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)

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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



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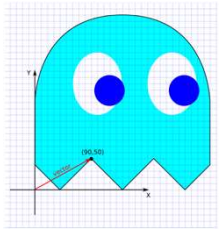
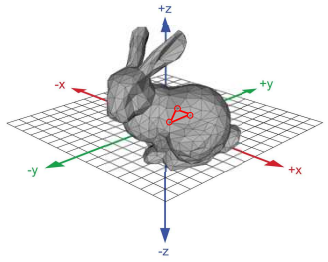
From 2D Graphics to 3D Graphics

- 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

3

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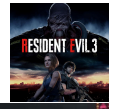
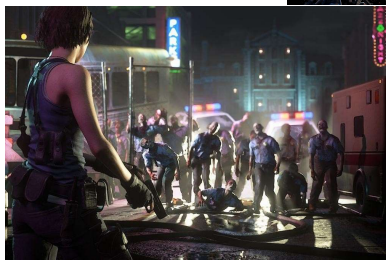
What Happened in Previous 20 Years

Resident Evil 3 (1999)

Resident Evil 3 Remake (2020)

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Which Cat is Real? (Goose or Reggie)

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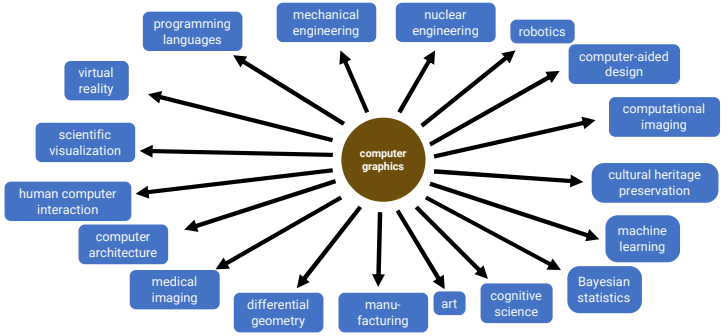
Why Computer Graphics is Important

- Graphics push advances in many fields



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Applications of Computer Graphics

- Lighting and architecture design

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Applications of Computer Graphics (cont.)

- Visualization of scientific data and physical simulation

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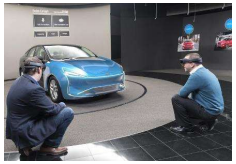
Applications of Computer Graphics (cont.)

- Games, AR, MR, and VR

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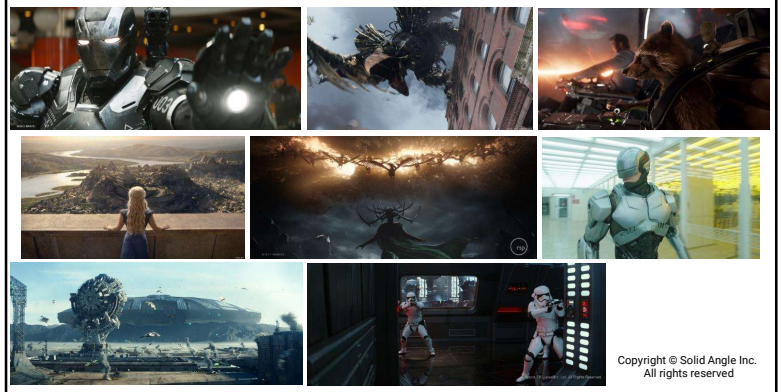
Applications of Computer Graphics (cont.)

- Film production



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Applications of Computer Graphics (cont.)

- Training data generation for deep learning

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Description of a 3D World

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

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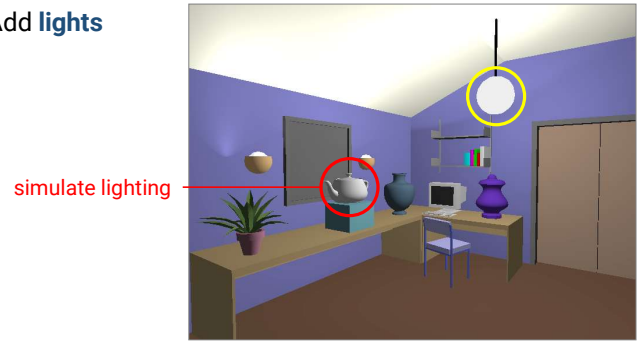
Description of a 3D World (cont.)

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

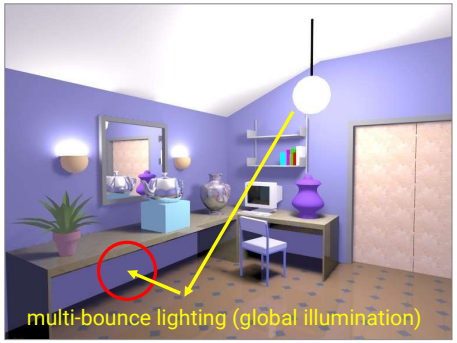


Description of a 3D World (cont.)

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

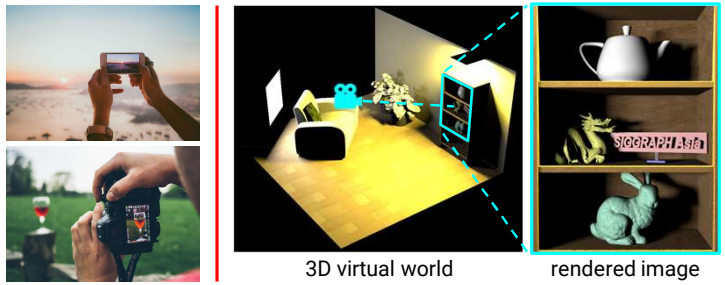
Description of a 3D World (cont.)

- Simulate more **light paths**

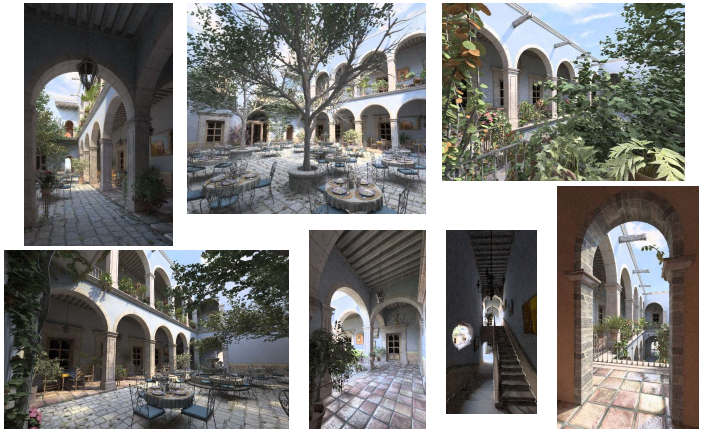


Generate Images from the 3D World

- 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**



Generate Images from the 3D World (cont.)



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Are These 3D?

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Are These 3D? (cont.)

- 3D is much more difficult than 2D!

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Are These 3D? (cont.)

- 3D is much more difficult than 2D!

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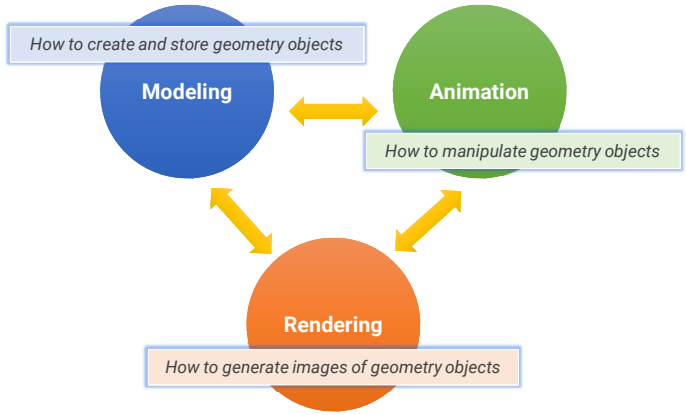
The Differences between Relevant Fields

- 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



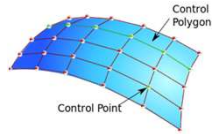
Modeling

- World geometries are diverse!

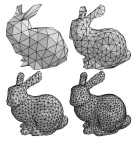
Modeling (cont.)

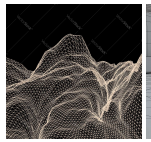
- How to model/represent **curves**, **surfaces**, and **volumes**

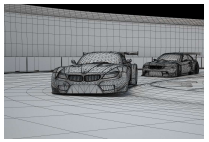
curves



patches (by control points and curves)





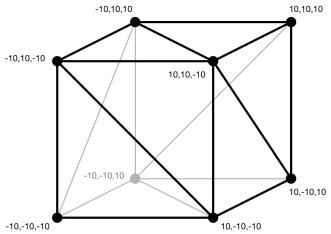


meshes (by polygons, usually triangles)

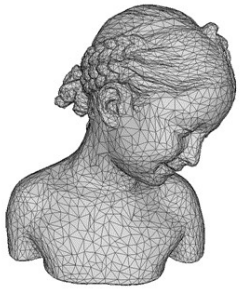
volume data

Modeling (cont.)

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



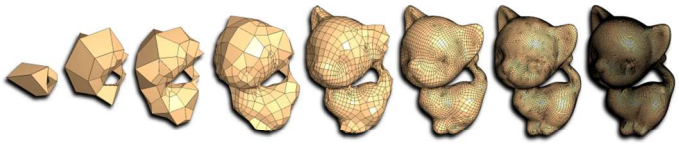
12 triangles



10K triangles

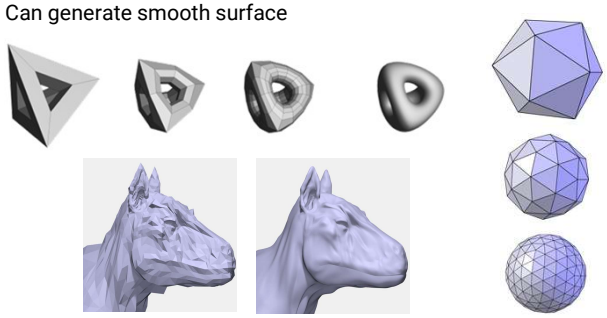
Modeling (cont.)

- 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

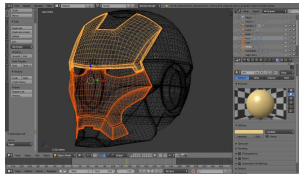
Toy story 1 (1995)

Modeling (cont.)

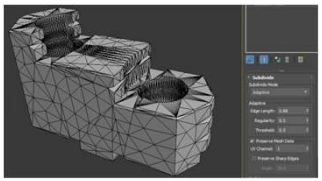
- **Subdivision surface**
  - Geri's game by Pixar (1997)

Modeling (cont.)

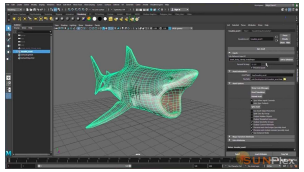
- **Lots of 3D editing software**



Blender



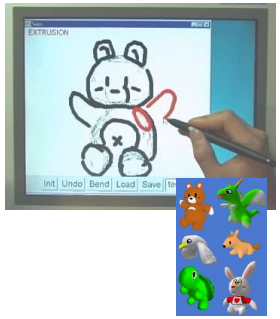
3dsMax



Maya

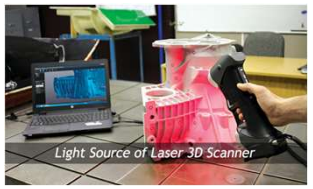
Modeling (cont.)

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



Modeling (cont.)

- **Capture the real-world geometries**



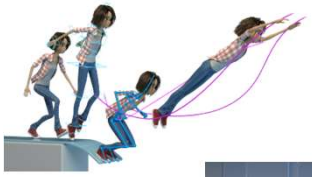
3D scanner

multi-view geometry

depth camera

Animation

- How do the geometry change / move over time

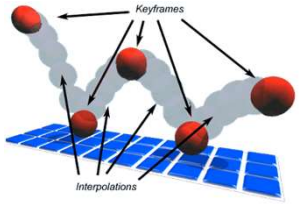


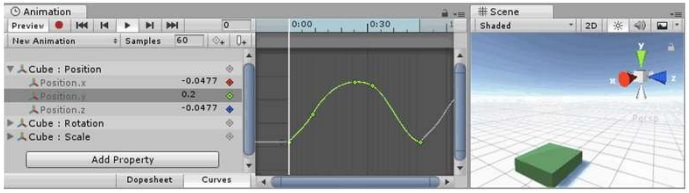
Animation (cont.)

- **Physically-based character animation**

Animation (cont.)

- **Keyframe animation**



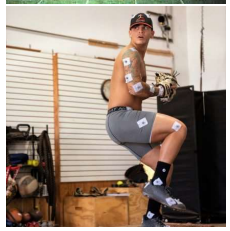


Animation (cont.)

- **Keyframe animation**

Animation (cont.)

- Motion capture



Animation (cont.)

- Motion capture

Animation (cont.)

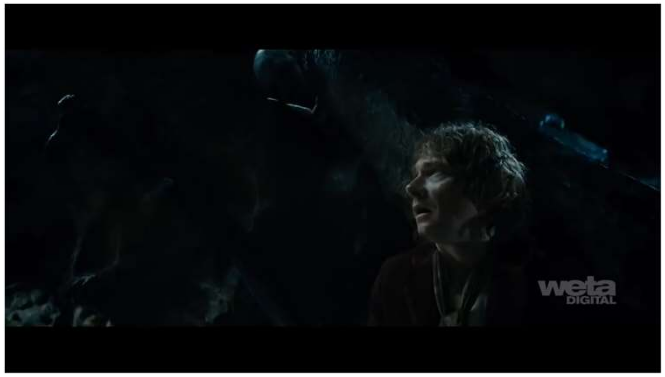
- Facial capture

Animation (cont.)

- facial capture

Animation (cont.)

- **Motion and facial capture**



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Animation (cont.)

- **Motion and facial capture**

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Animation (cont.)

- **Group behavior**

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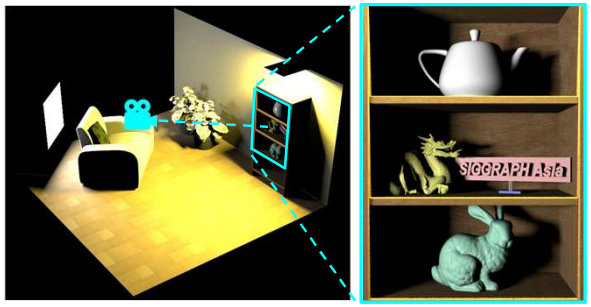
Rendering

- How do we model appearance and perceive things



3D virtual world rendered image

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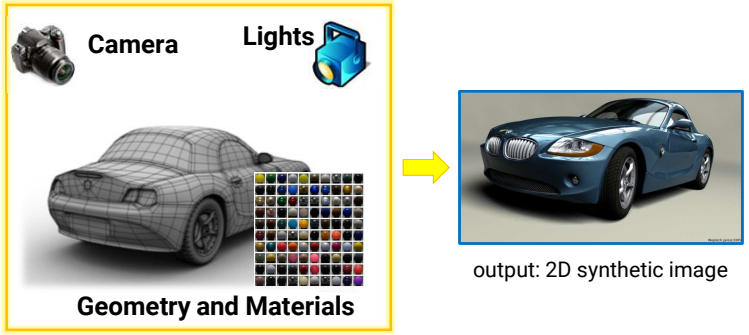
Rendering

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

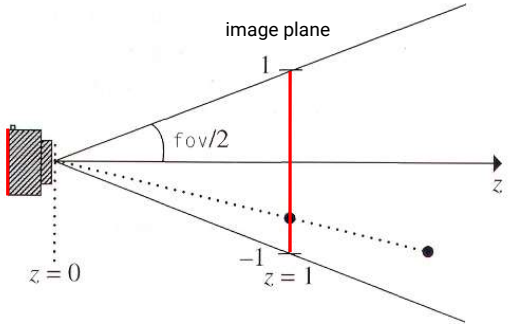


input: 3D description of a scene

output: 2D synthetic image

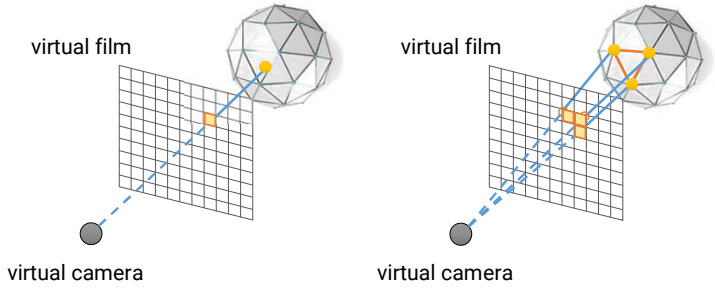
Rendering (cont.)

- **Perspective pinhole camera** in graphics



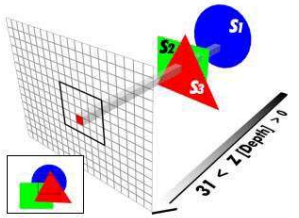
Rendering (cont.)

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



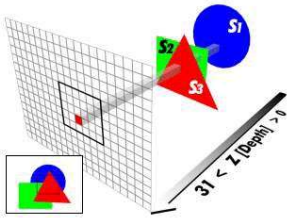
Rendering (cont.)

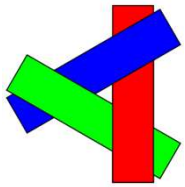
- How to determine the **closest** surfaces for rasterization?



Rendering (cont.)

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

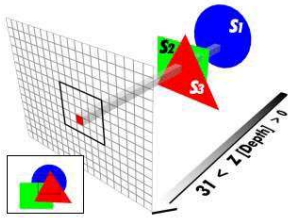


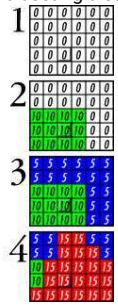


failure case

Rendering (cont.)

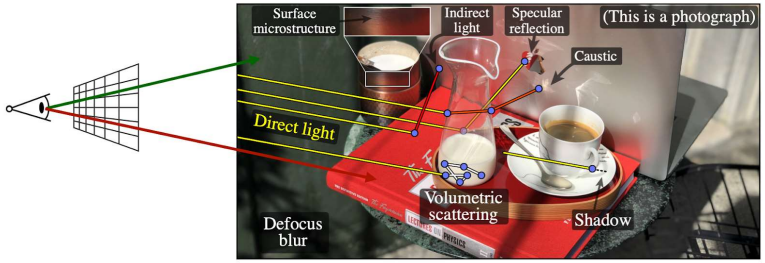
- How to determine the **closest** surfaces for rasterization?
  - **Z-buffer**
    - Use an additional buffer for keeping the closeting distance





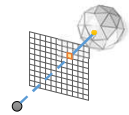
Rendering (cont.)

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



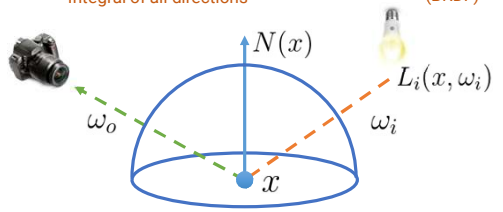
Rendering (cont.)

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



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

recursive! — emitted radiance — incident radiance — geometry term — Integral of all directions — bidirectional reflectance distribution function (BRDF)

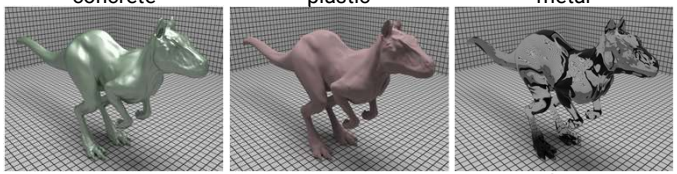


Rendering (cont.)

- **Materials**

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

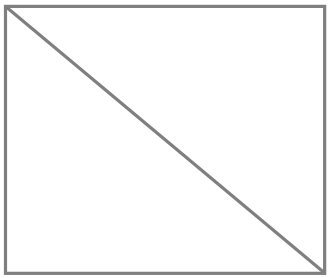
concrete | plastic | metal



substrate | clay | glass

Texture

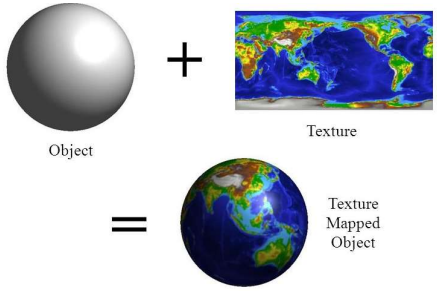
how to model a painting
in the virtual world?



can we model its geometry
with 2 triangles?

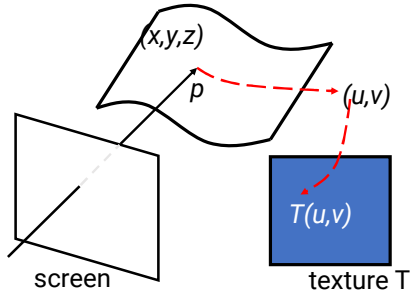
Texture (cont.)

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



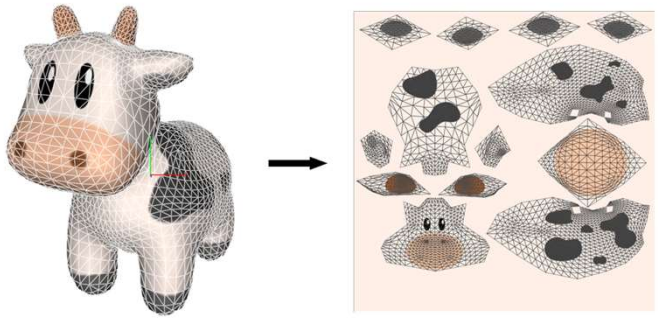
Texture (cont.)

- Need **parameterization of surface**
  - Map from 3D vertices to 2D texture coordinate
    (x, y, z) → (u, v)



Texture (cont.)

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



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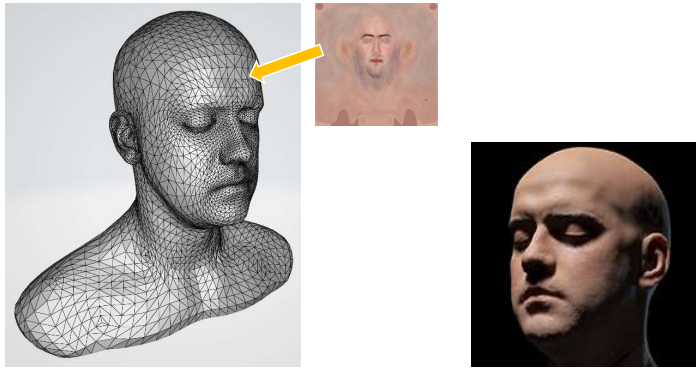
Texture (cont.)

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



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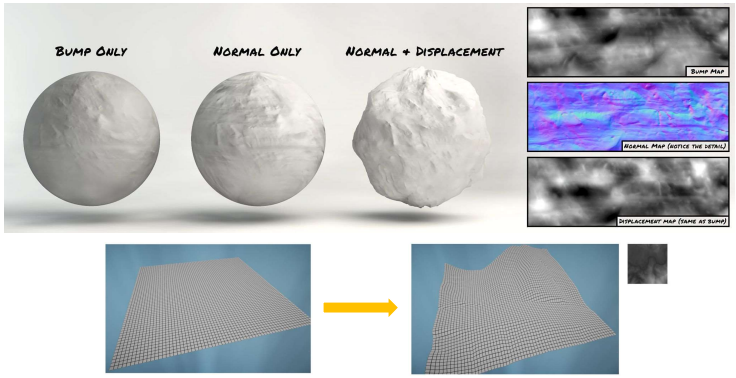
Texture (cont.)

- More texture types



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How to Generate a Realistic Image?

- Complex lighting

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How to Generate a Realistic Image? (cont.)

- Refraction and dispersion

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How to Generate a Realistic Image? (cont.)

- Caustics

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How to Generate a Realistic Image? (cont.)

- Realistic materials

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How to Generate a Realistic Image? (cont.)

- Realistic materials + textures

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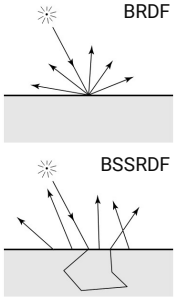
How to Generate a Realistic Image? (cont.)

- Translucent objects



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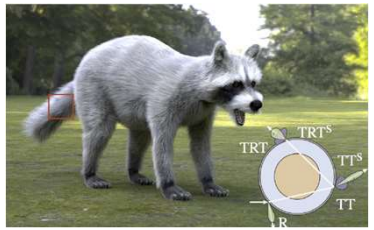
How to Generate a Realistic Image? (cont.)

- Hairs and fur



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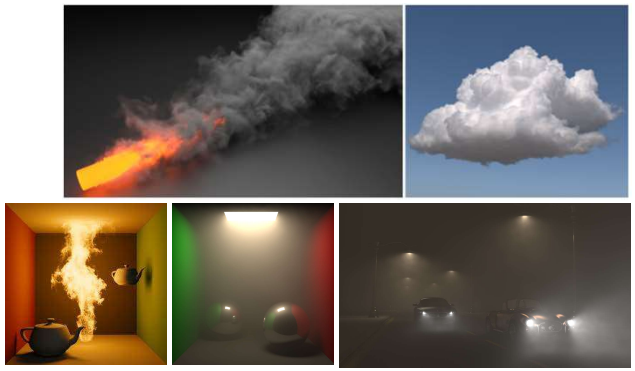
How to Generate a Realistic Image? (cont.)

- Volume (participating media)



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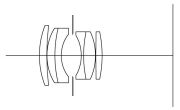
How to Generate a Realistic Image? (cont.)

- Depth of field



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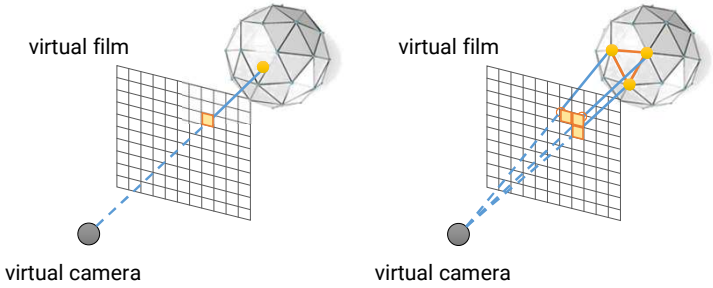
How to Generate a Realistic Image? (cont.)

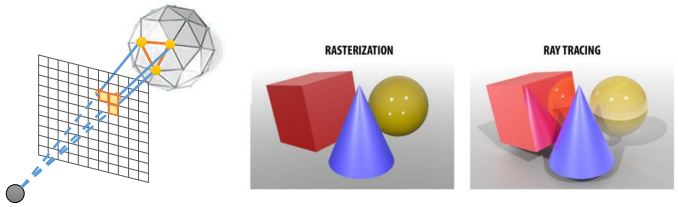
- Motion blur

Revisit: Ray Tracing v.s. Rasterization



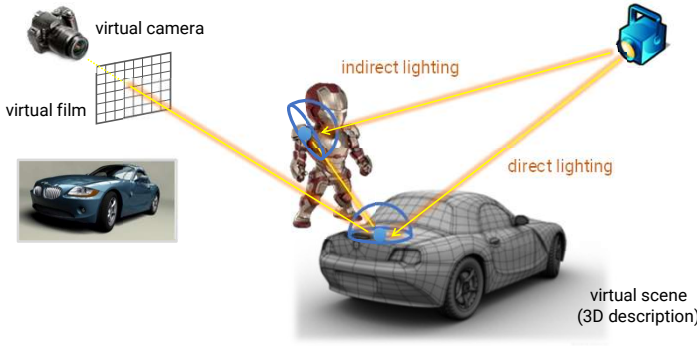
Rasterization

- 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

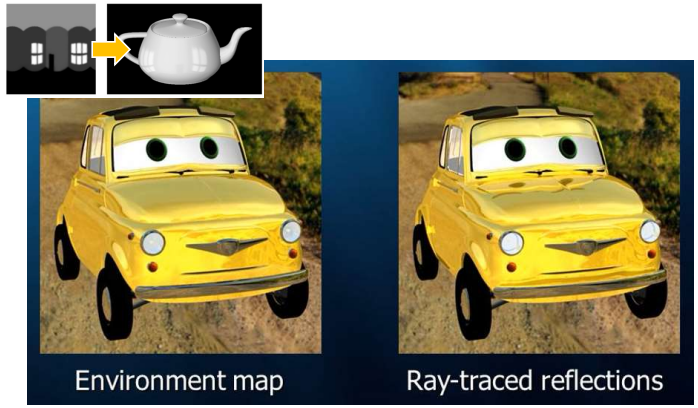
- Ray tracing is more general for simulating a wide variety of light transport paths



Ray Tracing

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

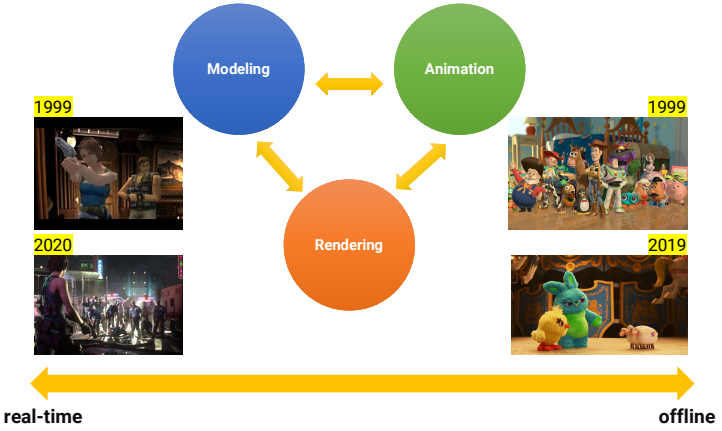
Why Ray Tracing



Real-time Ray Tracing

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

Real-time v.s. Offline Graphics



Animation Production Pipeline


story

text treatment


storyboard


voice


storyreel


look and feel

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Animation Production Pipeline (cont.)


modeling / articulation


layout


animation


shading / lighting


rendering


final touch

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Animation Production Pipeline

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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

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