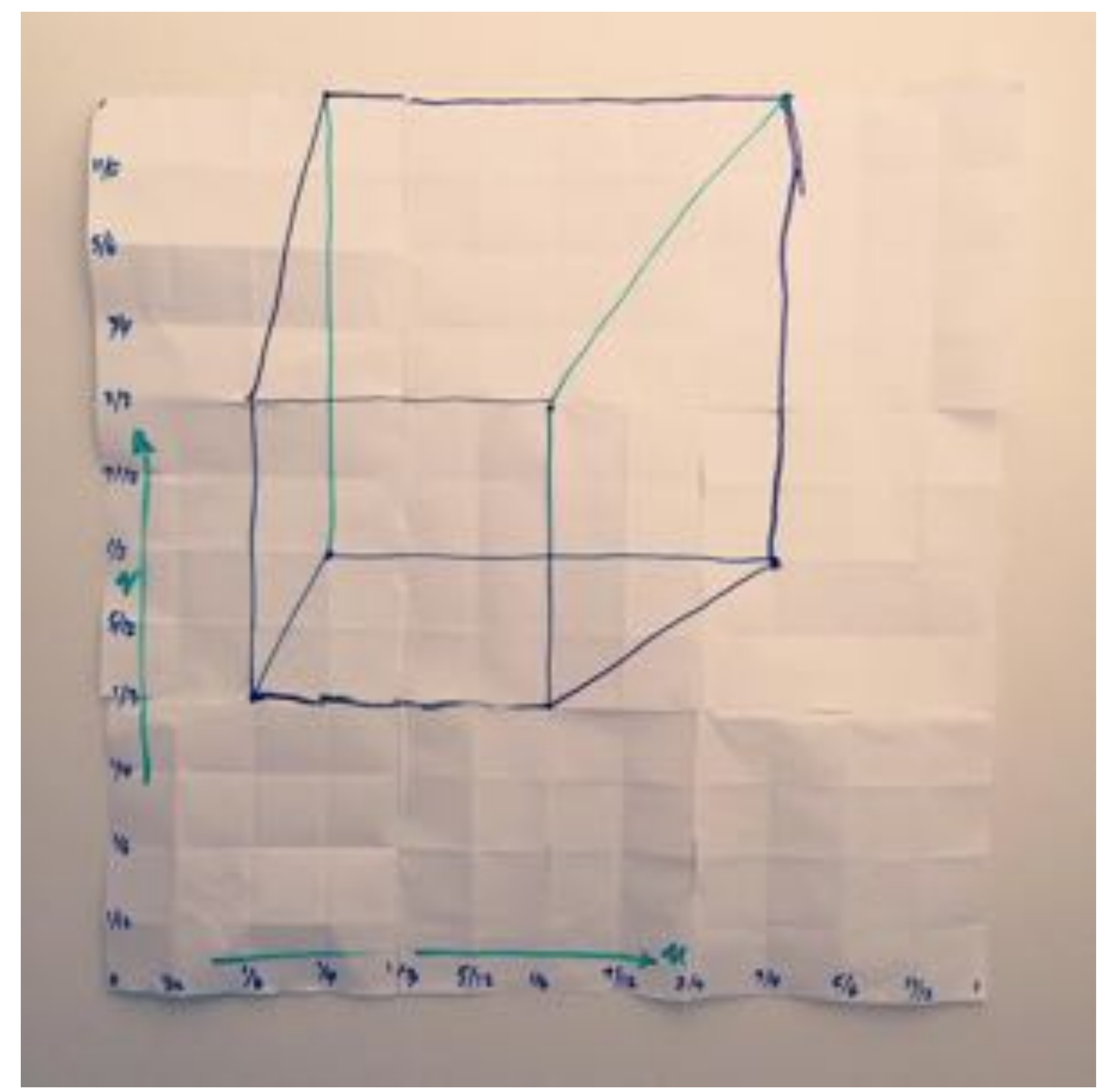
Lecture 1:

Course Intro:
Overview

Computer Graphics
CMU 15-462/662

TODAY: Overview Computer Graphics

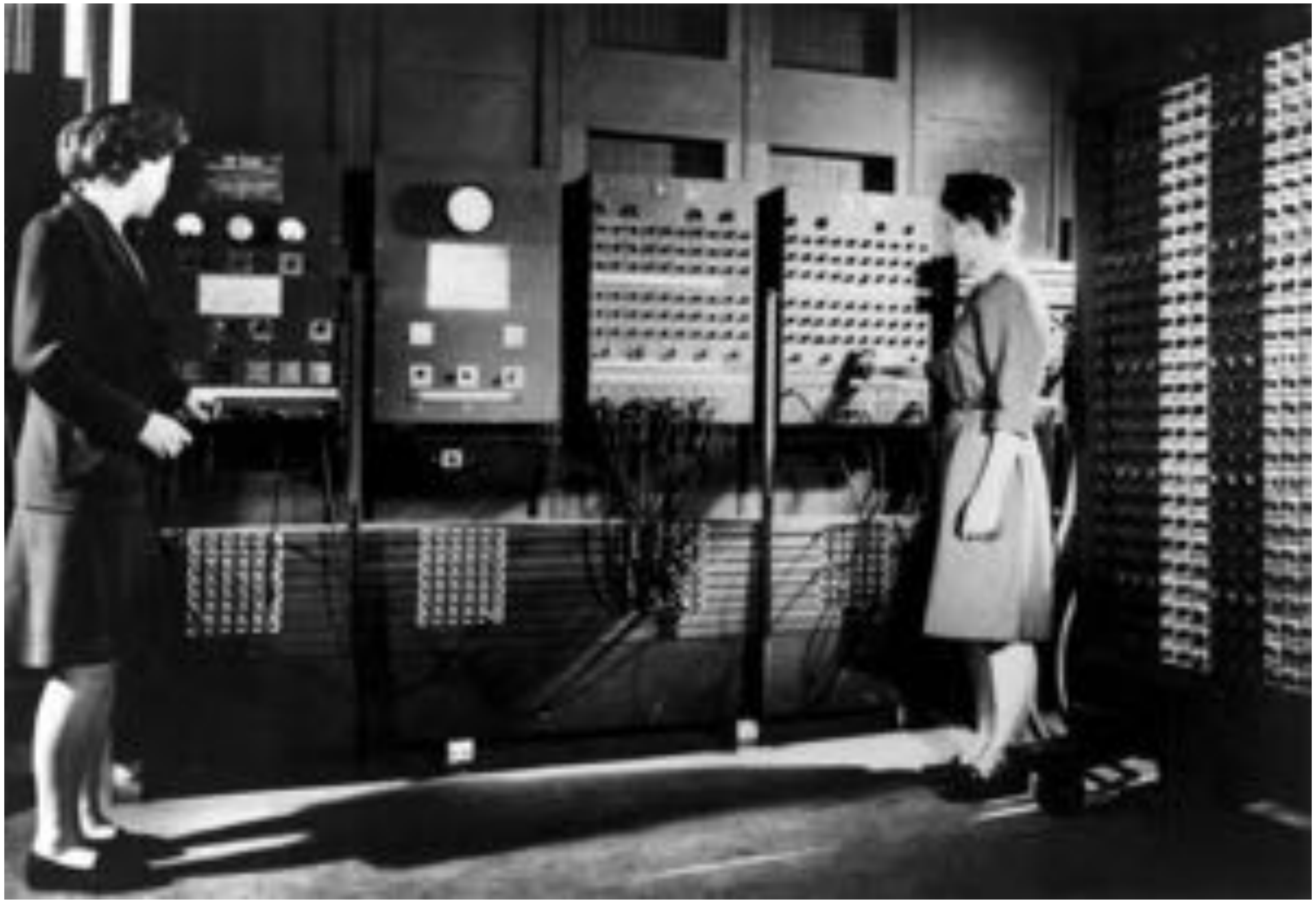
- Two main objectives:
  - Try to understand broadly what computer graphics is about
  - "Implement" our 1st algorithm for making images of 3D shapes



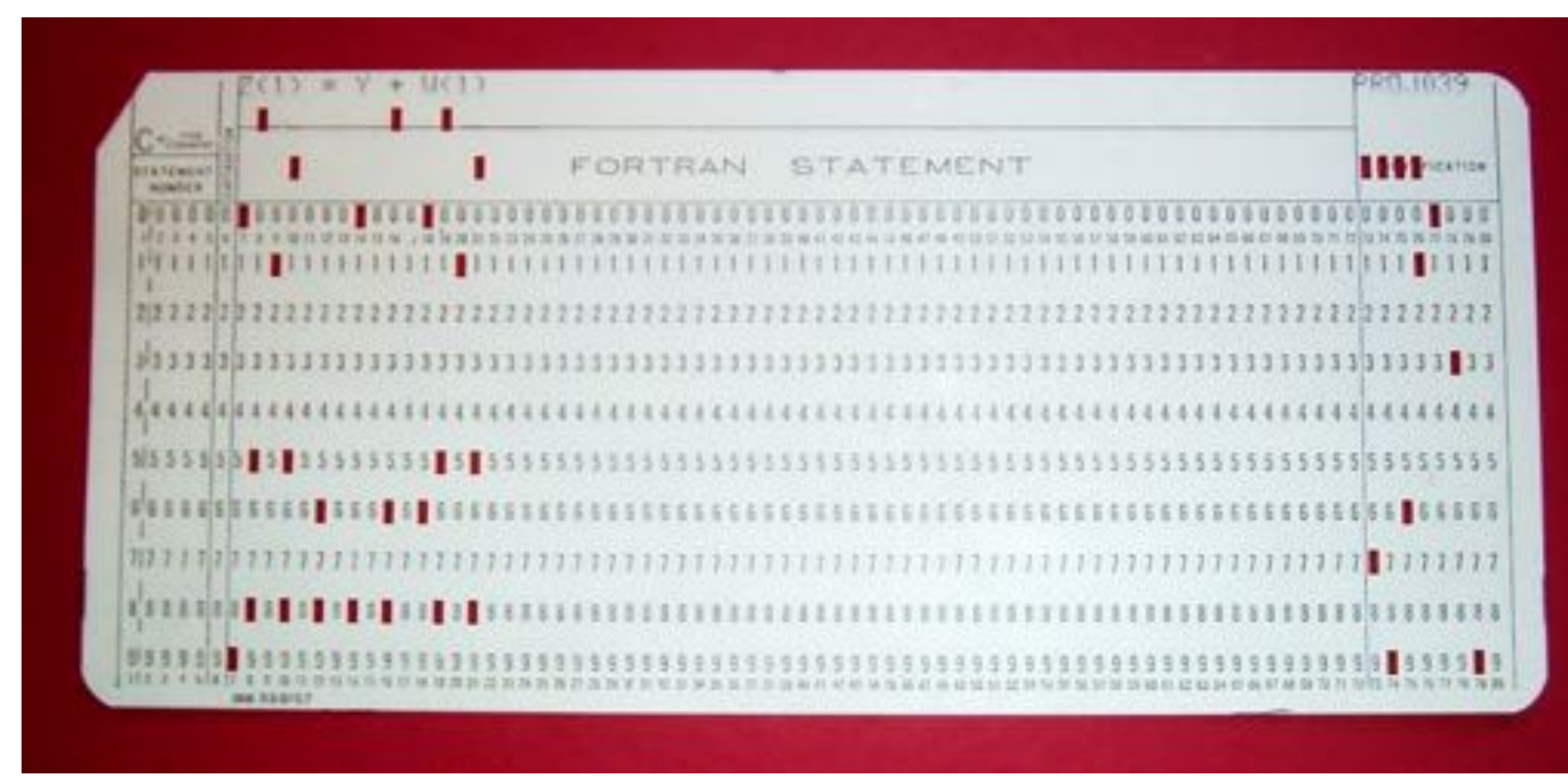
Q: What is computer graphics?

Probably an image like this comes to mind:

Q: . . . ok, but more fundamentally: What is computer graphics—and why do we need it?

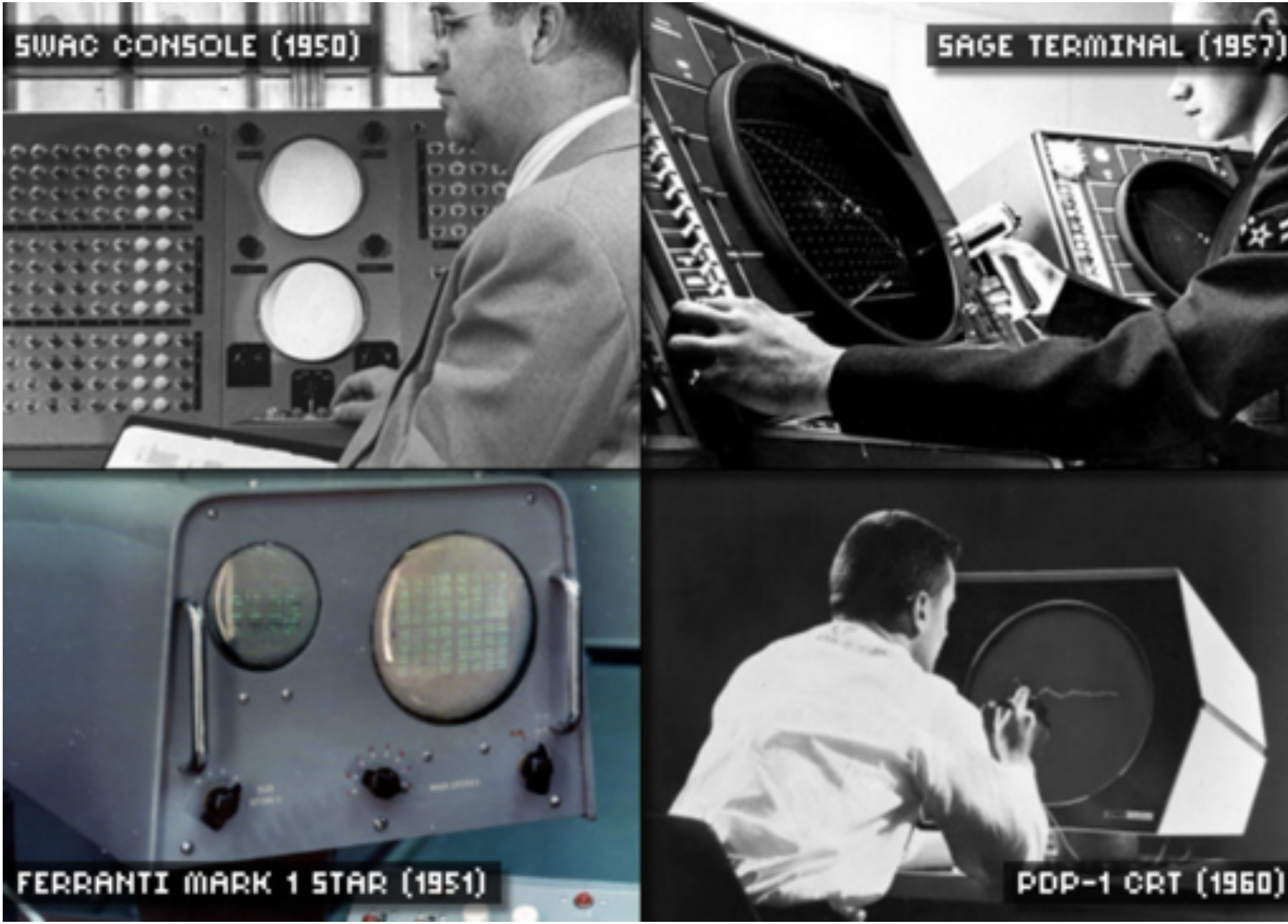


Early computer (ENIAC), 1945



punch card (~120 bytes)

There must be a better way!



Credit: PC World, "A Brief History of Computer Displays"

Sketchpad (Ivan Sutherland, 1963)

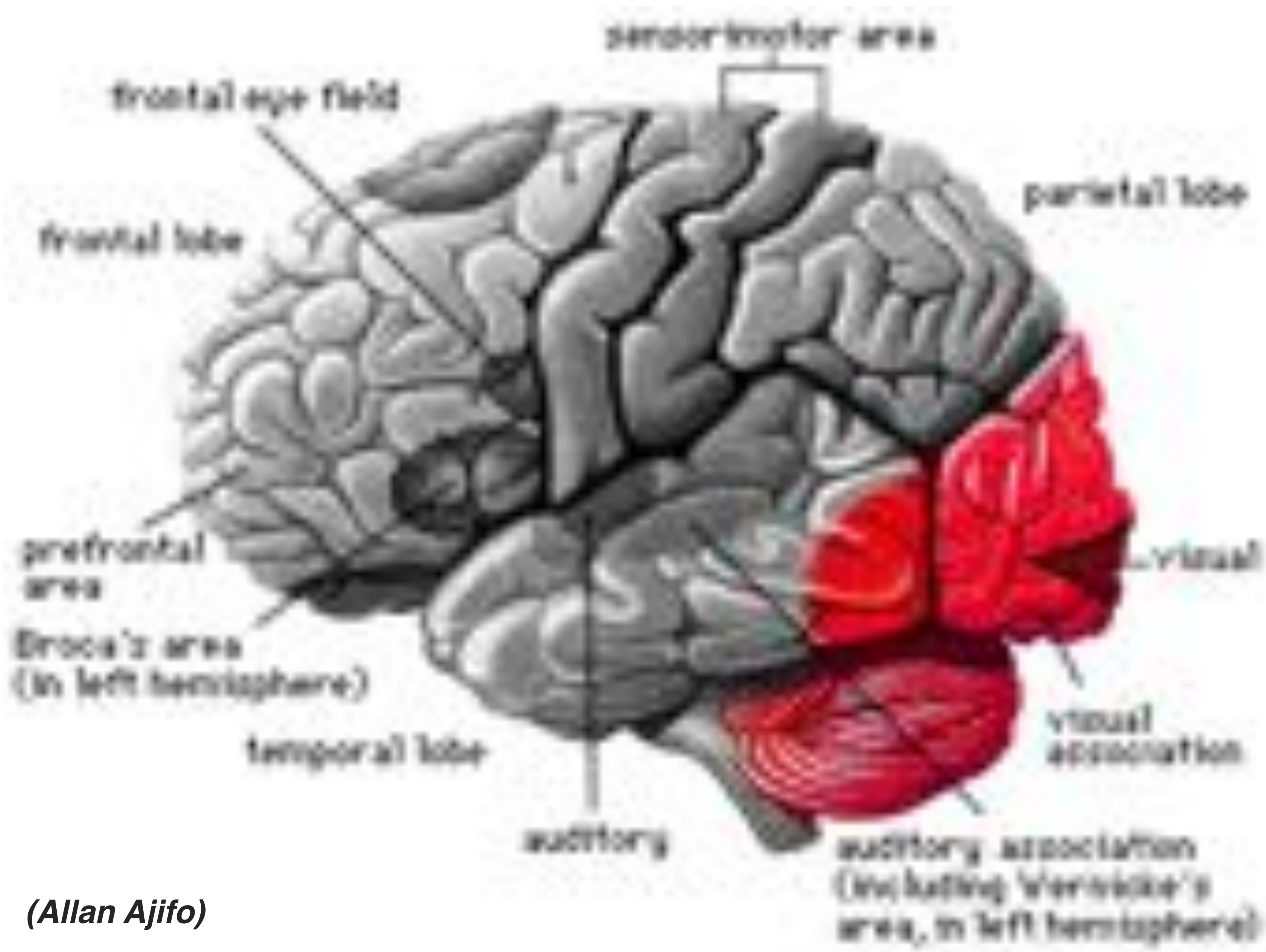
2021: 8k monitor
7680x4320 (~130MB)

Coming down the pipe…

2021 virtual reality headset: 2x 2160x2160 @ 90Hz => 2.3GB/s

Why visual information?

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



(Allan Ajifo)

(Petar Milošević)

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

What is computer graphics?

com•put•er graph•ics /kəmˈpyo͞odər ˈgrafiks/ *n.*

The use of computers to synthesize visual information.

digital information

computation →

visual information

What is computer graphics?

Why only visual?

com•put•er graph•ics /kəmˈpyoodər ˈgrafiks/ *n.*

The use of computers to synthesize visual information.

digital information

computation

visual information

Graphics has evolved a lot since its early days… no longer just about turning on pixels!

Turning digital information into sensory stimuli

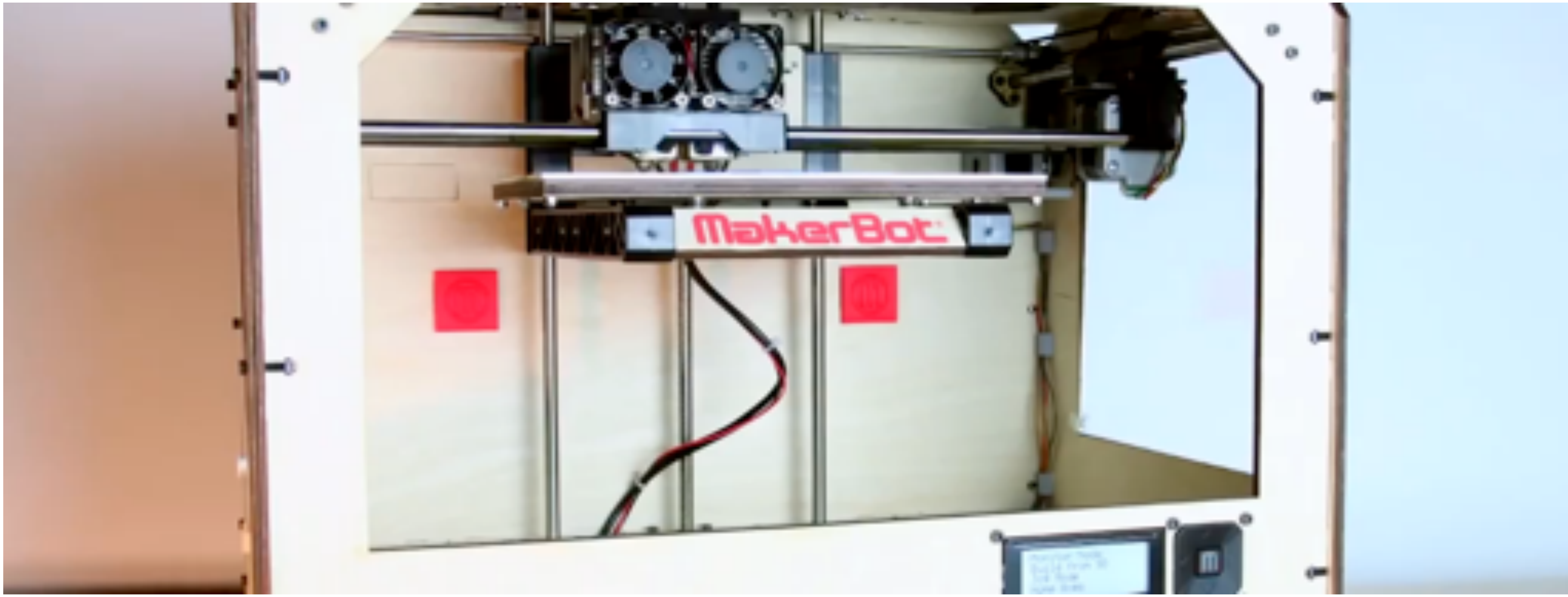
(sound)

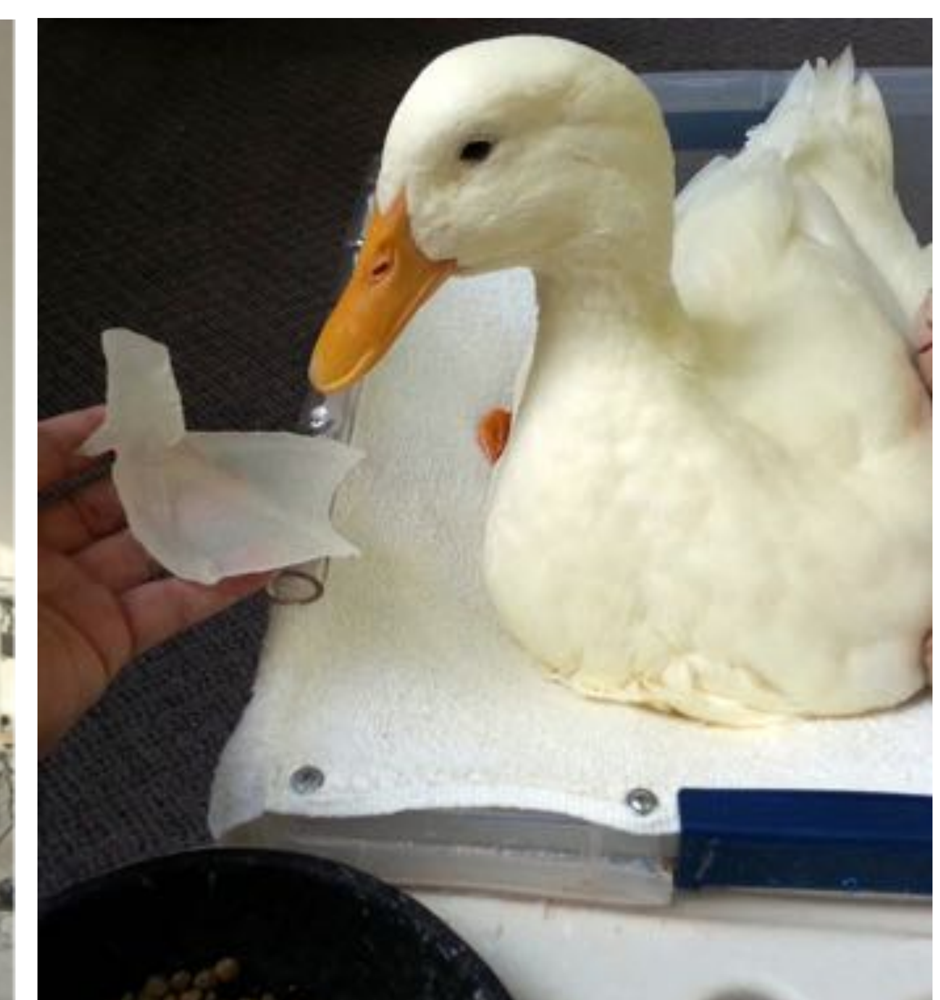
(touch)

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

(…What about taste? Smell?!)

Turning digital information into physical matter





Definition of Graphics, Revisited

com•put•er graph•ics /kəmˈpyo͞odər ˈgrafiks/ *n.*
The use of computation to turn **digital information** into **sensory stimuli**.

Even this definition is too narrow…

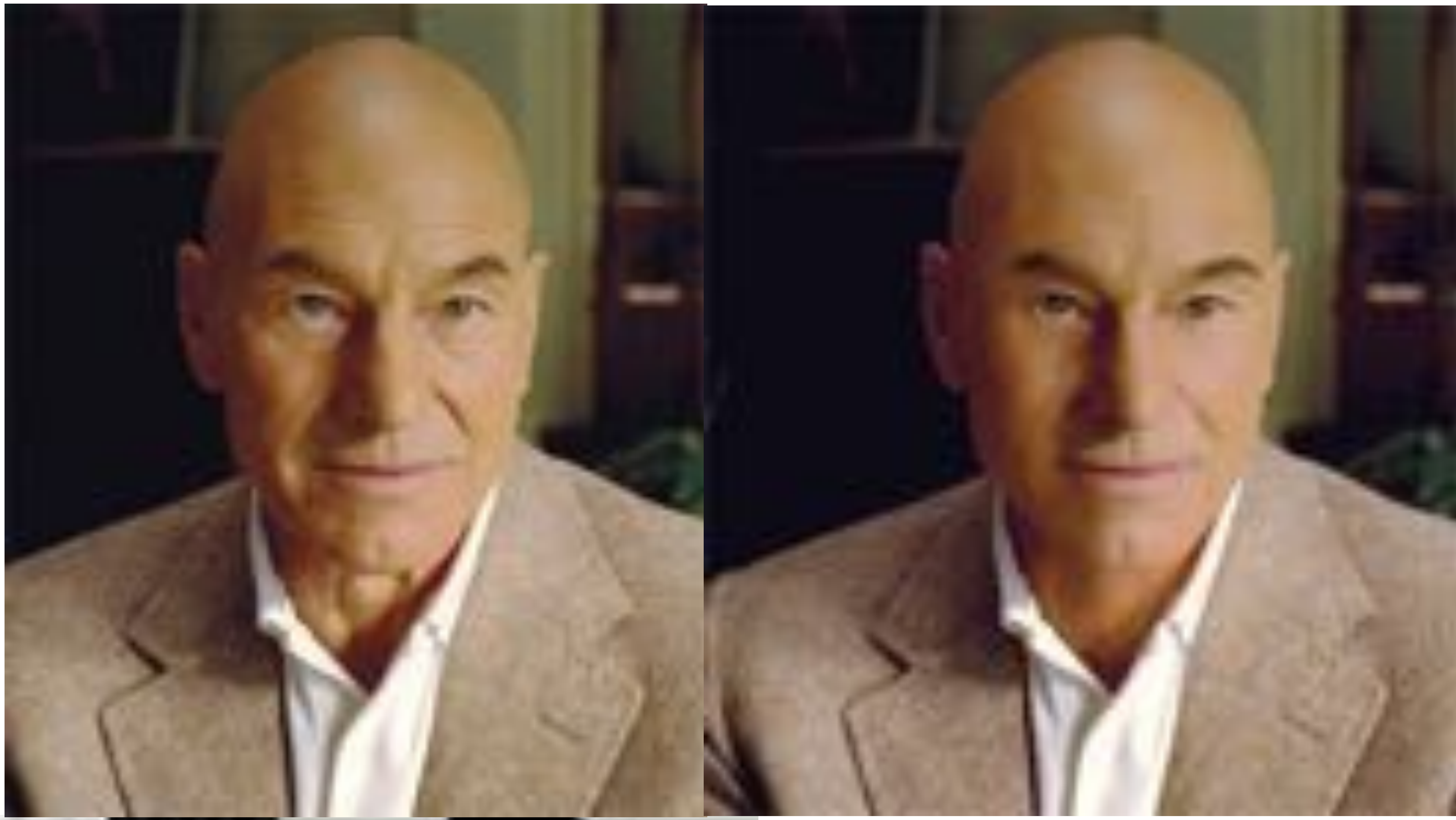
SIGGRAPH 2020 Technical Papers Trailer

Computer graphics is everywhere!

Entertainment (movies, games)

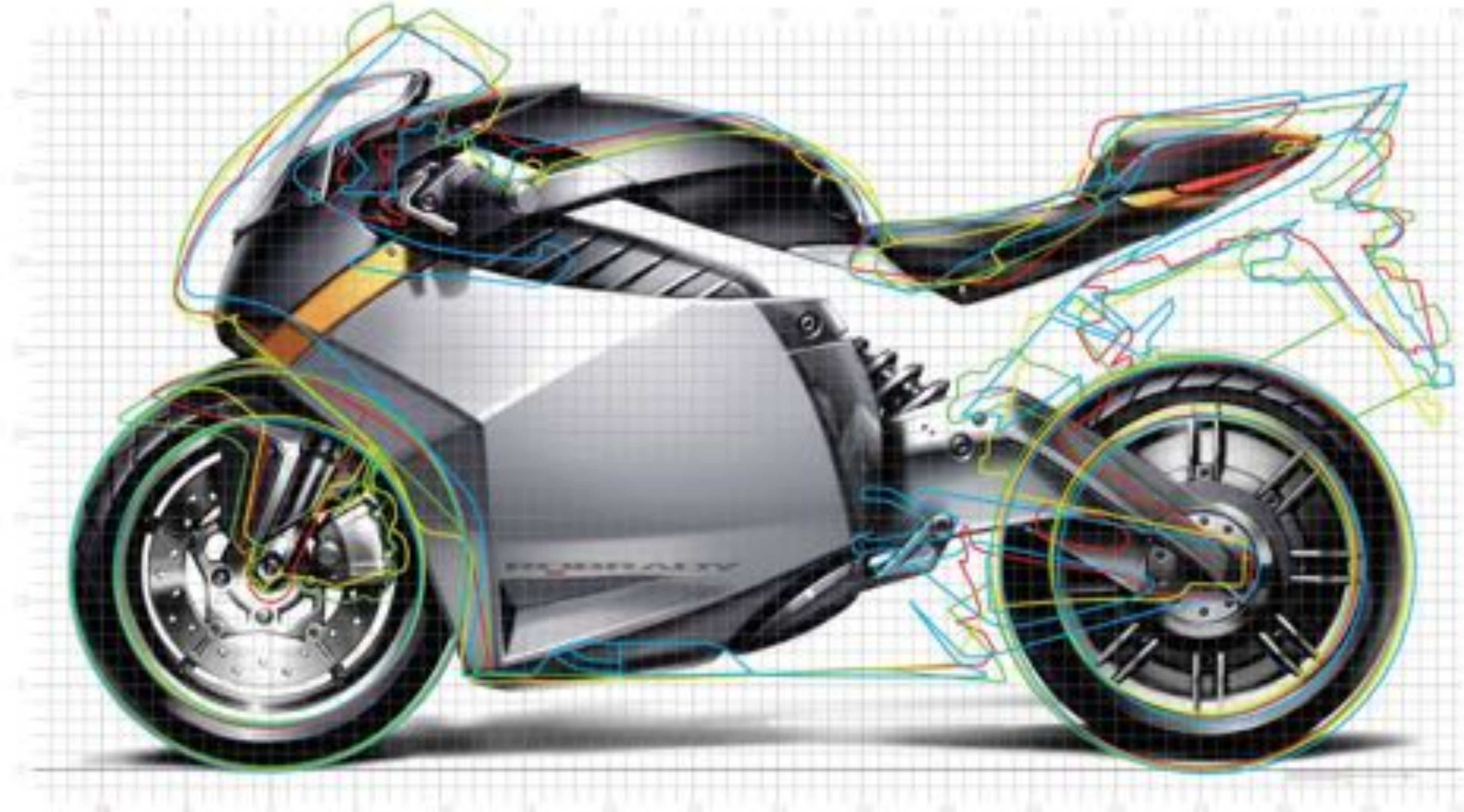
Entertainment

- Not just cartoons!

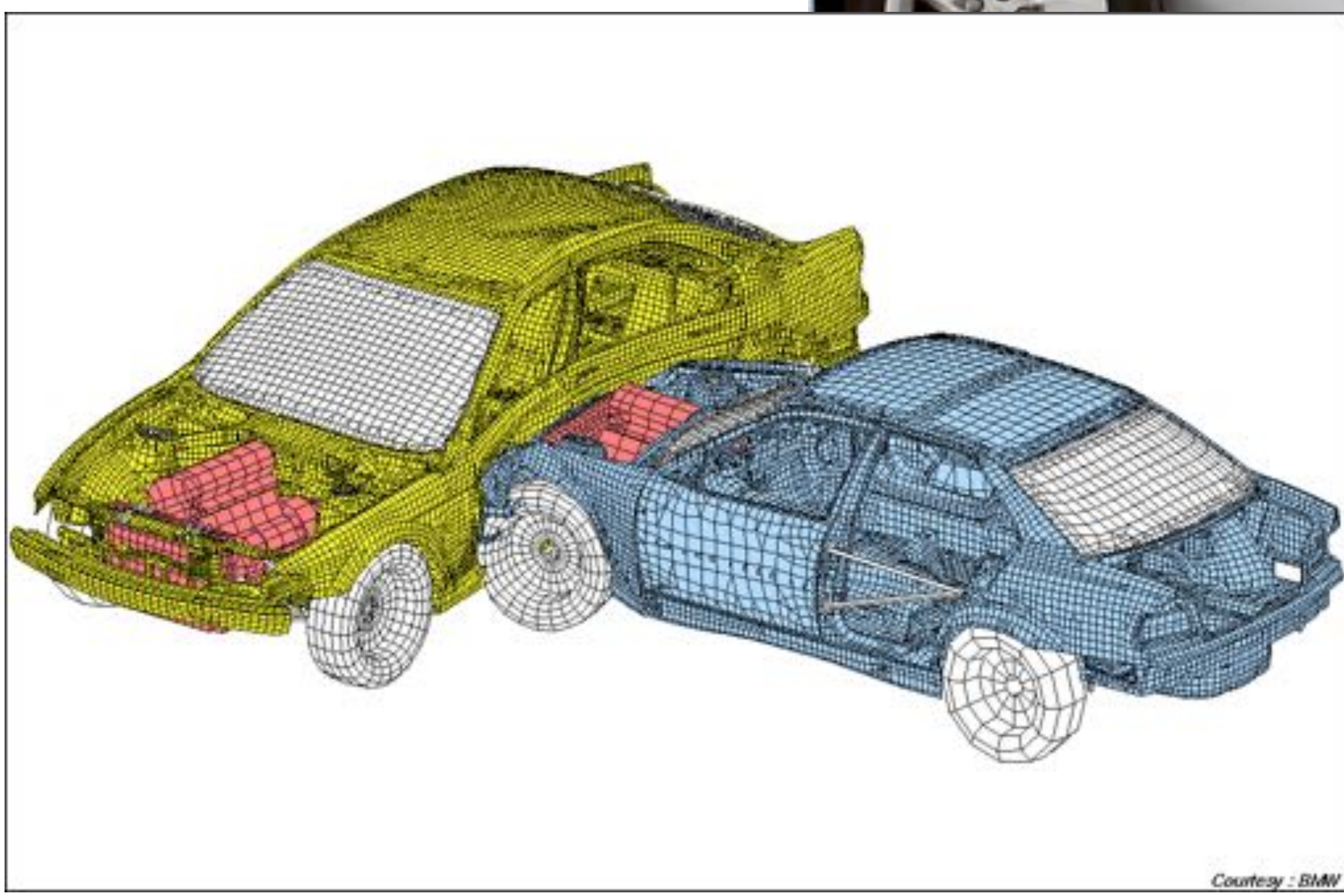


Art and design

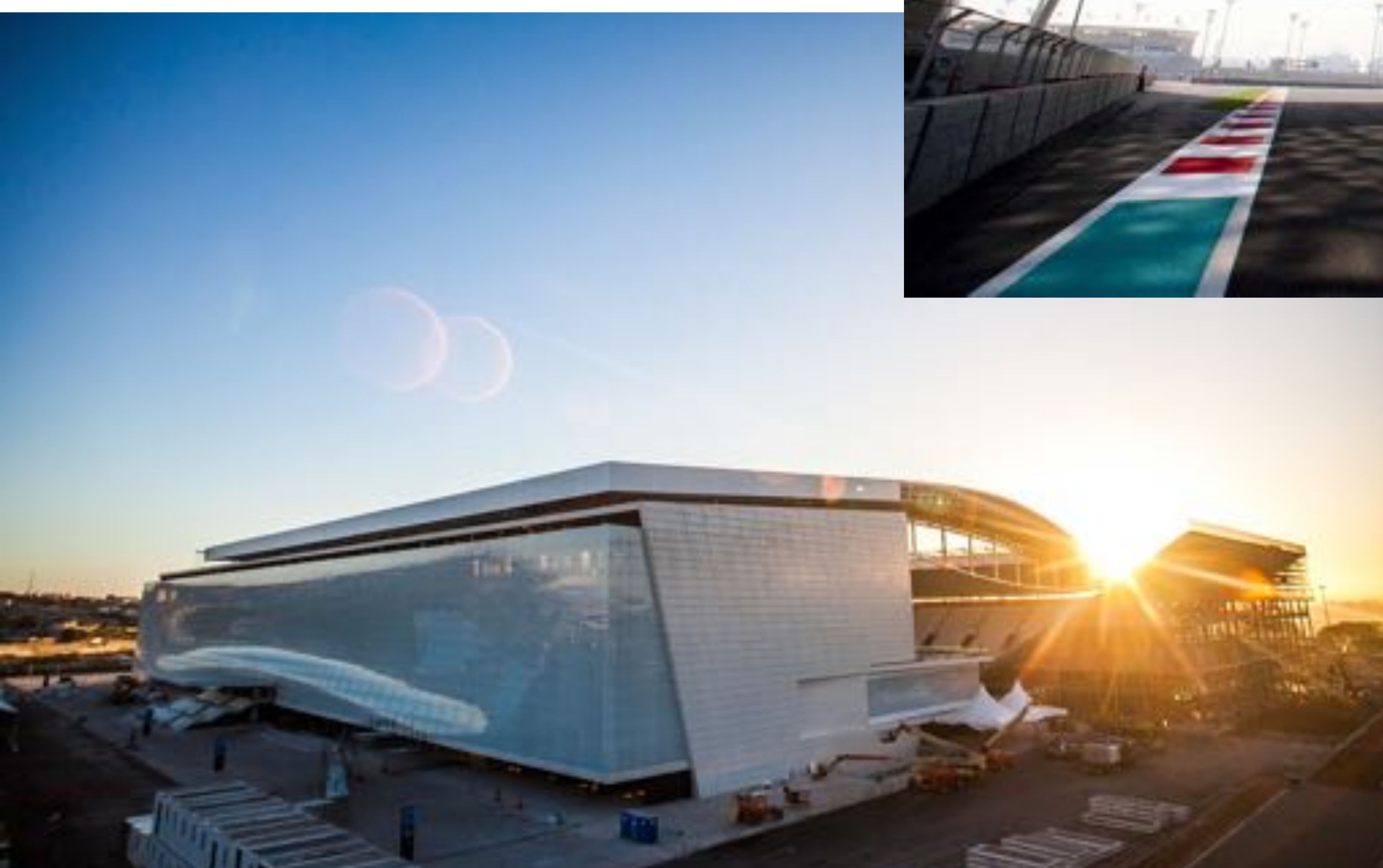
Industrial design



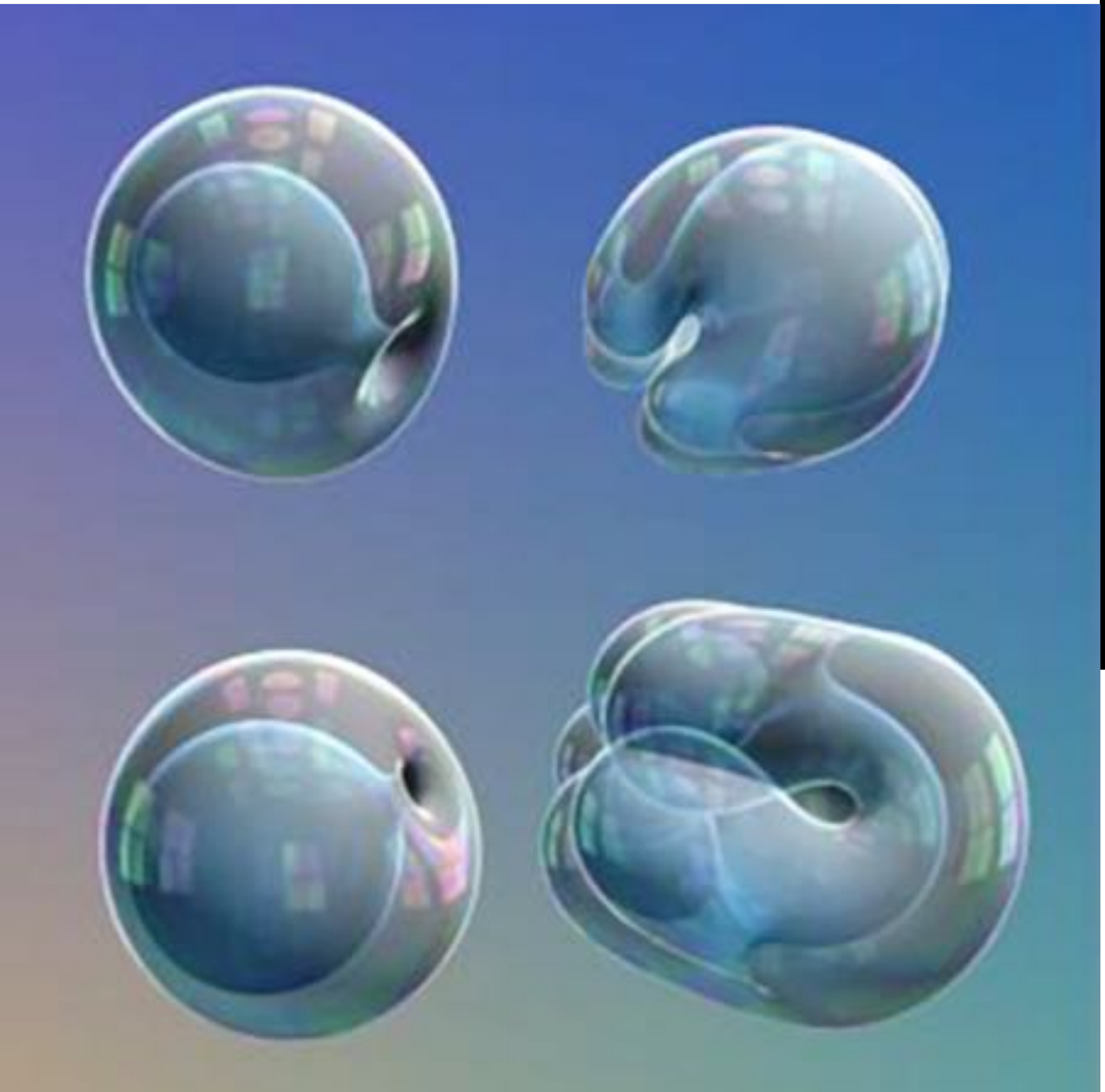
Computer aided engineering (CAE)

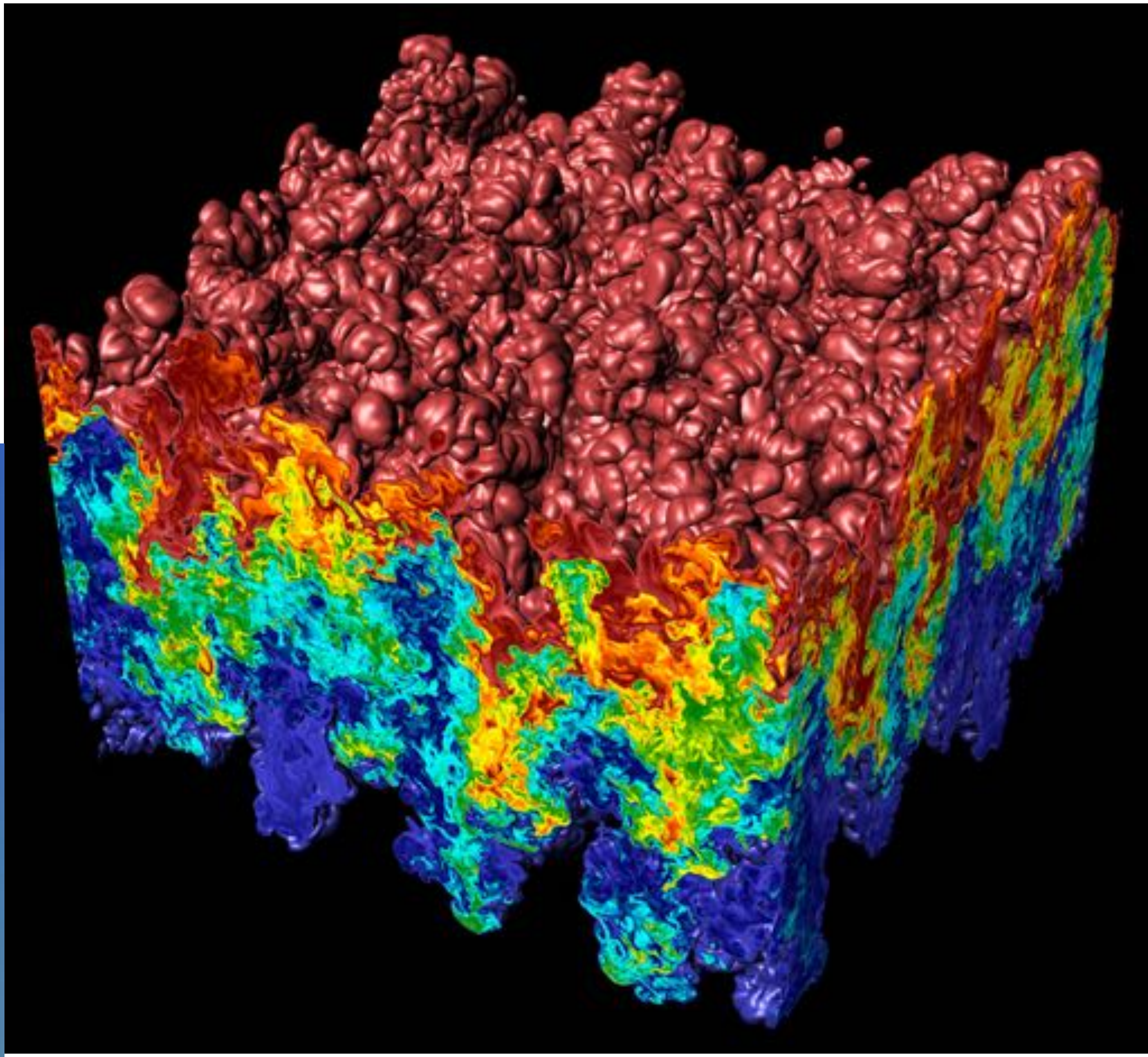


Architecture

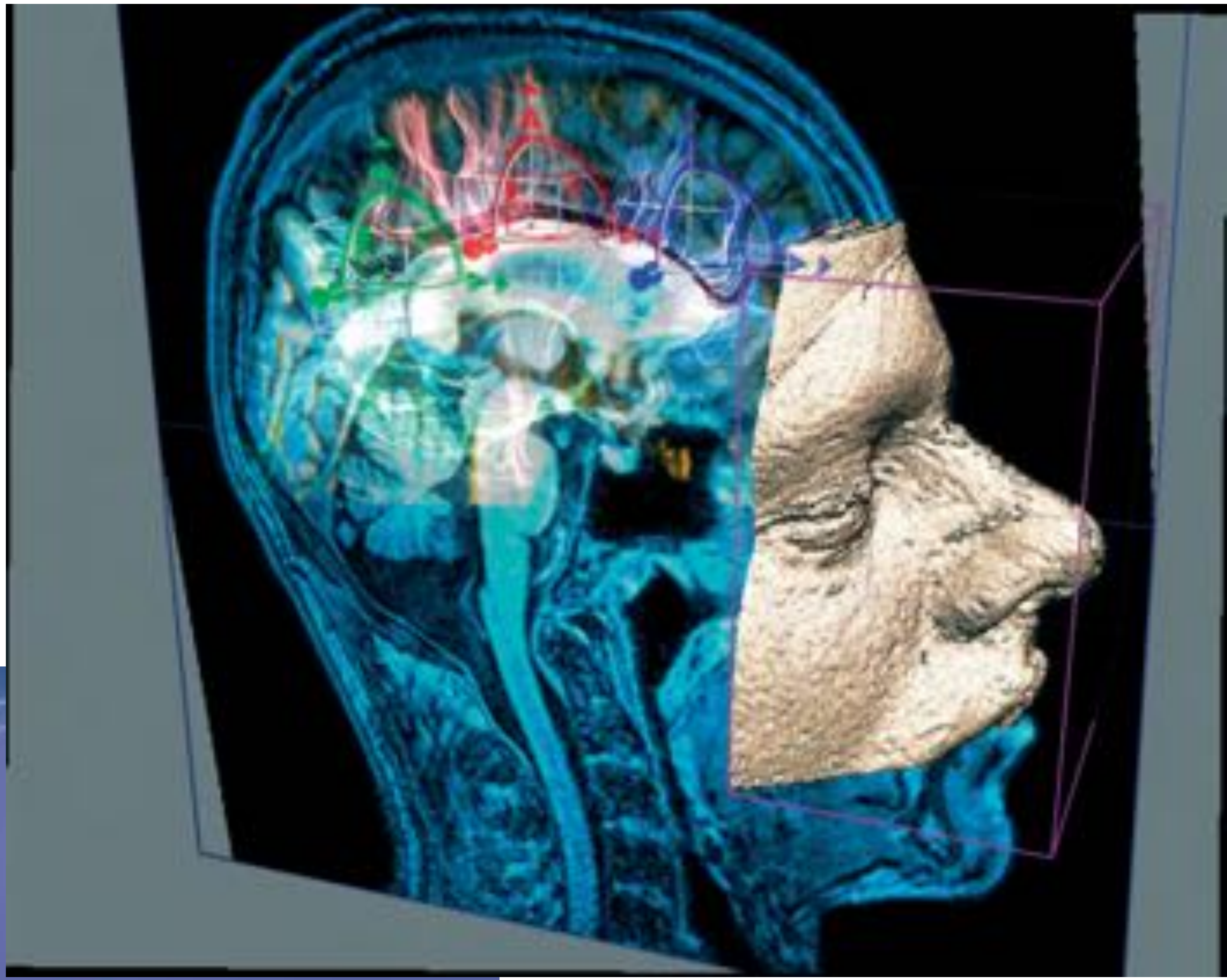


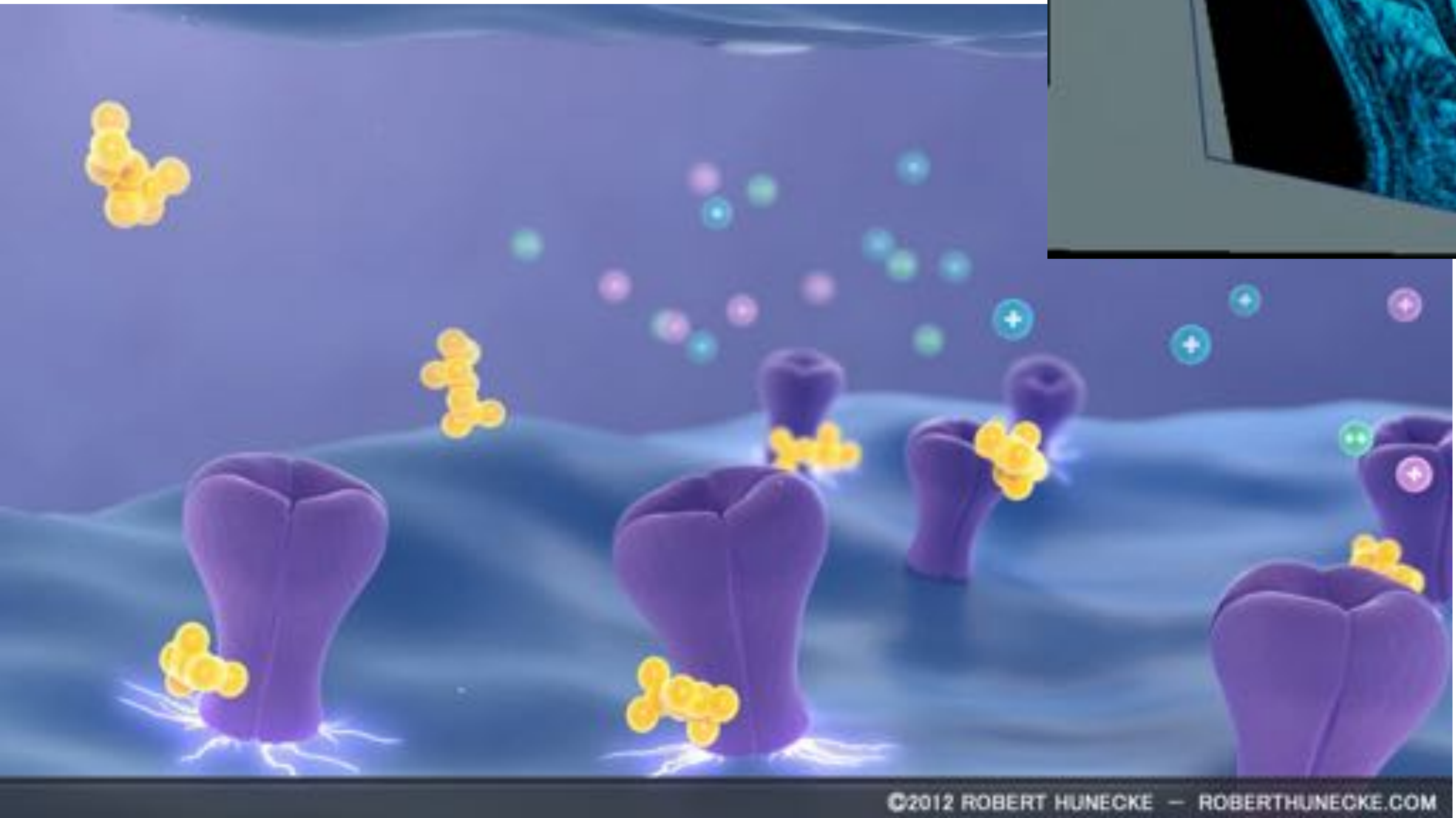
Scientific/mathematical visualization



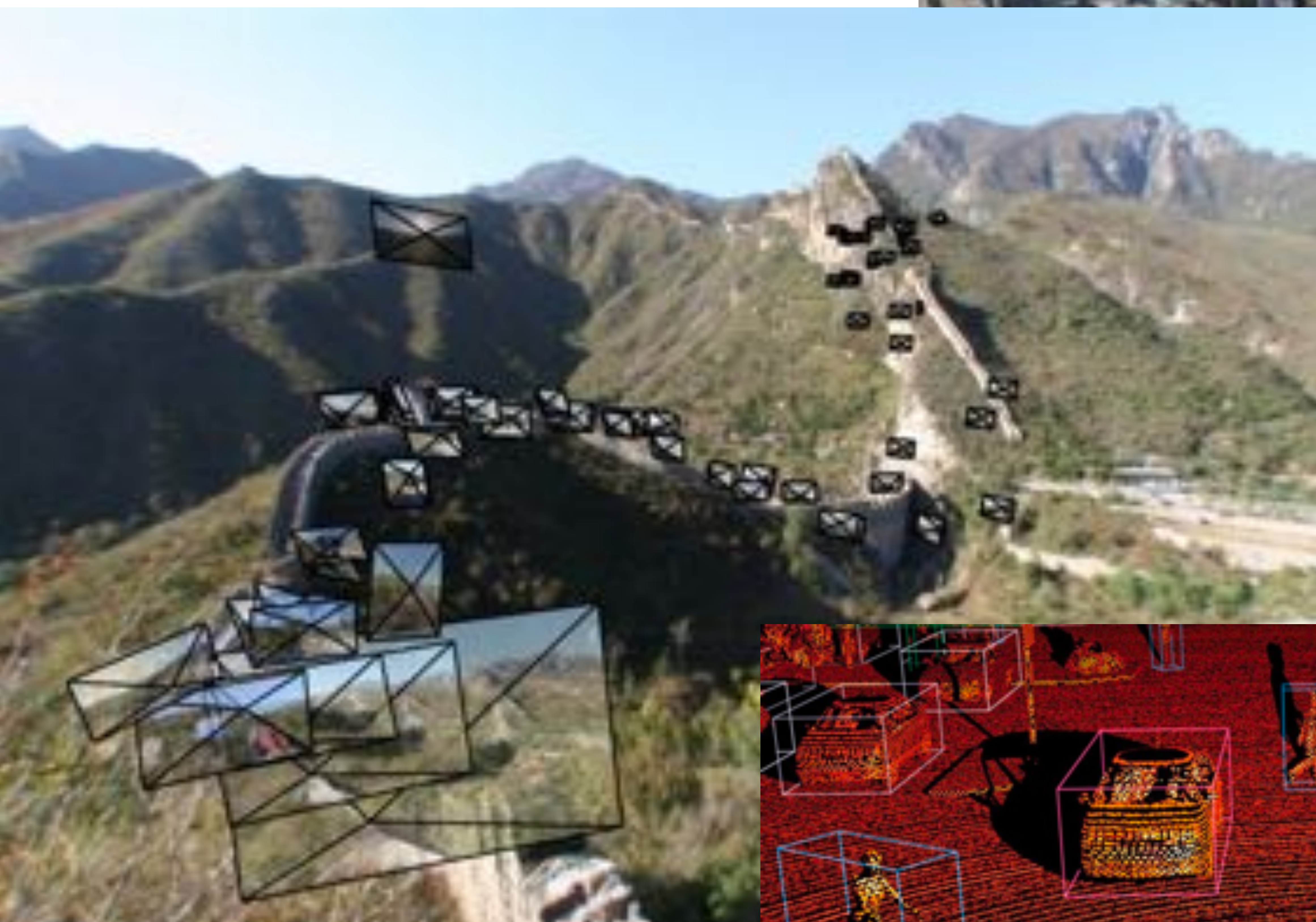


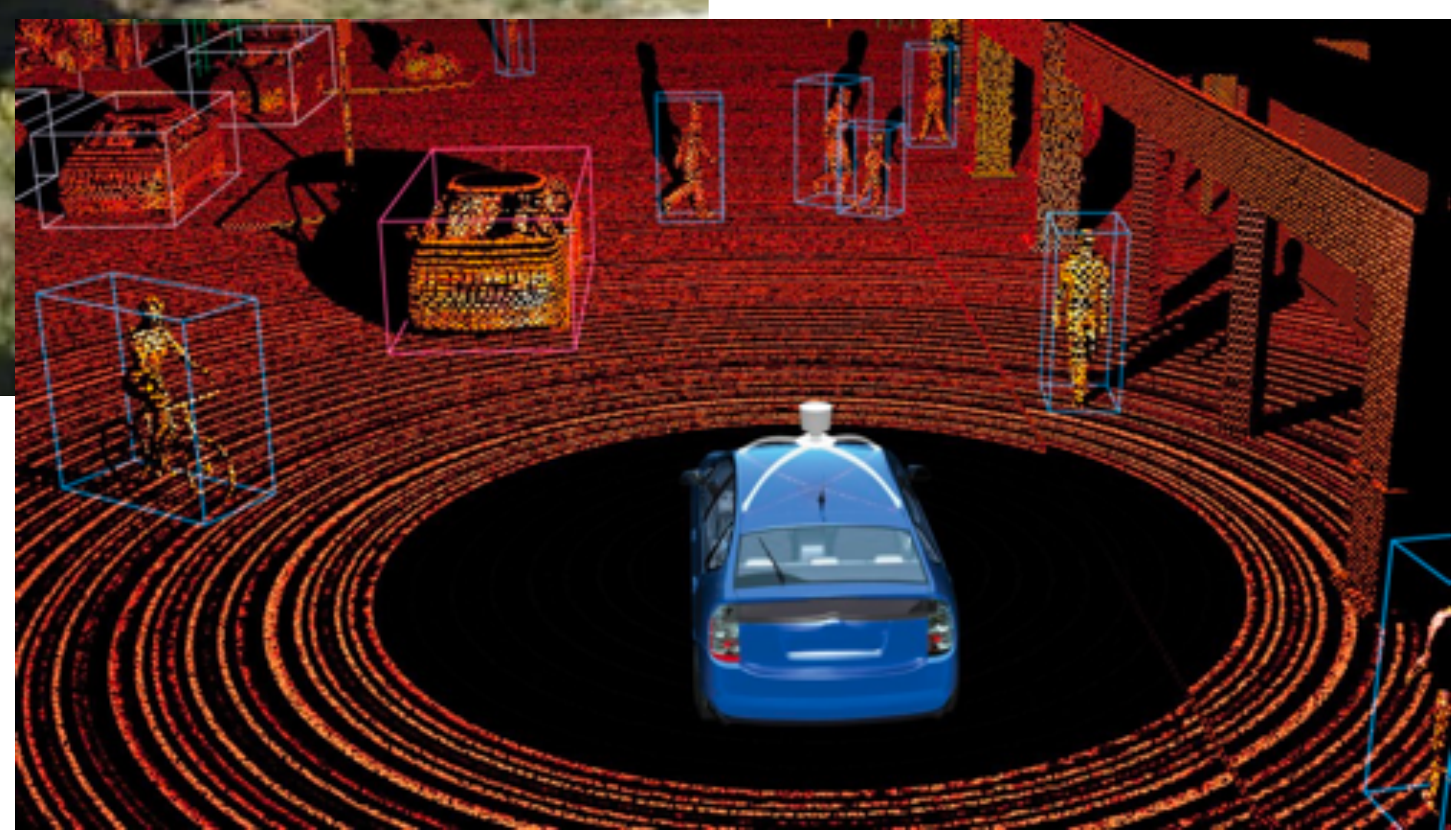
Medical/anatomical visualization



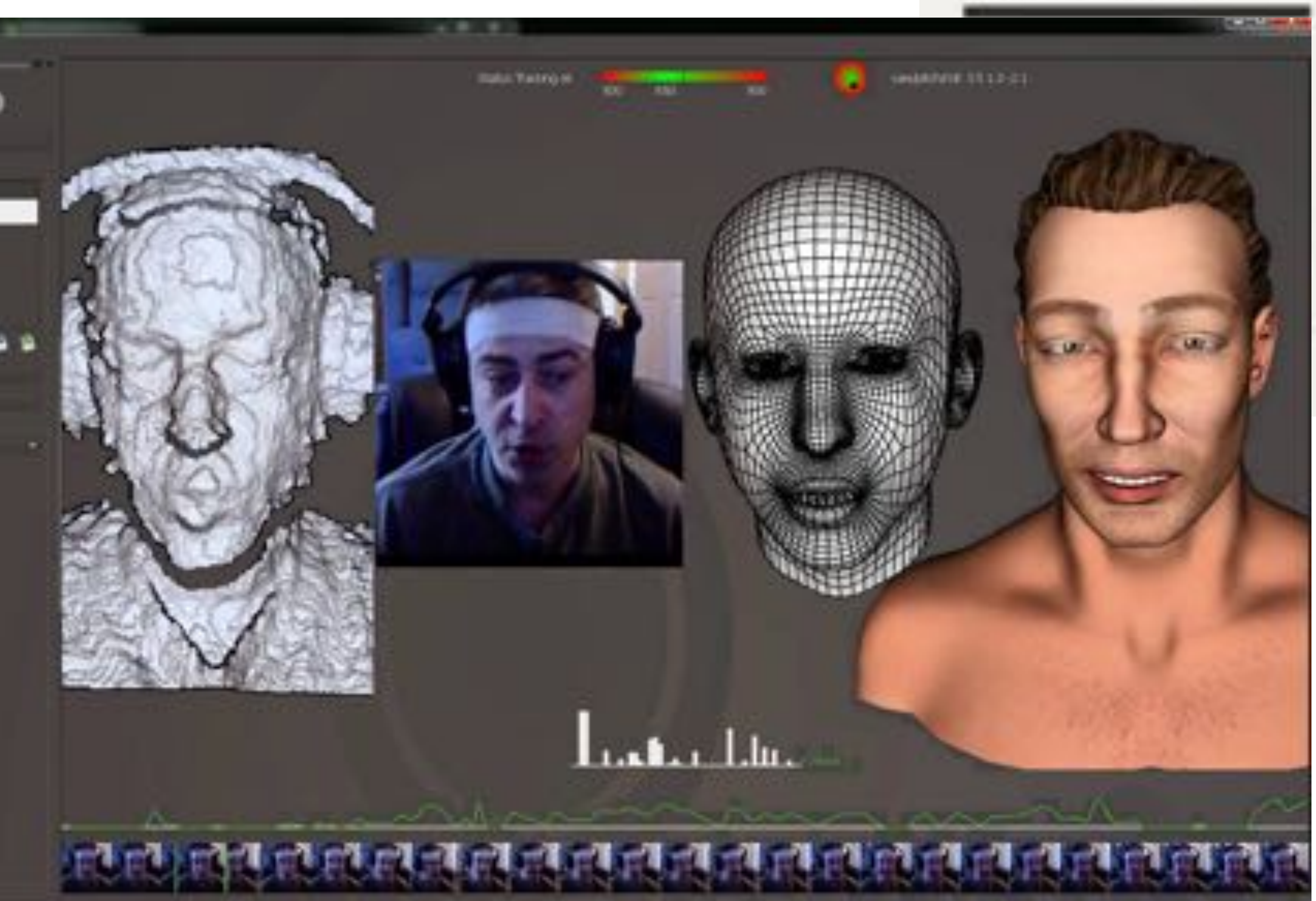


Navigation





Communication



Foundations of computer graphics

- **All these applications demand sophisticated theory & systems**
- **Theory**
  - **basic representations** (how do you digitally encode shape, motion?)
  - **sampling & aliasing** (how do you acquire & reproduce a signal?)
  - **numerical methods** (how do you manipulate signals numerically?)
  - **radiometry & light transport** (how does light behave?)
  - **perception** (how does this all relate to humans?)
  - …
- **Systems**
  - **parallel, heterogeneous processing**
  - **graphics-specific programming languages**
  - …

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**
  - **edges are aligned with x/y/z axes**
- **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

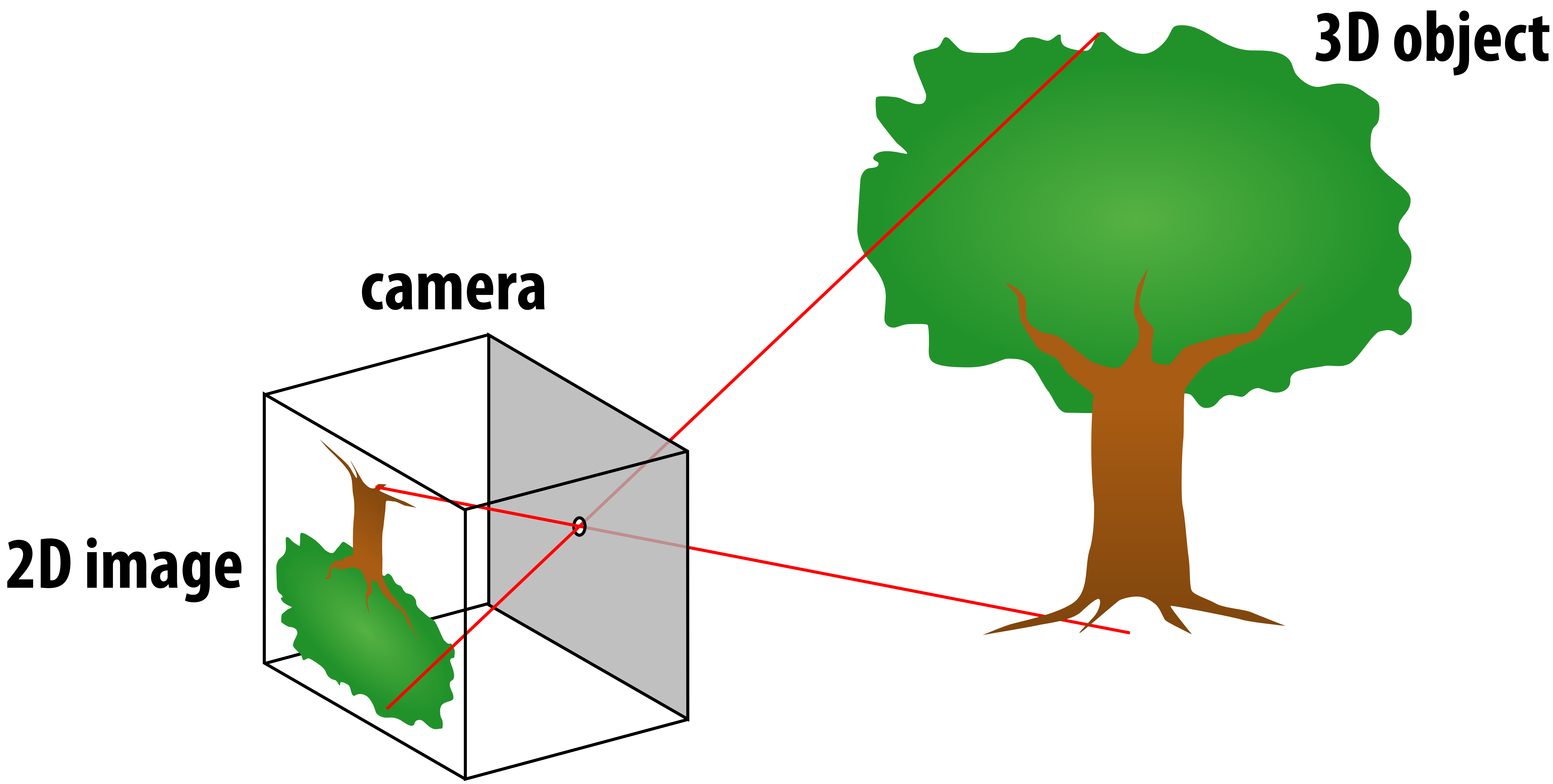
- **Now have a digital description of the cube:**

```
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?**

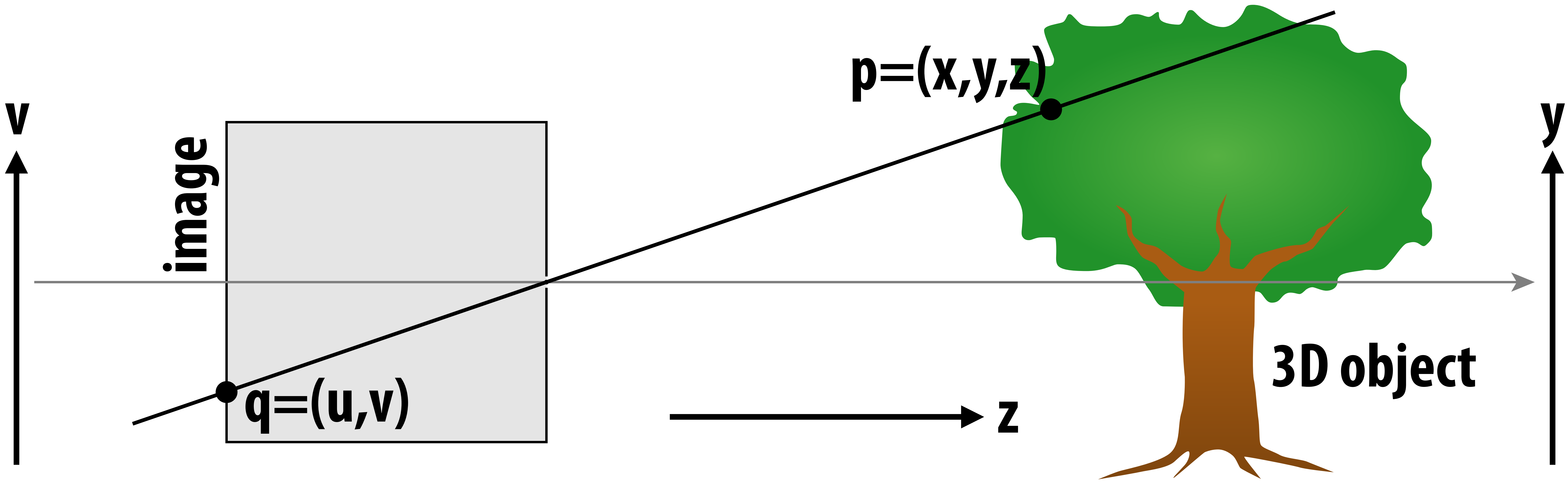
Perspective projection

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



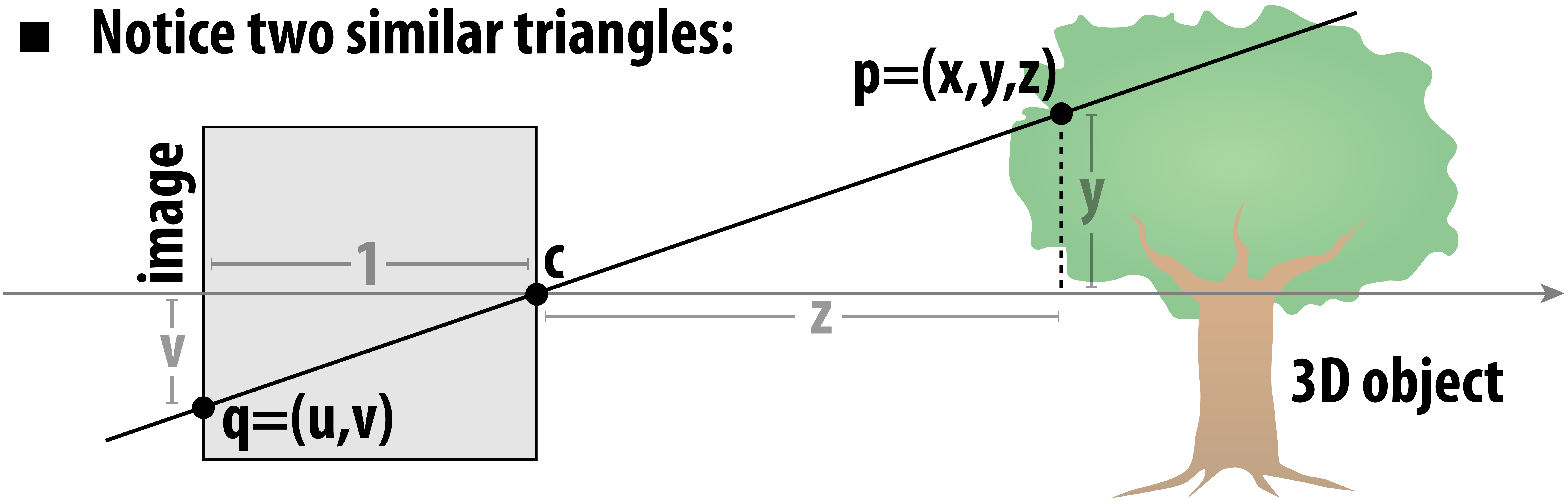
Perspective projection: side view

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



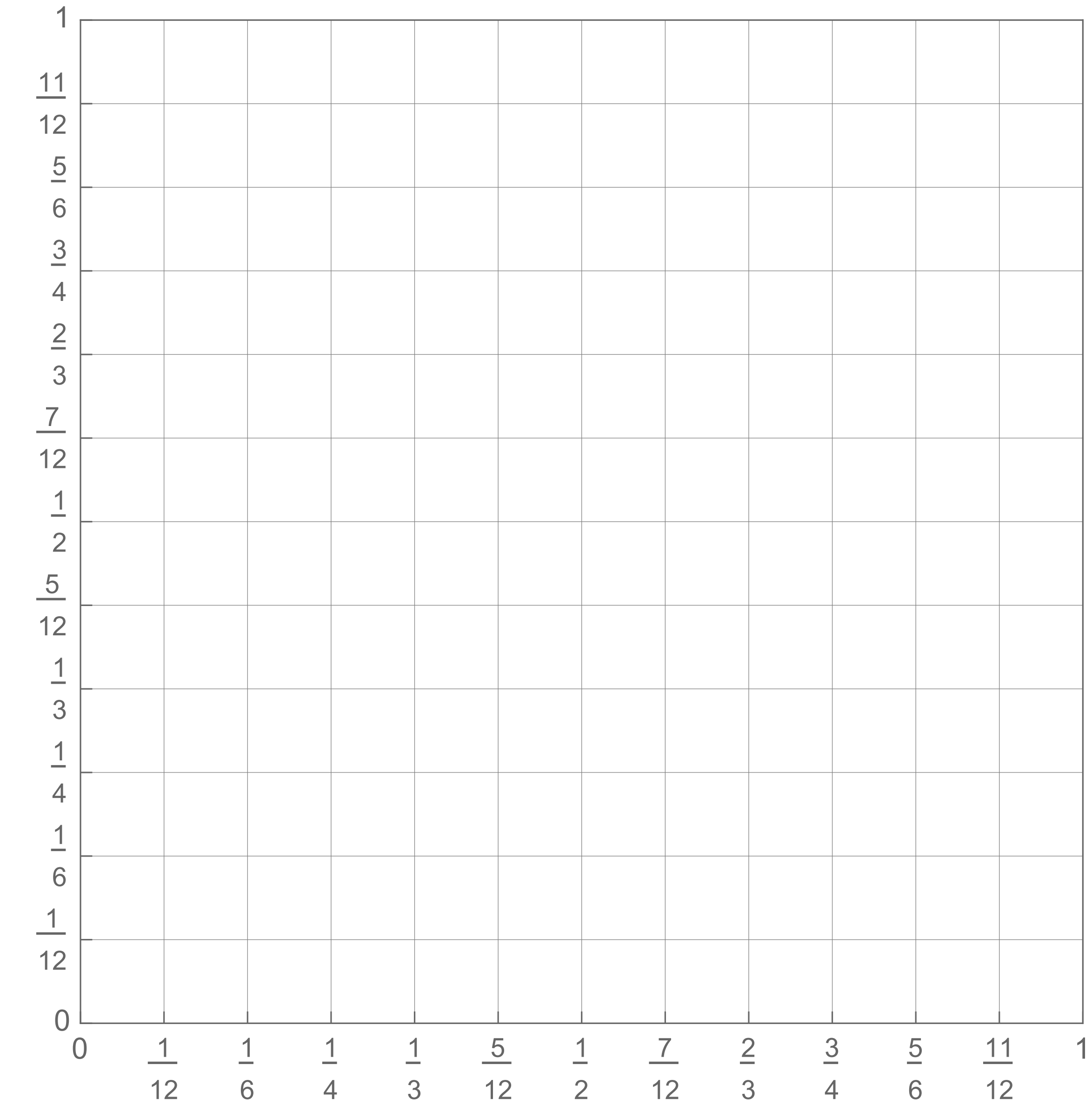
Perspective projection: side view

- 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, origin is at pinhole c
- Then v/1 = y/z, i.e., vertical coordinate is just the slope y/z
- Likewise, horizontal coordinate is u=x/z

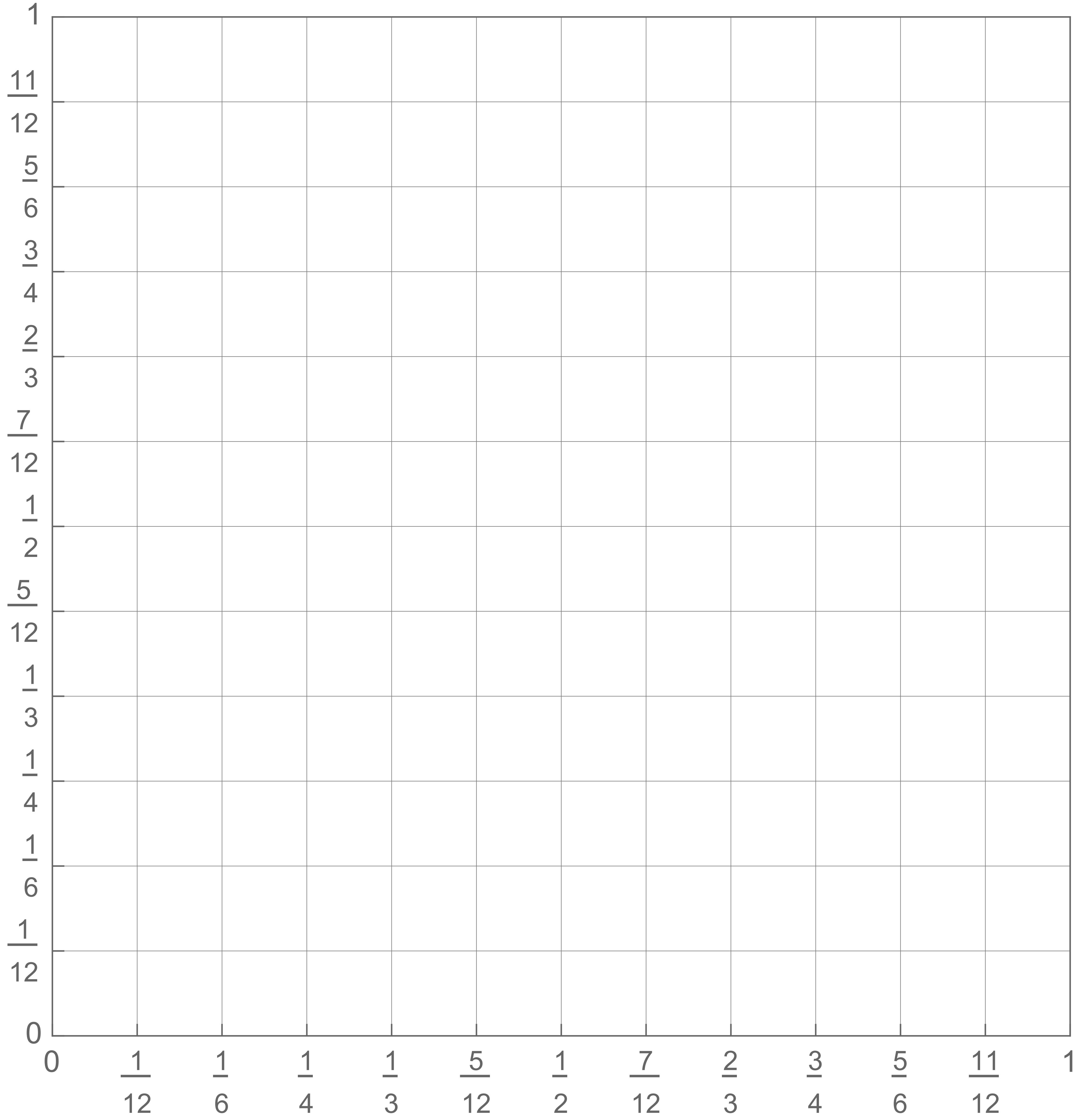
ACTIVITY: now draw it!



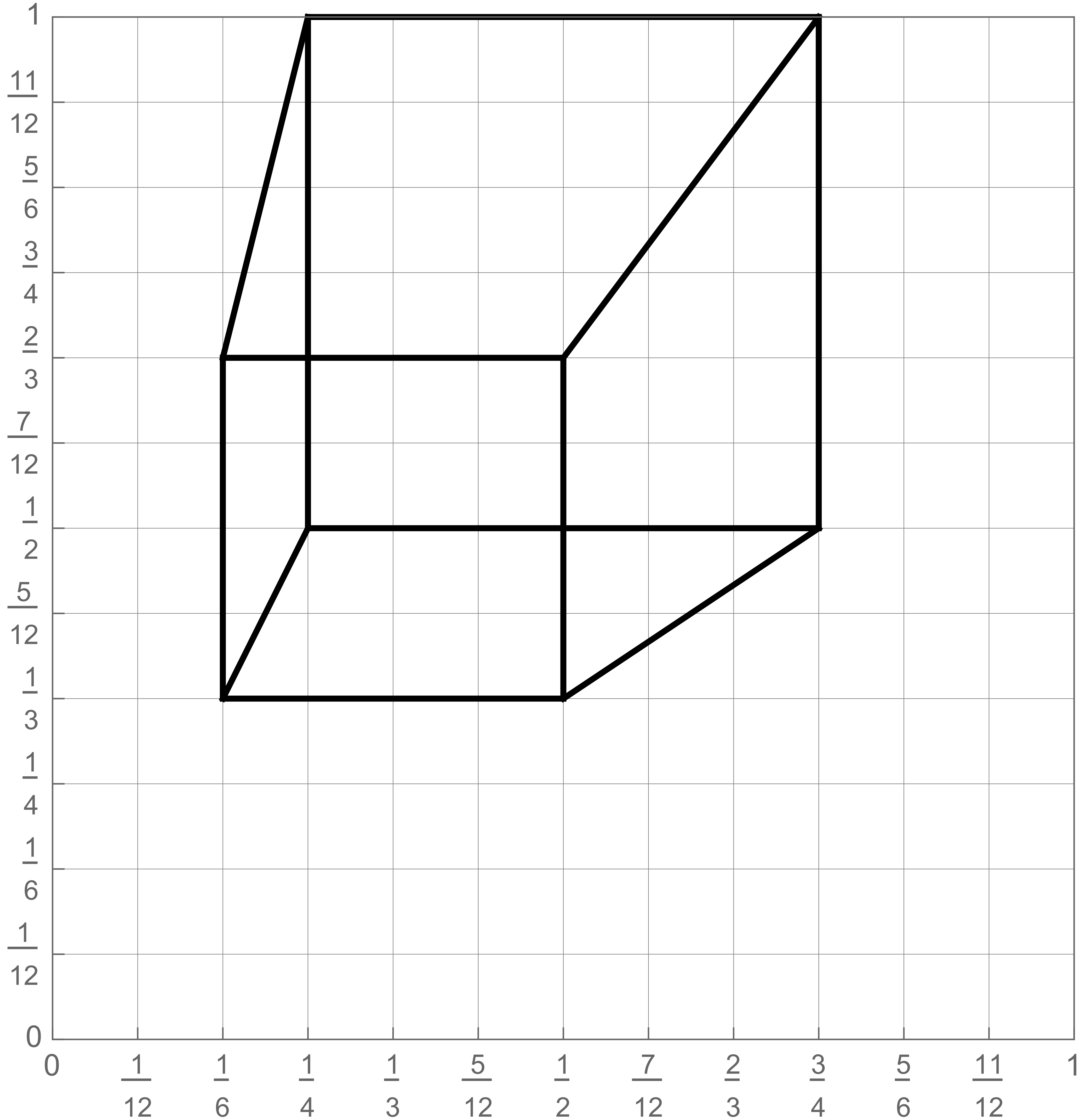
- **Repeat the same simple algorithm 12 times**
  - **Once for each edge**
  - **Assume camera is at c=(2,3,5)**
  - **Convert (X,Y,Z) of both endpoints to (u,v):**
    1. **subtract camera c from vertex (X,Y,Z) to get (x,y,z)**
    2. **divide (x,y) by z to get (u,v)—write as a fraction**
  - **Draw line between (u1,v1) and (u2,v2)**

```
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
```

ACTIVITY: output on graph paper



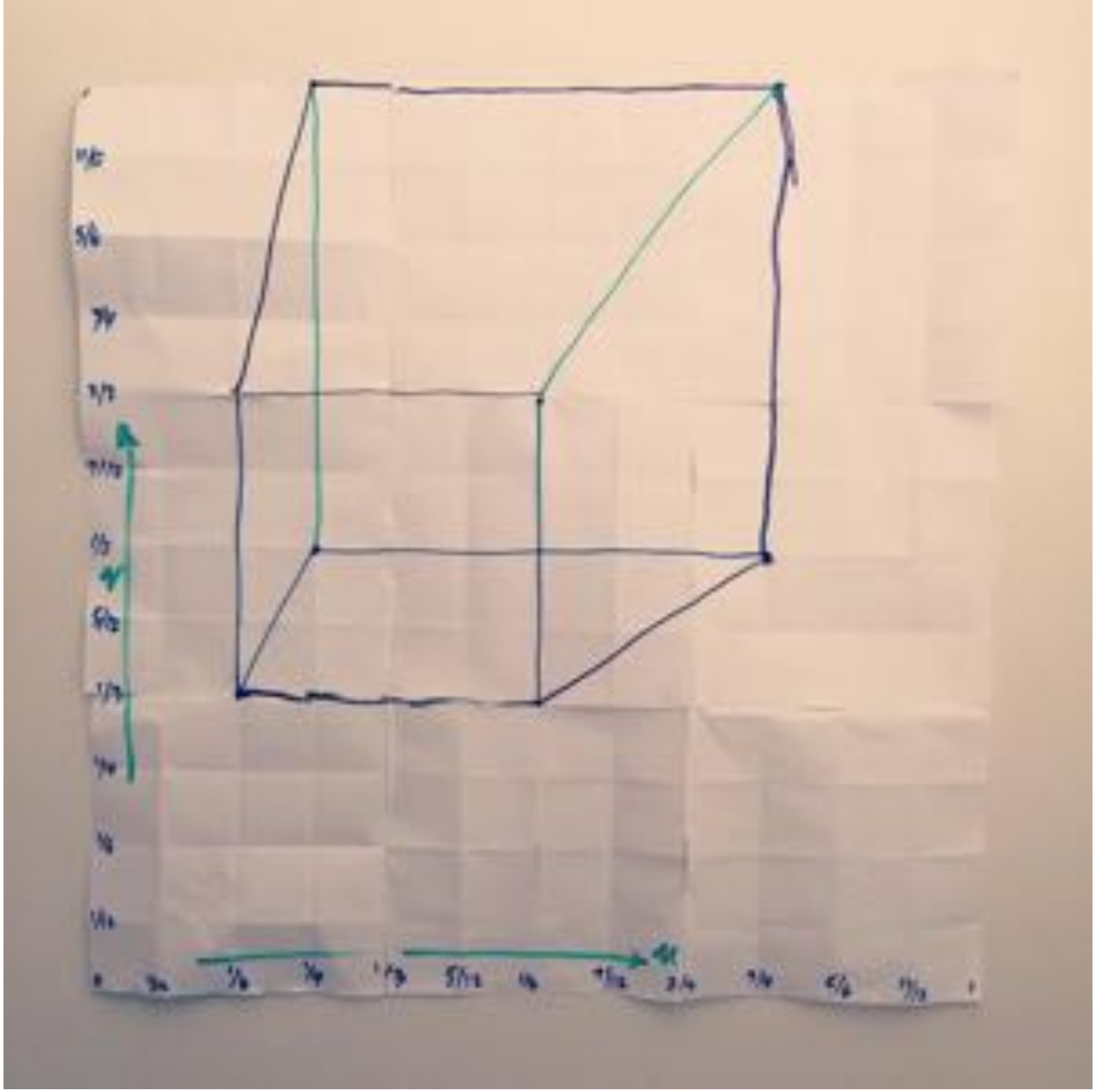
ACTIVITY: How did you do?



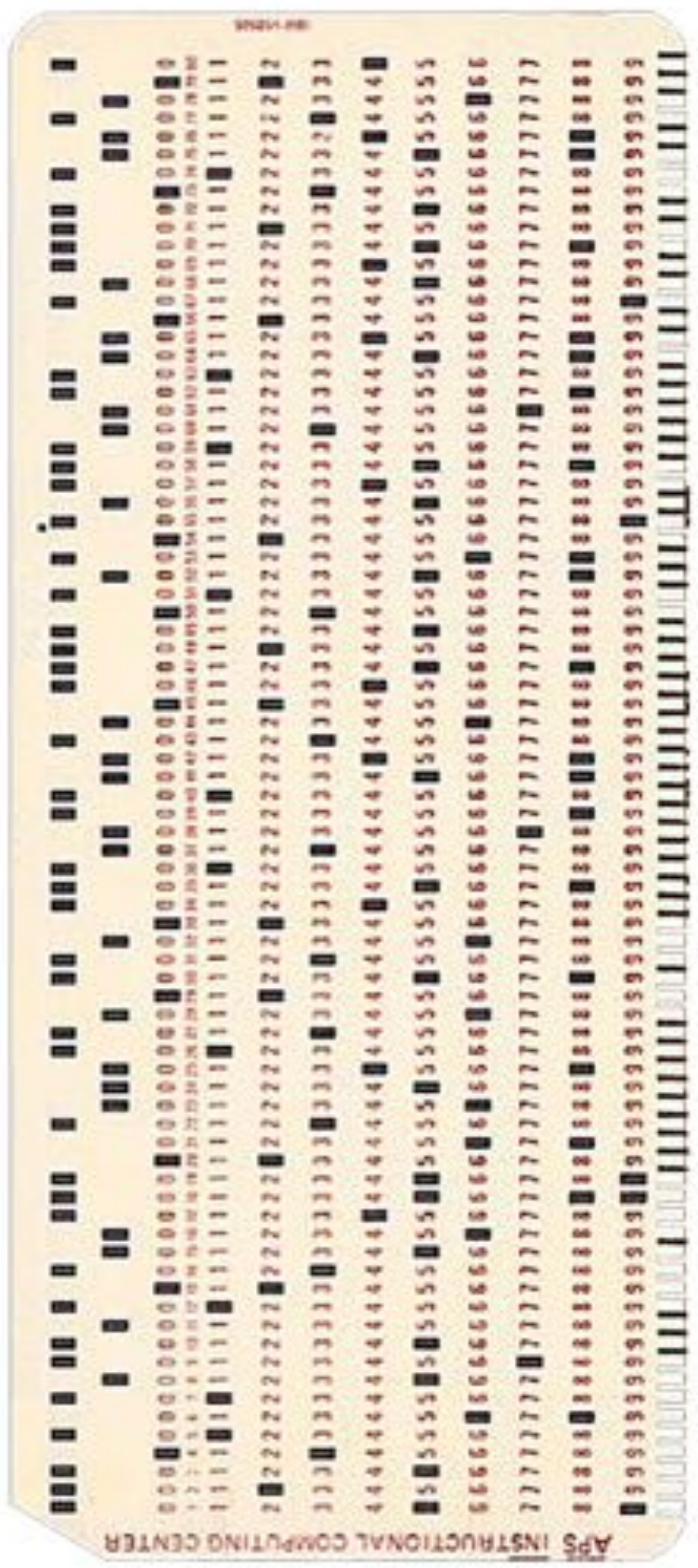
2D coordinates:

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

ACTIVITY: Previous year's result



Success! We turned purely <u>digital</u> information into purely <u>visual</u> information, using a completely <u>algorithmic</u> procedure.



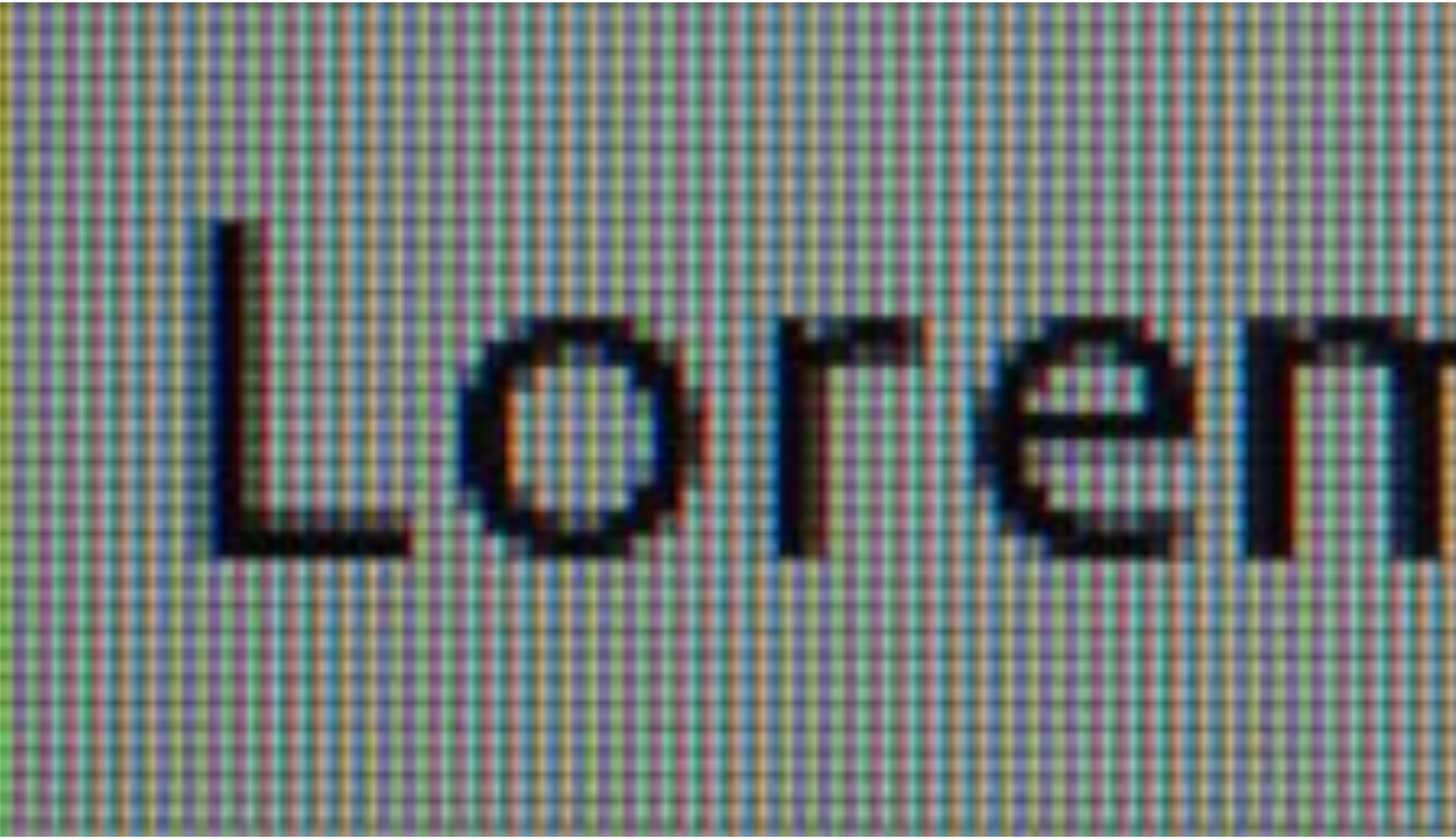
digital information

computation →

visual information

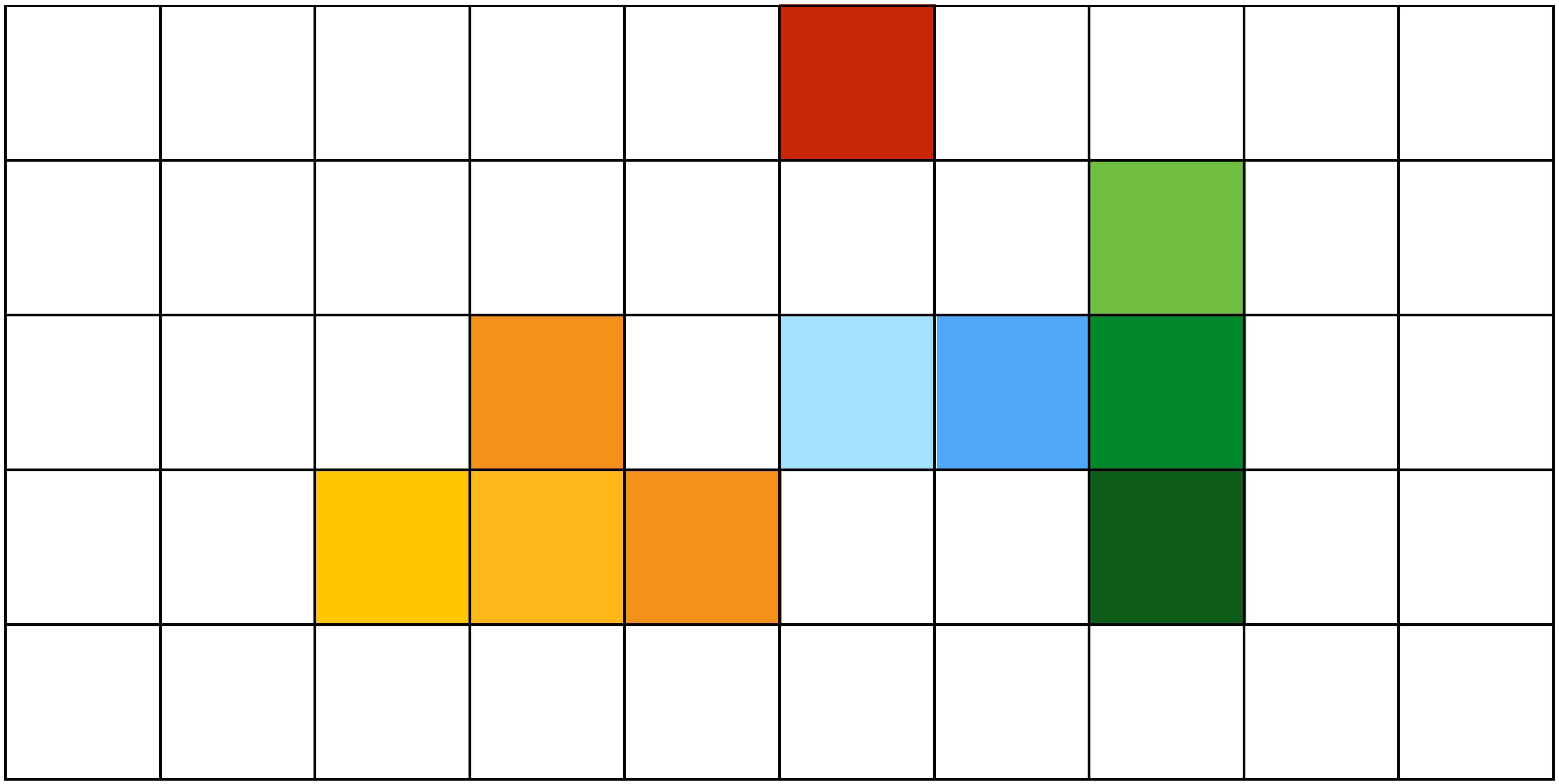
But wait…
How do we draw lines on a computer?

Close up photo of pixels on a modern display



Output for a raster display

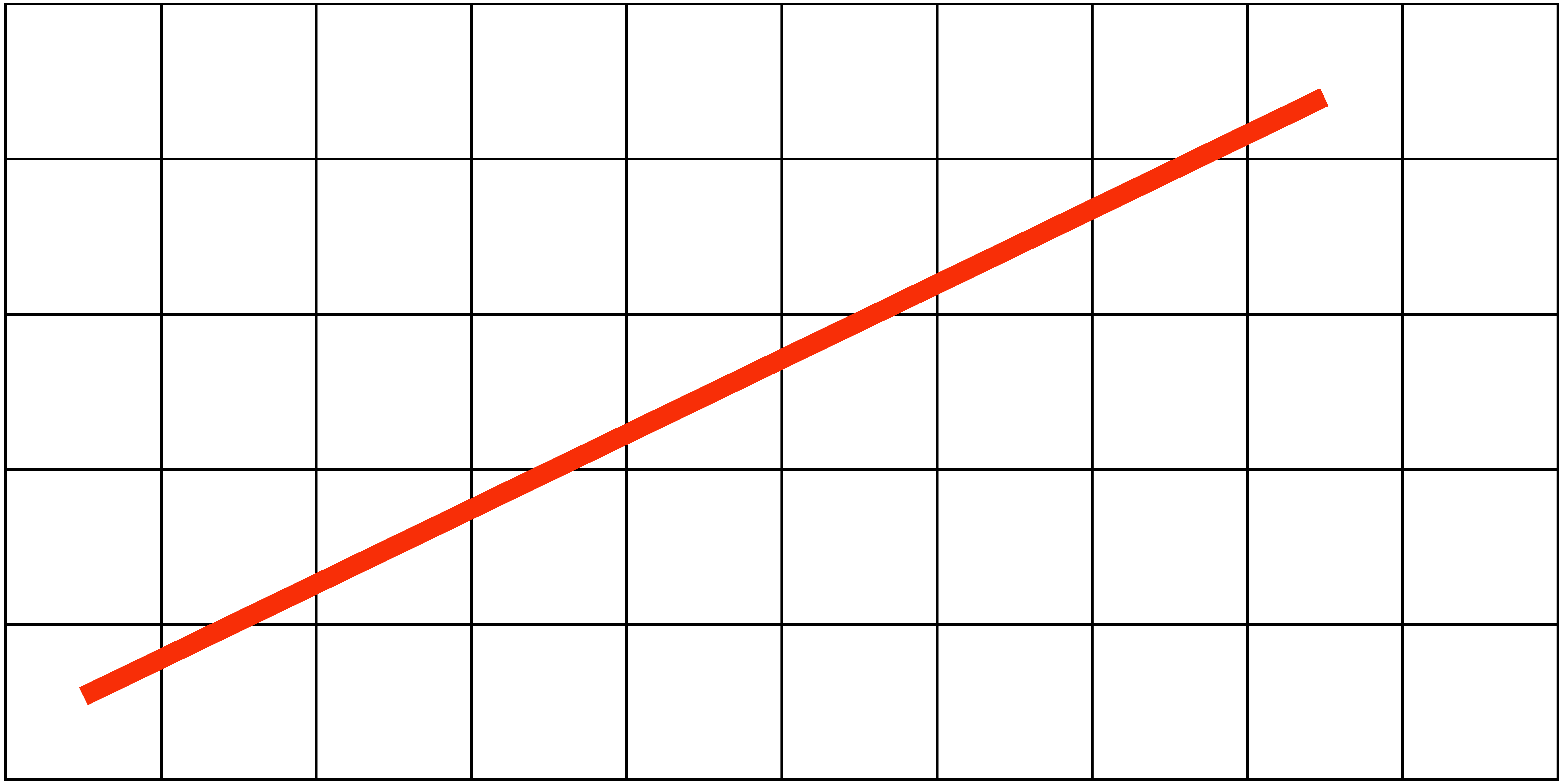
- Common abstraction of a raster display:
  - Image represented as a 2D grid of "pixels" (picture elements) **
  - Each pixel can can take on a unique color value



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

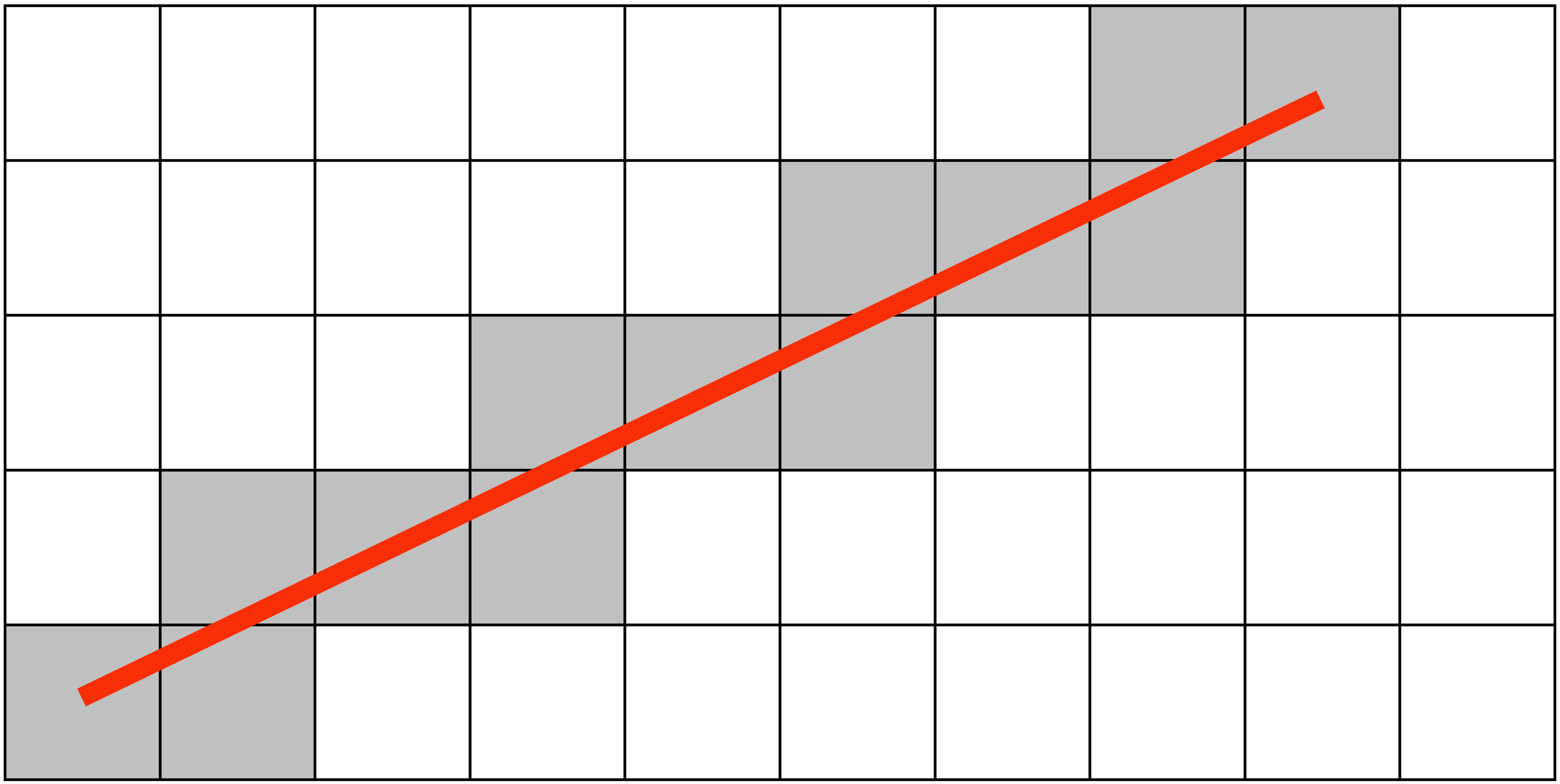
What pixels should we color in to depict a line?

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



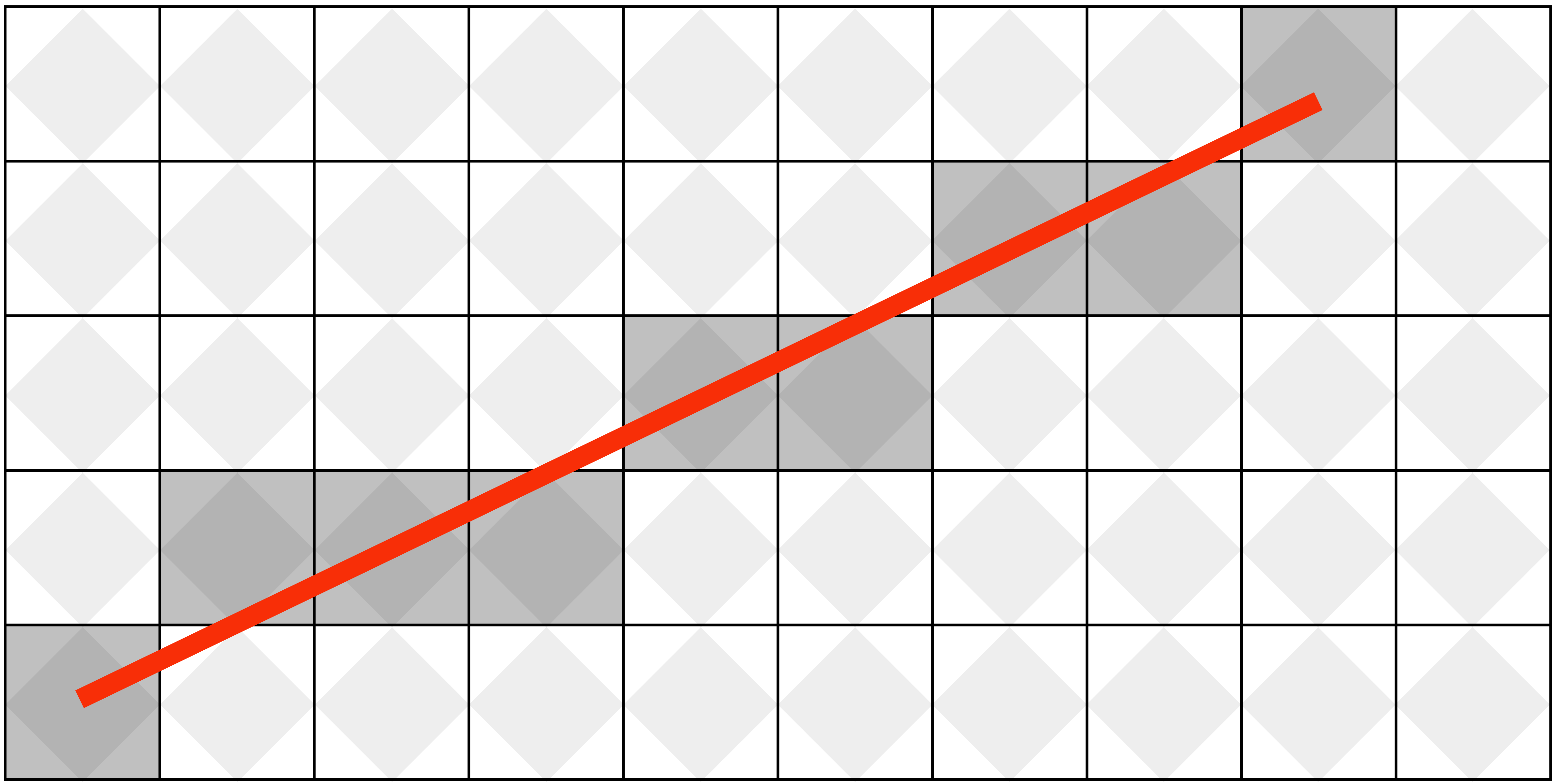
What pixels should we color in to depict a line?

Light up all pixels intersected by the line?



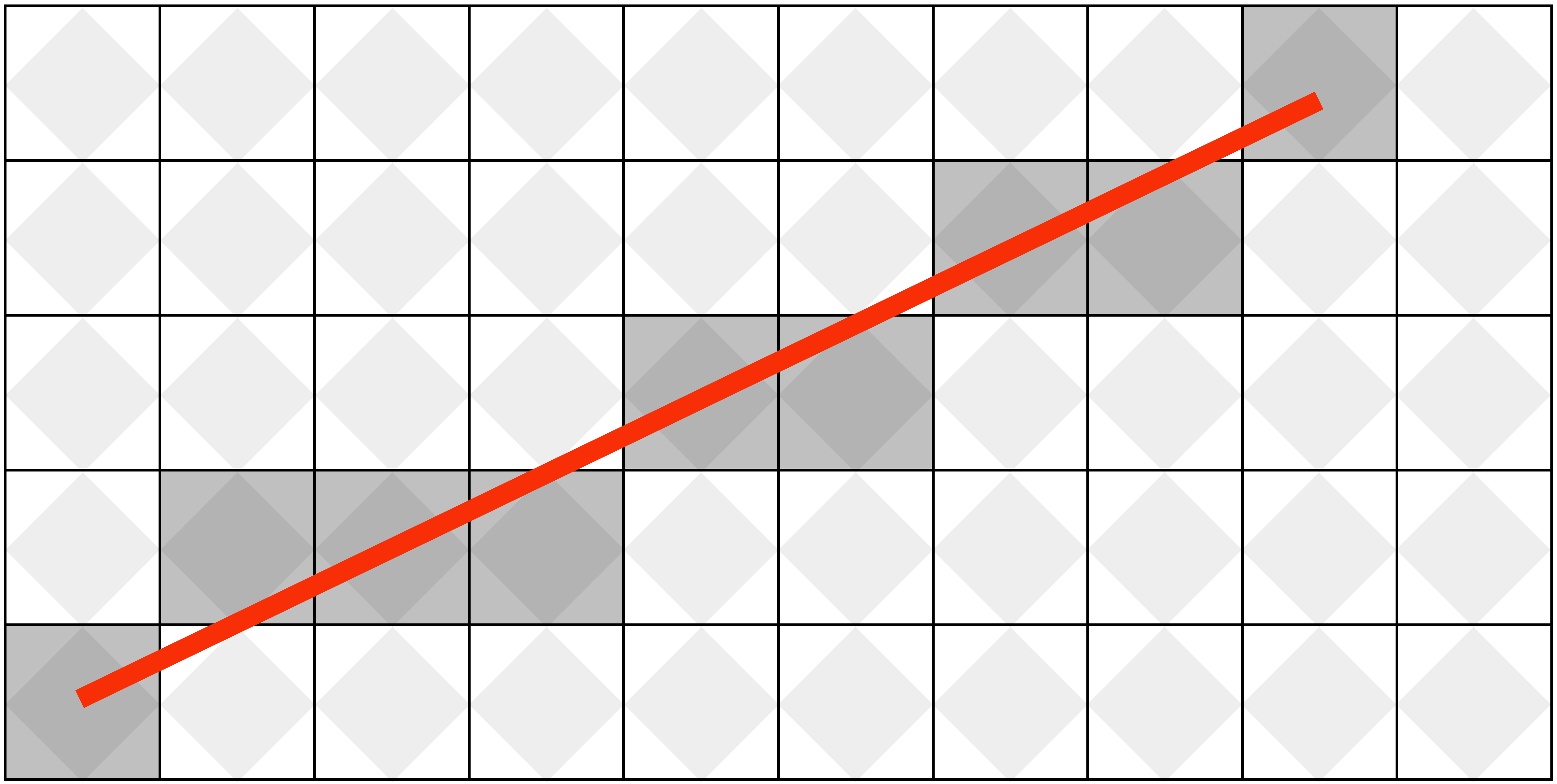
What pixels should we color in to depict a line?

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)



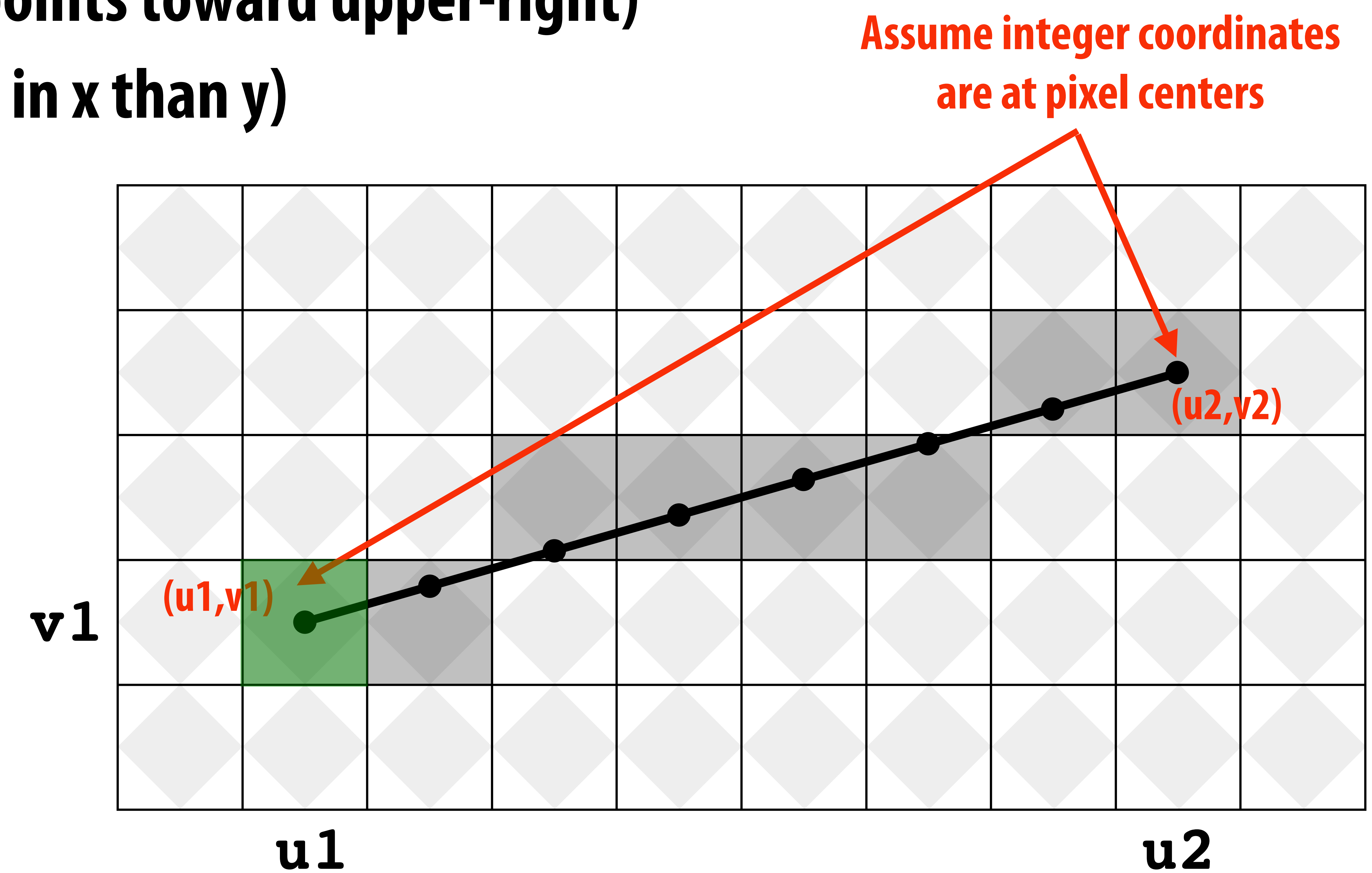
How do we find the pixels satisfying a chosen rasterization rule?

- **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., 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))
}
```



Easy to implement… <u>not</u> how lines are drawn in modern software/hardware!

We now have our first complete graphics algorithm!

Digital information

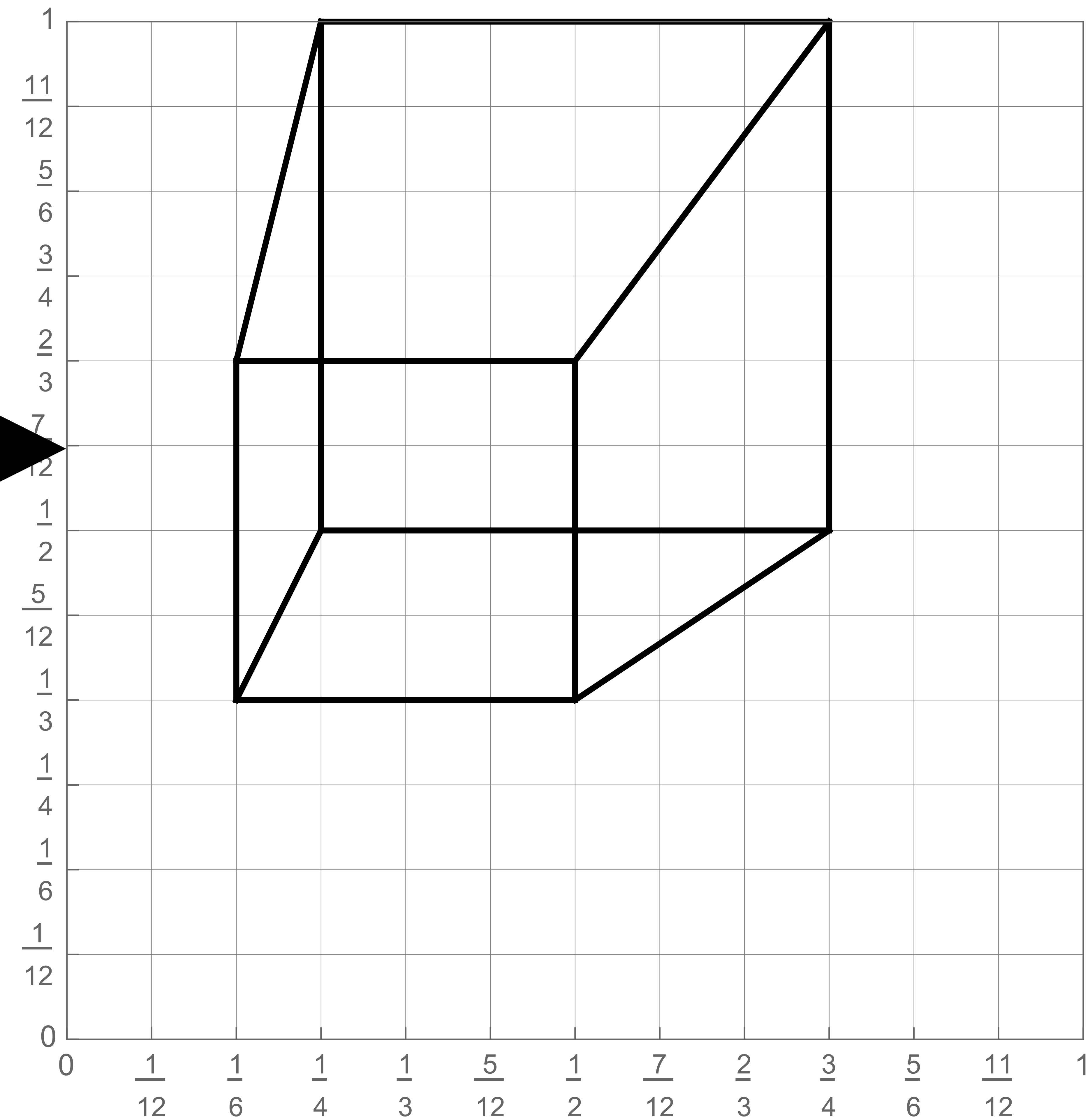
```
VERTICES
A: ( 1, 1, 1 )
B: (-1, 1, 1 )
C: ( 1,-1, 1 )
D: (-1,-1, 1 )
E: ( 1, 1,-1 )
F: (-1, 1,-1 )
G: ( 1,-1,-1 )
H: (-1,-1,-1 )

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

CAMERA
C = (2,3,5)
```

computation

Visual information



This is fundamentally what computer graphics is all about…

So far, just made a simple line drawing of a cube.

For more realistic pictures, will need a <u>much</u> richer model of the world:

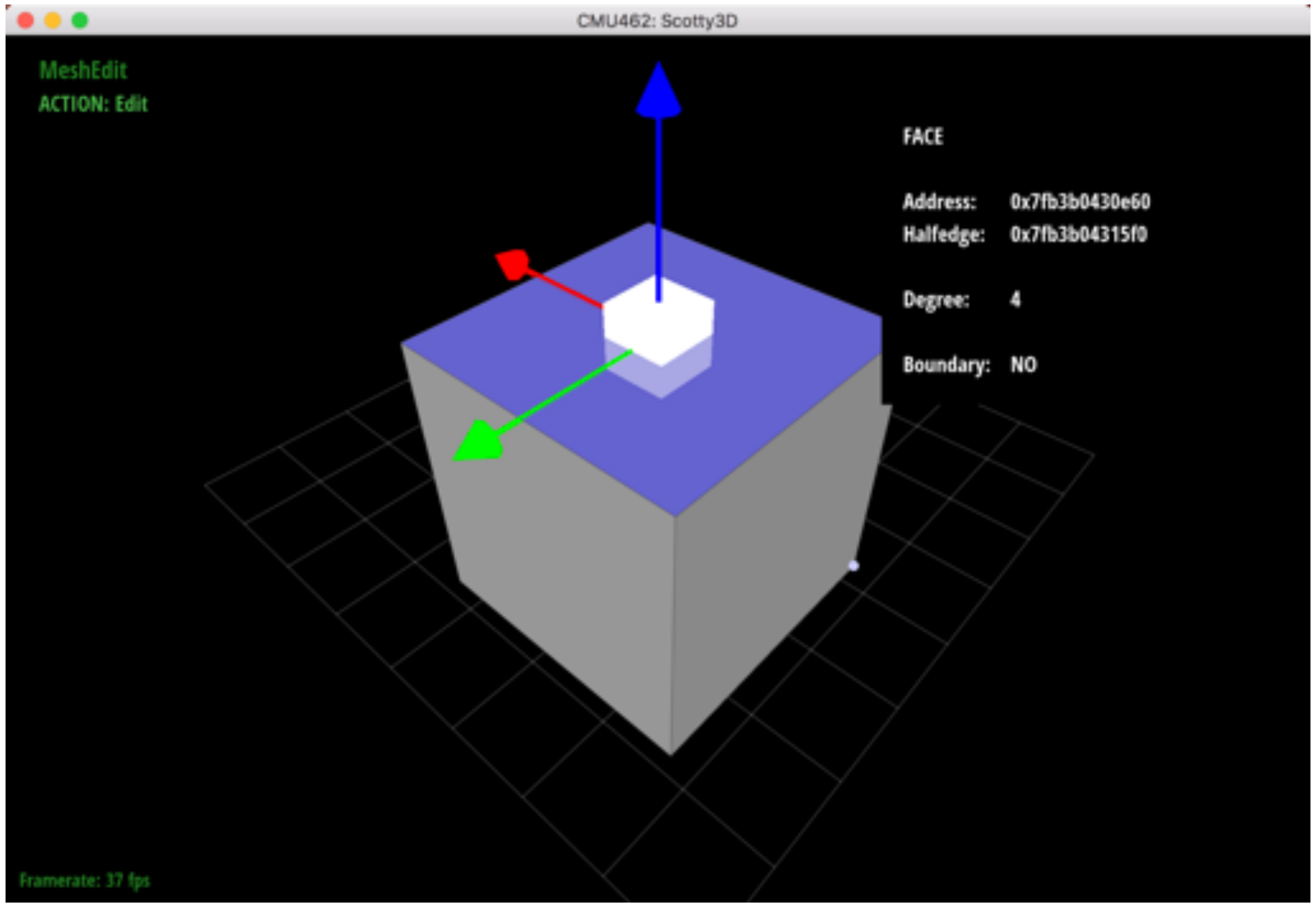
GEOMETRY
MATERIALS
LIGHTS
CAMERAS
MOTION
...

Will see all of this (and more!) as our course progresses.

Learn by making/doing!

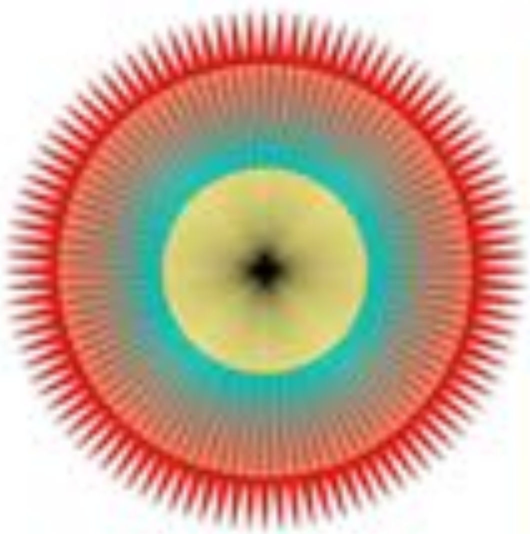
- Build up "Scotty3D" package for modeling/rendering/animation

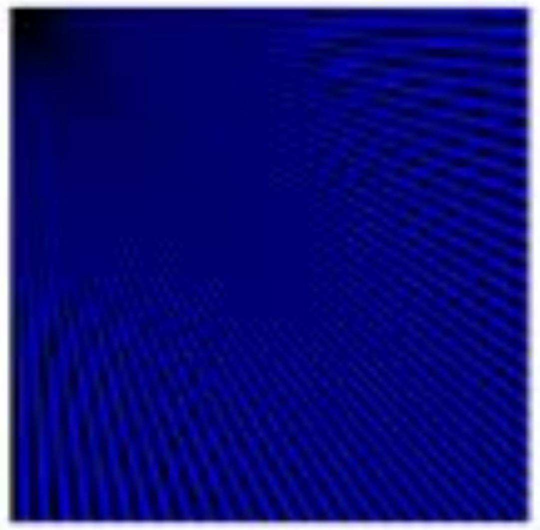
Scotty3D



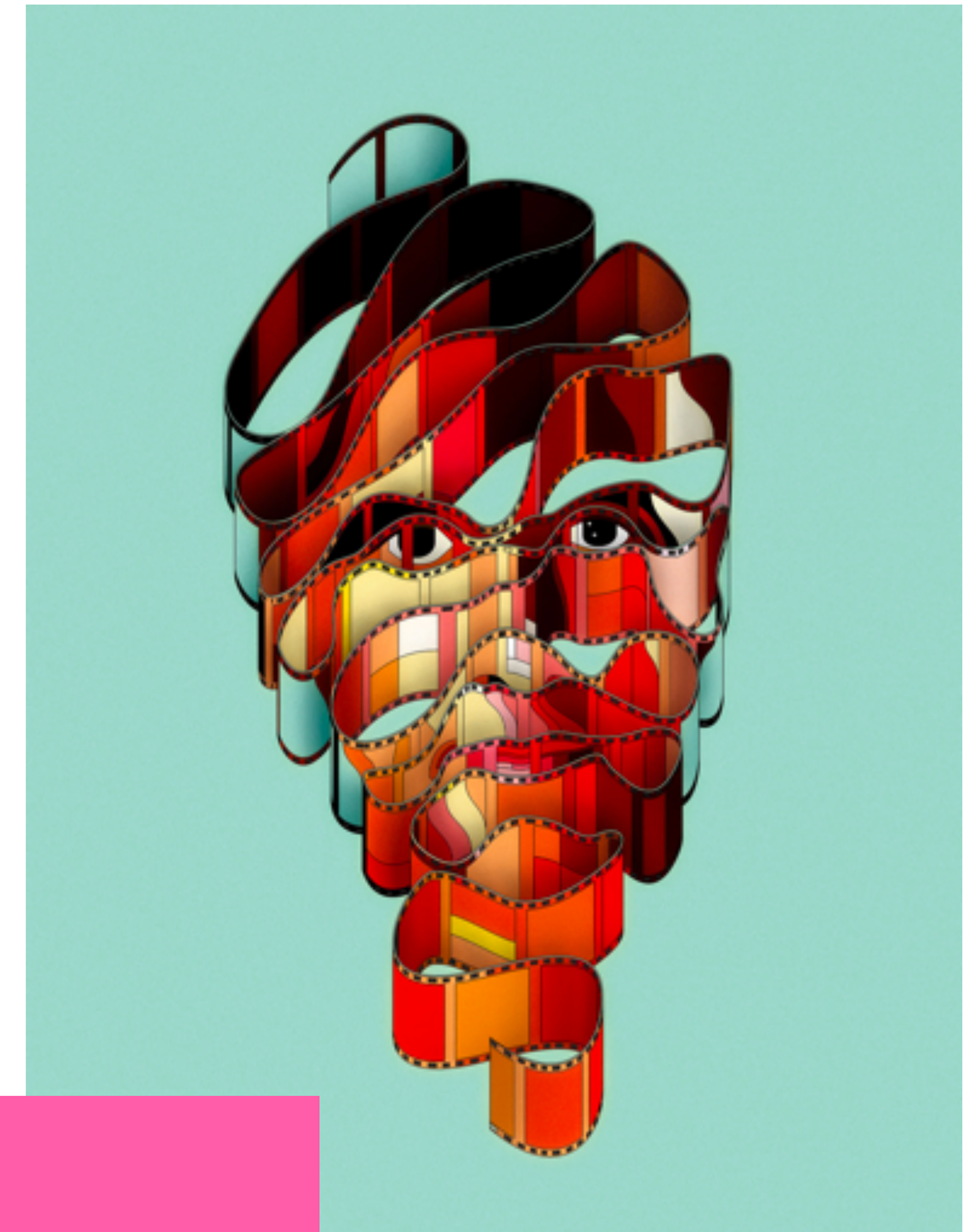
Broken up into four major assignments…

Assignment 1: Rasterization



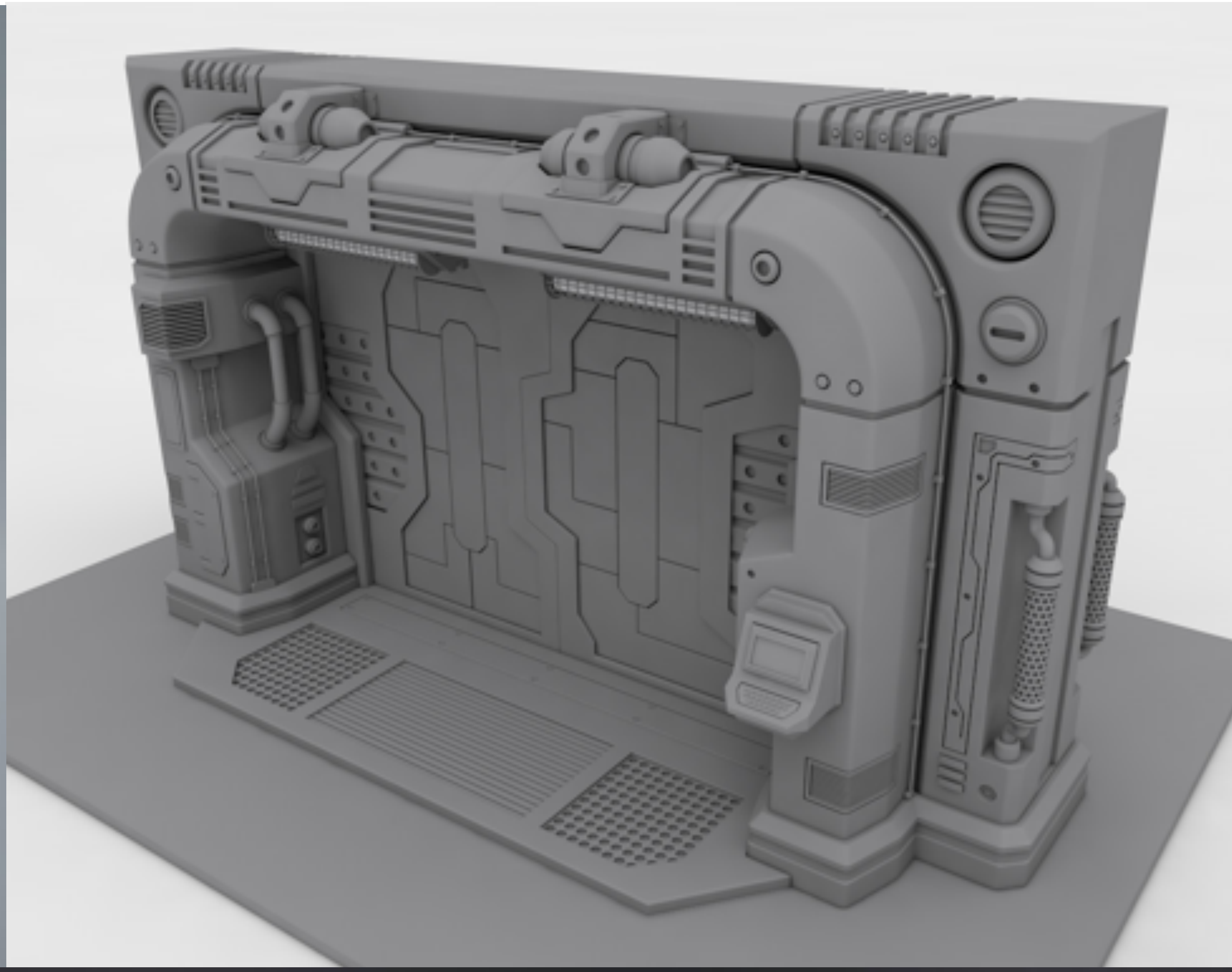
Motivation: display images like these!



[sources: Charles Williams, @xlavoc on codepen.io]

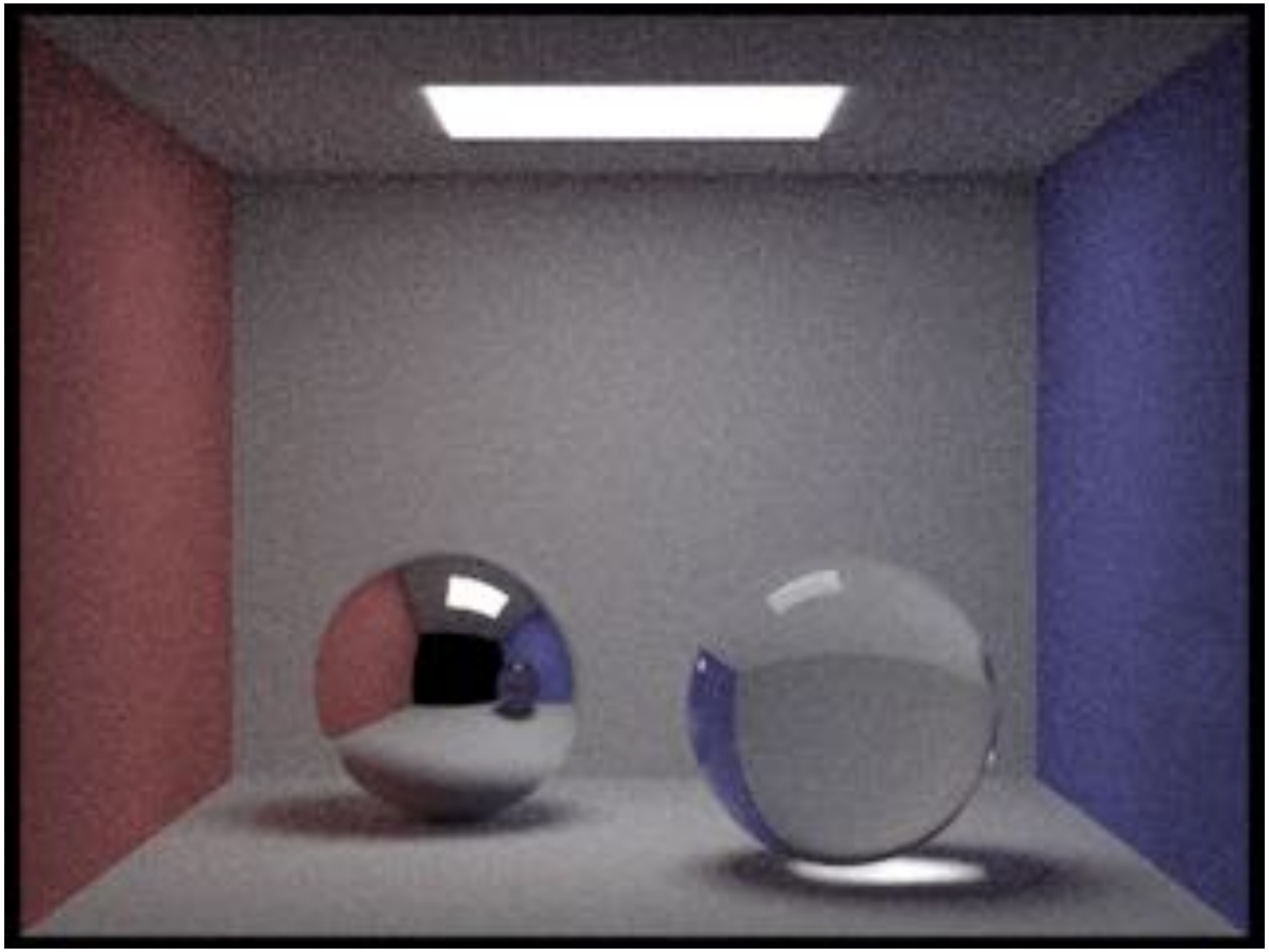
Assignment 2: Geometric Modeling

Motivation: create models like these!



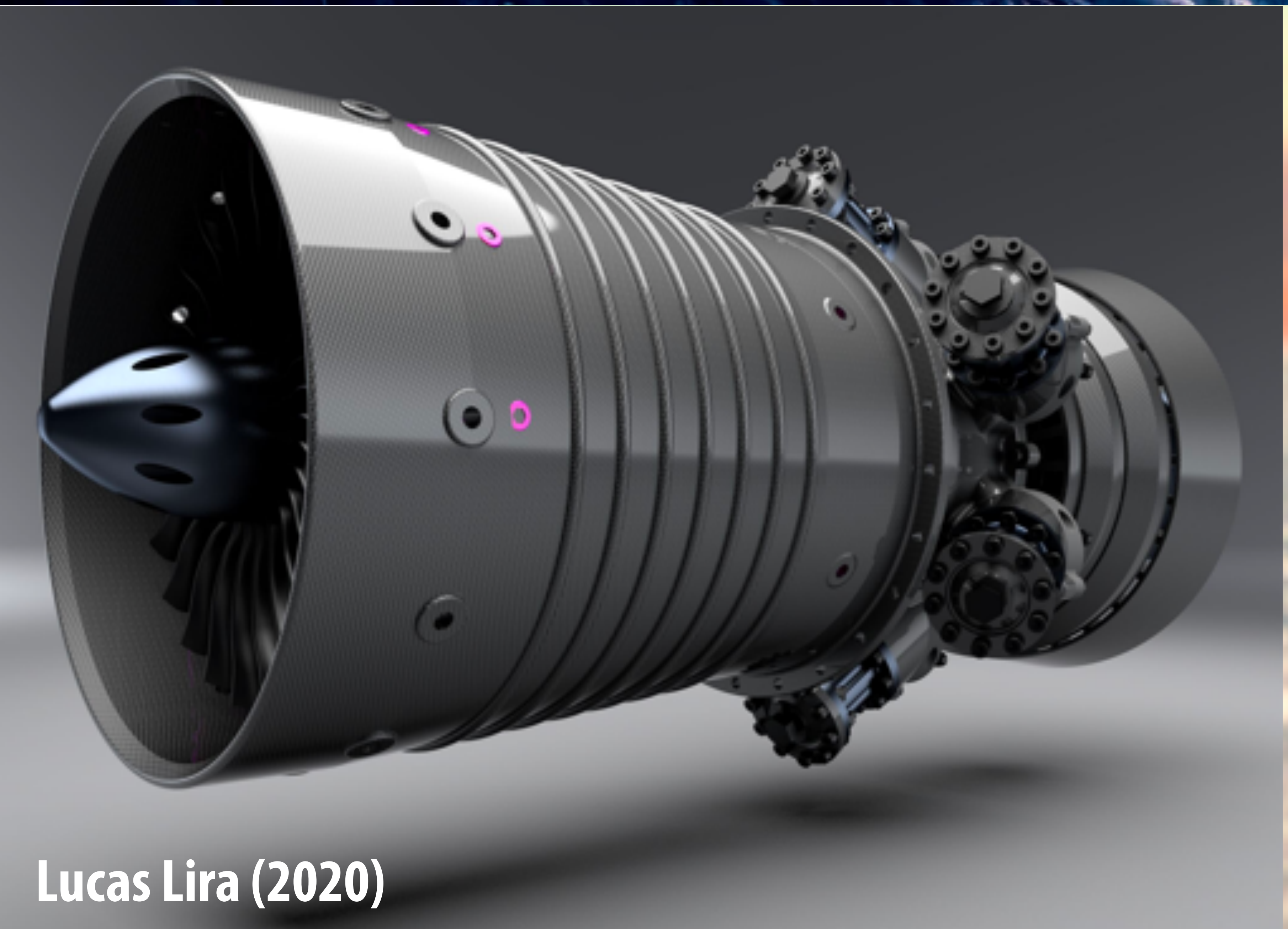
[sources: Richard Yot, 3D-Ace, contrafibbularities,3ddd.ru]

Assignment 3: Photorealistic Rendering



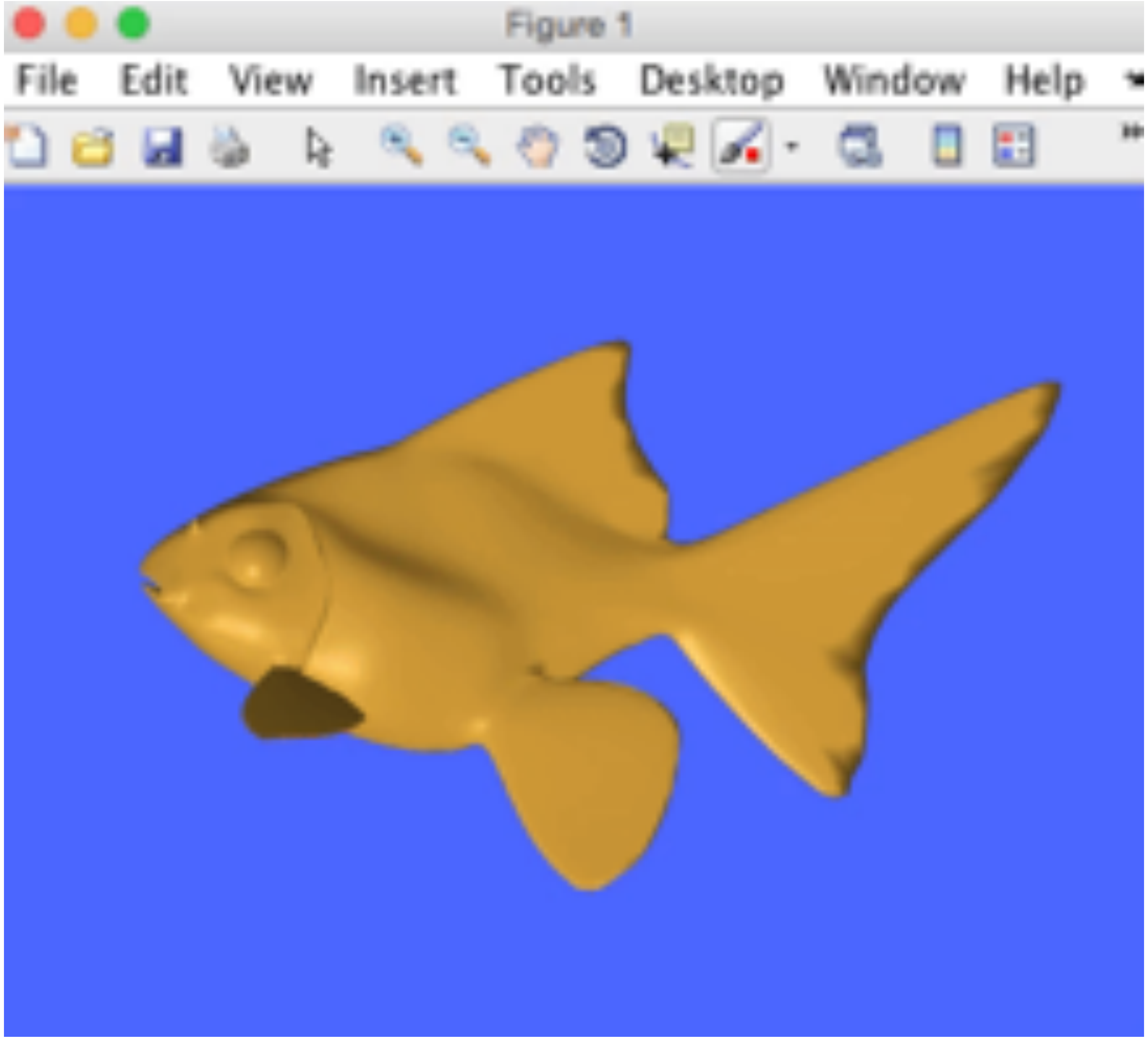
Motivation: render images like these!


WALL-E (Pixar 2009)


Lucas Lira (2020)

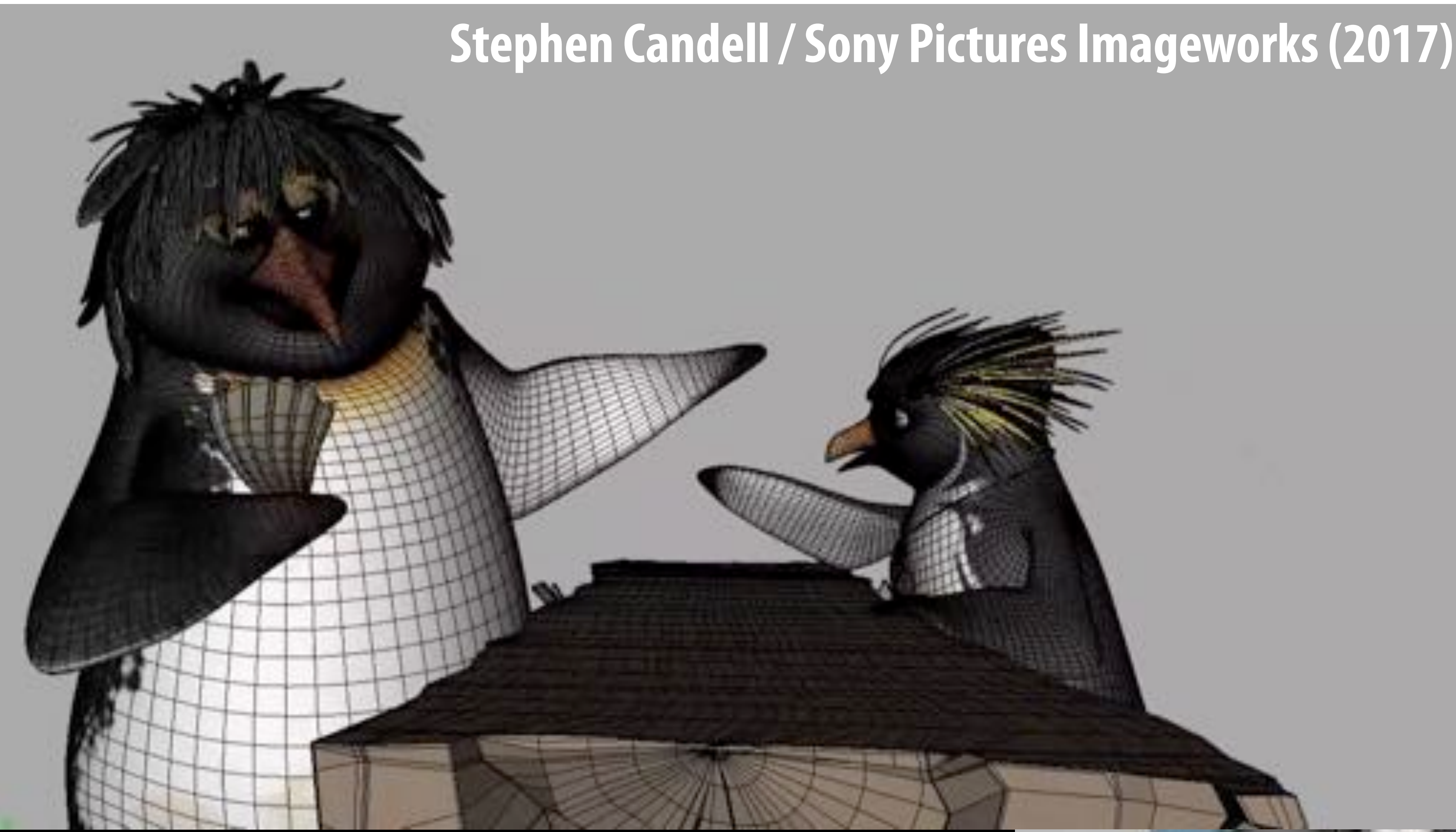

Moana (Disney 2016)

Assignment 4: Animation



(cribbed from Alec Jacobson)

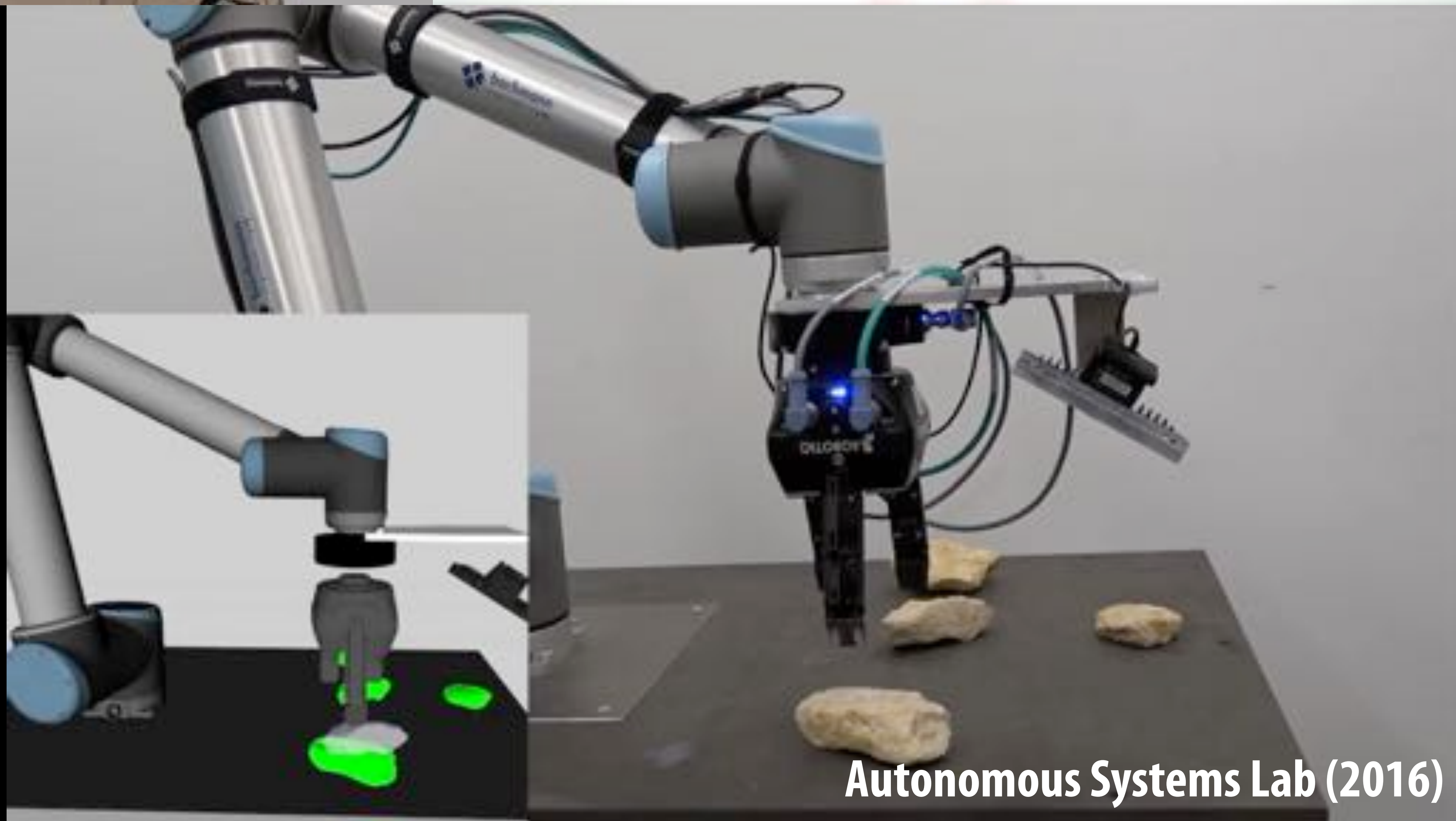
Motivation: make animations like these!



Stephen Candell / Sony Pictures Imageworks (2017)

Yans Media (2015)

Pixar (2016)



Autonomous Systems Lab (2016)

A little bit more detail..

Meet our staff!

- **Course web page:** http://15462.courses.cs.cmu.edu/spring2021/home
- **Piazza page:** https://piazza.com/class/kjsthko53ls2hy
- **Staff**

Oscar Dadfar
[odadfar at andrew]
Office hours:
Thursday 3-5pm
Location: See Piazza

Anne He
[afhe at andrew]
Office hours:
Monday 7-9pm
Location: See Piazza

Emma Liu
[emmaliu at andrew]
Office hours:
Wednesday 6-8pm
Location: See Piazza

Ryan Po
[rlpo at andrew]
Office hours:
Monday 7-9pm
Location: See Piazza

Maxwell Slater
[mjslater at andrew]
Office hours:
Saturday noon-2pm
Location: See Piazza

Hesper Yin
[hyin2 at andrew]
Office hours:
Wednesday 6-8pm
Location: See Piazza

Spring 2021 Schedule

Feb 1	**Course Introduction**
Feb 3	**Math Review Part I (Linear Algebra)** Assignment 0.0 OUT
Feb 8	**Math Review Part II (Vector Calculus)** Assignment 0.0 DUE Assignment 0.5 OUT
Feb 10	**Drawing a Triangle** Assignment 0.5 DUE Assignment 1.0 OUT
Feb 15	**Coordinate Spaces and Transformations**
Feb 17	**3D Rotations and Complex Representations**
Feb 22	**Perspective Projection and Texture Mapping** Assignment 1.0 DUE Assignment 1.5 OUT
Feb 24	**Depth and Transparency**
Mar 1	**Midterm Review** Assignment 1.5 DUE
Mar 3	**MIDTERM EXAM**
Mar 8	**Intro to Geometry / Meshes and Manifolds** Assignment 2.0 OUT
Mar 10	**Digital Geometry Processing**
Mar 15	**Geometric Queries**
Mar 17	**Spatial Data Structures** Assignment 2.0 DUE Assignment 2.5 OUT
Mar 22	**Color**
Mar 24	**Radiometry** Assignment 2.5 DUE Assignment 3.0 OUT
Mar 29	**The Rendering Equation**
Mar 31	**Numerical Integration**
Apr 5	**BREAK DAY NO CLASSES**
Apr 7	**Monte Carlo Ray Tracing** Assignment 3.0 DUE Assignment 3.5 OUT
Apr 12	**Variance Reduction**
Apr 14	**Guest Lecture**
Apr 19	**Introduction to Animation** Assignment 3.5 DUE Assignment 4.0 OUT
Apr 21	**Dynamics and Time Integration**
Apr 26	**Introduction to Optimization**
Apr 28	**Physically-Based Animation and PDEs** Assignment 4.0 DUE Assignment 4.5 OUT
May 3	**Character Simulation and Control**
May 5	**Final Review** Assignment 4.5 DUE May 7
TBD	**FINAL EXAM**

Mini homework 0 — Due before class next Monday

- http://15462.courses.cs.cmu.edu/spring2021/article/1

MiniHW0 - Tell us about yourself

The first mini-homework is simple. Before you begin, please read the Welcome + Logistics Post on Piazza (let a course staff member know if you do not have access to Piazza).

1. Tell us who is in your group and how you know each other (include everyone's name and andrewID).
2. For each member in your group write one thing you want to learn from this course and/or one reason you decided to take the course.
3. When are A0.0/0.05 due?
4. How many people in your group need to submit a mini-hw? How do you make sure your other group members get credit?
5. Please join the class Discord. What's the point of the class Discord?
6. Please post the links to the following services to ensure you have access to them. If you cannot access them, please make a note that you will get in touch with the course staff to help you get set up:

- Course Website
- Piazza
- Autolab
- Gradescope
- OHQueue
- Lecture Zoom
- Discord

For this and all other mini-homeworks, you should submit your solutions via Gradescope. There is no template or required formatting, though we appreciate typeset :)

See you next time!

- **Before diving in, we'll do a math review & preview**
  - **Linear algebra, vector calculus**
  - **Help make the rest of the course easier!**