## Lecture 1:

# Introduction

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## Computer Graphics and Imaging
## UC Berkeley CS184/284A

# Welcome to CS184 / 284A!

Prof. Ren Ng

- Ph.D. 2006 on Digital Light Field Photography (evolving camera design using graphics technology)
- Founder of Lytro, a light field camera company
- Research interests: color, computational imaging systems, computer graphics, computer vision, human vision
- Fun fact: born Malaysian, became Australian, naturalized American. Had all three speaking accents!

# Welcome to CS184 / 284A!

CO-HEAD TA

20 HOUR

Ashley Chiu

she/her

GSI

20 HOUR

Ethan Weber

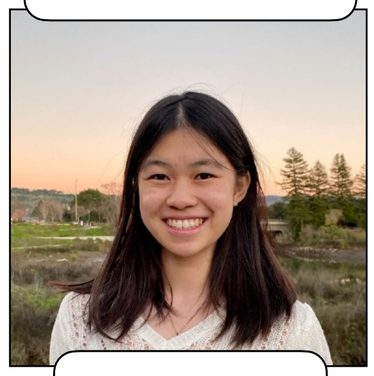
he/him

GSI

James Fong

he/him

CO-HEAD TA



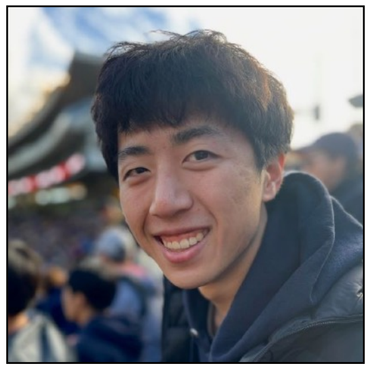
20 HOUR

Jennifer Zhao

he/him

Joshua You

he/him



Preston Fu

he/him

Raine Koizumi

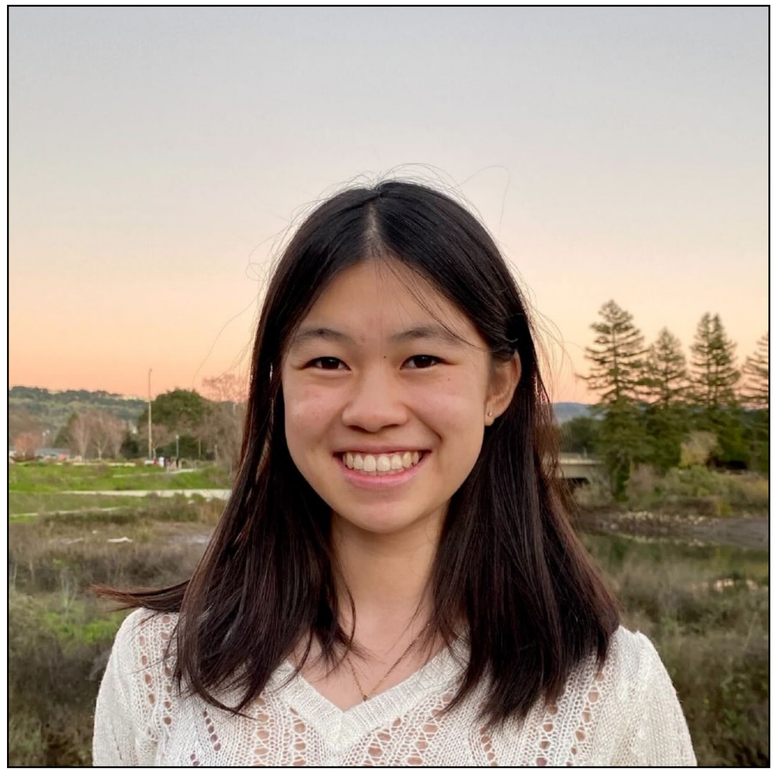
he/him

Rebecca Feng

she/her

# Acknowledgment & Thank You

Ashley Chiu



Jennifer Zhao

Our Co-Head TAs have done an outstanding job getting us ready for a smooth class kickoff, a huge effort even before the semester started.

**CS184/284A** **Ren Ng**

# Your Names: An Important Request

- We want to get to know you
- It starts with your names
- We want to remember, but there are many of us
- Please help us with this rule:
    - Every time you participate in class, section, office hours, please remind us your name.
    - Example: “Hi, this is Xu Yi. My question is about…”
- Thank you very much!

# CS184/284A: Computer Graphics & Imaging

## Why Study Computer Graphics?

## Course Overview

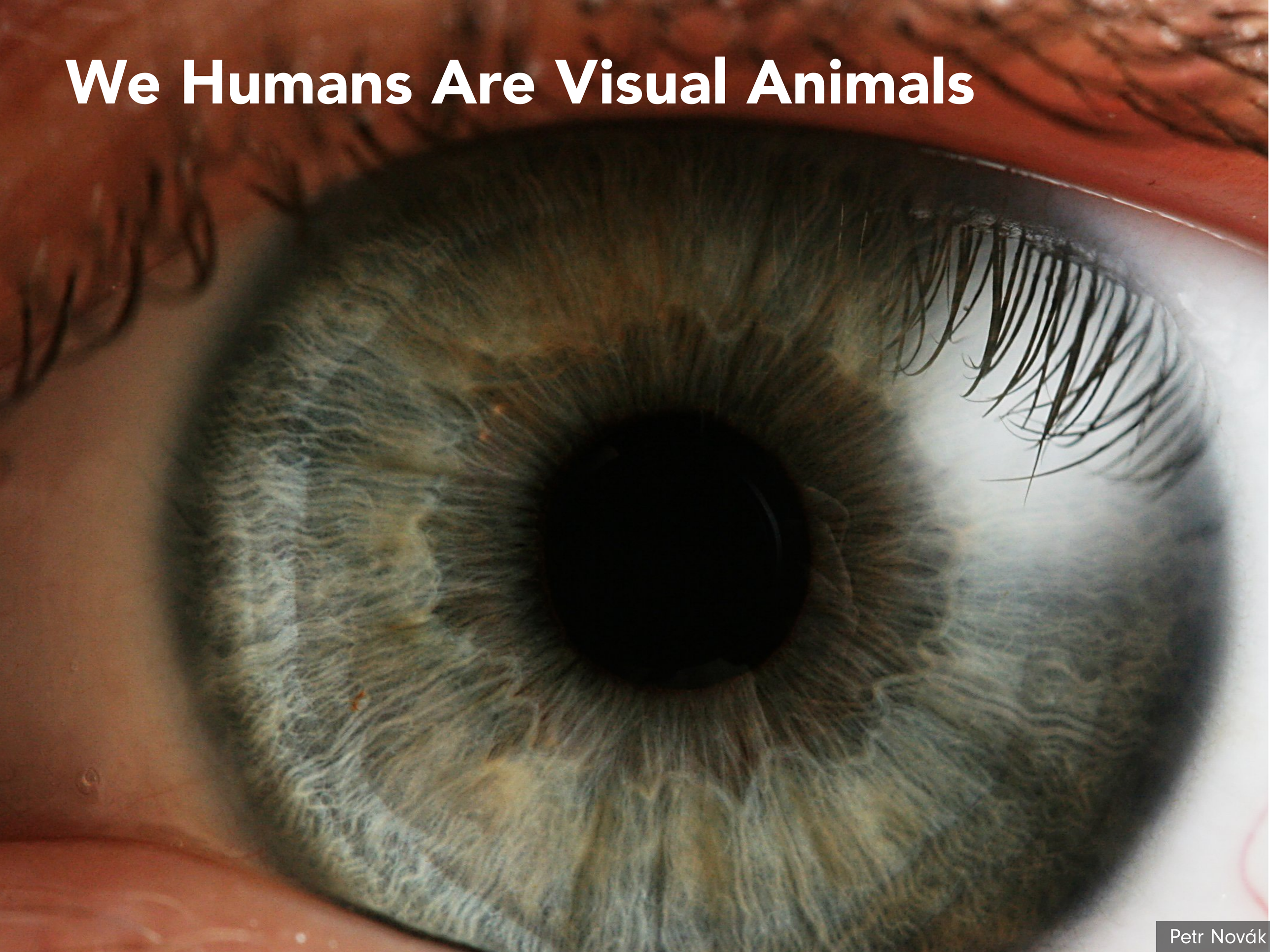
## Logistics

# What is Computer Graphics?

**com•put•er graph•ics** /kəmˈpyo͞odər ˈgrafiks/ n.
The use of computers to synthesize and manipulate visual information.

# Why Visual Information?

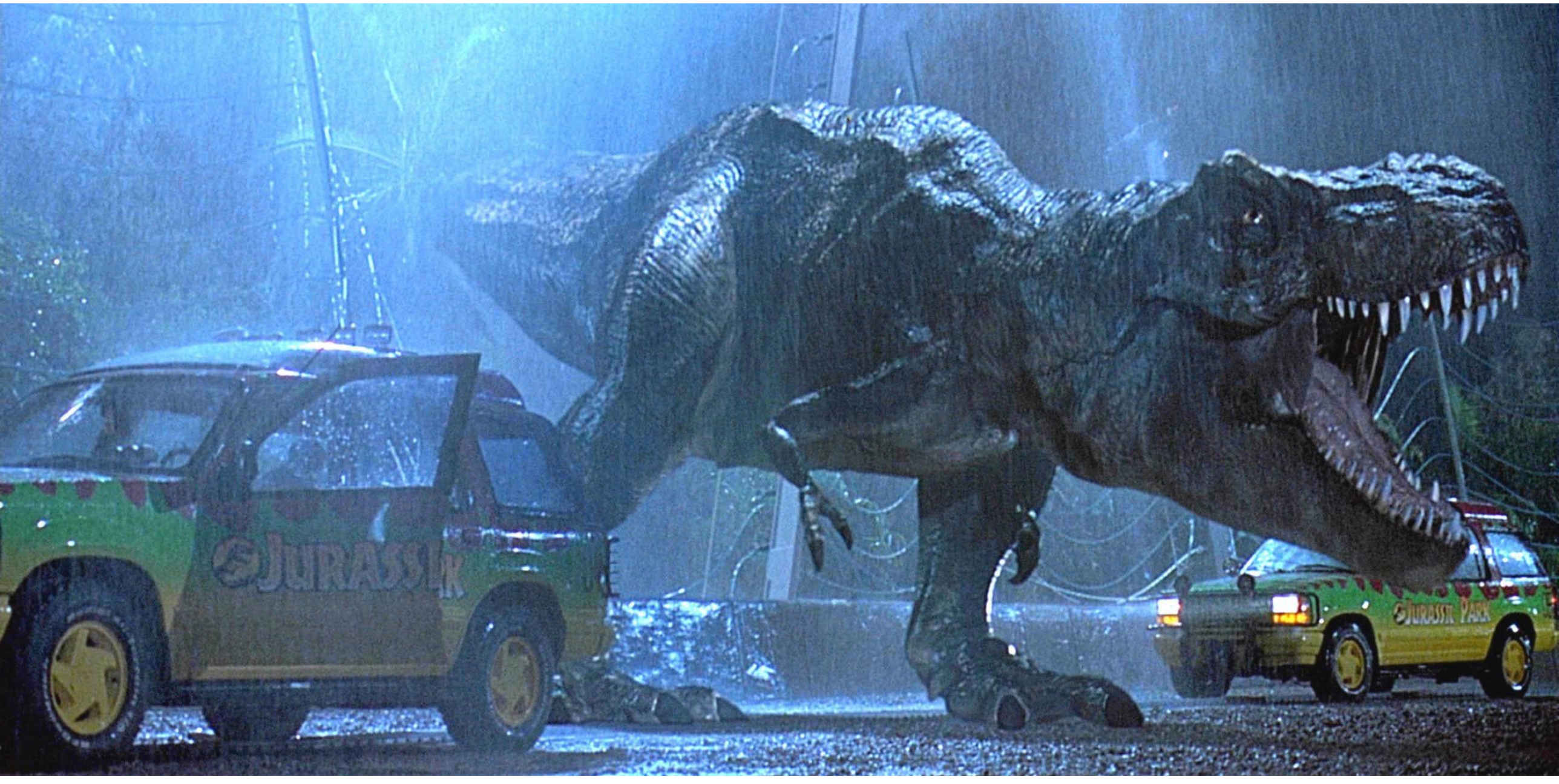
# We Humans Are Visual Animals



Petr Novák

# Why Study Computer Graphics and Imaging?

# Movies




Jurassic Park (1993)


Moments That Changed The Movies: Jurassic Park
https://www.youtube.com/watch?v=KWsbcBvYqN8

# Movies - 3D Geometry, Materials, Lighting


Toy Story (1995)

# Movies - Image-Based Computer Graphics

The Matrix (1999)

# Movies - Image-Based Computer Graphics

The Matrix (1999)

# The Campanile

Debevec, Taylor and Malik SIGGRAPH 1996

https://www.pauldebevec.com/Campanile/

# Motion Capture

## Andy Serkis in The Two Towers

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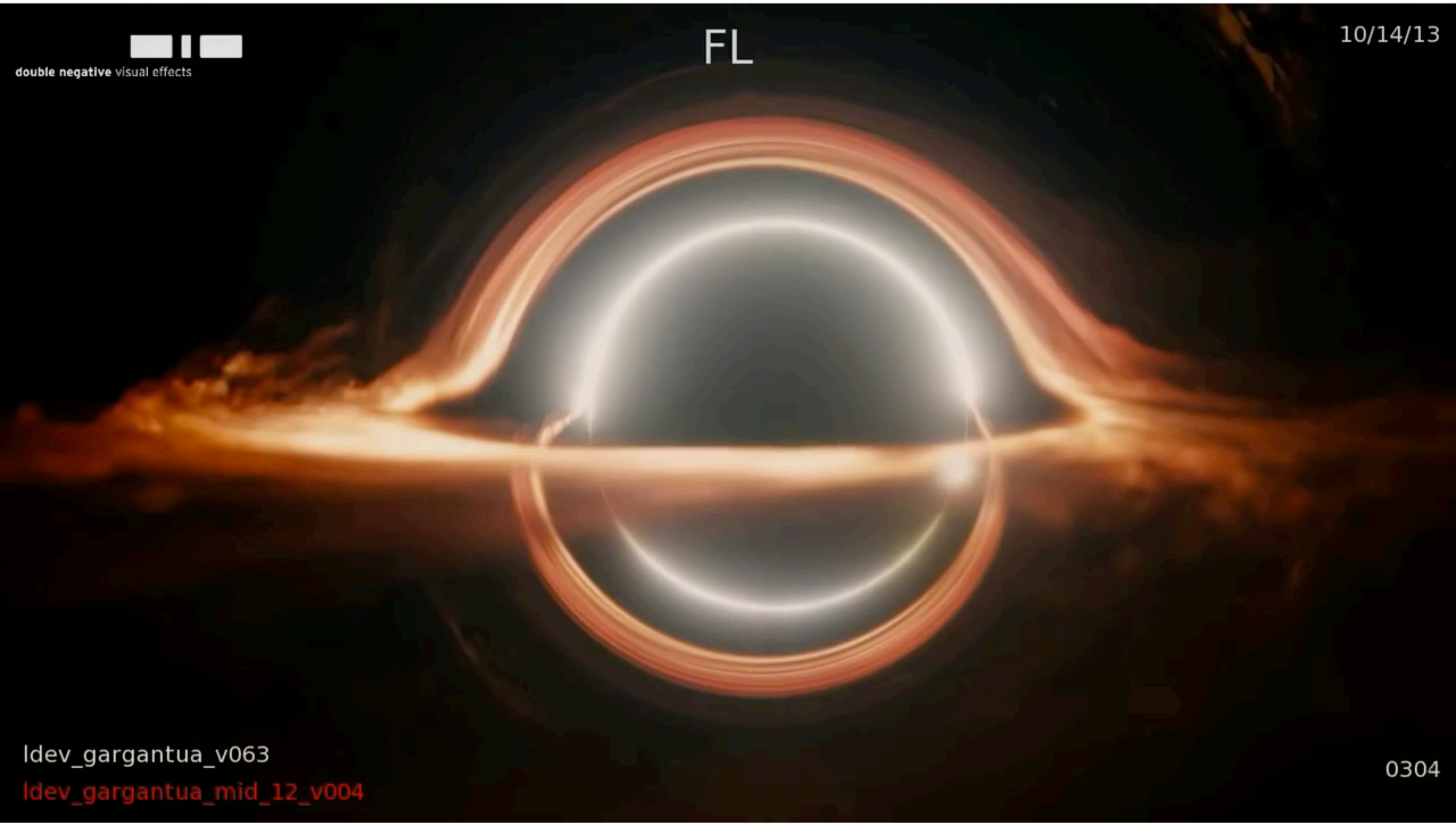
# Avatar (2009)

# Interstellar (2014)

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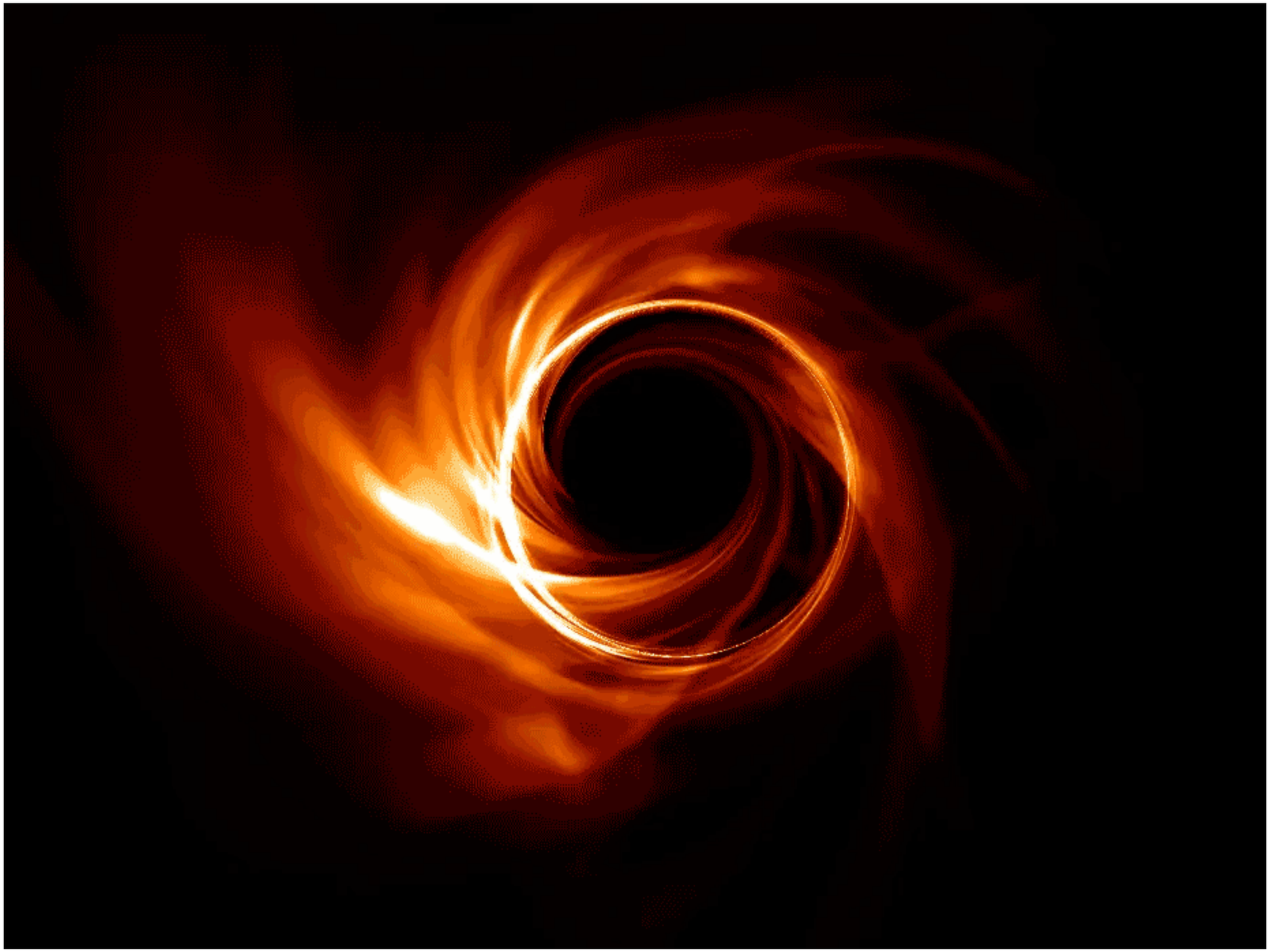
# Computational Imaging - Event-Horizon Telescope



Event Horizon Telescope collaboration et al.

# Computational Imaging - Event-Horizon Telescope



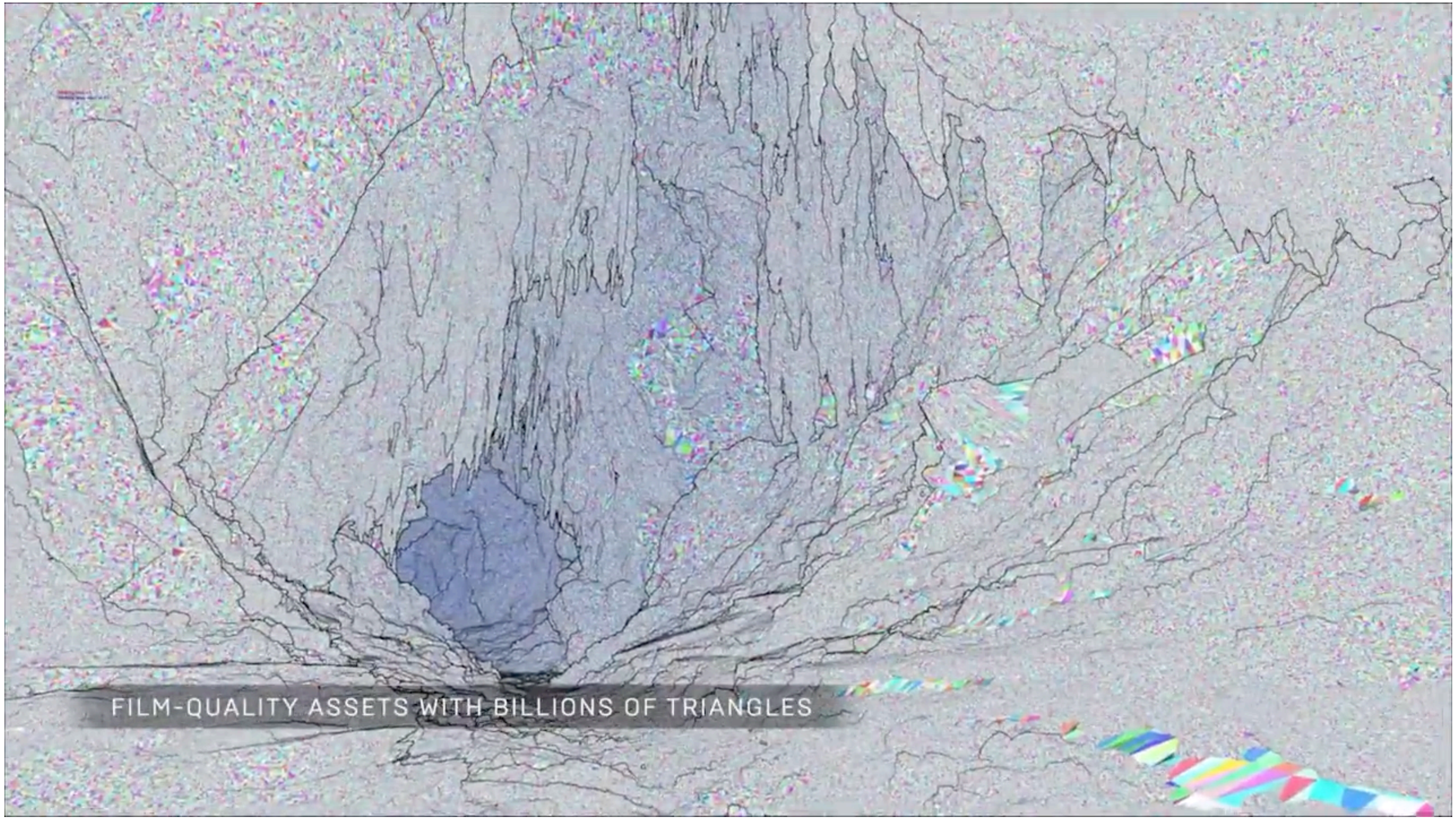


Event Horizon Telescope collaboration et al.

# Games


Super Mario World

# Games




## Unreal Engine Demo - Realtime in PS5

# Games


Indiana Jones and the Great Circle (2024)

Realtime ray tracing (path tracing) for global illumination

# Visual Simulation

**CS184/284A** Aviator.aero; CAE Inc. **Ren Ng**

# Visual Simulation


**Driving simulator**
**Toyota Higashifuji Technical Center**

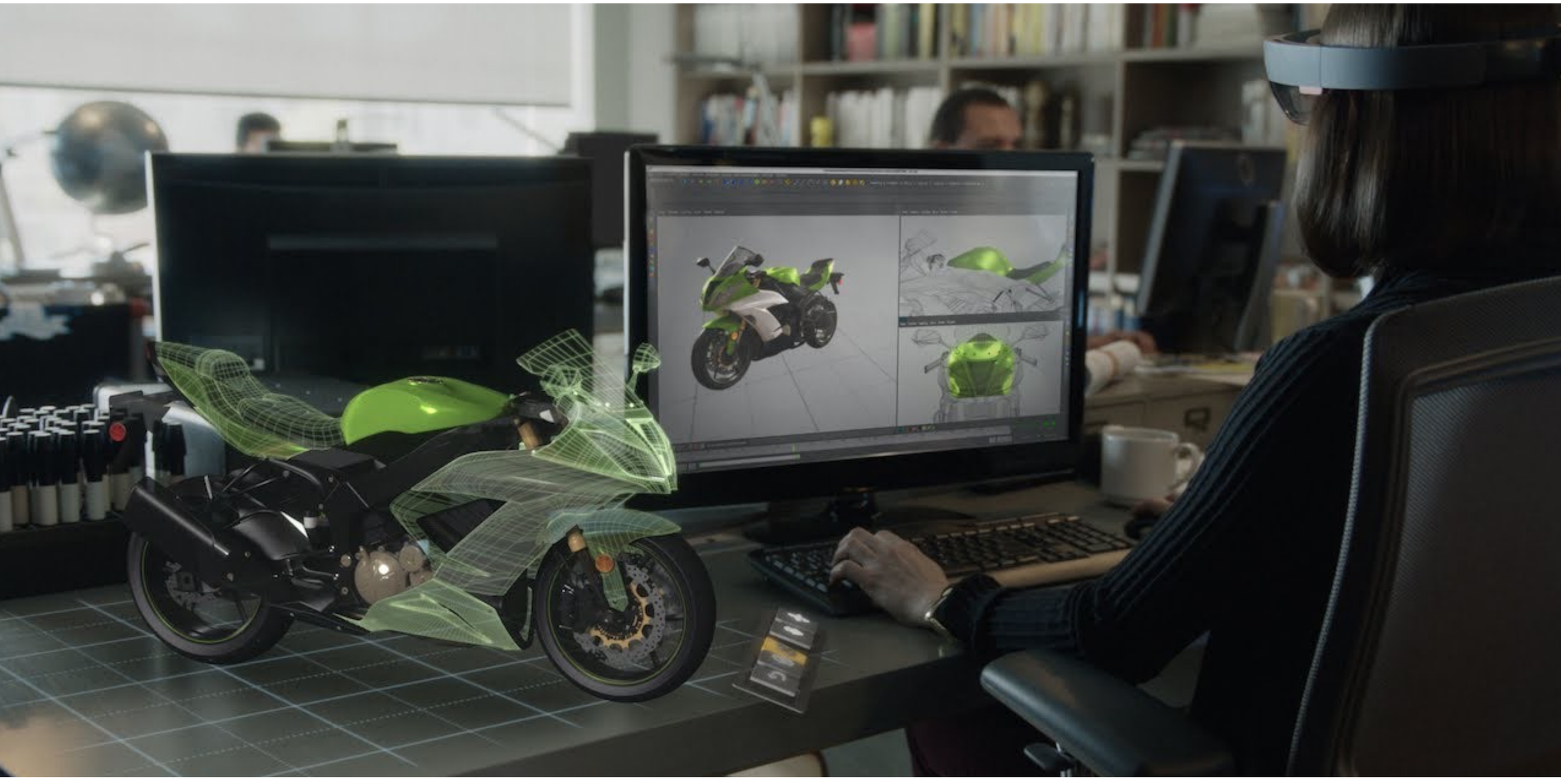

**da Vinci surgical robot**
**Intuitive Surgical**

Flight simulator, driving simulator, surgical simulator, …

# Virtual Reality


HTC Vive headset and controllers

# Augmented Reality



Microsoft Hololens augmented reality headset concept

# “Mixed Reality”


vive.com

# Product Design and Visualization

Ikea - over 75% of catalog is rendered imagery

# Product Design and Visualization

Photograph


Simulation

# Product Design and Visualization

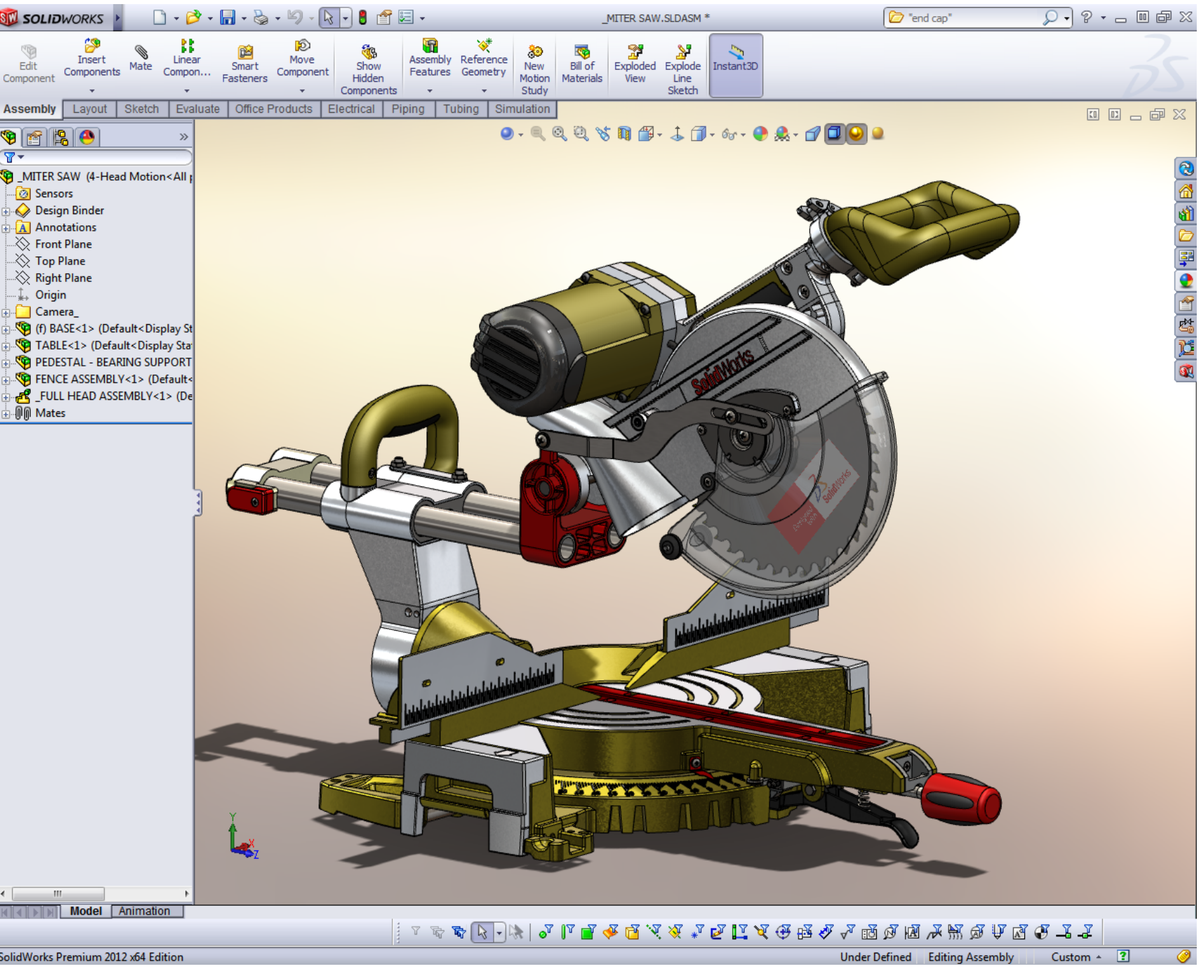
Tesla Model X concept (2012)

# Product Design and Visualization

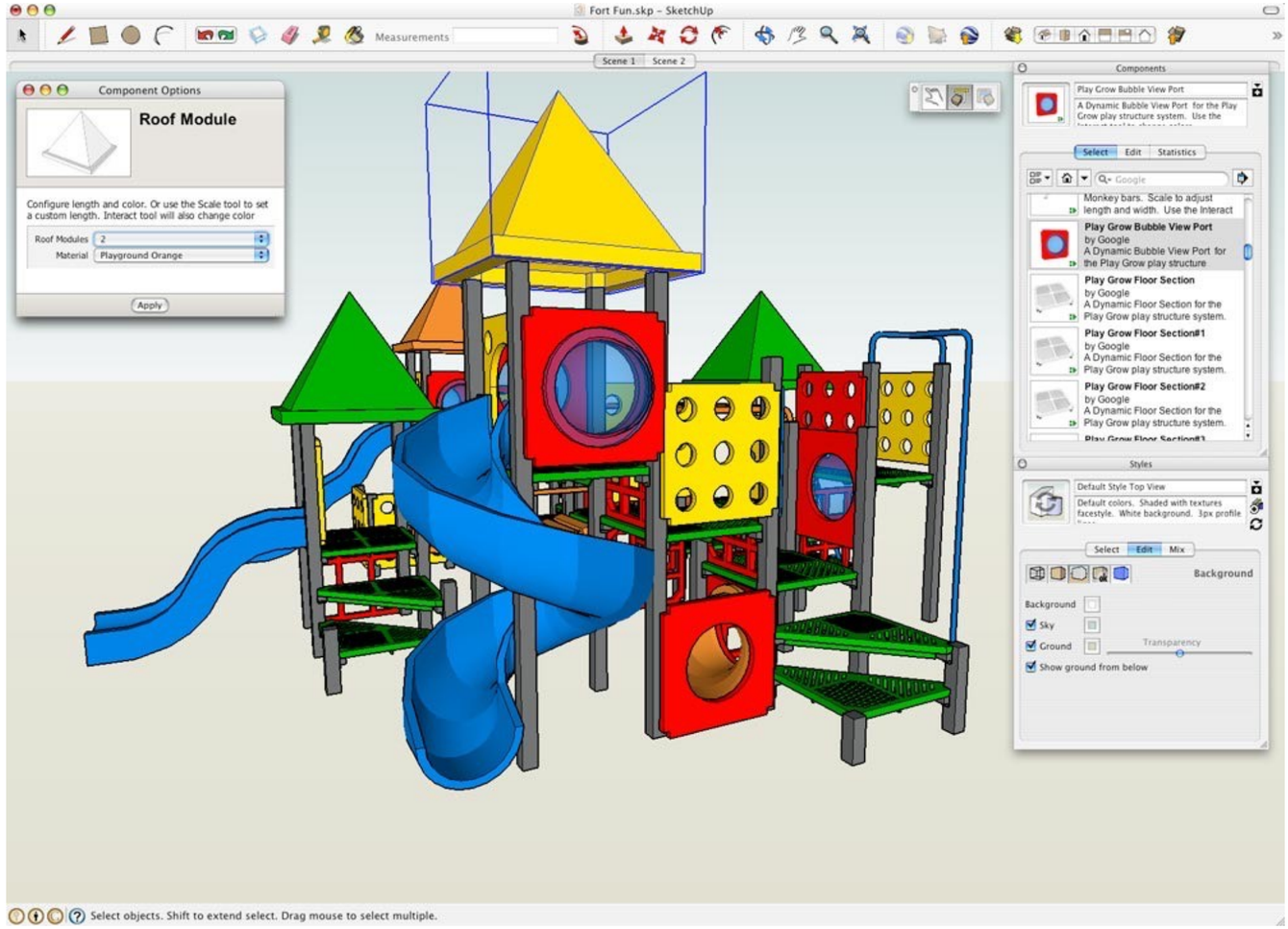
Credit: EV obsession.com, James Ayre

Tesla Model X production

# Computer-Aided Design



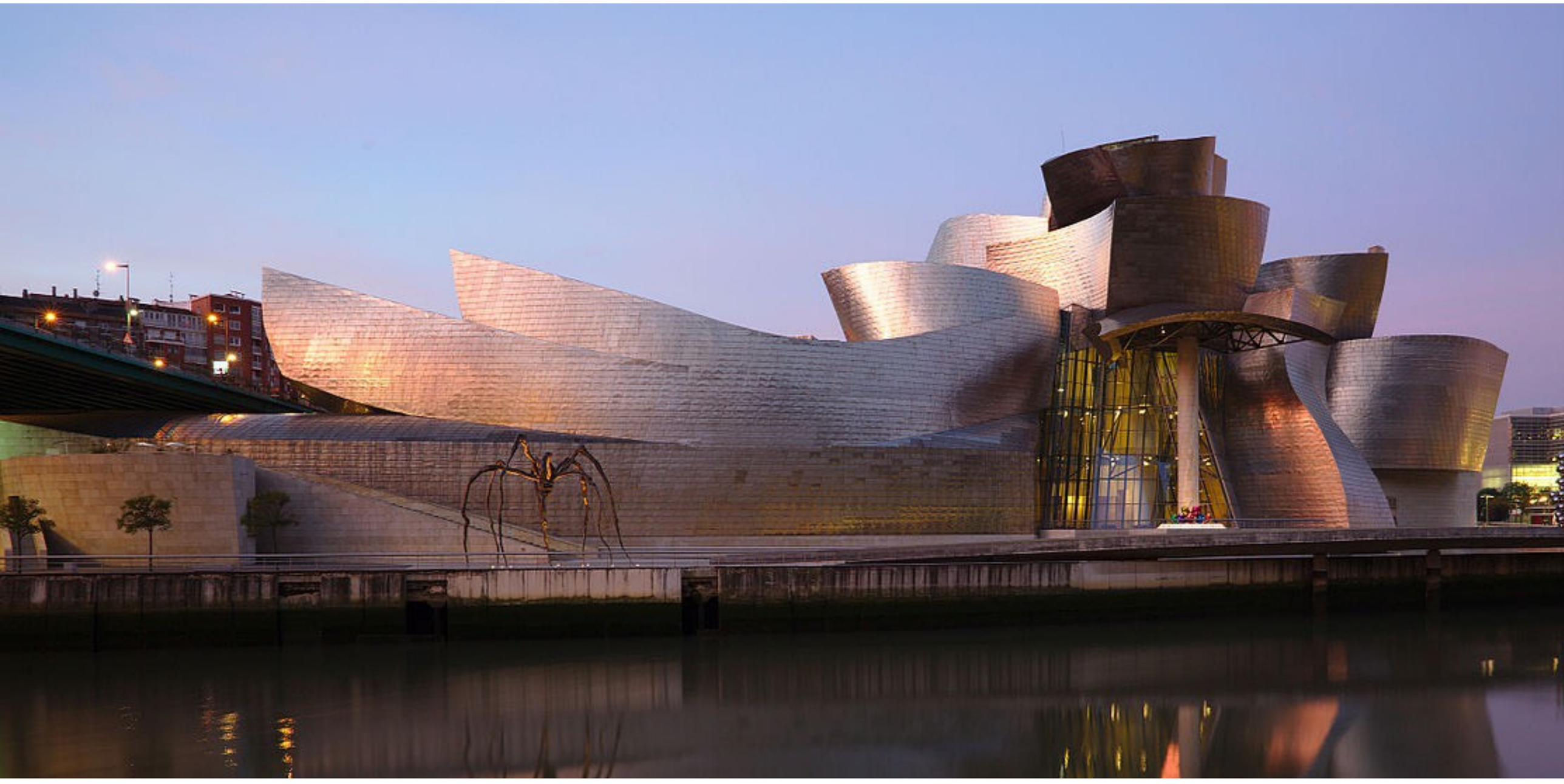

SolidWorks




SketchUp

For mechanical, architectural, electronic, optical, ...

# Architectural Design

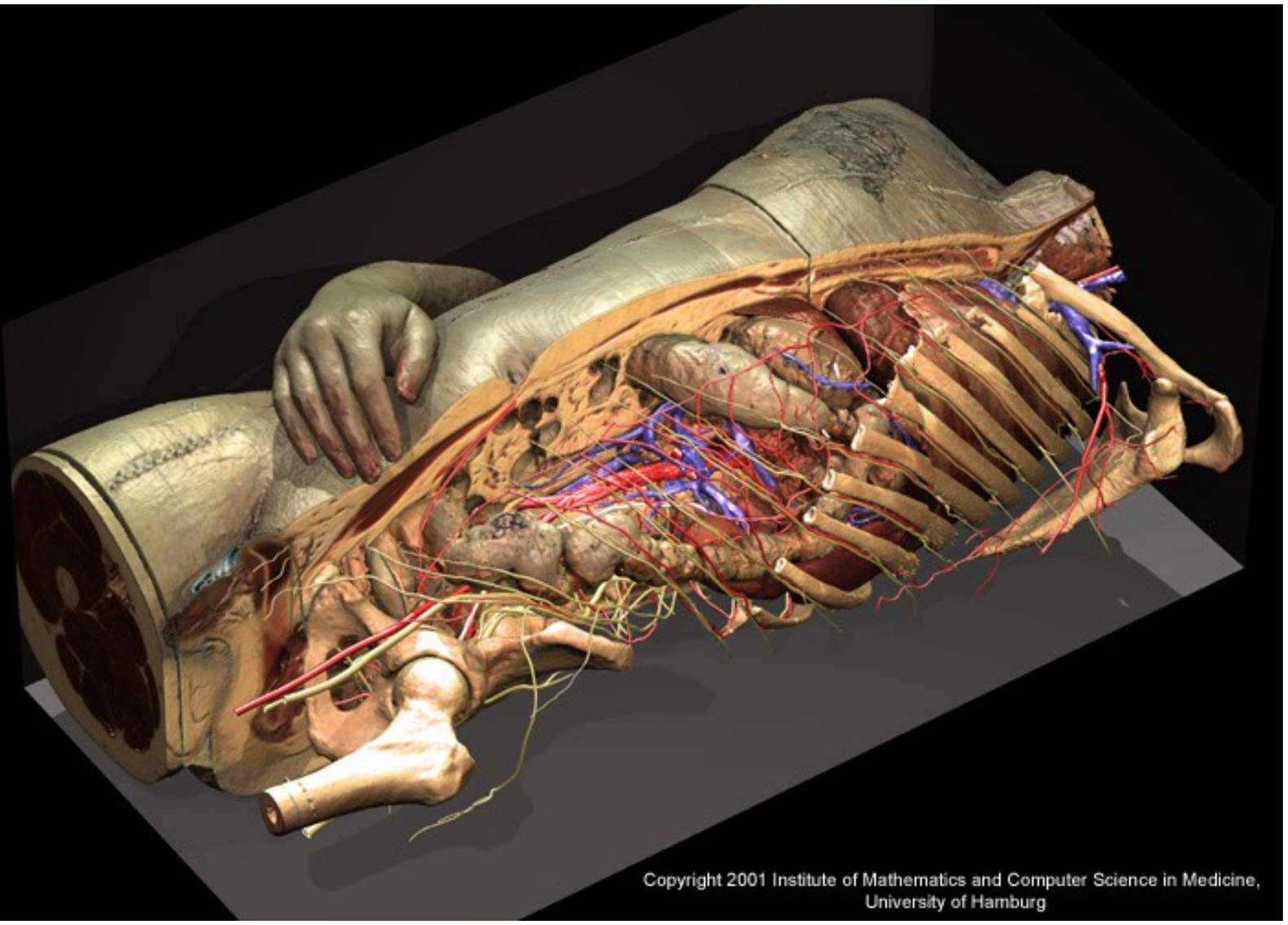


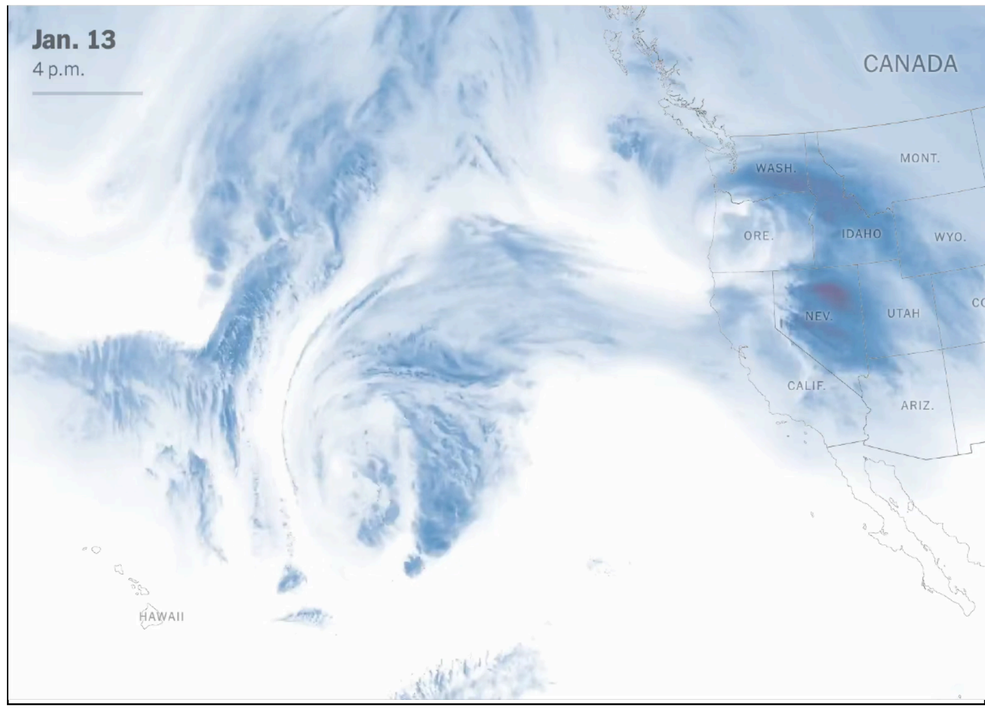
Bilbao Guggenheim, Frank Gehry

# Architectural Design

## Heydar Aliyev Center, Zaha Hadid Architects

# Visualization



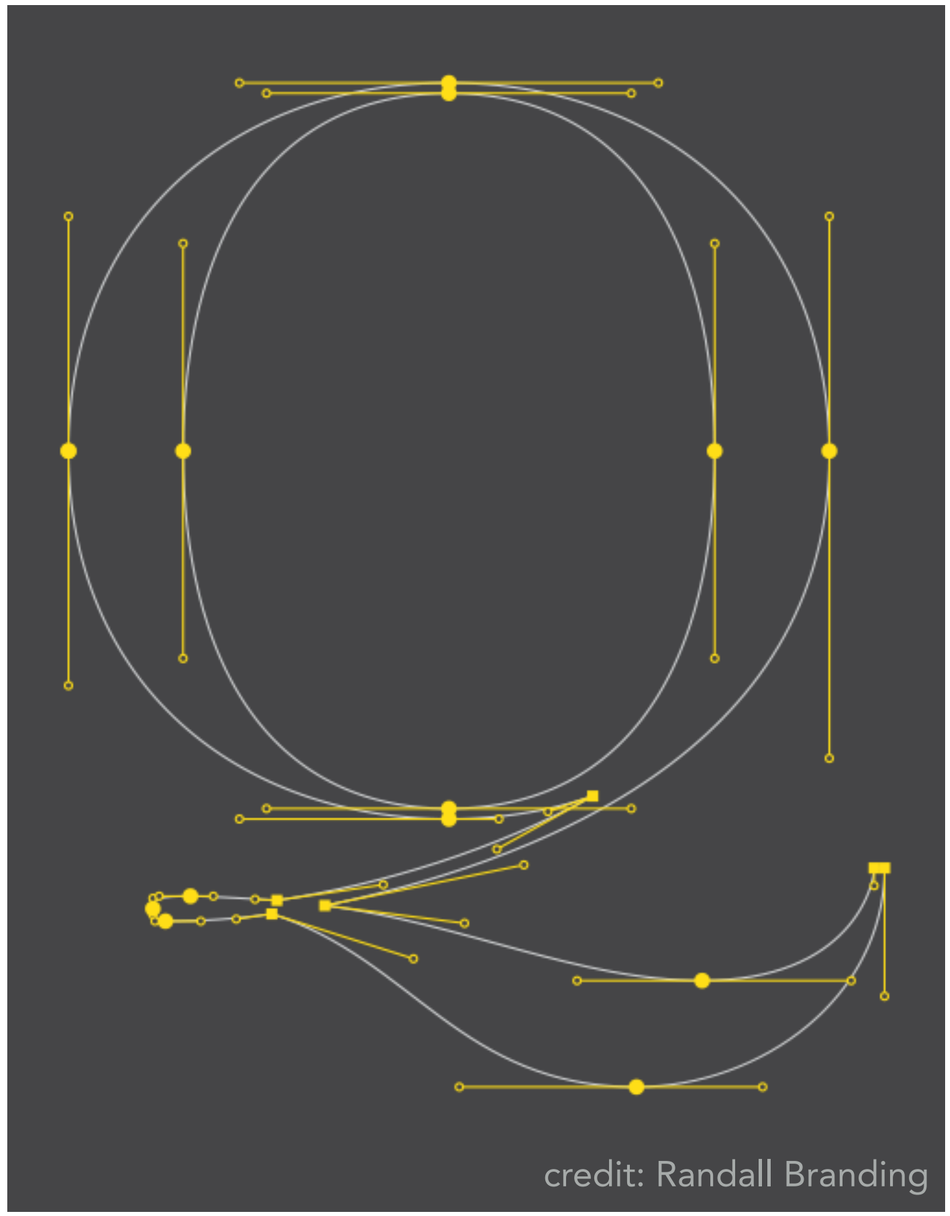


Science, engineering, medicine, journalism, …

# Typography

The Quick Brown Fox Jumps Over The Lazy Dog

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz 0123456789



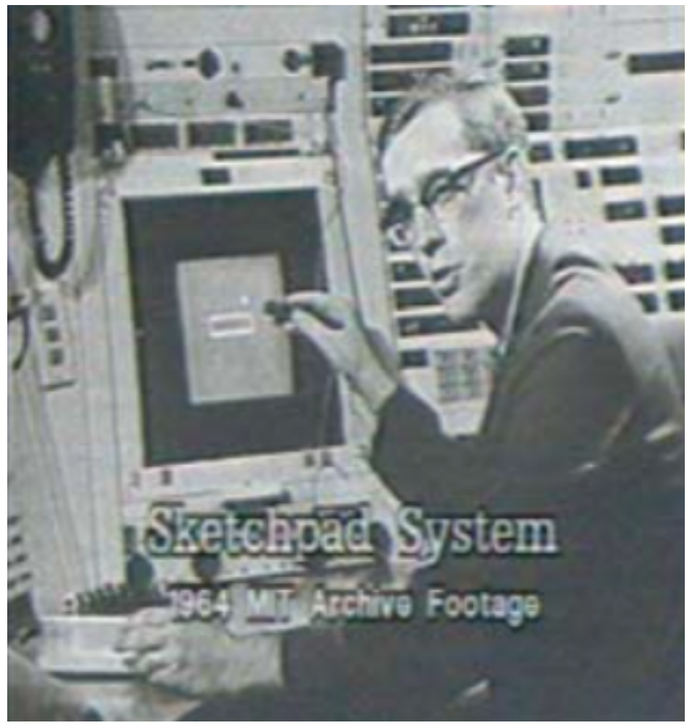
credit: Randall Branding

## Baskerville

# Graphical User Interfaces

Desktop metaphor

- Input: Keyboard, mouse
- Ouput: Cathode-ray tube




**Ivan Sutherland, Sketchpad**
**Light pen, vector display**

**Doug Engelbart**
**Mouse**

# Graphical User Interfaces



2D drawing and animation are ubiquitous in computing.
Typography, icons, images, transitions, transparency, ...

# Graphical User Interfaces

2D drawing and animation are ubiquitous in computing.

Typography, icons, images, transitions, transparency, ...

# Graphical User Interfaces

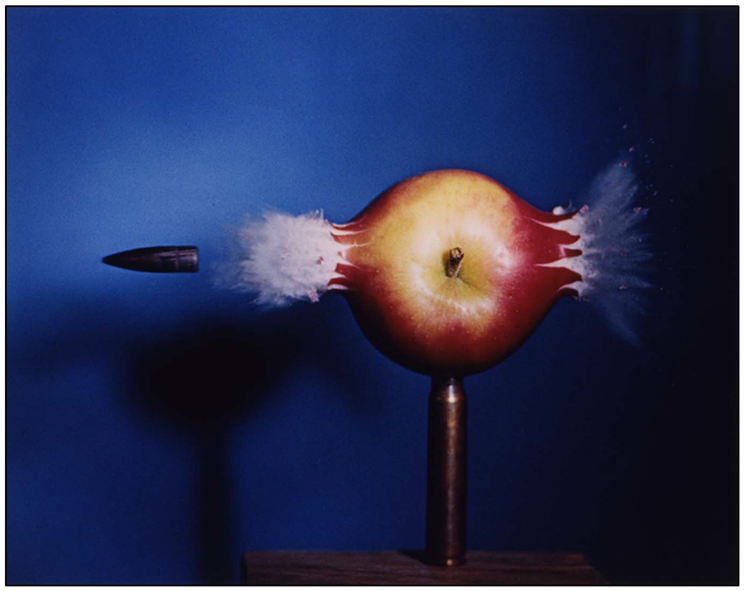

https://www.youtube.com/watch?v=YndL315tQq8

# Digital Illustration

Meike Hakkart

http://maquenda.deviantart.com/art/Lion-done-in-illustrator-327715059

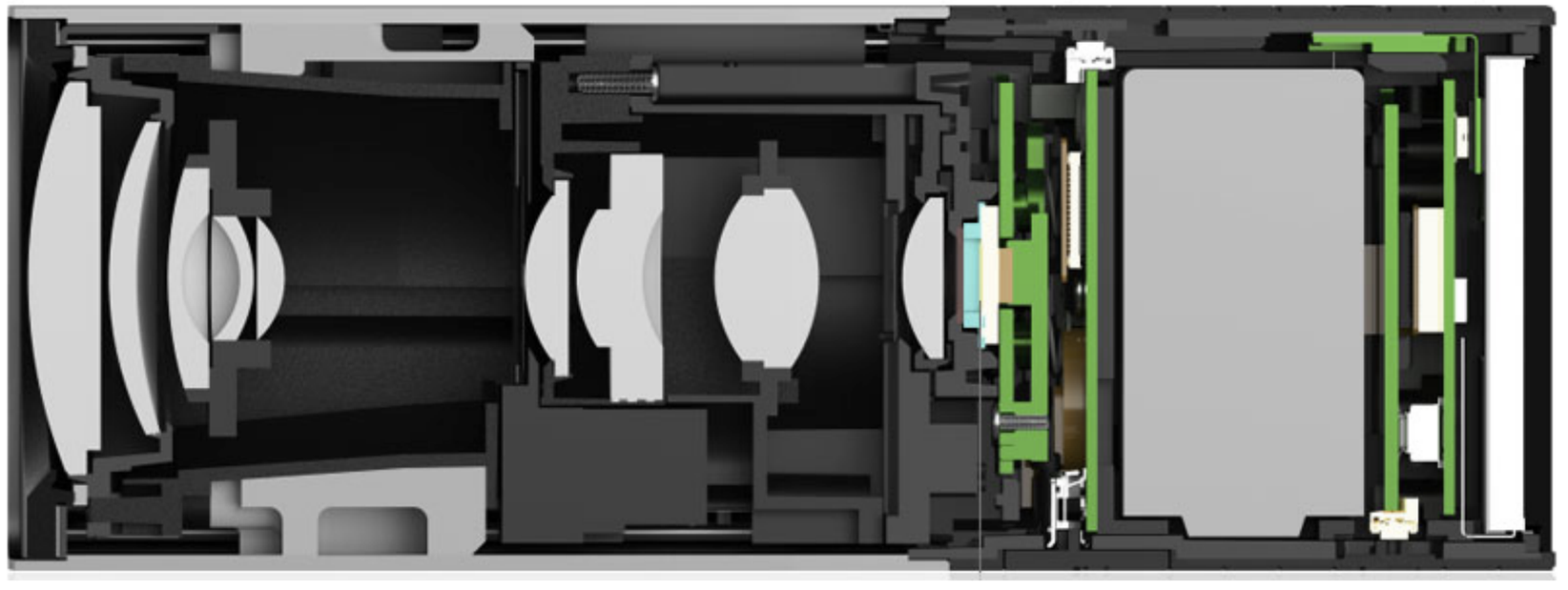
# Photography

NASA | Walter Iooss | Steve McCurry
Harold Edgerton | NASA | National Geographic

# Digital and Computational Cameras



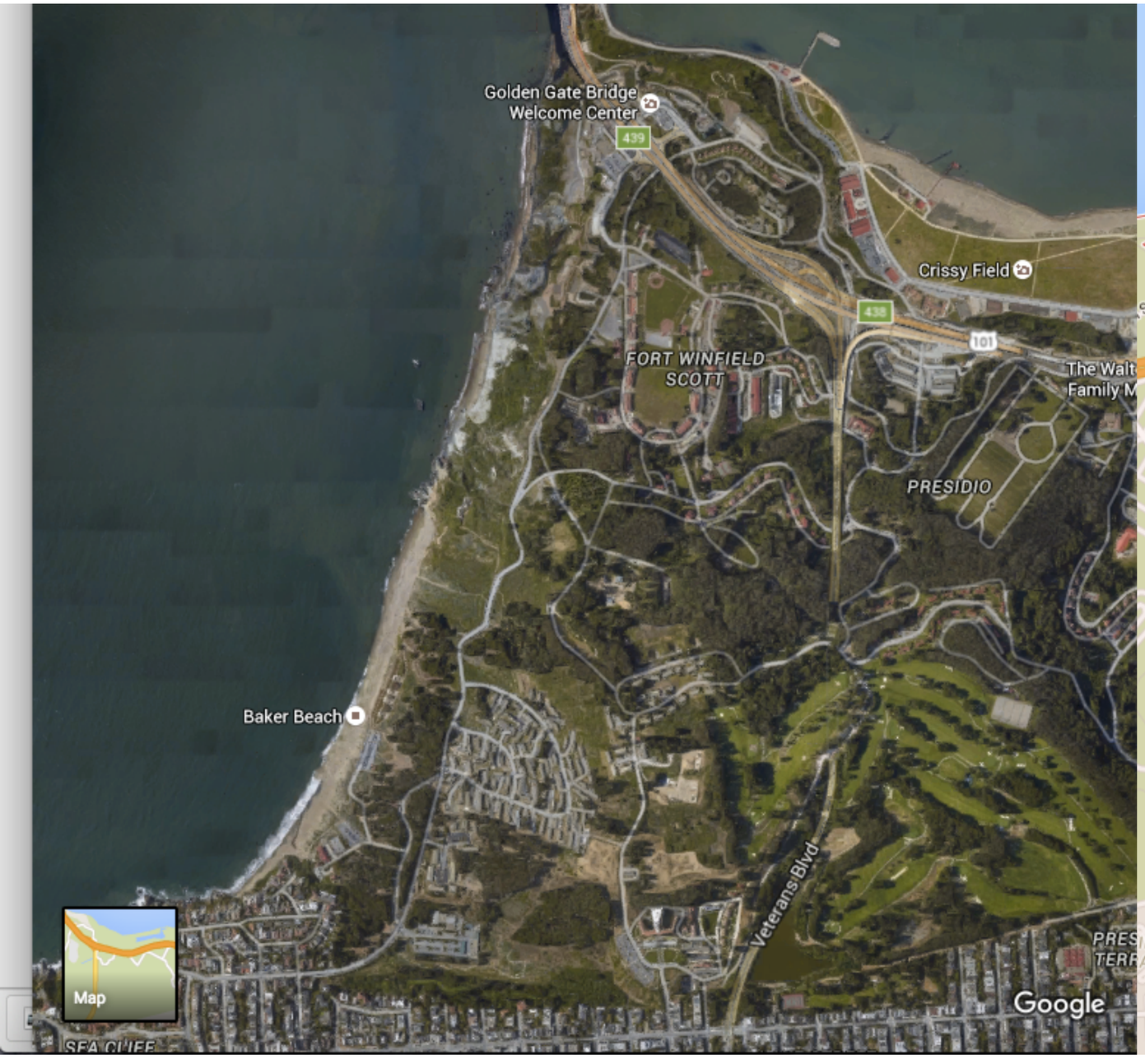


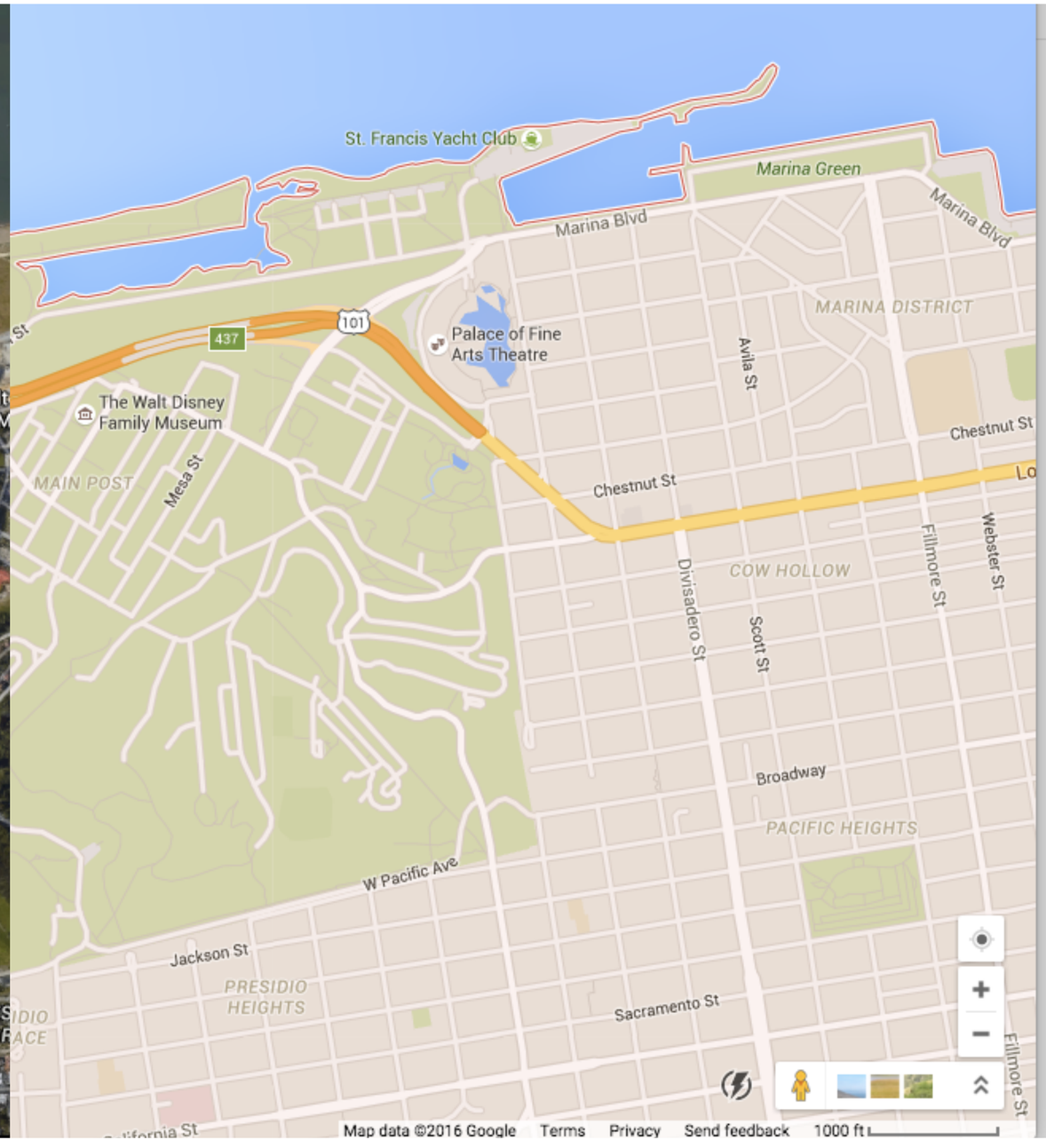
Panaromic stitching, HDR photos, light field cameras, …

# Ubiquitous Imaging

## Cameras everywhere

# Imaging in Mapping




Maps, satellite imagery, street-level imaging,...

# Imaging in Mapping


Maps, satellite imagery, street-level imaging,...

# Imaging for Computer Vision

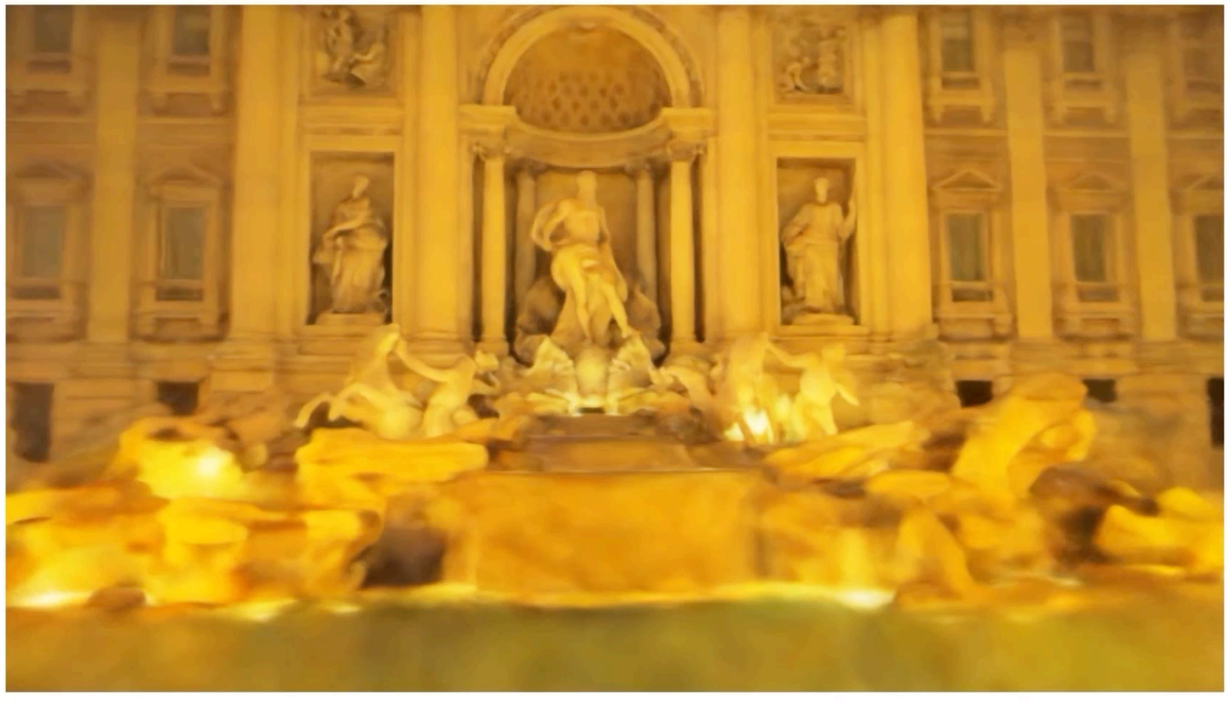
ImageNet: 15M images, 22K categories

http://image-net.org

# Imaging for Robotics


Google's "Arm Farm"

# Neural Radiance Fields



# Generative Visual AI

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## Photoshop GenFill

Ren Ng

# Generative Visual AI

CS184/284A

## Photoshop GenFill

Ren Ng

# Foundations of Graphics and Imaging

These applications require sophisticated theory and systems

Science and Mathematics

- Physics of light, color, optics, …
- Math of curves, surfaces, geometry, perspective, …

Technology and Systems

- Displays, GPUs, input devices, …
- Cameras, lenses, sensors, …

Perception and Art

- Perception: color, stereo, motion, image quality, …
- Art and design: composition, form, lighting, ...

# Course Goals

Overview of core ideas in graphics and imaging

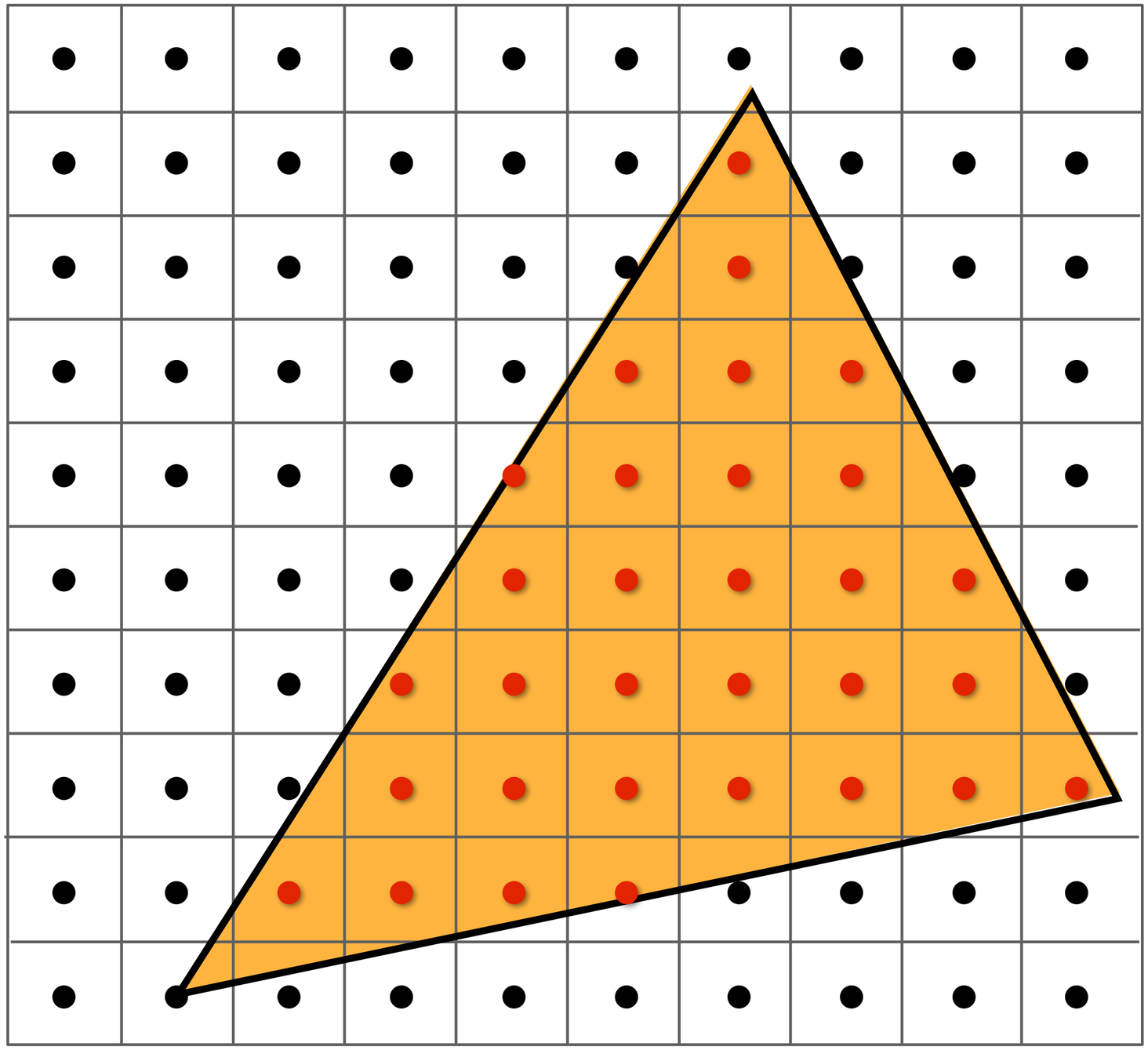
- Modeling the world, image synthesis
- 3D graphics: geometry, rendering, animation
- Image capture, manipulation and display

Acquire core concepts and skills

- Representations (geometry, images, transforms, …)
- Algorithms (sampling, subdivision, ray-tracing, …)
- Technology (GPUs, displays, cameras, …)

# Course Topics

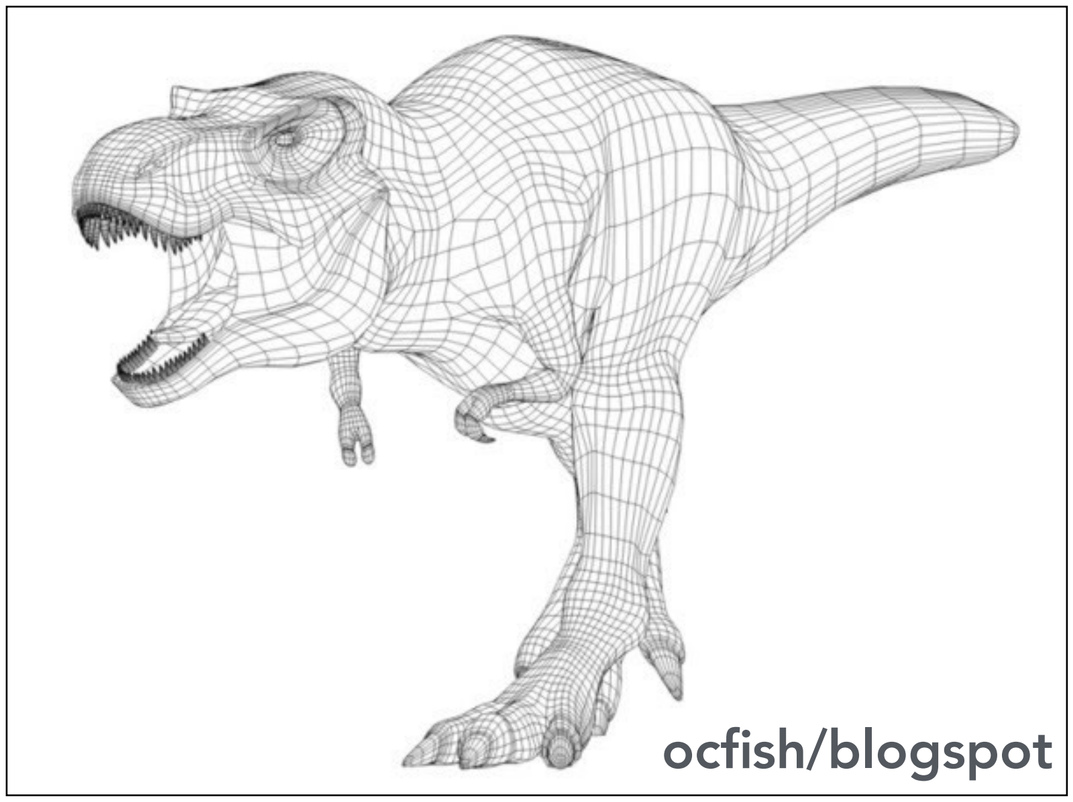
# Drawing Digital Images (Rasterization)



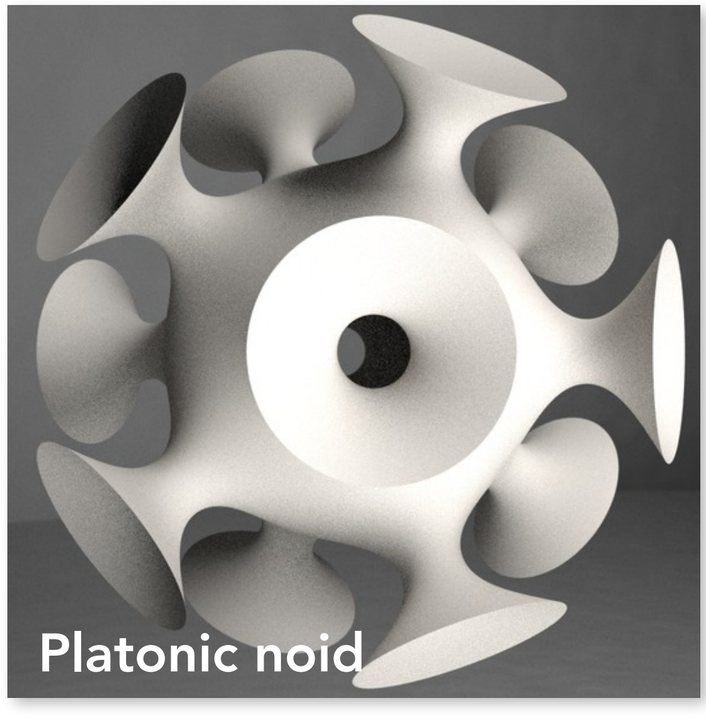
# Filtering and Sampling

No Jaggies

# Modeling Geometry

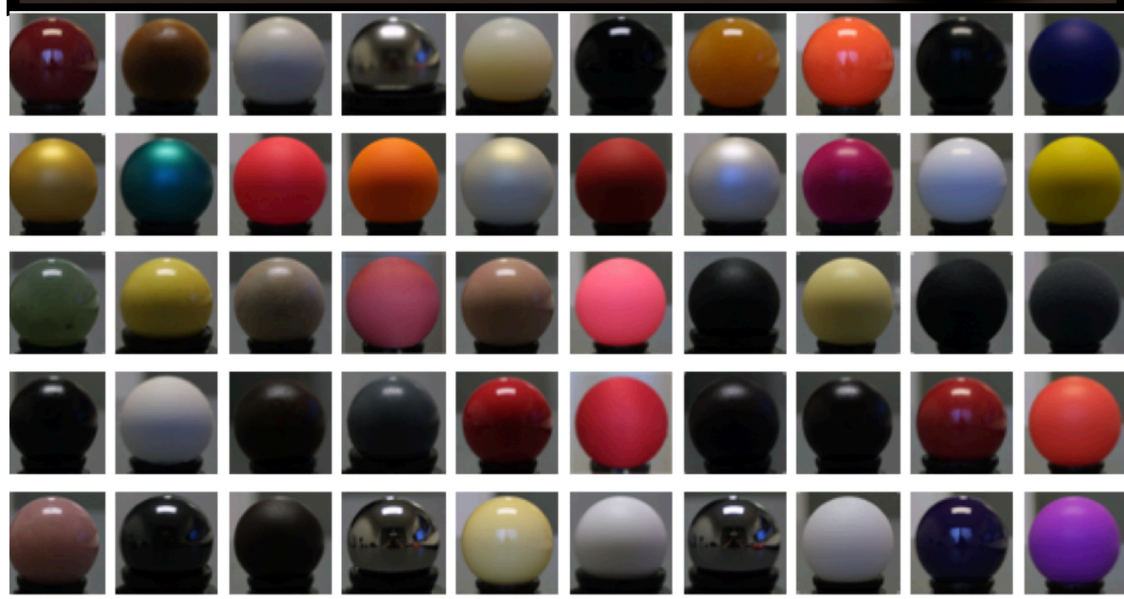







# Modeling Material Properties





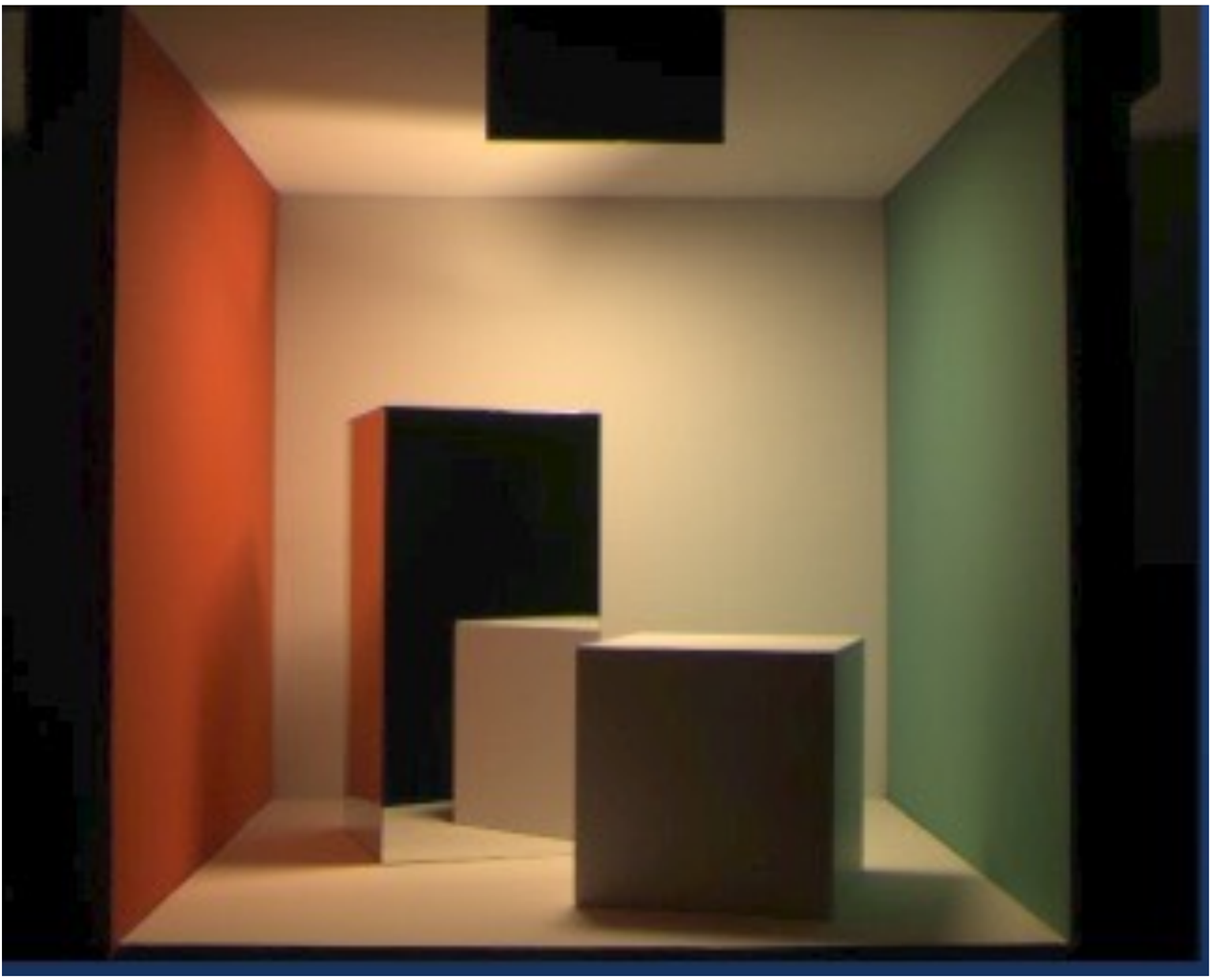
# Modeling Lighting

Monster’s Inc., 2001

# Modeling Lighting

Monster’s U., 2013

# Light Transport and Image Synthesis



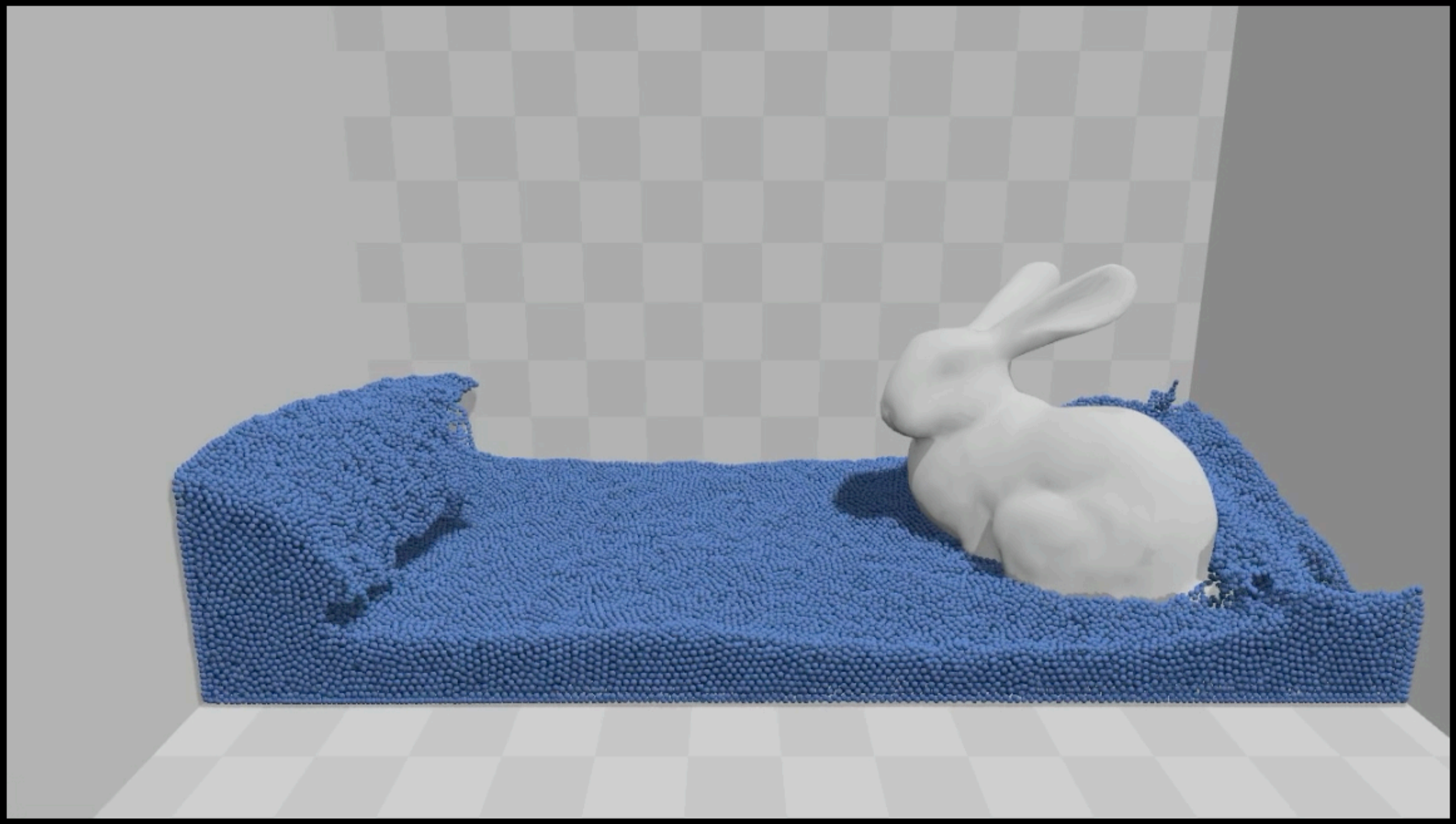
Photograph (CCD) vs. computer rendering

# How Do Cameras and Lenses Work?


Glenn Derene, Popular Mechanics

**CS184/284A** **Ren Ng**

# Animation and Physical Simulation

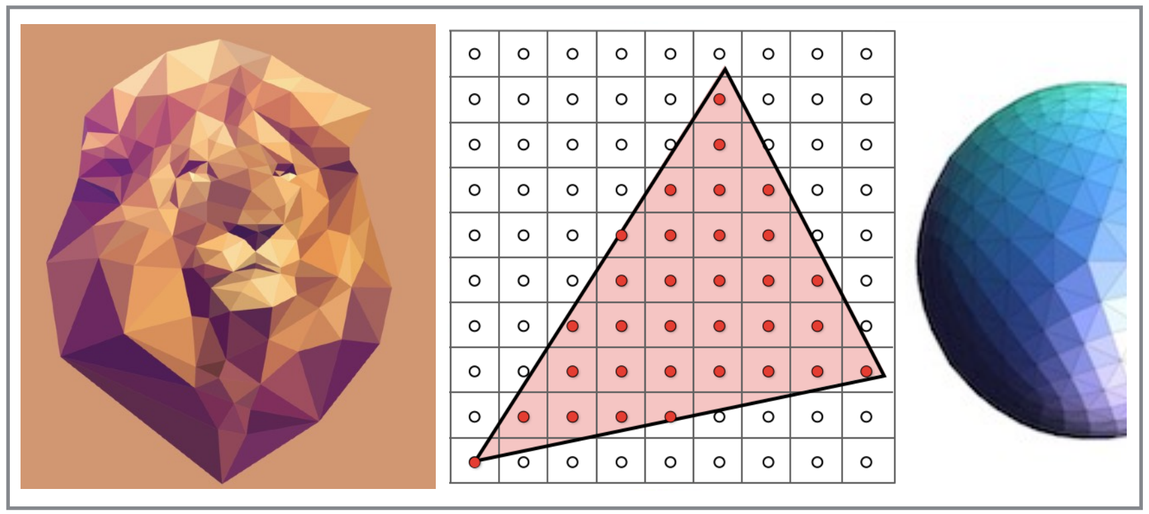


Position  Based Fluids, Macklin and Müller

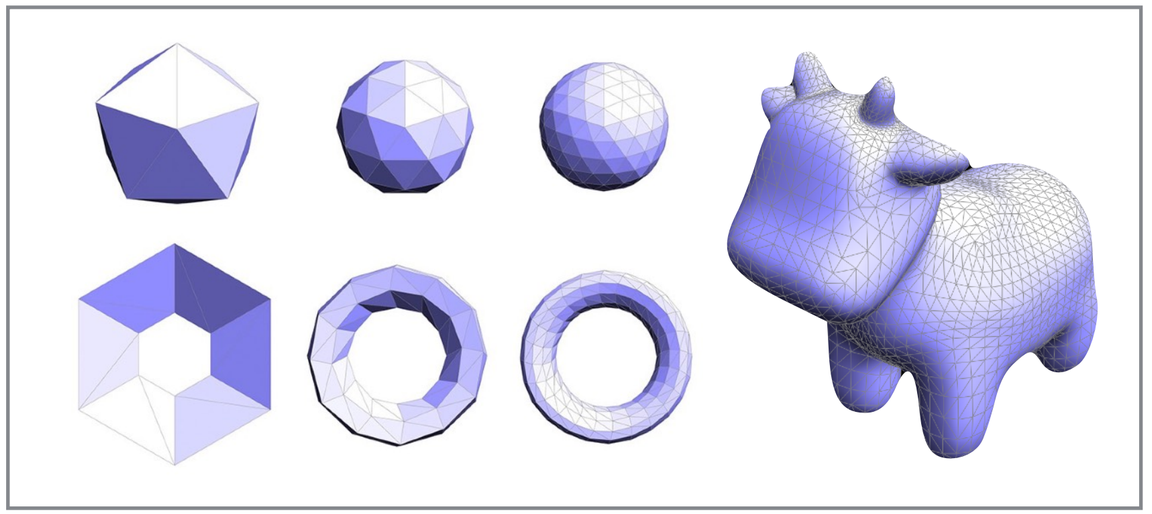
# Virtual Reality

# Hands-On Learning

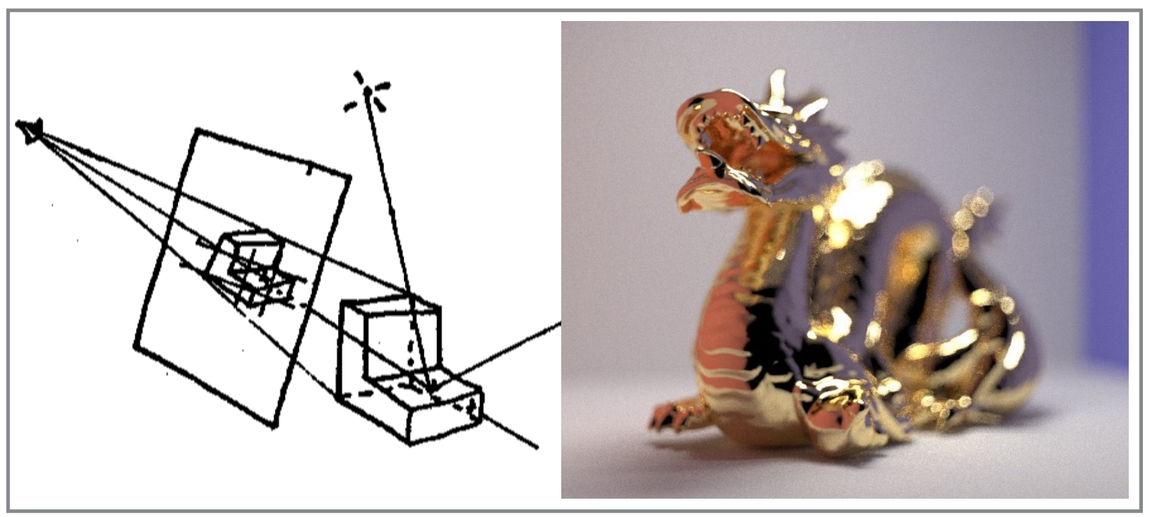
# Course Assignments



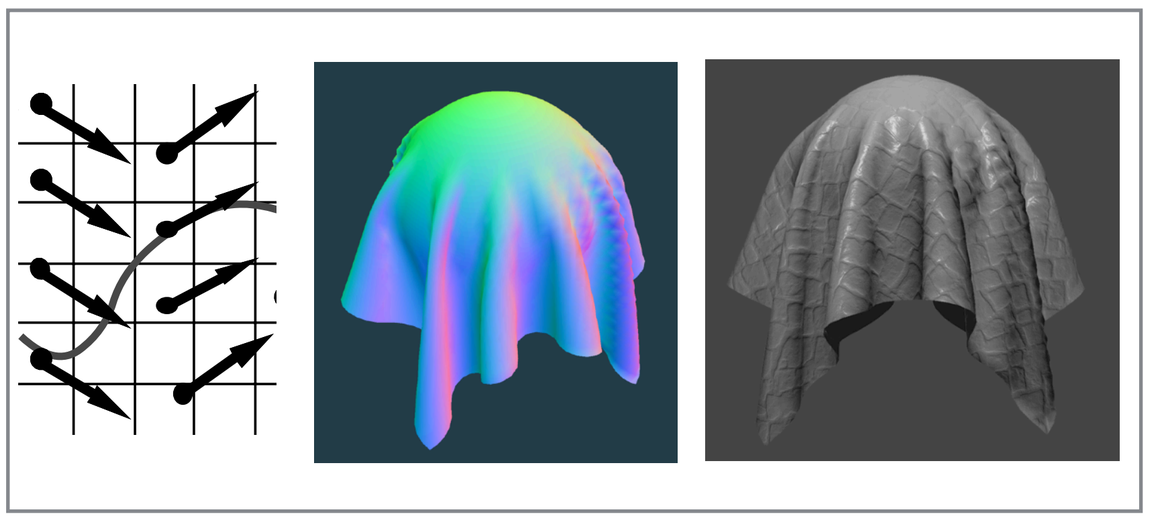
1. Digital Drawing (2 weeks)



2. Geometry (2 weeks)



3. Ray-Tracing (2 weeks)



4. Animation (2 weeks)

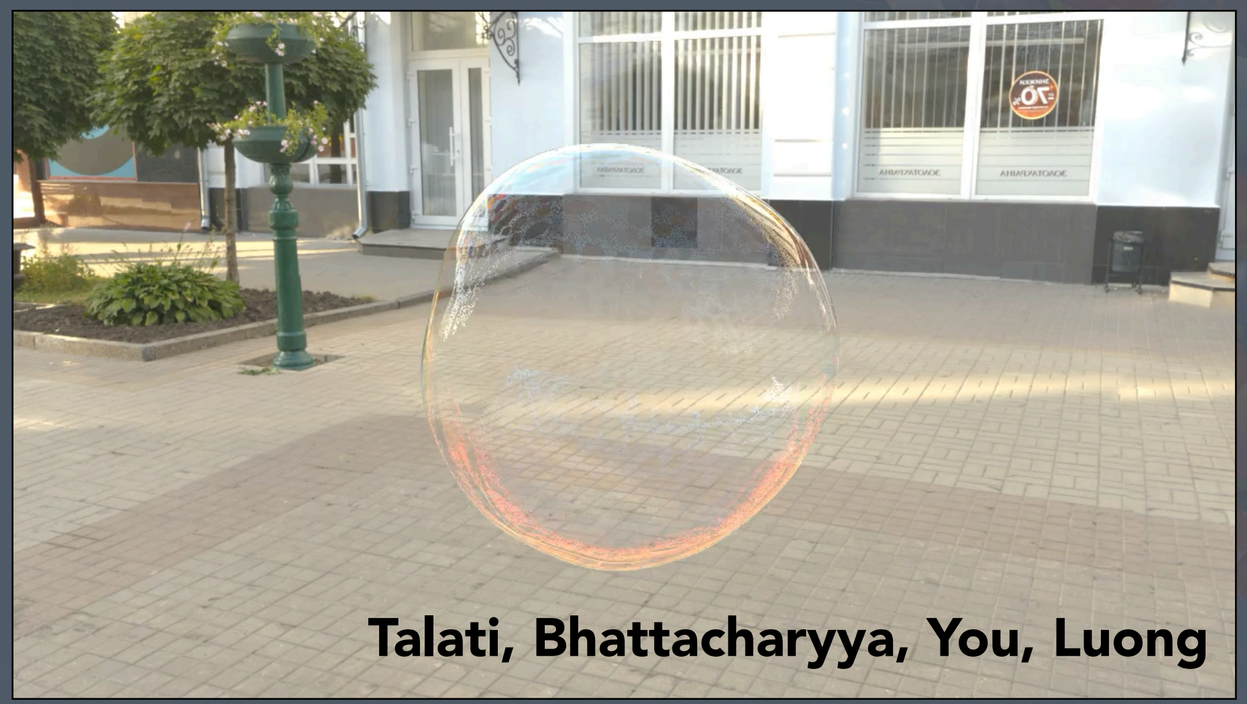
# Final Project

## Project Competition

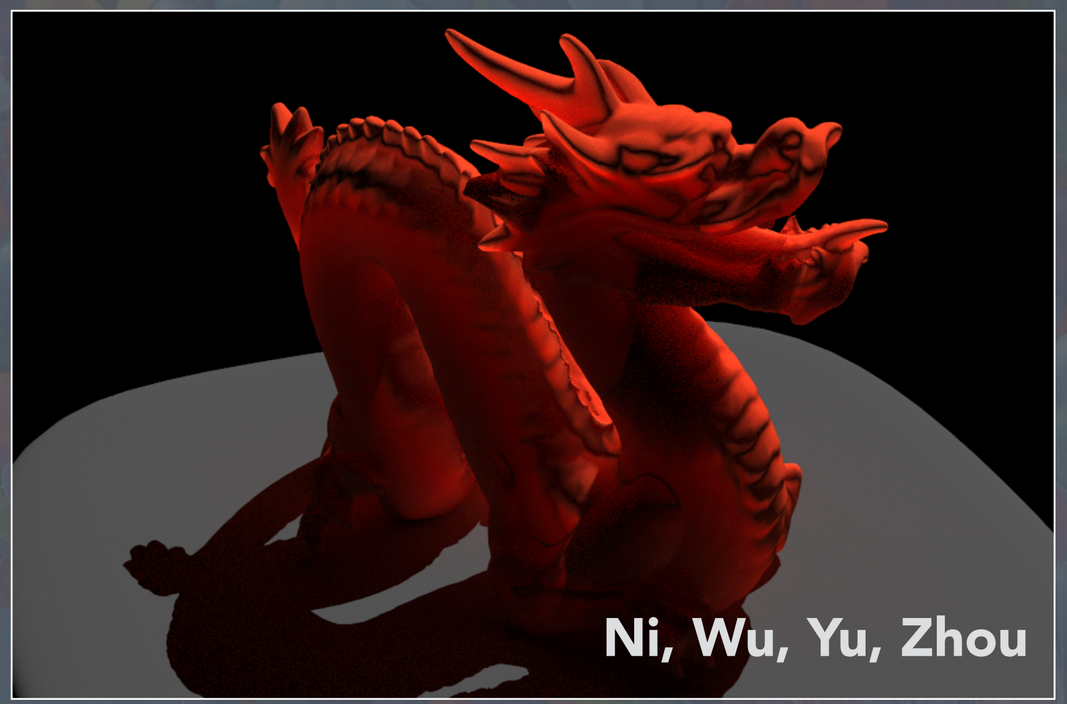
- 4 weeks, let your creativity take flight!
  (we will have suggested projects)
- Proposal; checkpoint; presentation, video, report

Credit: Pixar, Up

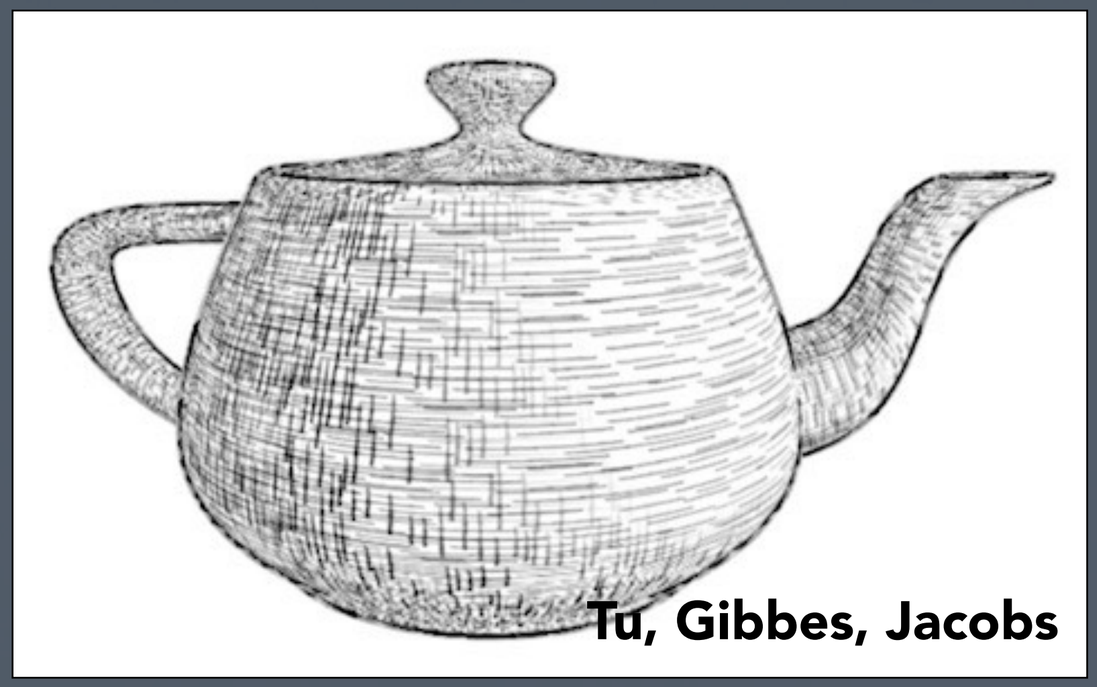
# Final Project - Examples



Talati, Bhattacharyya, You, Luong



Ni, Wu, Yu, Zhou

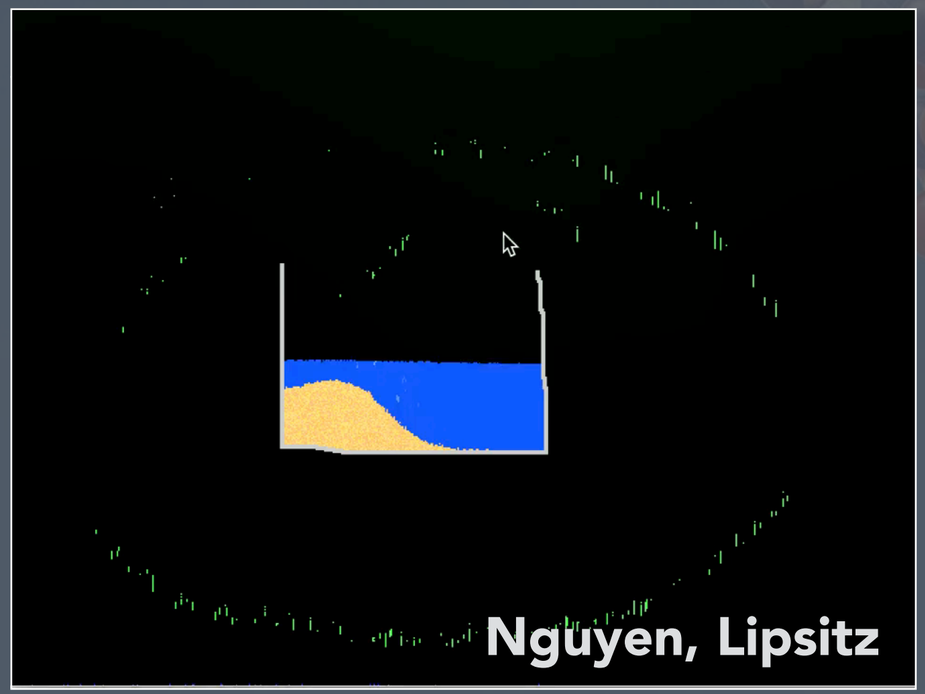


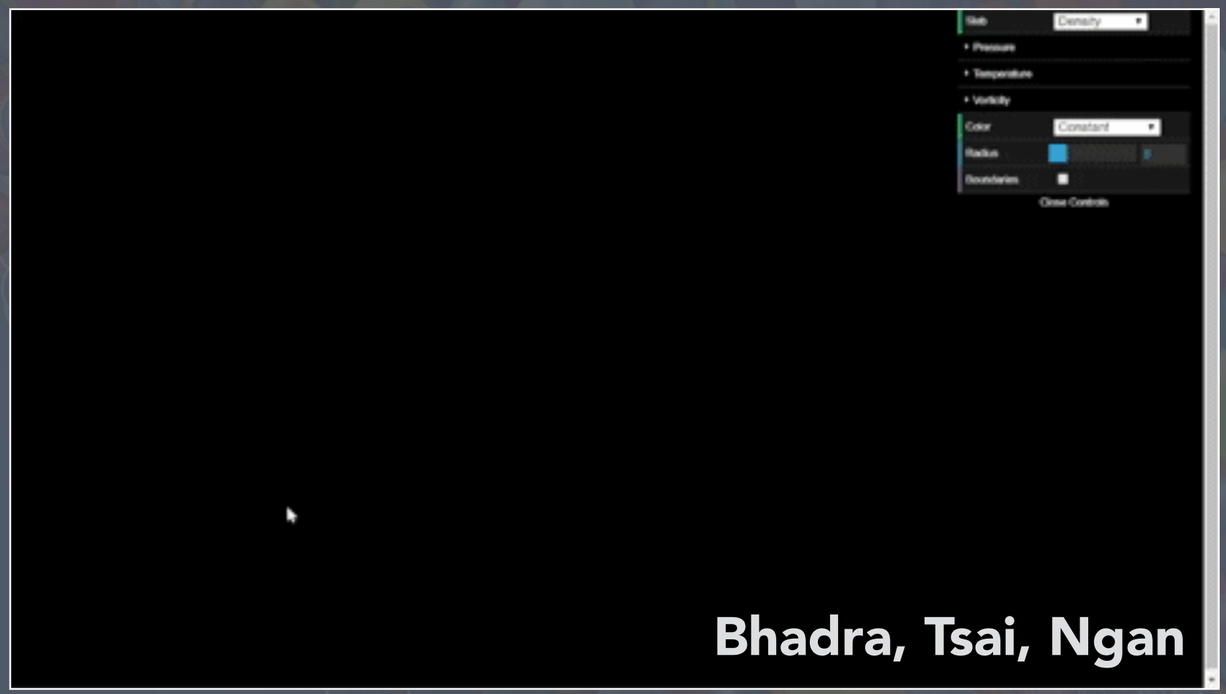
Tu, Gibbes, Jacobs

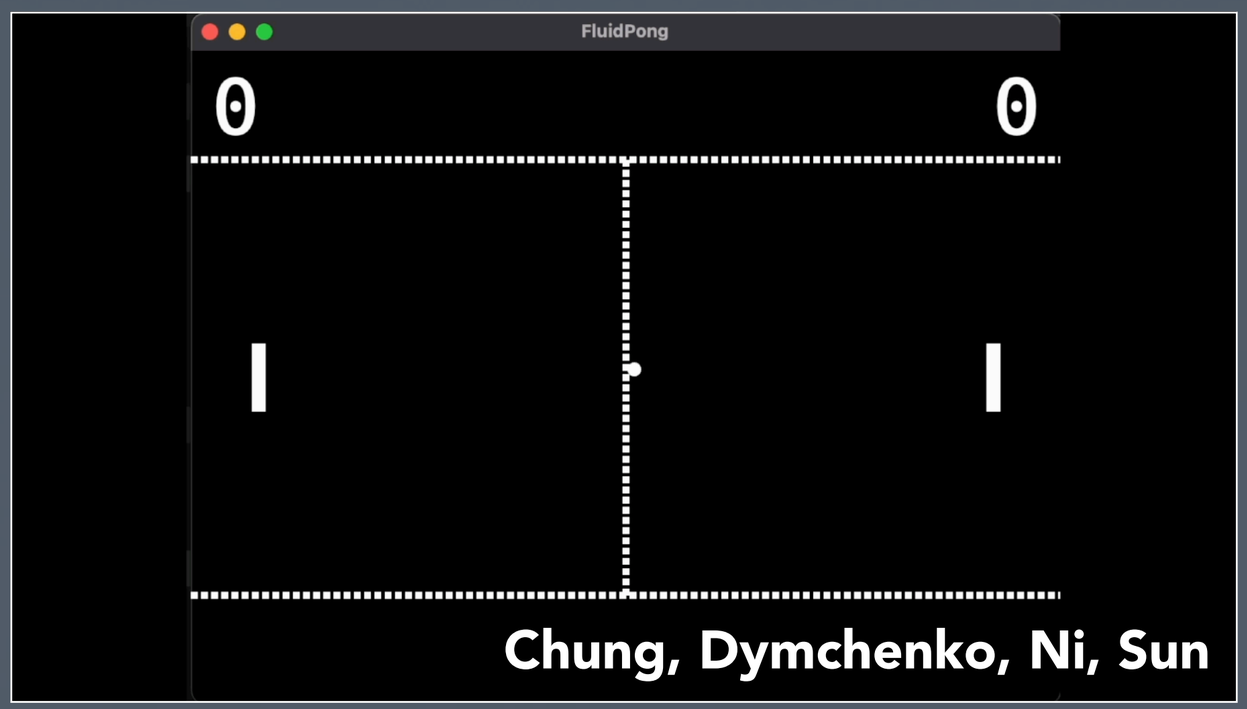
Doriwala, Kamat, Lim, Feguson

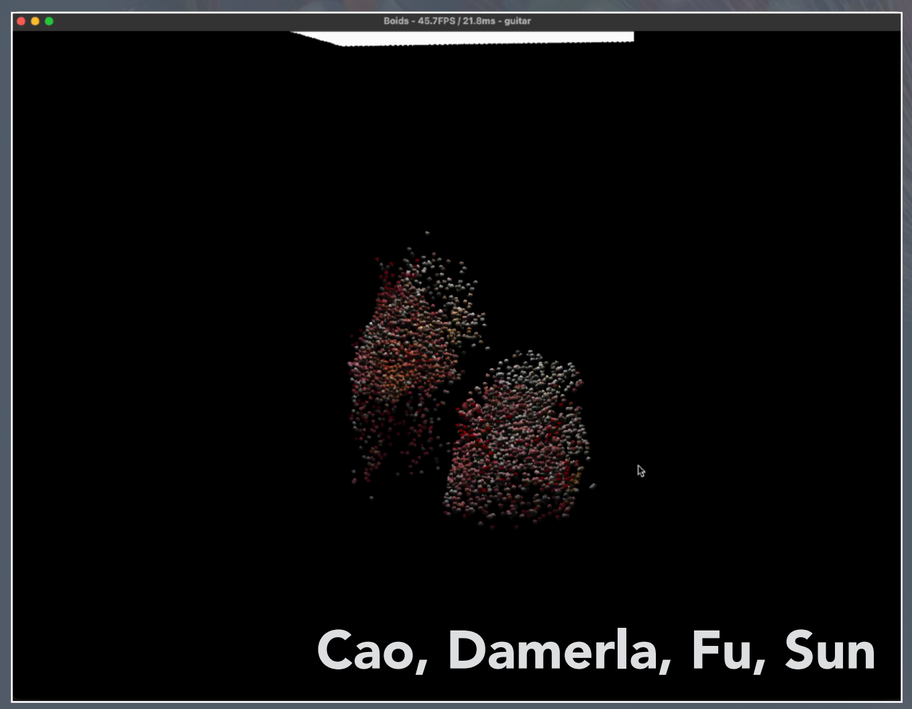
More examples and project reports on prior year course websites: cs184.eecs.berkeley.edu

# Final Project - Examples

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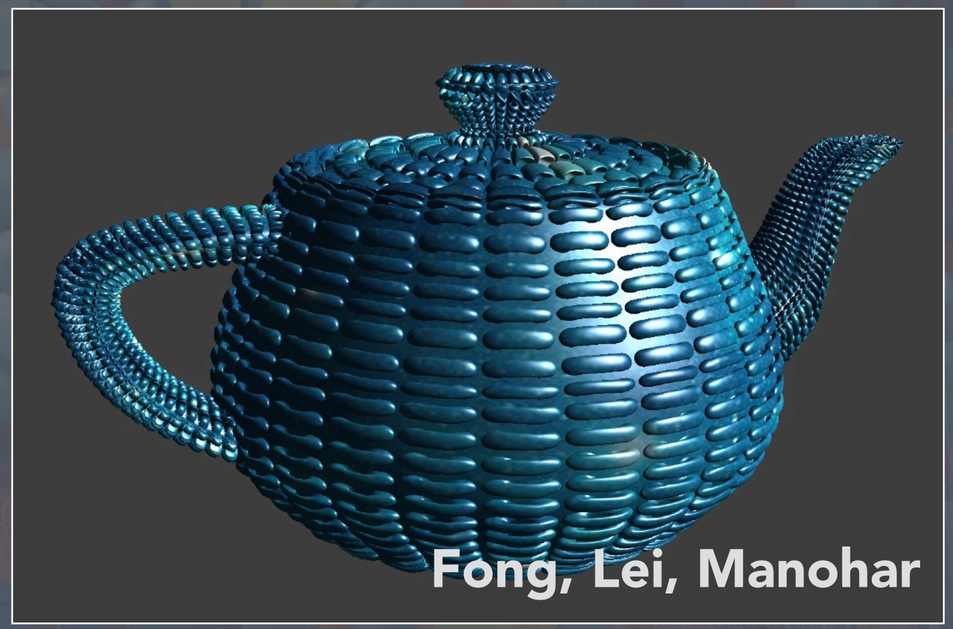
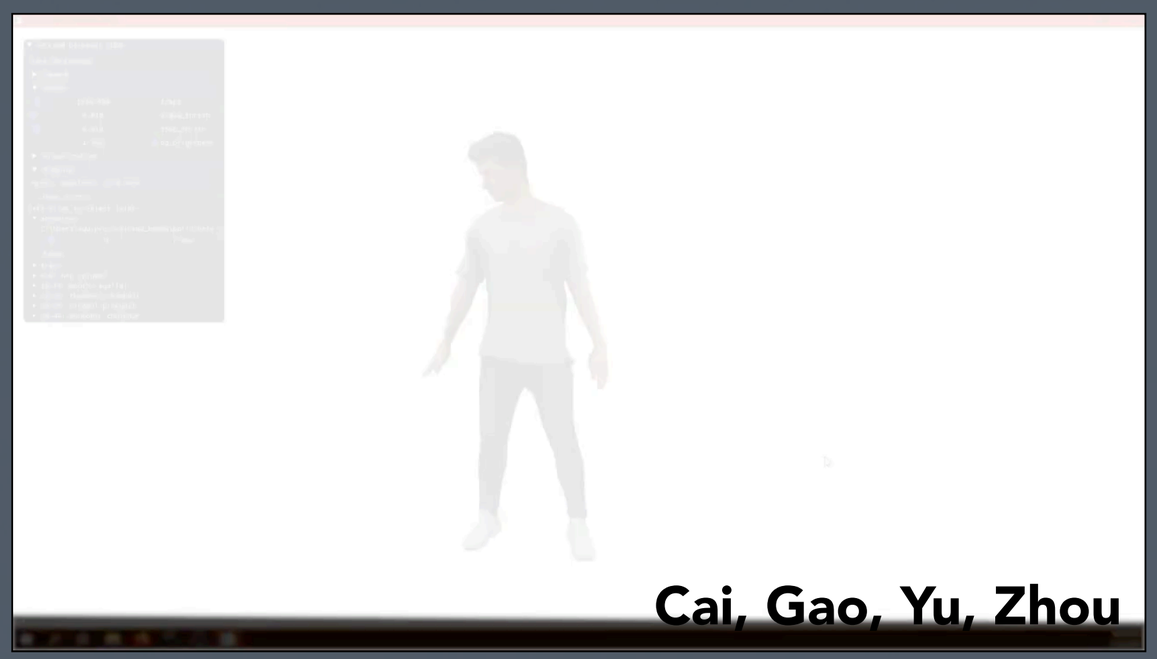
# Final Project - Examples



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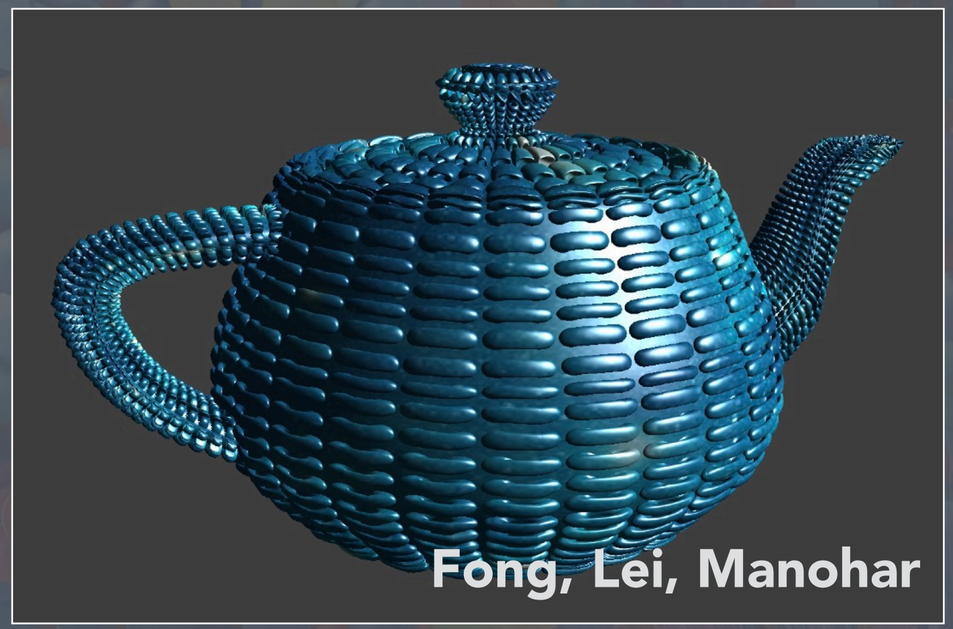
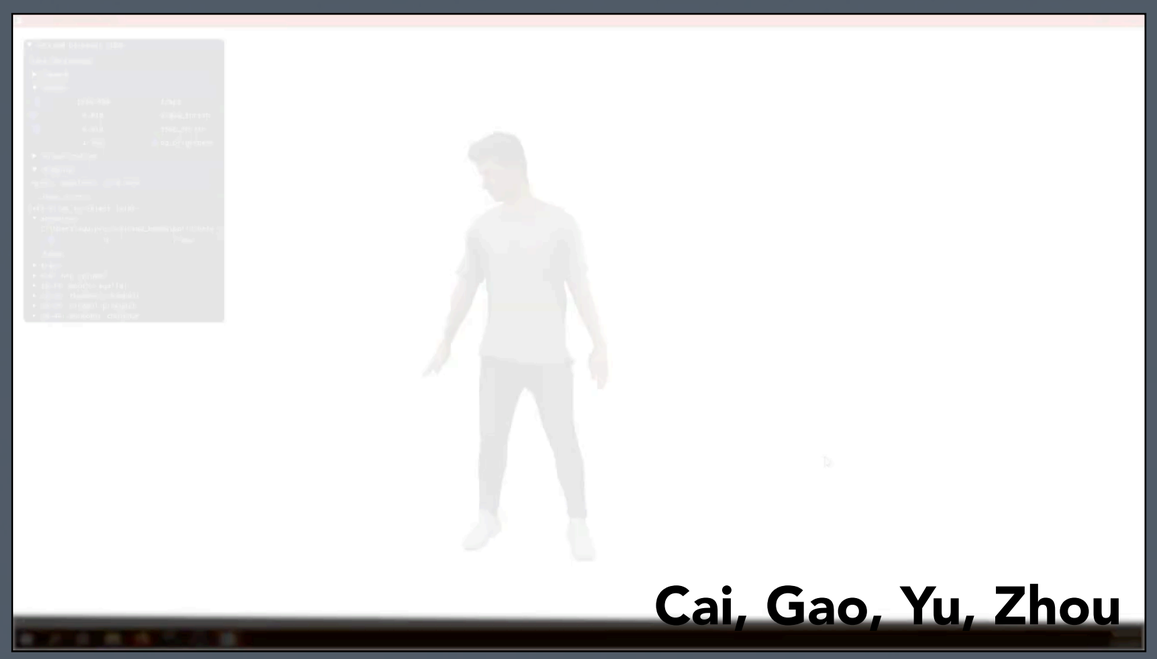
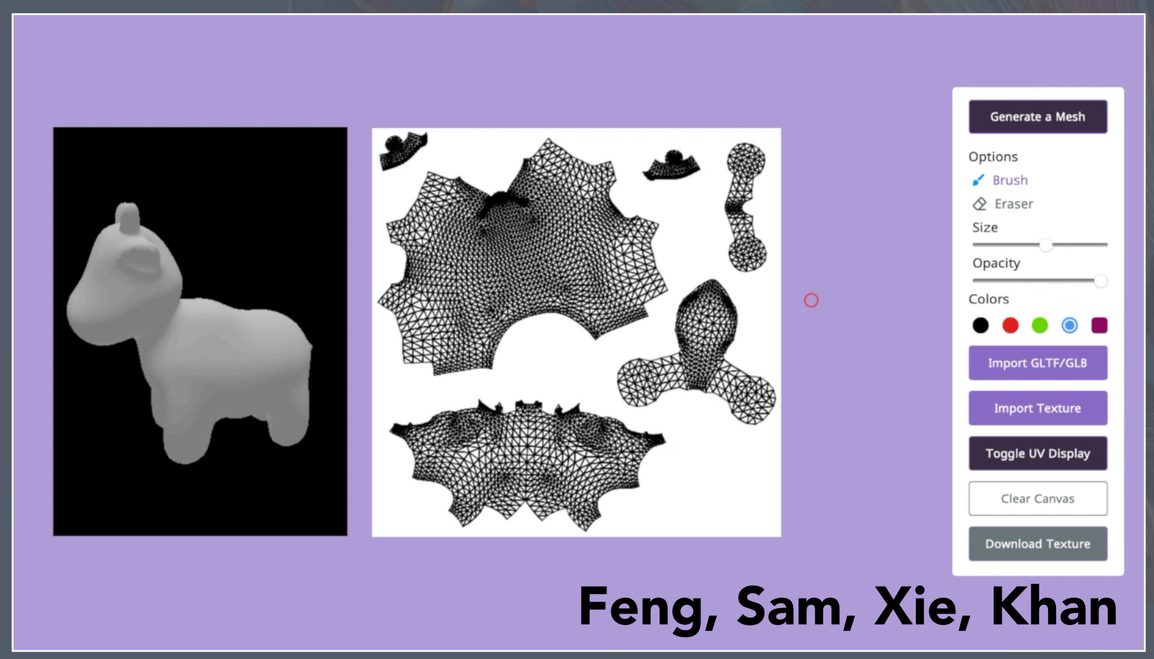
# Final Project - Examples


More examples and project reports on prior year course websites: cs184.eecs.berkeley.edu

# Course Logistics

# Prerequisites

## Math

- Vectors, matrices, basic linear algebra
- Helpful: exposure to stats, signal processing, Fourier transform

## Programming

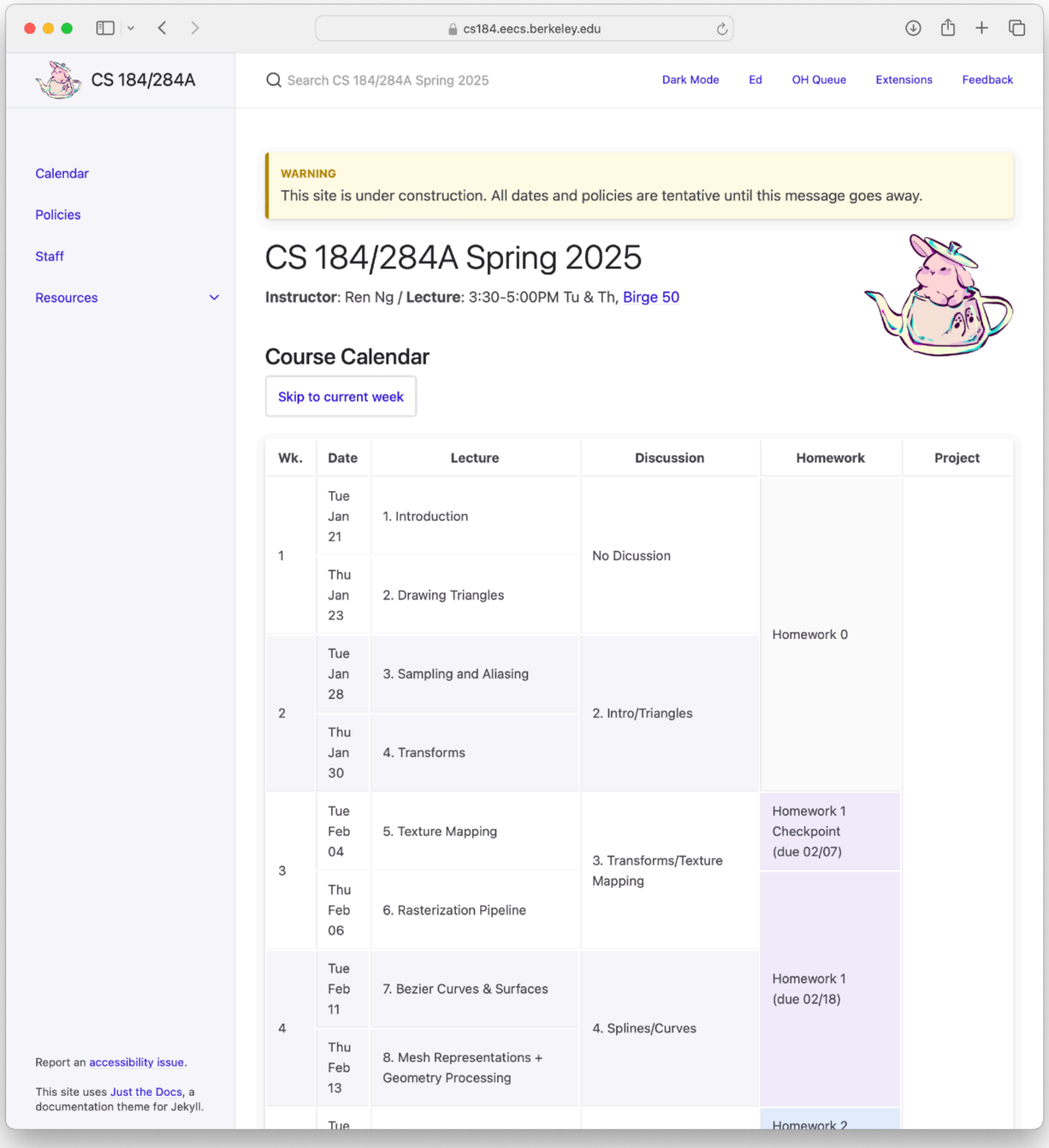
- Data structures (CS61B)
- Fluency with development environment, debugging, etc.
- Fluency with C and C++

# Enrollment

- Past years, high turnover from wait list
- Questions about enrollment:
  - Undergraduate students (CS184): ask EECS course scheduler (Cindy Conners) cs-scheduling@berkeley.edu
  - Graduate students (CS284A): contact course staff on Ed
  - Concurrent enrollment: can enroll after UCB waitlist clears, by order of CE application — CE/EECS course scheduling has the order

# Course Website

- cs184.eecs.berkeley.edu
- Big shout-out to Ashley Chiu for bringing this inclusive template from CS161 to graphics
- Full schedule up on website calendar now



# Course Schedule - Important Dates

See course website for all dates and more info.

Exams

- Monday March 10th  7:00 - 9:00 pm
- Monday April 28th  7:00 - 9:00pm

Final Project Presentations

- Report/Video due May 4th
- In-Person Presentations: Monday May 5th

Please check calendars and save these dates now!

- Send a private Ed message to staff this week if you have an exceptional circumstance

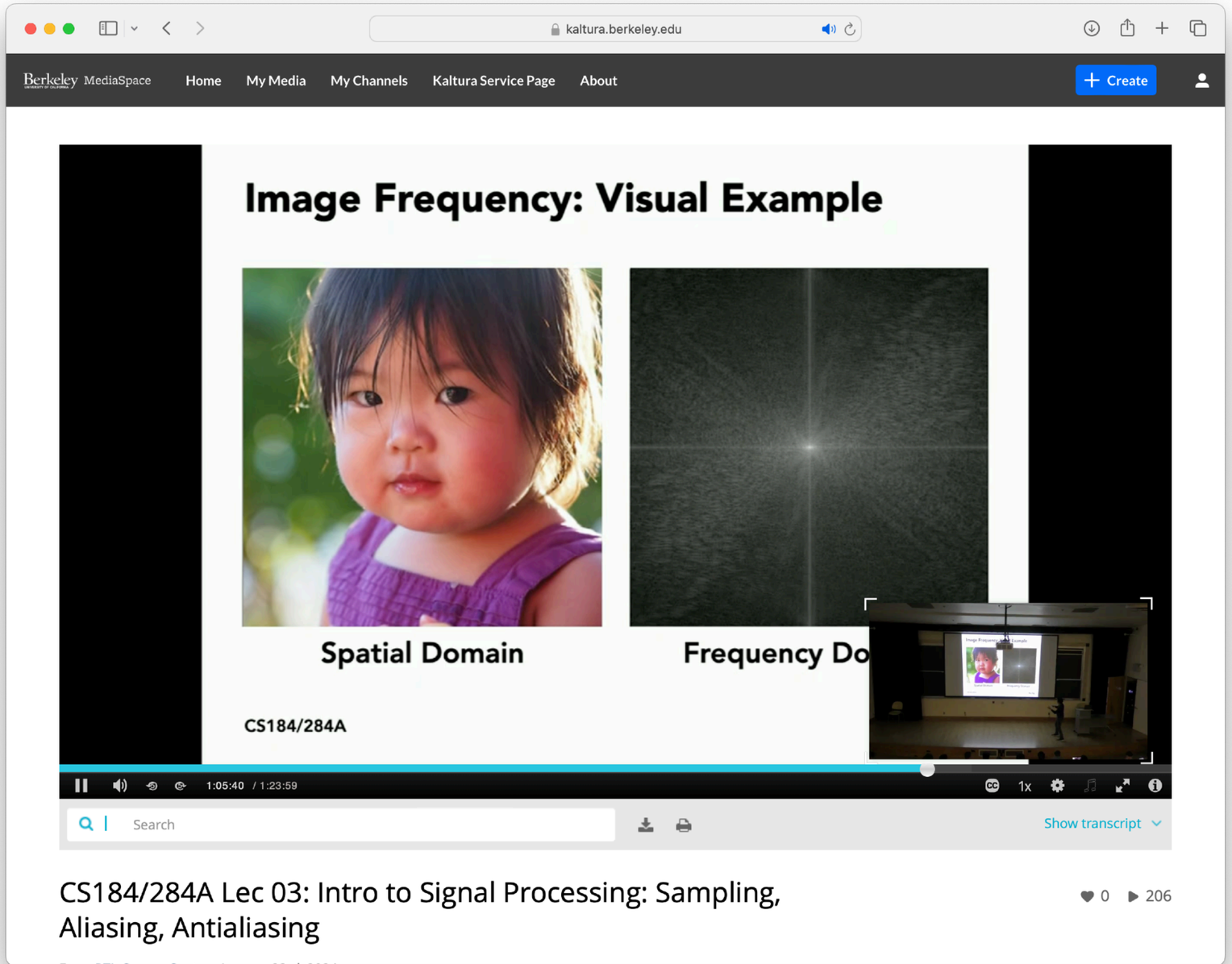
# Ed

edstem.org, course Ed link on course website

- You should be added already (if not, please sign up)!
- Please use Ed instead of email for logistics and general communication / discussion
- Conceptual questions and intellectual discussions will be hosted on lecture-specific threads (connected to class participation points)

# Lecture Will Be Recorded

Videos will be linked on the course website shortly after lecture



# Discussion Section

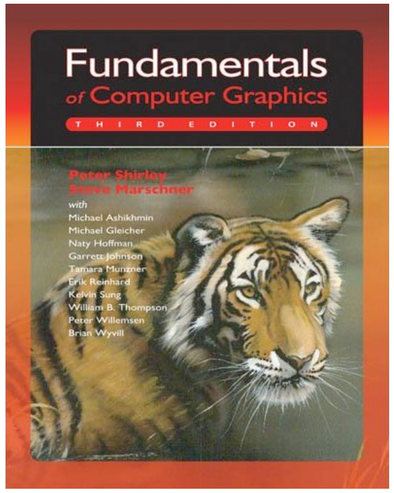
Sections start next week, and TAs will give a primer on C++ and building class projects

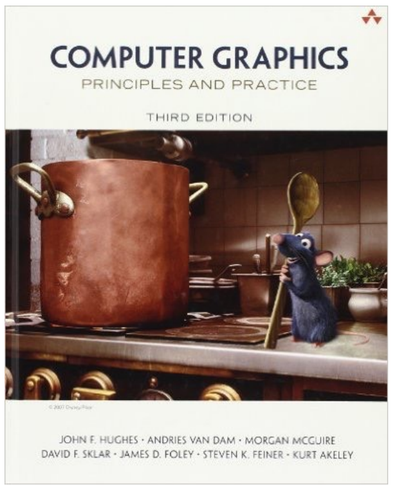
# Resources

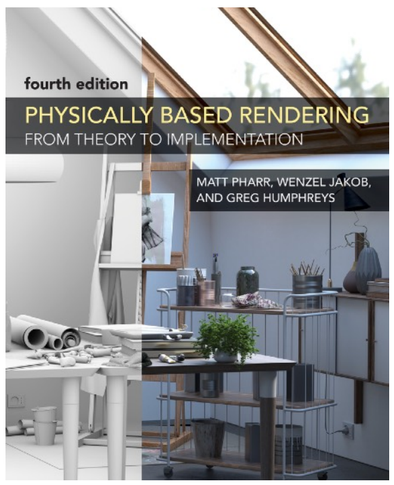
Lectures will be primary source

Textbook reference material (optional):

- Fundamentals of Computer Graphics
  by P. Shirley, S. Marschner, et al.
- Computer Graphics: Principles and Practice
  (3rd Edition)
  by Hughes, van Dam, et al.
- Physically Based Rendering, Fourth
  Edition: From Theory to Implementation
  by Pharr, Jakob and Humphreys




Other optional reading resources on class website

# Learning, Grading, Collaboration & Culture

Goals:

- Enable you to increase focus on learning rather than assessment
- Encourage your learning through collaboration
- Entrust you with and support you in maintaining academic integrity

Main Ideas (details on course website policies page — please review):

- The class is not graded on a curve.
- Collaboration in pairs is encouraged on homework assignments.
- Final project in teams of four.
- Two in-person exams.

Details

- Please read the Policies page on the course website; ask questions on Ed.

# Course Deliverables and Assessment

CS184: your course grade is out of 100 total points

- Four homework assignments, 12.5 points each
  - Pair projects encouraged.  Programming and written reports.
- Two in-person, closed-book exams, 10 points each
  - Check dates on website schedule.  No exam during Finals Week.
- Final project, 25 points
  - In teams of four, with final presentation, video, report.
- Participation, 5 points
  - Attend lectures/discussion

CS284A students: Project is 40% of grade, remainder normalized.

# Late Days Policy

You have 8 late days for the semester

- Extend a homework assignment deadline (not the final project) by 24 hours using one late day.
- No more than 4 late days on last homework (#4)
- If you do not have remaining late days, 1 course point penalty per day (out of 12.5 course points for 184, or 10 course points for 284A)
- Late days are meant to be used for personal schedule conflicts, illness, submission issues and other unforeseen circumstances.
- For exceptional circumstances, contact staff or see website for extension request form.

# Participation Policy

Every week, starting week 2, you are eligible for up to 2 participation credits.

- 1 credit for attending lecture
- 0.75 credits for attending discussion, and
- 0.5 credit for making one well thought-out comment on any designated Ed lecture thread

Note that you must earn participation credits week-to-week and cannot “make up” participation at the end of the semester

# Policy on Use of Generative-AI Tools

You are welcome to use AI tools for coding and writing reports. But a few rules / comments:

- Must describe use and what you learned
- Exams are in-person, closed-book. Likely will have coding questions
- Current AI tools are not perfect, so supervise your tools closely if you use them
- Minimal-effort use of AI tools may result in no partial credit
- We encourage you to explore AI tools in a way that augments rather than reduces your learning in class

# What We Are Looking For In Lecture Ed Posts

## Try to explain the slide (as if teaching your classmate to study for an exam)

- "Ren said this, but if you think about it this way it is much clearer"

## Explain what is confusing you

- "What I was totally confused about here was…"

## Challenge classmates with a question

- For example, make up a question you think might be on an exam

## Provide a link to an alternative explanation

- "This site has a really good animation of pre-filtering to avoid aliasing"

## Mention real-world examples

- For example, describe what default interpolation functions are used in iOS.

## Constructively respond to another student's question

- "@nojaggies, are you sure that is correct?  I thought that Ren said…"

## It is OK, and even encouraged, to address the same topic (or repeat someone else's summary, explanation or idea) in your own words

- "@cornellbox's point is that subdivision is also used to…"

# Class Philosophy

We want to build an active, engaged class community.

Come to class, participate in lecture, discussion, office hour parties, homework parties.

Practice cooperative, supportive learning.

Contribute on the website.

Uphold academic honor individually and collectively.

# Inclusive Classroom

We are committed to creating a learning environment welcoming and supportive of all students. Towards this goal, we call on our class community to:

- Respect, welcome and learn from each other as individuals with unique backgrounds, perspectives and identities.
- Collaboration and team learning are encouraged, and will be supported through class staff and resources.
- Homework assignments and final project are a great way to meet new people and make friends; work on building trust and leveraging each other's unique strengths.
- If you feel that your learning is negatively affected by your experiences outside of class (e.g. family matters, current events), please don't hesitate to come and talk with the instructor and/or staff.  We want to support you.

# Course Roadmap

## Rasterization Pipeline

Core Concepts

- Sampling
- Antialiasing
- Transforms

## Geometric Modeling

Core Concepts

- Splines, Bezier Curves
- Topological Mesh Representations
- Subdivision, Geometry Processing

## Lighting & Materials

Core Concepts

- Measuring Light
- Unbiased Integral Estimation
- Light Transport & Materials

## Cameras & Imaging

- Rasterization
- Transforms & Projection
- Texture Mapping
- Visibility, Shading, Overall Pipeline
- Intro to Geometry
- Curves and Surfaces
- Geometry Processing
- Ray-Tracing & Acceleration
- Radiometry & Photometry
- Monte Carlo Integration
- Global Illumination & Path Tracing
- Material Modeling

# Questions?

# Acknowledgments

Thanks to Angjoo Kanazawa, Pat Hanrahan, Kayvon Fatahalian, Keenan Crane, Mark Pauly and James O’Brien for presentation resources.