Lecture 1:

Course Introduction:

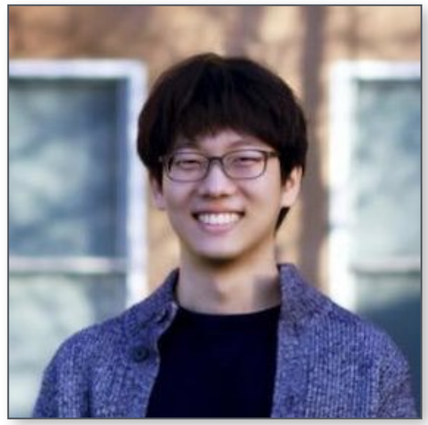
Welcome to Computer Graphics!

Interactive Computer Graphics
Stanford CS248, Spring 2018

Slide acknowledgements:
Thanks to Keenan Crane and Ren Ng

Hi!

Kayvon Fatahalian



Minjae Lee

Ishan Somshekar

Discussion:

Why study computer graphics?

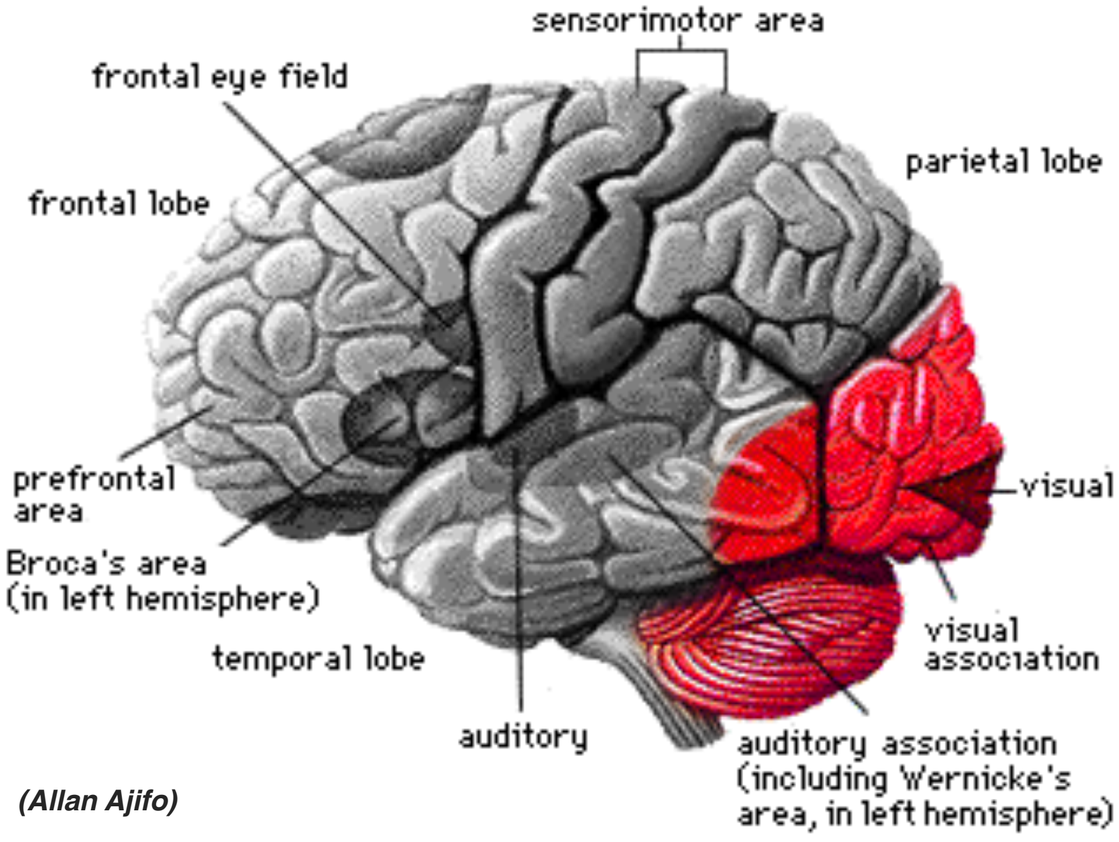
What is computer graphics?

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

Humans are visual creatures!

Why *visual* information?

About 30% of brain dedicated to visual processing...

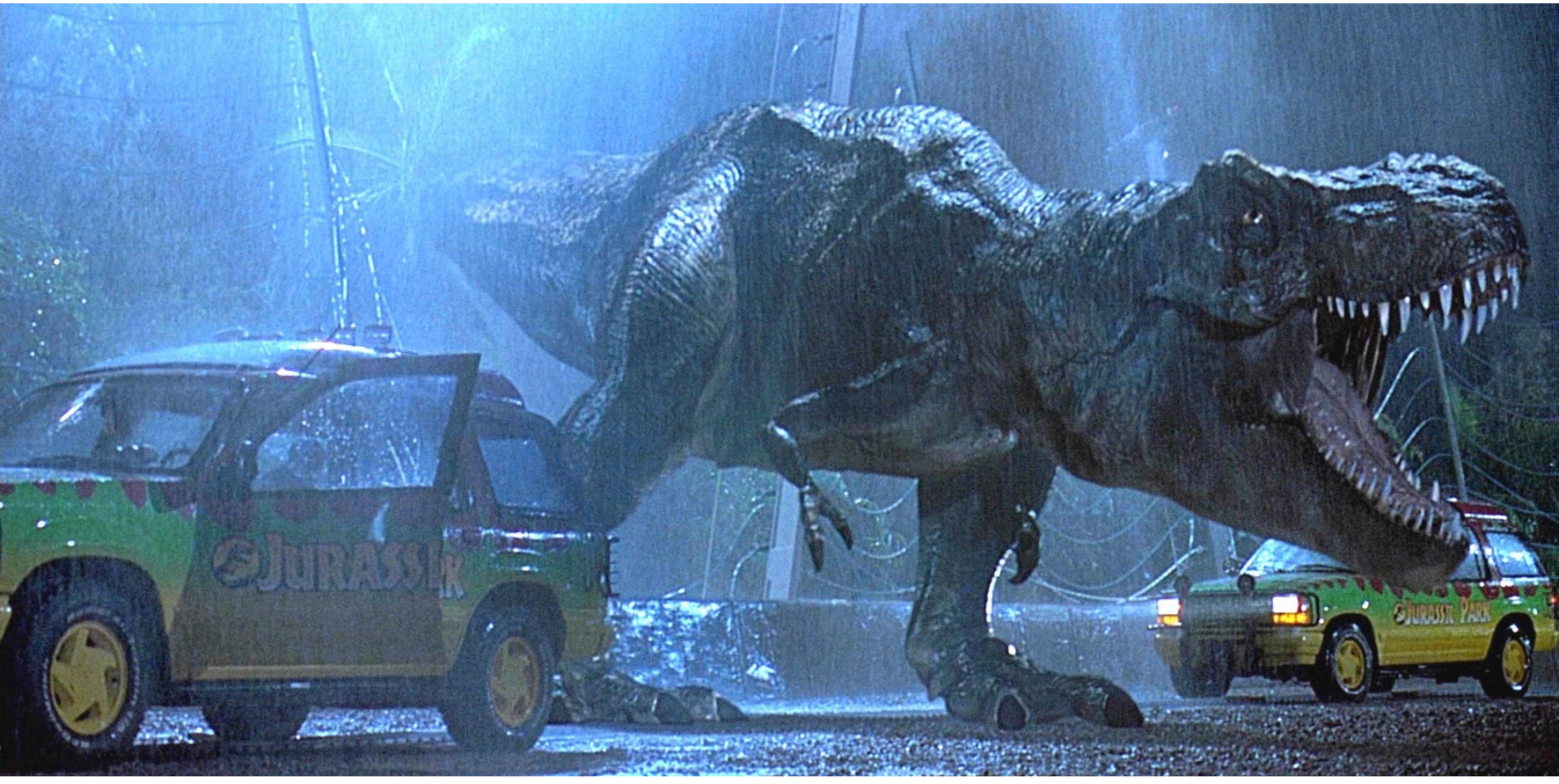


(Allan Ajifo)

(Petar Milošević)

...eyes are highest-bandwidth port into the head!

Movies



Jurassic Park (1993)

Movies

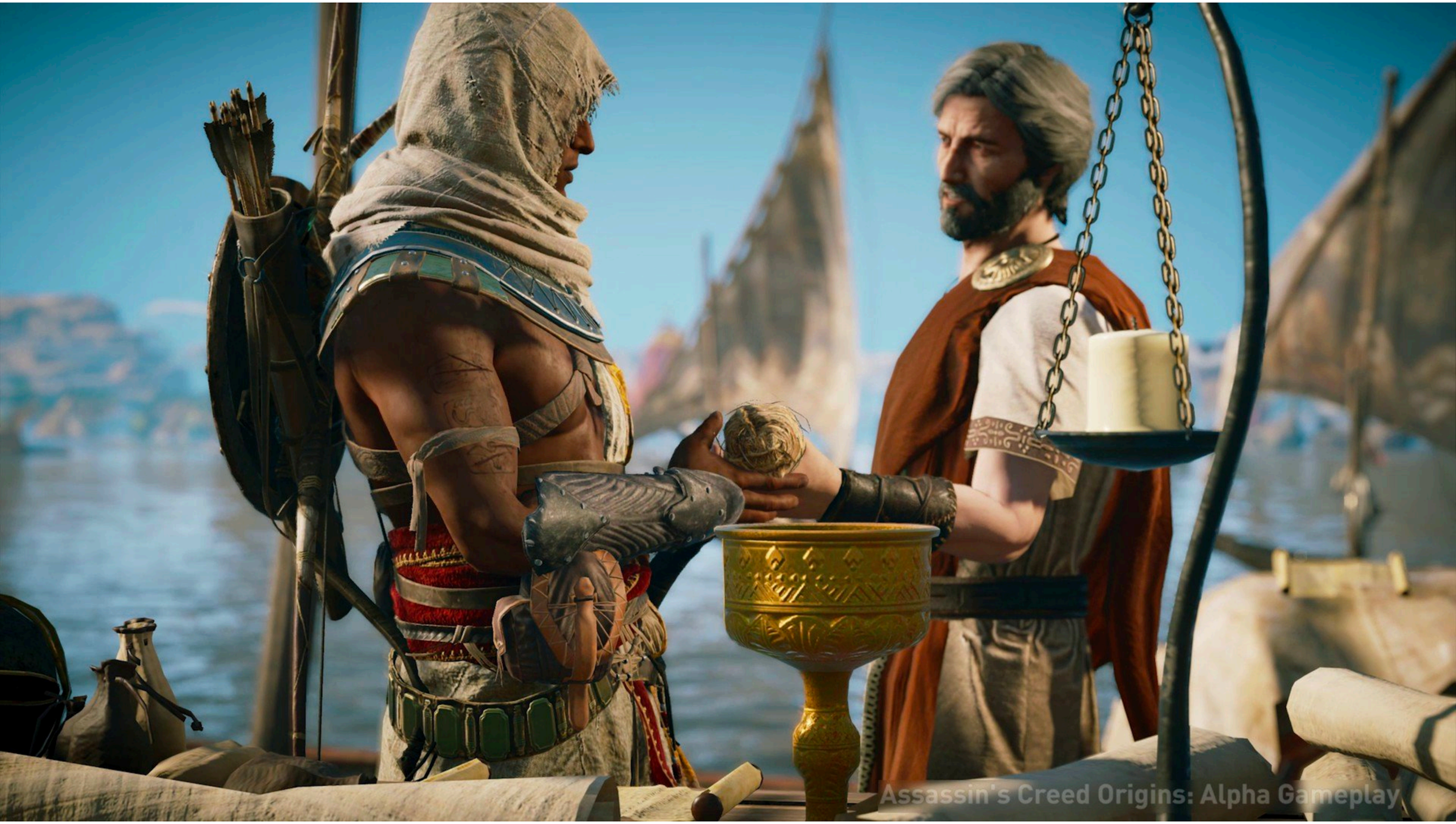
The Matrix (1999)

Games

Uncharted 4 (Naughty Dog, 2016)

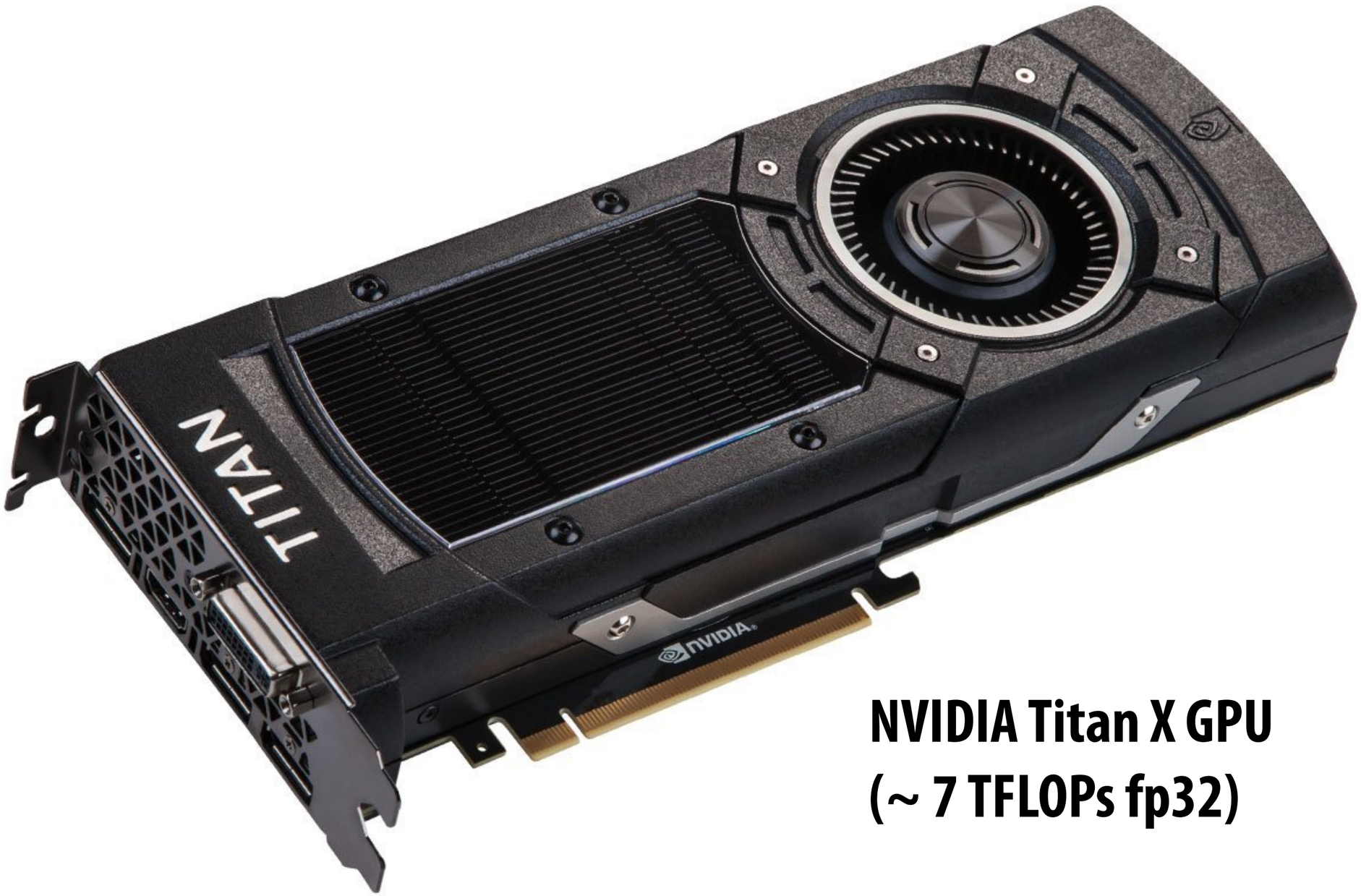
This image is rendered in real-time on a modern GPU

Games



Assassin's Creed Origins (Ubisoft 2017)

Supercomputing for games

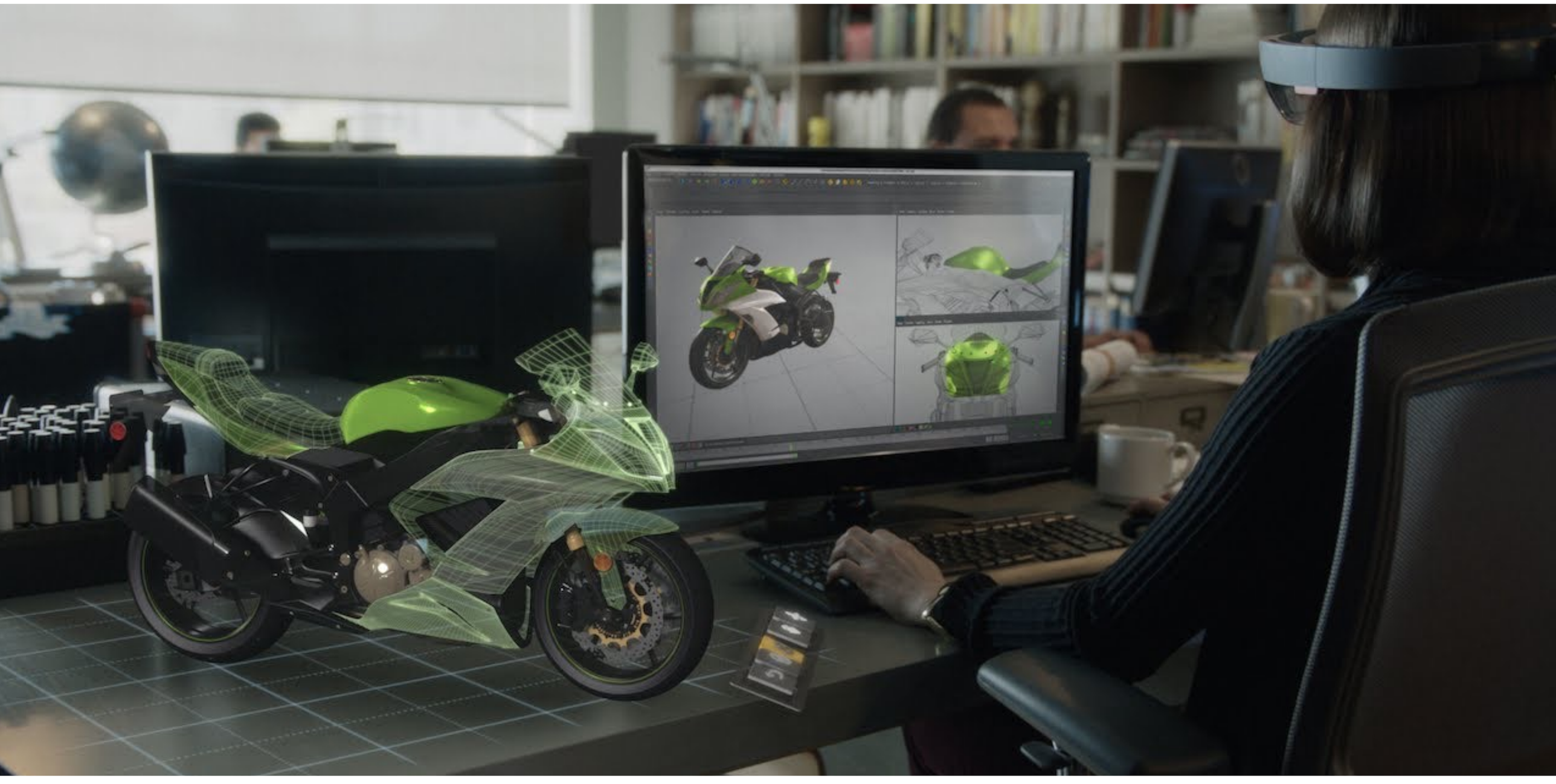


NVIDIA Titan X GPU
(~ 7 TFLOPs fp32)

Tesla generation NV chip ~ ASCI Red Supercomputer

Virtual reality experiences

Augmented reality



Microsoft Hololens augmented reality headset concept

Illustration

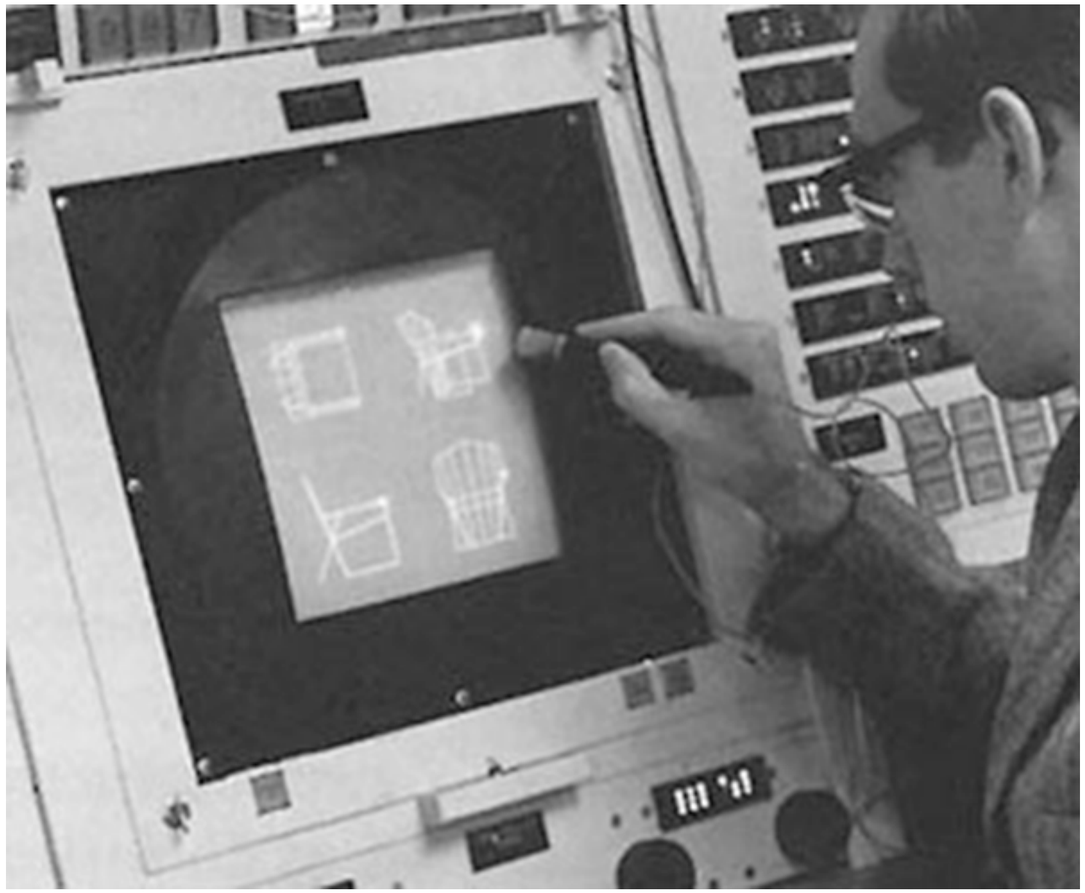
Indonesian cave painting (~38,000 BCE)

Digital Illustration

Meike Hakkart

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

Graphical user interfaces



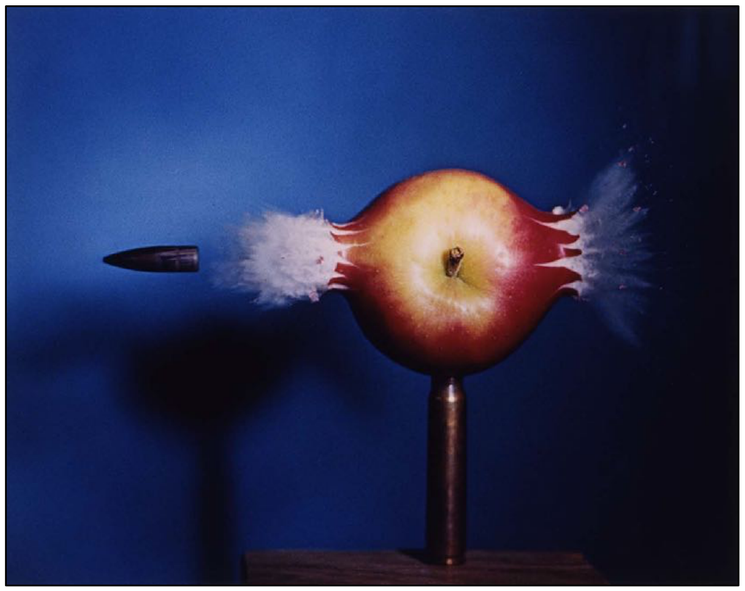
Ivan Sutherland, “Sketchpad” (1963)

Doug Engelbart
Mouse

Modern graphical user interfaces

2D drawing and animation are ubiquitous in computing.
Typography, icons, images, transitions, transparency, …
(all rendered at high frame rate for rich experience)

Digital photography

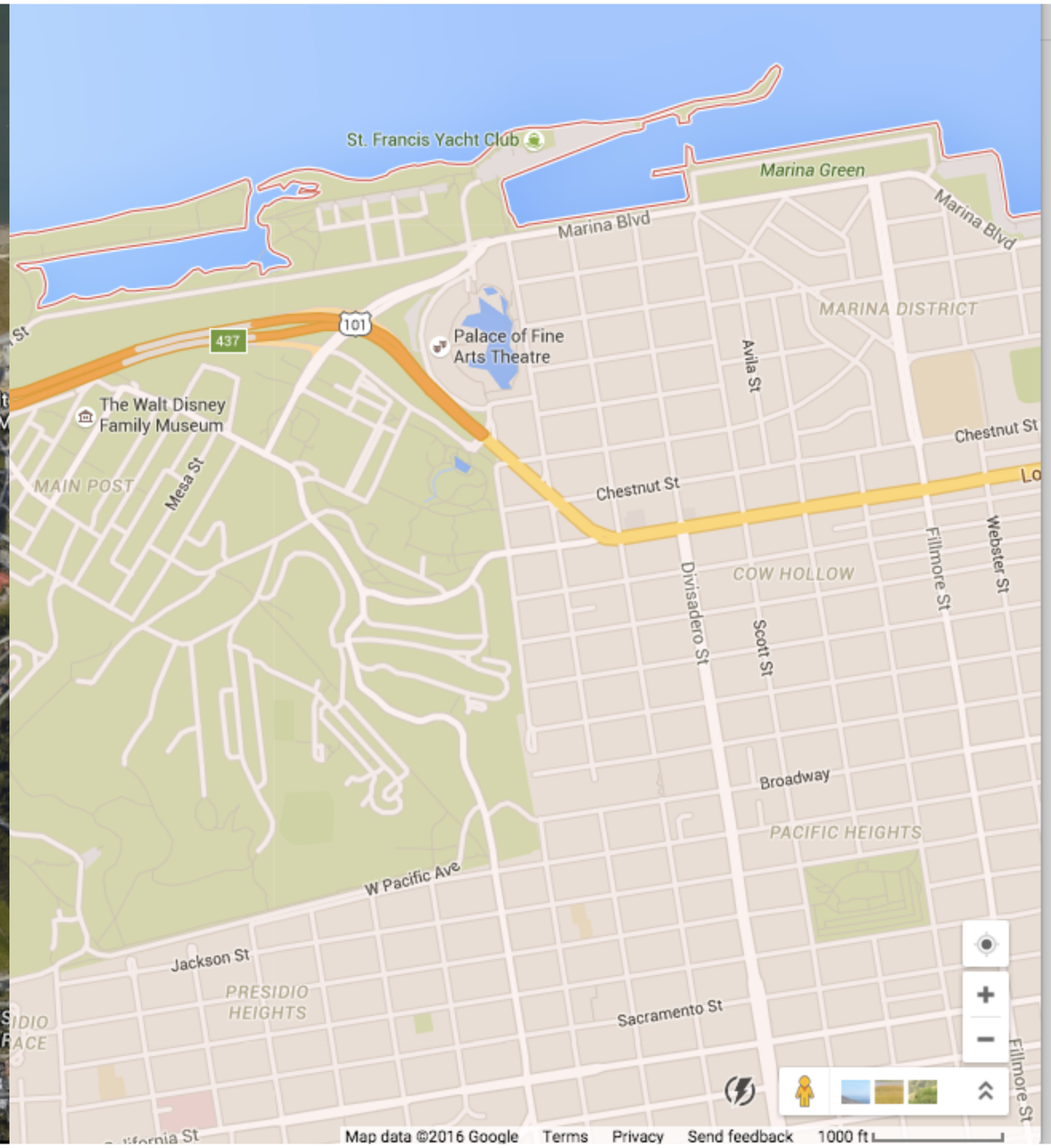


NASA | Walter Iooss | Steve McCurry
Harold Edgerton | NASA | National Geographic

Ubiquitous imaging

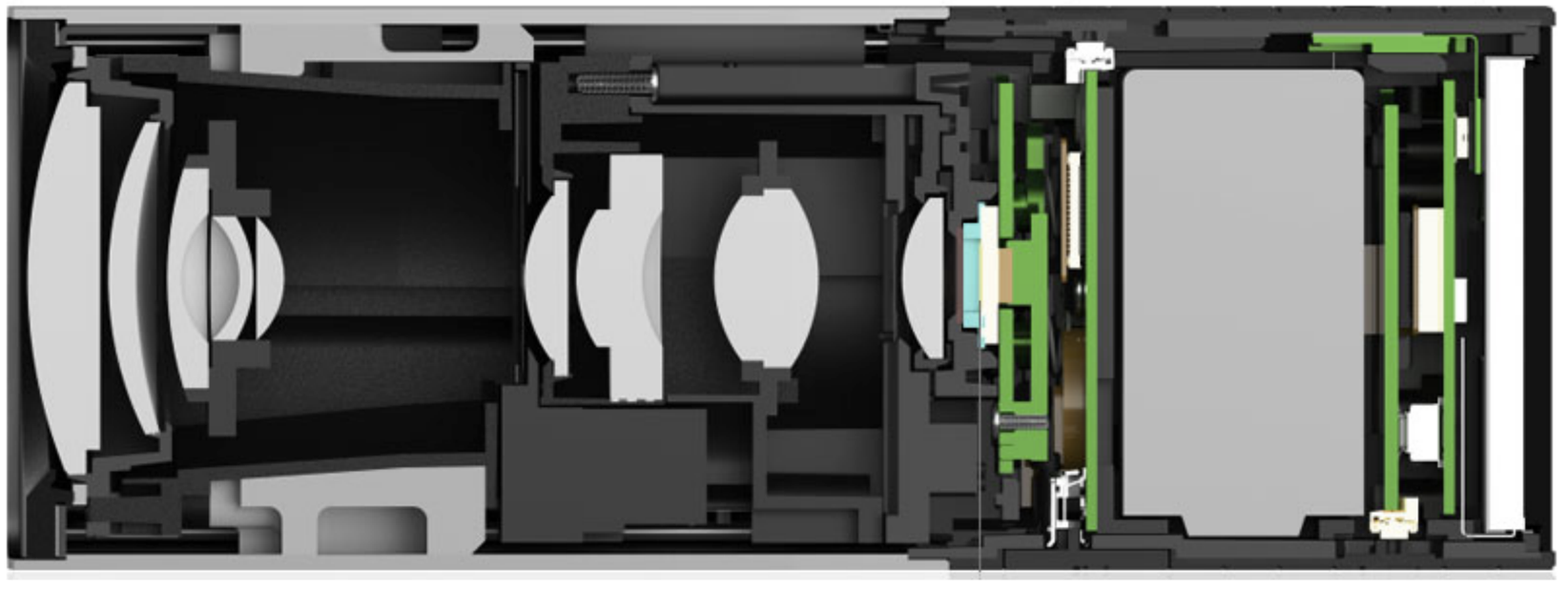
Cameras everywhere

Imaging in mapping



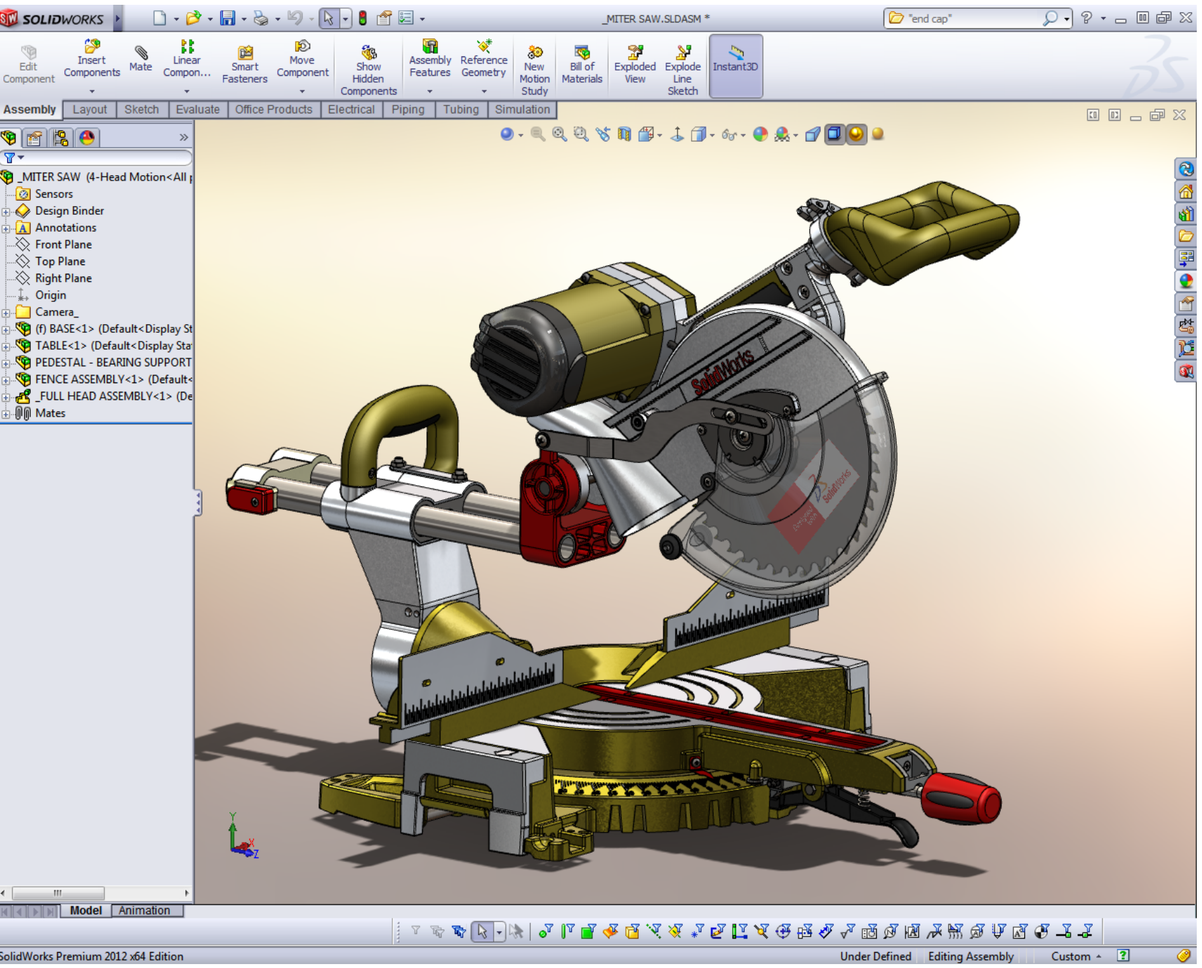
Maps, satellite imagery, street-level imaging,…

Computational cameras

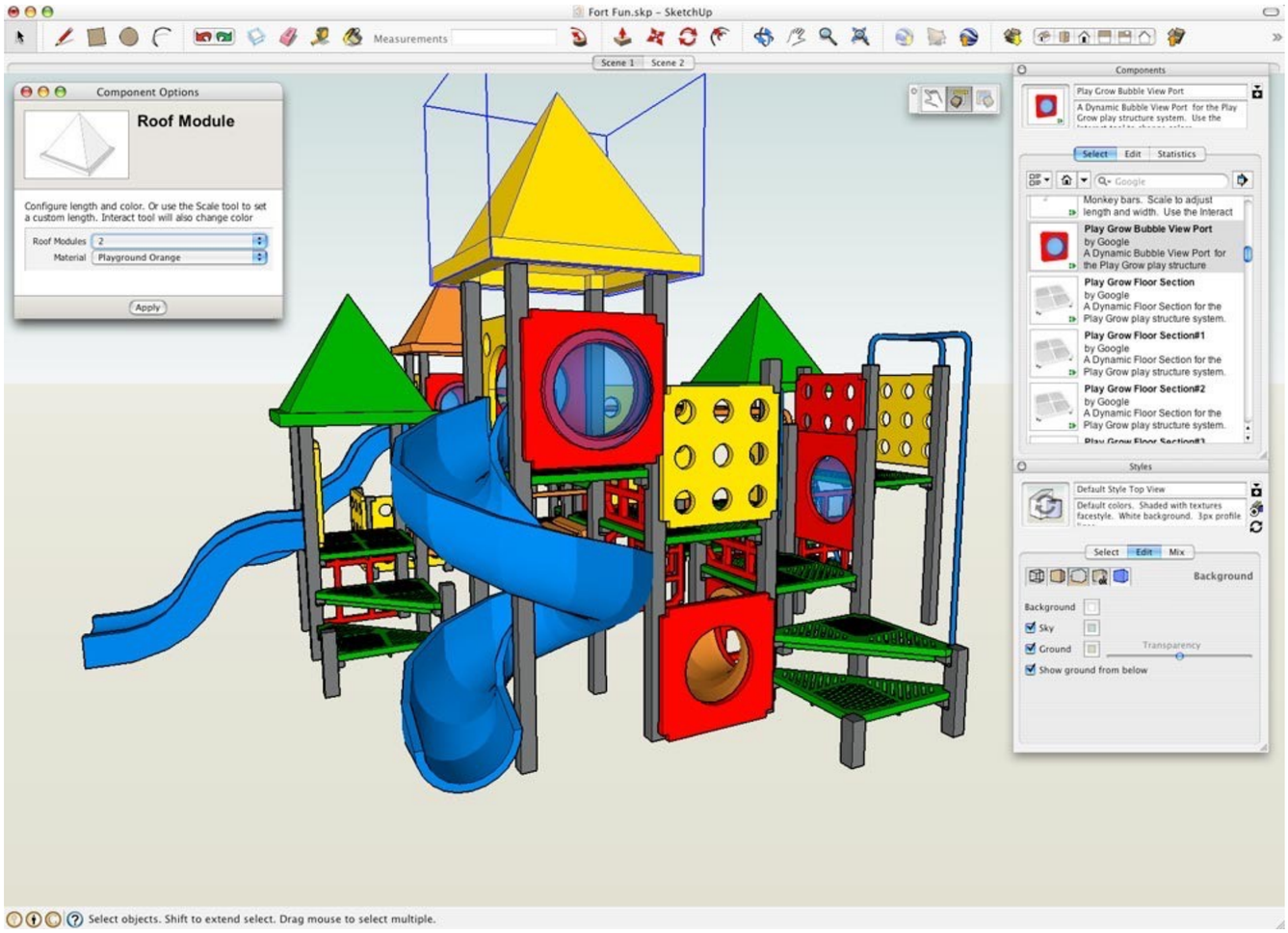


Panaromic stitching, HDR photos, light field cameras, …

Computer aided design



SolidWorks



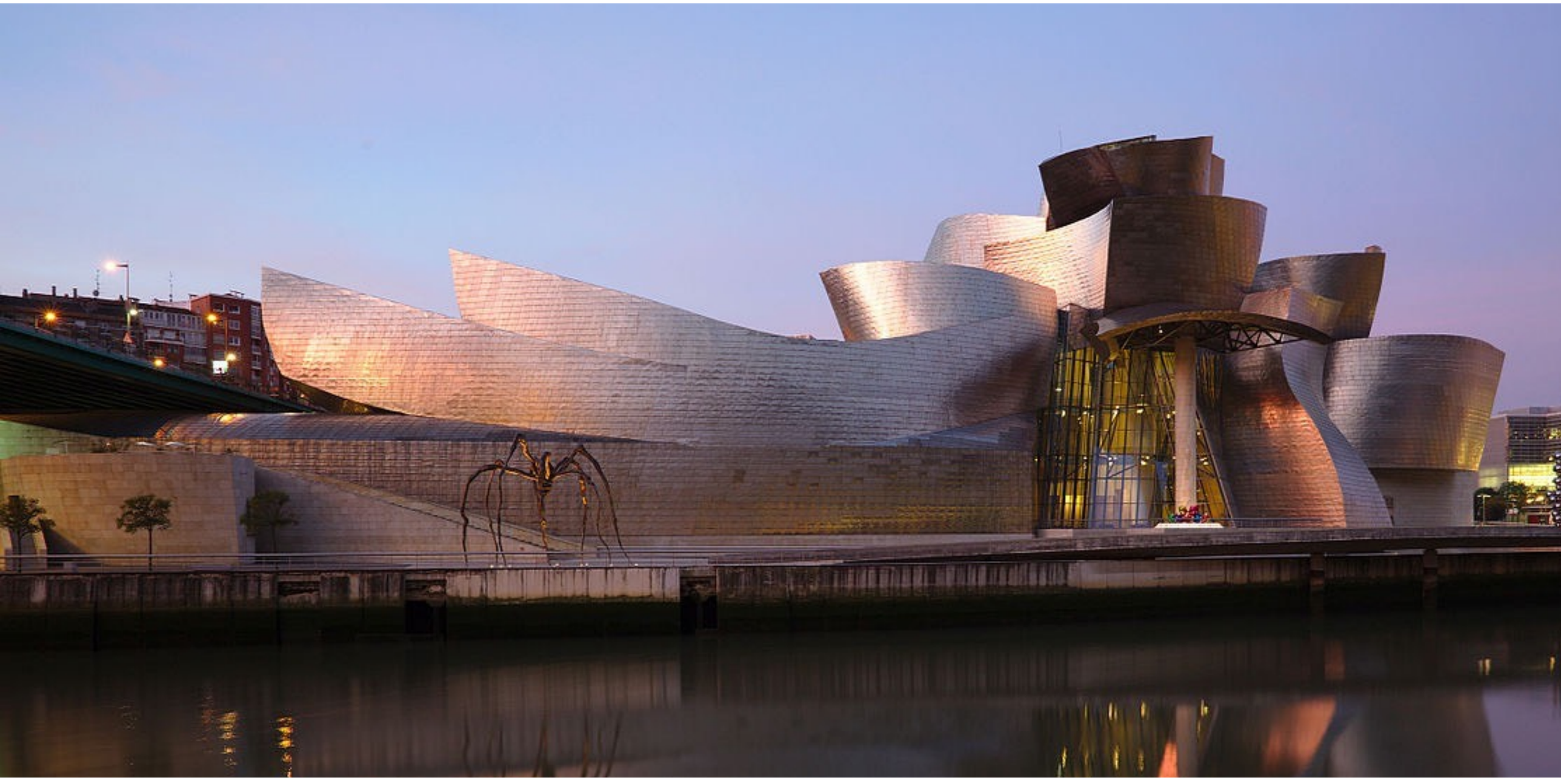
SketchUp

For mechanical, architectural, electronic, optical, …

Product design and visualization

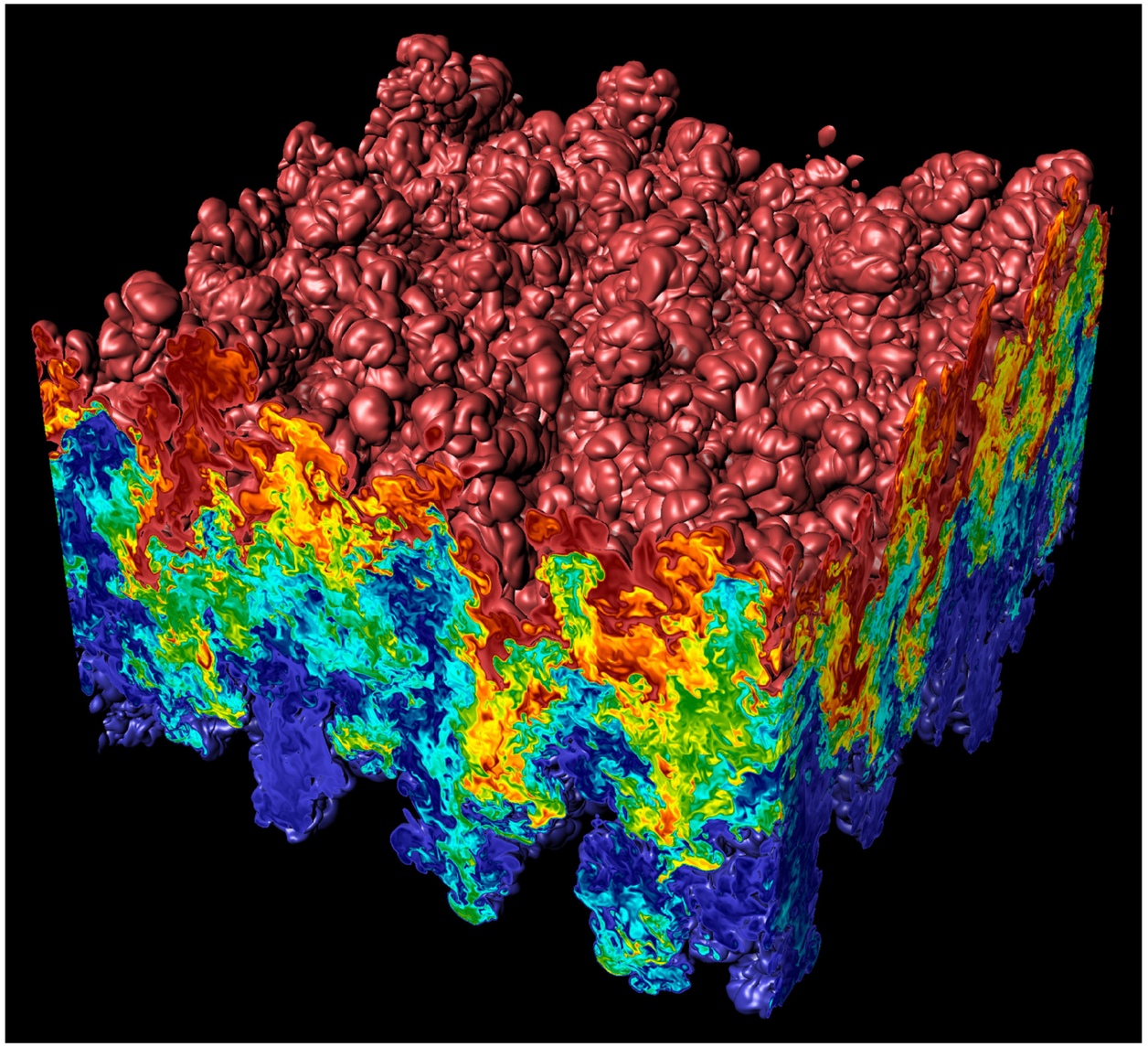
Ikea - 75% of catalog is rendered imagery

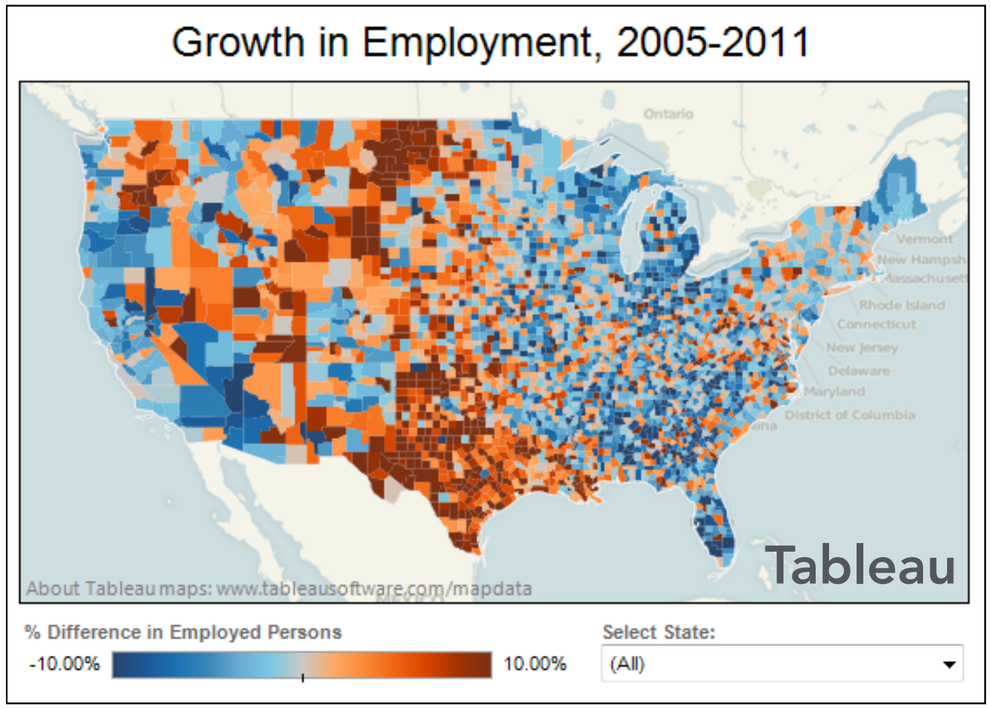
Architectural design



Bilbao Guggenheim, Frank Gehry

Visualization





Science, engineering, medicine, journalism, …

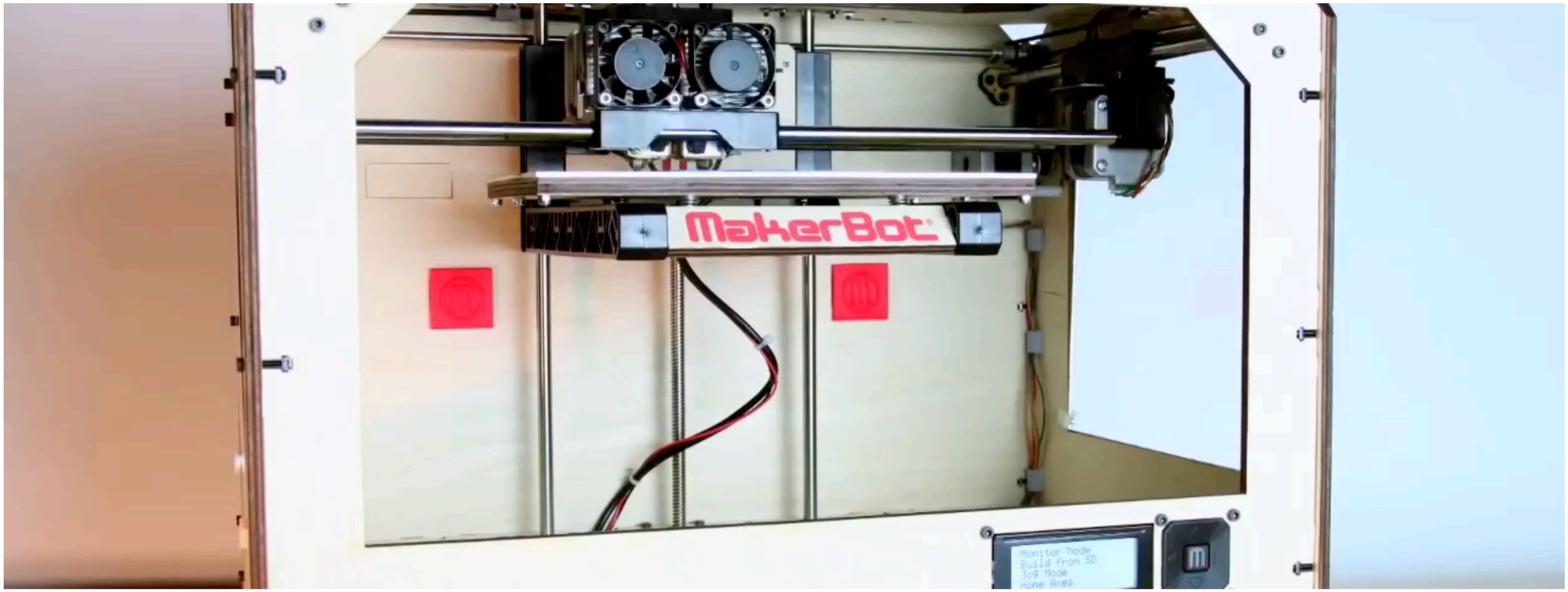
Simulation

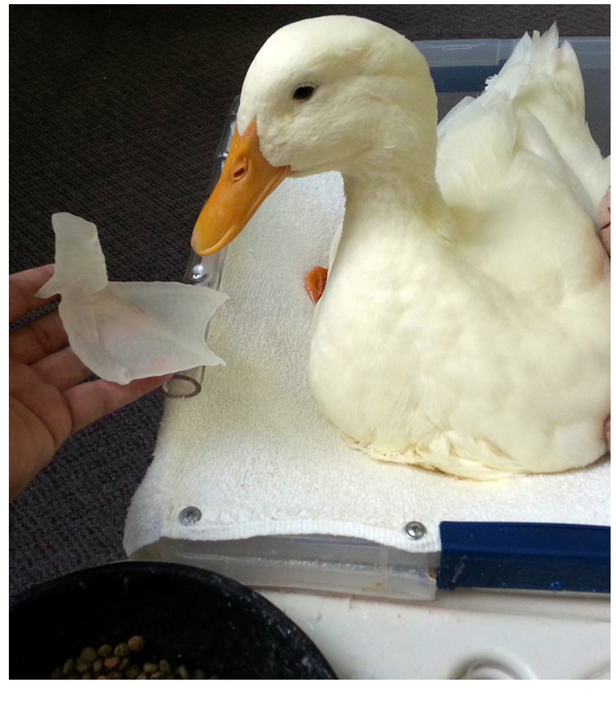
Driving simulator
Toyota Higashifuji Technical Center

da Vinci surgical robot
Intuitive Surgical

Flight simulator, driving simulator, surgical simulator, …

Visual technology: 3D fabrication





Computer graphics is *everywhere!*

Foundations of computer graphics

- All these applications demand *sophisticated* theory & systems

- Science and mathematics
  - Physics of light, color, optics
  - Math of curves, surfaces, geometry, perspective, …
  - Sampling

- Systems
  - parallel, heterogeneous processing
  - input/output devices
  - graphics-specific programming systems

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

ACTIVITY: modeling and drawing a cube

- Goal: generate a realistic drawing of a cube
- Key questions:
  - *Modeling:* how do we describe the cube?
  - *Rendering:* how do we then visualize this model?

ACTIVITY: modeling the cube

- Suppose our cube is...
  - centered at the origin (0,0,0)
  - has dimensions 2x2x2
- QUESTION: What are the coordinates of the cube vertices?

```
A: ( 1, 1, 1 )    E: ( 1, 1,-1 )
B: (-1, 1, 1 )    F: (-1, 1,-1 )
C: ( 1,-1, 1 )    G: ( 1,-1,-1 )
D: (-1,-1, 1 )    H: (-1,-1,-1 )
```

- QUESTION: What about the edges?

```
AB, CD, EF, GH,
AC, BD, EG, FH,
AE, CG, BF, DH
```

ACTIVITY: drawing the cube

- Now have a digital description of the cube:

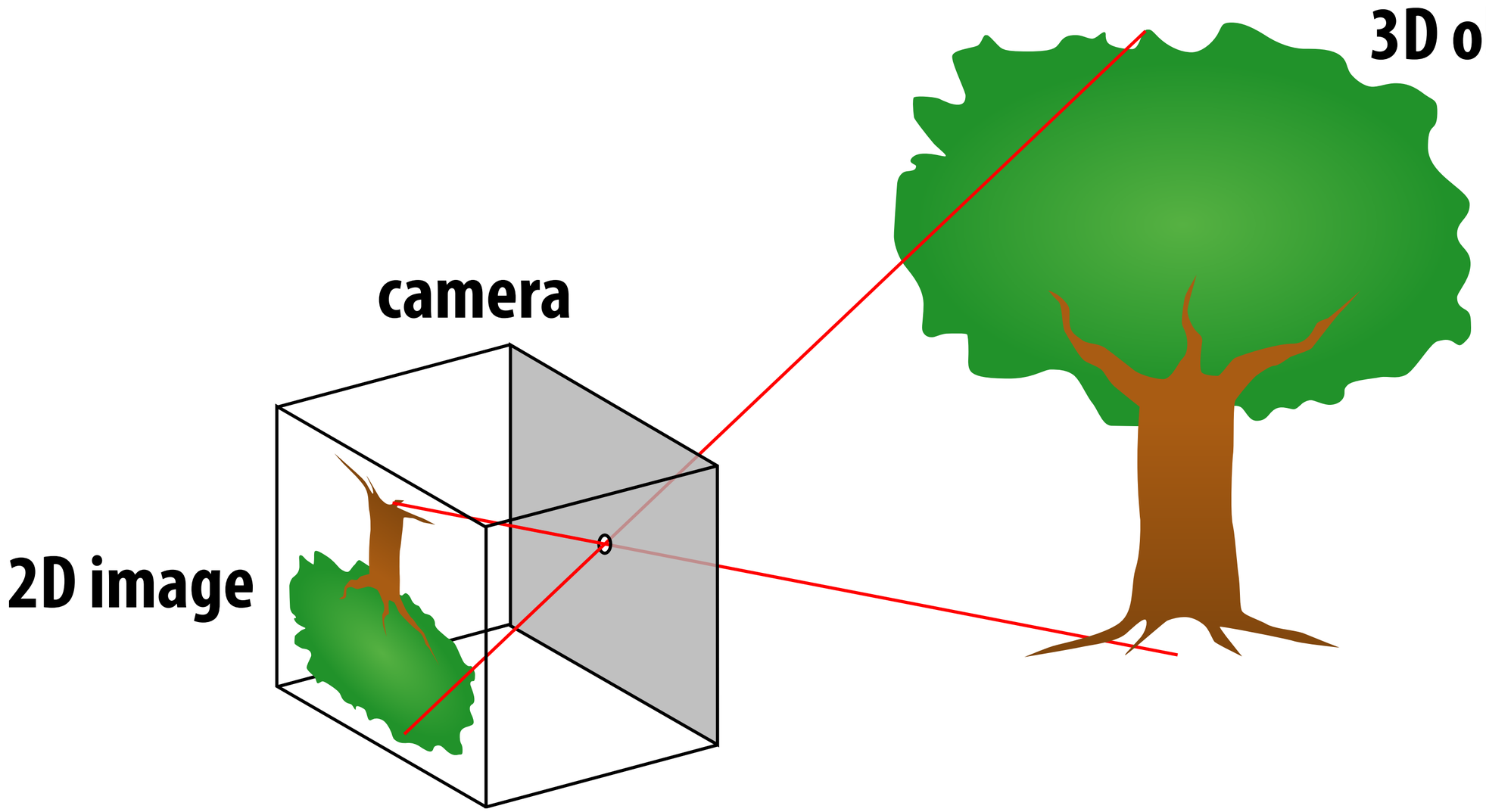
```
VERTICES                                          EDGES
A: ( 1, 1, 1 )    E: ( 1, 1,-1 )
B: (-1, 1, 1 )    F: (-1, 1,-1 )                  AB, CD, EF, GH,
C: ( 1,-1, 1 )    G: ( 1,-1,-1 )                  AC, BD, EG, FH,
D: (-1,-1, 1 )    H: (-1,-1,-1 )                  AE, CG, BF, DH
```

- How do we draw this 3D cube as a 2D (flat) image?

- Basic strategy:
  1. map 3D vertices to 2D points in the image
  2. connect 2D points with straight lines
- ...Ok, but how?

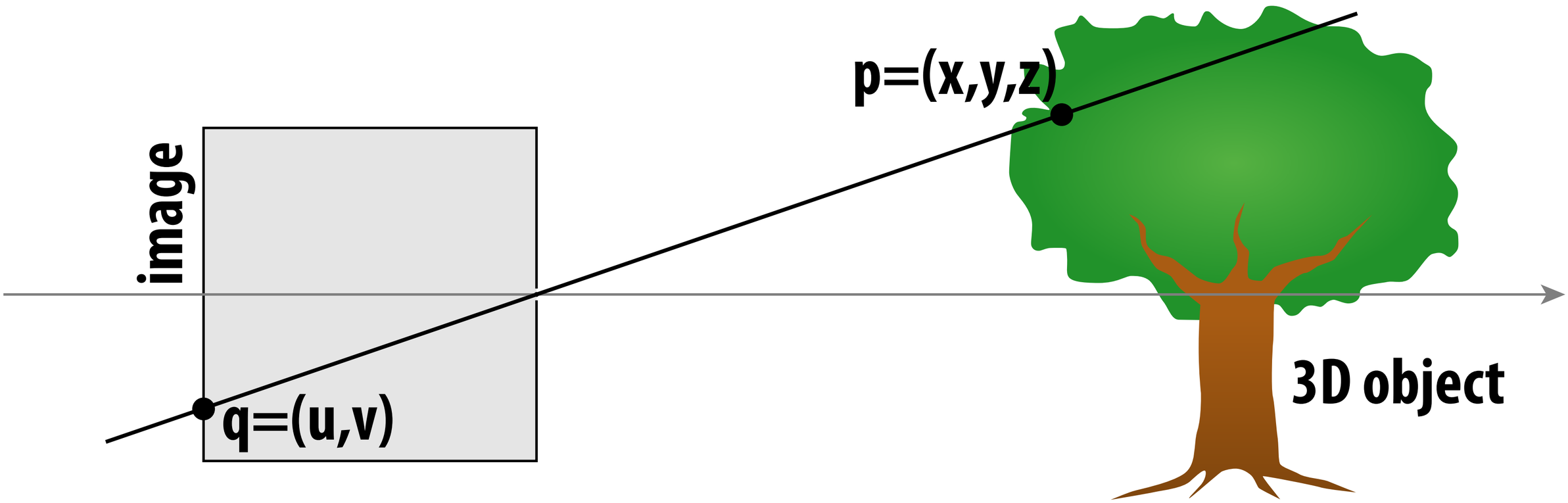
Perspective projection

- Objects look smaller as they get further away (“perspective”)
- Why does this happen?
- Consider simple (“pinhole”) model of a camera:



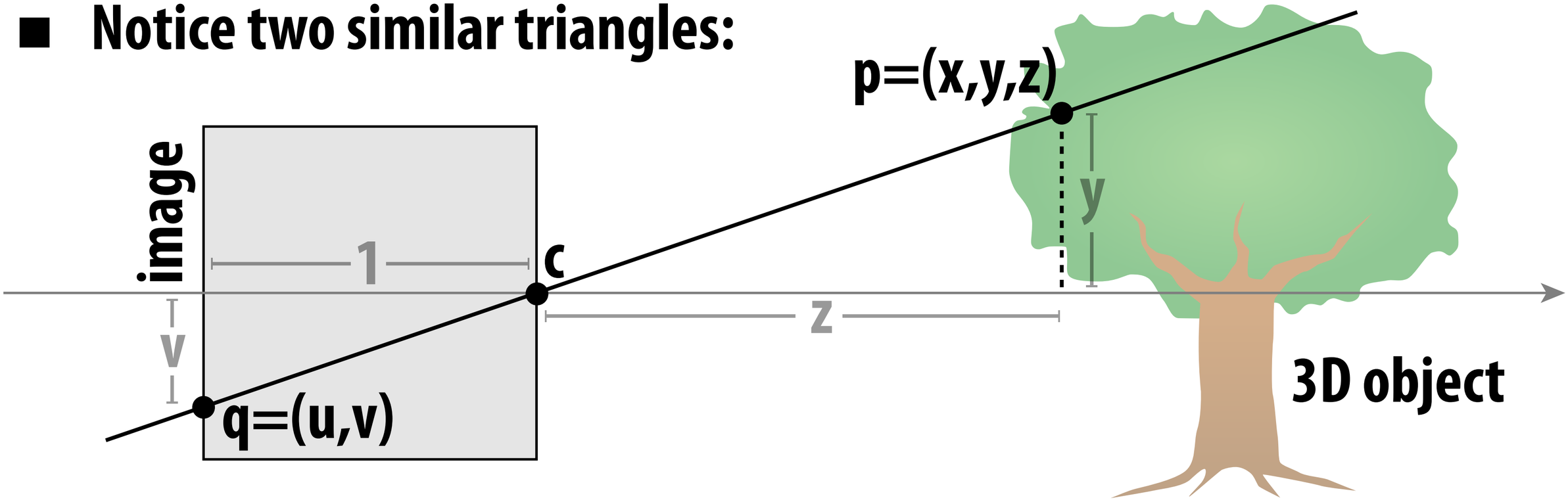
Perspective projection: side view

- Where exactly does a point p = (x,y,z) end up on the image?
- Let's call the image point q=(u,v)



Perspective projection: side view

- Where exactly does a point p = (x,y,z) end up on the image?
- Let's call the image point q=(u,v)
- Notice two similar triangles:



- Assume camera has unit size, coordinates relative to pinhole c
- Then v/1 = y/z, i.e., vertical coordinate is just the slope y/z
- Likewise, horizontal coordinate is u=x/z

ACTIVITY: now draw image made by pinhole camera

- Need 12 volunteers
  - each person will draw one cube edge
  - assume camera is at c=(2,3,5)
  - convert (X,Y,Z) of both endpoints to (u,v):
    1. subtract camera c from vertex (X,Y,Z) to get (x,y,z)
    2. divide x and y by z to get (u,v)—*write as a fraction*
  - draw line between (u1,v1) and (u2,v2)

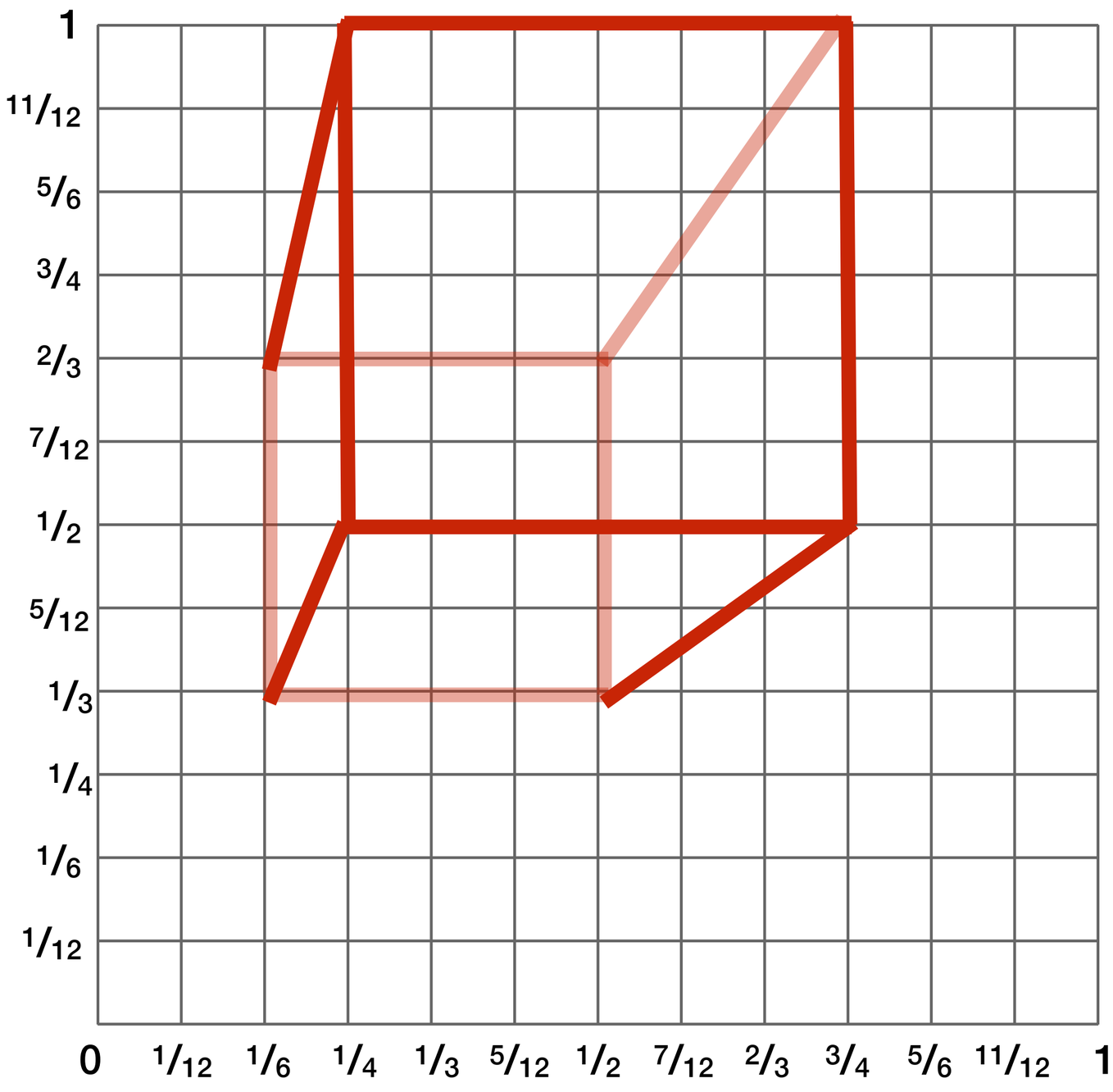
VERTICES

```
A: ( 1, 1, 1 )    E: ( 1, 1,-1 )
B: (-1, 1, 1 )    F: (-1, 1,-1 )
C: ( 1,-1, 1 )    G: ( 1,-1,-1 )
D: (-1,-1, 1 )    H: (-1,-1,-1 )
```

EDGES

```
AB, CD, EF, GH,
AC, BD, EG, FH,
AE, CG, BF, DH
```

ACTIVITY: how did we do? *



2D coordinates:

```
A: (1/4, 1/2)
B: (3/4, 1/2)

C: (1/4, 1)
D: (3/4, 1)

E: (1/6, 1/3)
F: (1/2, 1/3)

G: (1/6, 2/3)
H: (1/2, 2/3)
```

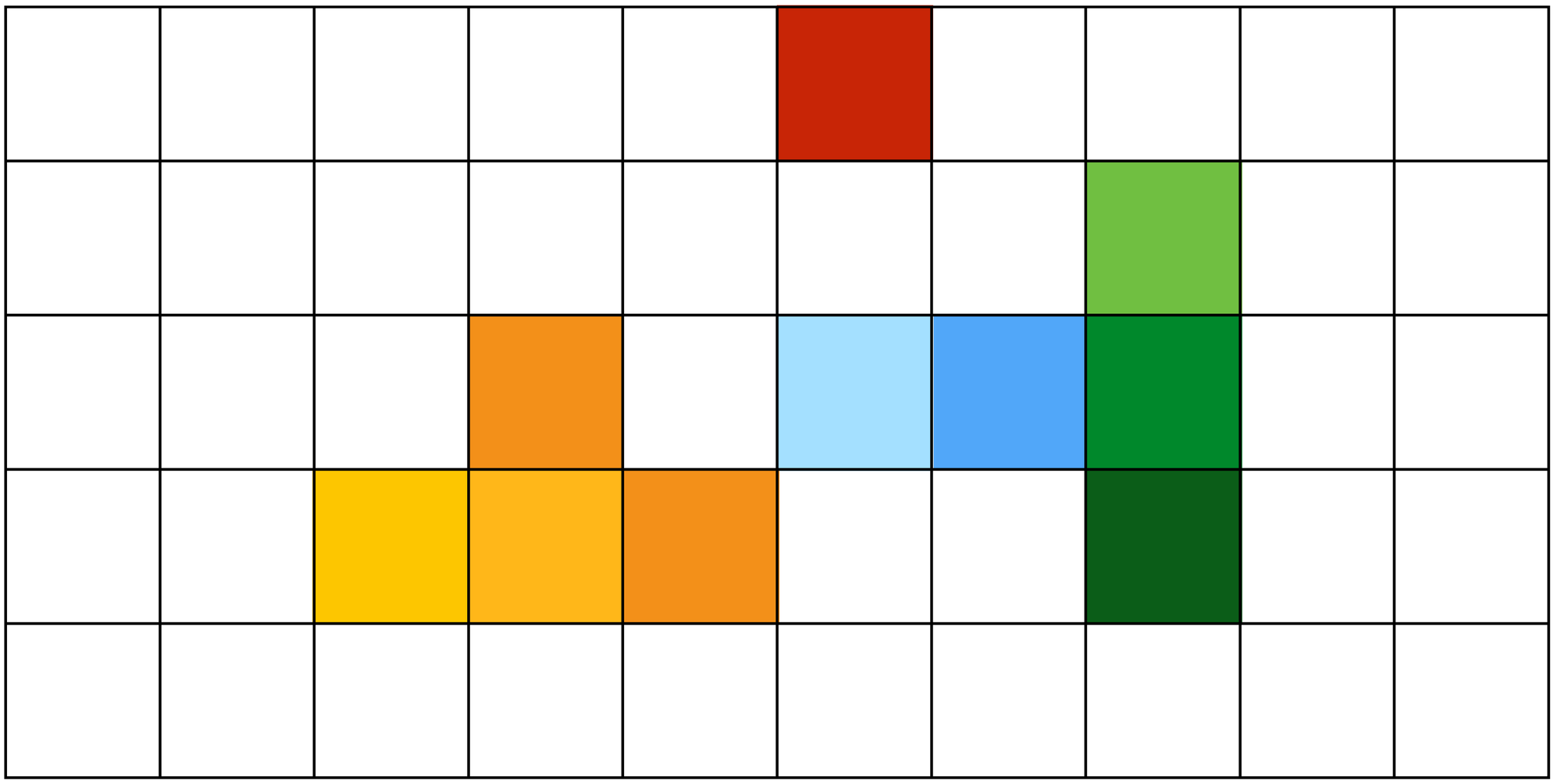
*** keep in mind, this image is mirrored since it's a pinhole projection**

But wait…

How do we draw lines on a computer?

Output for a raster display

- Common abstraction of a raster display:
  - Image represented as a 2D grid of "pixels" (picture elements) **
  - Each pixel can can take on a unique color value

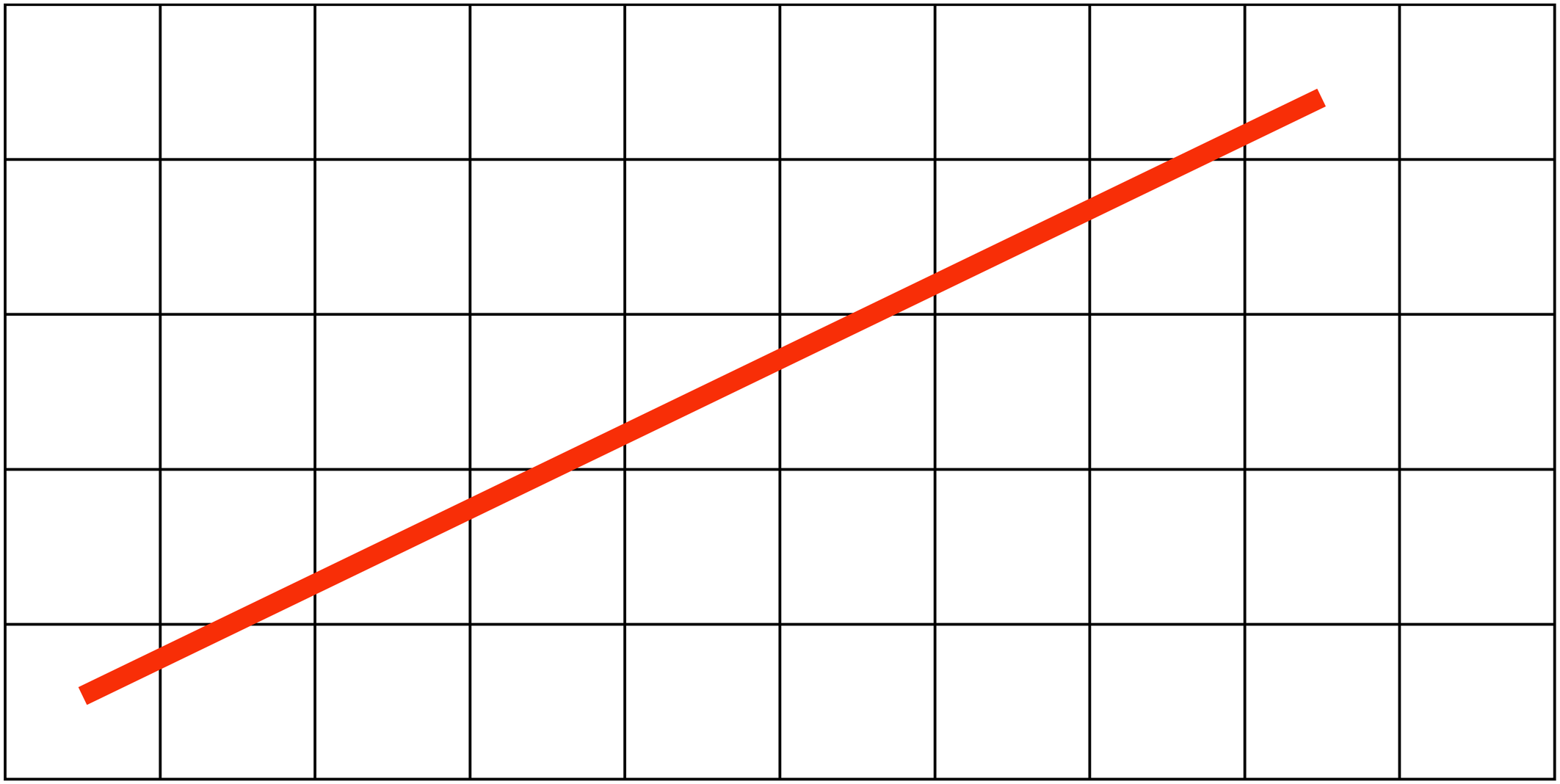


** Kayvon will strongly challenge this notion of a pixel "as a little square" next class.
But let's go with it for now. ;-)

Close up photo of pixels on a modern display

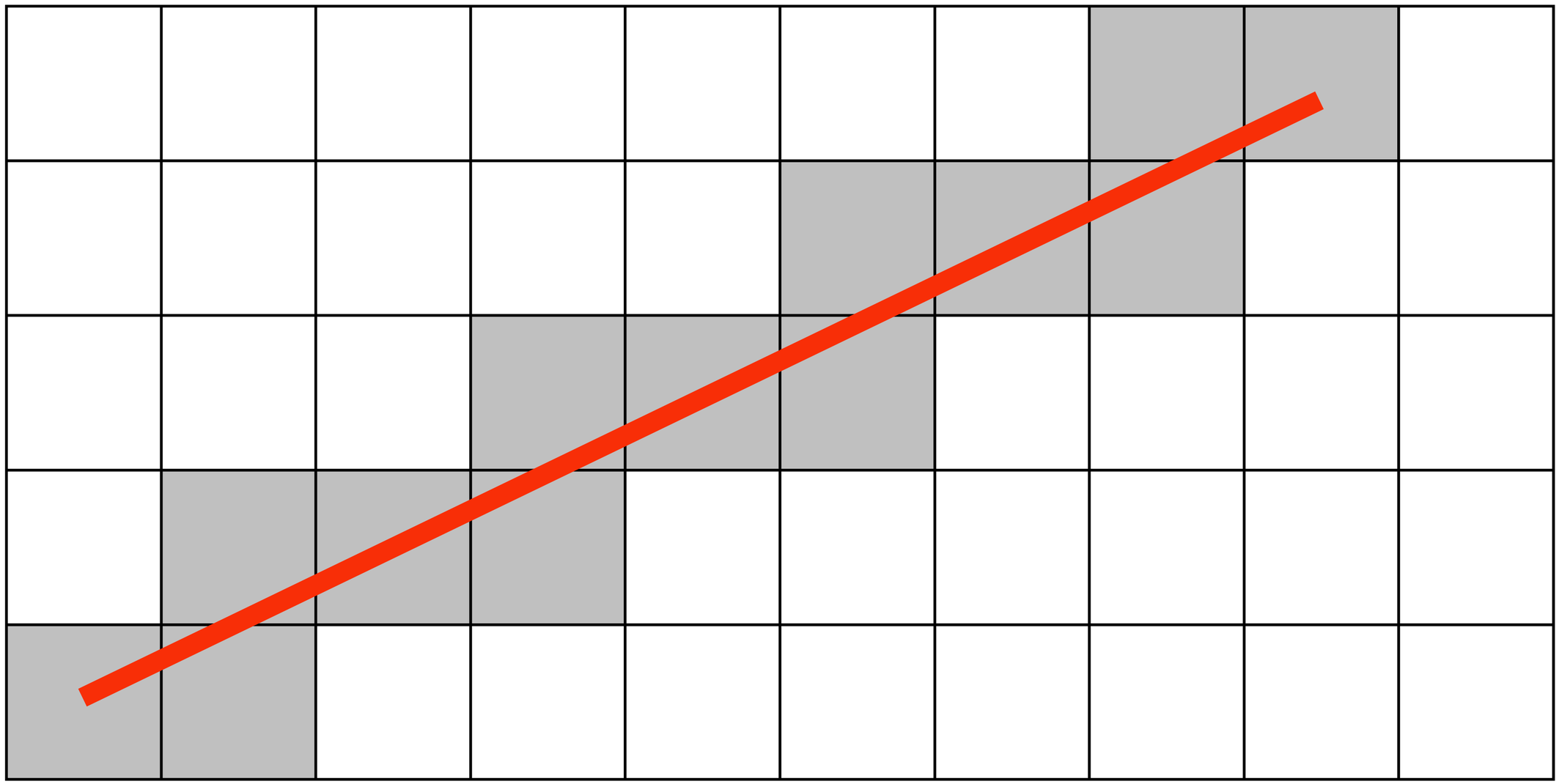
What pixels should we color in to depict a line?

"Rasterization": process of converting a continuous object to a discrete representation on a raster grid (pixel grid)



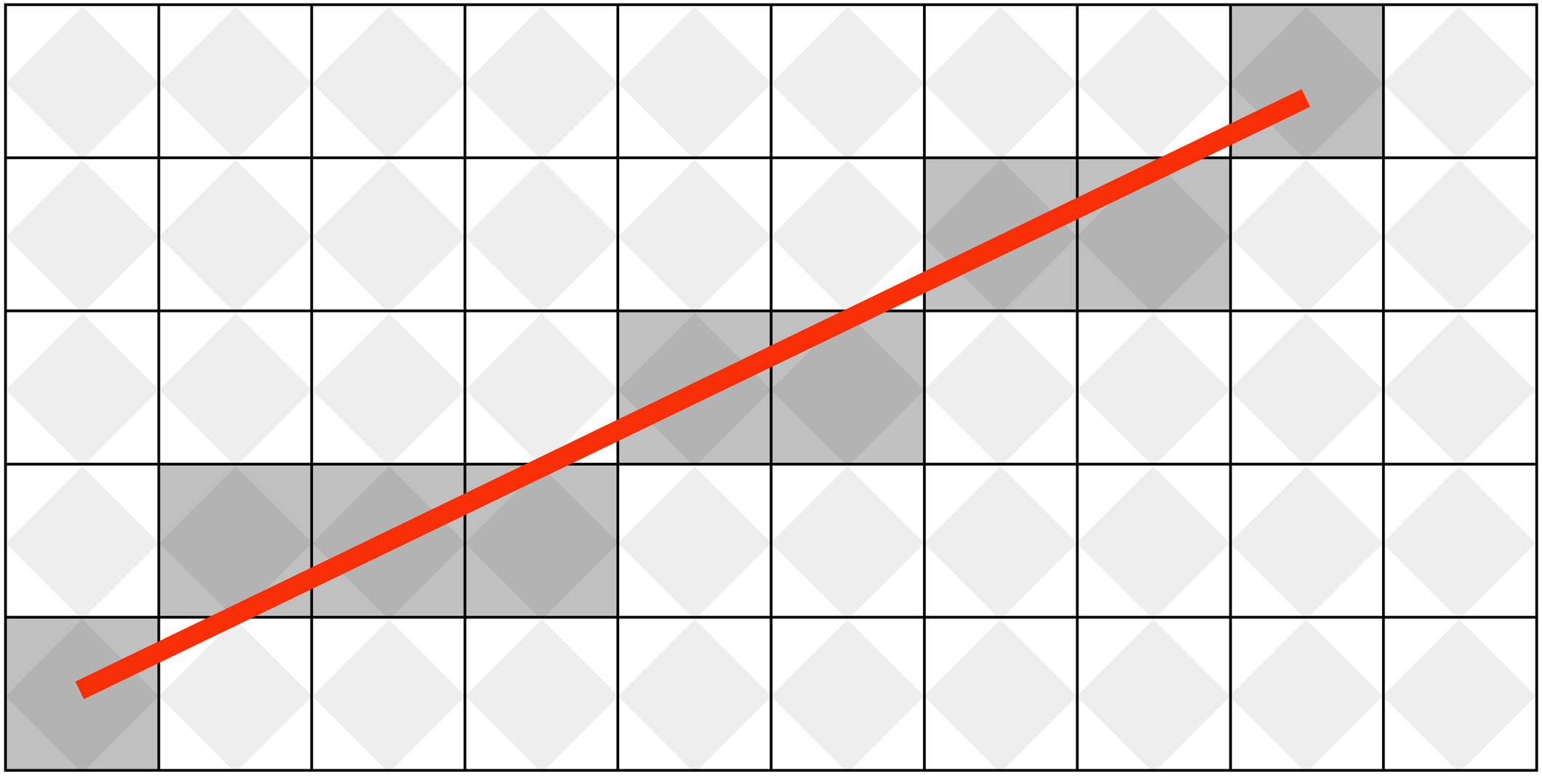
What pixels should we color in to depict a line?

Light up all pixels intersected by the line?



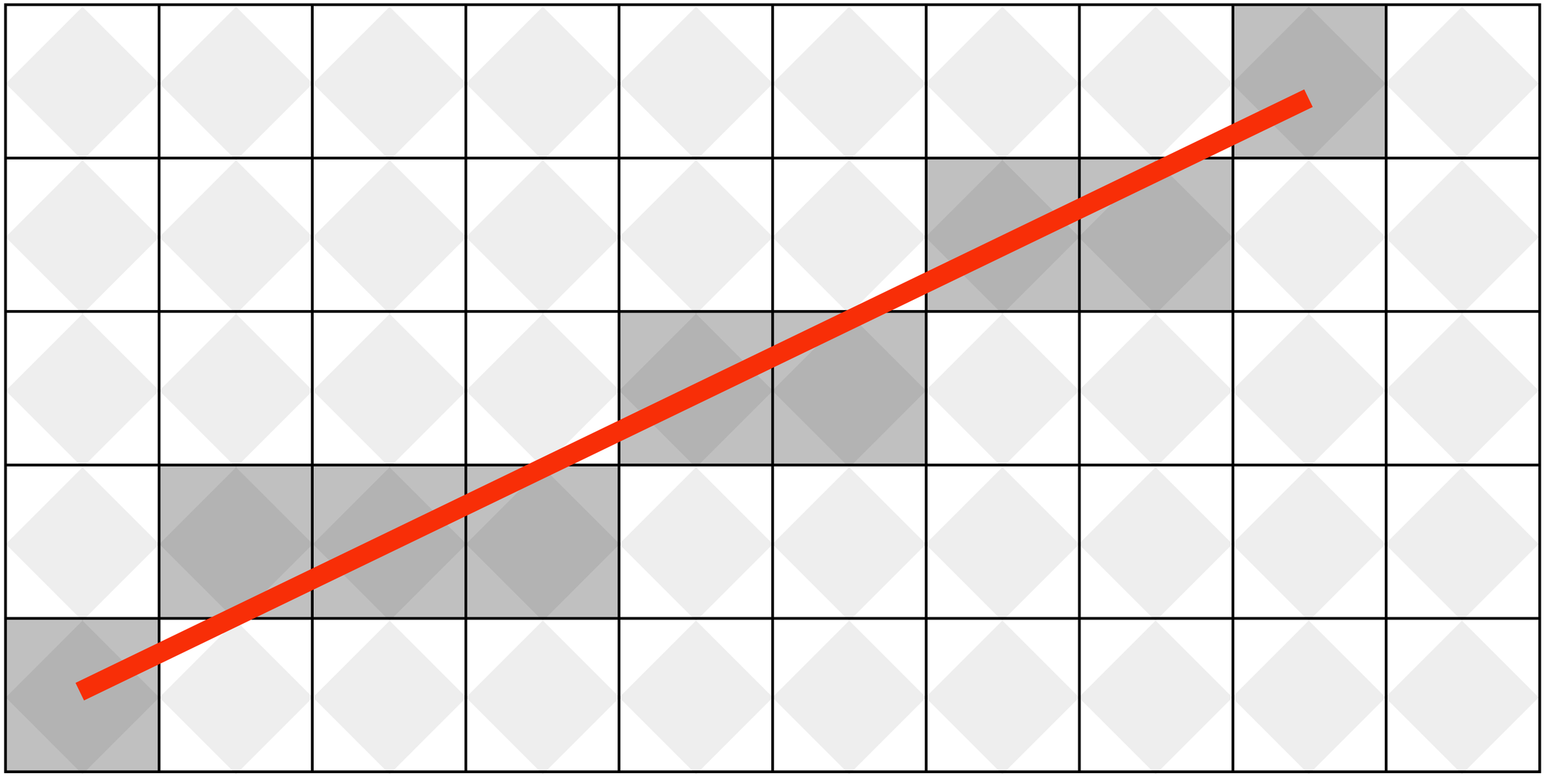
What pixels should we color in to depict a line?

Diamond rule (used by modern GPUs):
light up pixel if line passes through associated diamond



What pixels should we color in to depict a line?

Is there a right answer?
(consider a drawing a "line" with thickness)



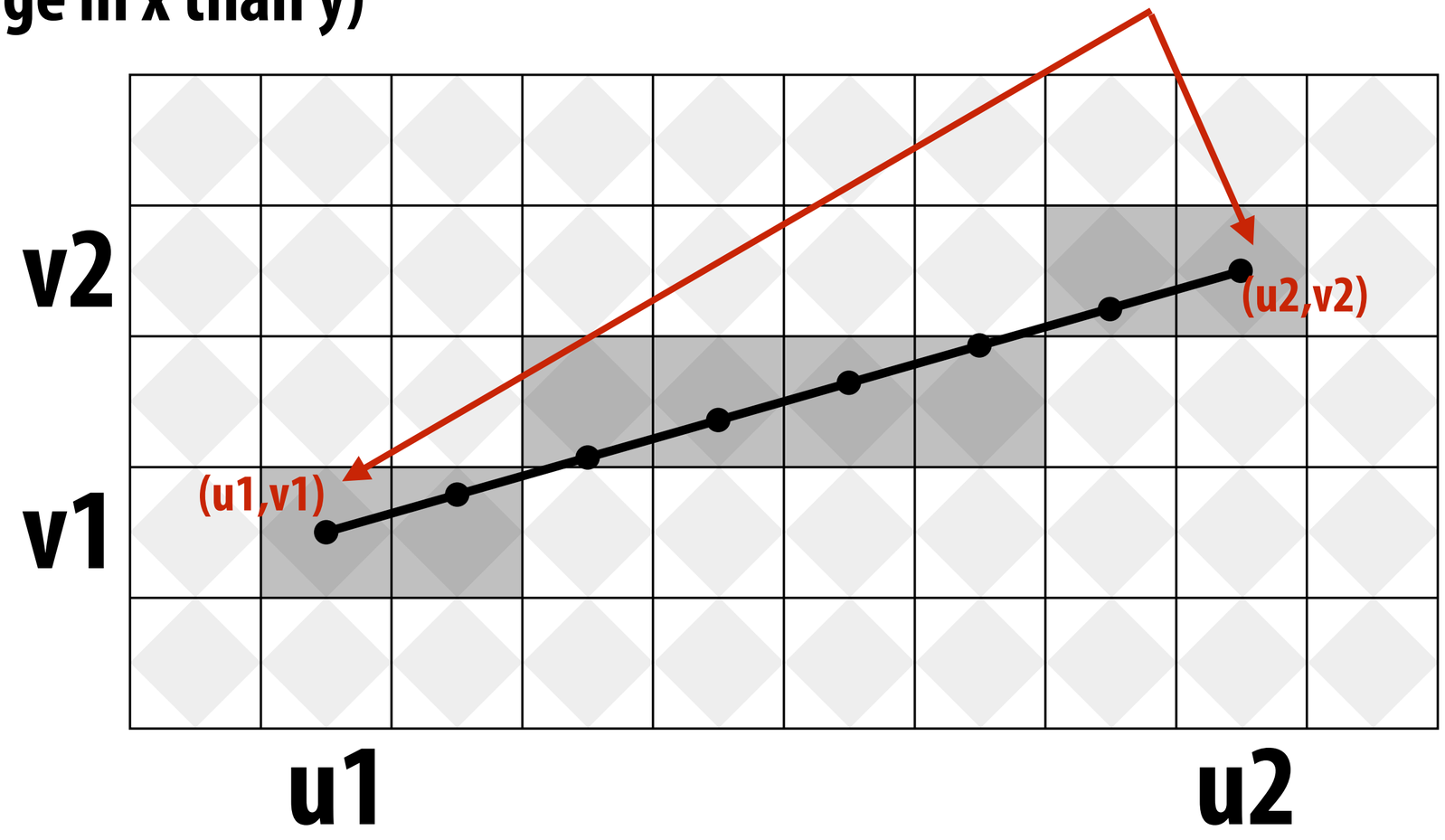
How do we find the pixels satisfying a chosen rasterization rule?

- Could check every single pixel in the image to see if it meets the condition...
  - $O(n^2)$ pixels in image vs. at most $O(n)$ "lit up" pixels
  - *must* be able to do better! (e.g., seek algorithm that does work proportional to number of pixels in the drawing of the line)

Incremental line rasterization

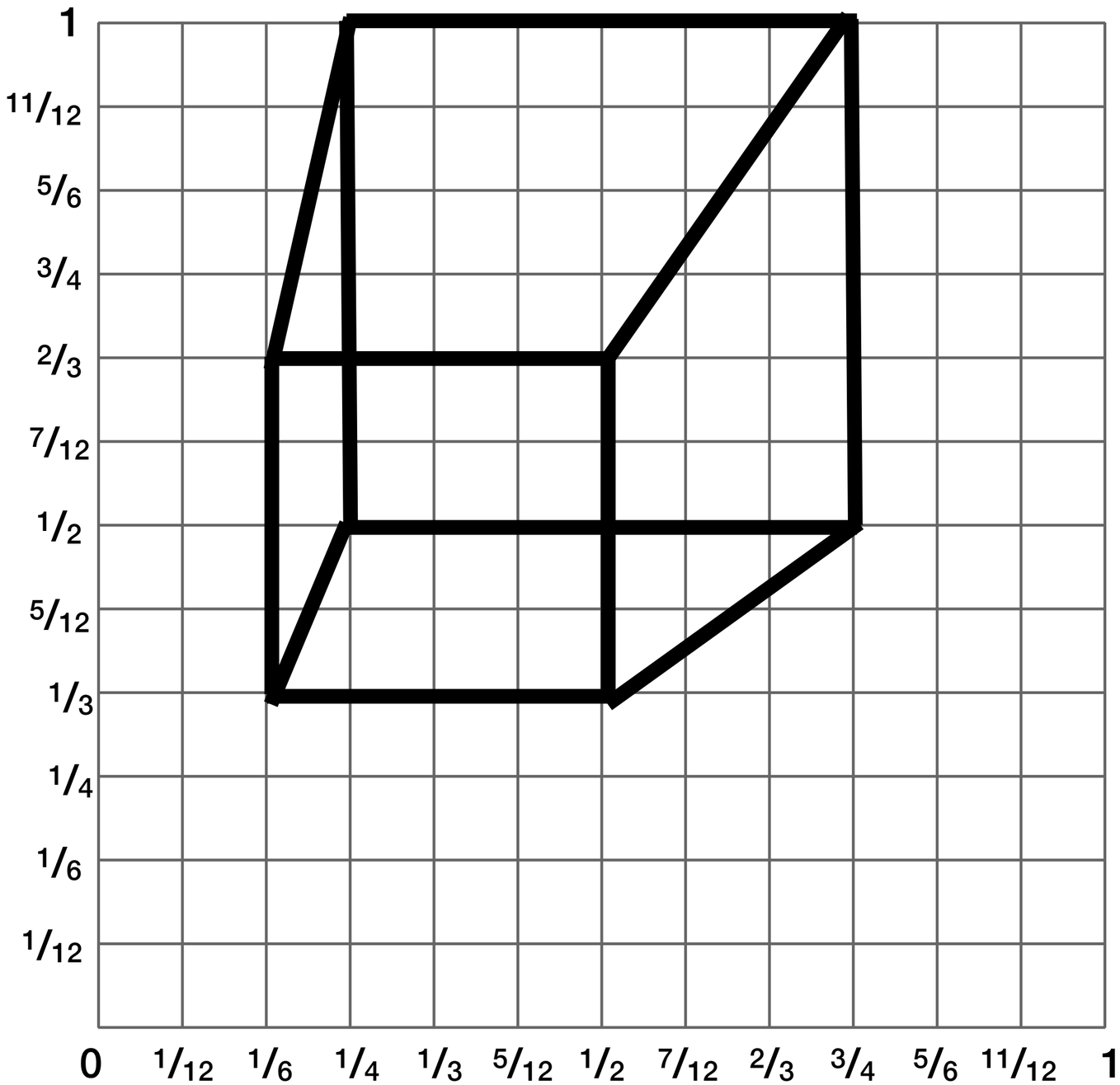
- Let's say a line is represented with integer endpoints: (u1,v1), (u2,v2)
- Slope of line: s = (v2-v1) / (u2-u1)
- Consider an easy special case:
  - u1 < u2, v1 < v2 (line points toward upper-right)
  - 0 < s < 1 (more change in x than y)

```
v = v1;
for( u=u1; u<=u2; u++ )
{
    v += s;
    draw( u, round(v) )
}
```



Common optimization: rewrite algorithm to use only integer arithmetic (Bresenham algorithm)

Line drawing of cube



2D coordinates:

A: (1/4, 1/2)
B: (3/4, 1/2)

C: (1/4, 1)
D: (3/4, 1)

E: (1/6, 1/3)
F: (1/2, 1/3)

G: (1/6, 2/3)
H: (1/2, 2/3)

*** keep in mind, this image is mirrored since we simulated the result of pinhole projection**

We just rendered a simple line drawing of a cube.

But to render more realistic pictures (or animations) we need a much richer model of the world.

surfaces

motion

materials

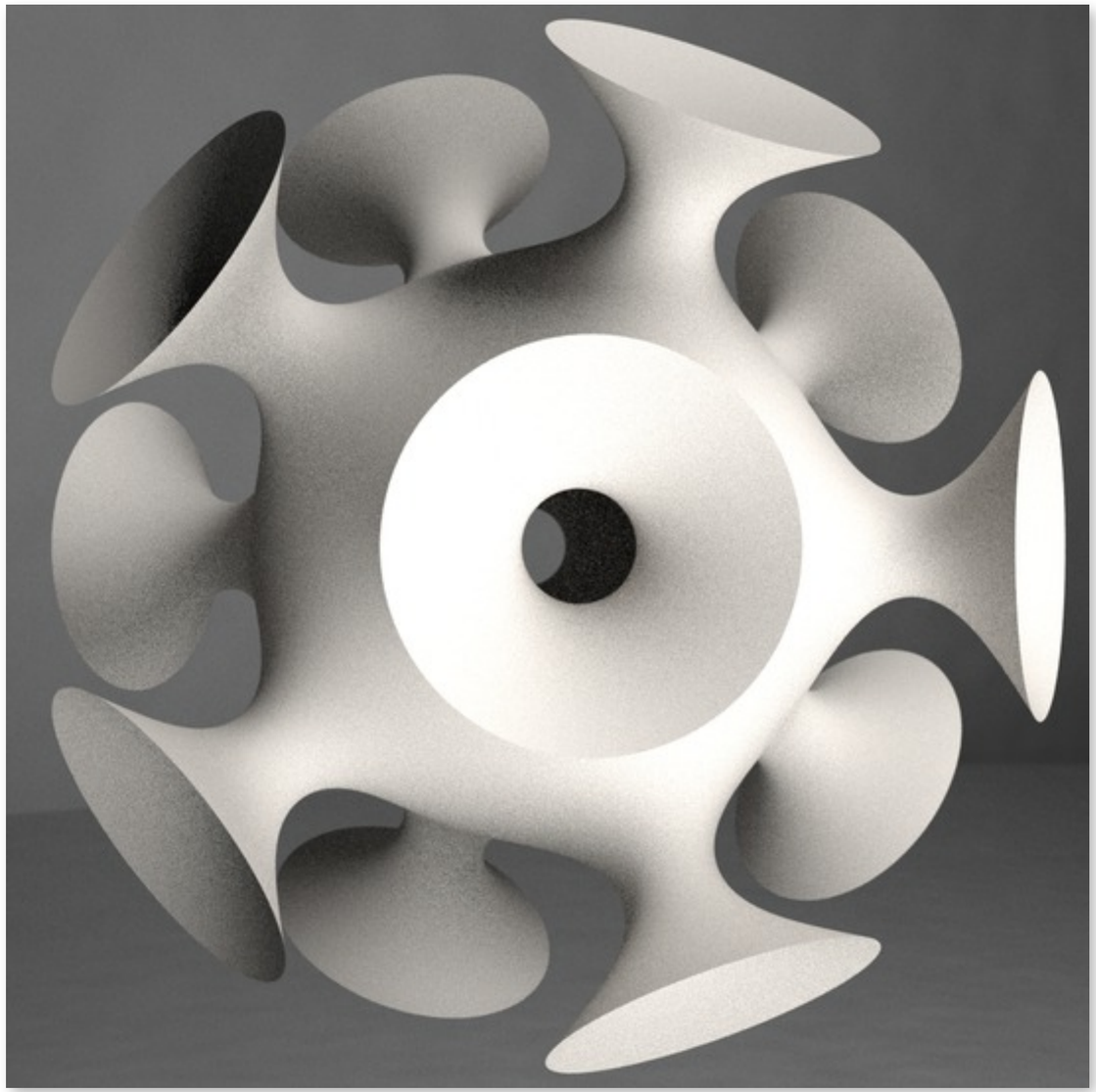
lights

cameras

2D shapes

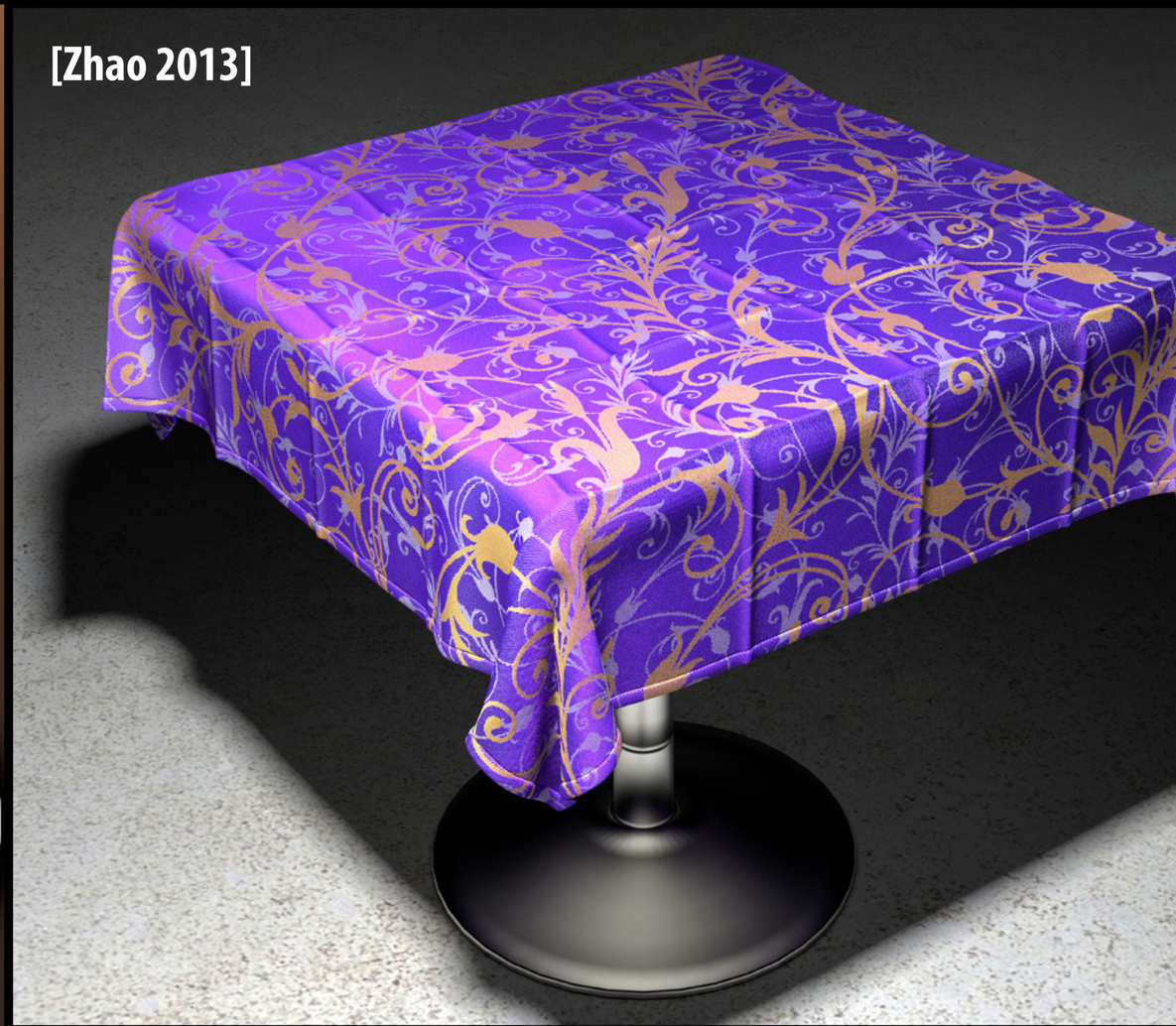
[Source: Batra 2015]

Complex 3D surfaces



Platonic noid

Modeling material properties

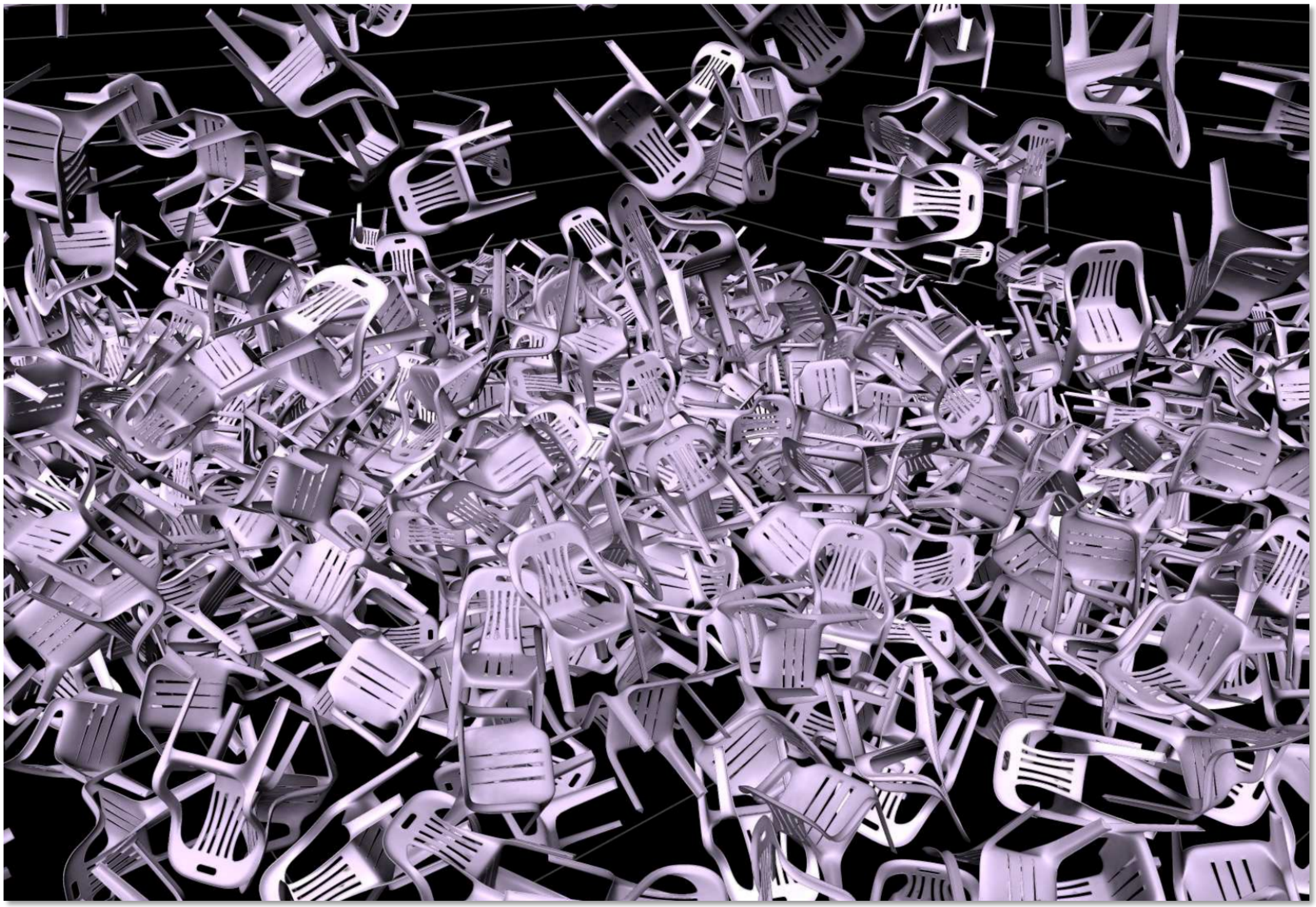


Realistic lighting environments

Animation: modeling motion

https://www.youtube.com/watch?v=6G3060o5U7w

Physically-based simulation of motion



https://www.youtube.com/watch?v=tT81VPk_ukU

[James 2004]

Course Logistics

About this course

- A broad overview of major topics and techniques in interactive computer graphics: geometry, rendering, animation, imaging

- Changes this quarter:
  - All new assignments (bear with us)
  - Focus on implementing fundamental data structures and algorithms that are reused across all areas of graphics

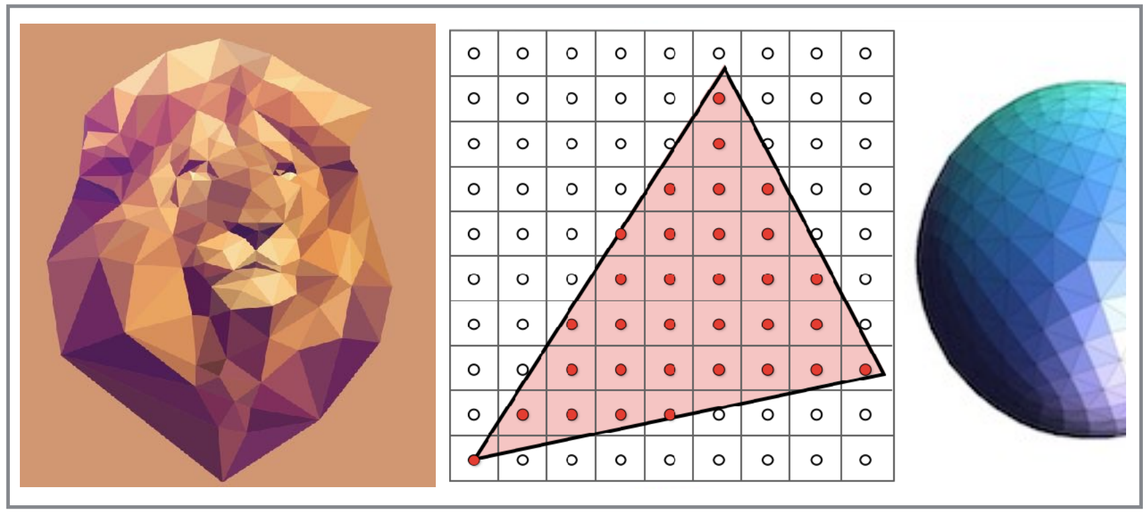
Getting started

- Sign up for an account on the course web site
  - http://cs248.stanford.edu

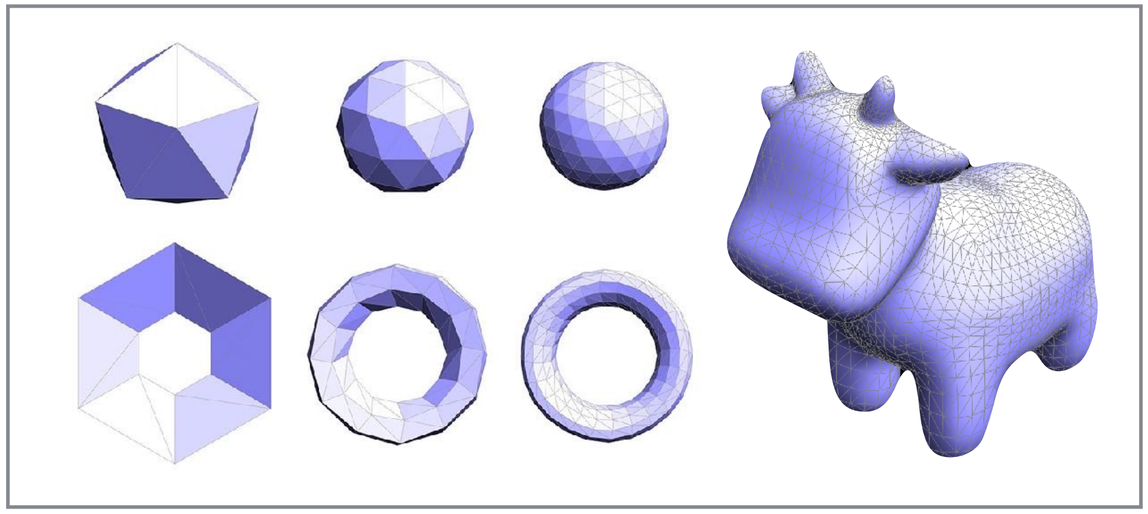
- Sign up for the course on Piazza
  - https://piazza.com/stanford/spring2018/cs248/home

- There is no textbook for this course, but please see the course website for references (there are some excellent graphics textbooks)

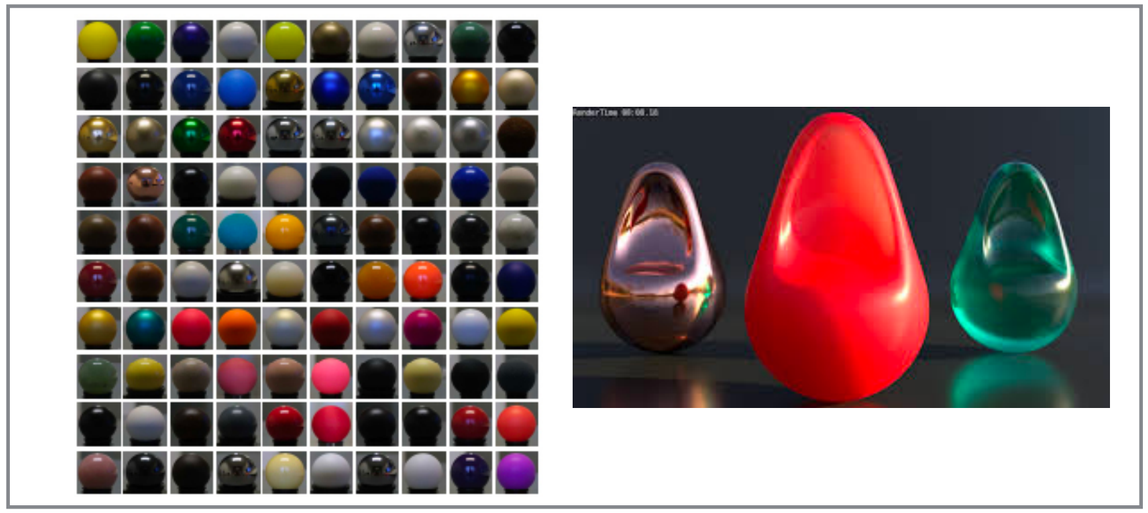
Course programming assignments



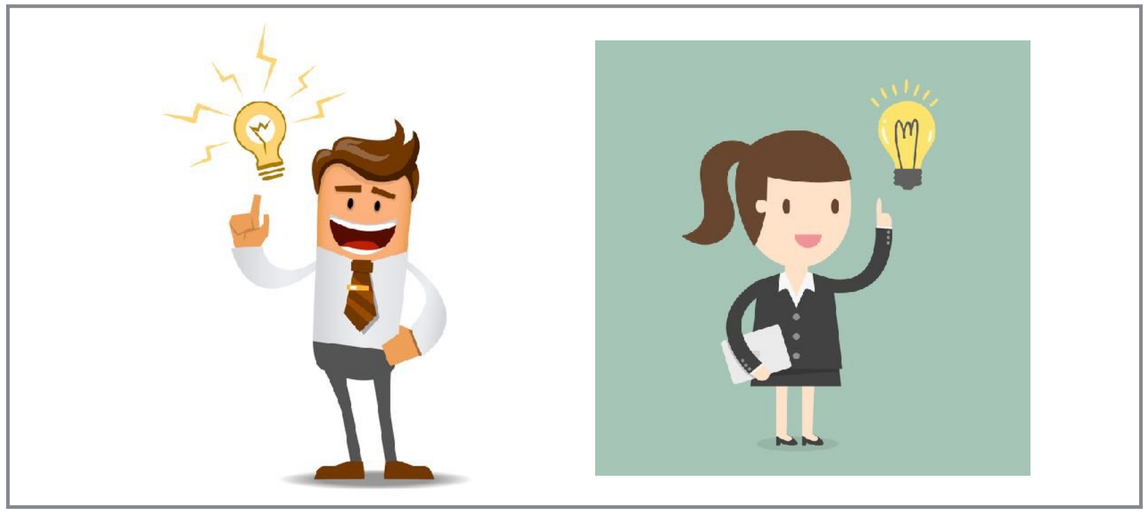
1. 2D drawing (2 weeks)



2. Geometry editing (2 weeks)



3. Materials and lighting in a 3D renderer (2 weeks)



4. Self-selected project
extend existing project, take on optional animation project, choose your own
(4 weeks)

Man Designed by Alekksall / Freepik. Woman designed by Dooder / Freepik

Assignments / Grading

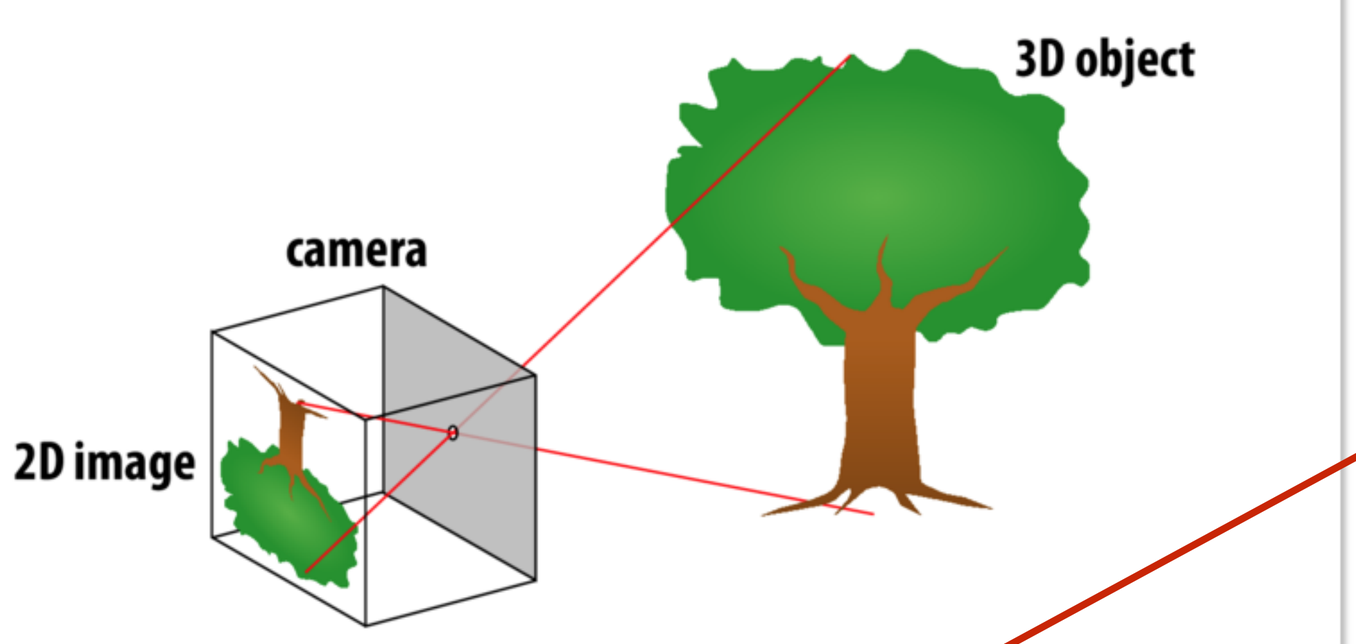
- **(45%) Three programming assignments**
  - Each worth 15% of grade
  - In teams of up to two
- **(25%) Self-selected final project**
  - Extend an earlier assignments, or do your own thing!
- **(25%) Midterm / final**
  - Both cover cumulative material seen so far
- **(5%) Class participation**
  - In-class/website comments, other contributions to class

The course web site

We have no textbook for this class and so the lecture slides and instructor/TA/ student discussions on the web are the primary course reference

Perspective projection

- Objects look smaller as they get further away ("perspective")
- Why does this happen?
- Consider simple ("pinhole") model of a camera:



CMU 15-462/662, Fall 2015

Previous | **Next** --- Slide 30 of 65

Back to **Lecture Thumbnails**

Add Private Note

kayvonf about an hour ago

Question: During class Keenan asked a question about why do objects look smaller when hey are viewed at a distance. I liked one of the arguments made because it appealed to the angle subtended by an object. Could someone elaborate on that here?

Prompt Edit Delete Archive [0 Upvote Downvote]

"Add private note" button:

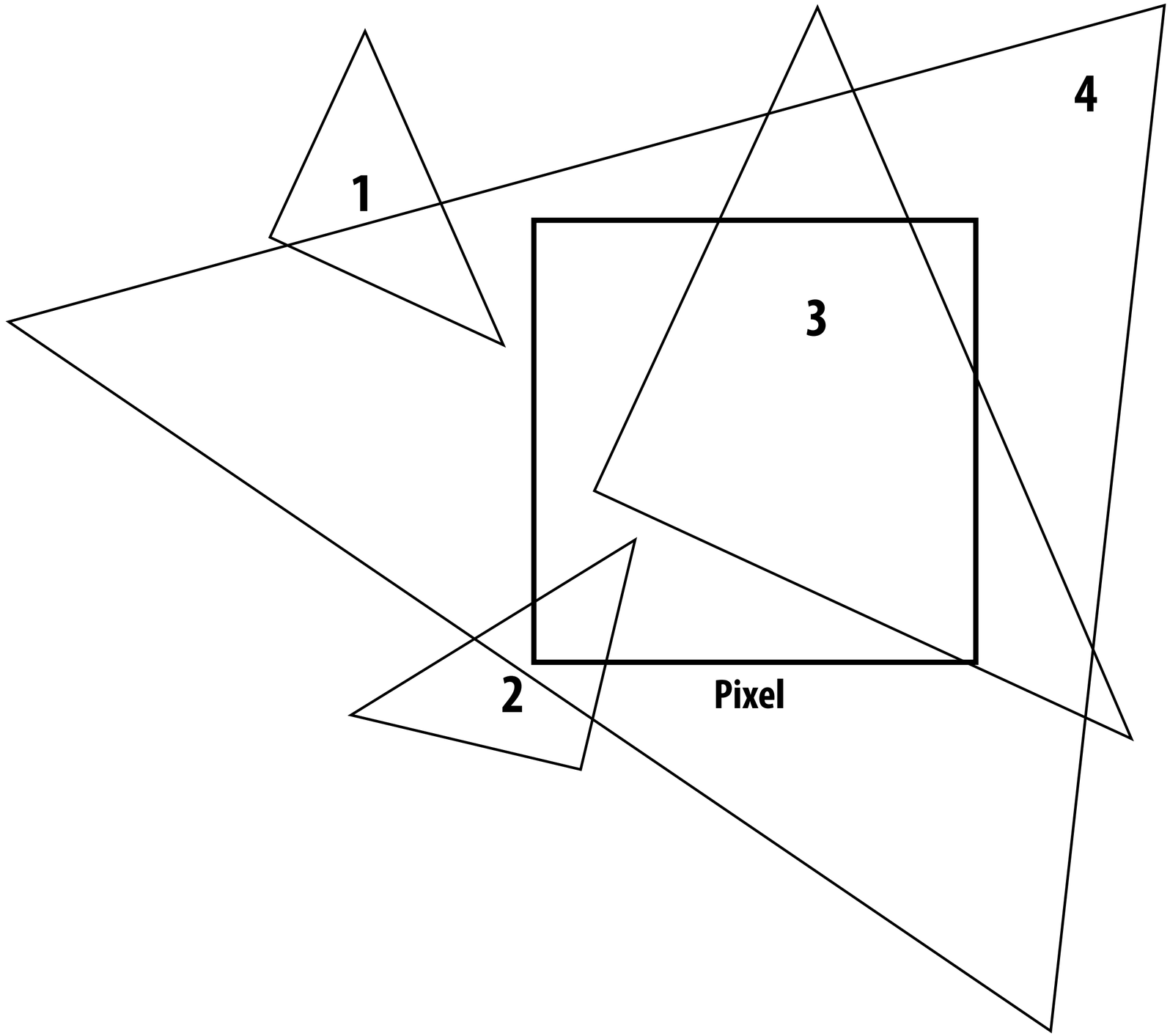
You can add notes to yourself about this slide here.

Slide comments and discussion

Thought question for next time:

What does it mean for a pixel to be covered by a triangle?

Question: which triangles "cover" this pixel?



See you next time!

- Next time, we'll talk about drawing a triangle
  - And it's a lot more interesting than it might seem…
  - Also, what's up with these "jagged" lines?