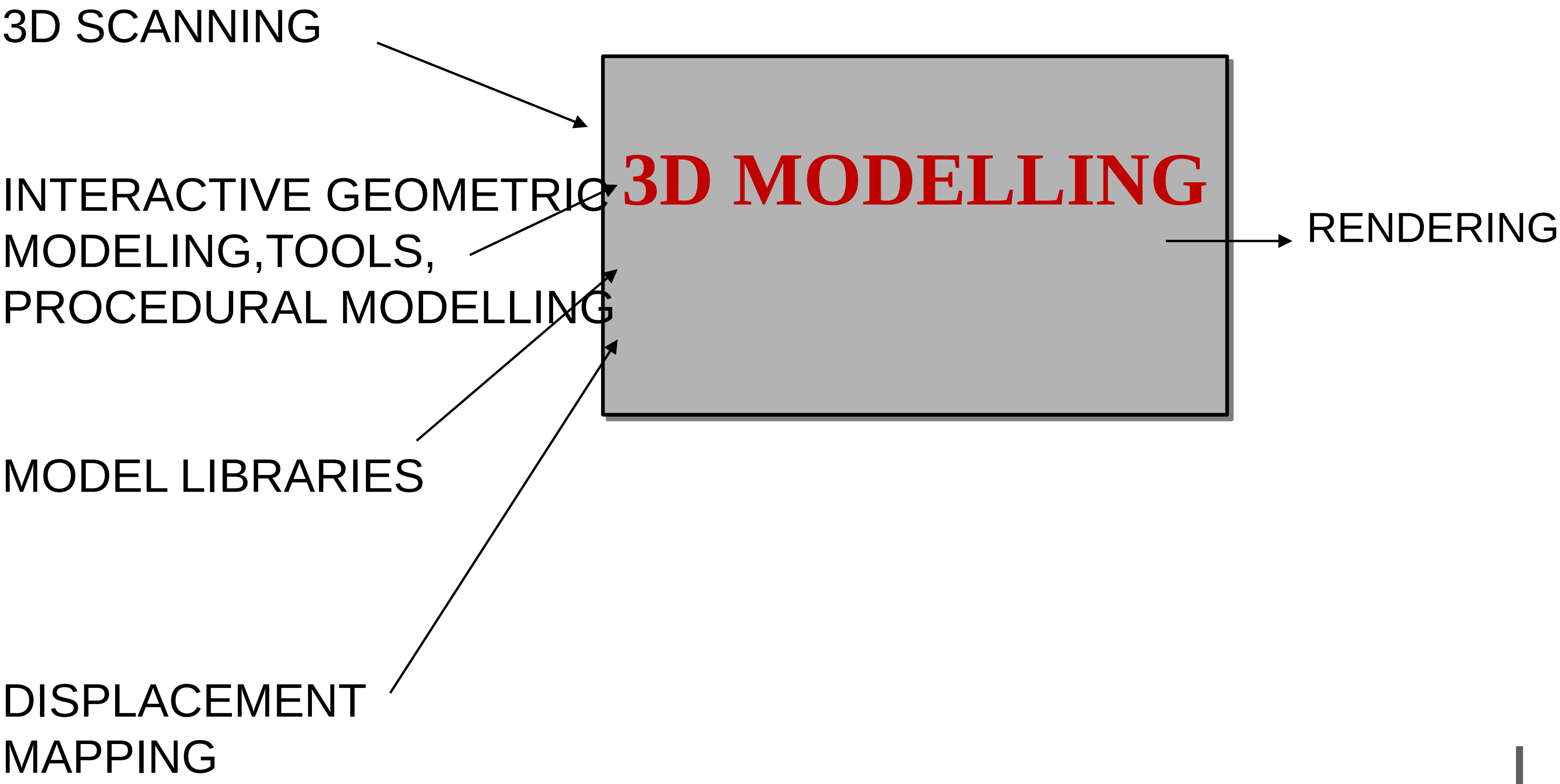
RENDERING

IMAGE STORAGE
DISPLAY

ANIMATION

TEXTURING

The graphics process:
Geometric Modeling



3D SCANNING

INTERACTIVE GEOMETRIC MODELING,TOOLS, PROCEDURAL MODELLING

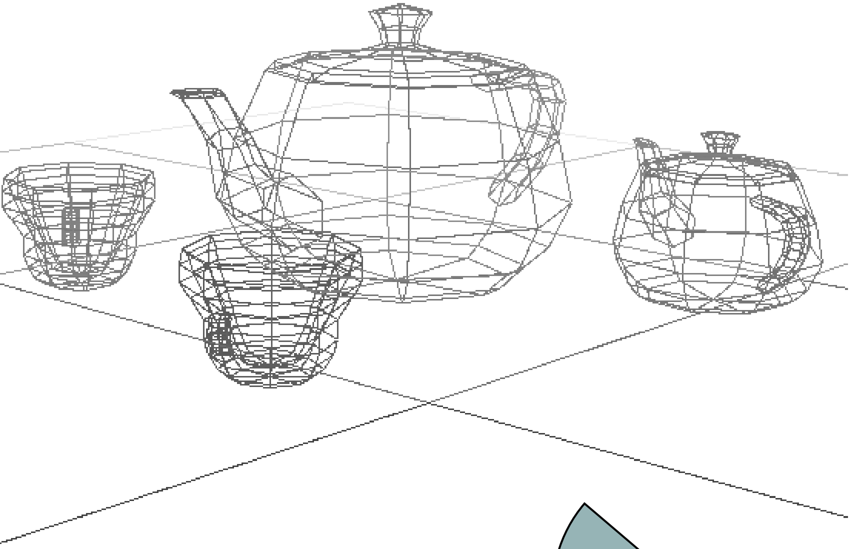
MODEL LIBRARIES

DISPLACEMENT MAPPING

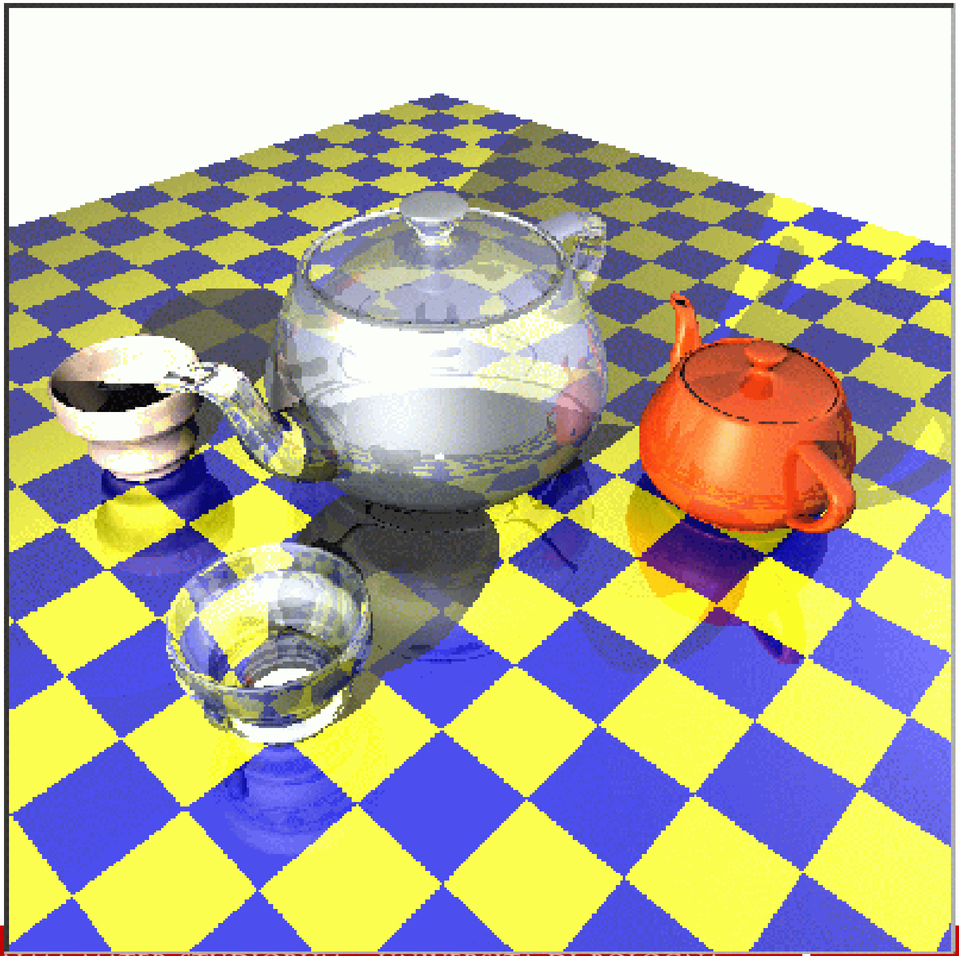
3D MODELLING

RENDERING

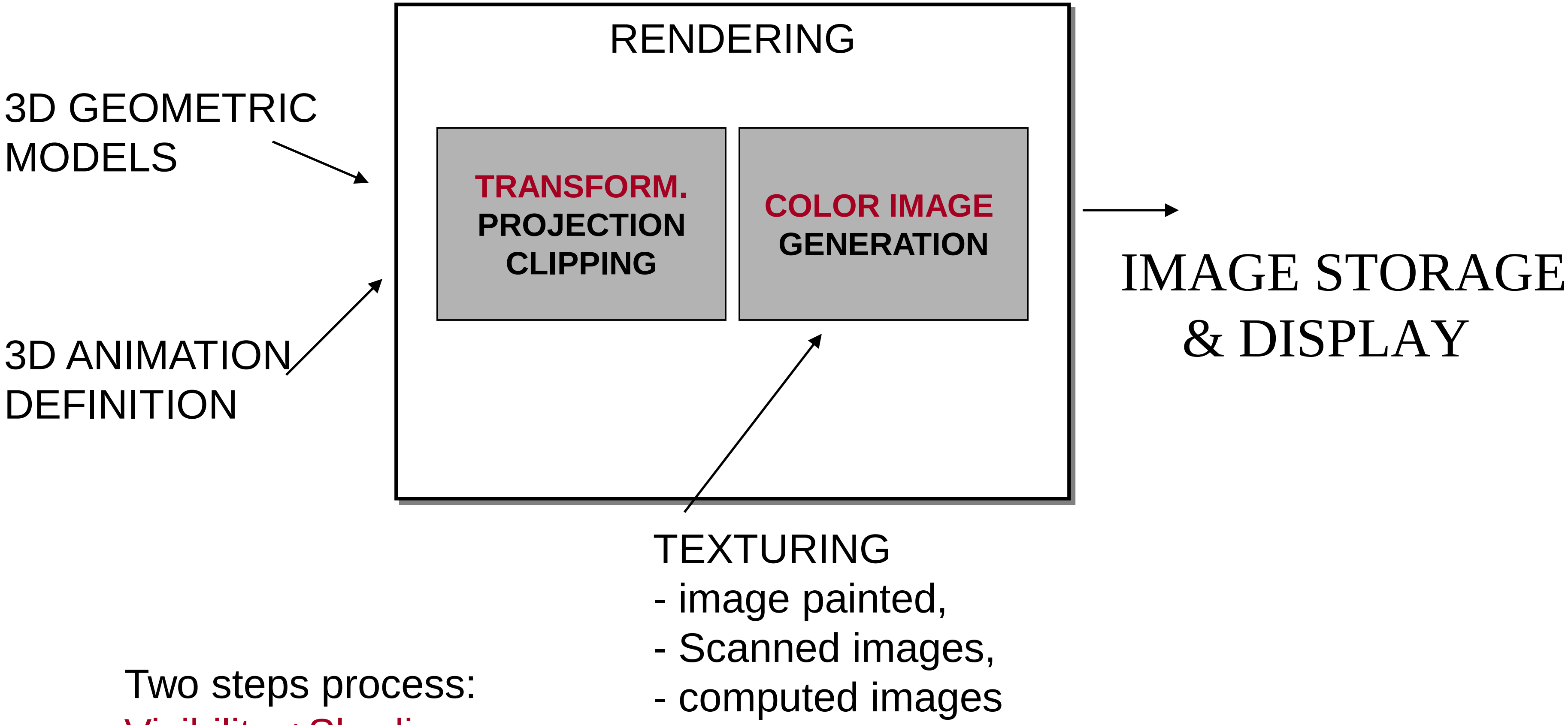
The graphics process: Rendering



Produce bidimensional images from a 3D scene and a camera



The graphics process: RENDERING



RENDERING

3D GEOMETRIC MODELS

3D ANIMATION DEFINITION

TRANSFORM.
PROJECTION
CLIPPING

COLOR IMAGE
GENERATION

IMAGE STORAGE & DISPLAY

TEXTURING
- image painted,
- Scanned images,
- computed images

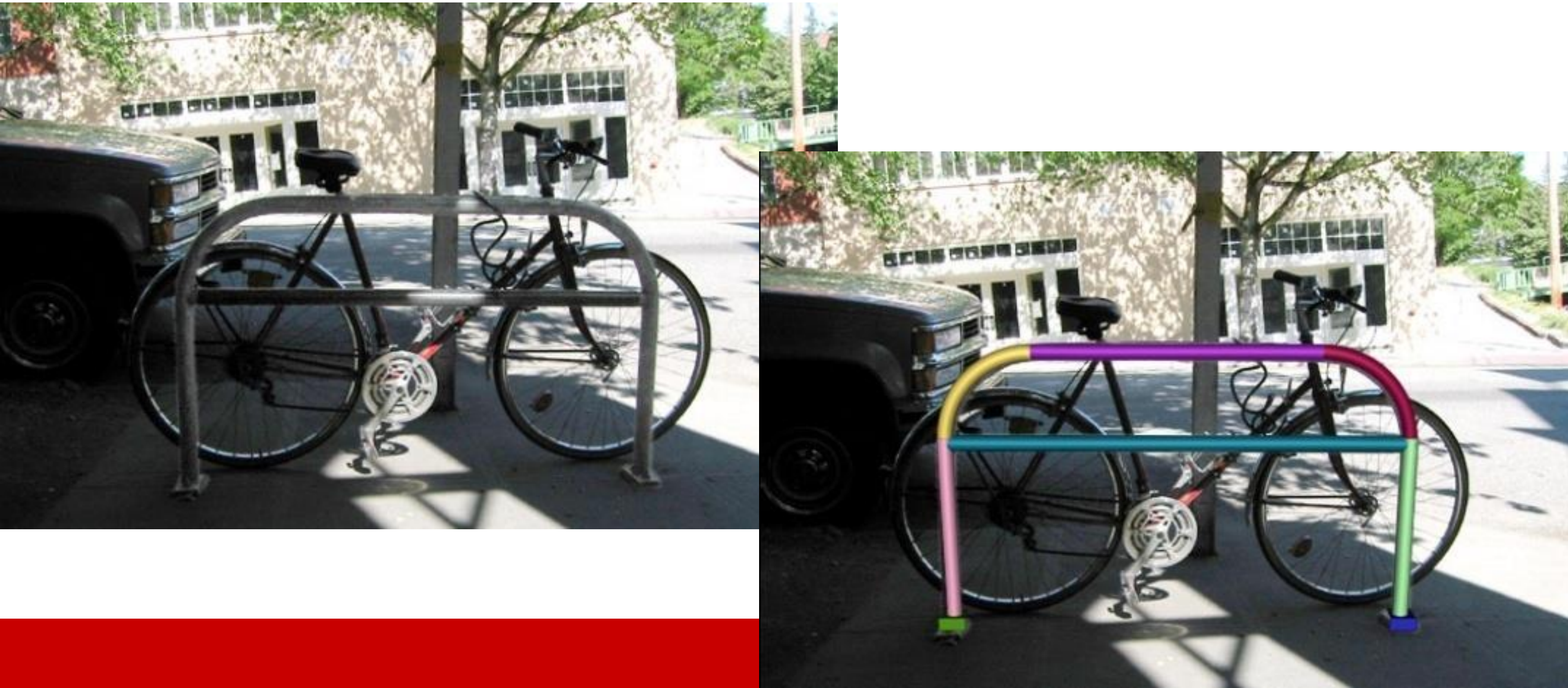
Two steps process:
Visibility +Shading

3D MODELLING

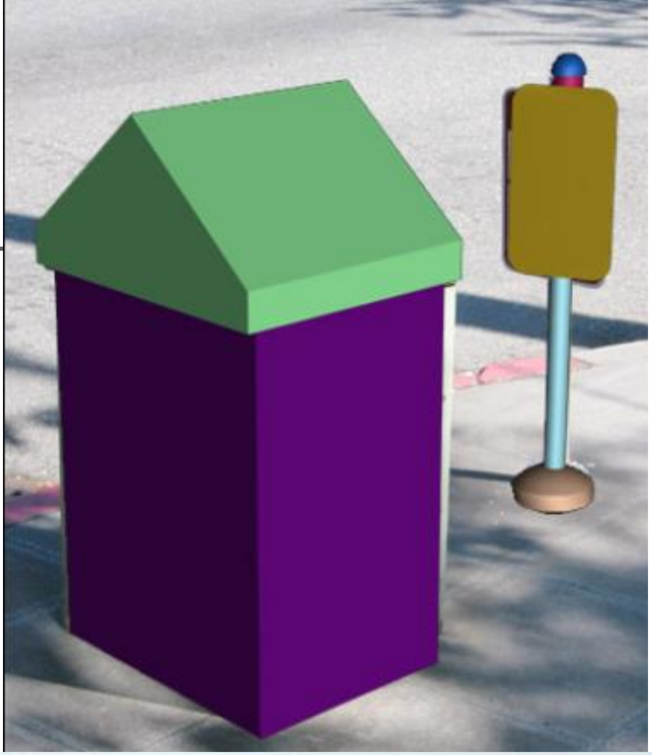
Design the shape of 3D objects

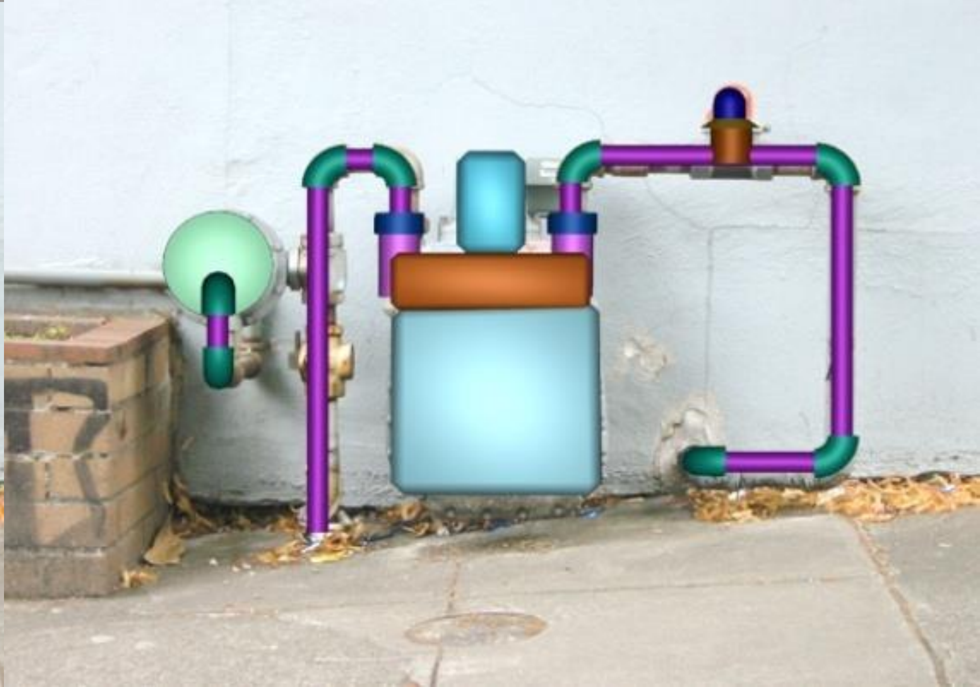
Seeing in 3D

- The world in basic shapes
- Shapes are instances of primitives (e.g., spheres, cubes, etc.)



Reduction to primitives (e.g., spheres, cubes, etc.)





Simple but not too simple

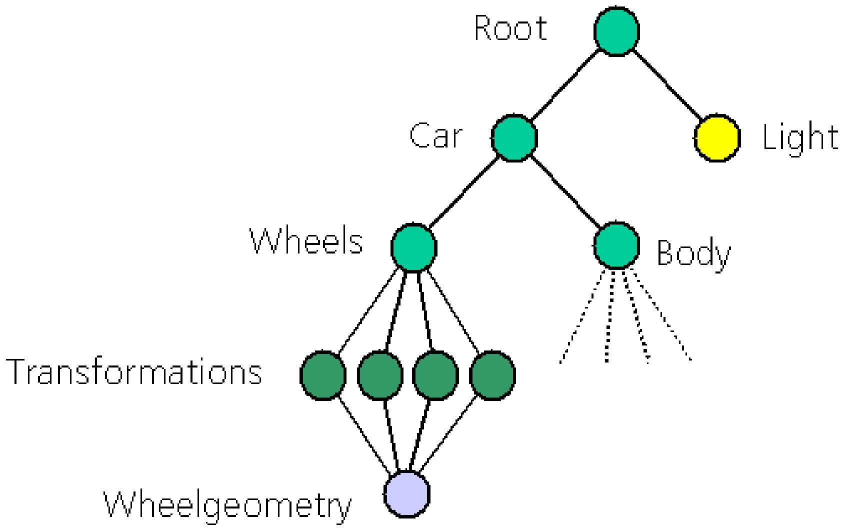
- Real shapes are complex
- More detail = more realism

  takes longer to model, longer to render, and occupies more disk space

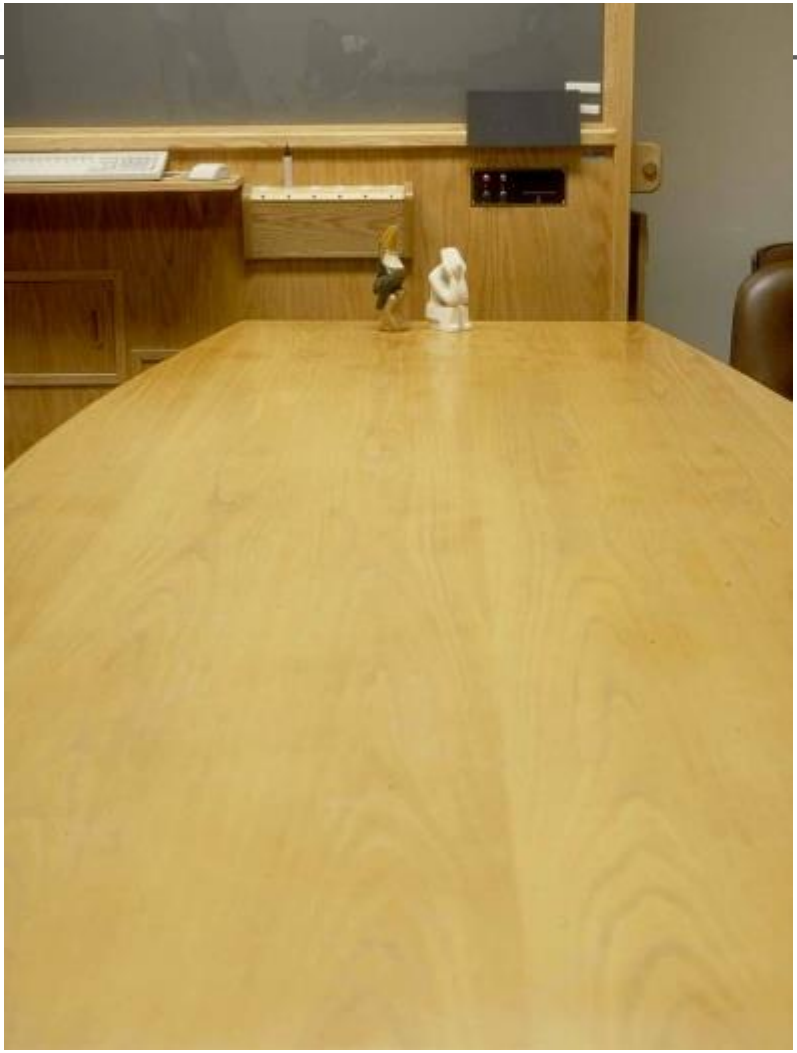
Primitives and instances

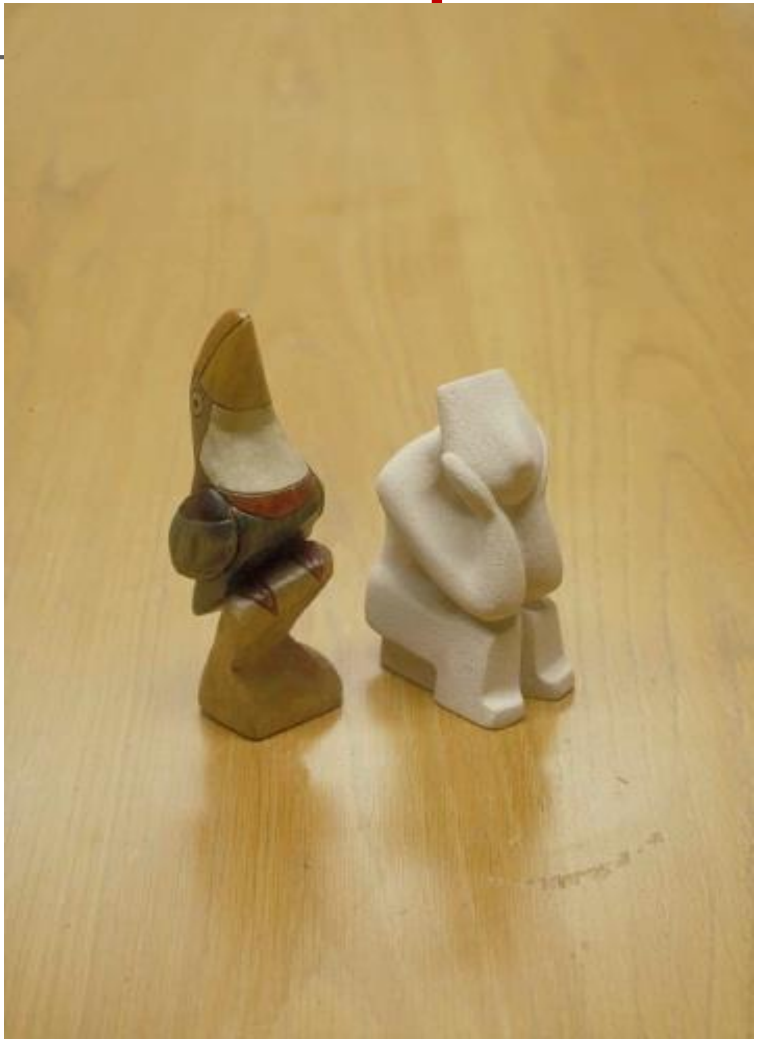
Object to be modeled is (visually) analyzed, and then decomposed into collections of primitive shapes.

Tree diagram provides visual method of expressing “composed of” relationships of model



Different detail when required



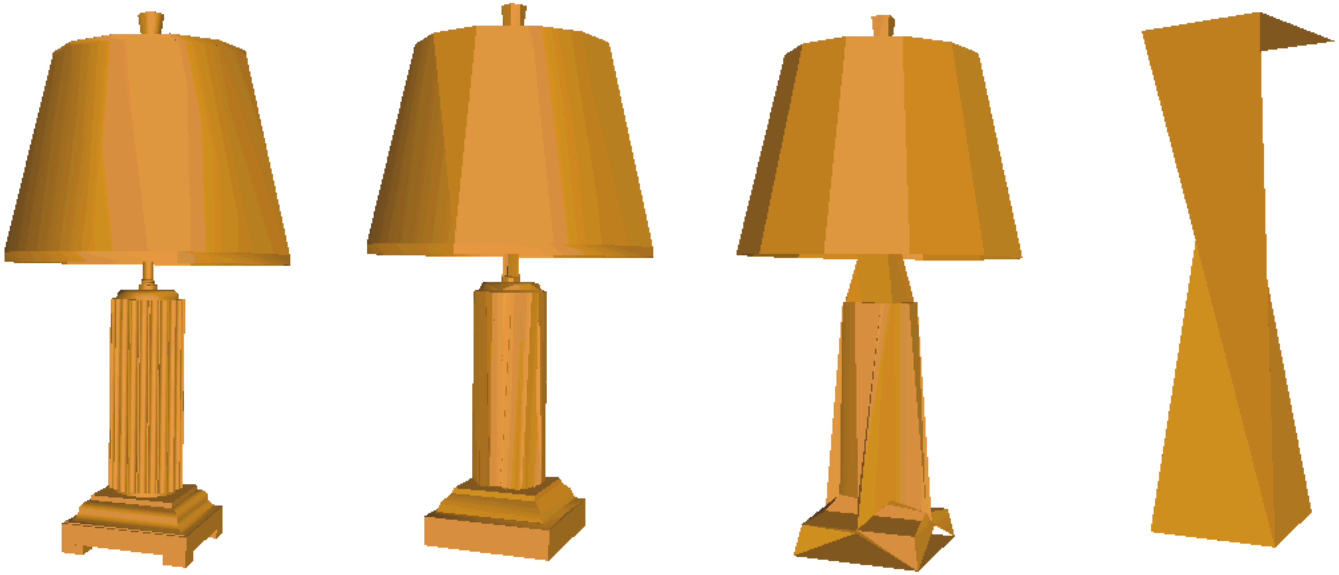


models from **coarse to fine**

Level-of-Detail(LOD):

As object gets farther away from viewer, replace it with a lower-polygon version or lower quality texture map.

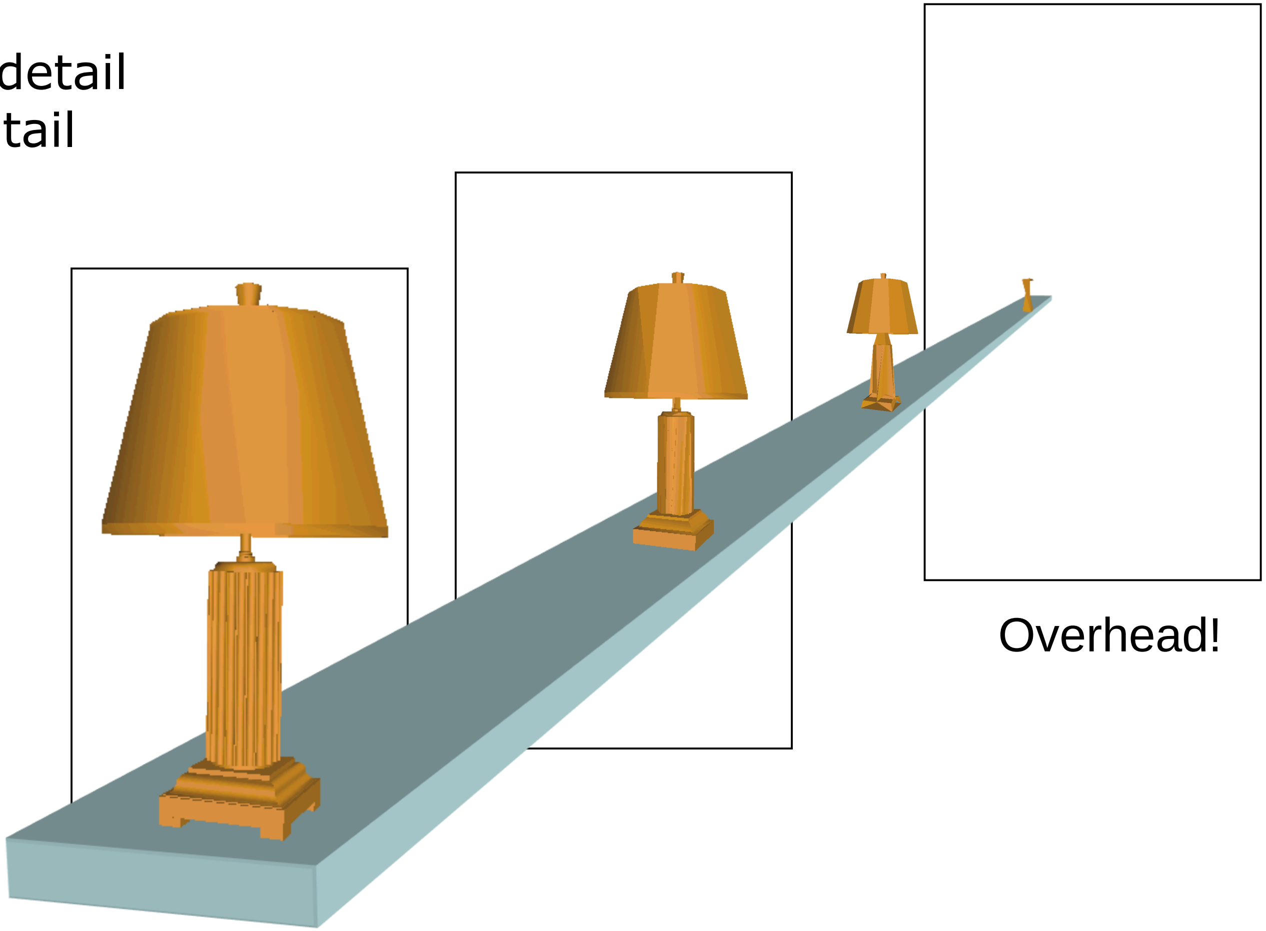
Discontinuous jumps in model detail



10,108 polys 1,383 polys 474 polys 46 polys

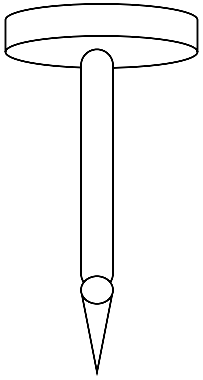
Courtesy IBM

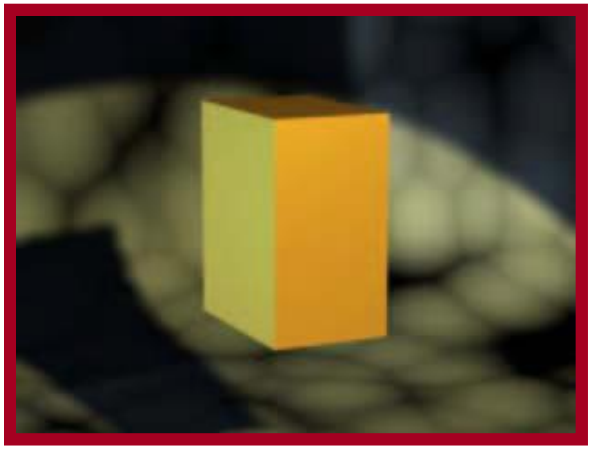
LOD:
- Use only enough detail
- Switch level of detail

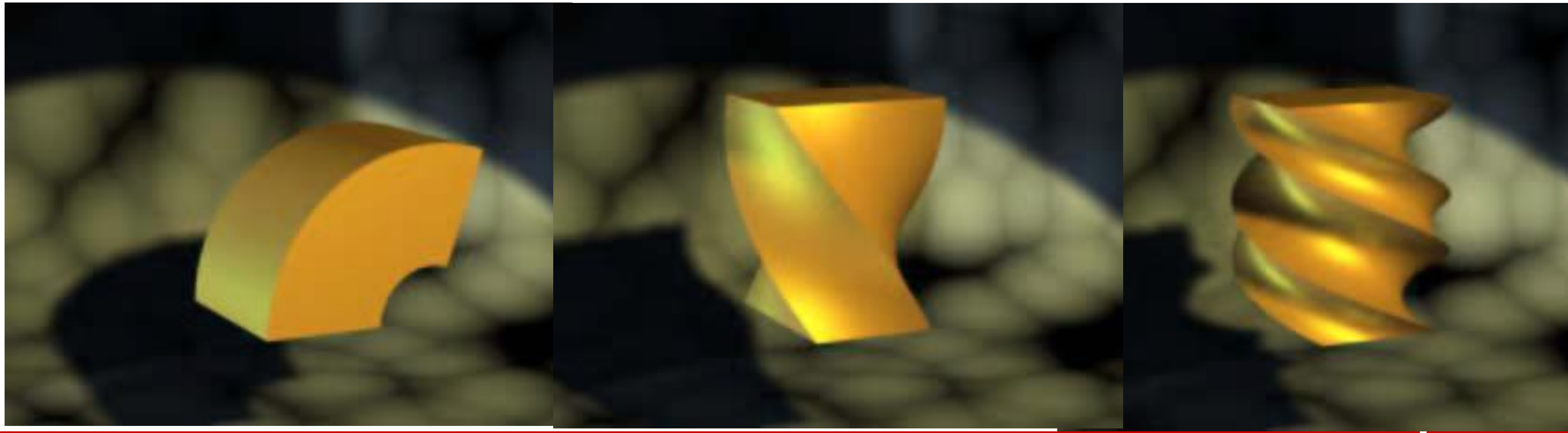


Types of Geometric Modelers

1) Box Modifiers

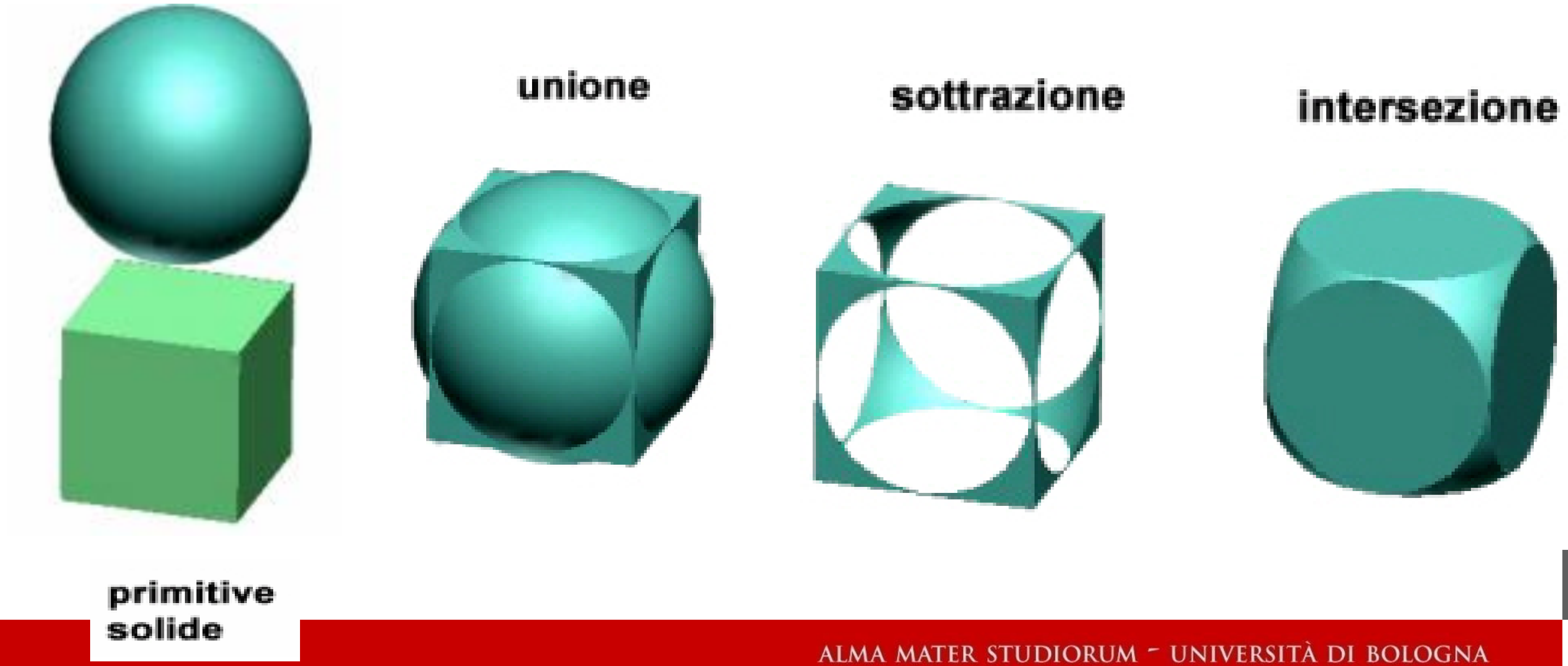






2)Constructive Solid Geometry (CSG)

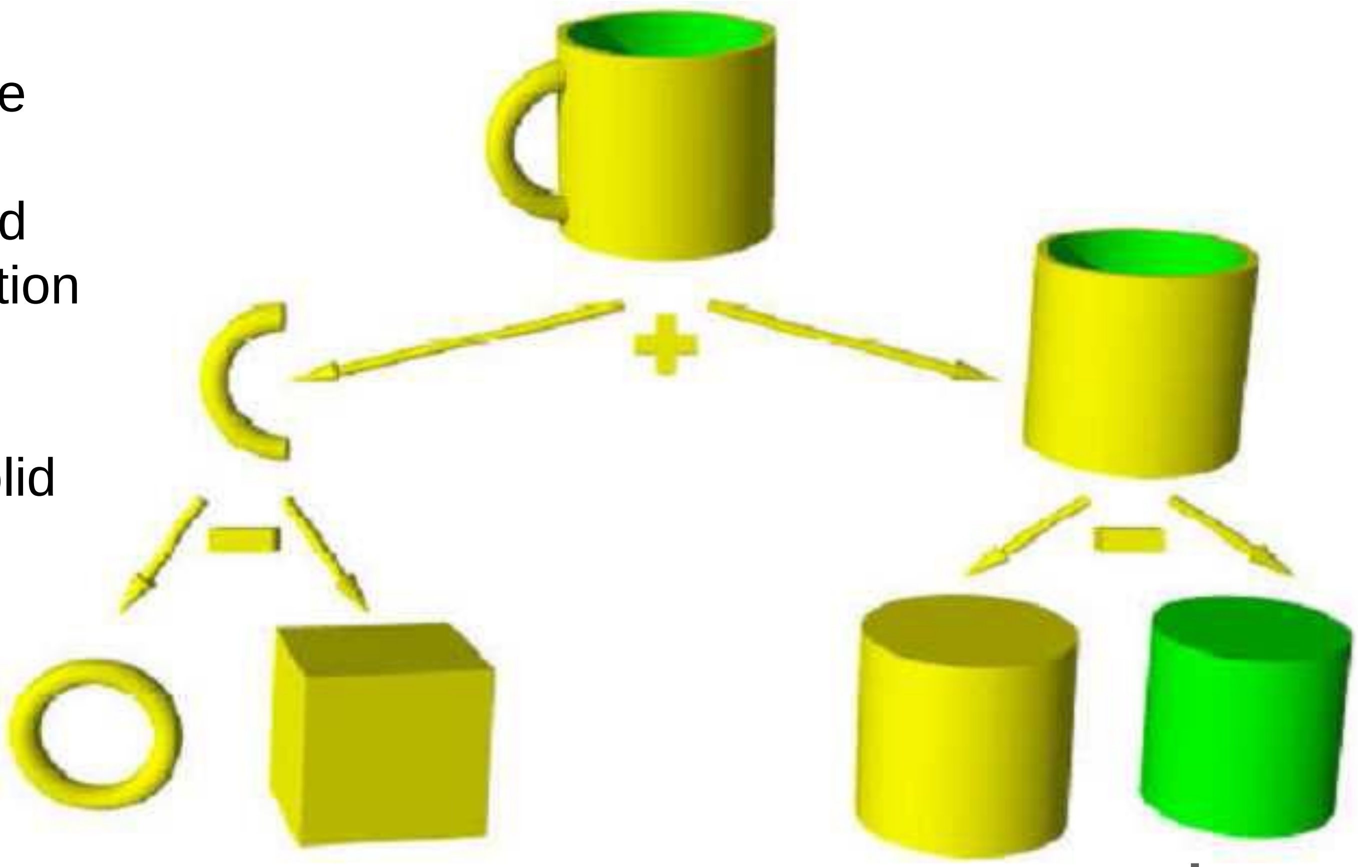
- Combination of Solid Primitives by boolean operators
- Each rule combines two solids



Constructive Solid Geometry

CSG TREE

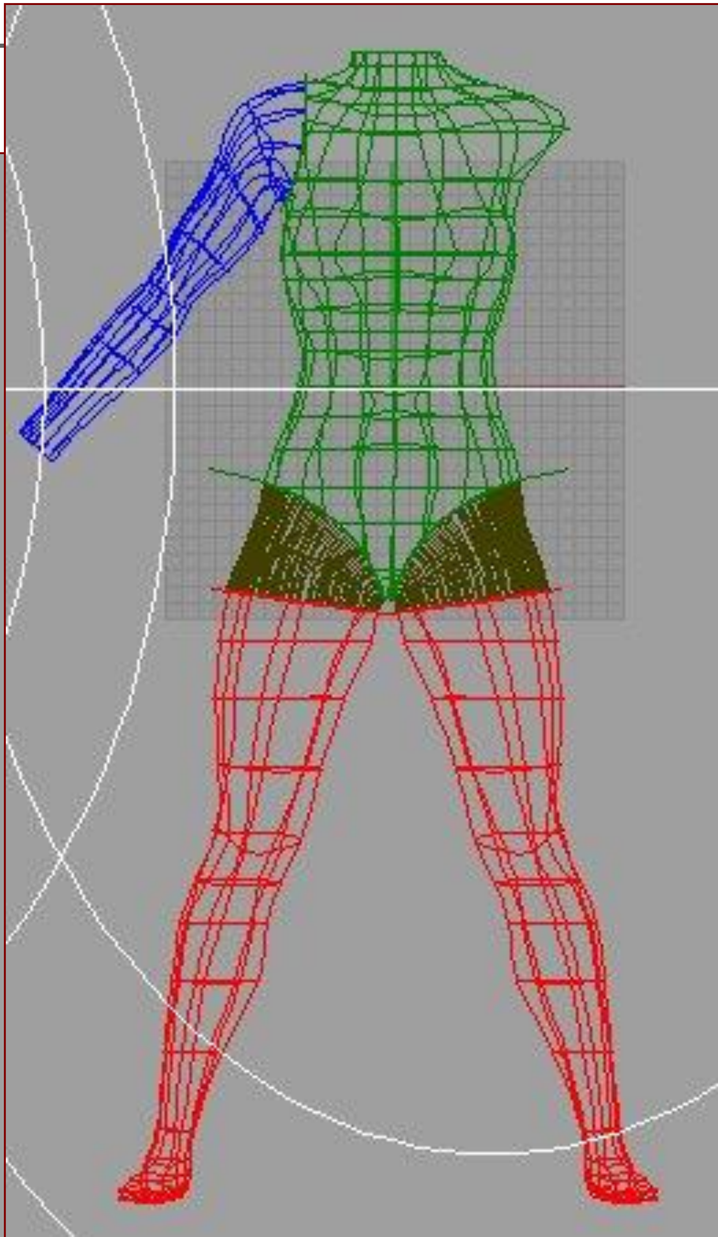
A solid object is representaed by a tree structure :
Boolean operation and geometric transformation at each level
Leafs: Solid issues
Root: the resulting solid

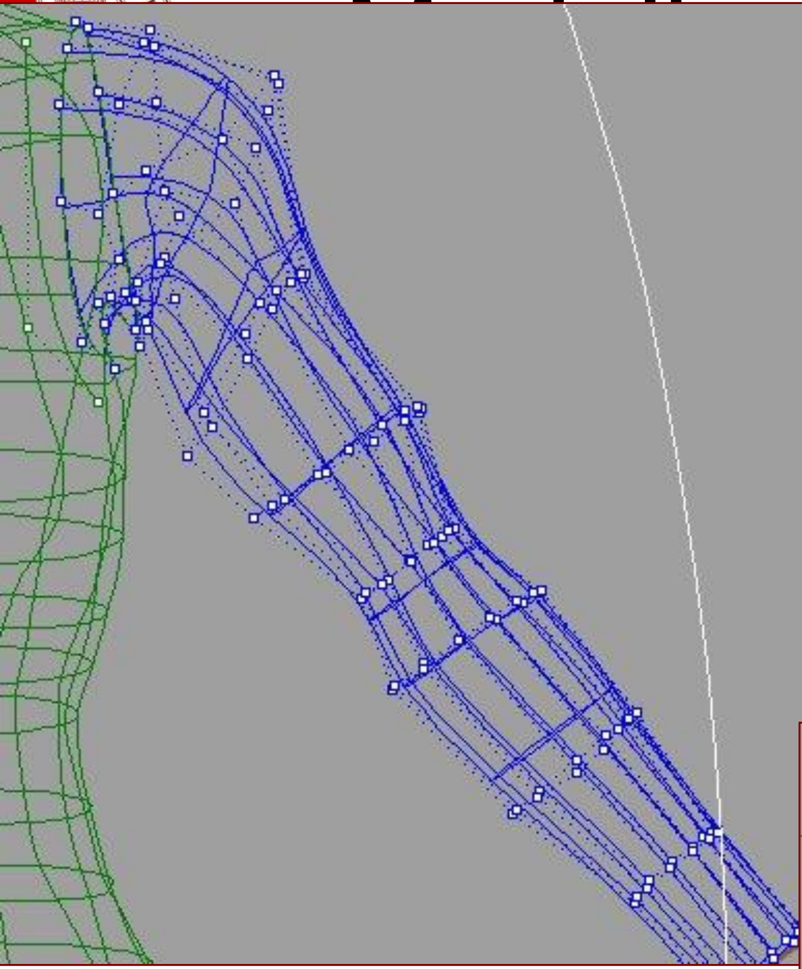


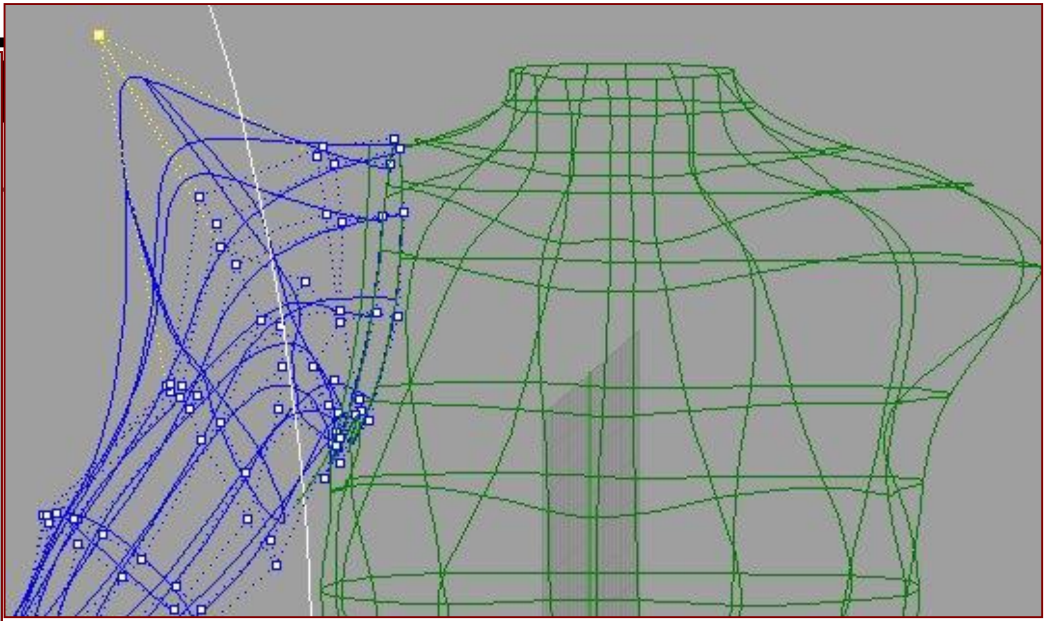
3) Interactive modeling: spline

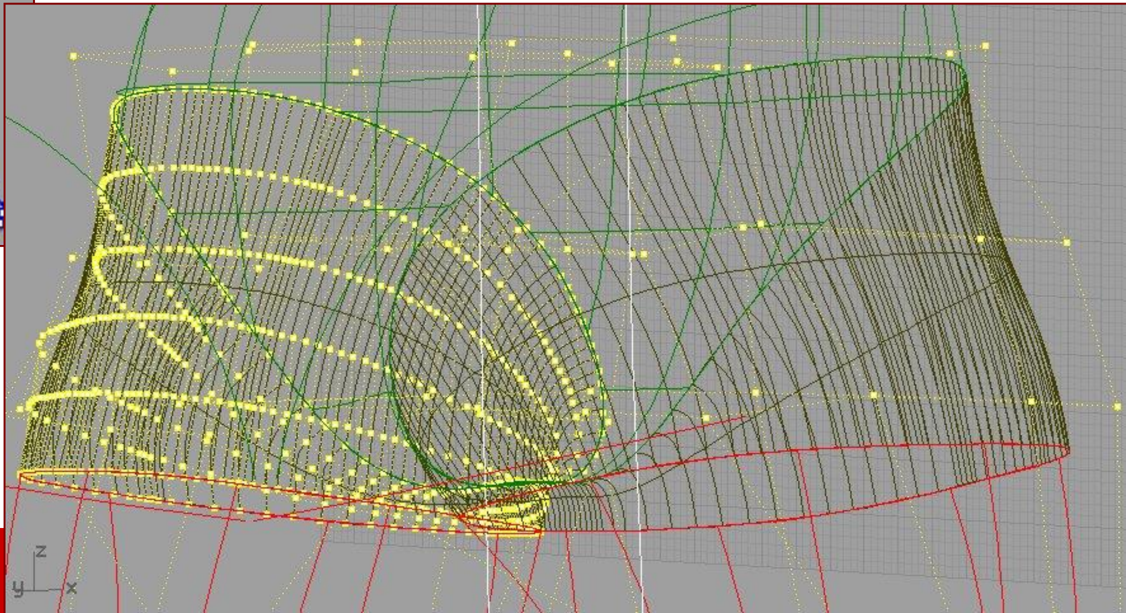
Patch: curved surfaces

Continuous mathematical surface representations

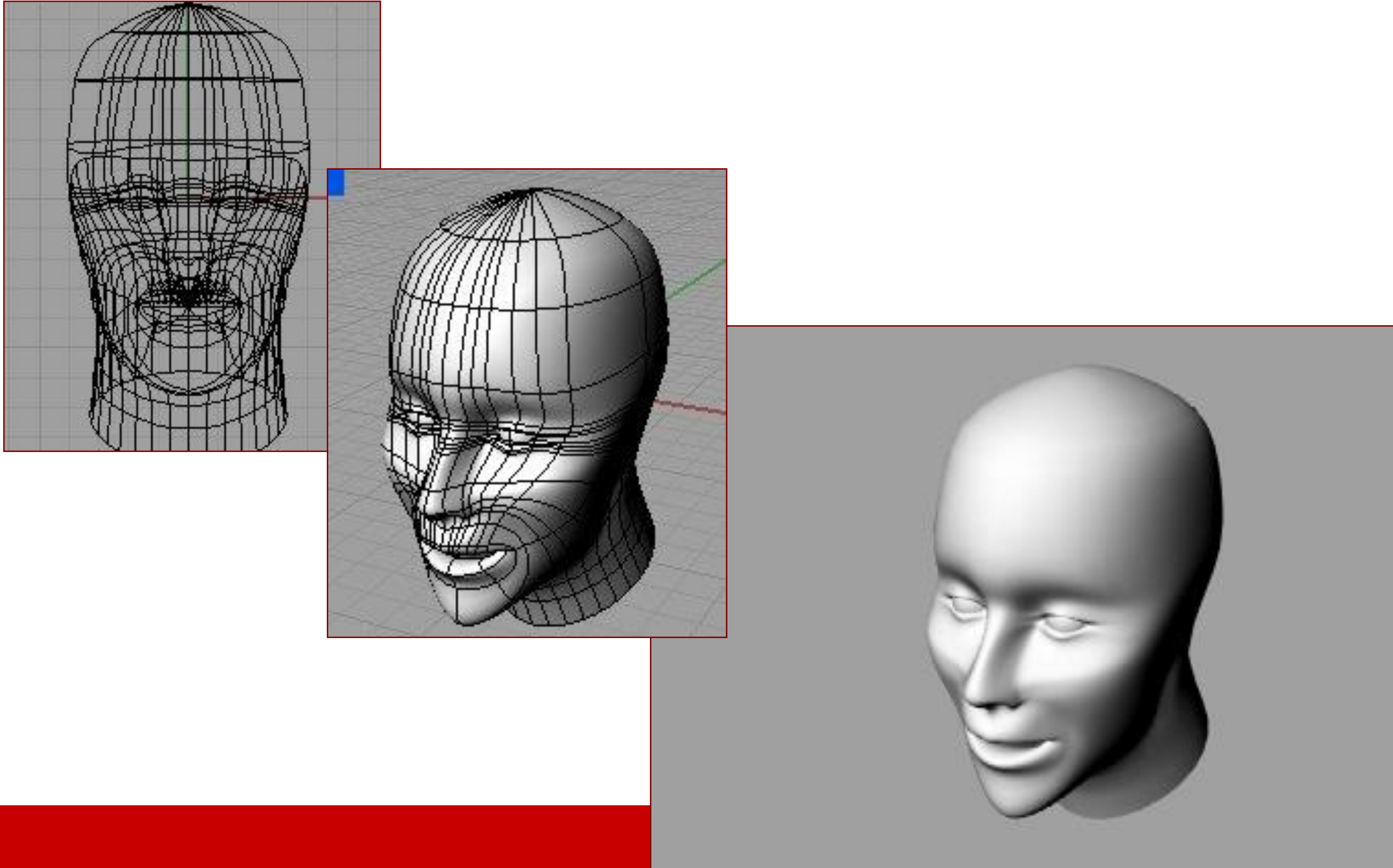




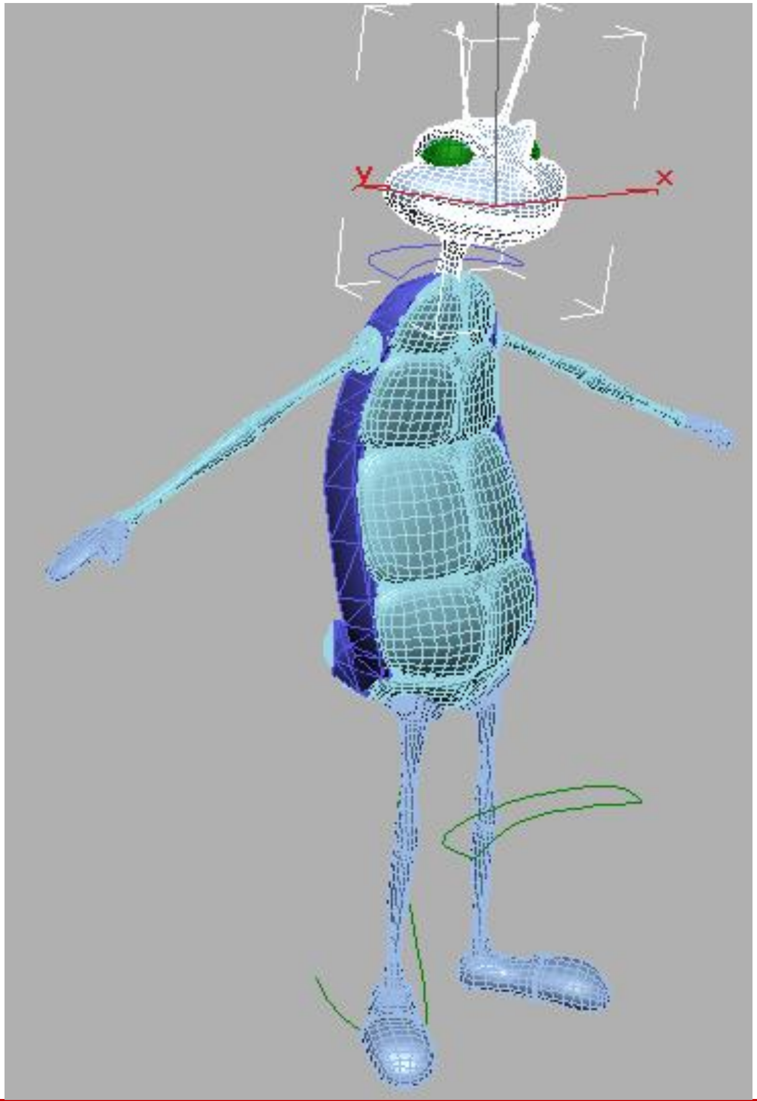



z
y
x

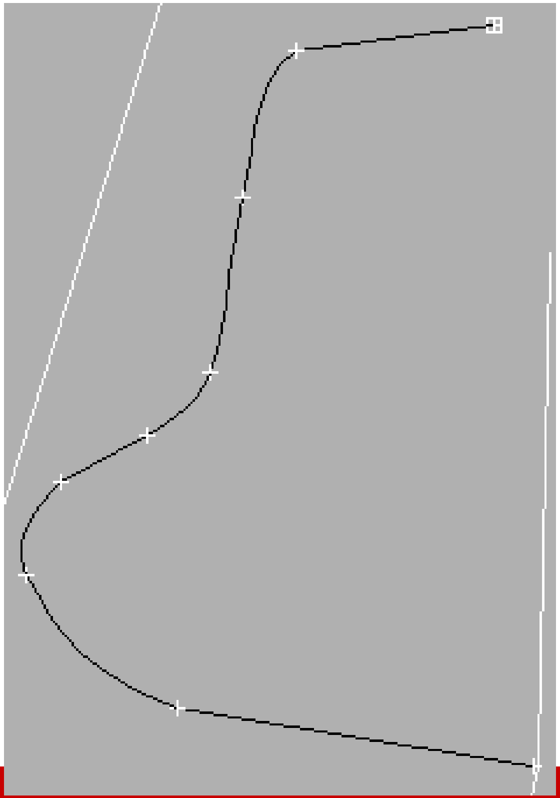
Interactive modeling: patch spline

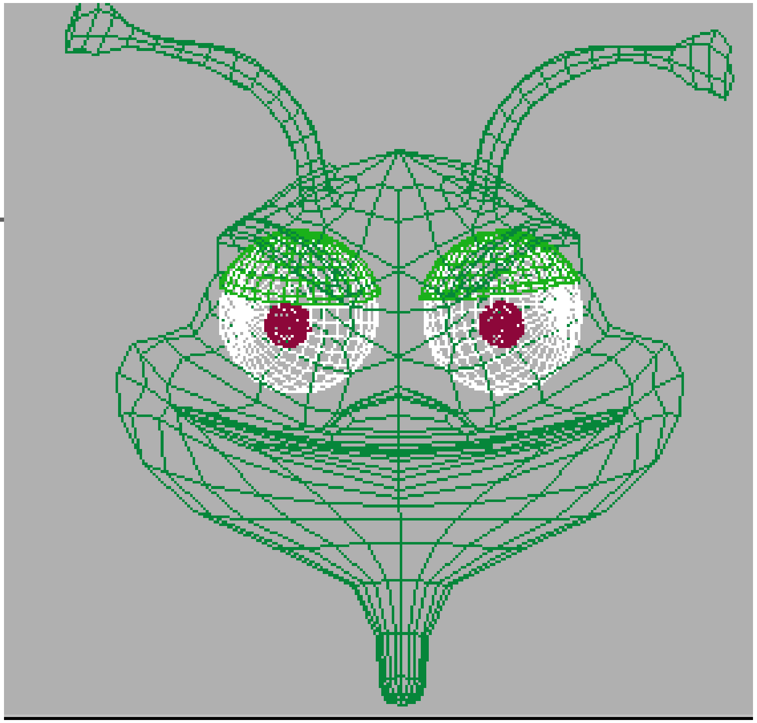


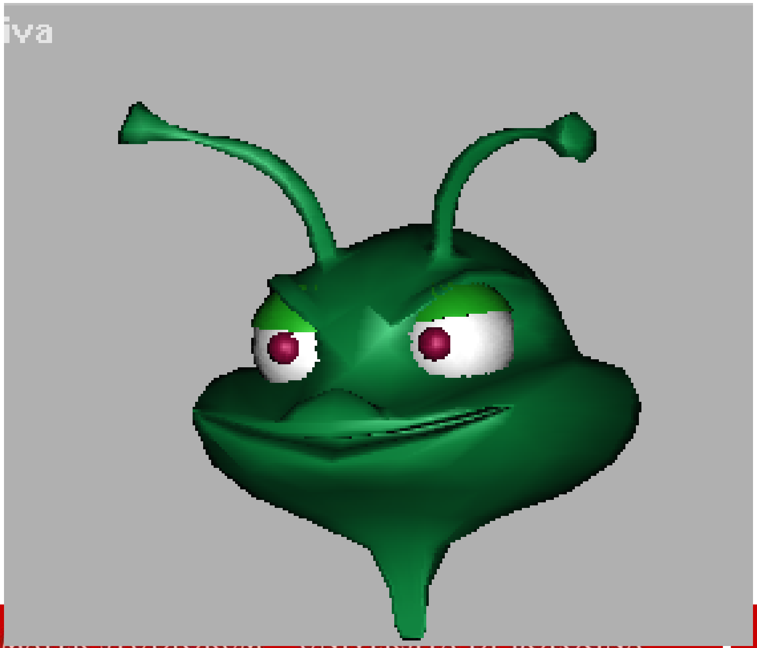
Surfaces from curves



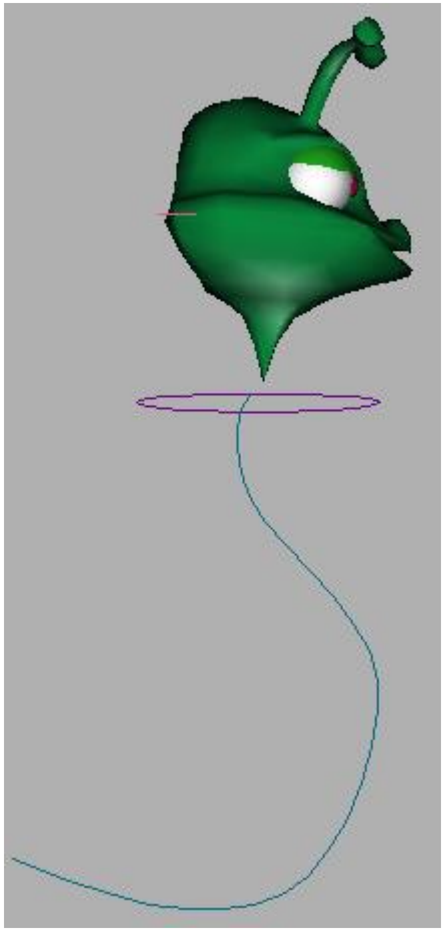
Rotation

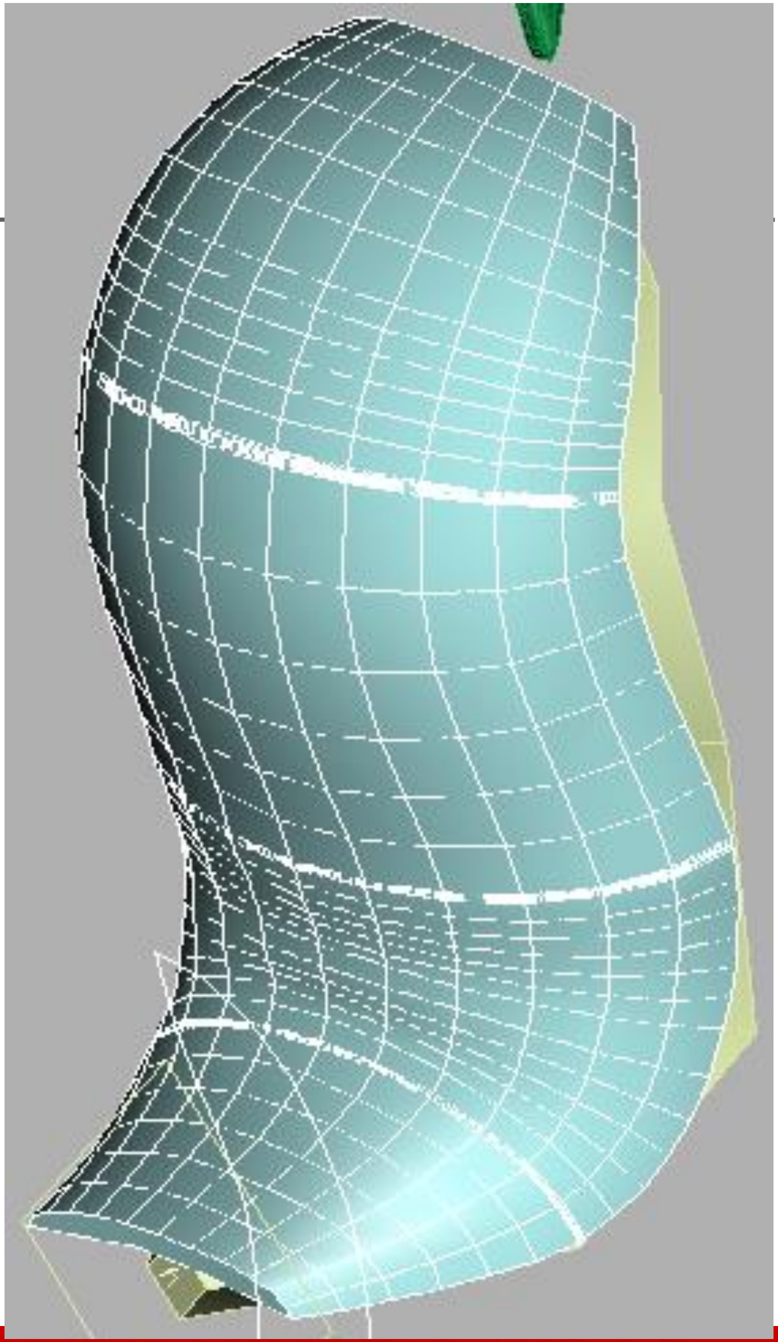




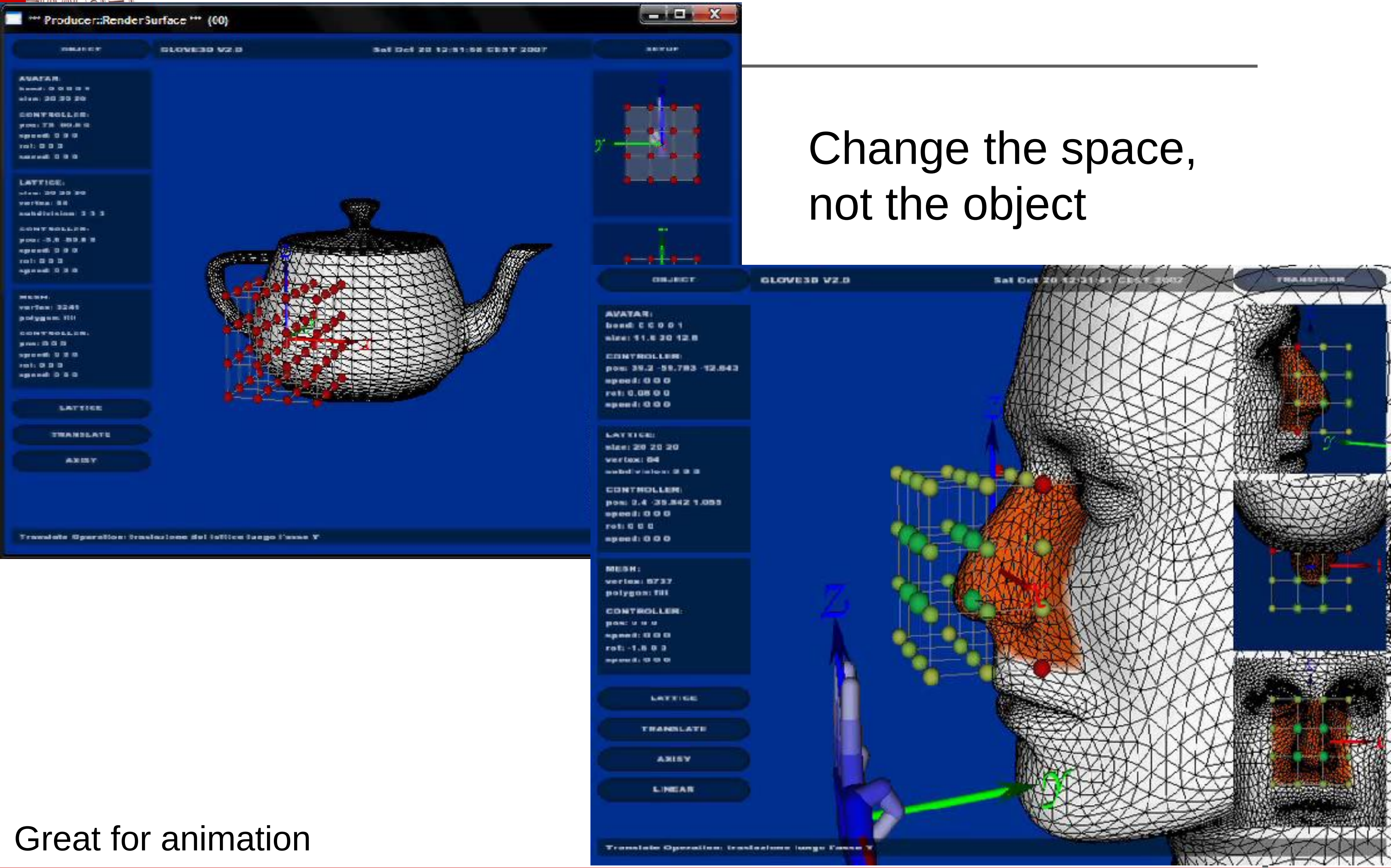


Swinging





4) Free-form deformation



*** Producer::RenderSurface *** (00)

OBJECT | GLOVE3D V2.0 | Sat Oct 20 12:51:58 CEST 2007 | SETUP

AVATAR:
band: 0 0 0 0 1
size: 20 20 20

CONTROLLER:
pos: 73 -80.8 0
speed: 0 0 0
rot: 0 0 0
speed: 0 0 0

LATTICE:
size: 20 20 20
vertex: 64
subdivision: 3 3 3

CONTROLLER:
pos: -5.8 -80.8 0
speed: 0 0 0
rot: 0 0 0
speed: 0 0 0

MESH:
vertex: 3241
polygon: fill

CONTROLLER:
pos: 0 0 0
speed: 0 0 0
rot: 0 0 0
speed: 0 0 0

LATTICE
TRANSLATE
AXISY

Translate Operation: traslazione del lattice lungo l'asse Y

OBJECT | GLOVE3D V2.0 | Sat Oct 20 12:31:41 CEST 2007 | TRANSFORM

AVATAR:
band: C C 0 0 1
size: 11.6 20 12.8

CONTROLLER:
pos: 39.2 -59.783 -12.643
speed: 0 0 0
rot: 0.08 0 0
speed: 0 0 0

LATTICE:
size: 20 20 20
vertex: 64
subdivision: 3 3 3

CONTROLLER:
pos: 2.4 -39.842 1.055
speed: 0 0 0
rot: 0 0 0
speed: 0 0 0

MESH:
vertex: 8737
polygon: fill

CONTROLLER:
pos: 0 0 0
speed: 0 0 0
rot: -1.6 0 3
speed: 0 0 0

LATTICE
TRANSLATE
AXISY
LINEAR

Translate Operation: traslazione lungo l'asse Y

Change the space,
not the object

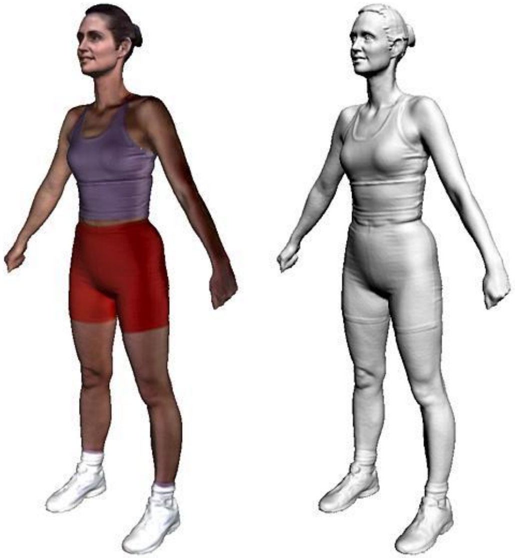
Great for animation

5)Captured Modeling:

Polygonal models (mesh)
by 3D scanners

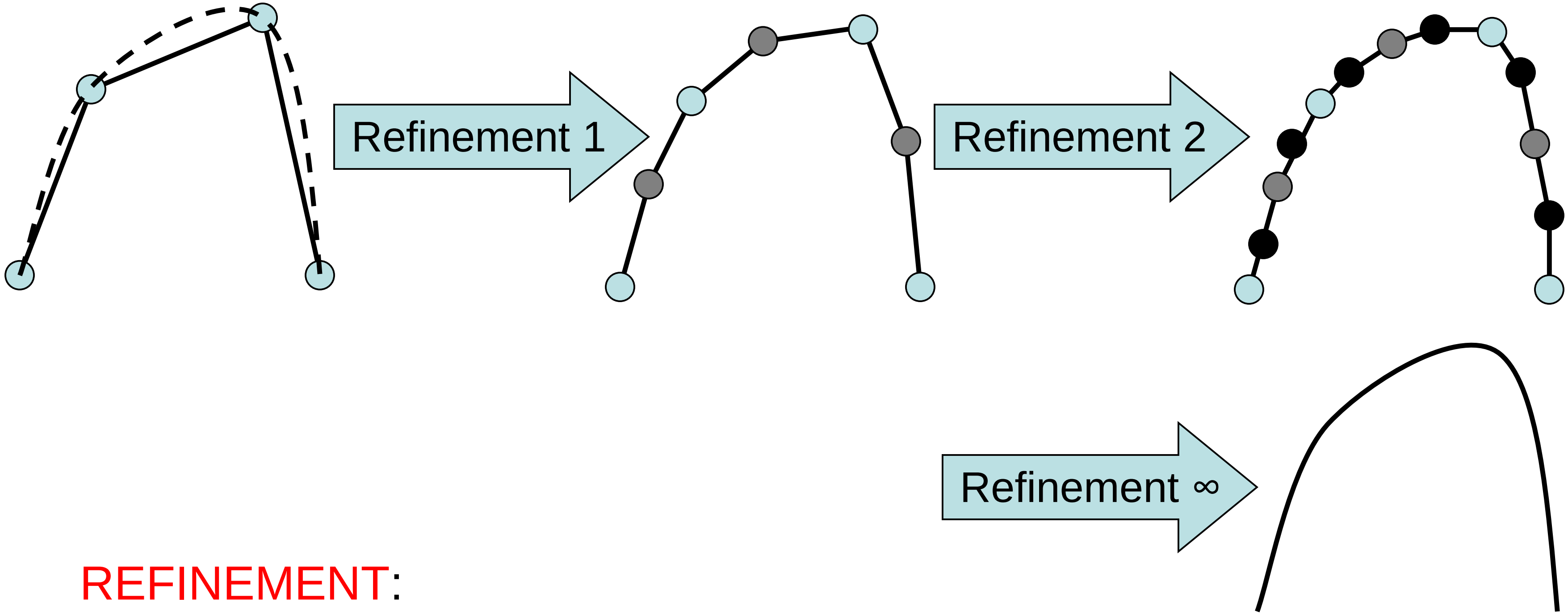
Microscribe
touch 3D scanner

3D laser scanner
WholeBody WP4 CyberWare



6) Subdivision Modelling

Subdivision curves: makes a smooth curve from a control polygon.

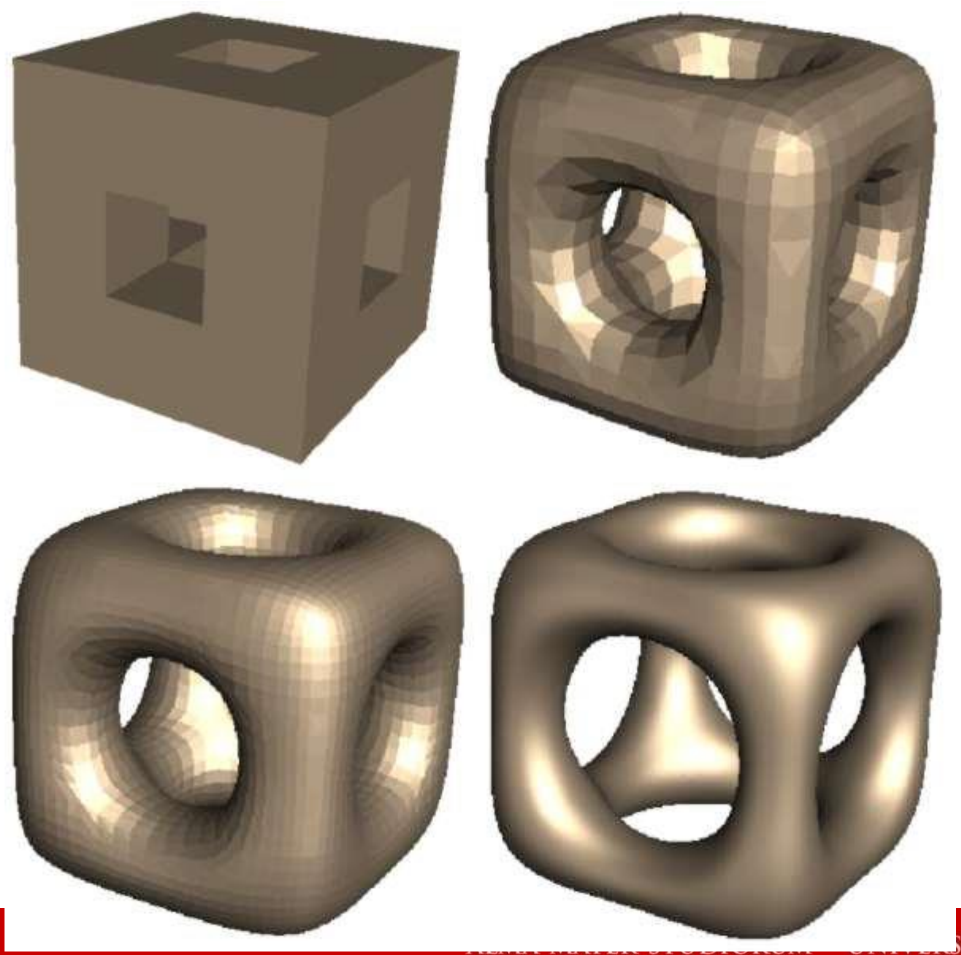


REFINEMENT:

The smoothed final curve is obtained iterating a refinement procedure

Subdivision Surfaces

subdivide triangles into more triangles, moving to a continuous limit surface

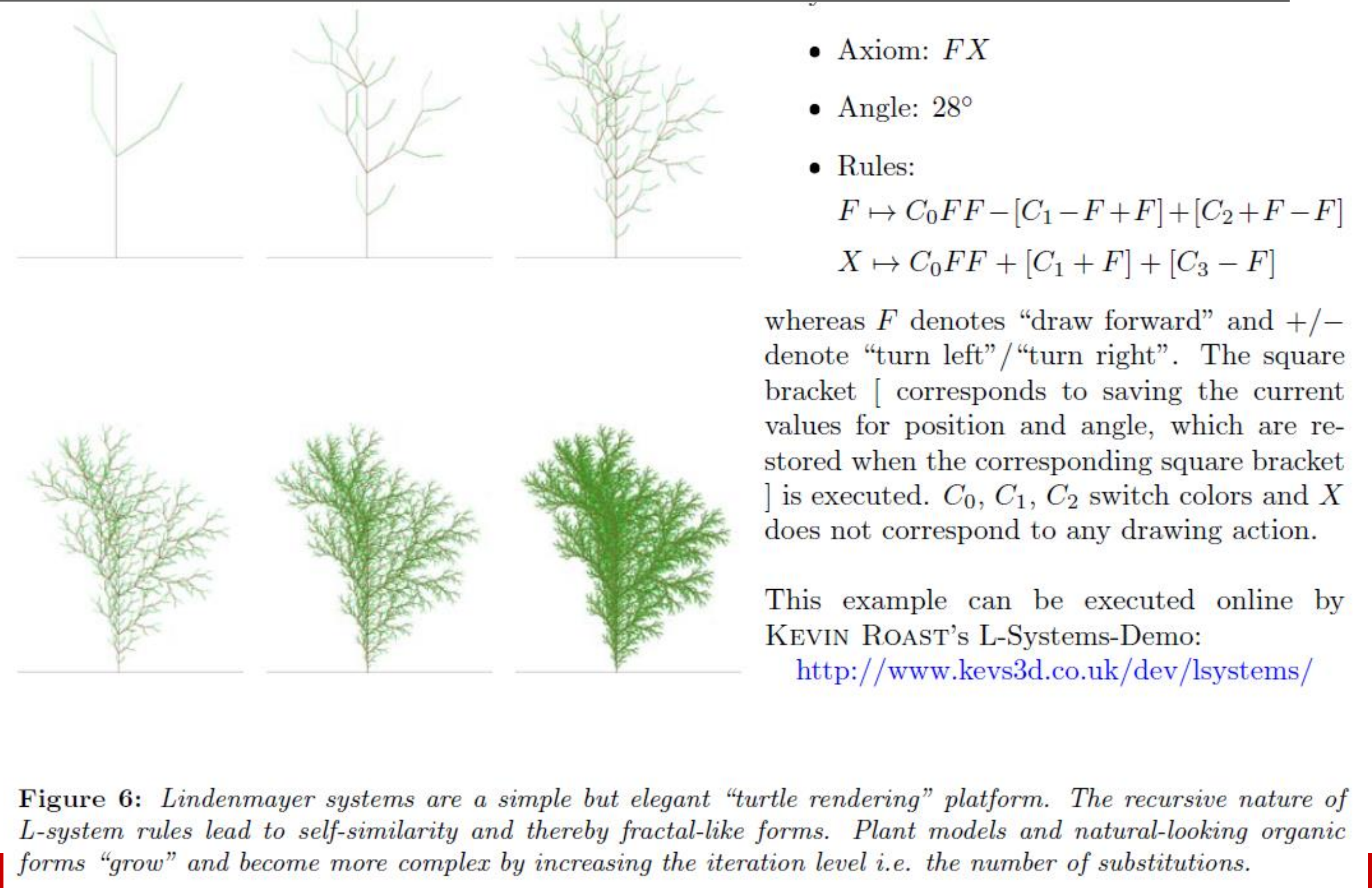


7) Procedural/generative Modeling

- Fractals
- Shape Grammars
- Particle Systems

generate highly complex objects based on a set of formal construction rules. This modeling paradigm describes a shape by a sequence of processing steps.

L-systems



- Axiom: FX
- Angle: 28°
- Rules:

$$F \mapsto C_0FF-[C_1-F+F]+[C_2+F-F]$$

$$X \mapsto C_0FF+[C_1+F]+[C_3-F]$$

whereas F denotes "draw forward" and $+/-$ denote "turn left"/"turn right". The square bracket [corresponds to saving the current values for position and angle, which are restored when the corresponding square bracket] is executed. C_0, C_1, C_2 switch colors and X does not correspond to any drawing action.

This example can be executed online by KEVIN ROAST's L-Systems-Demo: http://www.kevs3d.co.uk/dev/lsystems/

Figure 6: *Lindenmayer systems are a simple but elegant "turtle rendering" platform. The recursive nature of L-system rules lead to self-similarity and thereby fractal-like forms. Plant models and natural-looking organic forms "grow" and become more complex by increasing the iteration level i.e. the number of substitutions.*

Particle Systems

- Collection of simple objects rendered as point sources
- Large groups can produce interesting effects
- Simple motion - e.g., local rules, simple physics
- Supplement basic ballistic rules

  Collisions

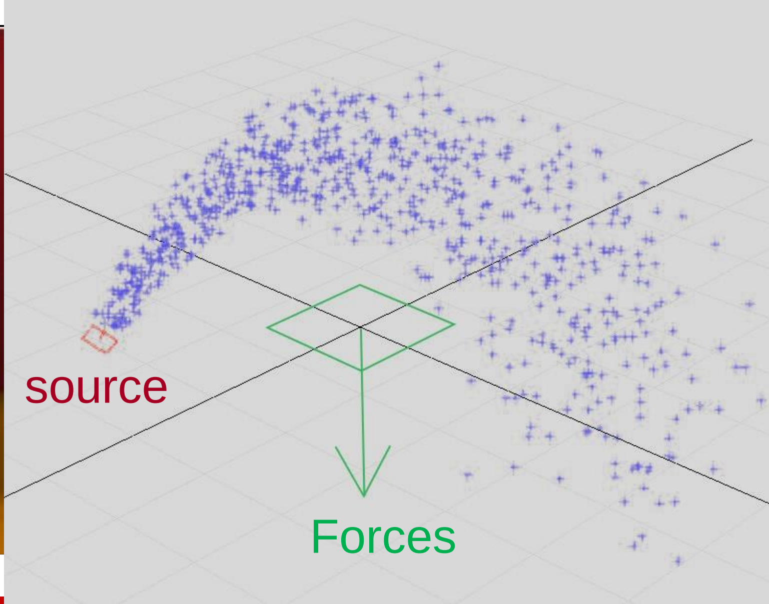
  Interactions

  Force fields

  Springs

  Others...

Karl Sims, SIGGRAPH 1990



3D MODELLING

Many primitives…many tools

Choose what you need and...

THINK BEFORE MODELLING!

RING:

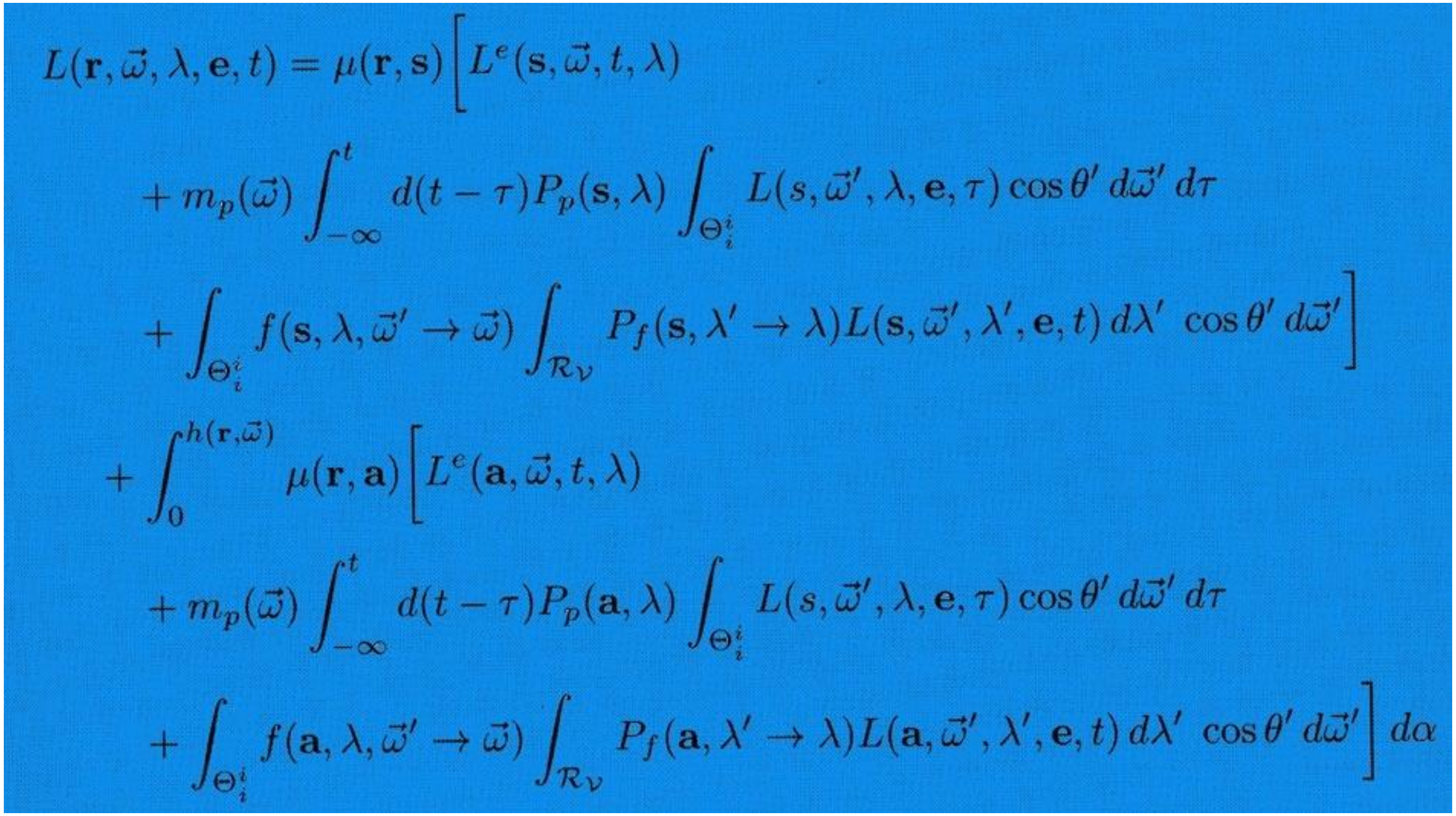
From

Shad s

‘Cars’,Pixar Animation Studios

The Rendering Equation

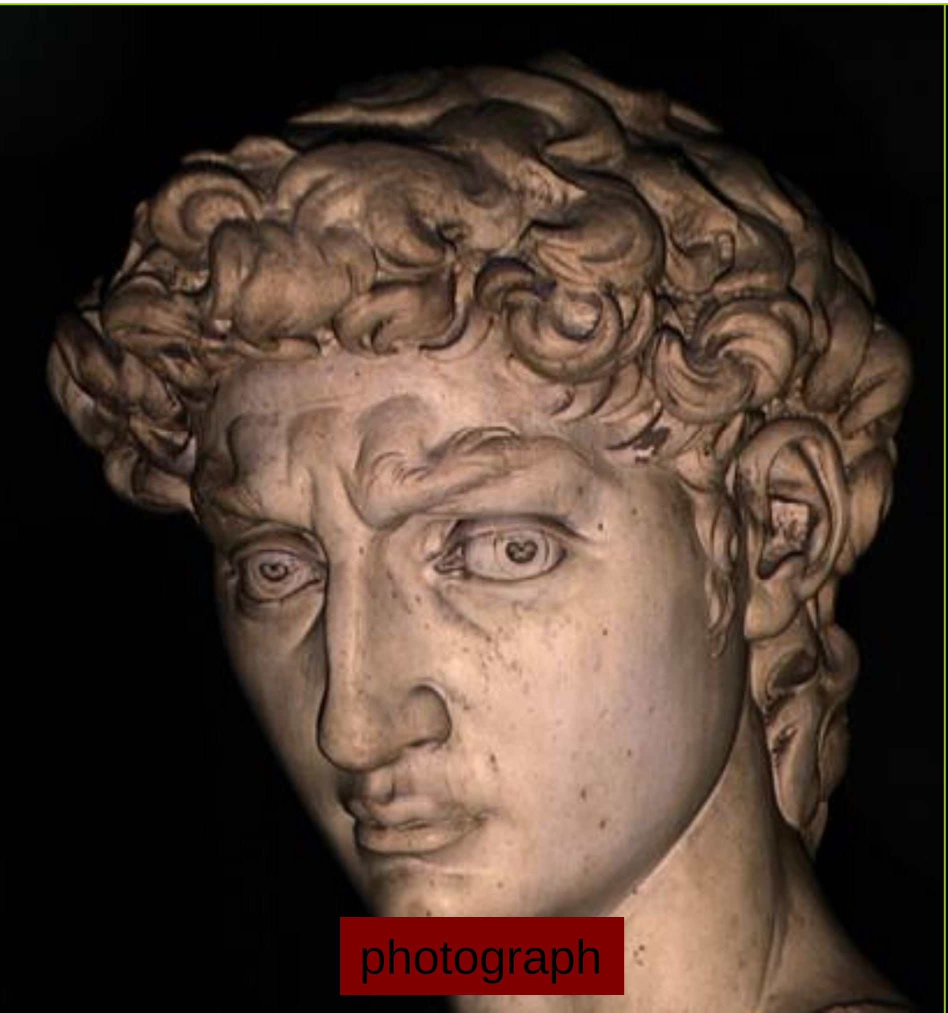
- Unifies all algorithms
- Based on nuclear physics
- Trivial and self-evident



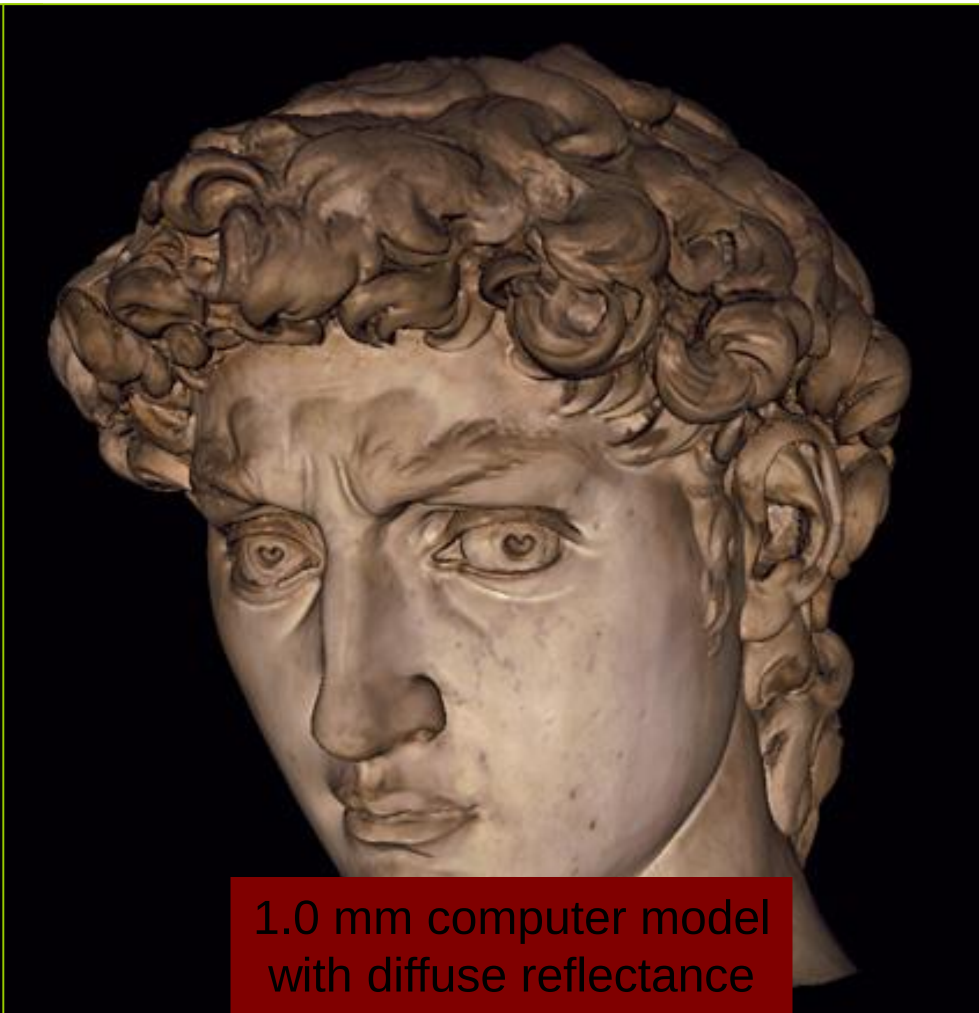
$$
\begin{aligned}
L(\mathbf{r},\vec{\omega},\lambda,\mathbf{e},t) = \mu(\mathbf{r},\mathbf{s}) \Big[& L^e(\mathbf{s},\vec{\omega},t,\lambda) \\
& + m_p(\vec{\omega}) \int_{-\infty}^{t} d(t-\tau) P_p(\mathbf{s},\lambda) \int_{\Theta_i^i} L(s,\vec{\omega}',\lambda,\mathbf{e},\tau) \cos\theta' \, d\vec{\omega}' \, d\tau \\
& + \int_{\Theta_i^i} f(\mathbf{s},\lambda,\vec{\omega}' \to \vec{\omega}) \int_{\mathcal{R}_\mathcal{V}} P_f(\mathbf{s},\lambda' \to \lambda) L(\mathbf{s},\vec{\omega}',\lambda',\mathbf{e},t) \, d\lambda' \; \cos\theta' \, d\vec{\omega}' \Big] \\
+ \int_0^{h(\mathbf{r},\vec{\omega})} \mu(\mathbf{r},\mathbf{a}) \Big[& L^e(\mathbf{a},\vec{\omega},t,\lambda) \\
& + m_p(\vec{\omega}) \int_{-\infty}^{t} d(t-\tau) P_p(\mathbf{a},\lambda) \int_{\Theta_i^i} L(s,\vec{\omega}',\lambda,\mathbf{e},\tau) \cos\theta' \, d\vec{\omega}' \, d\tau \\
& + \int_{\Theta_i^i} f(\mathbf{a},\lambda,\vec{\omega}' \to \vec{\omega}) \int_{\mathcal{R}_\mathcal{V}} P_f(\mathbf{a},\lambda' \to \lambda) L(\mathbf{a},\vec{\omega}',\lambda',\mathbf{e},t) \, d\lambda' \; \cos\theta' \, d\vec{\omega}' \Big] \, d\alpha
\end{aligned}
$$

Photorealistic Rendering

..refers to rendering a 3D scene in a realistic way



photograph



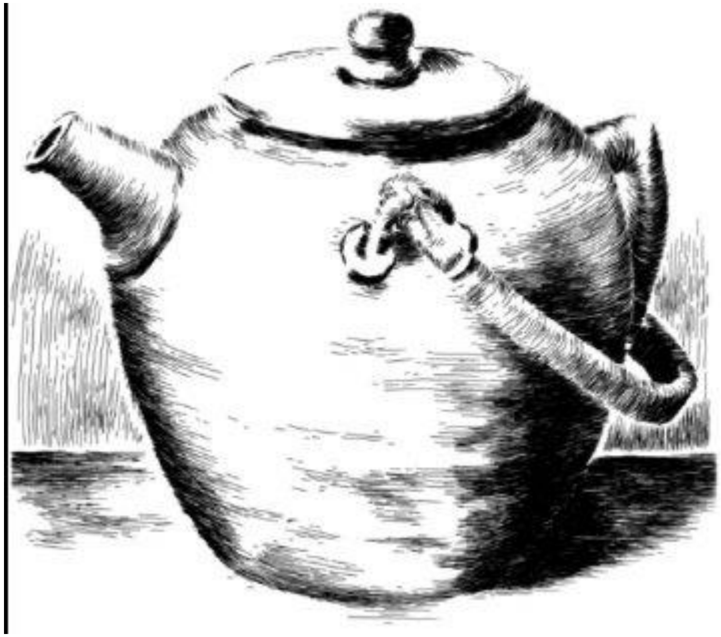
1.0 mm computer model
with diffuse reflectance

Photorealistic Rendering

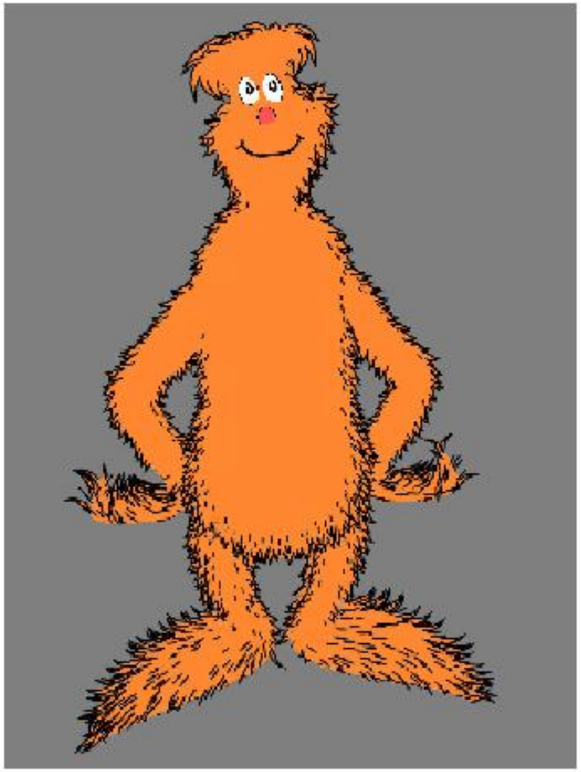
Modern photoreal rendering algorithms are essentially a physically based simulation of light propagation and scattering throughout a 3D environment.

Non-photorealistic rendering

Artistic rendering—trying to evoke hand-drawn or hand-painted styles, such as charcoal sketching, pen and ink illustration, or oil painting (Cartoon rendering style)

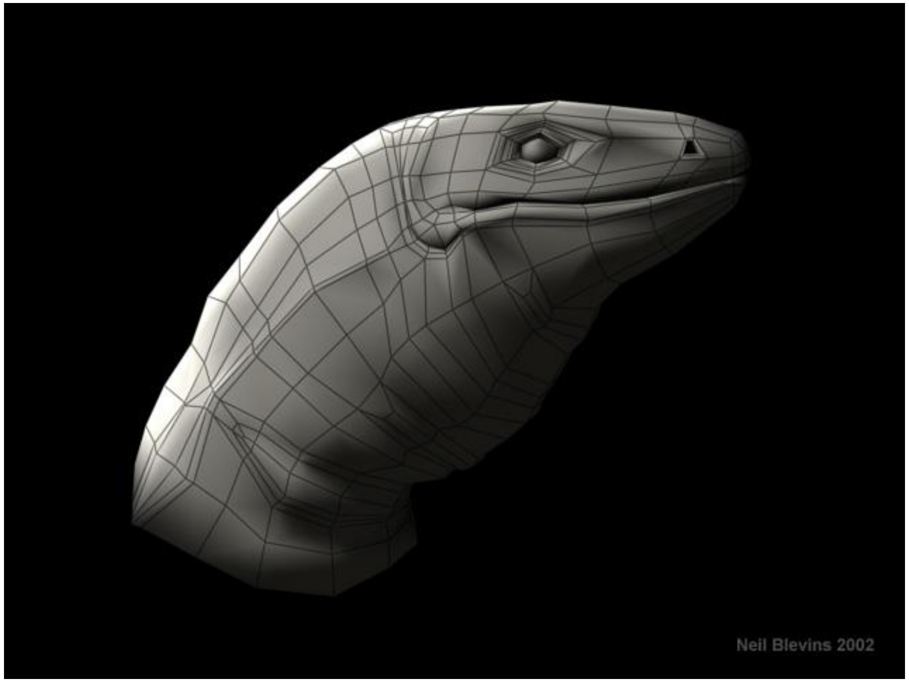


Tonal Art Maps



Rendering:

interaction between light and material


Neil Blevins 2002

Neil Blevins 2002

A 3D scene is:

Geometry (triangles, lines, points, and more)

Light sources, Material properties, Textures (images onto the geometry)

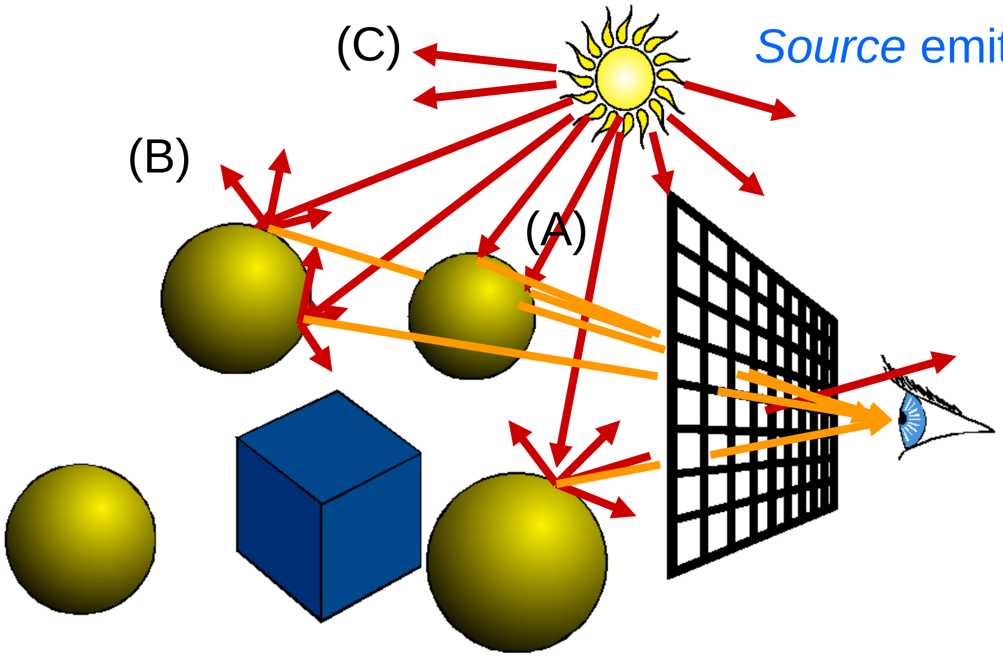
Lighting

When the rays hit an object they:

(A) reflect to the viewer

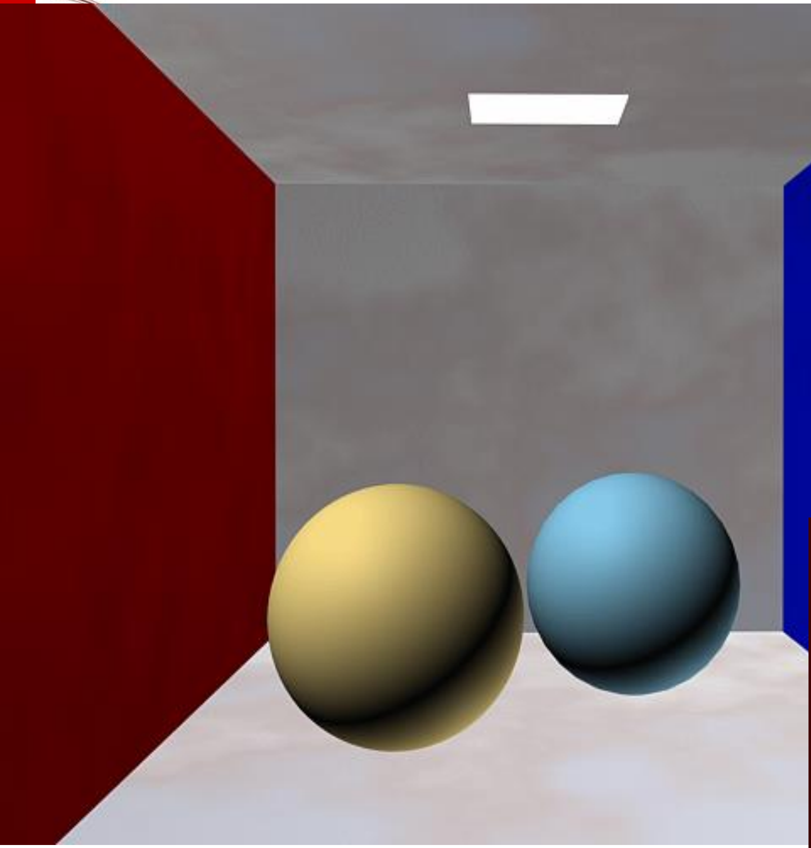
(B) bounce off in a new direction

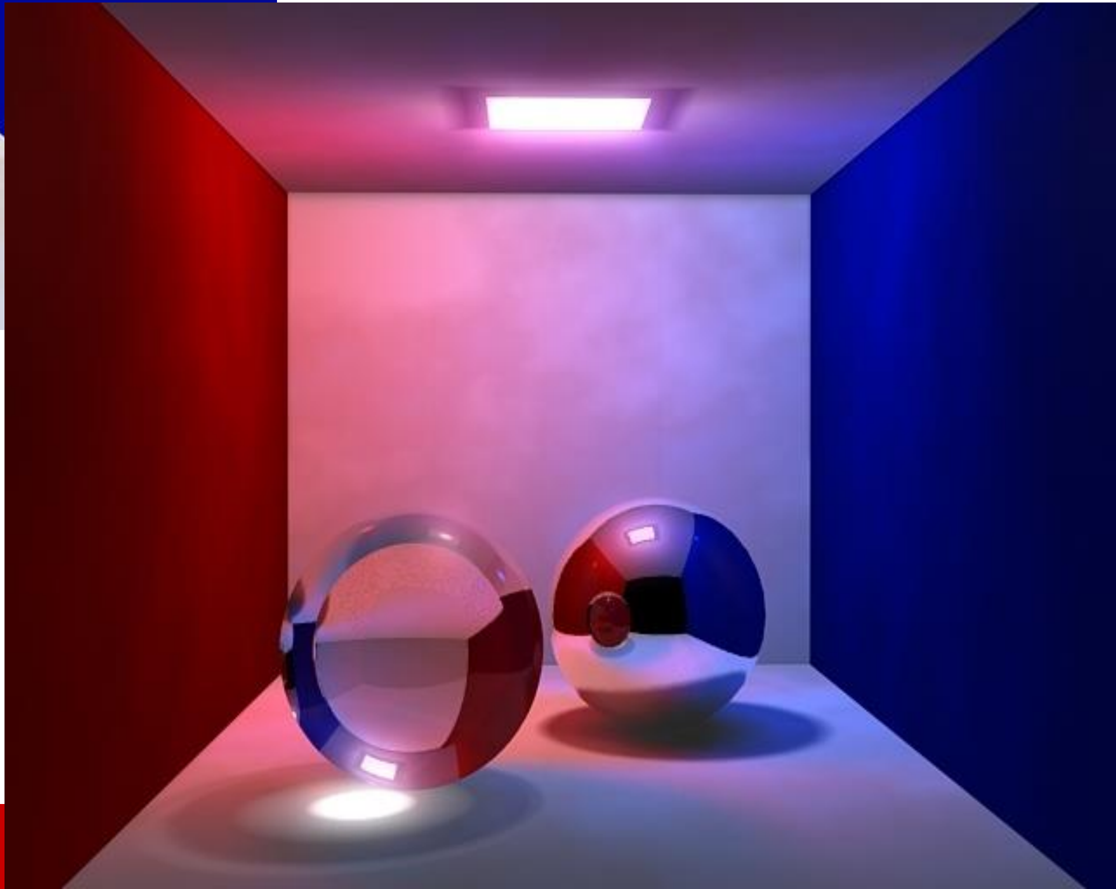
(C) out of room or are absorbed



Source emits photons

And then some reach the eye/camera.





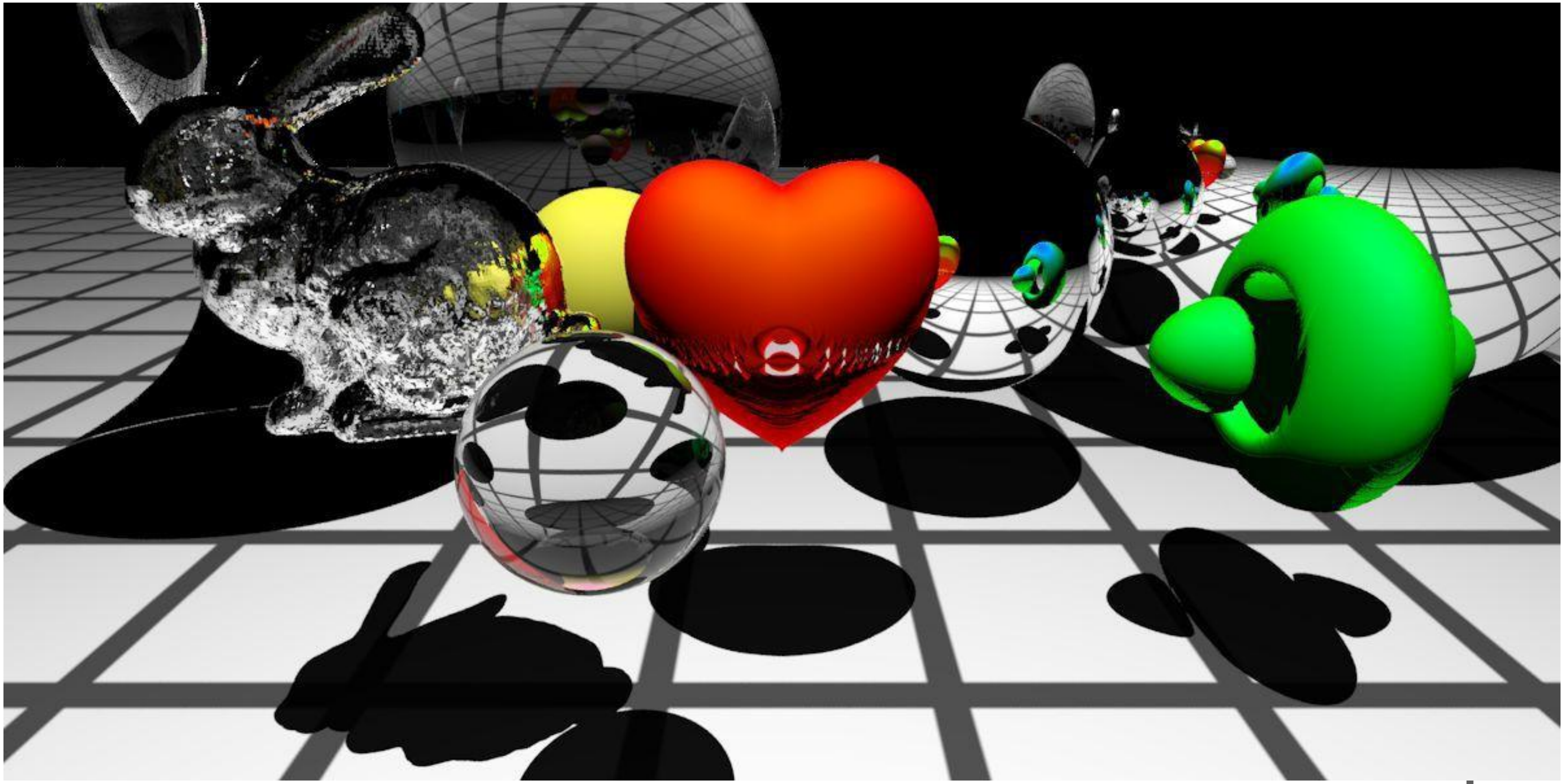
Shadows (visibility)
Interreflections

Material Properties

- Modeling Lighting
- Transparency
- Reflectance
- Shadows (visibility)
- Interreflections

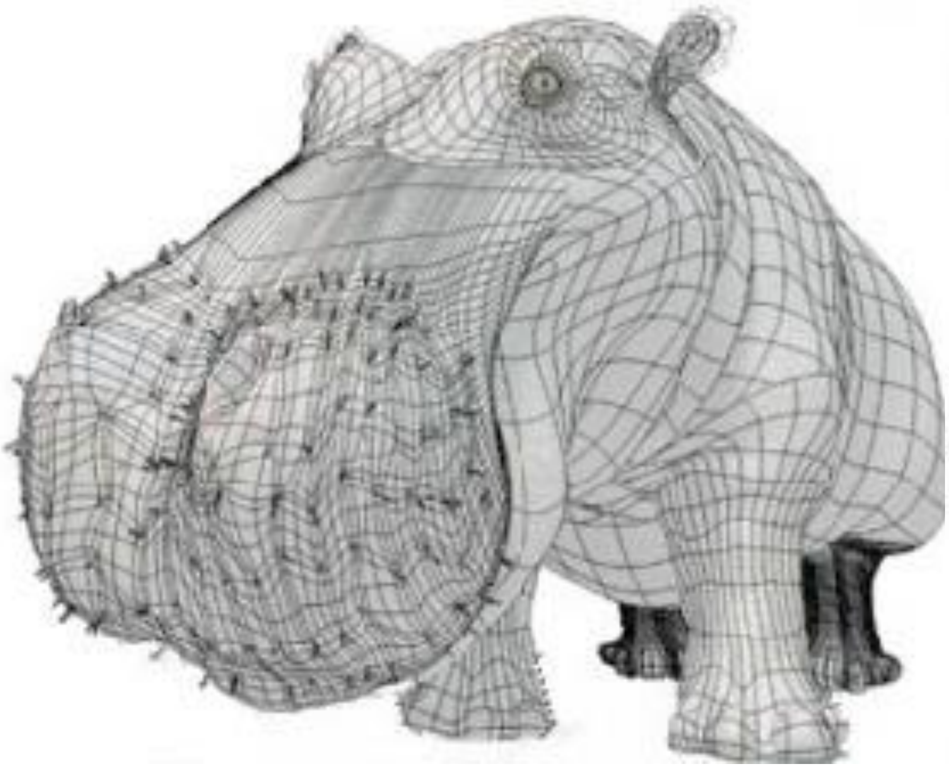
Lighting (Global Models)
Ray tracing

- Ray:shadows, lighting, reflection, transparency

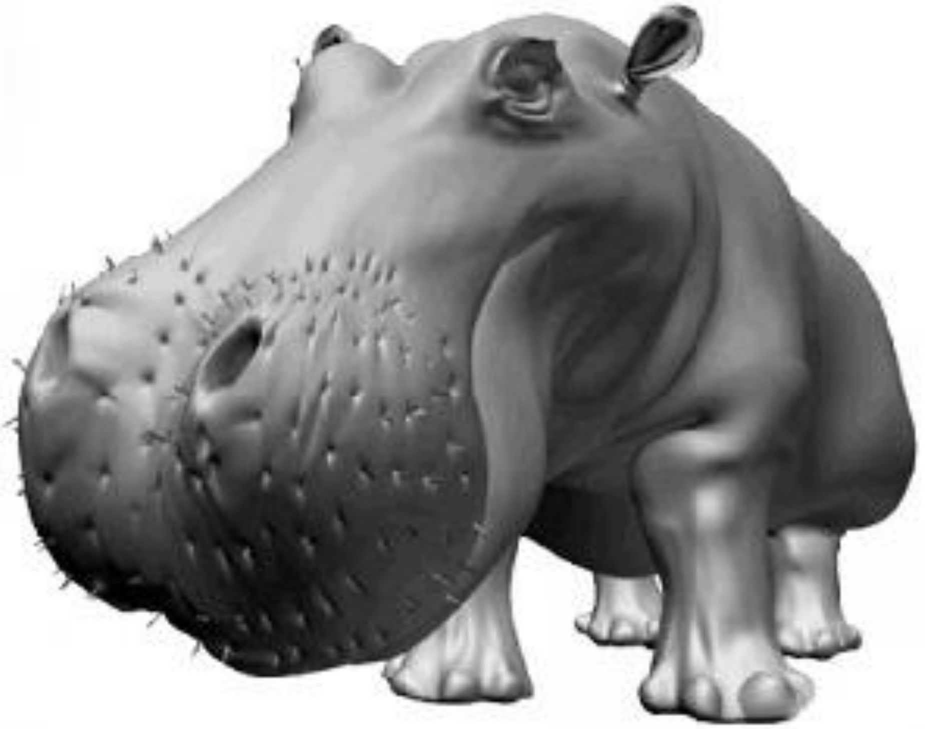


Texture Mapping

modelling



Modelling + shading



http://www.3drender.com/jbirn/productions.html

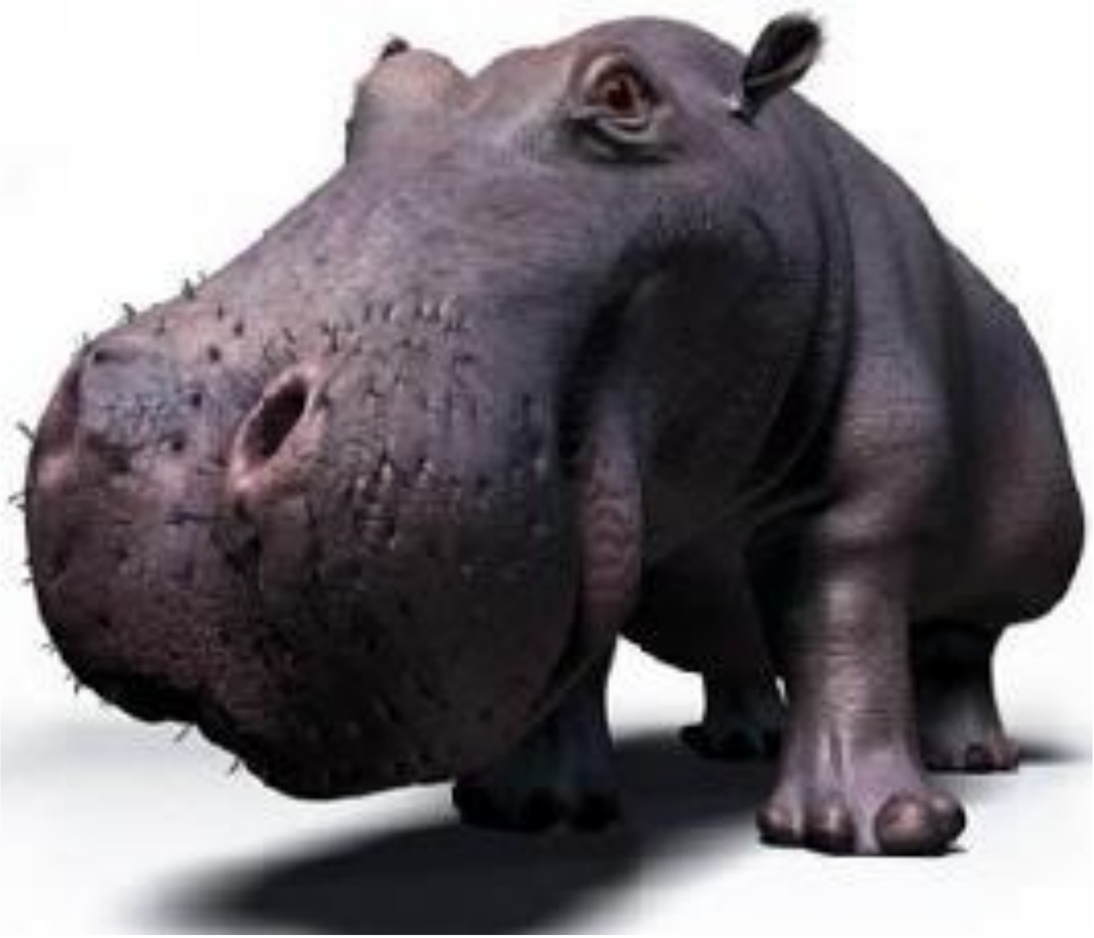
Texture Mapping

Modelling + shading + texturing

Details

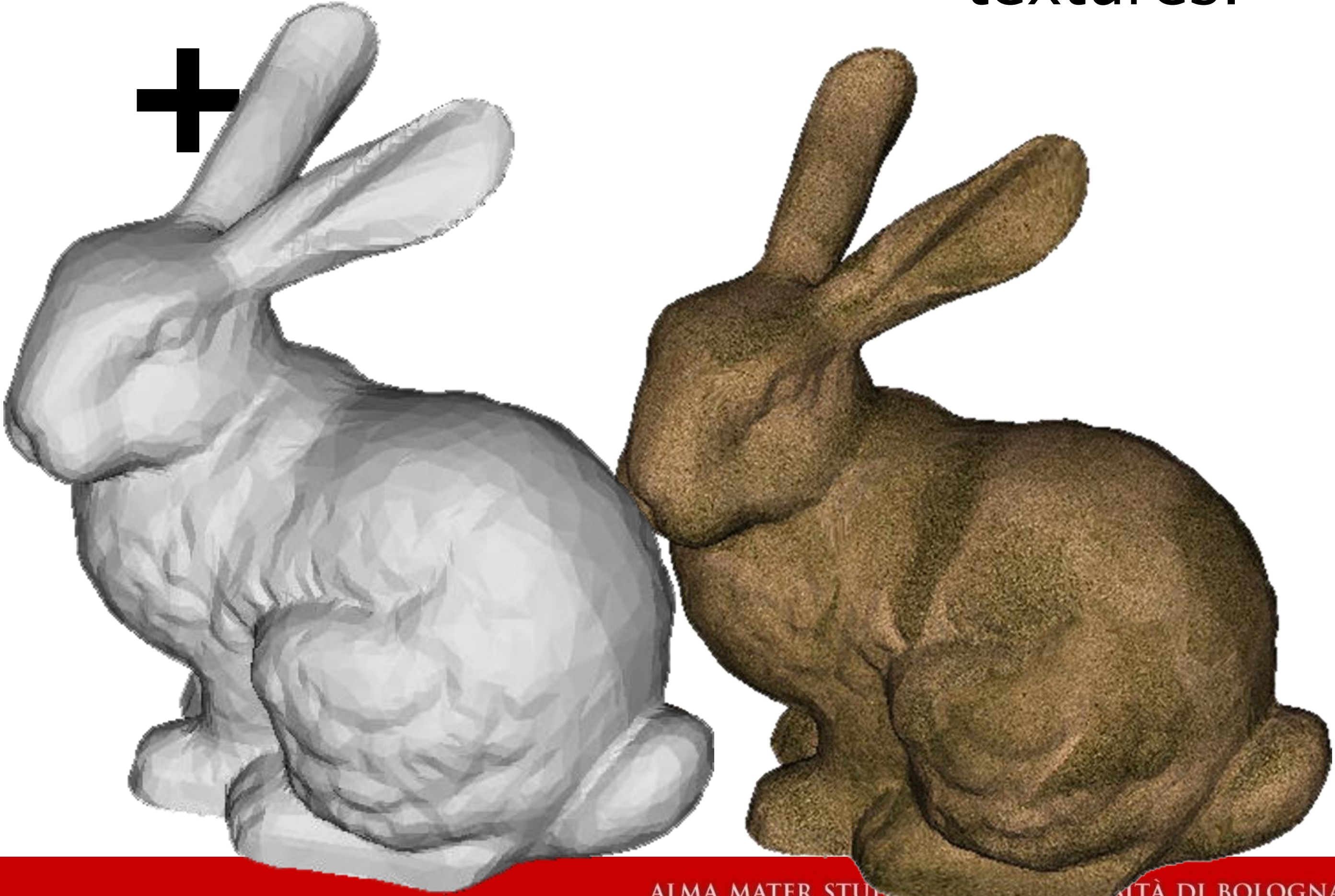
created

by texturing



At what point do things start looking real?

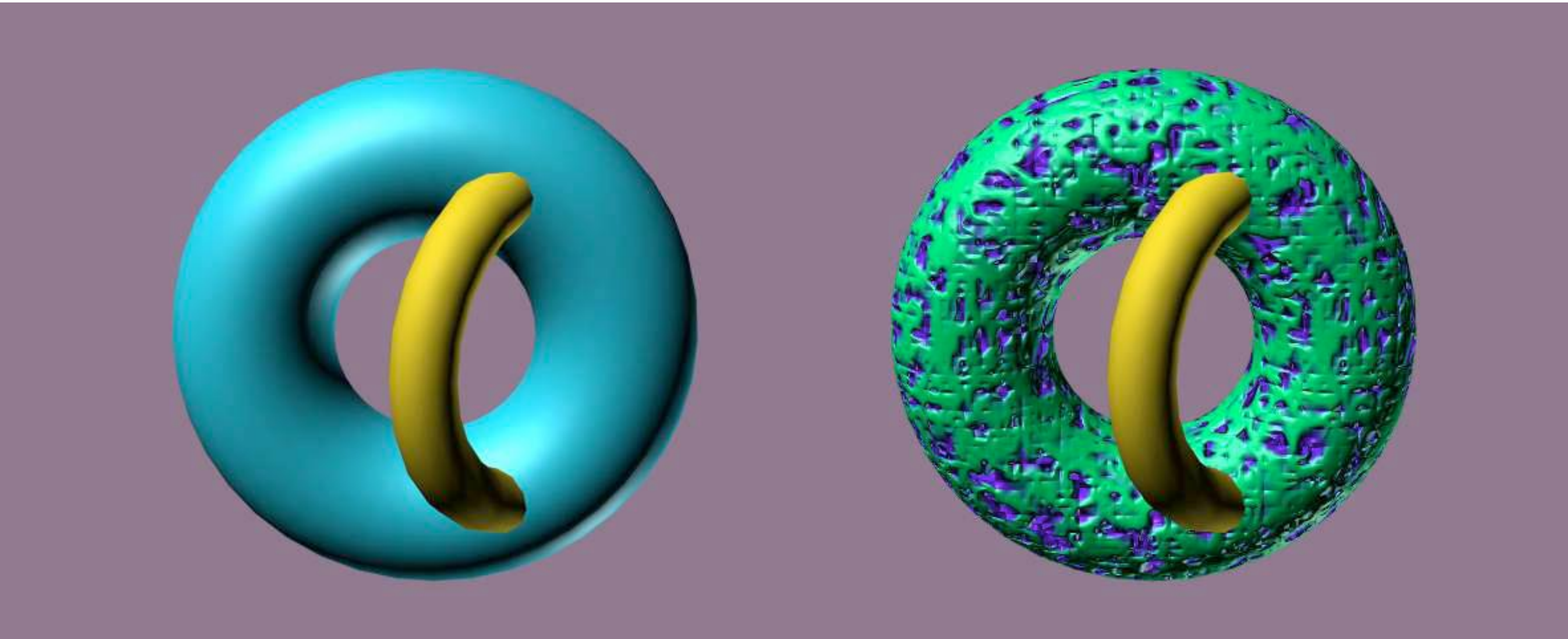
map an image onto surface geometry to create appearance of fine surface details. A high level of realism may require many layers of textures.



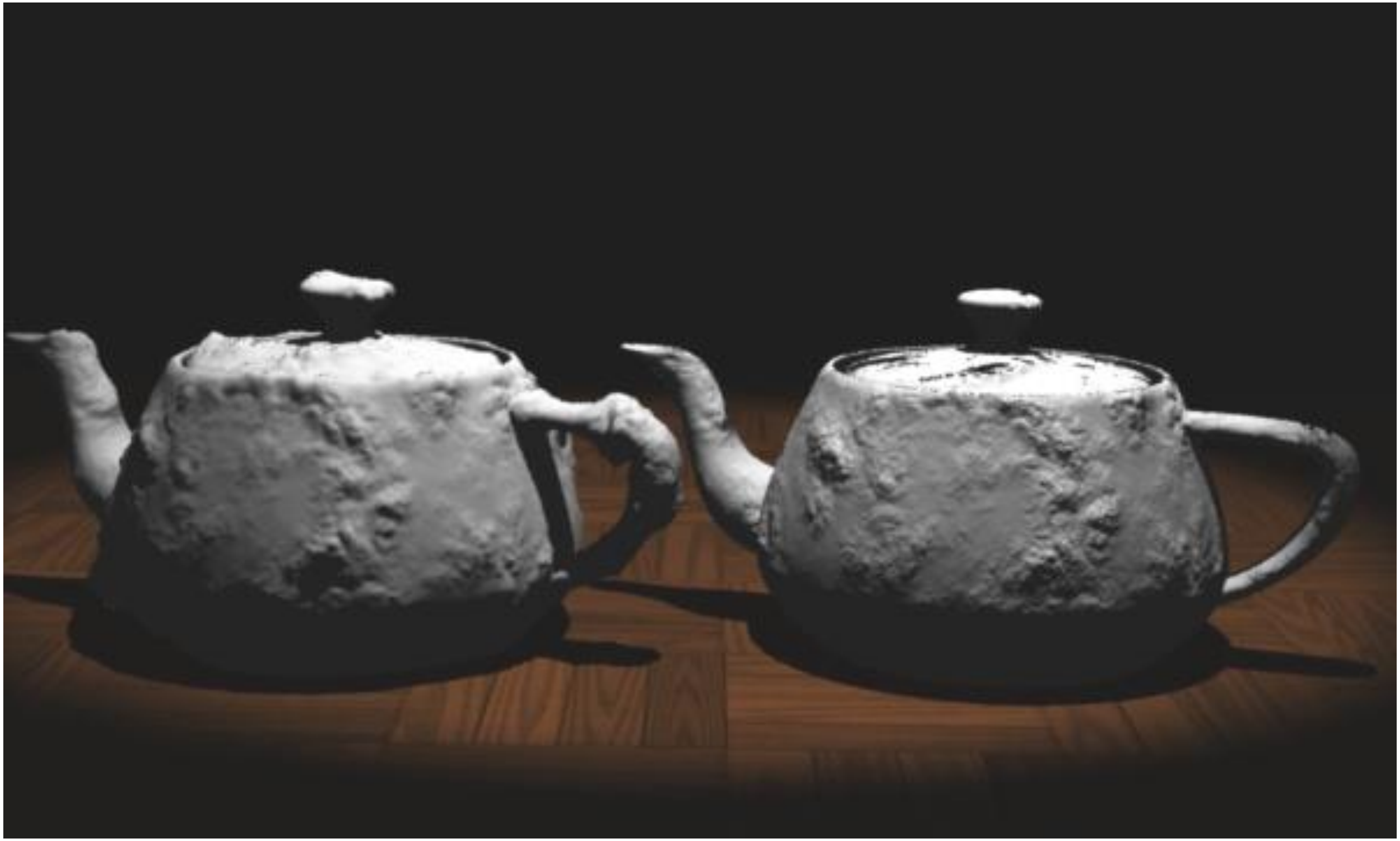
Bump Mapping

fake surface normals by applying height field (intensities in the map indicate height above surface).

From height field calculate gradient across surface and use this to perturb the surface normal.

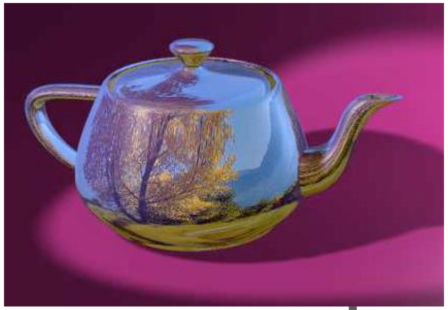


Displacement vs. Bump mapping



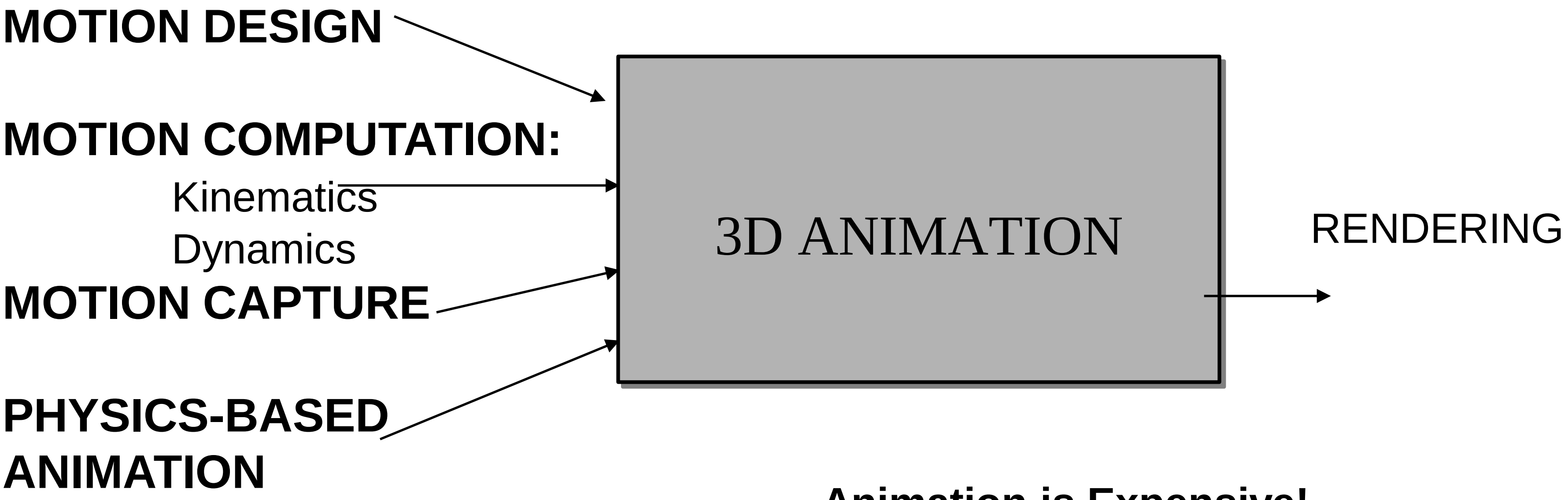
Environmental Mapping

multiple images (textures) which record global reflection and lighting on object. These images are resampled during rendering to extract view- specific information which is then applied as texture to object.



Computer Animation

Making things alive/Making them move



MOTION DESIGN

MOTION COMPUTATION:

Kinematics

Dynamics

MOTION CAPTURE

PHYSICS-BASED ANIMATION

3D ANIMATION

RENDERING

Animation is Expensive!
- 30 frames/second
- 30 minutes = 54,000 frames
- 5 minutes/frame, 12 hours/day ~1 year

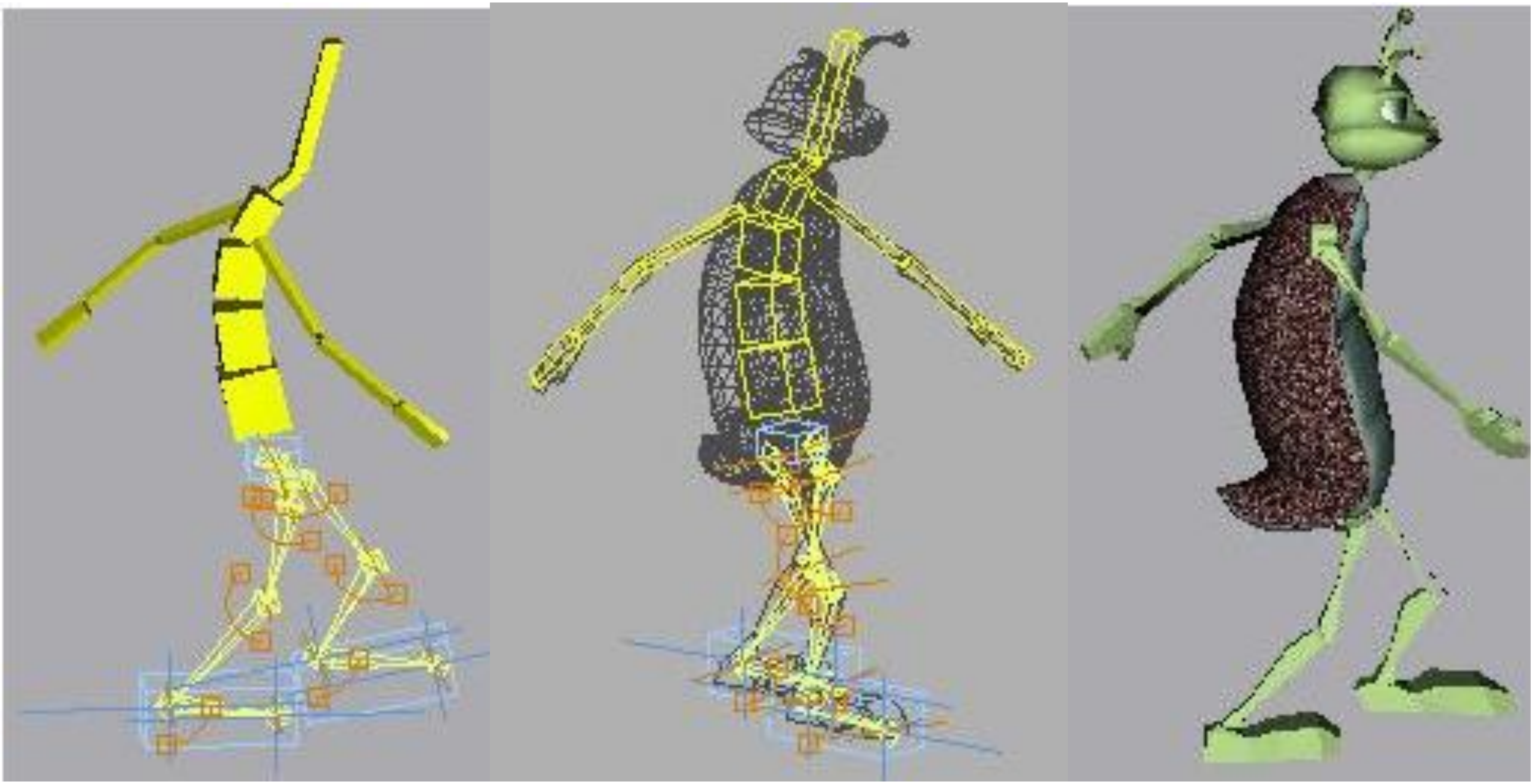
Actor+ motion law

Computer Animation

- **What is Animation?**
  - – Make objects change over time according to scripted actions

- **What is Simulation?**
  - – Predict how objects change over time according to physical laws

Link, joint, skinned mesh

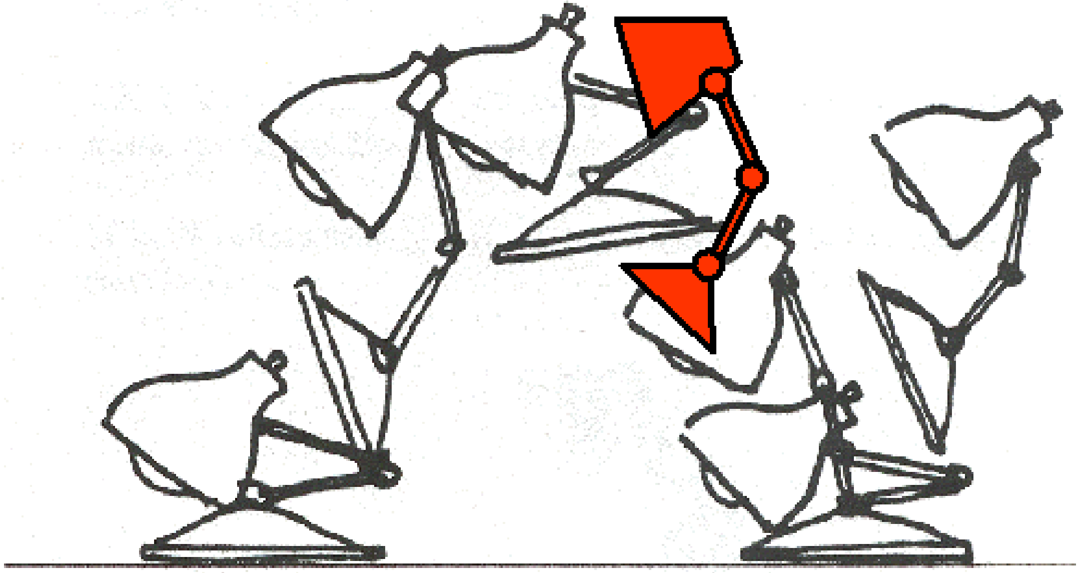


Animating actors

- Keyframe
- Physics-based animation
- Motion Capture

Keyframe

- **Keyframe:**
  Define Character Poses at Specific Time Steps Called "Keyframes"



- **Key and inbetween:**
  - Define pose vector
  - Define the keyframes,
  - Compute inbetween for a smooth animation(spline).

Computer Animation by keyframe

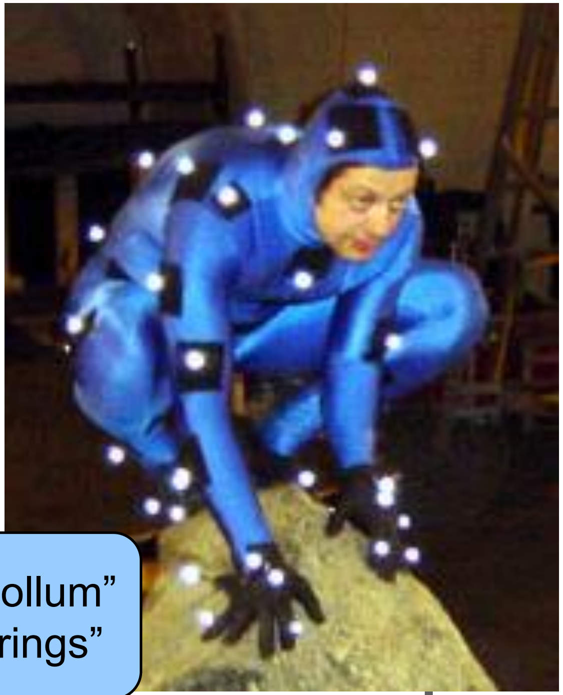
Realizzazione dell'animazione "Owen the Sweeper" (Tesi di Marchesini Stefano, 2004)

Realizzazione dell'animazione "Owen the Sweeper"
(Tesi di Marchesini Stefano, 2004)

Motion Capture

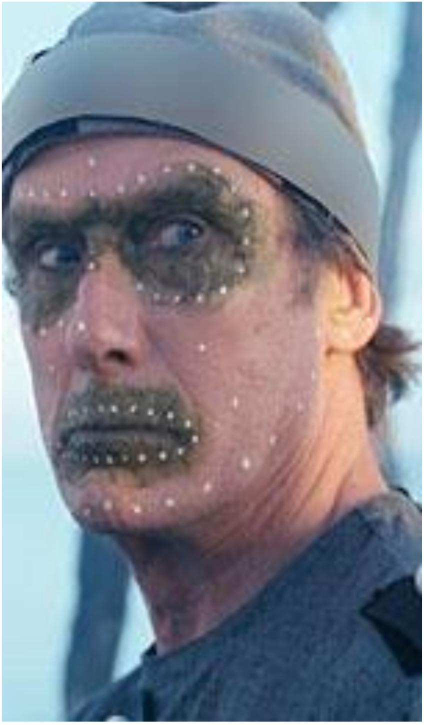
- Captur of motion of (human) actor:
  - Whole body
  - Upper body
  - face

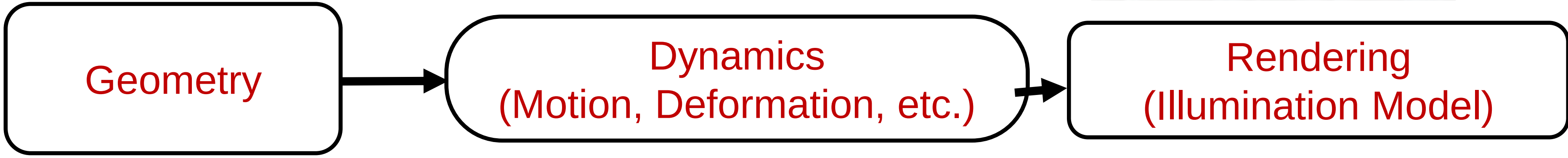
- One way of using a physical device to control animation



Andy Serkis in “Gollum”
“The lord of the rings”

MoCap: Facial Motion Capture





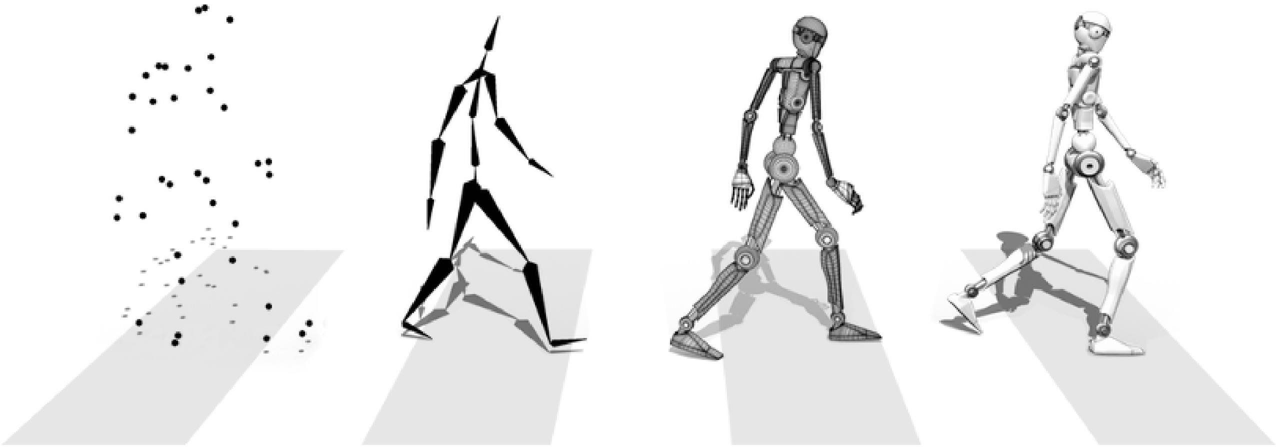
Geometry

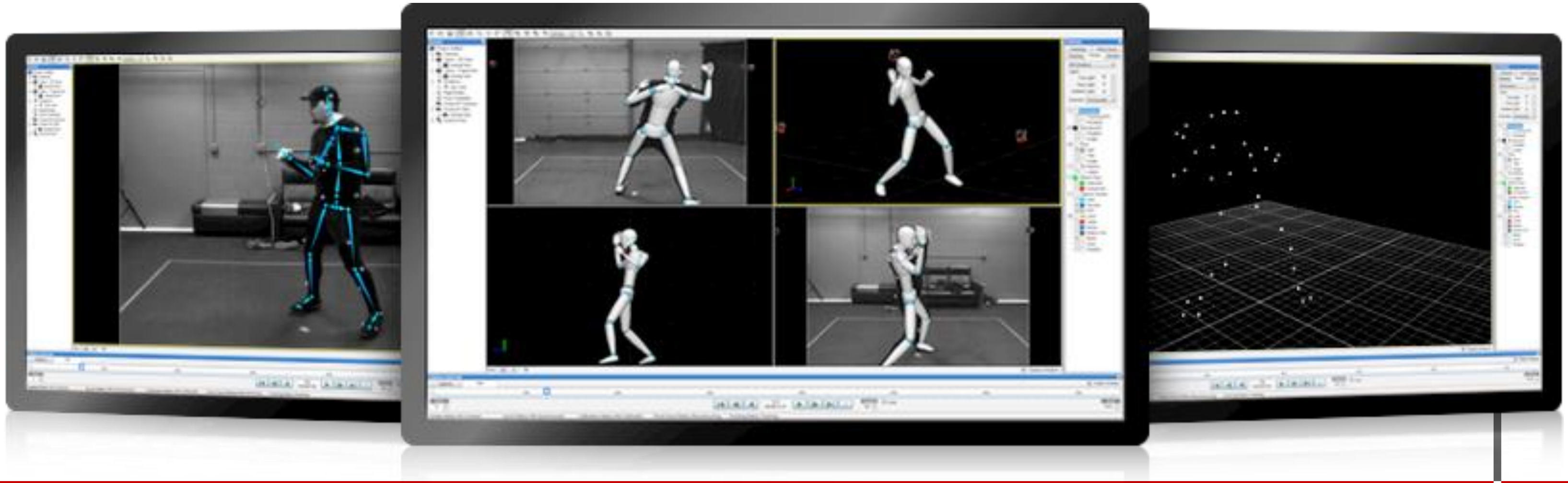
Dynamics
(Motion, Deformation, etc.)

Rendering
(Illumination Model)

MoCap: Body Motion Capture

OptiTrack - Optical Motion Capture Systems and Tracking Software





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