# CS5182
# Computer Graphics

2024/25 Semester A

# Instructor and TAs

- Instructor
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  - Email:  jh.hou@cityu.edu.hk
  - Research interests
    - Image/video representation, processing, and analysis
    - 3D geometry data representation, processing and analysis
    - Applied machine learning

# Instructor and TAs

- Teaching Assistants
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  - Mr. ZHANG Yifan (yzhang3362-c@my.cityu.edu.hk)
  - Mr. REN Siyu (siyuren2@cityu.edu.hk)
  - Mr. TANG Yingzhi (yztang4-c@my.cityu.edu.hk)
  - Ms. YOU Meng (mengyou2-c@my.cityu.edu.hk)

# Textbooks

- *Computer Graphics: Principles and Practice*, Third Edition

  J. Hughes, A. van Dam, M. McGuire, D. Sklar, J. Foley, S. Feiner, and K. Akeley, Addison Wesley, 2014.

- *Introduction to Computer Graphics*

  J. Foley, A. van Dam, S. Feiner, J. Hughes, and R. Phillips, Addison Wesley, 1994.

- *Computer Graphics with Open GL*, Fourth Edition

  D. Hearn, M. Baker, and W. Carithers, Pearson, 2014.

# Grading Policy

- Course project
  - 25% of the course grade
  - Research-driven project (apply deep learning on 3D geometry data, neural rendering, 2D/3D content generation…)
- Midterm quiz (In-class)
  - lecture time
  - 15% of the course grade
  - closed books/notes
- Final examination
  - 60% of the course grade
  - closed books/notes

# Tentative Course Schedule

**1 (Sep. 09):** Introduction to Computer Graphics

**2 (Sep. 14):** Object modeling

**3 (Sep. 23):** Course Project Information, Transformation

**4 (Sep. 30):** Projection and Clipping

**5 (Oct. 12):** Deep Learning for 3D Point Clouds

**6 (Oct. 14):** Hidden Surface Removal and Shading, The Rendering Pipeline

**7 (Oct. 21):** Ray-Tracing and Radiosity

**8 (Oct. 28):** Quiz (in-class)

**9 (Nov. 4):** Aliasing and Antialiasing

**10 (Nov. 11):** Real-time rendering

**11 (Nov. 18):** GPU Architecture, Computer Animation

**12 (Nov. 25):** neural rendering, image-based rendering, Course Revision,

**13 (Dec. 02):** Course Project Presentation

# Introduction to Computer Graphics

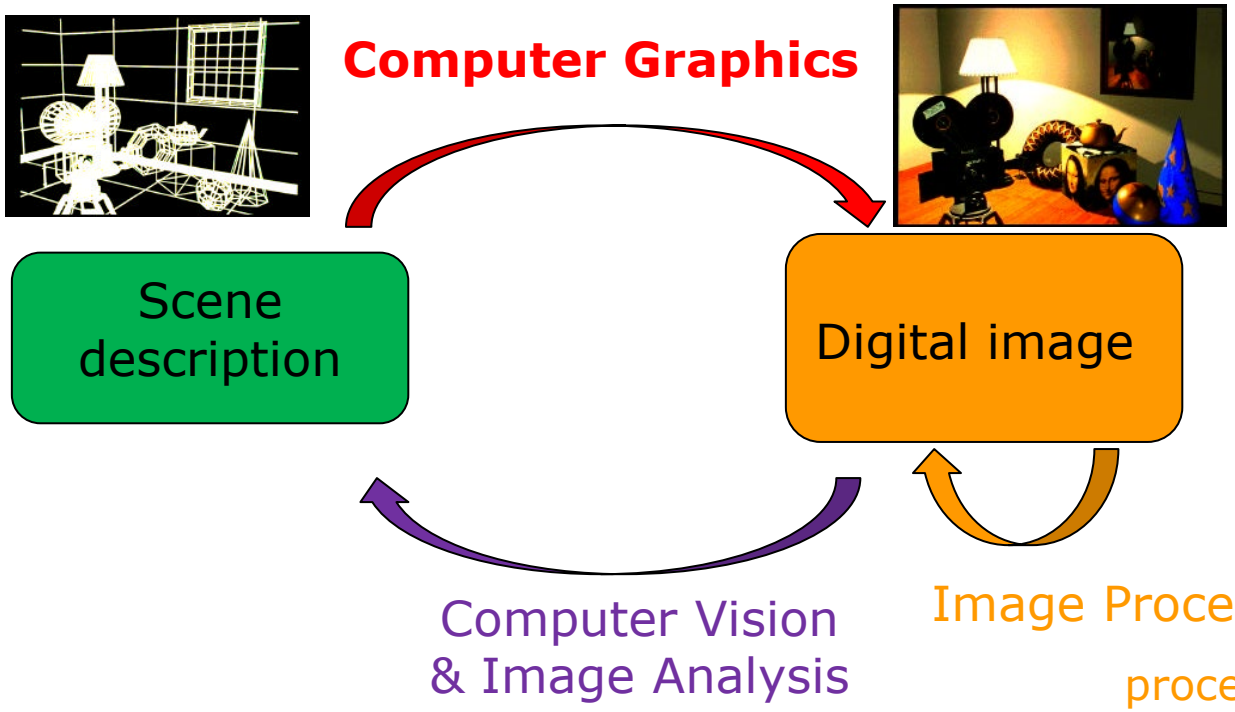
2024/25 Semester A

# Outline

- What is Computer Graphics?
- Why Computer Graphics?
- How Computer Graphics Works?
- AI Generated Content
- Course Focuses

# What is Computer Graphics?

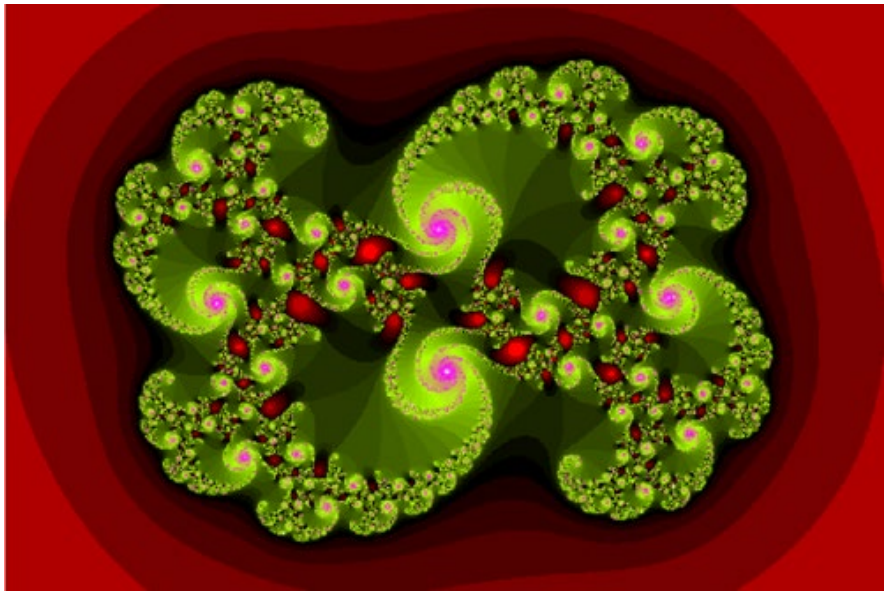
- Technically, it's about the pictorial synthesis of *real* or *imaginary* objects from their computer-based 2D/3D models.



# Why Graphics?

- A picture is worth a thousand words. -- Chinese proverb
- About 50% of the brain neurons are associated with vision.
- More of the human brain is devoted to **visual processing** and **visual thinking** than to any other form of sensory input!

It looks like a swirl. There are smaller swirls at the edges. It has different shades of red at the outside, and is mostly green at the inside. The smaller swirls have purple highlights. The green has also different shades. Each small swirl is composed of even smaller ones. The swirls go clockwise. Inside the object, there are also red highlights. Those have different shades of red also. The green shades vary in a fan, while the purple ones are more uni-color...



Julia set (complex dynamic)

# Why Computer Graphics?

- Computer graphics is application-driven!
  - Movie and computer animation
  - Video game
  - Computer-aided design (CAD)
  - Simulation
  - Computer art
  - Graphical User interface (GUI)
  - Scientific visualization
  - …

# Movies and Computer Animations

- If you can imagine it, it can be done with computer graphics.
- Computer graphics is now as much a part of the video and movie production industry as stuntmen and makeup. More than several billion dollars on special effects

Ice Age

Kung Fu Panda

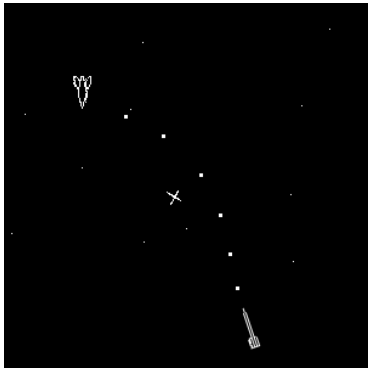

Cars 3

The Matrix


Zootopia

# Video Games

- Games are the driving force in computer graphics.
- Focus on interactivity and try to avoid expensive computation



Spacewar 1961

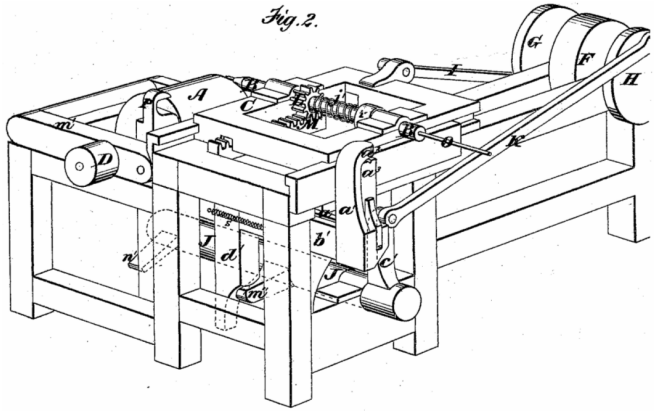
Counter Strike 2005


World of Warcraft 2004


League of Legends 2009

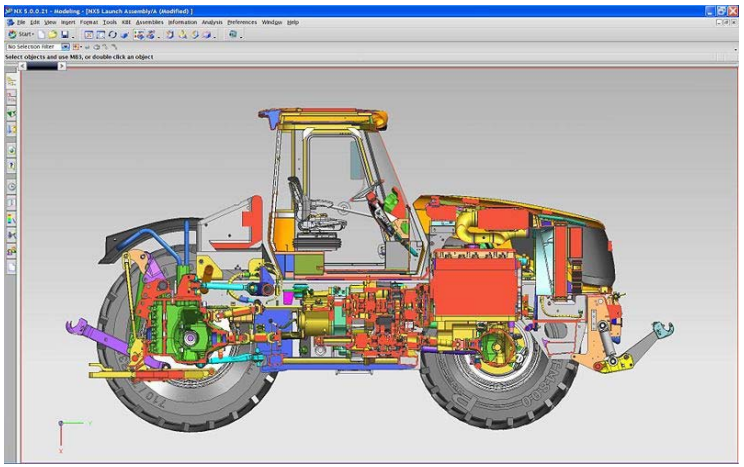
# Computer-Aided Design (CAD)

- CAD is to use computer systems to assist in the creation, modification, analysis and optimization of a design.




Mechanical drawing of a US patent (1874)

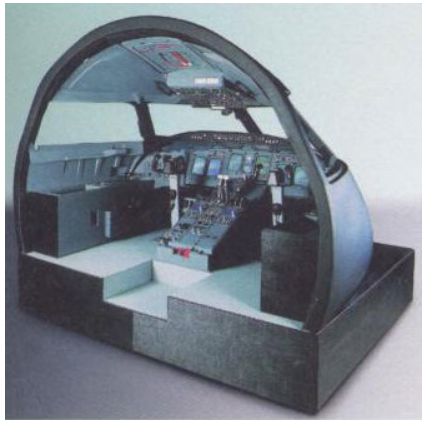
Architectural design



Machine design

# Simulation

- Simulating the behaviors of some devices for training or investigation purposes.



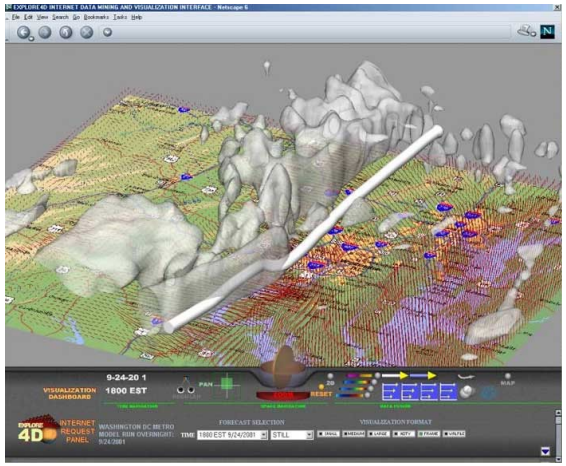
Flight simulator

Automobile simulator

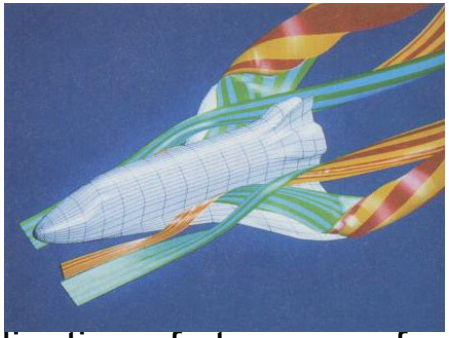
Surgery Simulator

# Scientific Visualization

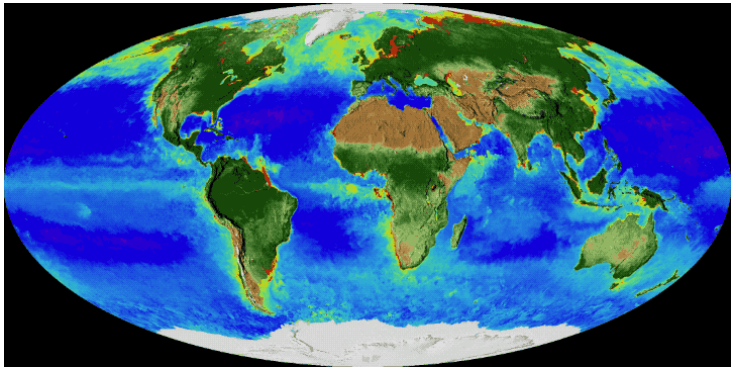
- Display of complex phenomena or multi-dimensional data, which may be too difficult for users to understand otherwise.



Numerical model of airflow inside a thunderstorm



Visualization of stream surfaces flowing past a space shuttle



Land vegetation and phytoplankton

Photoactivatable fluorescent protein

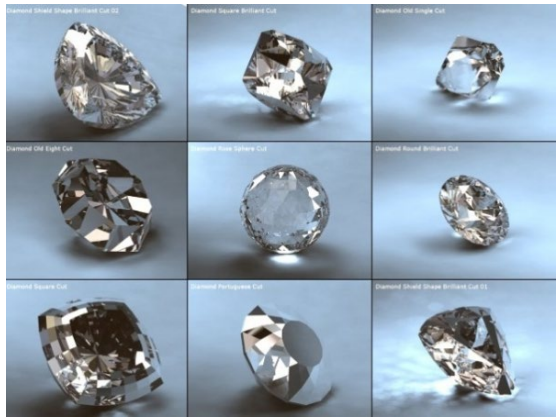
https://www.youtube.com/watch?v=xCFg5udYbAg

# Graphical User Interface (GUI)

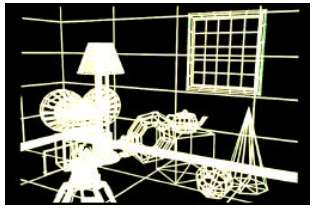
- User interface that allows users to interact with electronic devices through graphical icons and visual indicators.


# Computer Art

- Using computer graphics tools to assist artists in their design.

# How Computer Graphics Works?



Modeling → Animation → Rendering

- ❑ 2D/3D Shape representation
  - ▪Polygonal meshes
  - ▪Subdivision surfaces
  - ▪Splines
  - ▪Geometry images
  - ▪…
- ❑ Digital geometry processing
  - ▪ 3D scanning
  - ▪ Denoising
  - ▪ Shape editing
  - ▪ Simplification
  - ▪ Parameterization
  - ▪ Compression
  - ▪ …

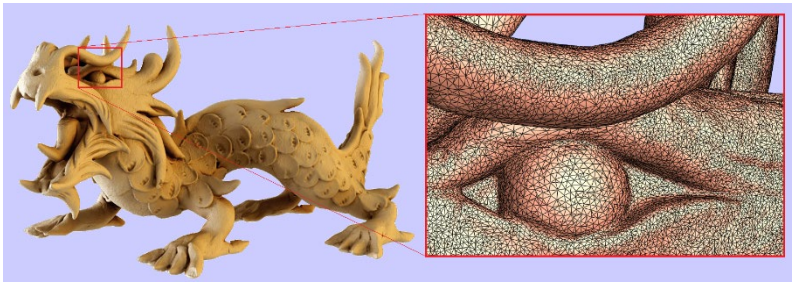
- ▪ Photo-realistic rendering
- ▪ Non-photorealistic rendering

- ▪Physics-based simulation (e.g. cloth simulation)
- ▪Natural phenomena simulation (fire, fog, water, etc.)
- ▪Motion capture
- ▪Animation transfer

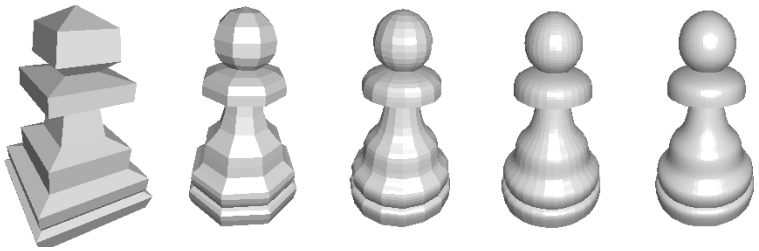
http://sgruenvo.web.th-koeln.de/wp-content/uploads/2016/02/walk2-1.gif

# 2D/3D Shape Representations

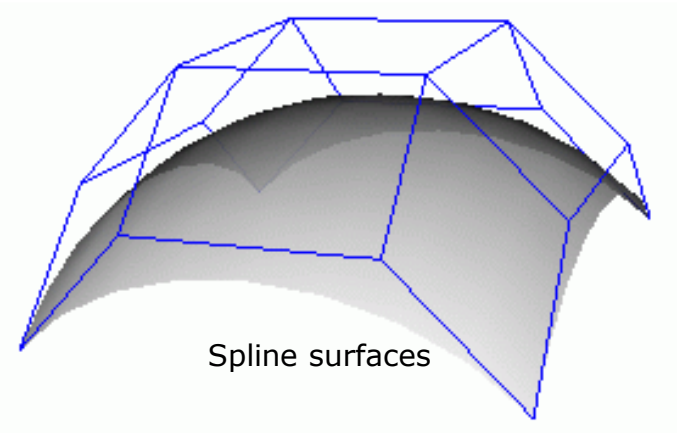
- Data structures for representing 2D/3D objects and scenes.
  - Polygonal meshes
  - Spline surfaces
  - Subdivision surfaces
  - Geometry images
  - …



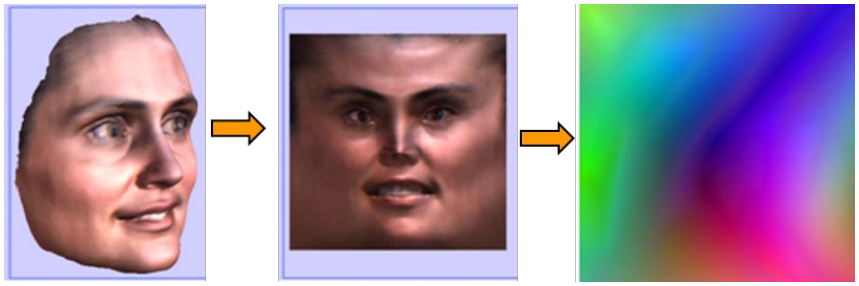
Polygonal meshes



Subdivision surfaces



Spline surfaces



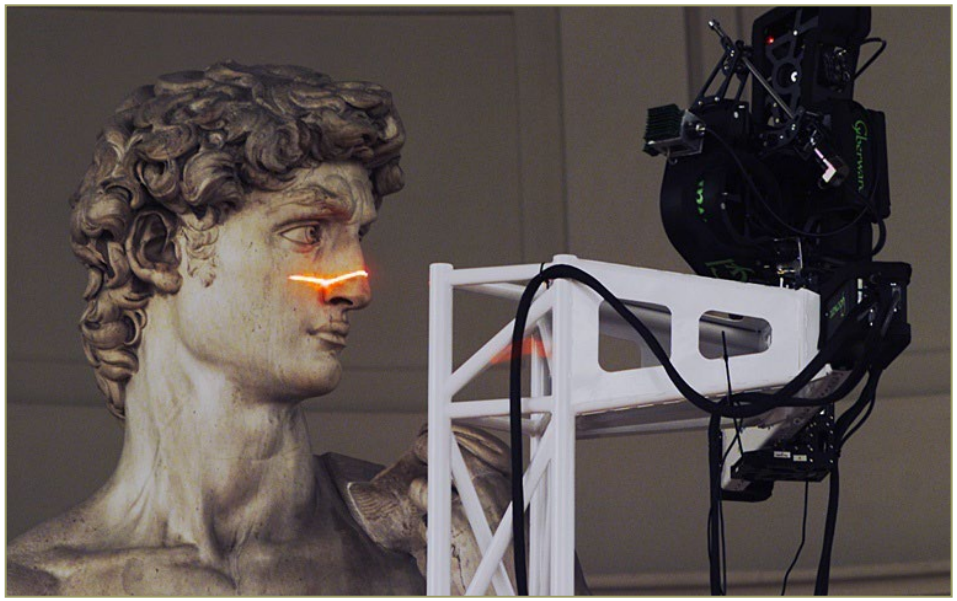
Geometry images

# Digital Geometry Processing (DGP)

- Use concepts from applied mathematics, computer science and engineering to design efficient algorithms for the acquisition, reconstruction, analysis, manipulation, simulation, and transmission of 3D models.
  - 3D acquisition
  - Surface reconstruction
  - Smoothing/denoising
  - Simplification
  - Shape registration
  - Morphing
  - …

# 3D Acquisition

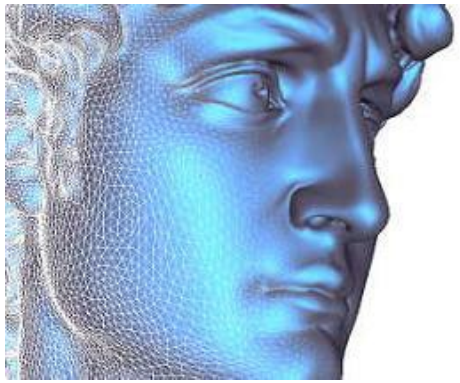
- Most of the real-world shapes have complex geometry and very fine details.
- 3D scanning equipment is making the use of complex 3D models accessible to a much larger audience.



The Digital Michelangelo Project
Stanford University 1999

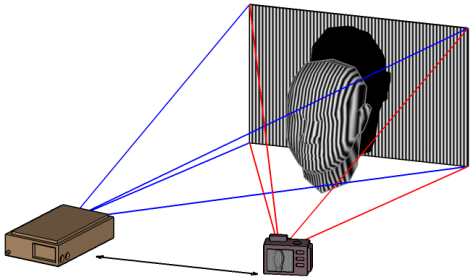
# The Digital Michelangelo Project

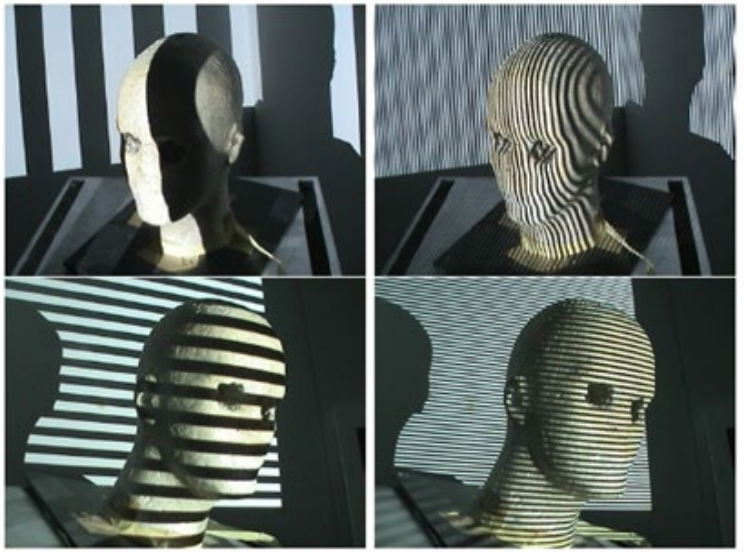
- The statue
  - Height without pedestal: 517 cm
  - Surface area: 19 $m^2$
  - Volume: 2.2 $m^3$
  - Weight: 5,800 kilograms
- Statistics of scan
  - Total weight of equipment shipped to Italy: 4 tons
  - 22 people
  - 30 nights of scanning
  - 480 individually aimed scans
  - 2 billion polygons
  - 7,000 color images
  - 32 gigabytes



# 3D Acquisition

- Real-time 3D model acquisition with a structured light based depth sensor
  - Speed: 40 frames/s
  - Resolution: 532 × 500

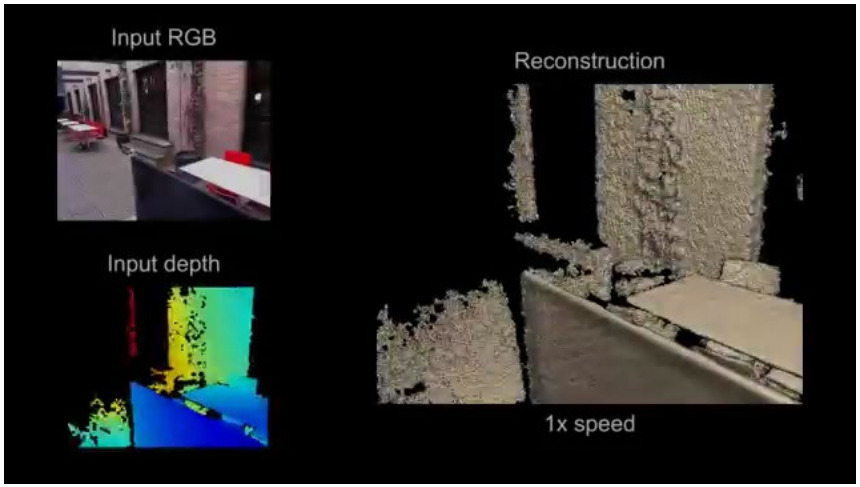


https://www.youtube.com/watch?v=U0Q9QnYRsoU

# 3D Acquisition

- Commercial depth sensors
  - Microsoft Kinect
  - Intel realsense
  - …


From Chen *et al*. *Siggraph* 2013

From Dou *et al*. *Siggraph* 2016

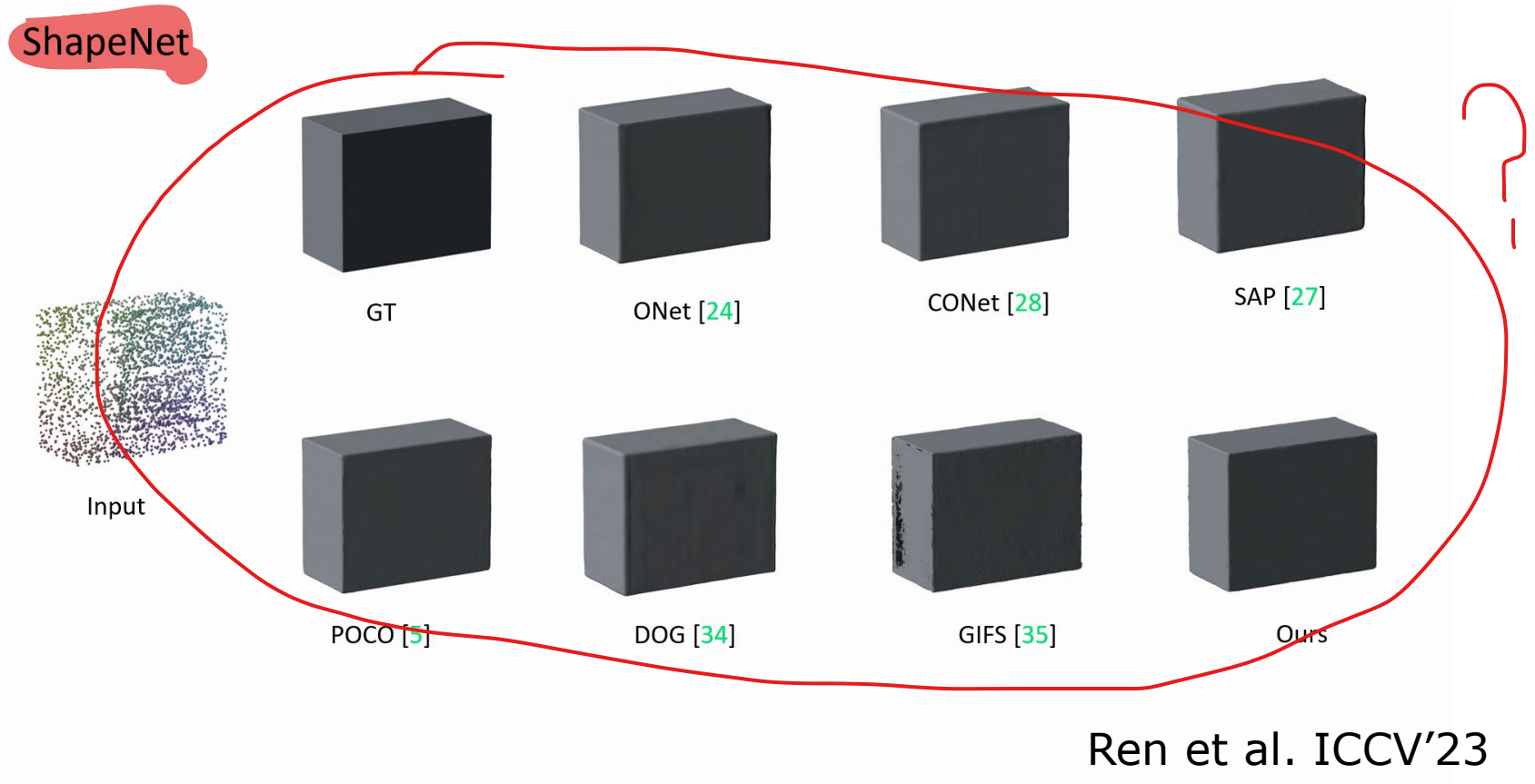
# AI for 3D Content Creation

- Using learning techniques to generate 3D models from texts/images/latent features…

# Surface Reconstruction

- Reconstruction of a continuous surface from it raw, discrete point cloud observation.
- a long-standing, challenging, and fundamental problem.

想起来之前是采样蛋白表面的点，**然后重建曲面**




Ren et al. ICCV'23

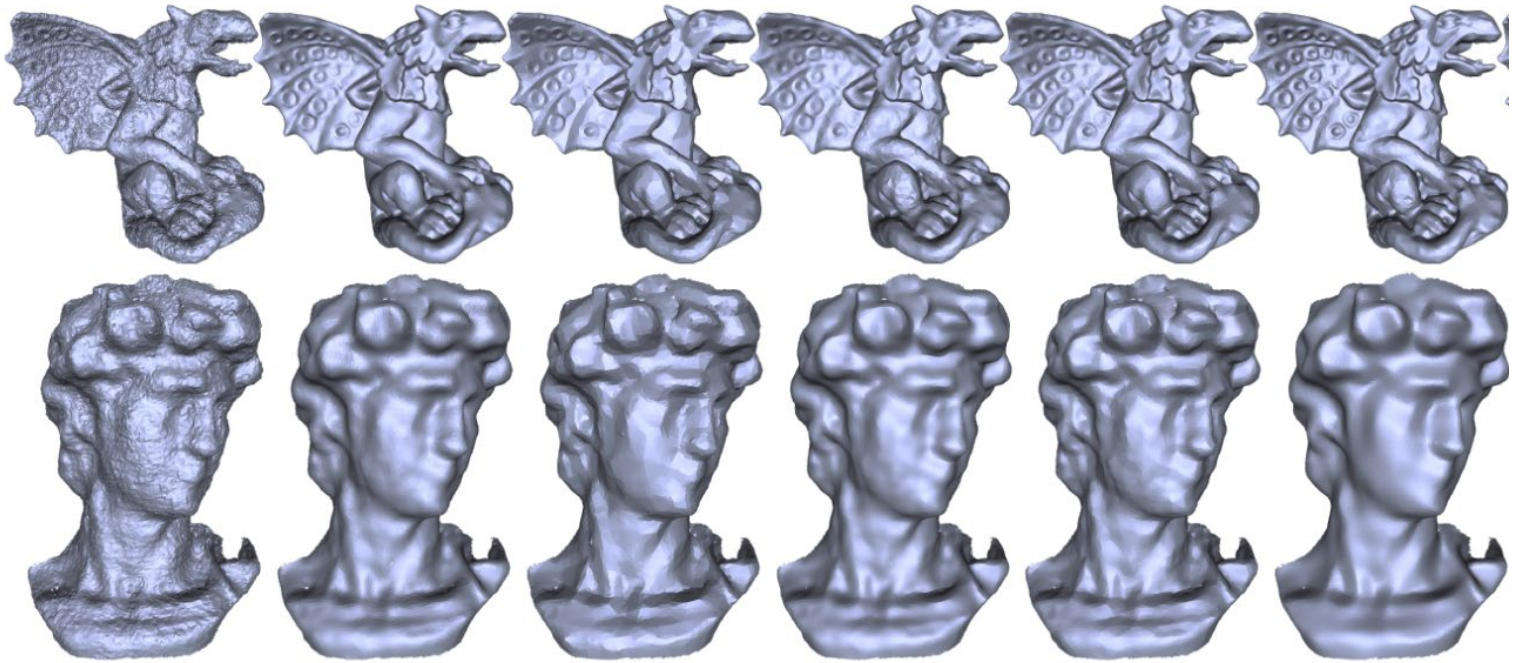
# Dynamic Surface Reconstruction

- Reconstruct temporally consistent surfaces from a 3D point cloud sequence without correspondence.

Yao et al. ECCV'24

# Smoothing/Denoising

- Even with high-fidelity scanners, the acquired 3D models are inevitably noisy, and thus require smoothing/denoising.
- Remove the noise while preserving the salient features.

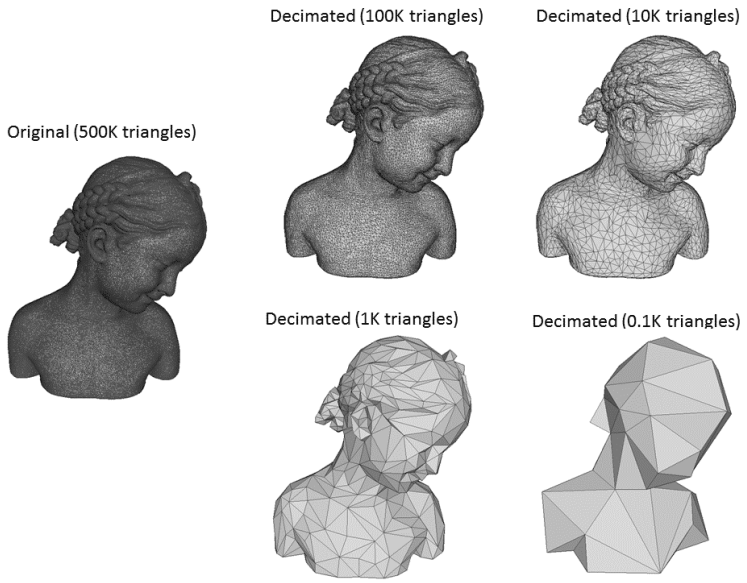


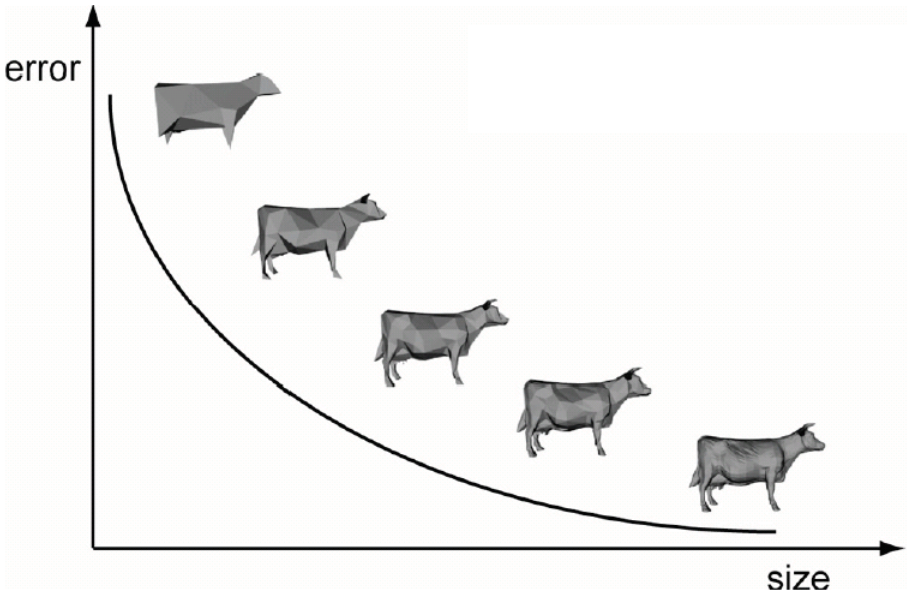
(a) Noisy input (b) Bilateral normal (c) $L_0$ smoothing (d) Guided normal (e) Bayesian (f) Our method

From Wang *et al*. *Siggraph Asia* 2016

# Simplification

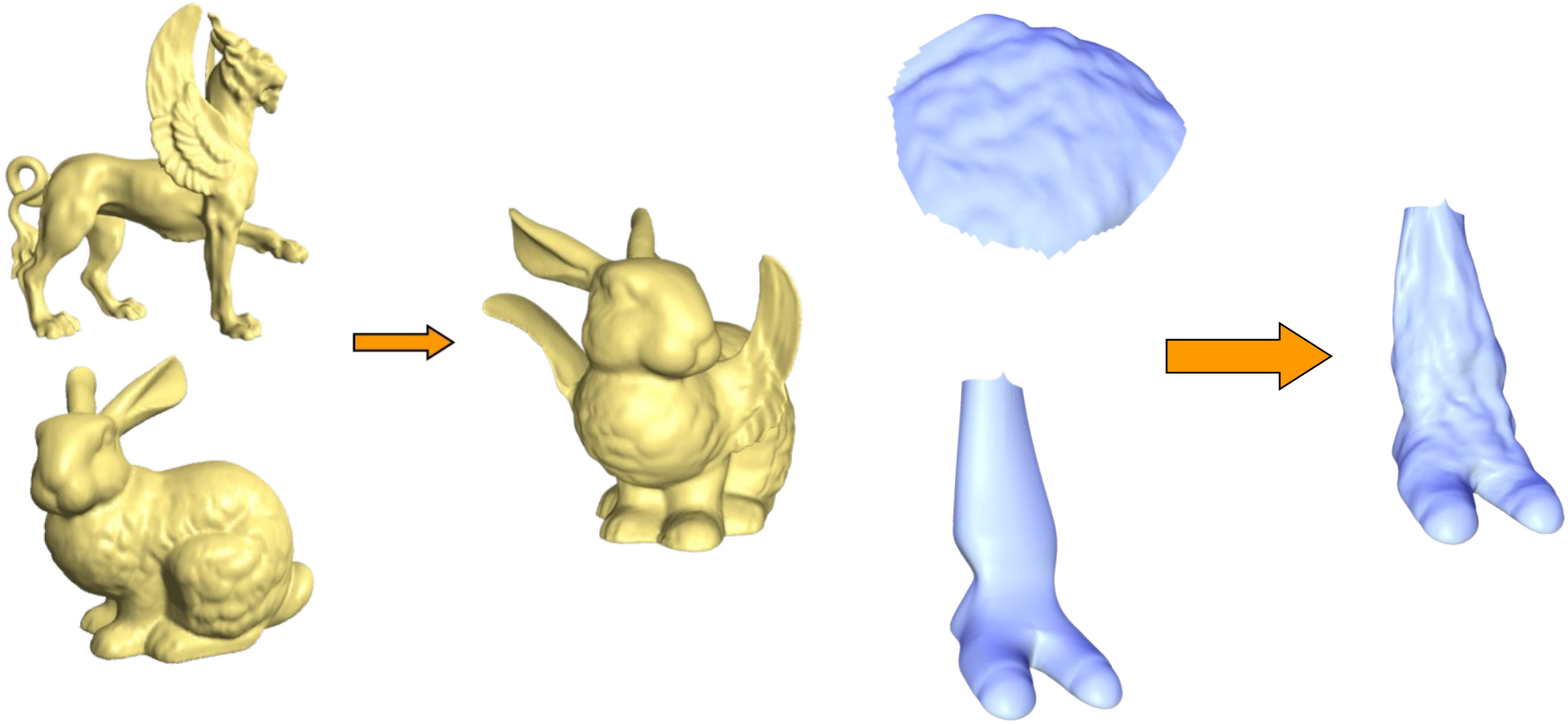
- Scanned data are always oversampled, which are not efficient for rendering and processing
- Reduce the number of polygons used in a surface while preserving the overall shape and details as much as possible.
- Error (Rendering quality) - size (storage/rendering efficiency) tradeoff.



# Shape Editing

- Manipulate and modify a surface

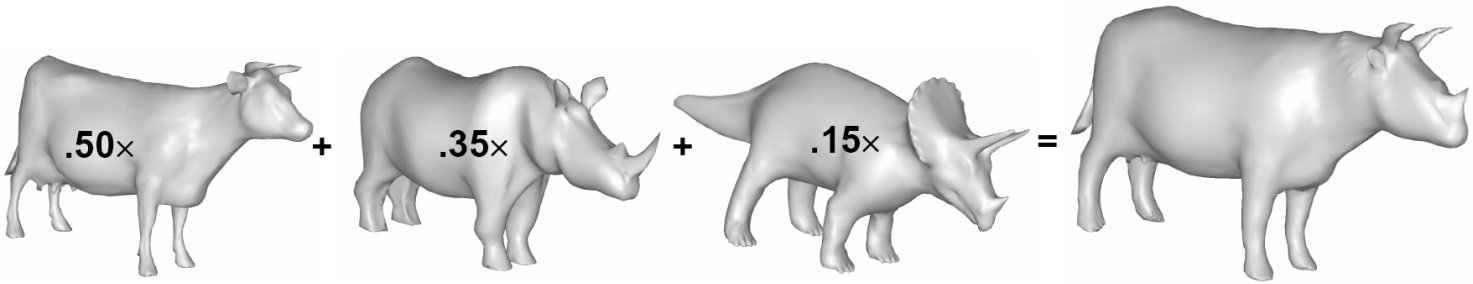


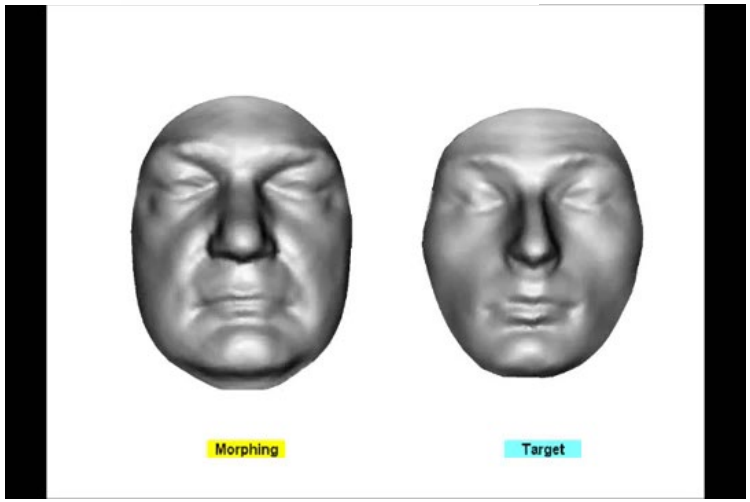
Cut and paste

Deformation

# Morphing

- An interpolation technique used to create from two objects a series of intermediate objects that change continuously to make a smooth transition from the source to the target.

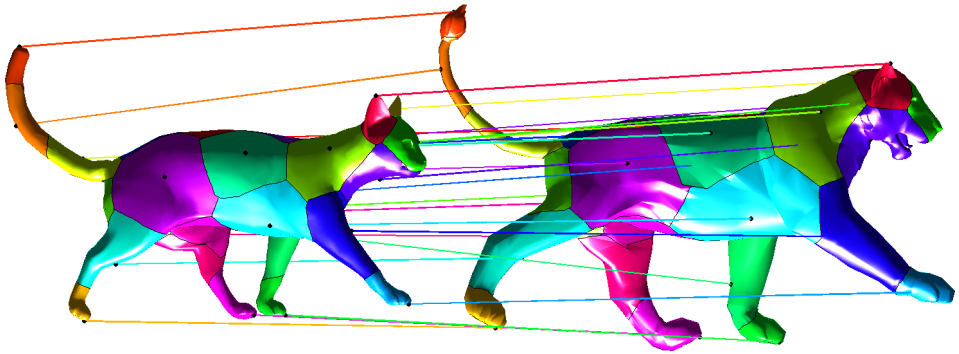


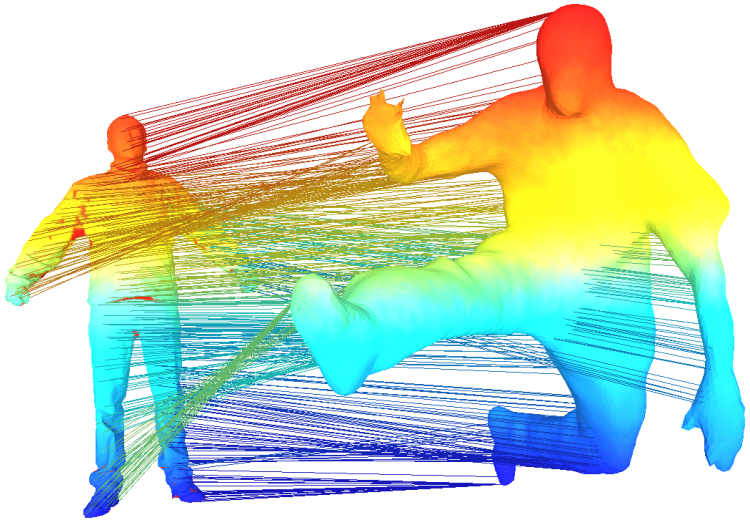



# 3D Shape Registration

- Find the best alignment between two objects or between several instances of the same object, in order to bring the shape data into the same reference system. It is a challenging task, due to
  - Local deformation in non-rigid shapes
  - Variation in shape acquisition techniques
  - Large acquisition discrepancies (e.g., holes)
  - Local scale change

确实，当时有好几个算法，**其中大多挺费时间的**



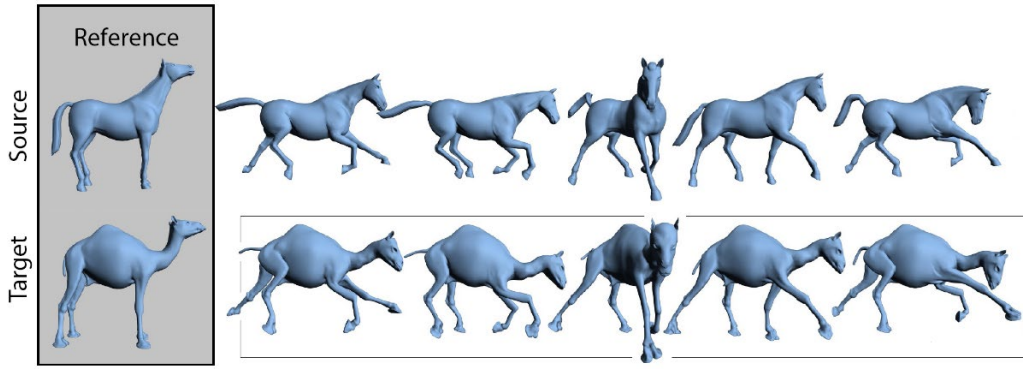


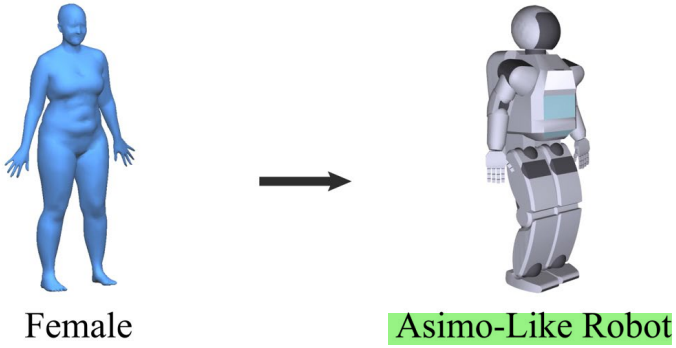
# Animation: Motion Capture

- The creation of a 3D representation of a live performance.
  - A performer wears markers near each joint to identify the motion by the positions or angles between the markers.
  - Markers are tracked in high frequency. The motion capture computer software records the positions, velocities and accelerations, providing an accurate digital representation of the motion.
  - To detect and track subtle expressions (e.g., small movements of the eyes and lips), up to 250 markers are placed to the actor's face.

# Animation Transfer

- The user builds a correspondence map between the source and the target.
- Deformation transfer applies the deformation exhibited by a source mesh onto a different target mesh.



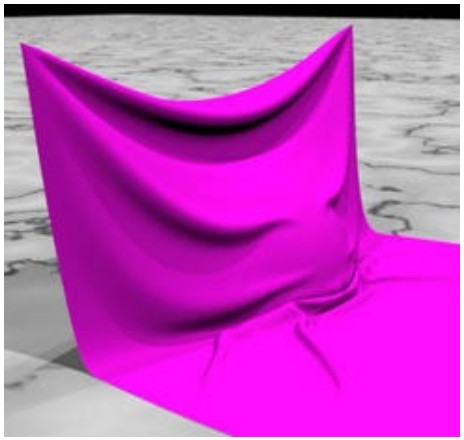

From Gao *et al. Siggraph Asia* 2018

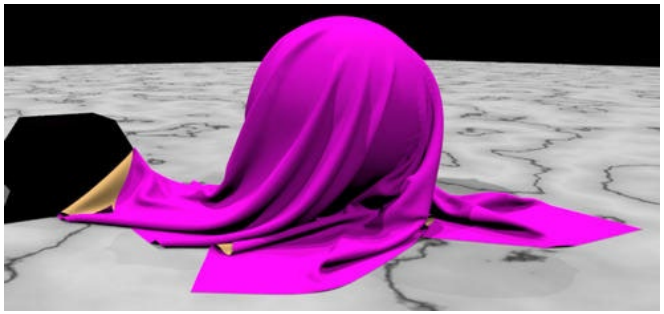
# Facial Expression Transfer

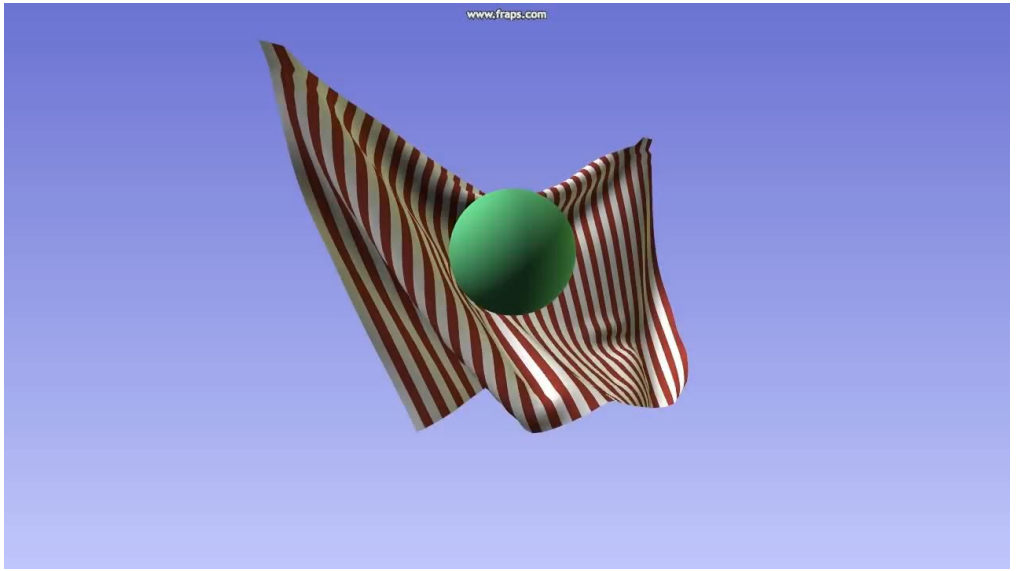
From Li *et al*. *Siggraph* 2013

# Cloth Simulation

- Physics-based animation

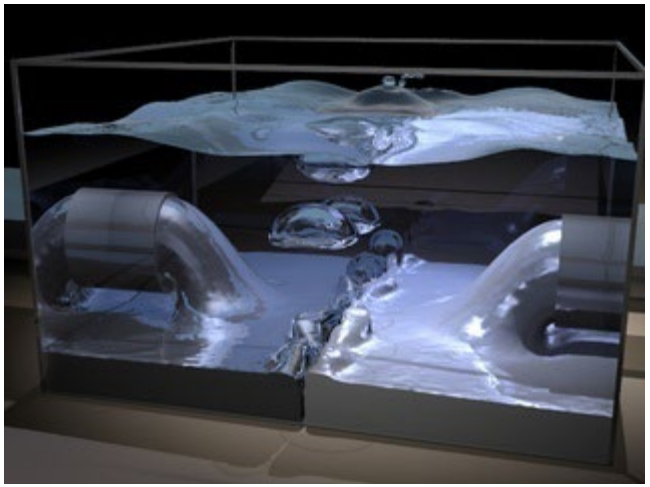


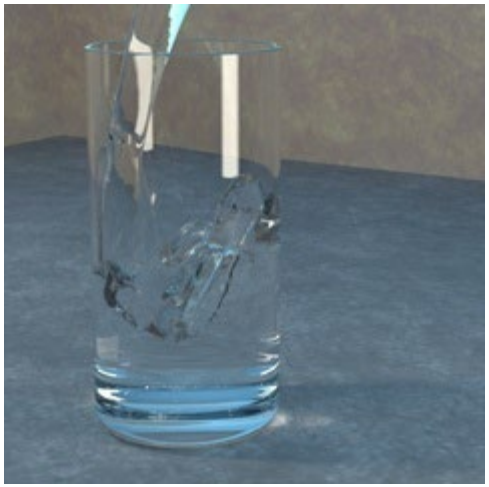
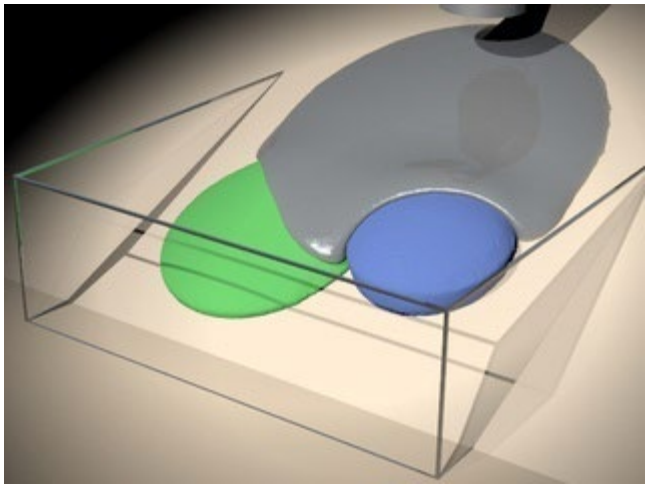




# Natural Phenomena Simulation

- The modeling of natural phenomena remains a challenging problem


# Rendering

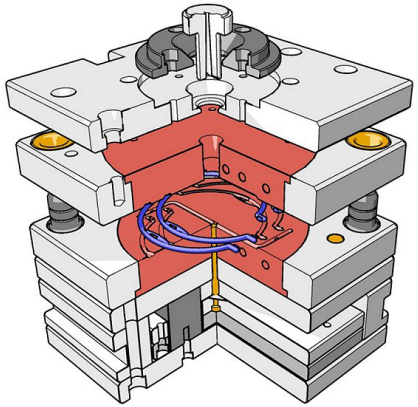
- The process of generating an image from a scene, which contains geometry, viewpoint, texture and lighting information. It is similar to photography or cinematography.
  - Photo-realistic rendering
  - Non-photorealistic rendering

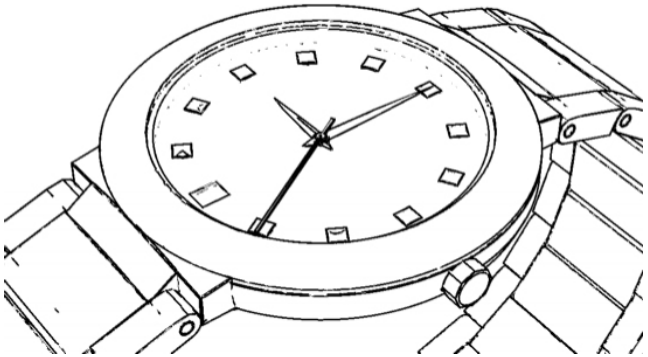
# Photo-Realistic Rendering

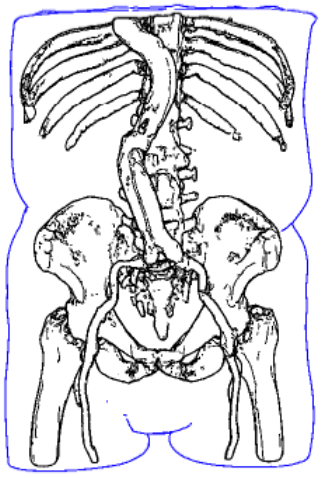
- Simulation of realistic lighting, shadows, atmosphere, color, texture and optical effects such as refraction of light or motion-blur seen on moving objects

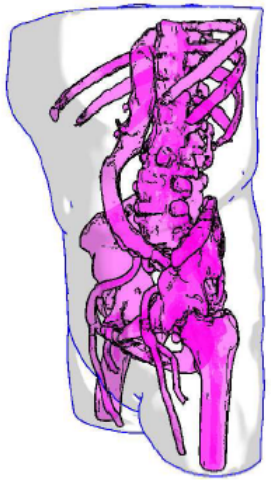
# Non-Photorealistic Rendering (NPR)

- Photographs are not always the best choice for presenting visual information. A simplified diagram is often preferred when an image is required to delineate and explain.
- NPR produces images that appear to have been drawn by hand.









# Neural Rendering

- A new and rapidly emerging field that combines generative machine learning techniques with physical knowledge from computer graphics, e.g., by the integration of differentiable rendering into network training.

A. Tewari et al. define **Neural Rendering** as *"Deep image or video generation approaches that enable explicit or implicit control of scene properties such as illumination, camera parameters, pose, geometry, appearance, and semantic structure."* <State of the Art on Neural Rendering, EG Course 2020>

# Neural Rendering

## Advances in Neural Rendering

A. Tewari[1,6⋆] J. Thies[2⋆] B. Mildenhall[3⋆] P. Srinivasan[3⋆] E. Tretschk[1] W. Yifan[4,8] C. Lassner[5] V. Sitzmann[6] R. Martin-Brualla[3]
S. Lombardi[5] T. Simon[5] C. Theobalt[1] M. Nießner[7] J. T. Barron[3] G. Wetzstein[8] M. Zollhöfer[5] V. Golyanik[1]

[1]MPI for Informatics [2]MPI for Intelligent Systems [3]Google Research [4]ETH Zürich [5]Reality Labs Research
[6]MIT [7]Technical University of Munich [8]Stanford University ⋆Equal contribution.

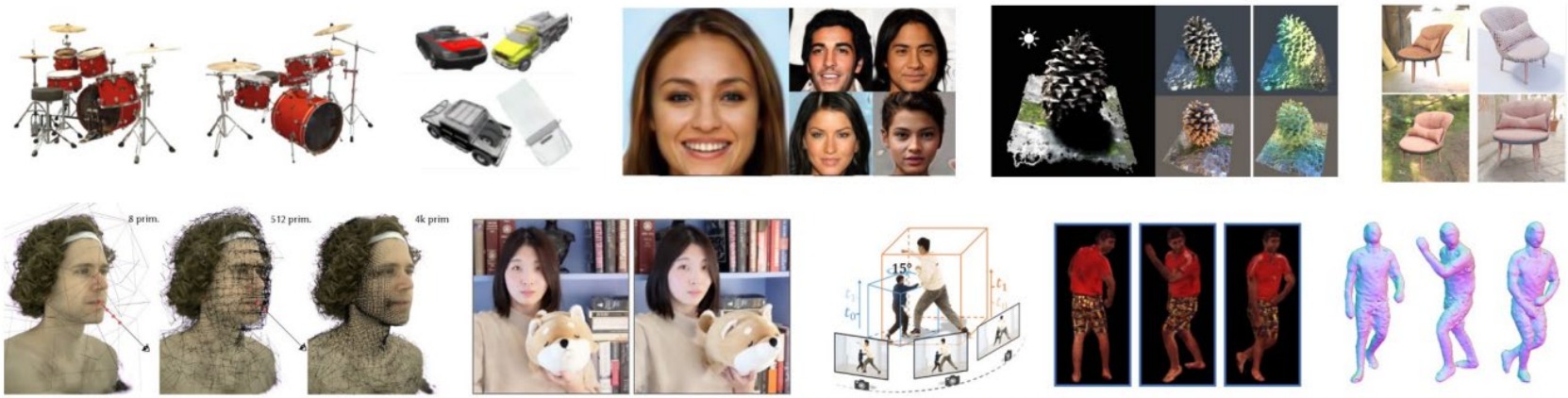



Figure 1: This state-of-the-art report discusses a large variety of neural rendering methods which enable applications such as novel-view synthesis of static and dynamic scenes, generative modeling of objects, and scene relighting. See Section 4 for more details on the various methods. Images adapted from [MST*20, TY20, CMK*21, ZSD*21, BBJ*21, LSS*21, PSB*21, JXX*21, PDW*21] ©2021 IEEE.

# Neural Rendering

- NeRF: Neural Radiance Fields (ECCV'20)

**NeRF**: Representing Scenes as Neural Radiance Fields for View Synthesis


Ben Mildenhall* UC Berkeley
Pratul P. Srinivasan* UC Berkeley
Matthew Tancik* UC Berkeley
Jonathan T. Barron Google Research
Ravi Ramamoorthi UC San Diego
Ren Ng UC Berkeley

* Denotes Equal Contribution


# AIGC: Image Generation

- Text → Image

PROMPT:

*Ge et al. Expressive Text-to-Image Generation with Rich Text. ICCV , 2023.*

# AIGC: Image Generation

- Sparse view images → Free view images

  https://github.com/ZHU-Zhiyu/NVS_Solver?tab=readme-ov-file

*You et al. NVS-Solver: Video Diffusion Model as Zero-Shot Novel View Synthesizer, Arxiv, 2024.*

# AIGC: Image Generation

- Sparse view images → Free view images

*Liu et al. ReconX: Reconstruct Any Scene from Sparse Views with Video Diffusion Model. Arxiv, 2024.*

# AIGC: Video Generation

- Text and 2D panorama → Free exploratory scene

*Yang et al. LayerPano3D: Layered 3D Panorama for Hyper-Immersive Scene Generation. Arxiv, 2024.*

# AIGC: Video Generation

- Single image and skeleton pose → Video

*Peng et al. ControlNeXt: Powerful and Efficient Control for Image and Video Generation. Arxiv, 2024.*

# AIGC: 3D Generation

- Text or image → 3D asset

*Zhang et al. CLAY: A Controllable Large-scale Generative Model for Creating High-quality 3D Assets. Siggraph, 2024.*

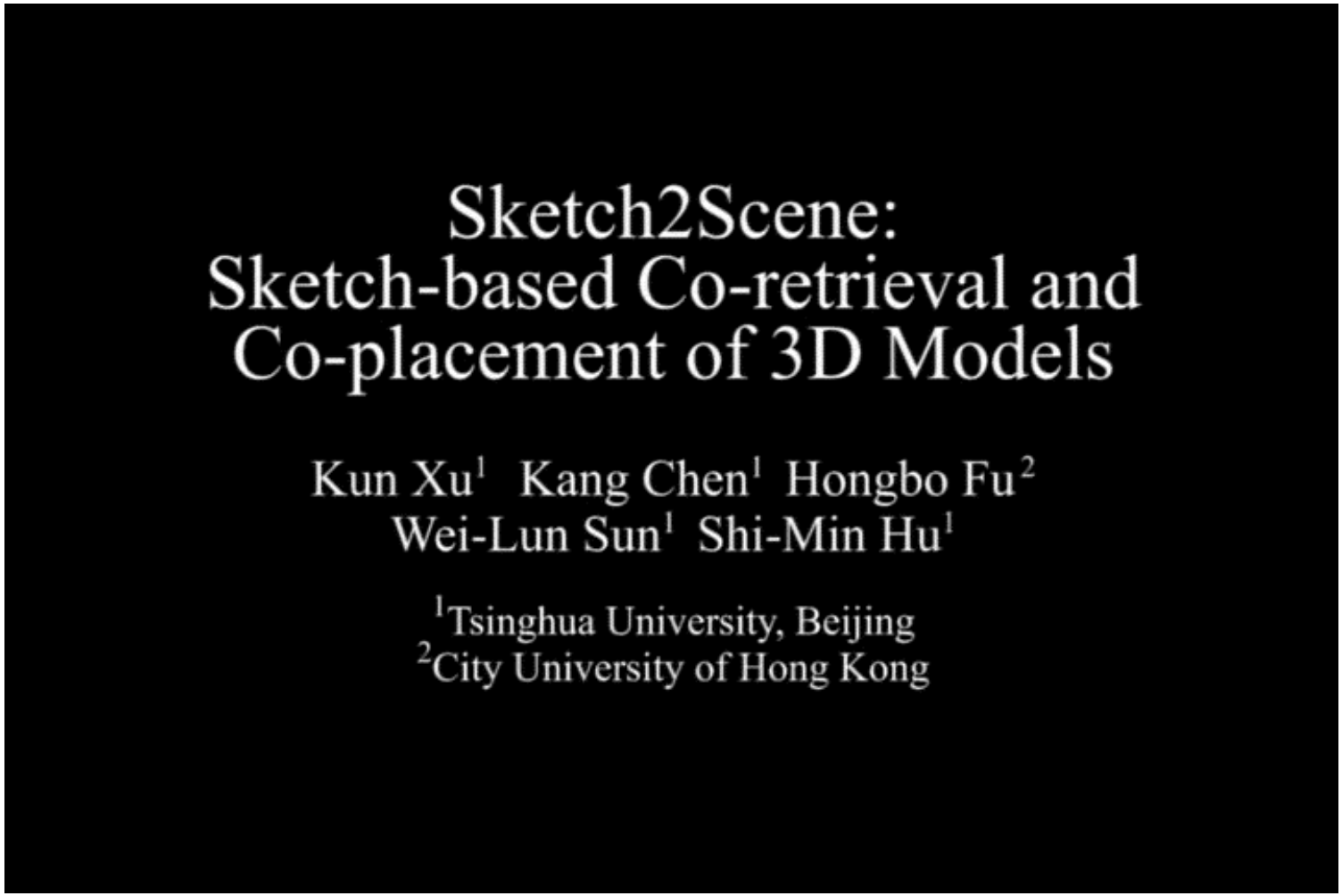
# AIGC: 3D Generation

- Text → Clothed human body

*He et al. DressCode: Autoregressively Sewing and Generating Garments from Text Guidance. Siggraph, 2024.*

# AIGC: 3D Generation

- Sketch → 3D scene




*Xu et al. Sketch2Scene: Sketch-based Co-retrieval and Co-placement of 3D Models. Siggraph, 2023.*

# AIGC: Interactive Generation

- Action → Game


*Valevski et al. Diffusion Models Are Real-Time Game Engines. Arxiv, 2024.*

# AIGC: Interactive Generation

- Text → Edited image

*Chen et al. MimicBrush: Zero-shot Image Editing with Reference Imitation. Arxiv, 2024.*

# Summary

- Modeling
  - Data structures for representing 2D/3D objects and scenes.
  - Algorithms for creating and processing these data structures.
  - On the inside, modeling is based on mathematics.
- Rendering
  - Given a 2D/3D model of the world, which contains geometry, material, viewpoint, texture and lighting information, generate a digital image or raster graphics image representing the scene
  - On the inside, rendering is based on a selective mixture of disciplines related to: optics (physics), visual perception and art.

光学（物理学），视觉感知和艺术

- Animation
  - Manipulate the 2D/3D objects according to the laws of physics (or at least pseudo-physics).
  - On the inside, animation is based on mechanics (physics) and mathematics.

# Course Focuses

- In this course, we will first focus on how to generate images to represent a synthetic scene, which is sometimes called a *virtual environment*.

  To generate an image:
  - Model objects in the virtual environment as geometry objects.

    lecture: drawing, object modeling, …
  - Transform them to the viewer space.

    lecture: transformation, projection and clipping
  - Render the transformed objects to 2D images for display.

    lecture: hidden surface removal and shading, ray-tracing and radiosity, antialising, …
- Then, we will look at some applications of computer graphics techniques.
  - Lecture: various technique for producing animations, …
  - Tutorial: deep learning-based research on computer graphics/vision and image processing