3D Computer Graphics

Multimedia Techniques & Applications

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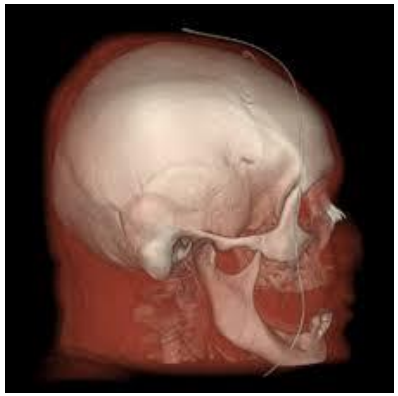
(with slides borrowed from Prof. Yung-Yu Chuang, Prof. Tzu-Mao Li, and Dr. I-Chao Shen)

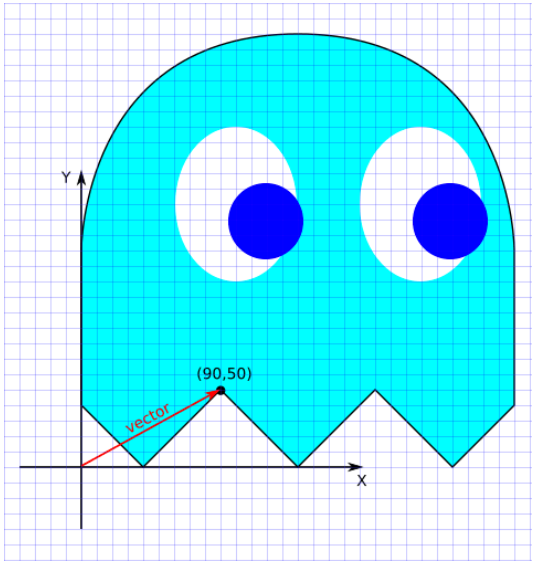
What is Computer Graphics

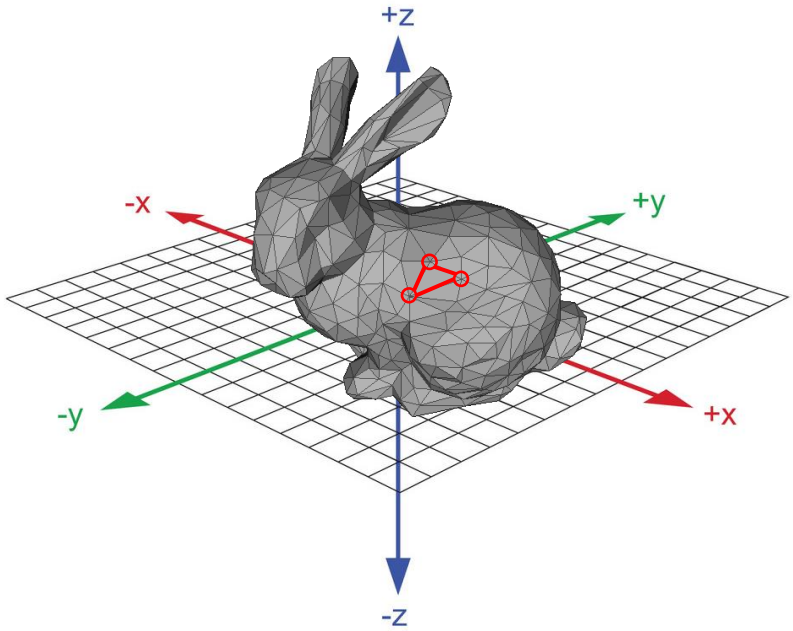
- Computer graphics are pictures and films created using computers
- Computer graphics is the process of creation, storage and manipulation of models and images using data structure and algorithms



From 2D Graphics to 3D Graphics

- We have talked about 2D vector graphics, now we will extend it to the **3D** world





2D coordinate (x, y)

2D shapes

2D transformation

3D coordinate (x, y, z)

3D shapes

3D transformation

What Happened in Previous 20 Years

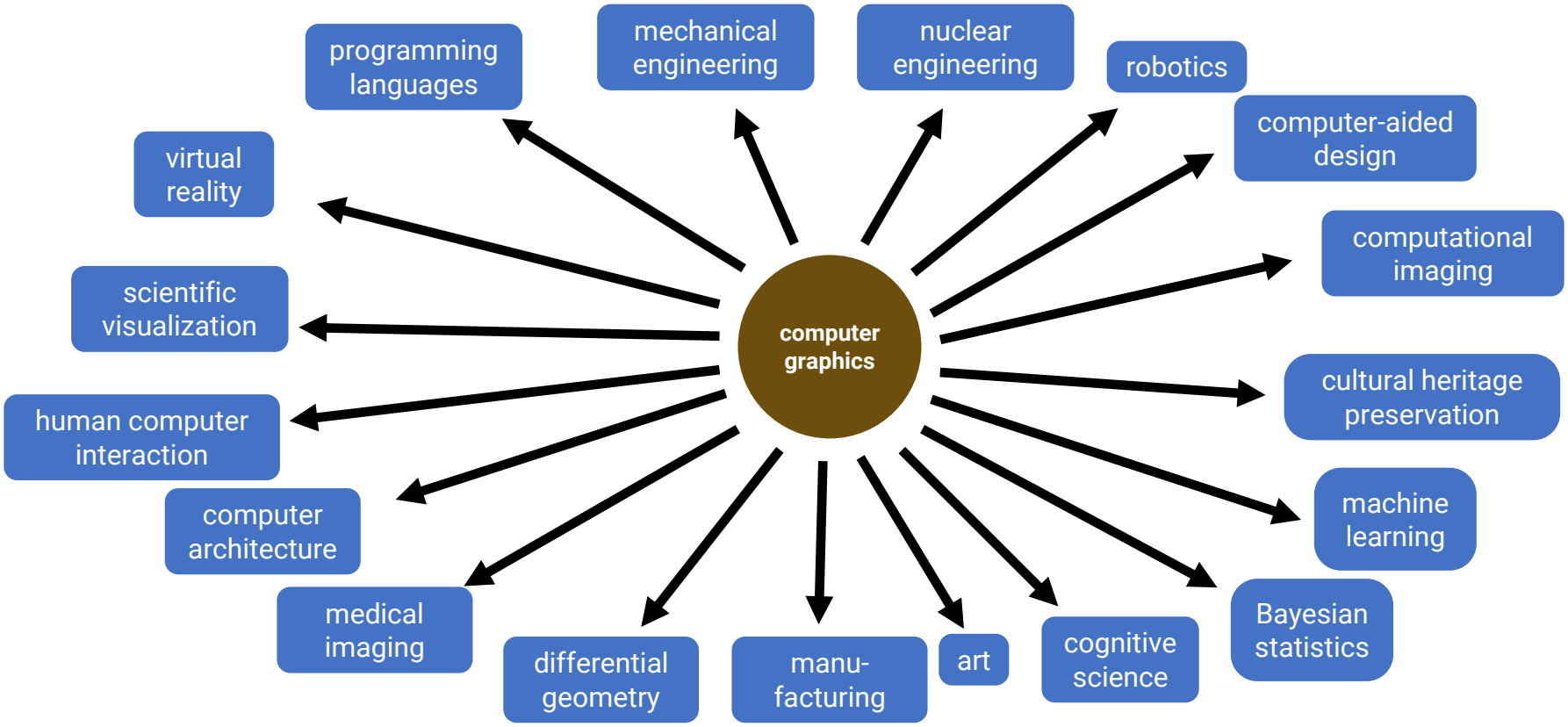
Resident Evil 3 (1999)

Resident Evil 3 Remake (2020)

Which Cat is Real? (Goose or Reggie)

Why Computer Graphics is Important

- Graphics push advances in many fields



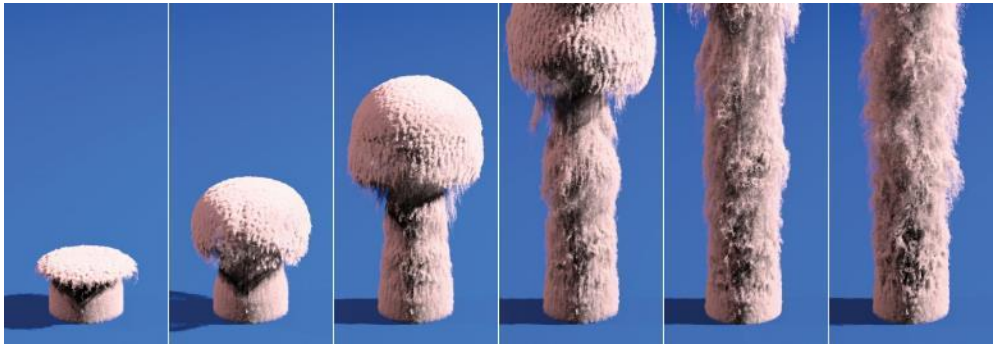
Applications of Computer Graphics

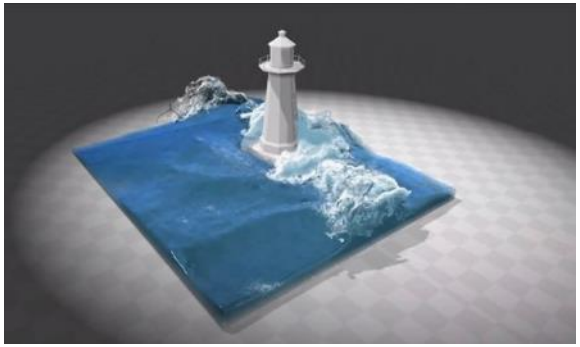
- Lighting and architecture design




Applications of Computer Graphics (cont.)

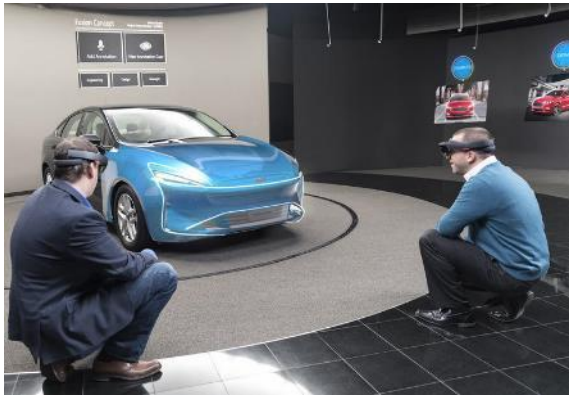
- Visualization of scientific data and physical simulation





Applications of Computer Graphics (cont.)

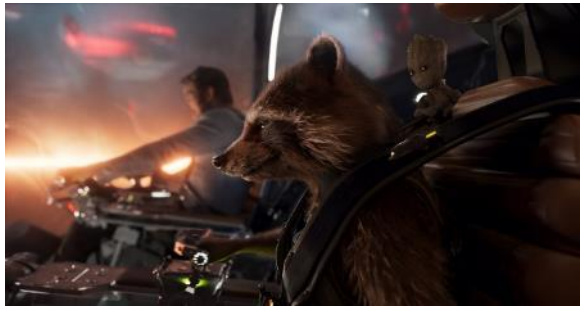
- Games, AR, MR, and VR



Applications of Computer Graphics (cont.)

- Film production








Applications of Computer Graphics (cont.)

- Training data generation for deep learning

Description of a 3D World

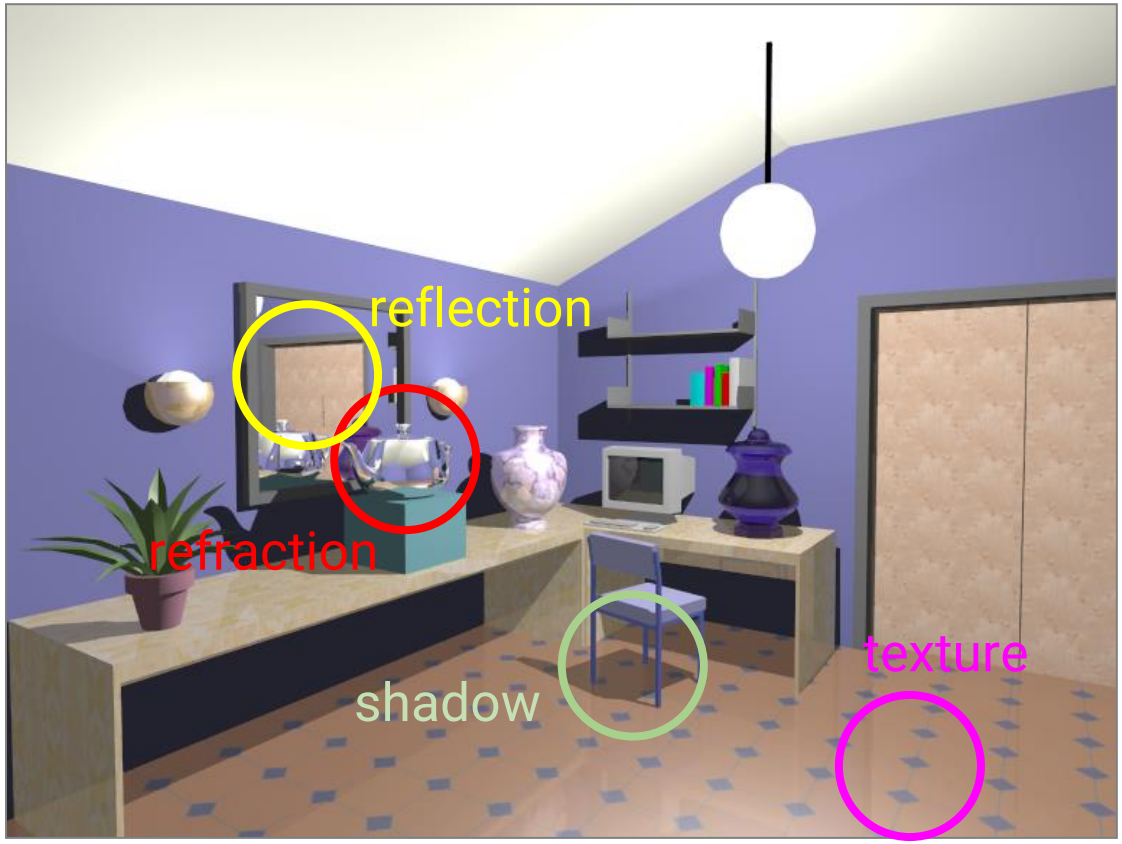
- Define **geometry** of the objects (or scene)
  - Represented by a set of 3D coordinates (**vertices**) and their adacencies

Description of a 3D World (cont.)

- Add **materials** of the objects (or scene)
  - Usually represented by math
- Add **lights**

Description of a 3D World (cont.)

- Simulate more realistic **materials** and consider more **light paths**

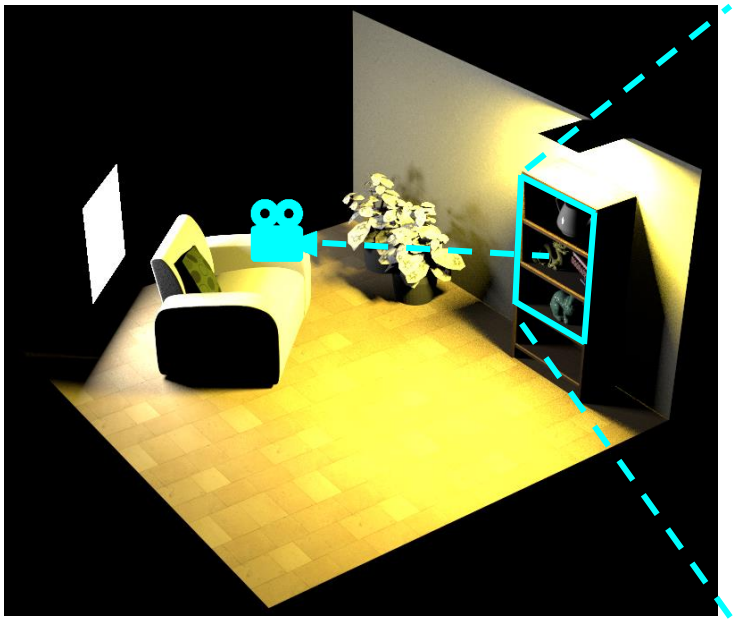


Description of a 3D World (cont.)

- Simulate more **light paths**

Generate Images from the 3D World

- Most displays are 2D, so we need to generate images from the 3D world
- Just like taking a picture with a camera in our daily lives
  - But with a **virtual camera** and a **virtual film**



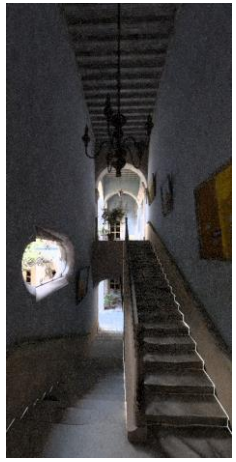
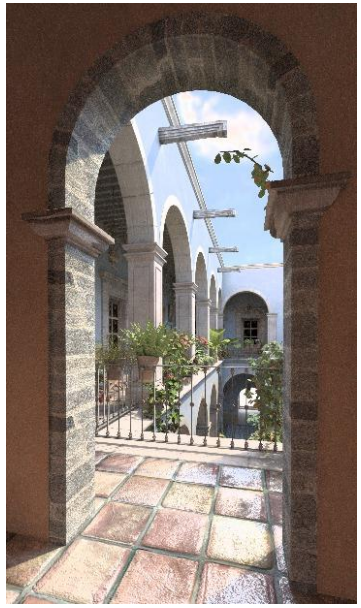
3D virtual world

rendered image

Generate Images from the 3D World (cont.)





Are These 3D?


あきら
たかし
あーちゃん
たかし
あきら
ケンジ
あーちゃん


移動
魔法
攻撃
撤退
道具
戰技
HP 4209
EP 160
CP 90
HP 3934
EP 160
CP 90
HP 7240
EP 227
CP 200
HP 7782
EP 304
CP 200
SBREAK X


小鱼儿
好，全给我包起来吧！

Are These 3D? (cont.)

- 3D is much more difficult than 2D!

Are These 3D? (cont.)

- 3D is much more difficult than 2D!

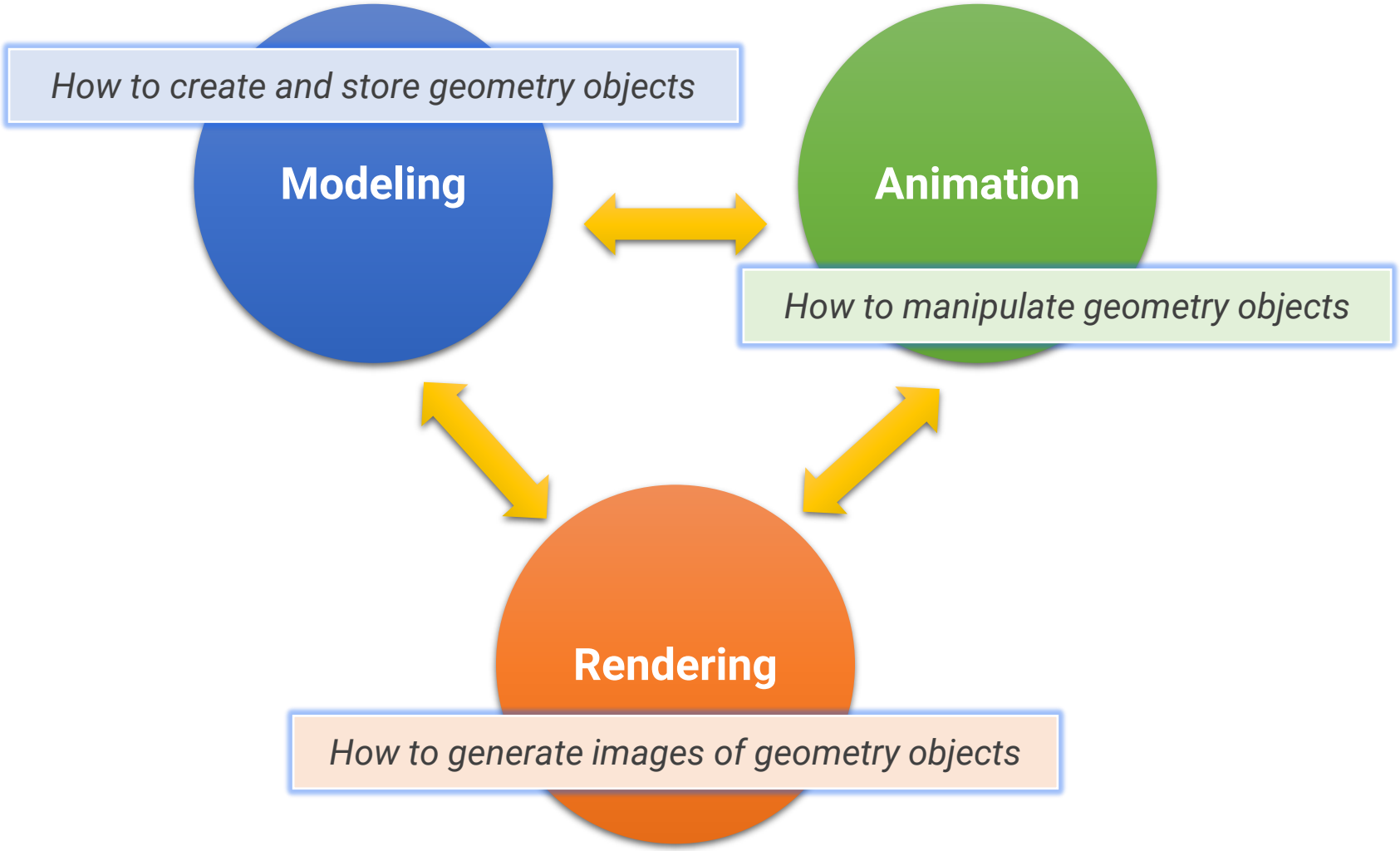
The Differences between Relevant Fields

- Traditionally we will categorize ***computer graphics***, ***computer vision***, and ***image processing*** by their inputs and outputs:

inputs \ outputs	descriptions	images
descriptions		***computer graphics***
images	***computer vision***	***Image processing***

- However, the gaps are much vaguer now!

Major Subfields of Computer Graphics

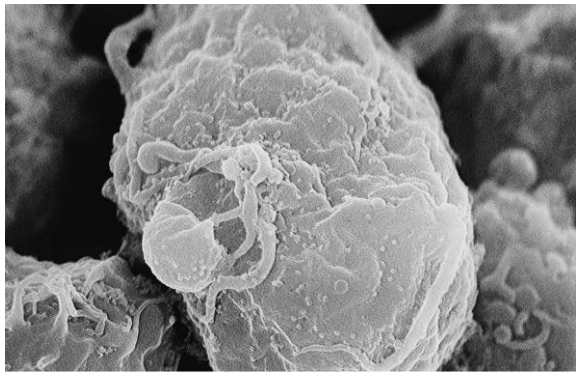


Modeling

- World geometries are diverse!



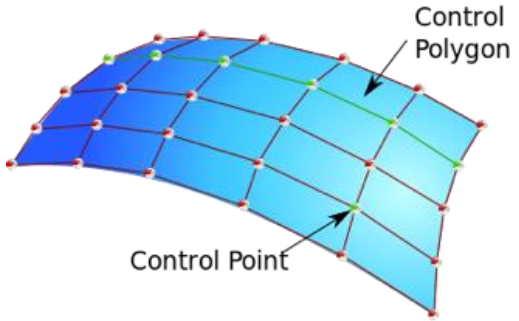




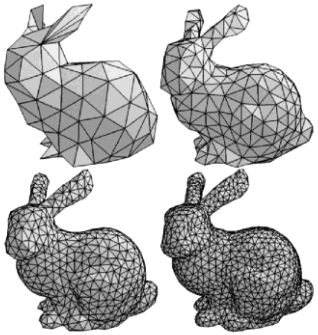

Modeling (cont.)

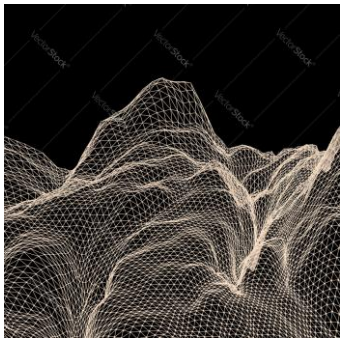
- How to model/represent **curves**, **surfaces**, and **volumes**

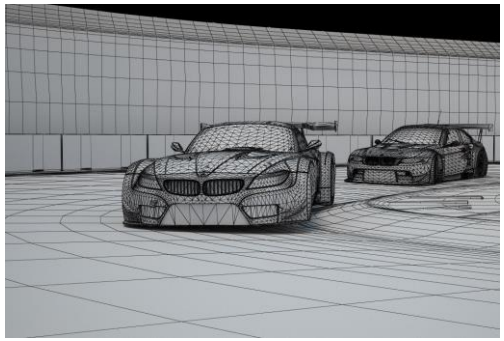
curves



patches (by control points and curves)





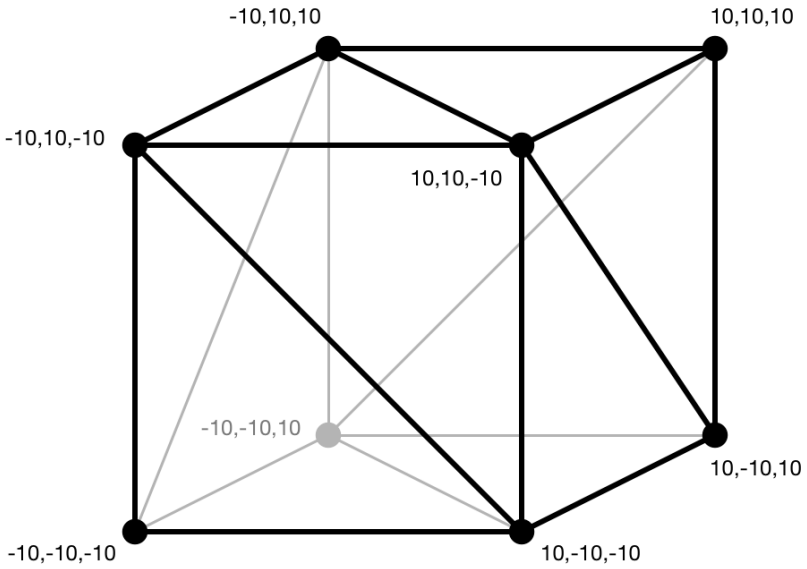


meshes (by polygons, usually triangles)

volume data

Modeling (cont.)

- How to model/represent **curves**, **surfaces**, and **volumes**
  - **Triangle mesh** (most popular!)

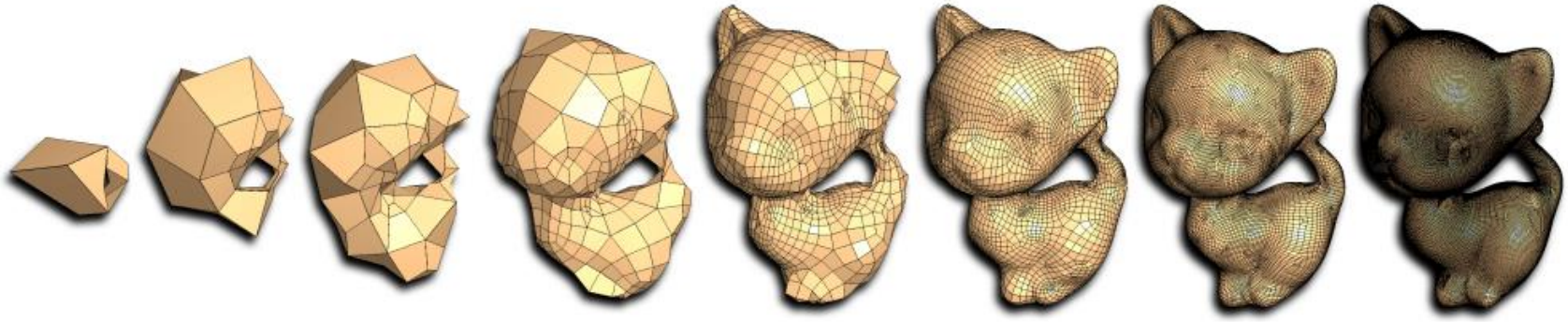


12 triangles

10K triangles

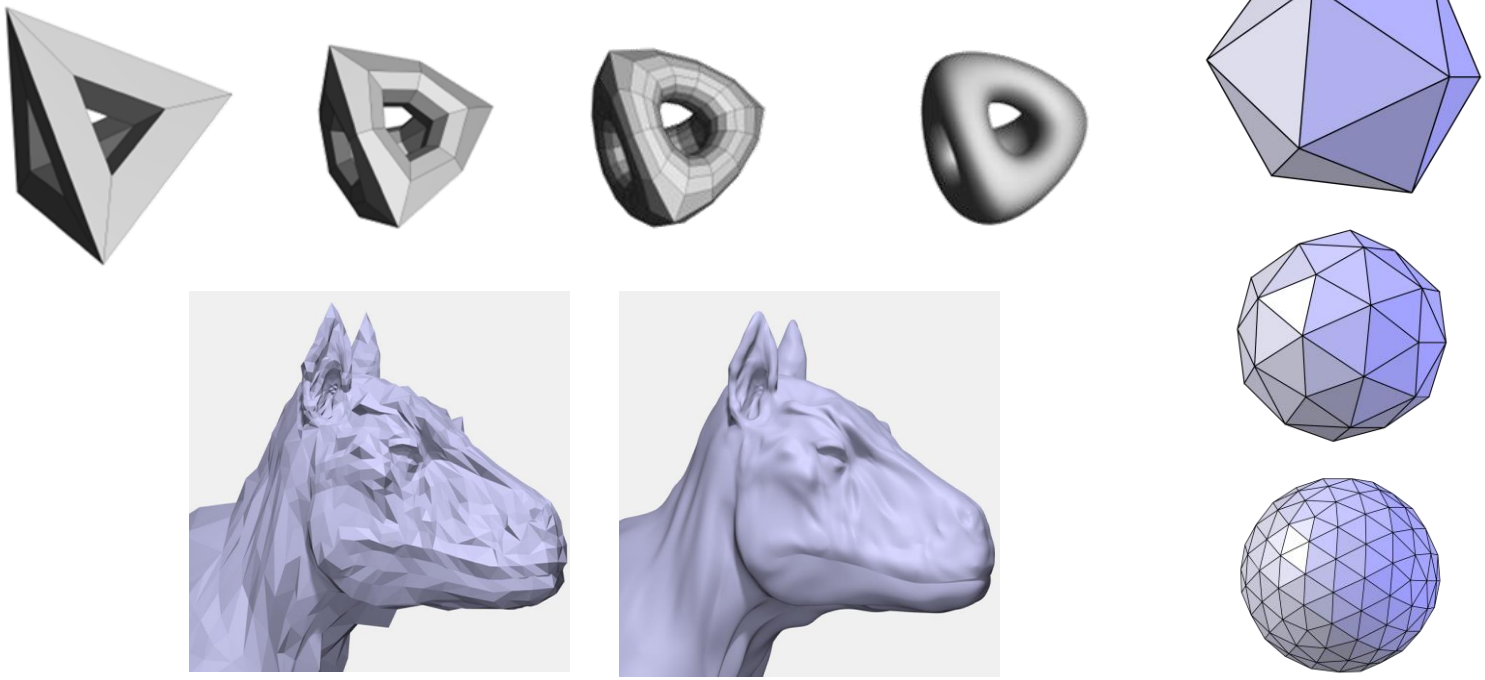
Modeling (cont.)

- How to model/represent **curves**, **surfaces**, and **volumes**
  - **Triangle mesh** (most popular!)



Modeling (cont.)

- **Subdivision surface**
  - Choose locations of new vertices as weighted average of original vertices in local neighborhood
  - Can generate smooth surface



Modeling (cont.)

- **Subdivision surface**
  - Won the Turing award

Pixar CG pioneers Pat Hanrahan and Edwin Catmull share $1M Turing Award

Devin Coldewey @techcrunch / 6:01 pm CST • March 18, 2020 Comment

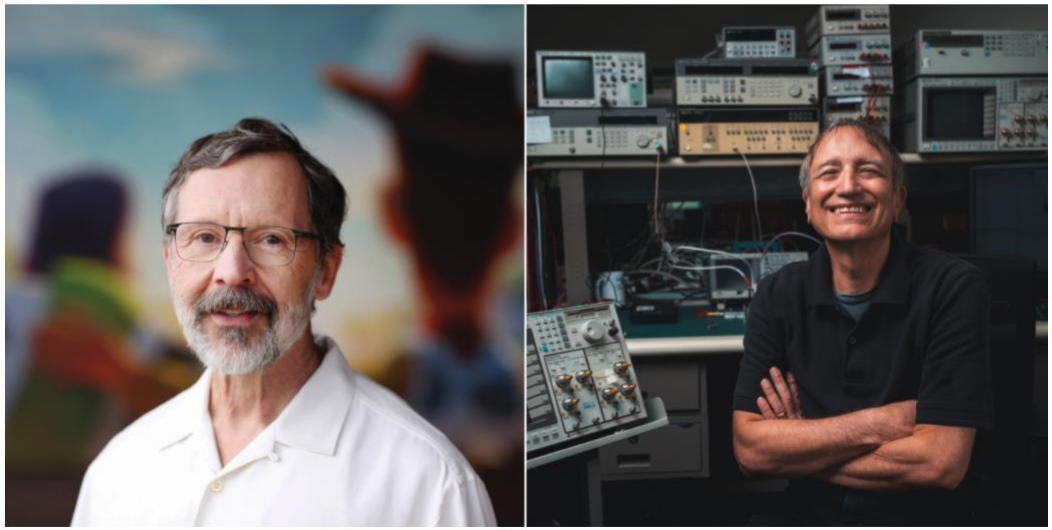


Image Credits: Deborah Coleman / Pixar; Andrew Brodhead / Stanford University

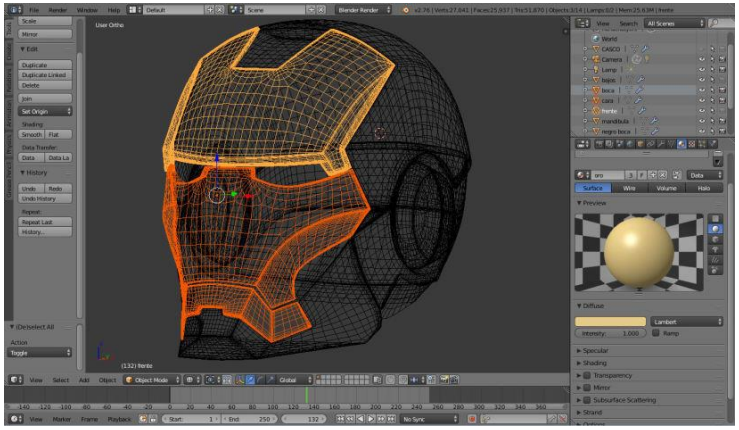
Toy story 1 (1995)

Modeling (cont.)

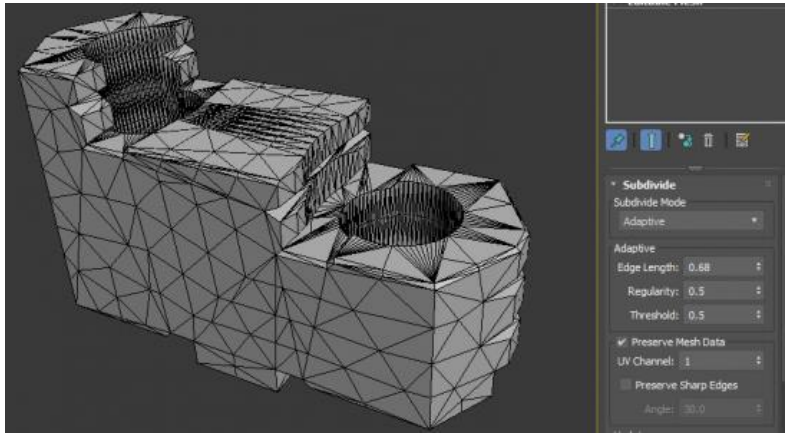
- **Subdivision surface**
  - Geri’s game by Pixar (1997)

Modeling (cont.)

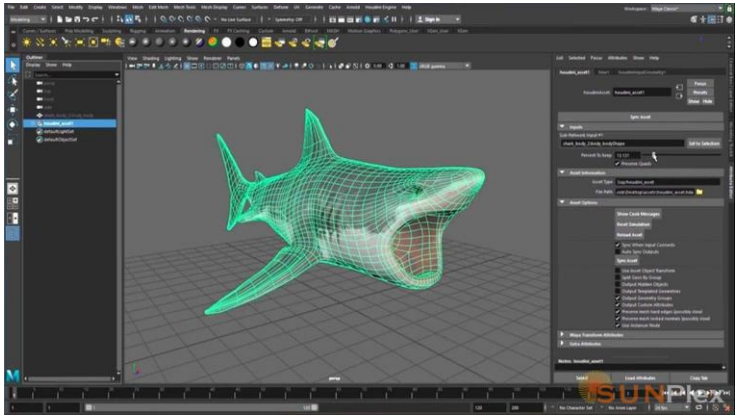
- **Lots of 3D editing software**



Blender



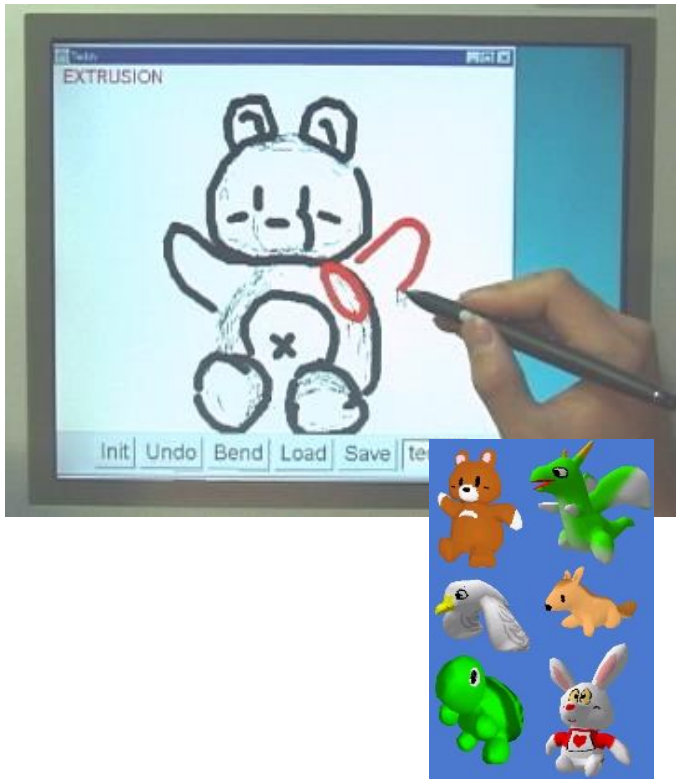
3dsMax



Maya

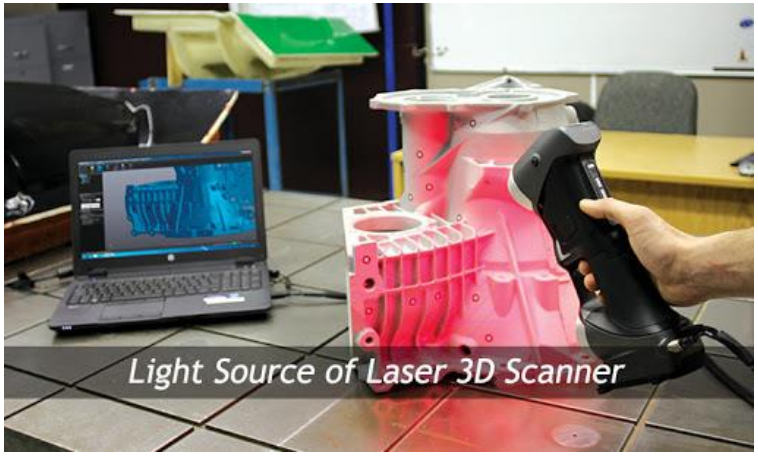
Modeling (cont.)

- **Teddy: sketch-based modeling system**
  - Igarashi et al. (SIGGRAPH 1999)



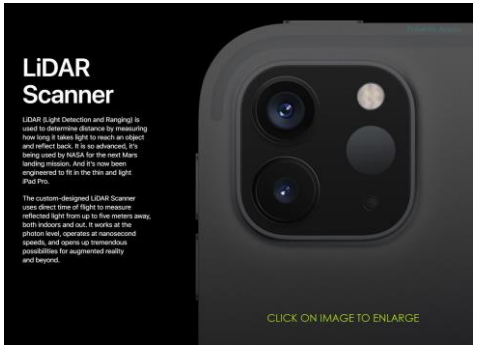
Modeling (cont.)

- **Capture the real-world geometries**



3D scanner

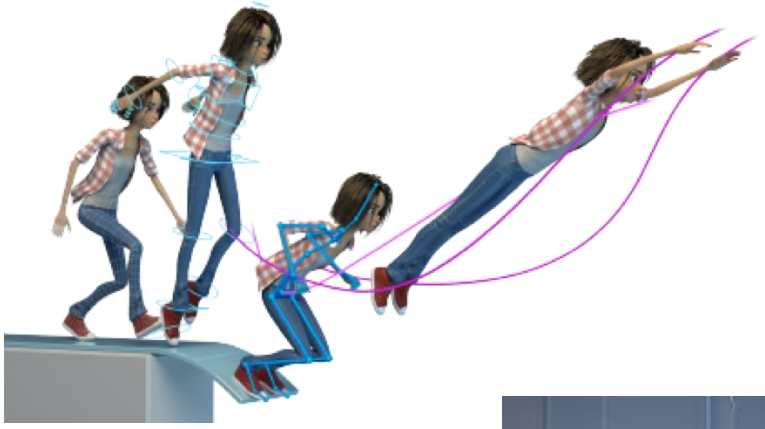
multi-view geometry

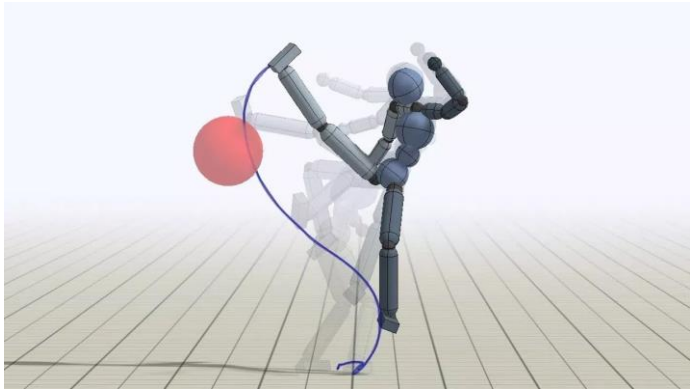


depth camera

Animation

- How do the geometry change / move over time



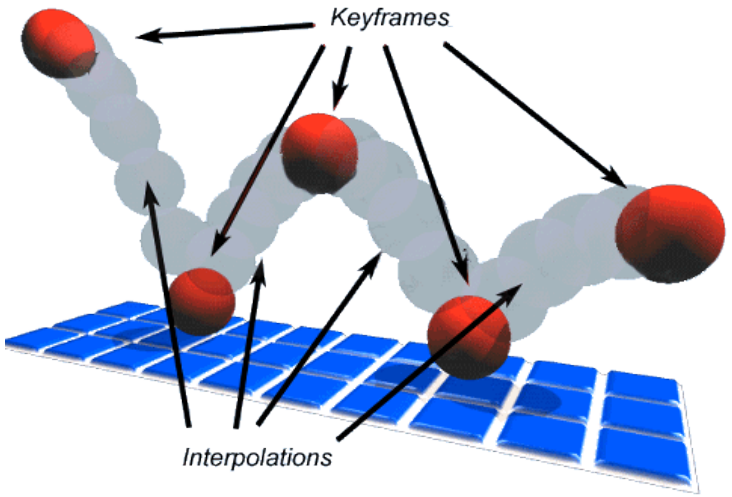


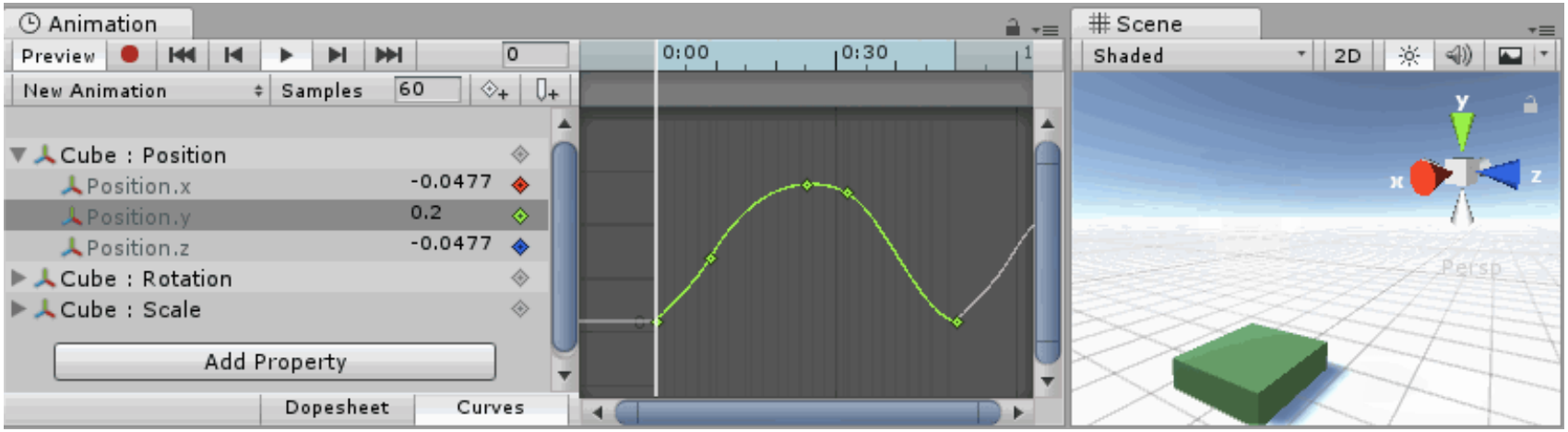
Animation (cont.)

- **Physically-based character animation**

Animation (cont.)

- **Keyframe animation**





Animation (cont.)

- **Keyframe animation**

Animation (cont.)

- **Motion capture**

Animation (cont.)

- **Motion capture**

Animation (cont.)

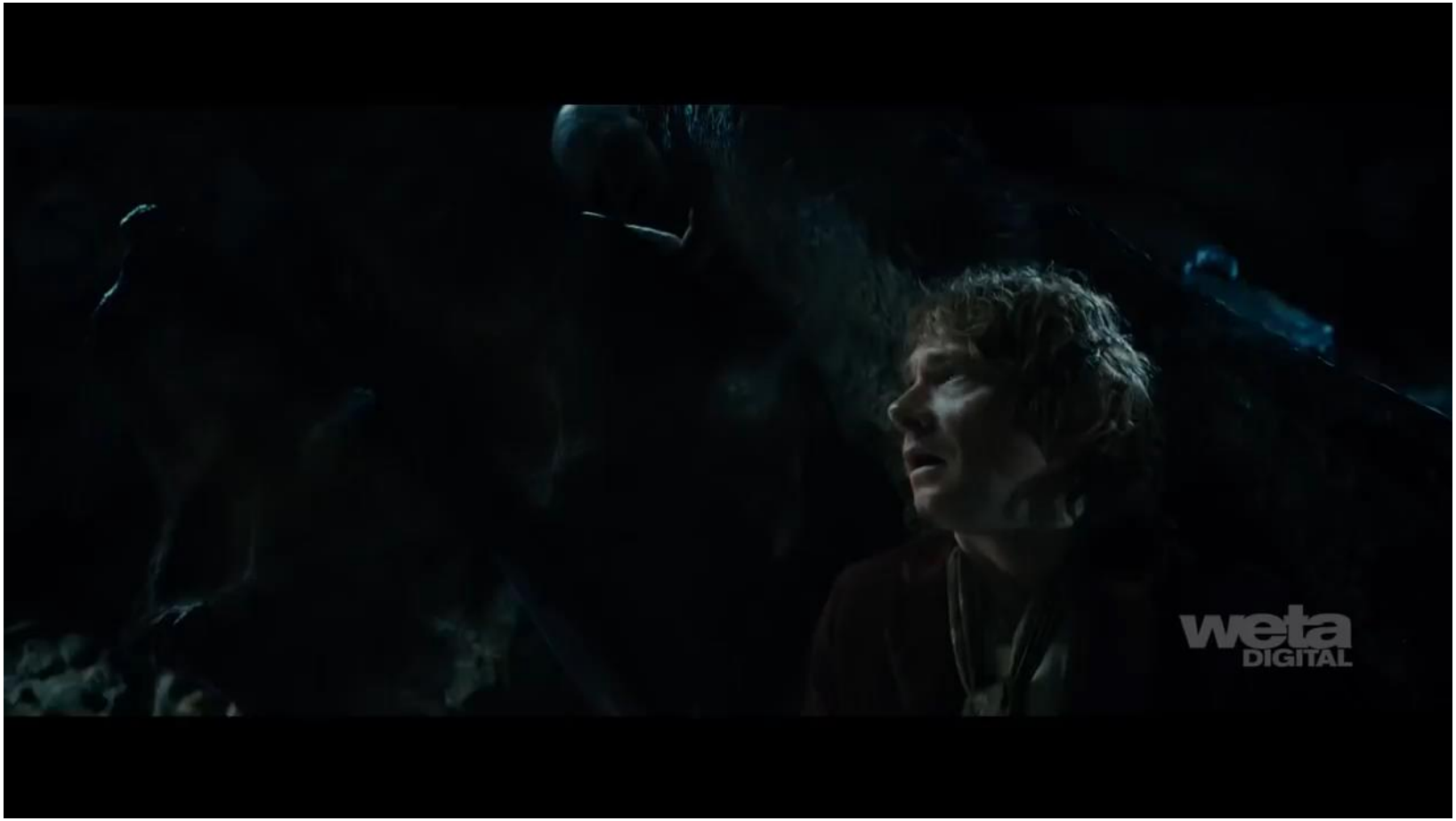
- **Facial capture**

Animation (cont.)

- **facial capture**

Animation (cont.)

- **Motion and facial capture**



Animation (cont.)

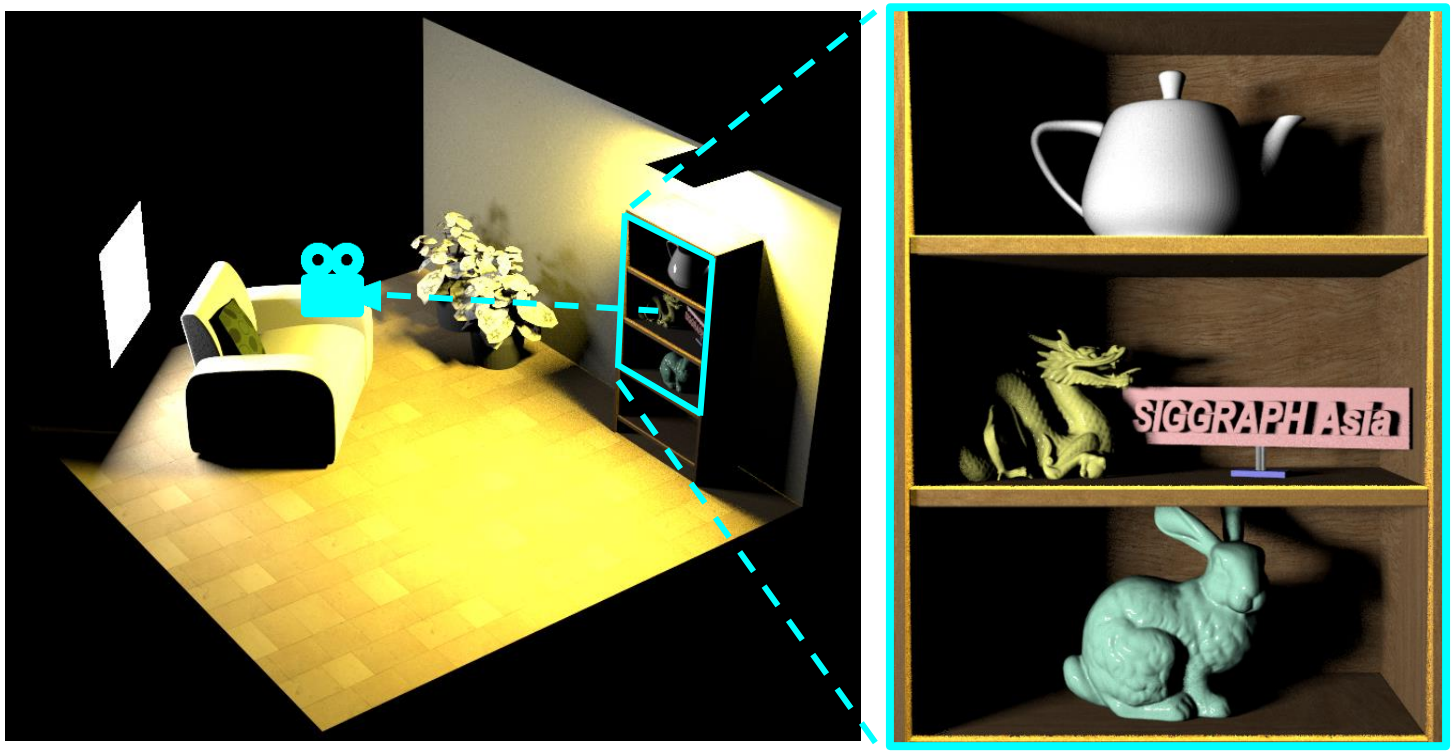
- **Motion and facial capture**

Animation (cont.)

- **Group behavior**

Rendering

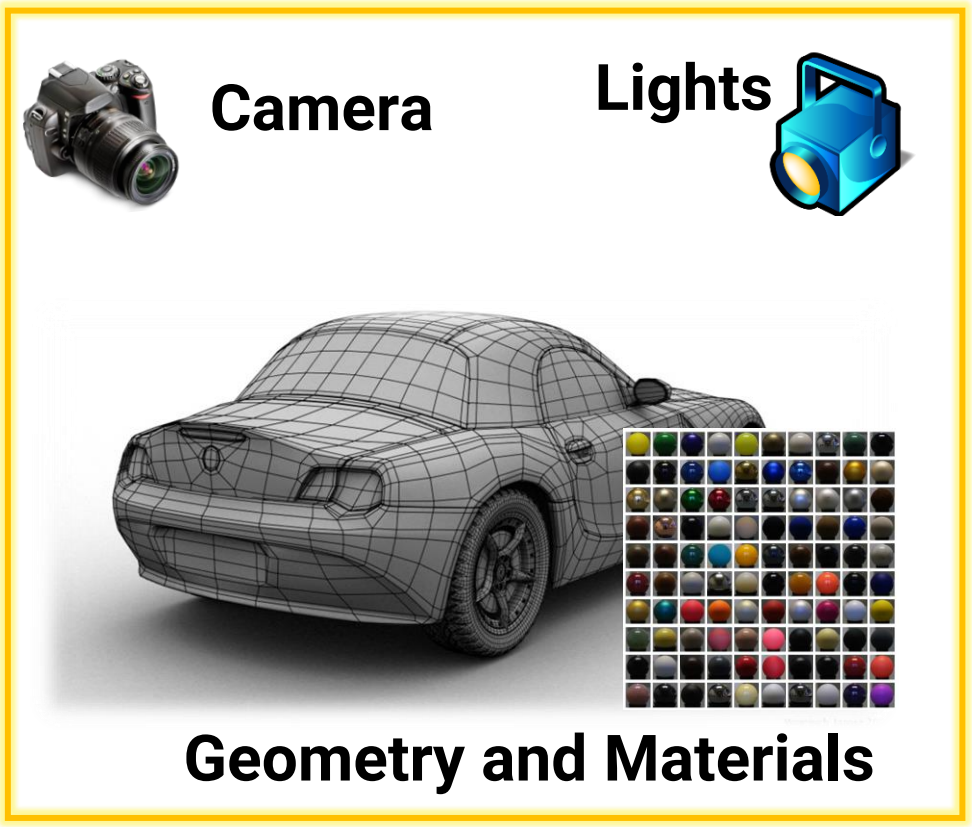
- How do we model appearance and perceive things



3D virtual world rendered image

Rendering

- Generate a 2D image from a 3D world description

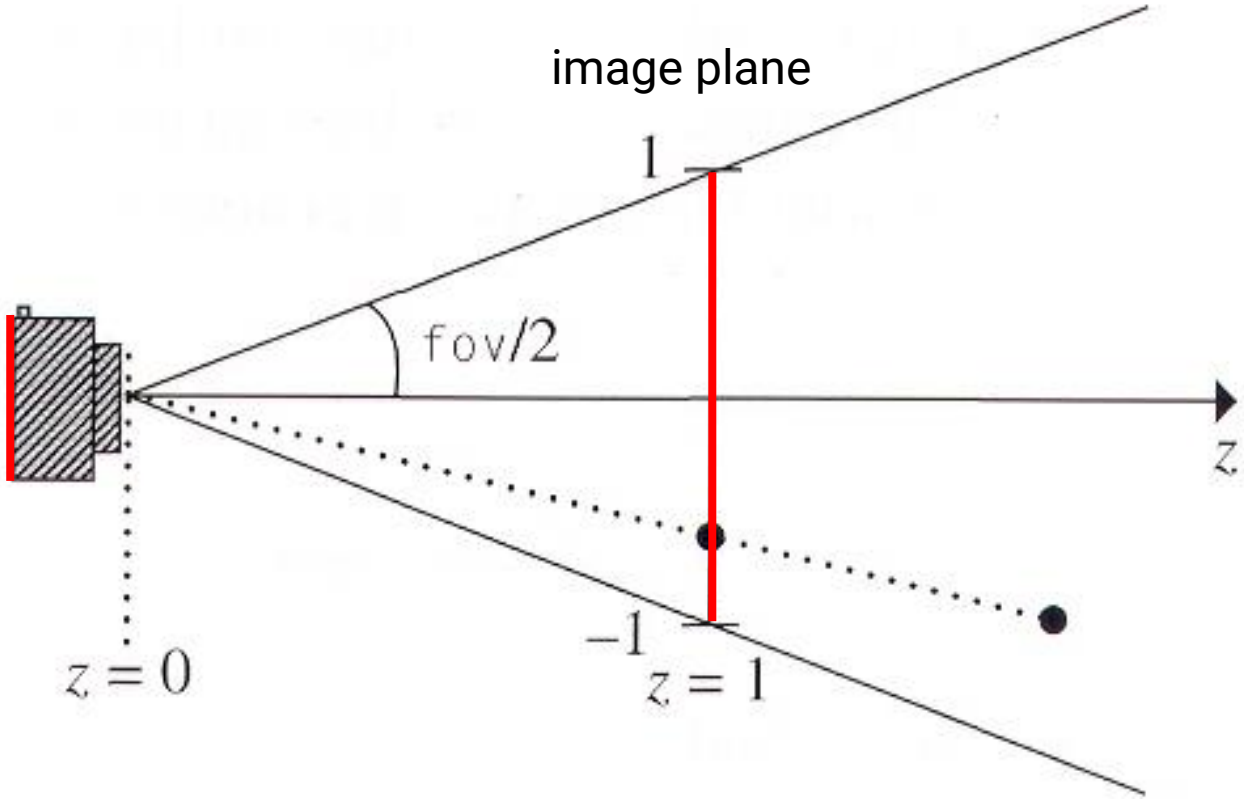


input: 3D description of a scene

output: 2D synthetic image

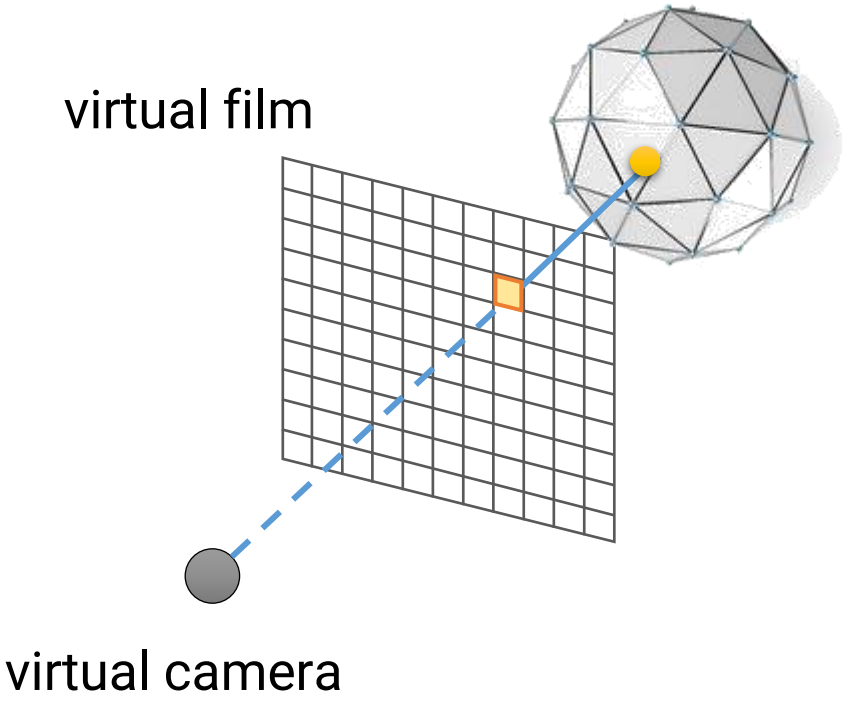
Rendering (cont.)

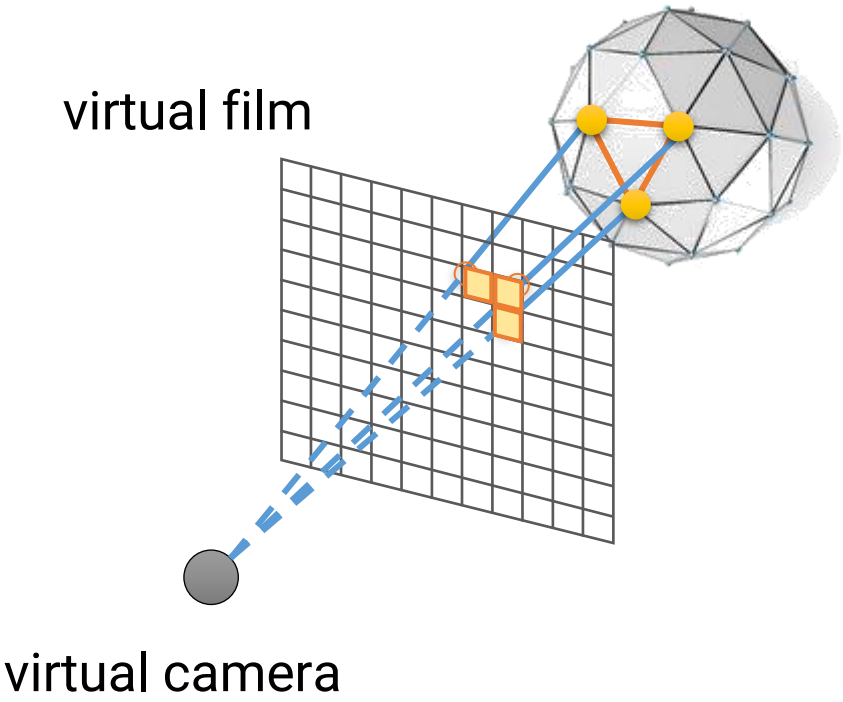
- **Perspective pinhole camera** in graphics



Rendering (cont.)

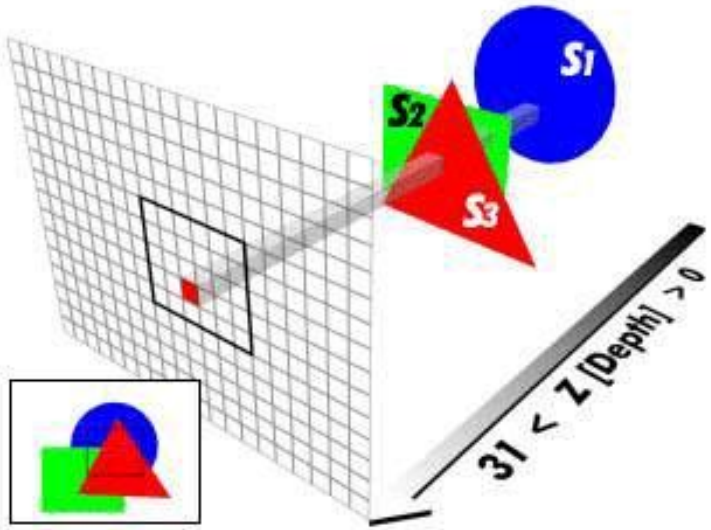
- **Ray tracing v.s. rasterization**





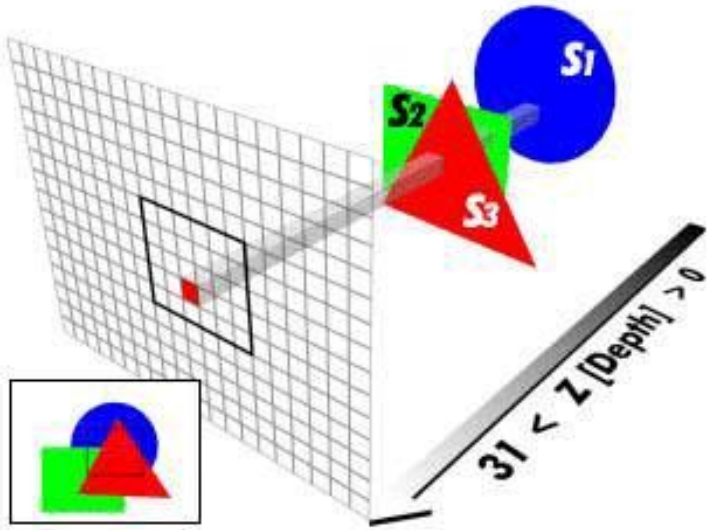
Rendering (cont.)

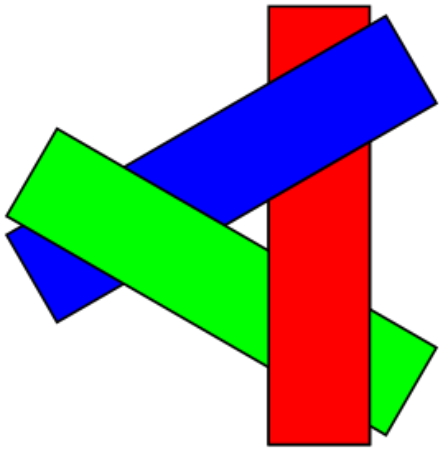
- How to determine the **closest** surfaces for rasterization?



Rendering (cont.)

- How to determine the **closest** surfaces for rasterization?
  - **Painter's algorithm**
    - Drawing order: S1 ➔ S2 ➔ S3

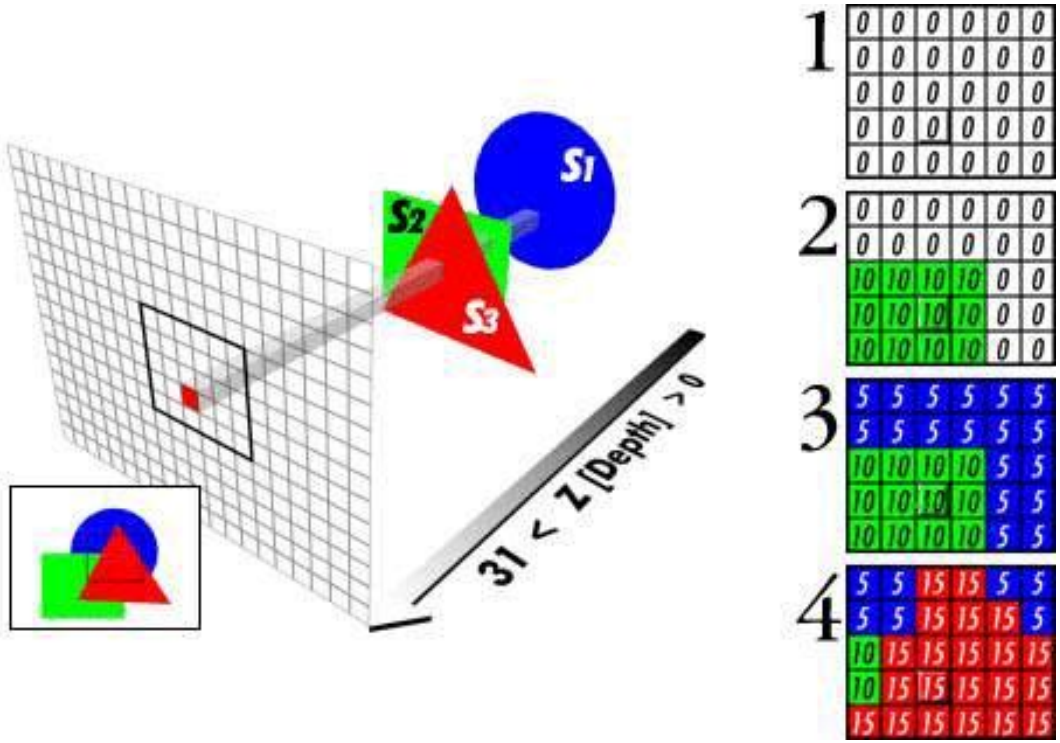




failure case

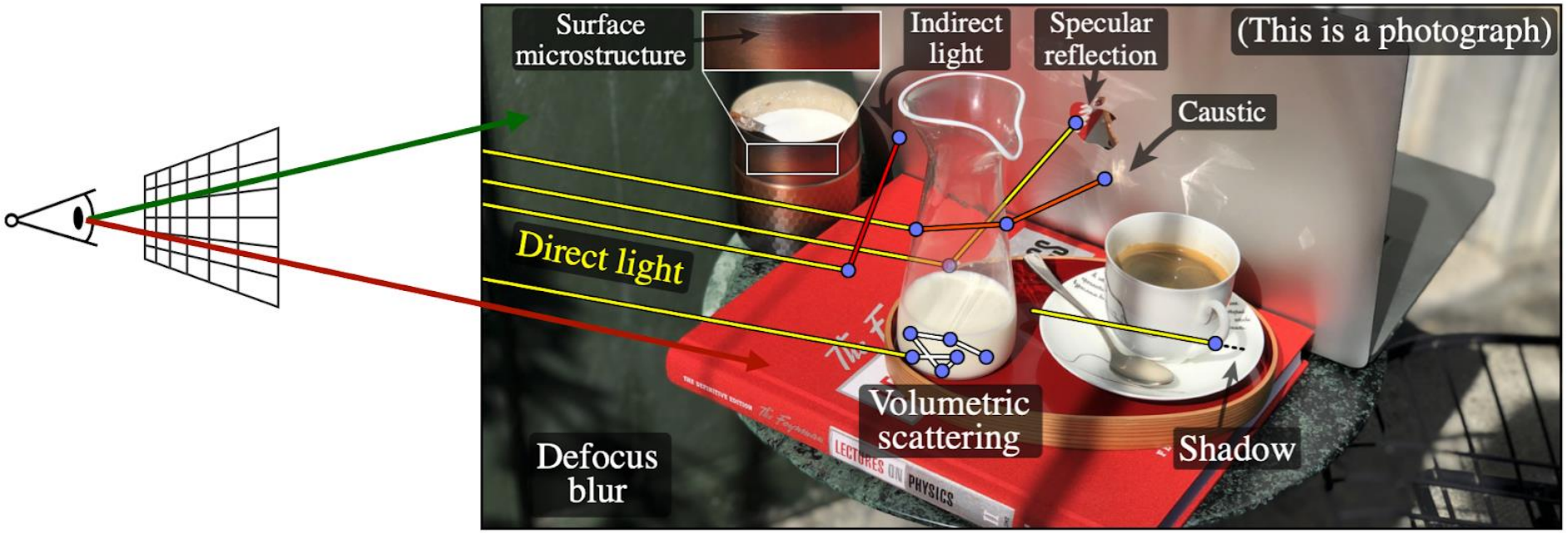
Rendering (cont.)

- How to determine the **closest** surfaces for rasterization?
  - **Z-buffer**
    - Use an additional buffer for keeping the closeting distance

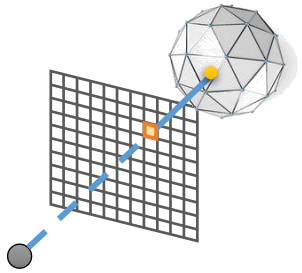


Rendering (cont.)

- **Physically-based rendering**
  - Uses **physics** and **math** to simulate the interaction between matter and lights, **realism** is the primary goal



Rendering (cont.)



- **Physically-based rendering**
  - The rendering equation [Kajiya 1986]

emitted radiance

incident radiance

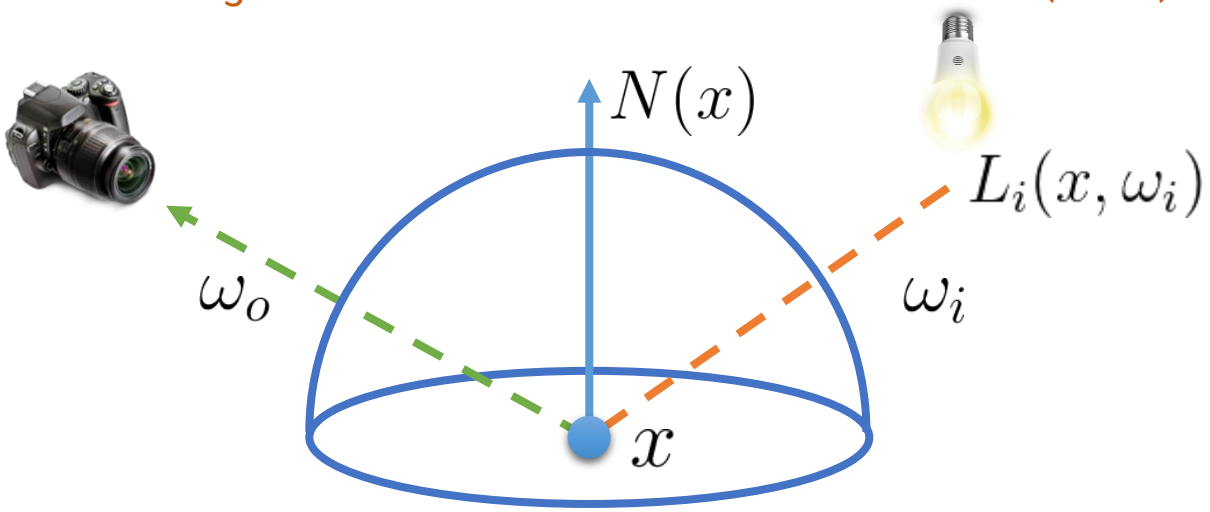
geometry term

$$L(x,\omega_o) = L_e(x,\omega_o) + \int_{\Omega} L_i(x,\omega_i) f_r(x,\omega_o \leftarrow \omega_i)(N(x)\cdot\omega_i)d\omega_i$$

recursive!

Integral of all directions

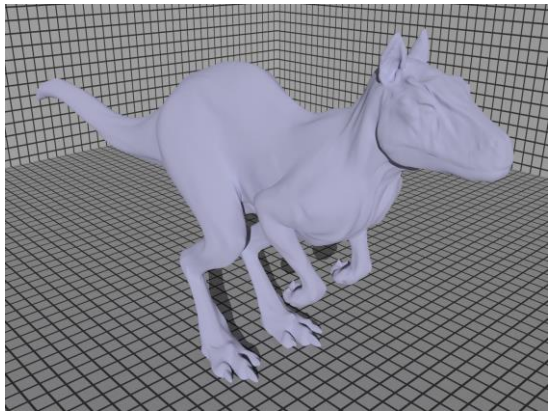
bidirectional reflectance distribution function (BRDF)

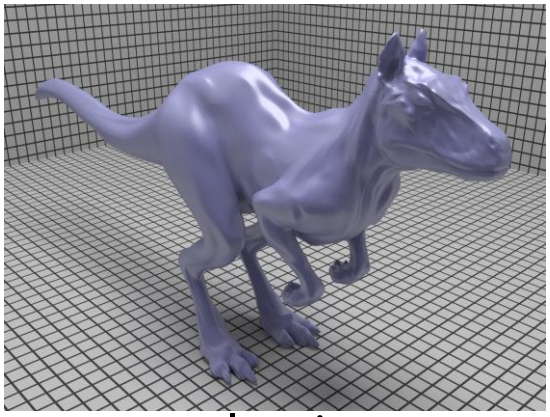


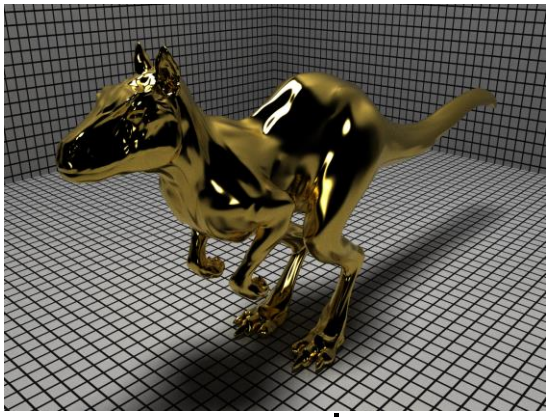
Rendering (cont.)

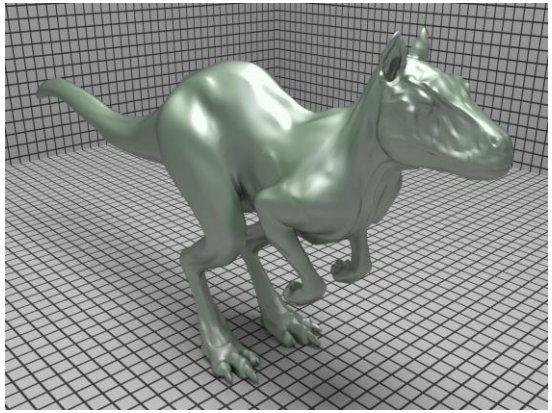
- **Materials**

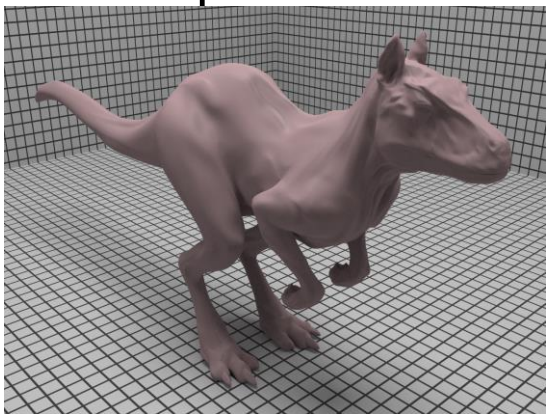
$$f_r(x, \omega_o \leftarrow \omega_i)$$

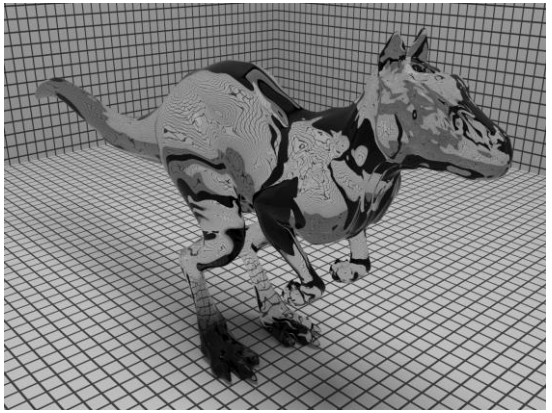

concrete


plastic


metal

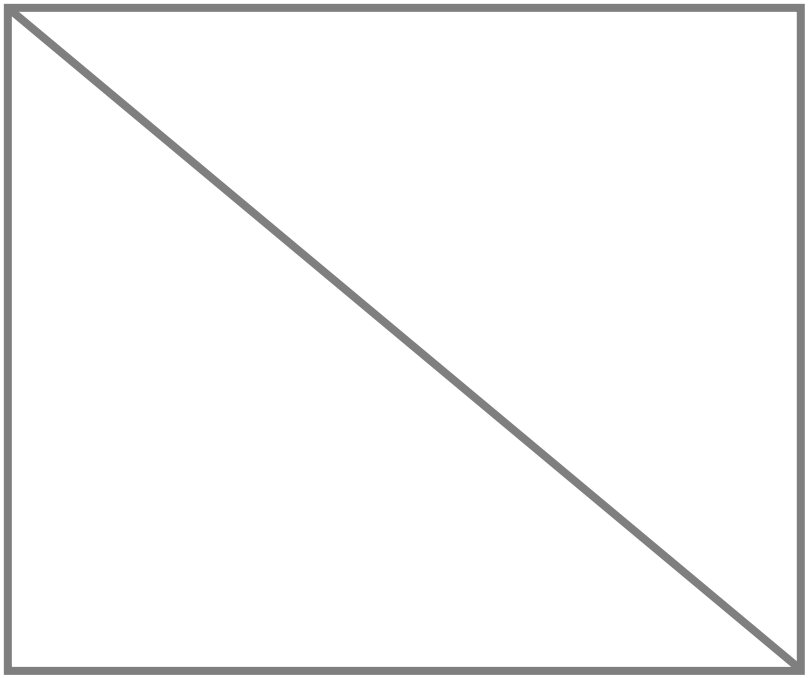

substrate


clay


glass

Texture

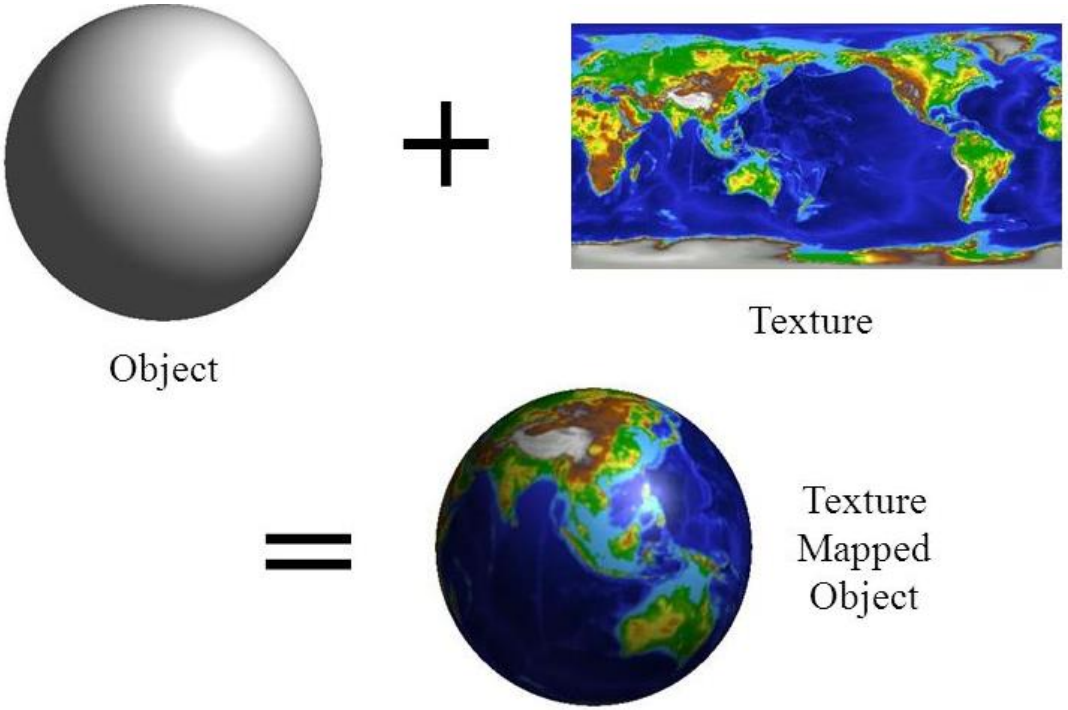
how to model a painting
in the virtual world?



can we model its geometry
with 2 triangles?

Texture (cont.)

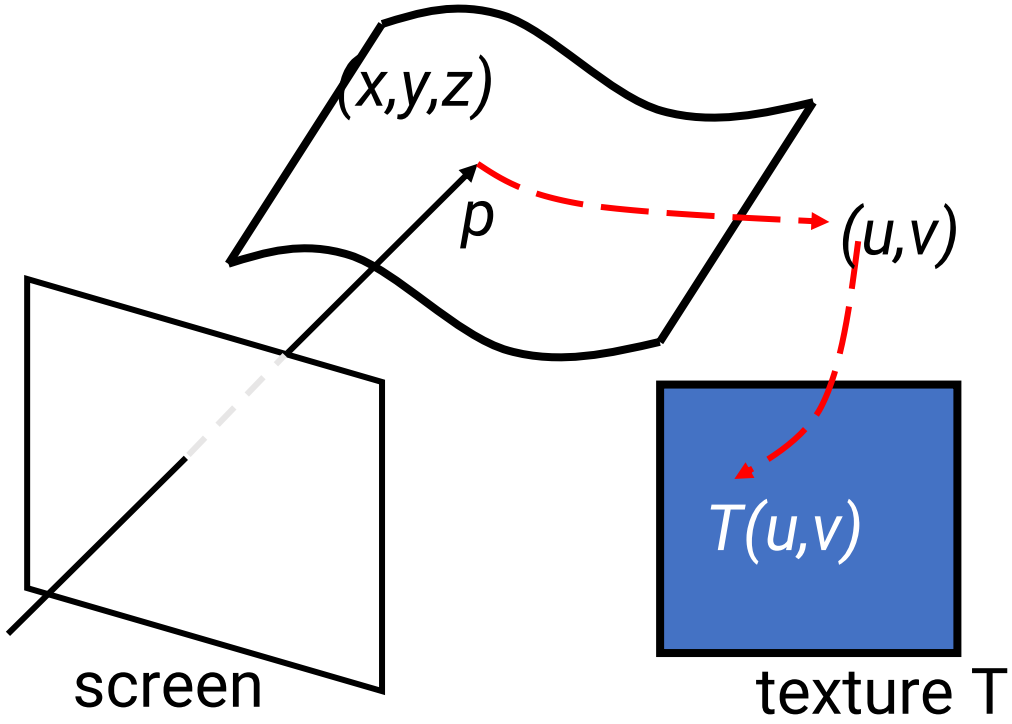
- Used to represent **spatially-varying** data
- Decouple materials from geometry



Texture (cont.)

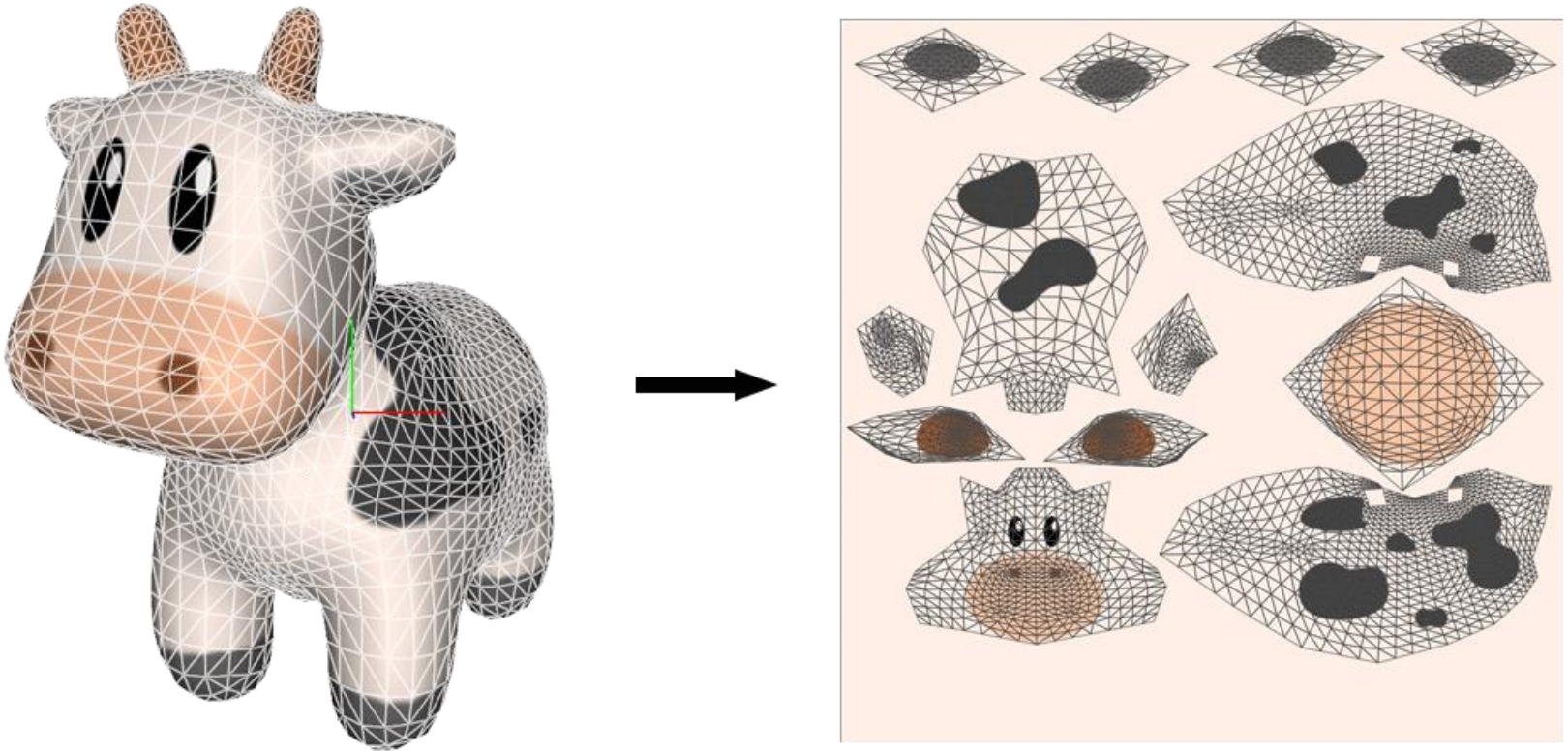
- Need **parameterization of surface**
  - Map from 3D vertices to 2D texture coordinate

    $(x, y, z) \rightarrow (u, v)$



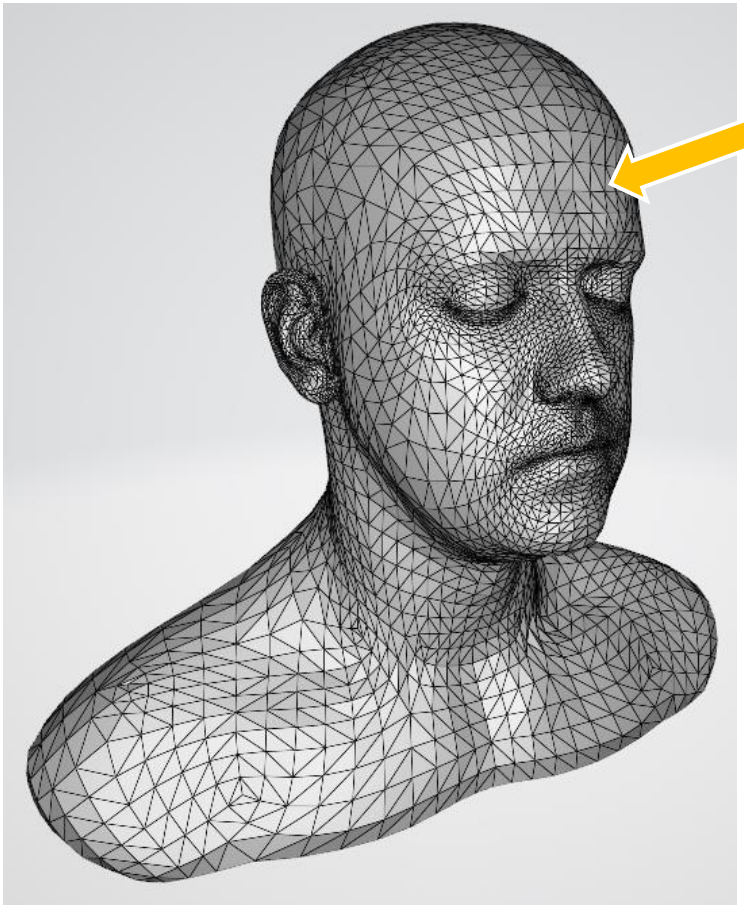
Texture (cont.)

- **Texture** and **parameterization (modeling)**



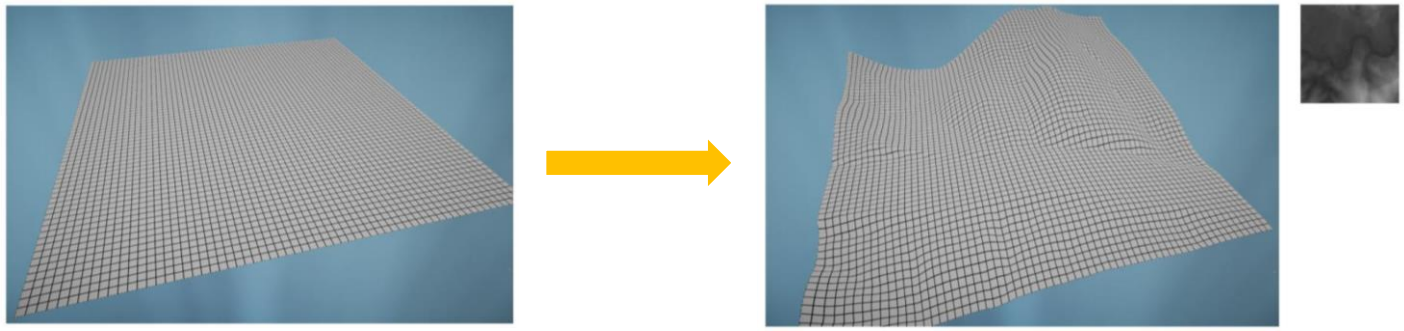
Texture (cont.)

- **Texture** and **parameterization (modeling)**



Texture (cont.)

- More texture types



How to Generate a Realistic Image?

- Complex lighting




How to Generate a Realistic Image? (cont.)

- Refraction and dispersion

How to Generate a Realistic Image? (cont.)

- Caustics

How to Generate a Realistic Image? (cont.)

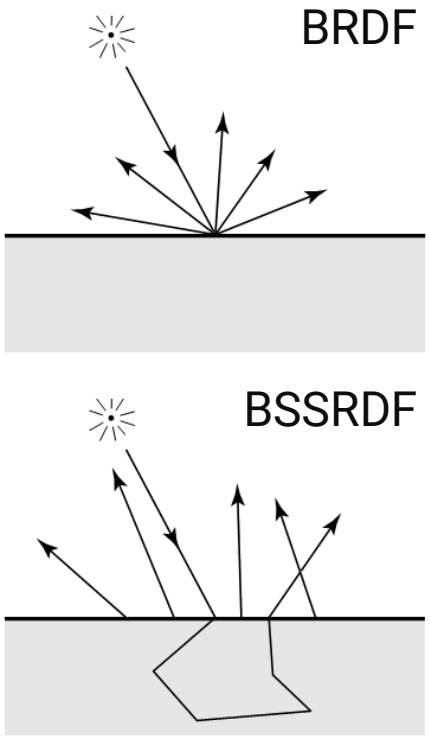
- Realistic materials

How to Generate a Realistic Image? (cont.)

- Realistic materials + textures

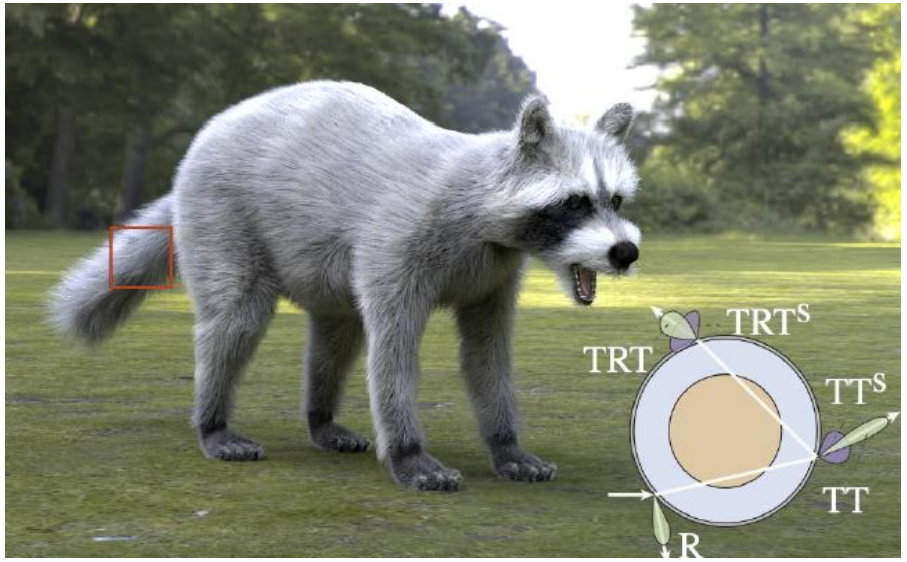
How to Generate a Realistic Image? (cont.)

- Translucent objects



How to Generate a Realistic Image? (cont.)

- Hairs and fur

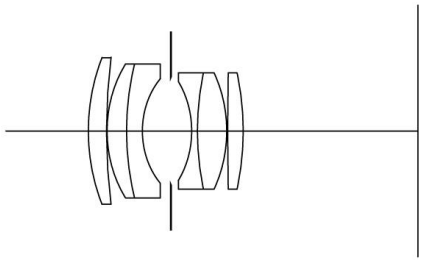


How to Generate a Realistic Image? (cont.)

- Volume (participating media)

How to Generate a Realistic Image? (cont.)

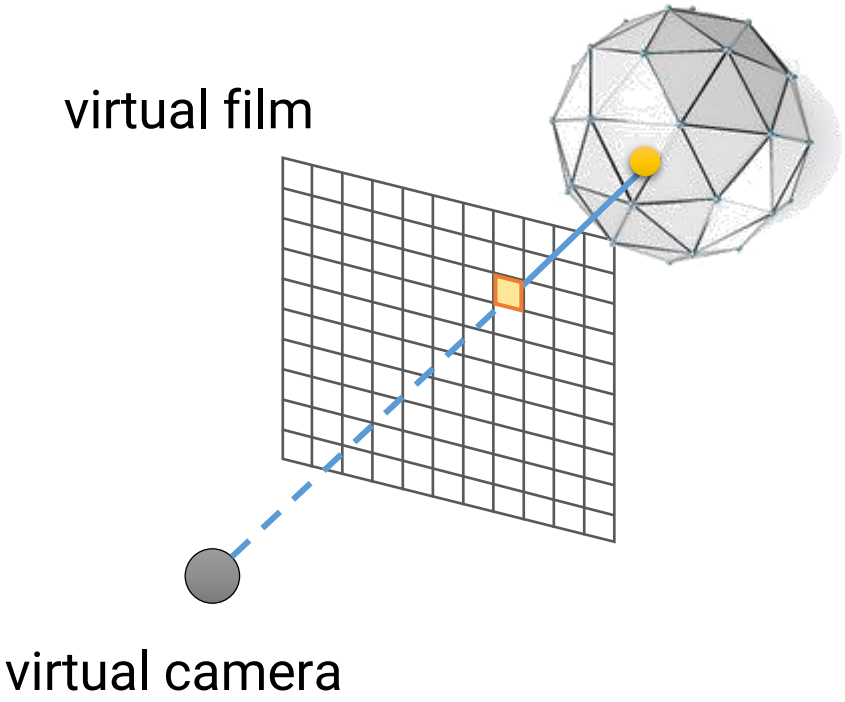
- Depth of field

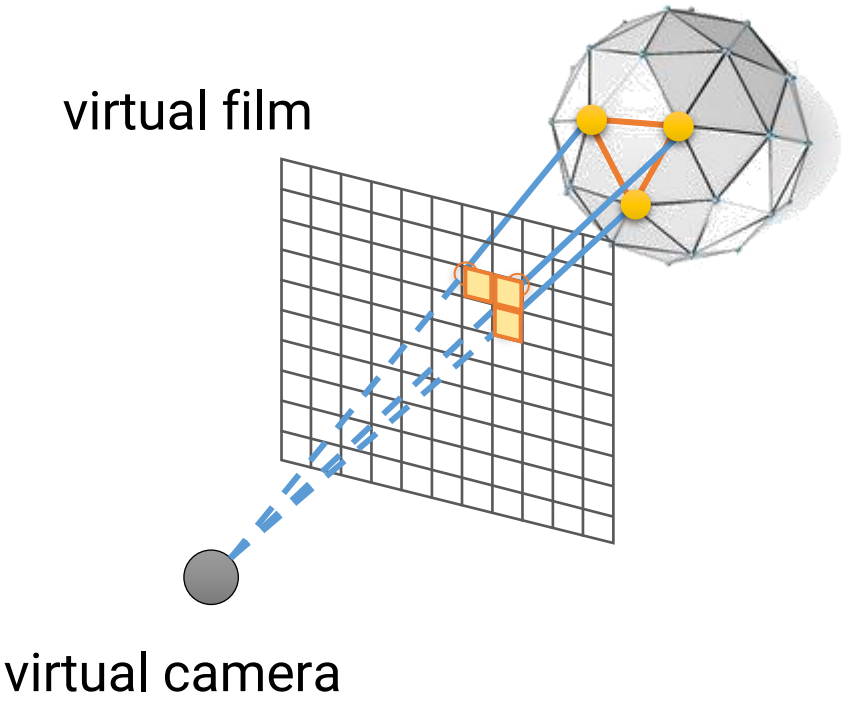


How to Generate a Realistic Image? (cont.)

- Motion blur

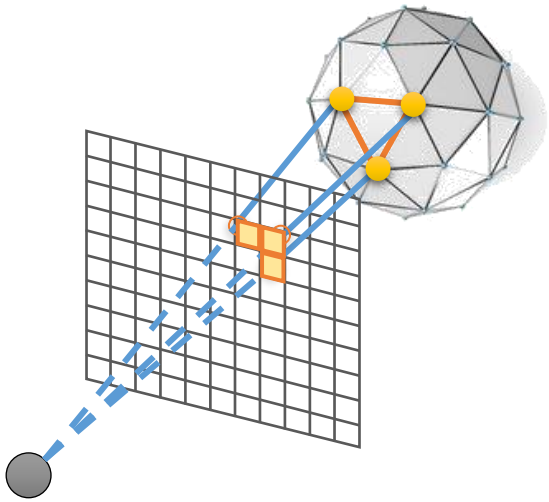
Revisit: Ray Tracing v.s. Rasterization

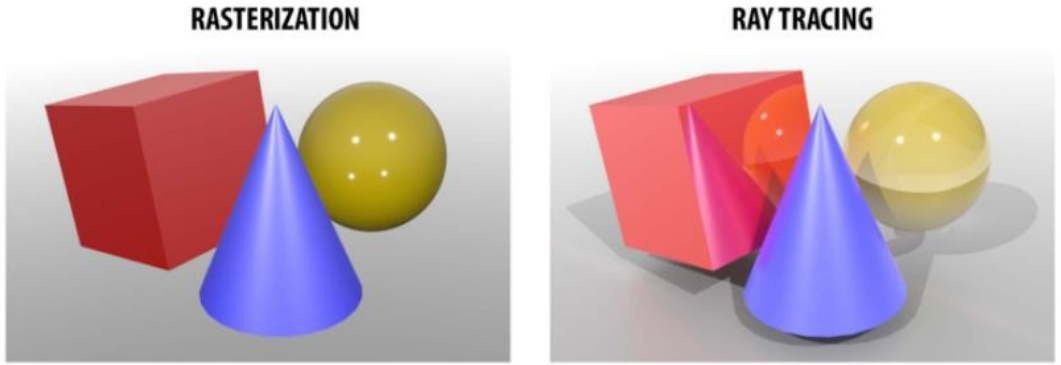




Rasterization

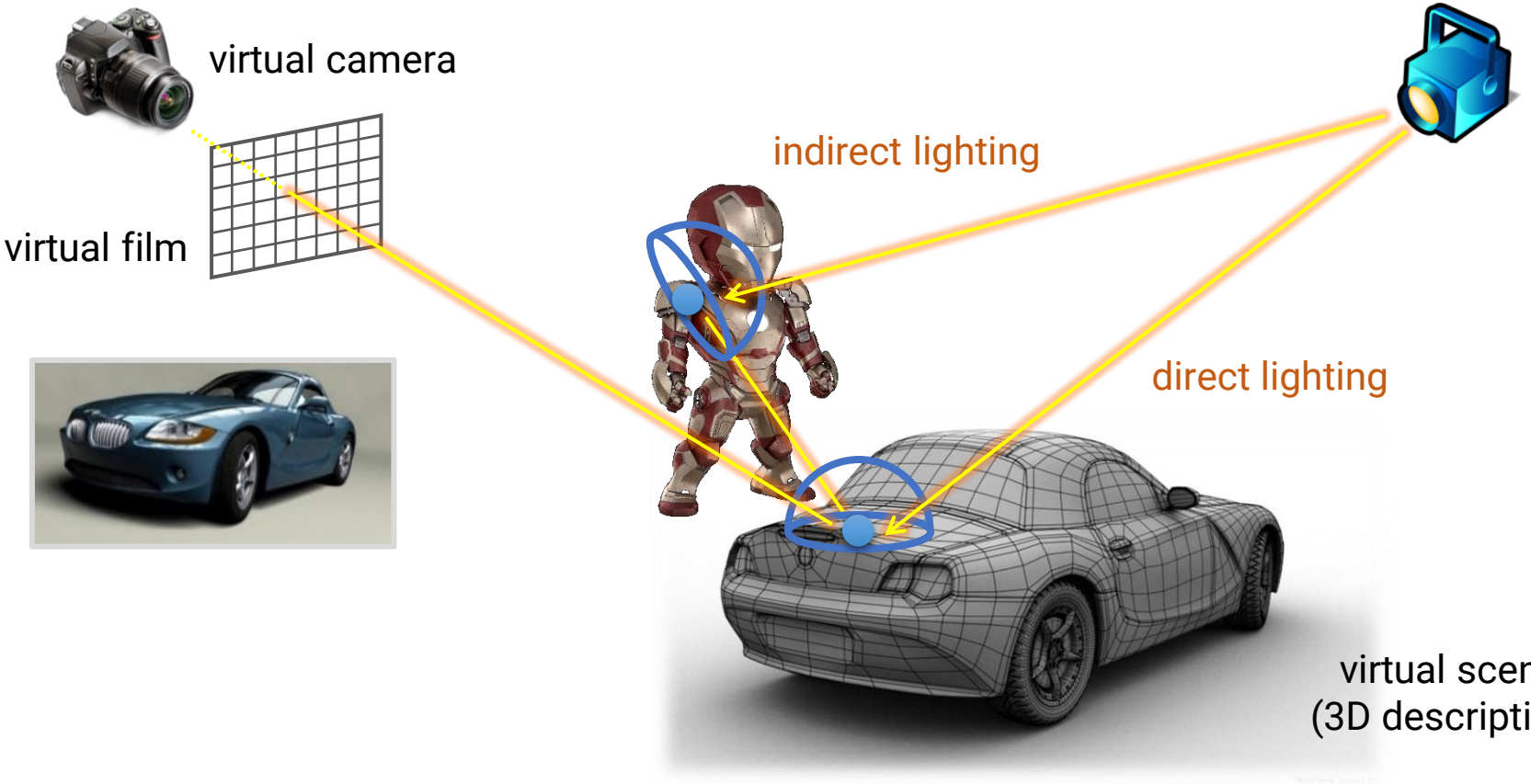
- Rasterization is more friendly to hardware and usually has higher parallelism
- But it is more difficult to simulate effects such as reflection, refraction, shadows, and global illumination
  - Need specialized algorithms





Ray Tracing

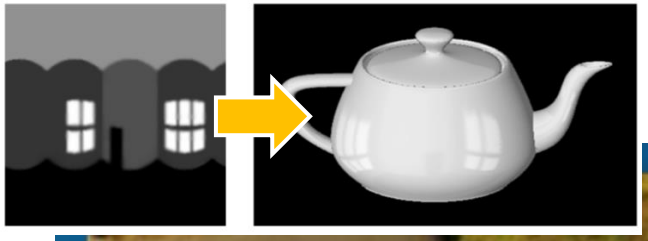
- Ray tracing is more general for simulating a wide variety of light transport paths

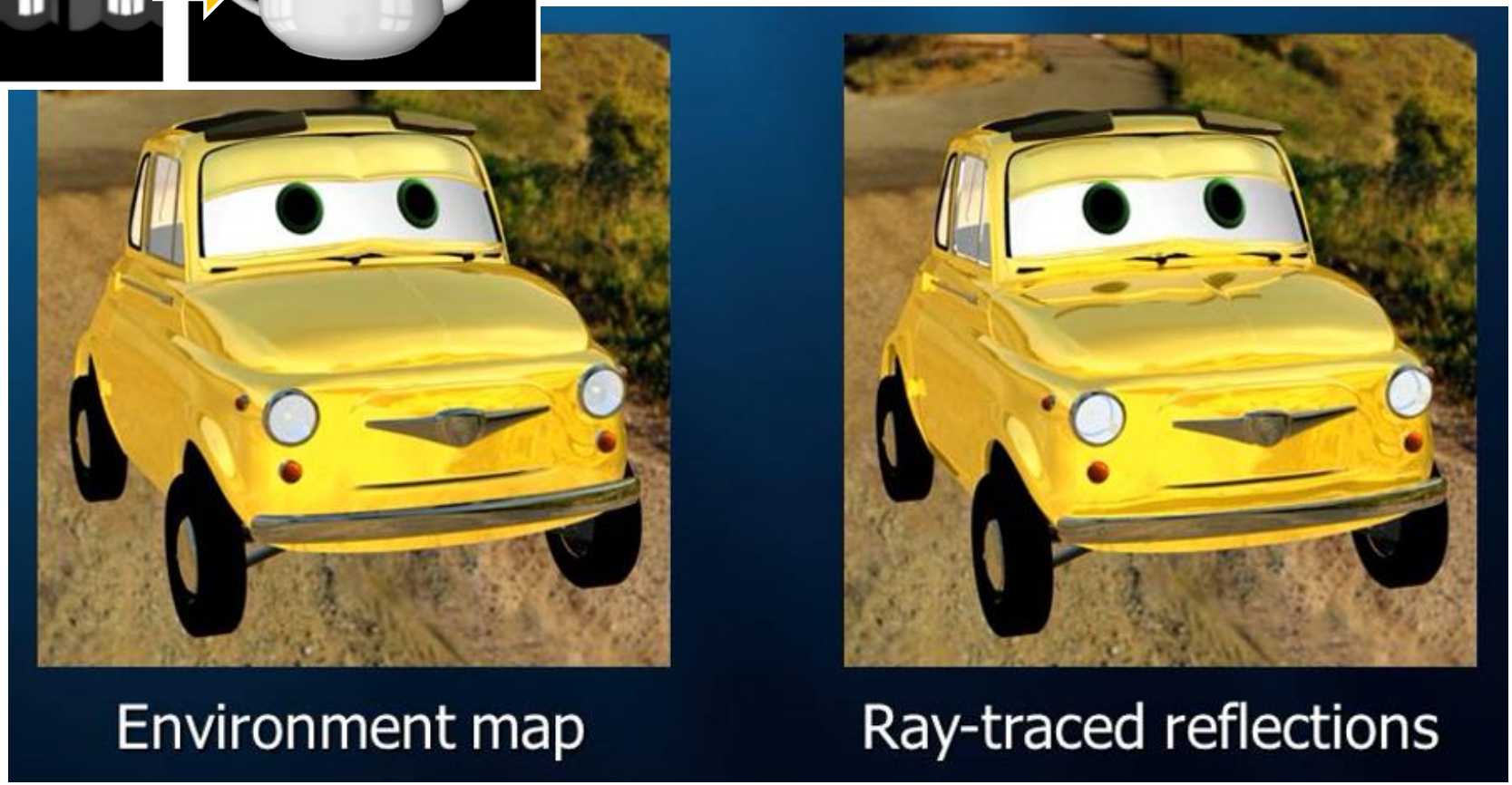


Ray Tracing

- However, its simulator usually has a slow convergence rate and produces lots of noises when samples are not enough

Why Ray Tracing

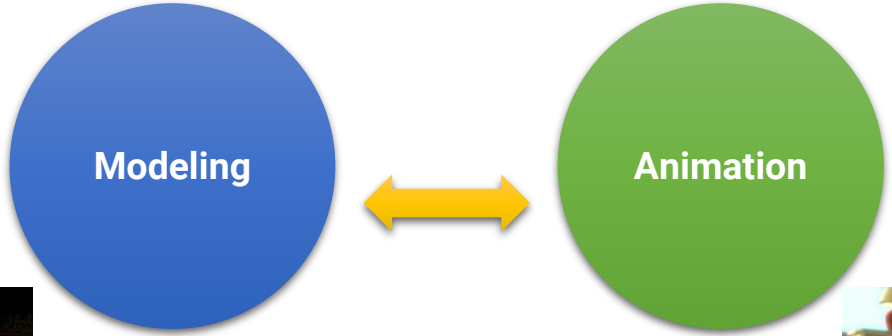




Real-time Ray Tracing

- FIRST DAY: A Star Wars short film made with UE5

Real-time v.s. Offline Graphics



1999

1999

2020

2019

real-time

offline

Animation Production Pipeline

story

text treatment

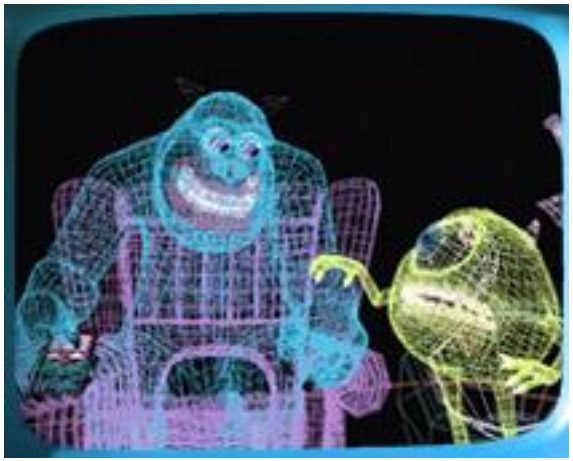
storyboard

voice

storyreel

look and feel

Animation Production Pipeline (cont.)



modeling / articulation

layout

animation

shading / lighting

rendering

final touch

Animation Production Pipeline

Next Week

- We will dive into 3D graphics deeper by
  - Giving an example of 3D model file
  - Talking about several different 3D coordinate systems and 3D transformation
  - Going through the graphics pipeline of rasterization-based rendering
  - Introducing some simple lighting models
  - Introducing some simple materials