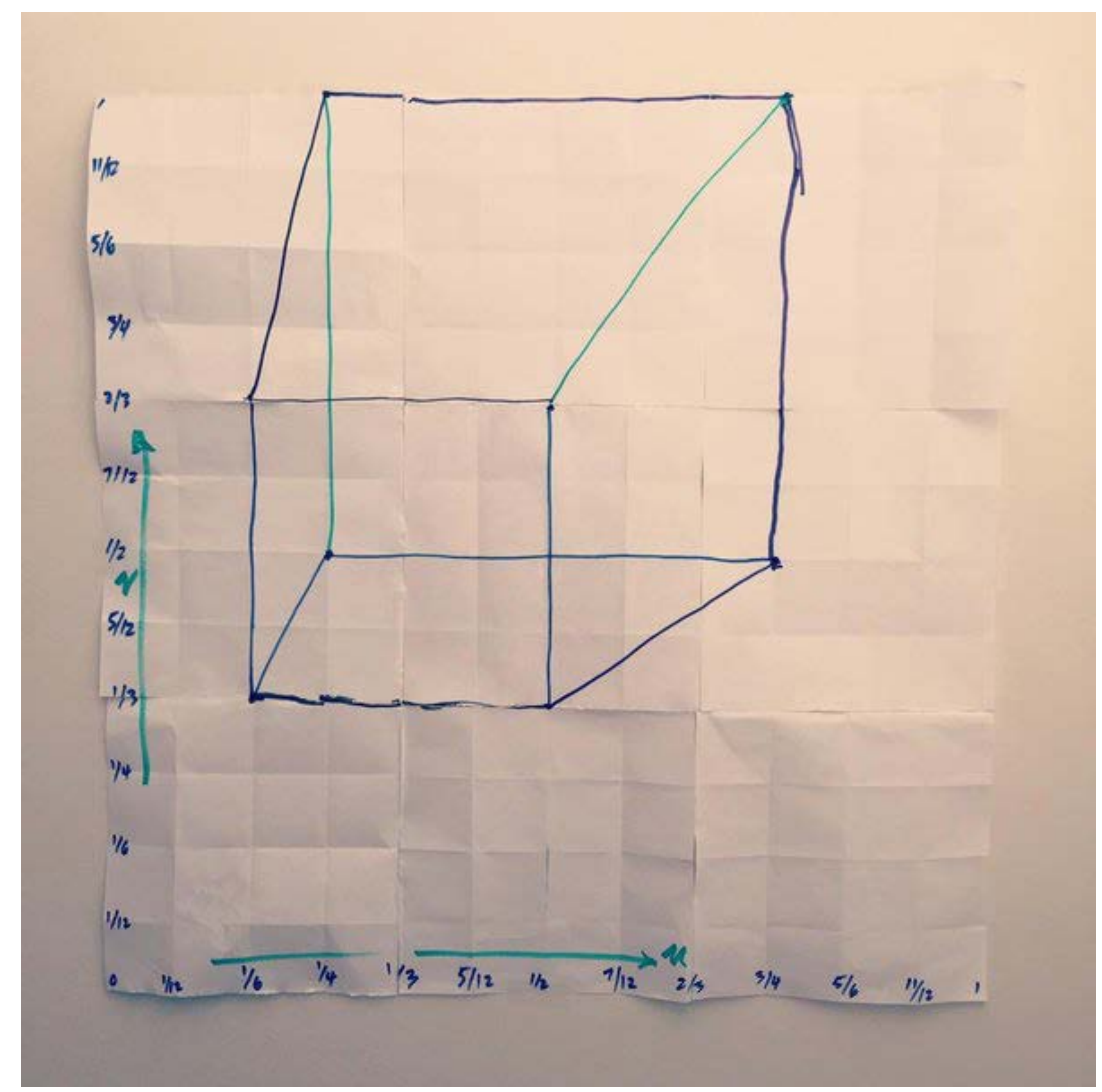
Lecture 1:

Introduction to Computer Graphics

Computer Graphics
CMU 15-462/662

TODAY: Overview Computer Graphics

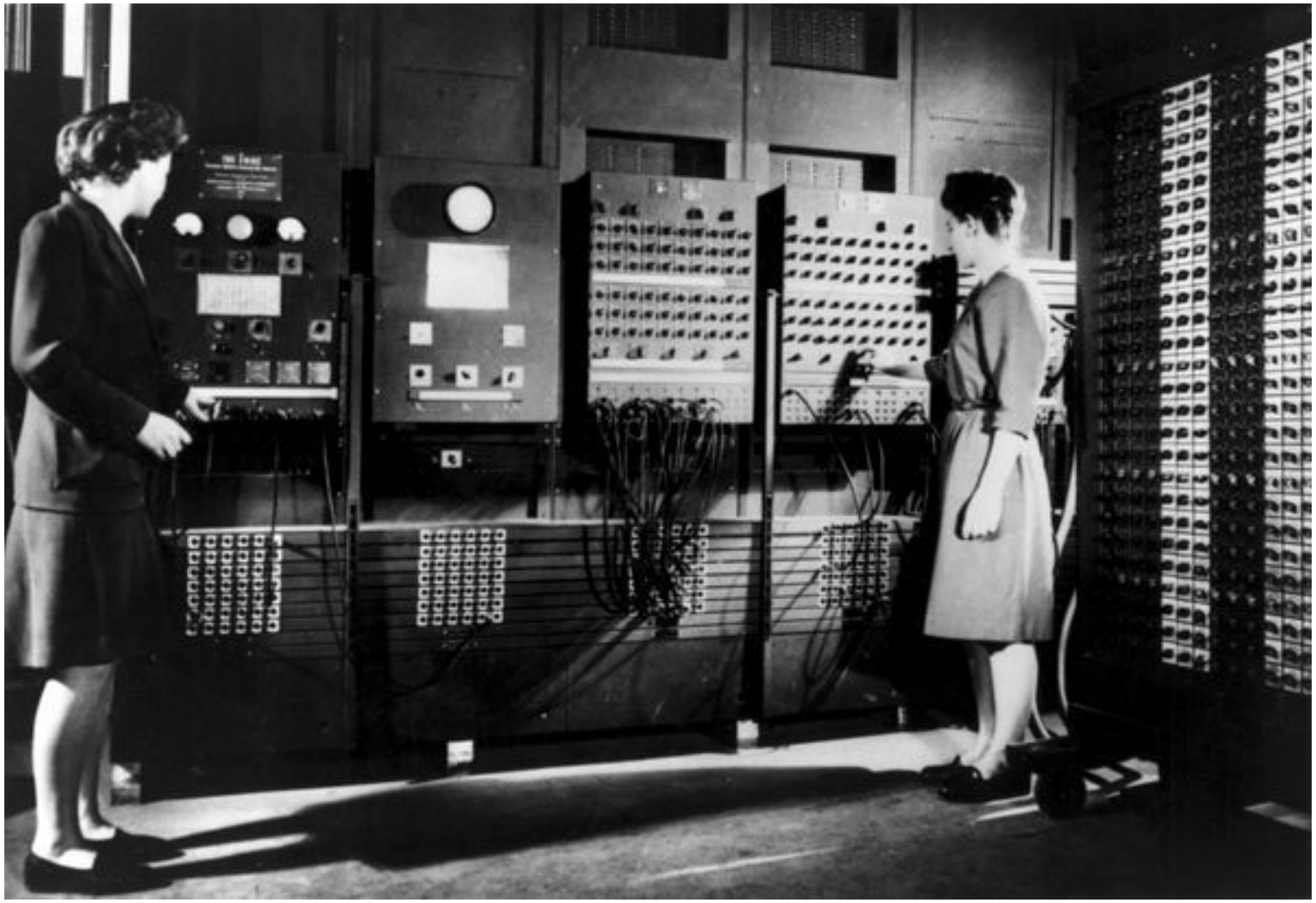
- Two main objectives:
  - Try to understand broadly what computer graphics is about
  - "Implement" our 1st algorithm for making images of 3D shapes
- Note: all logistics on course webpage



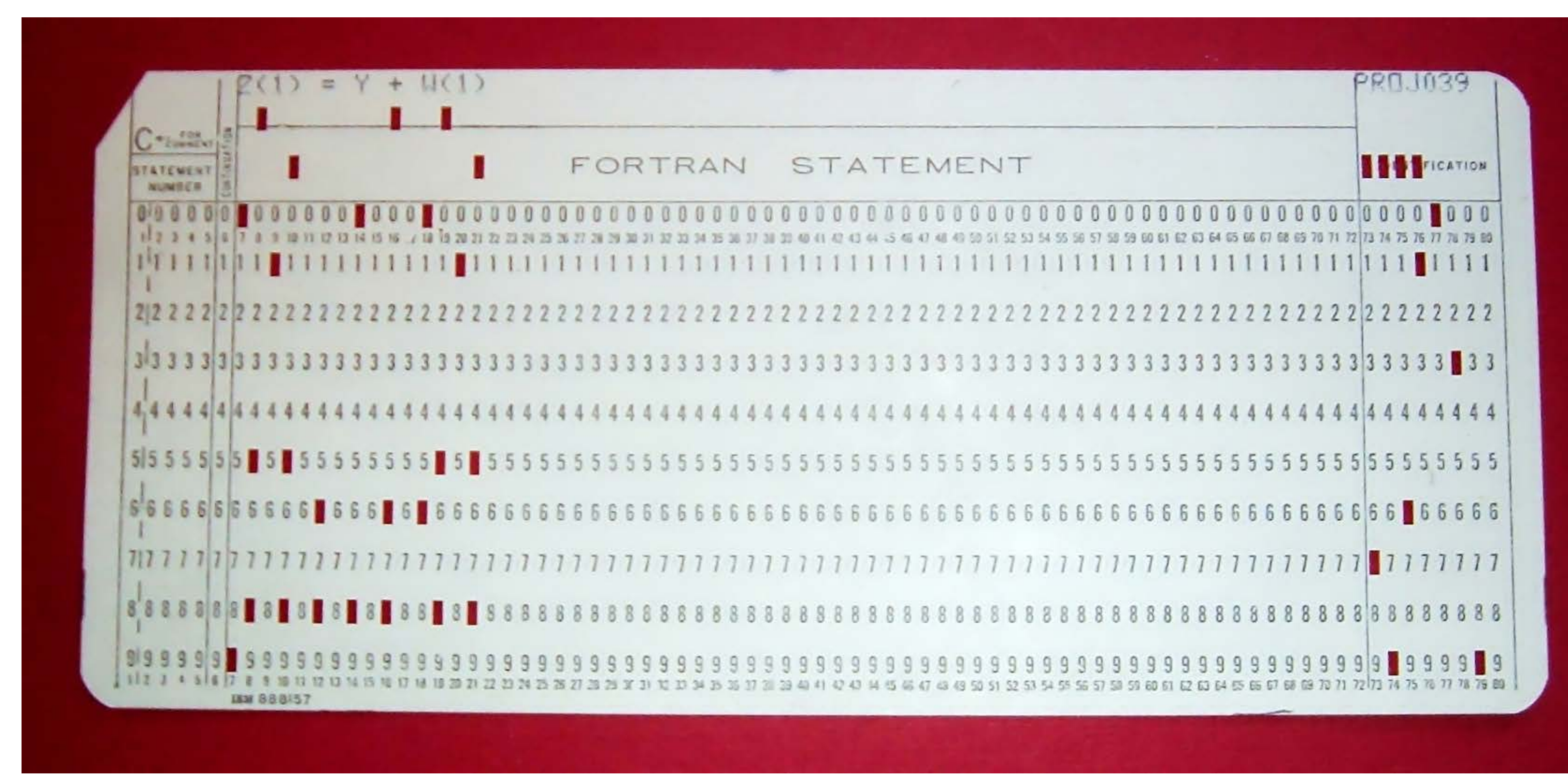
Q: What is computer graphics?

Probably an image like this comes to mind:

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

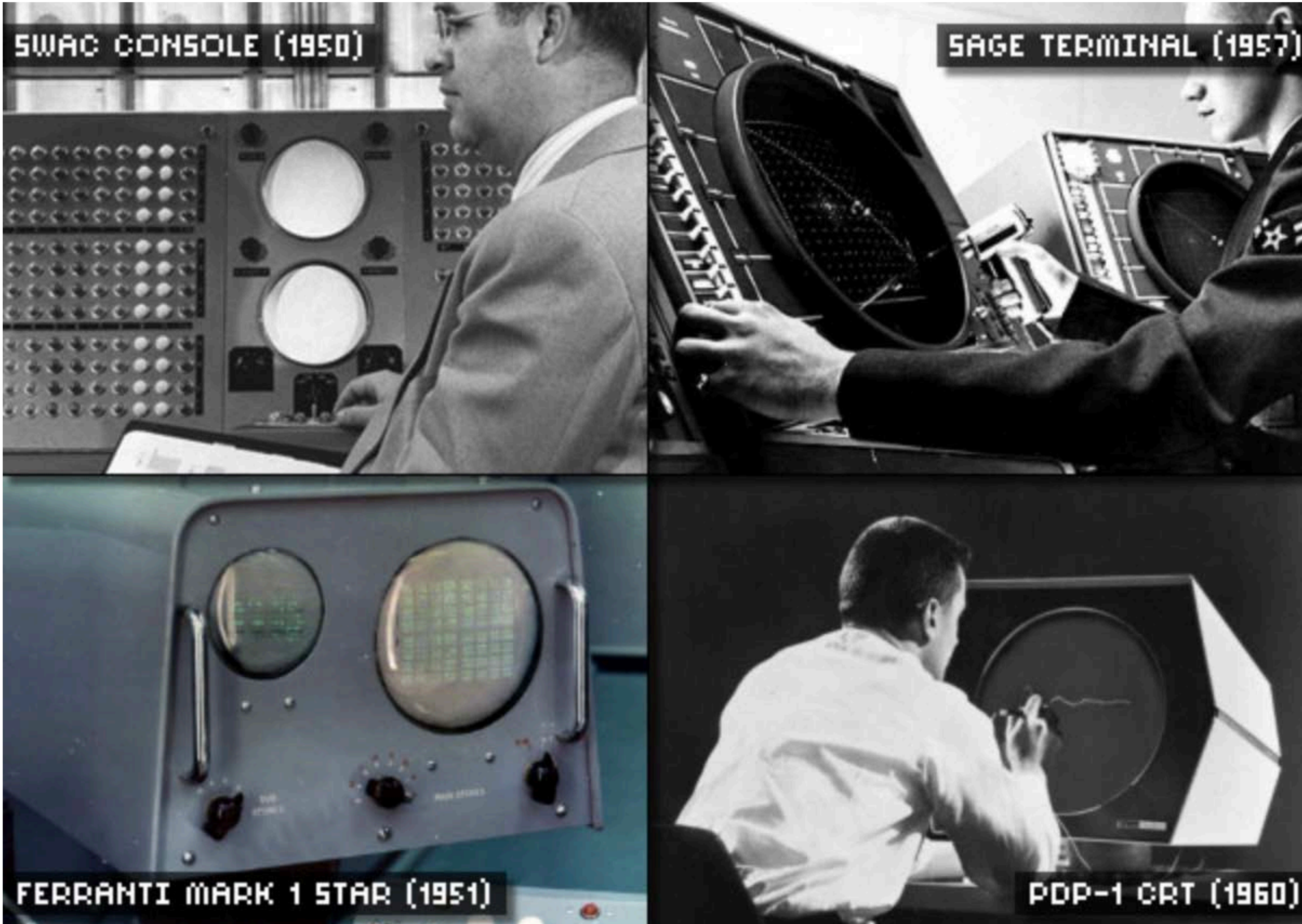


Early computer (ENIAC), 1945



punch card (~120 bytes)

There must be a better way!



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

Sketchpad (Ivan Sutherland, 1963)

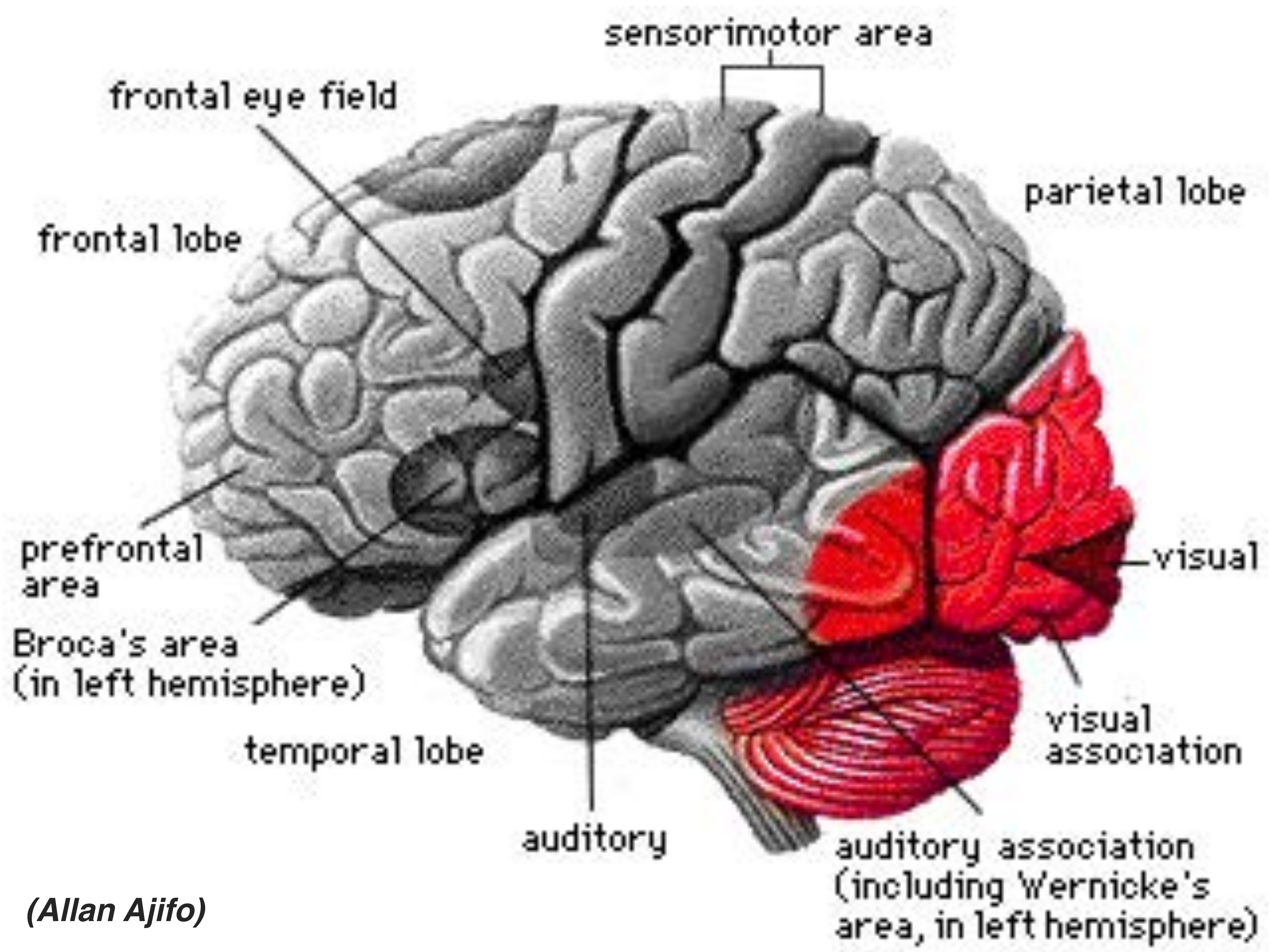
2020: 8k monitor
7680x4320 (~95MB)

Coming down the pipe…

2020 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.

<u>digital</u> information

computation →

<u>visual</u> information

What is computer graphics?

Why only visual?

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

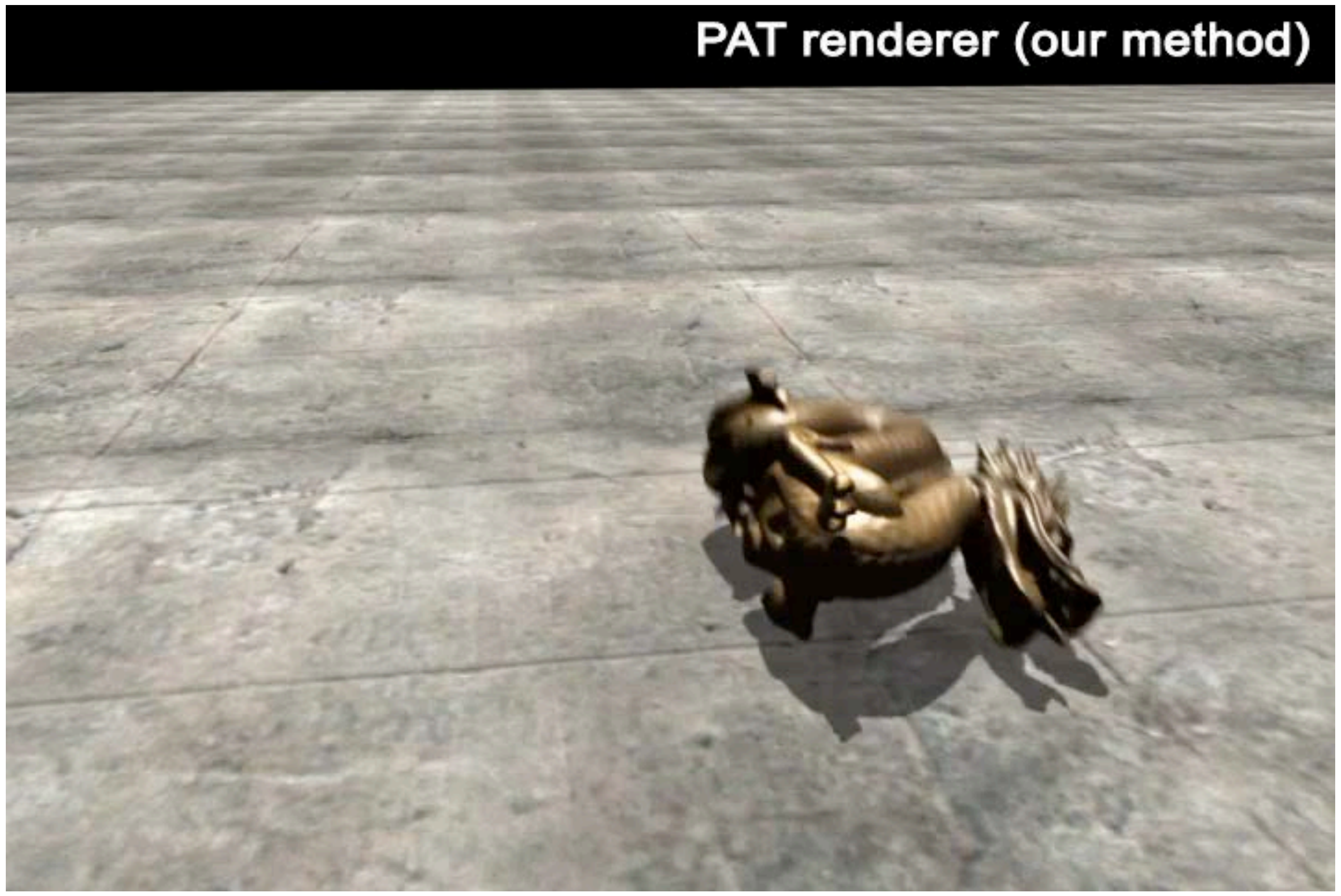
digital information

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



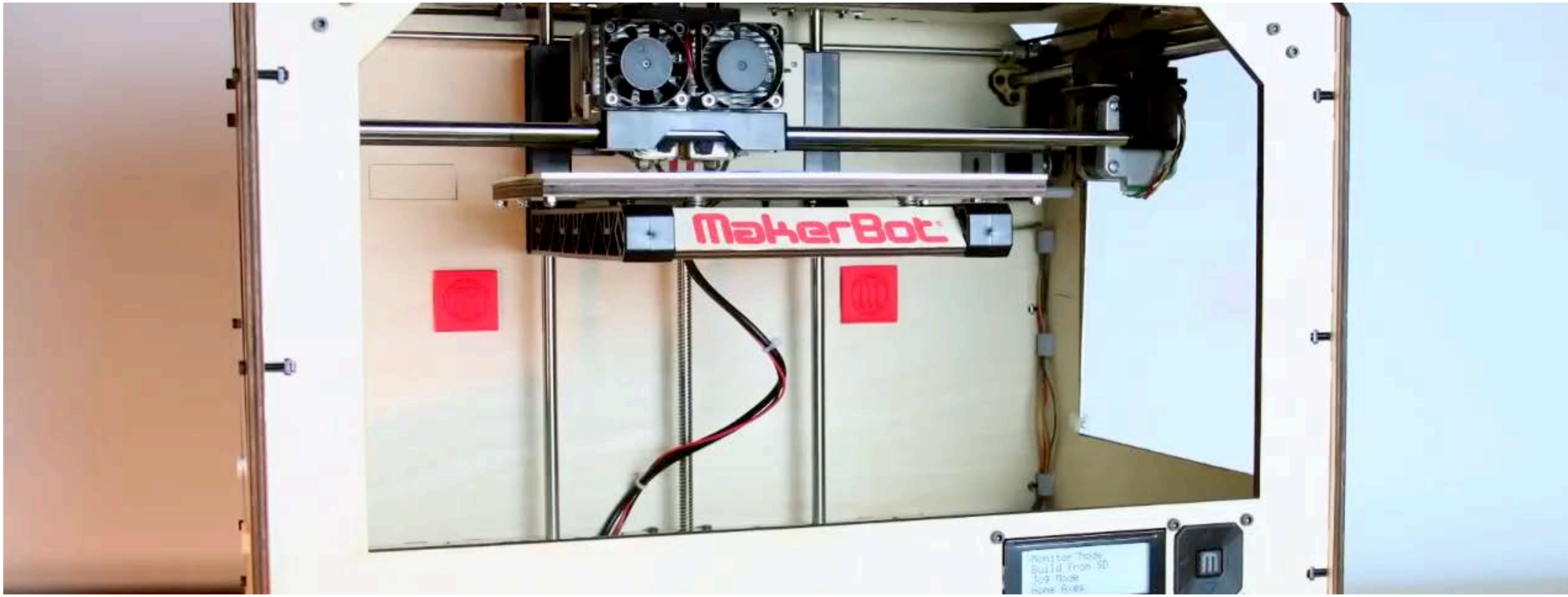
(sound)

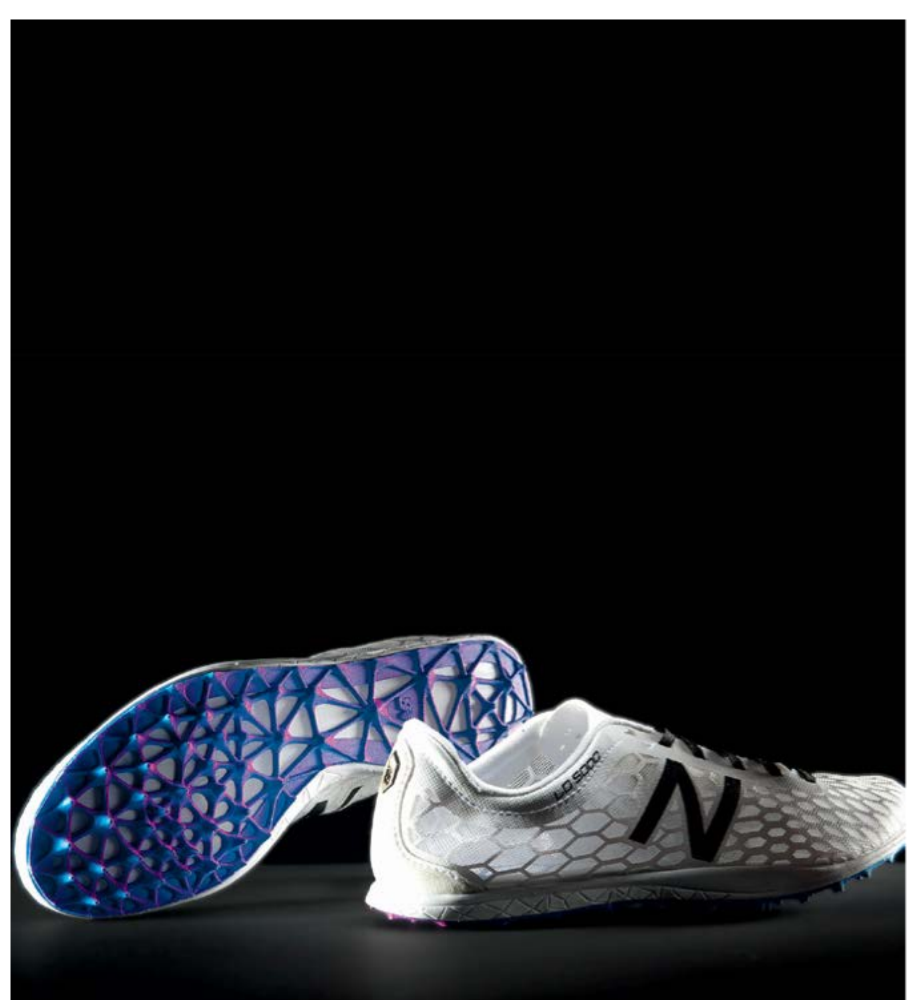
(touch)

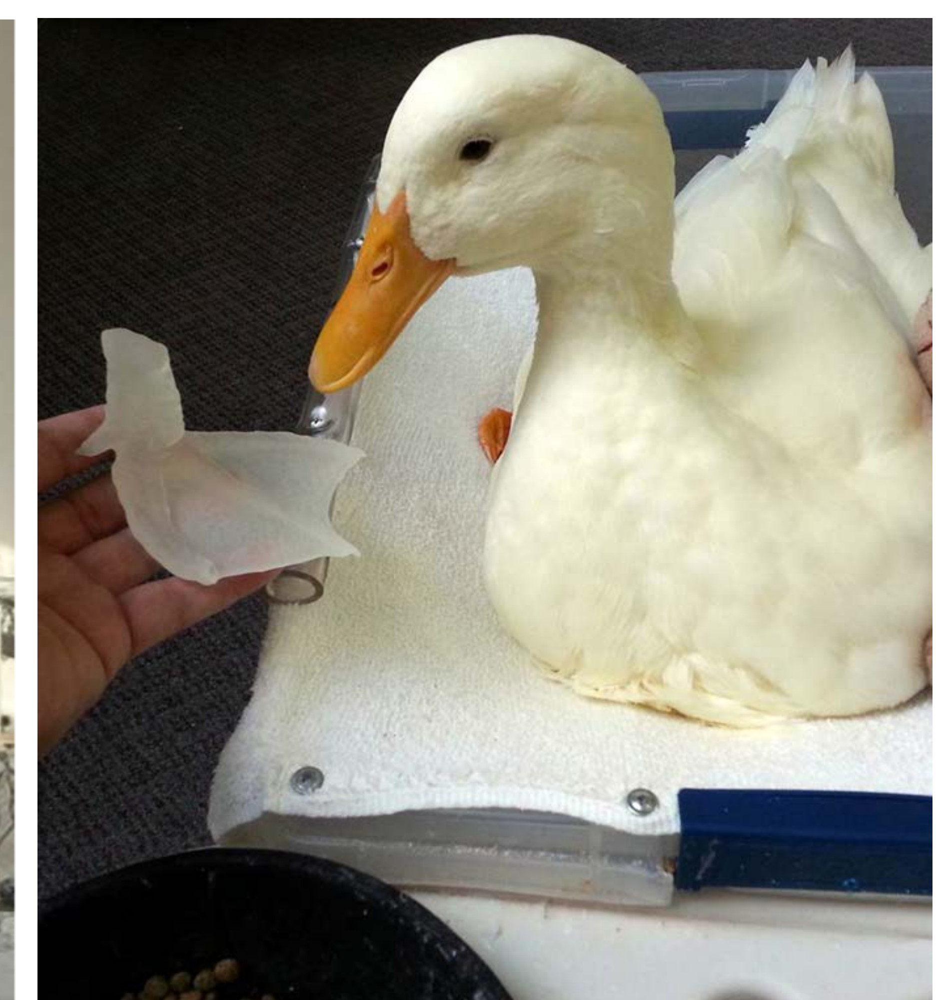
com•put•er graph•ics /kəmˈpyo͞odər ˈgrafiks/ *n.*
The use of computers to synthesize and manipulate **sensory** information.

(…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…

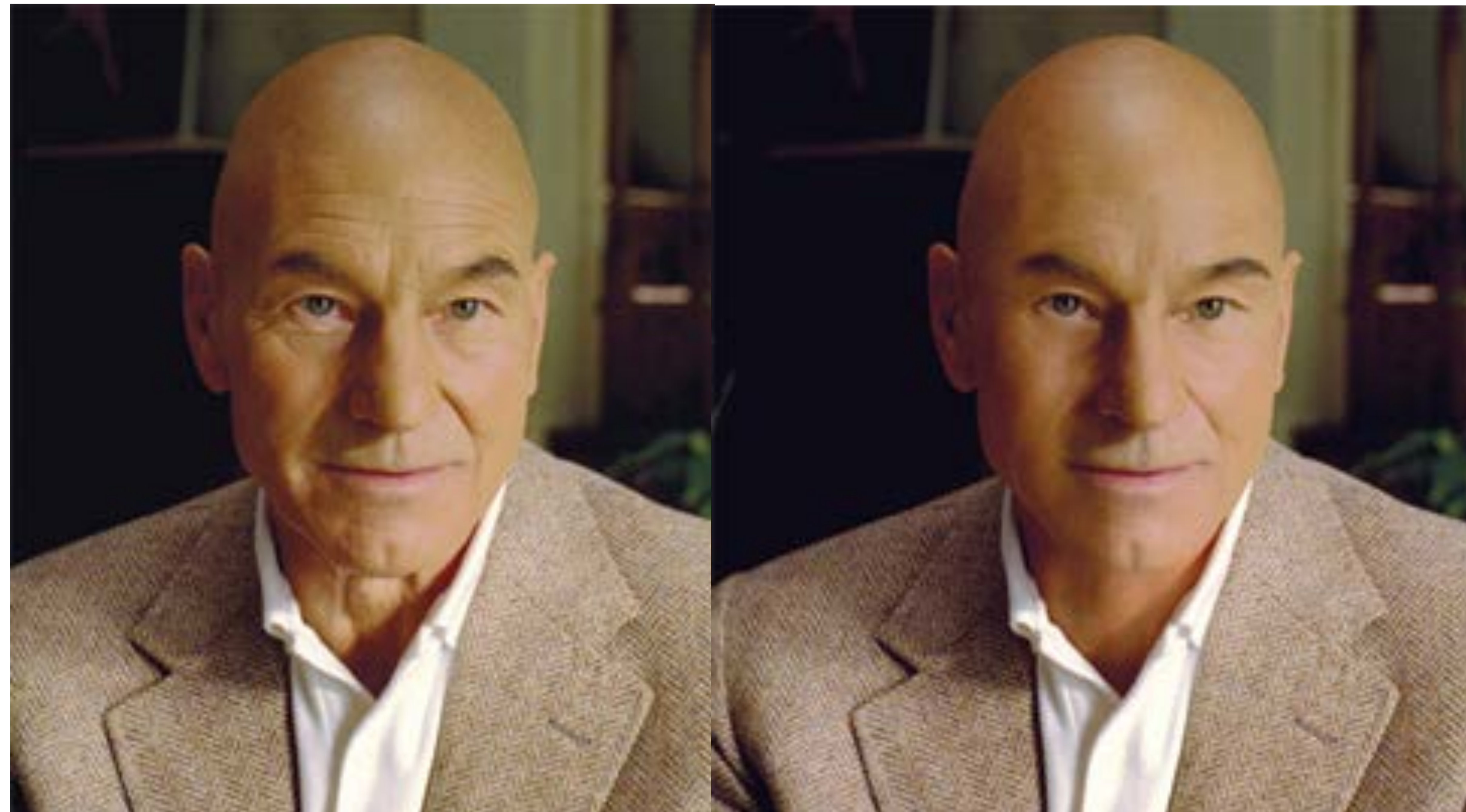
SIGGRAPH 2020 Technical Papers Trailer

Computer graphics is *everywhere!*

Entertainment (movies, games)

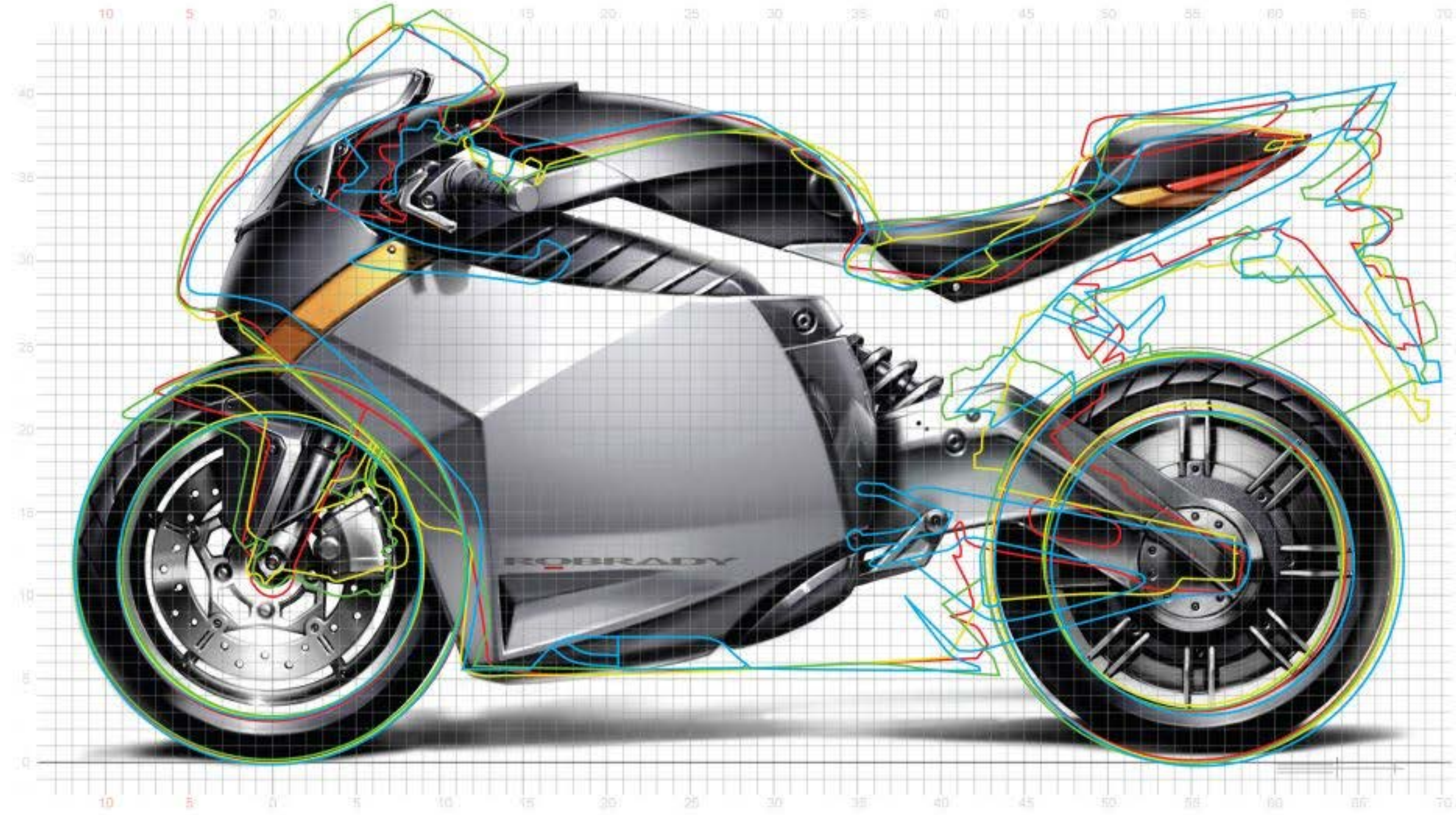
Entertainment

- Not just cartoons!

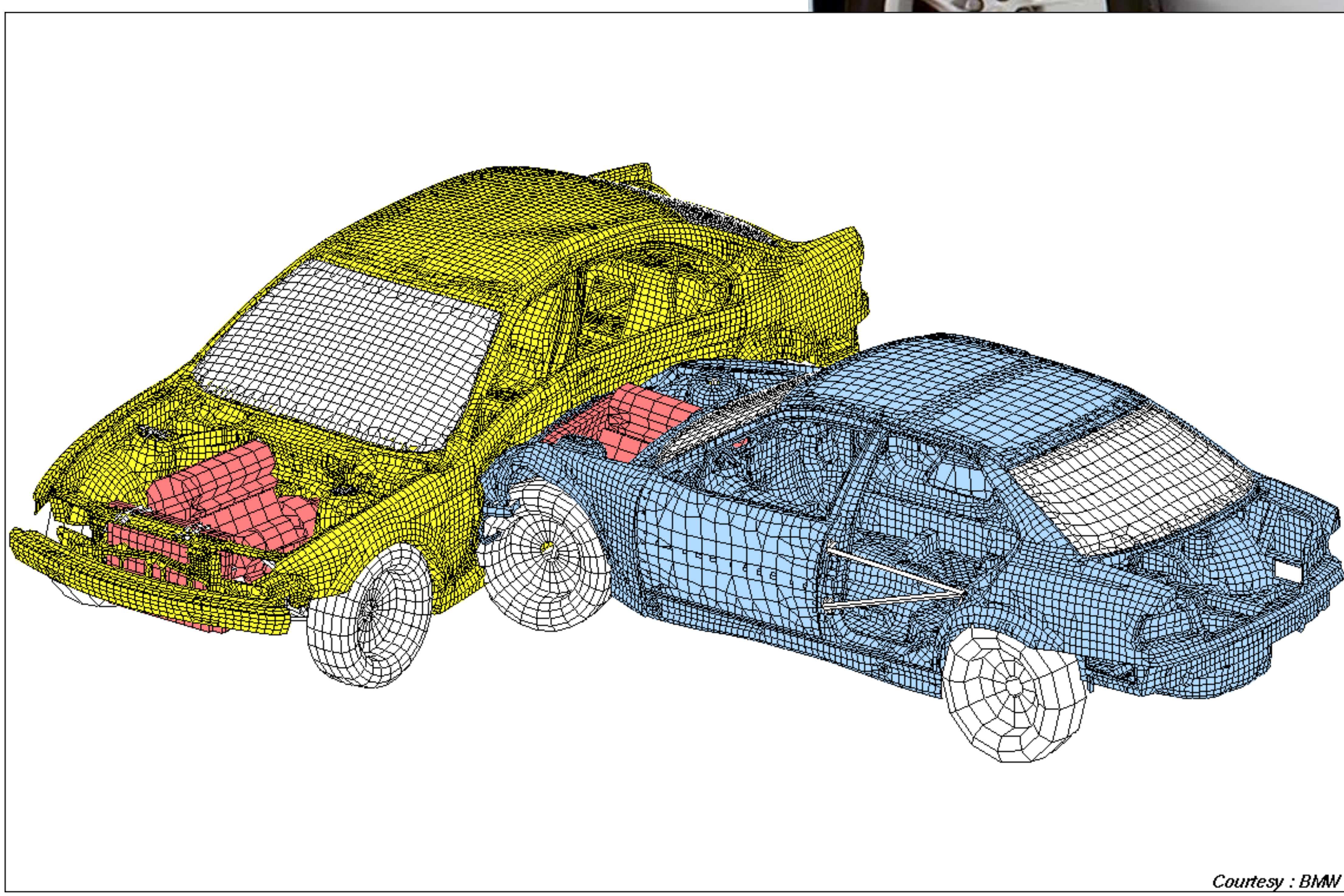


Art and design

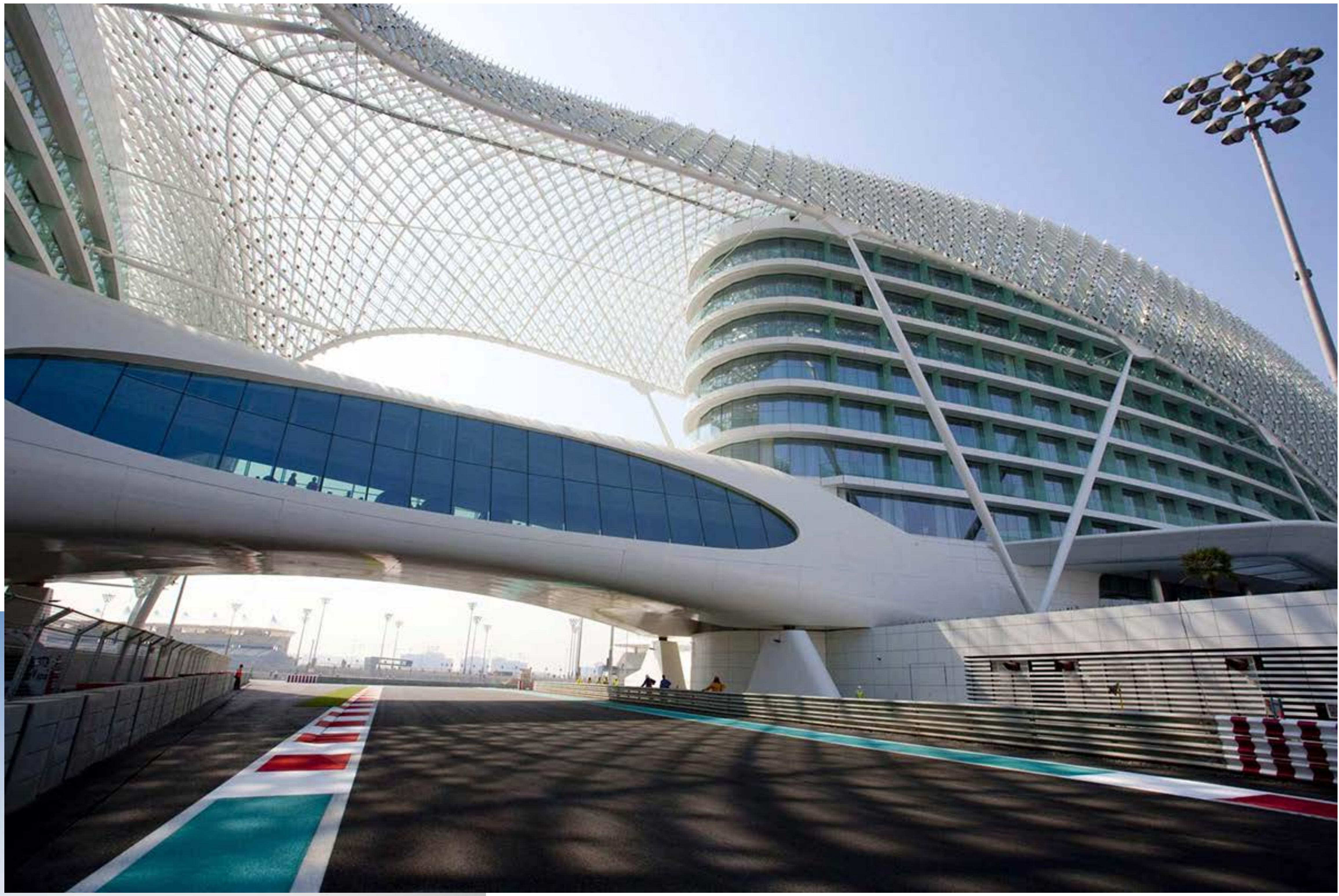
Industrial design

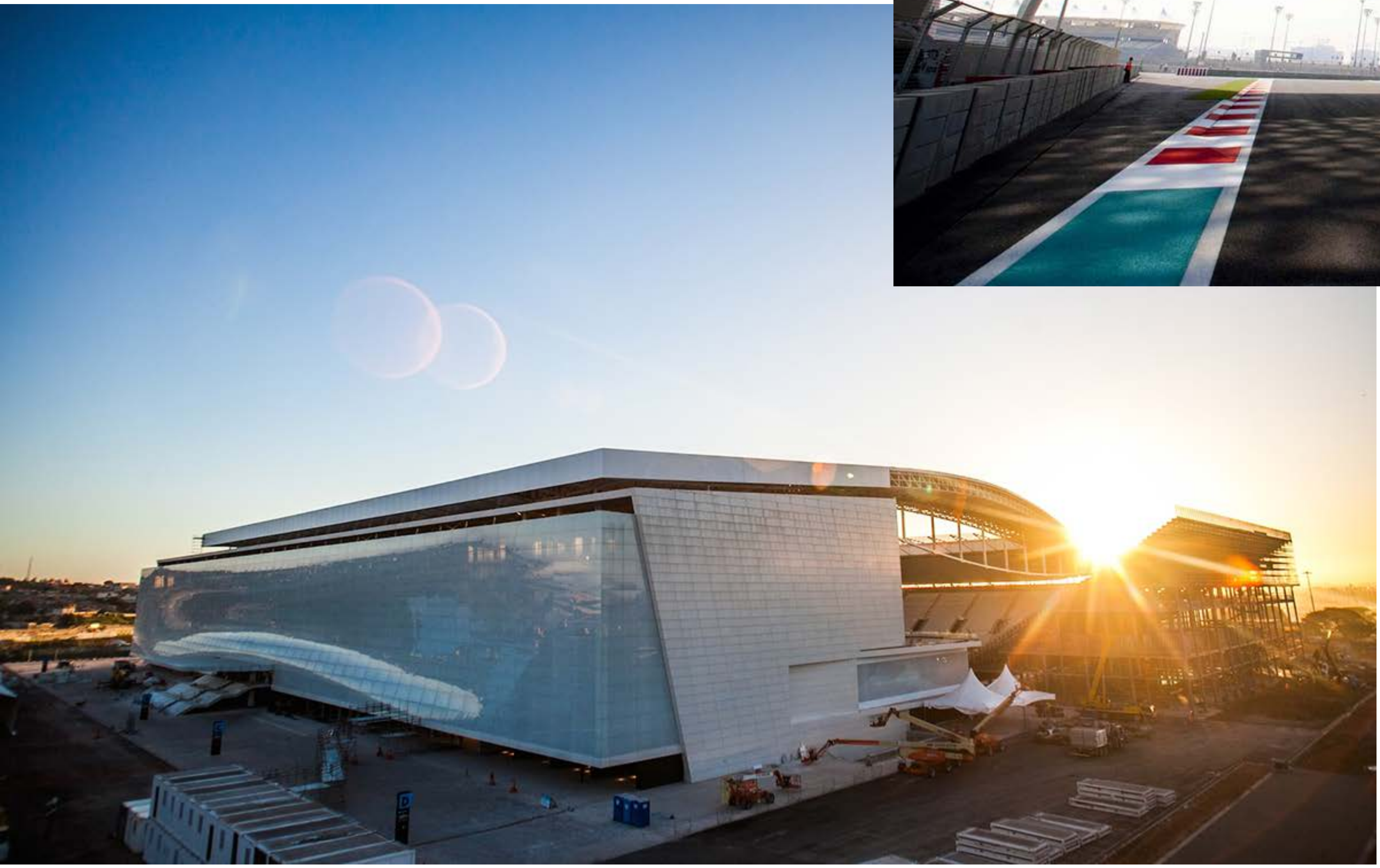


Computer aided engineering (CAE)

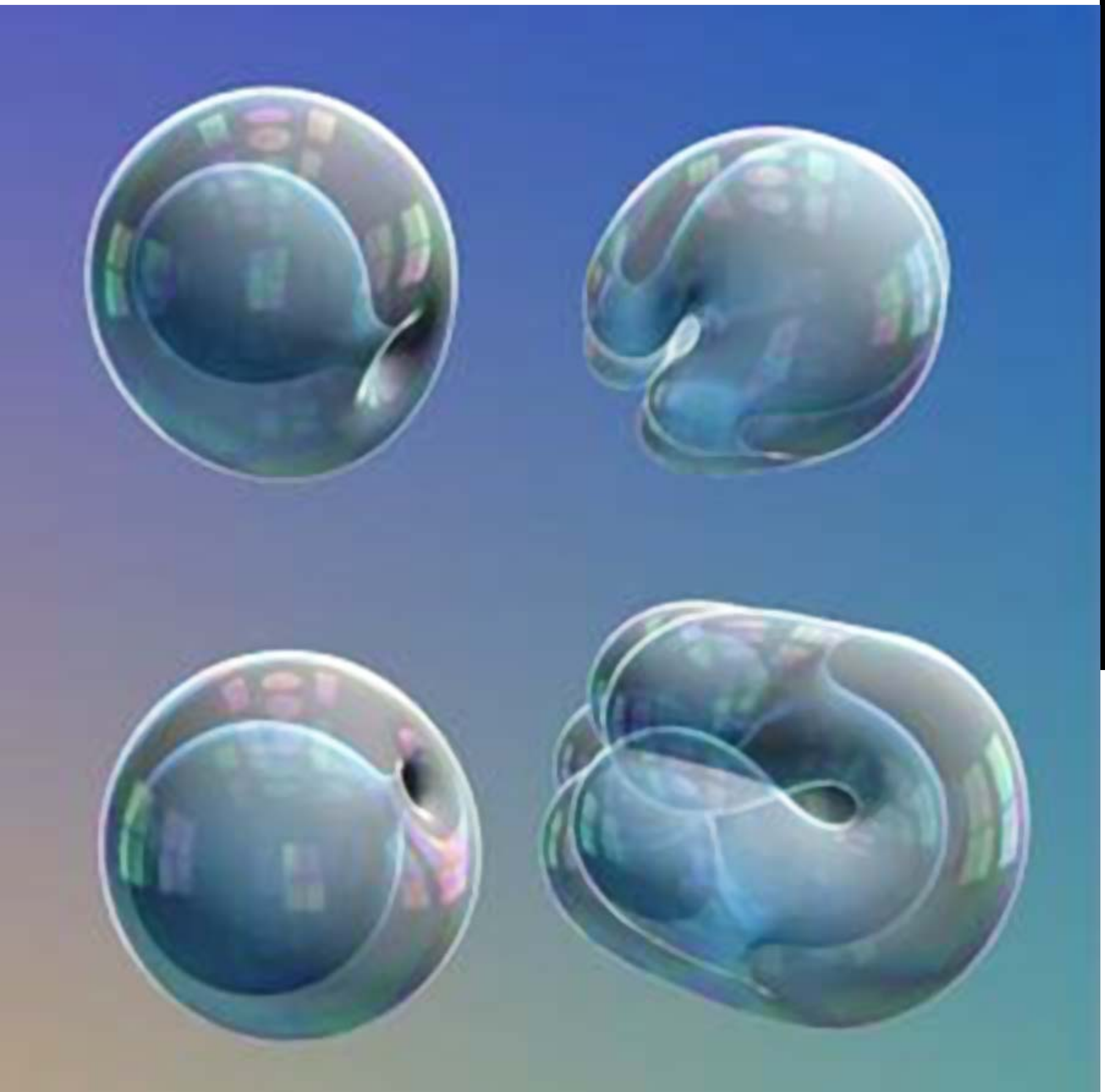


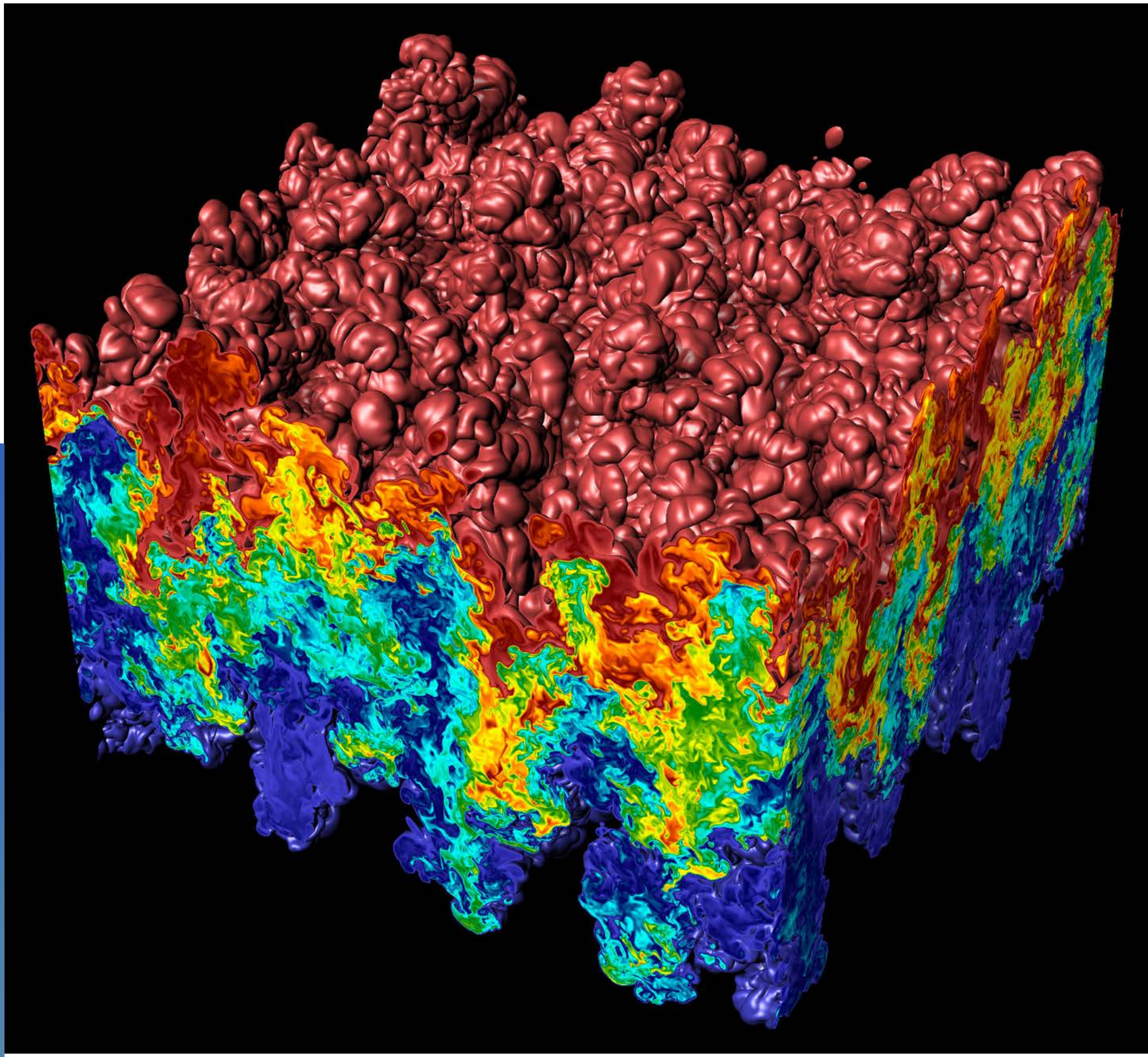
Architecture



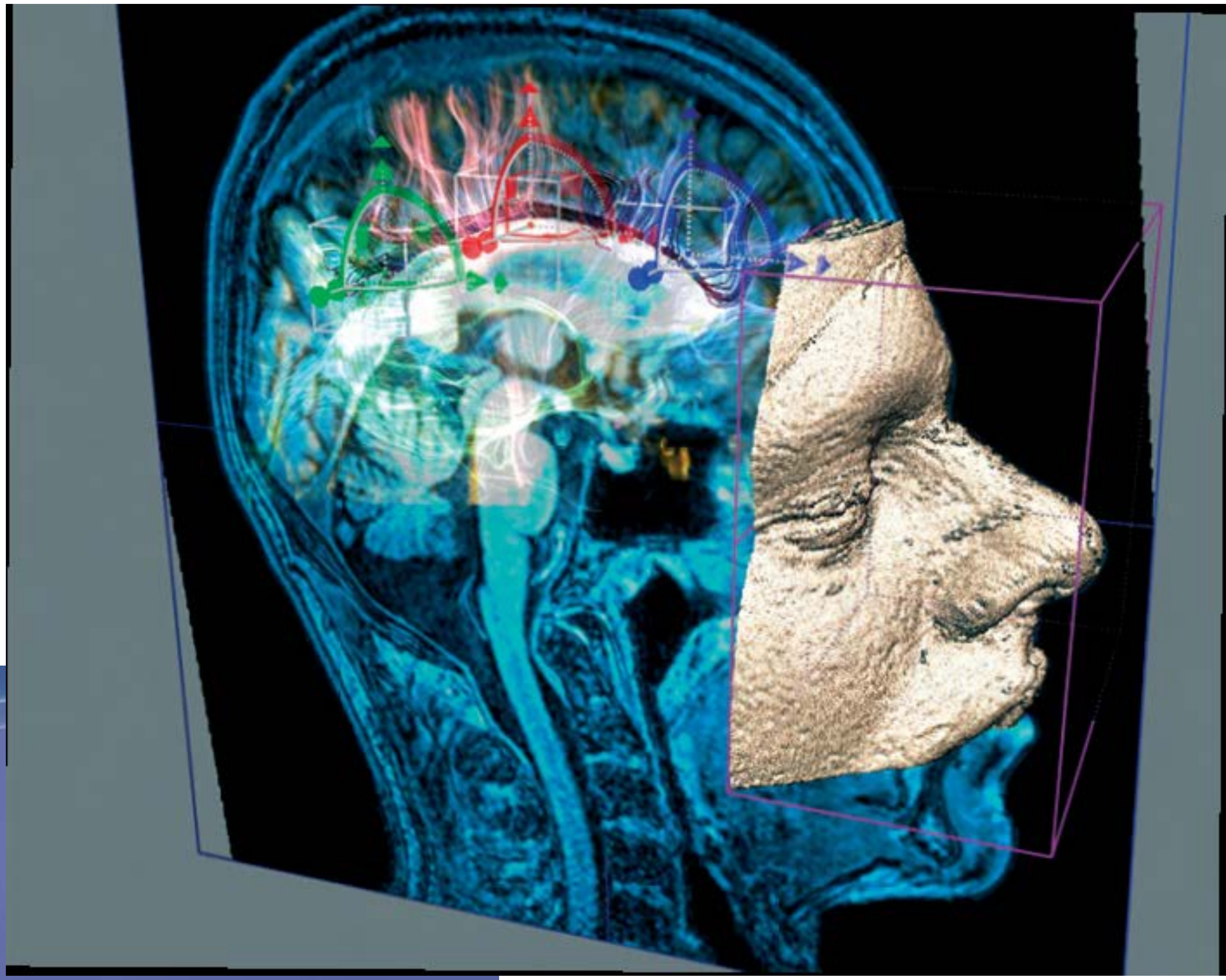


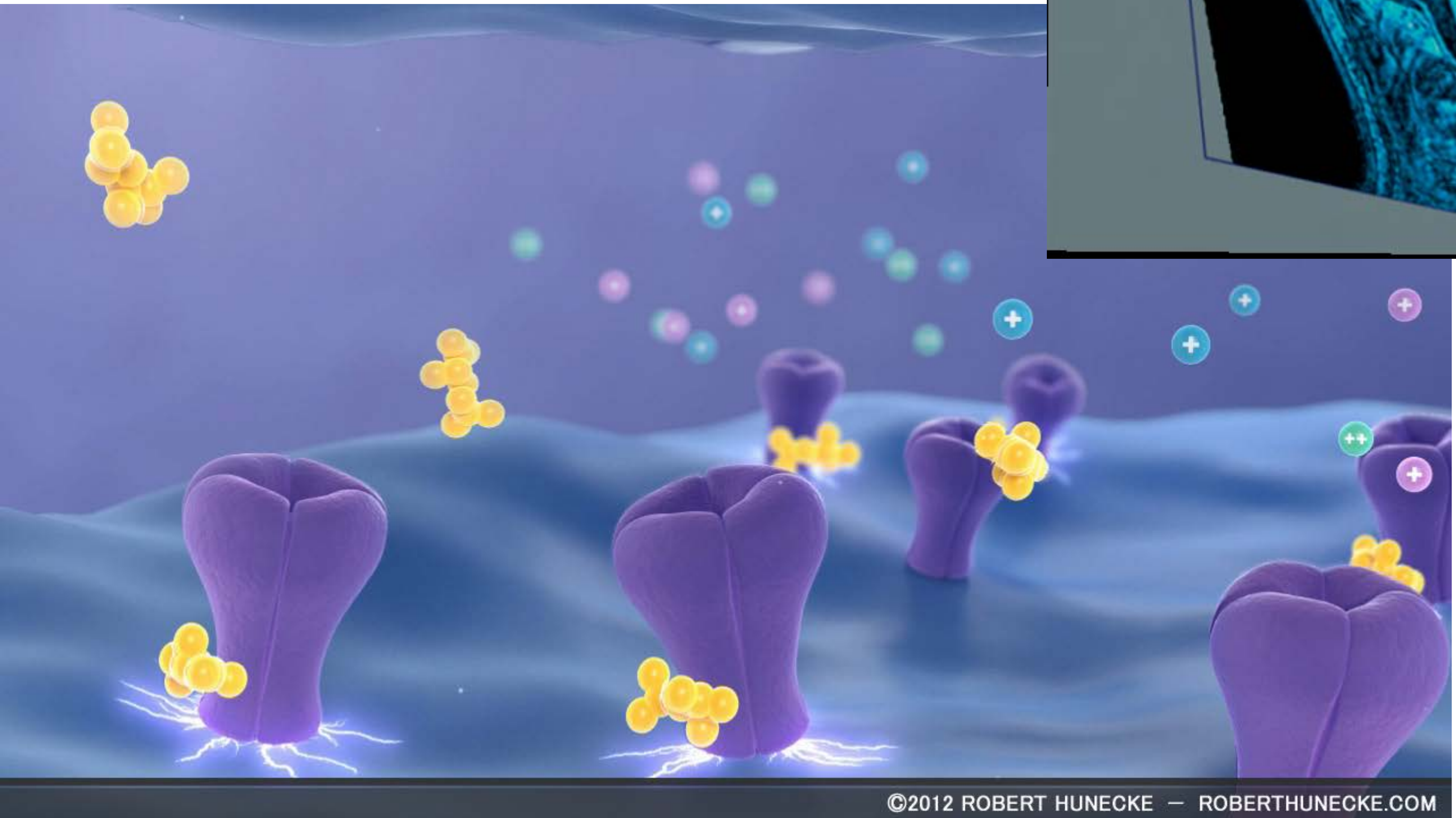
Scientific/mathematical visualization





Medical/anatomical visualization





Navigation


No SIM
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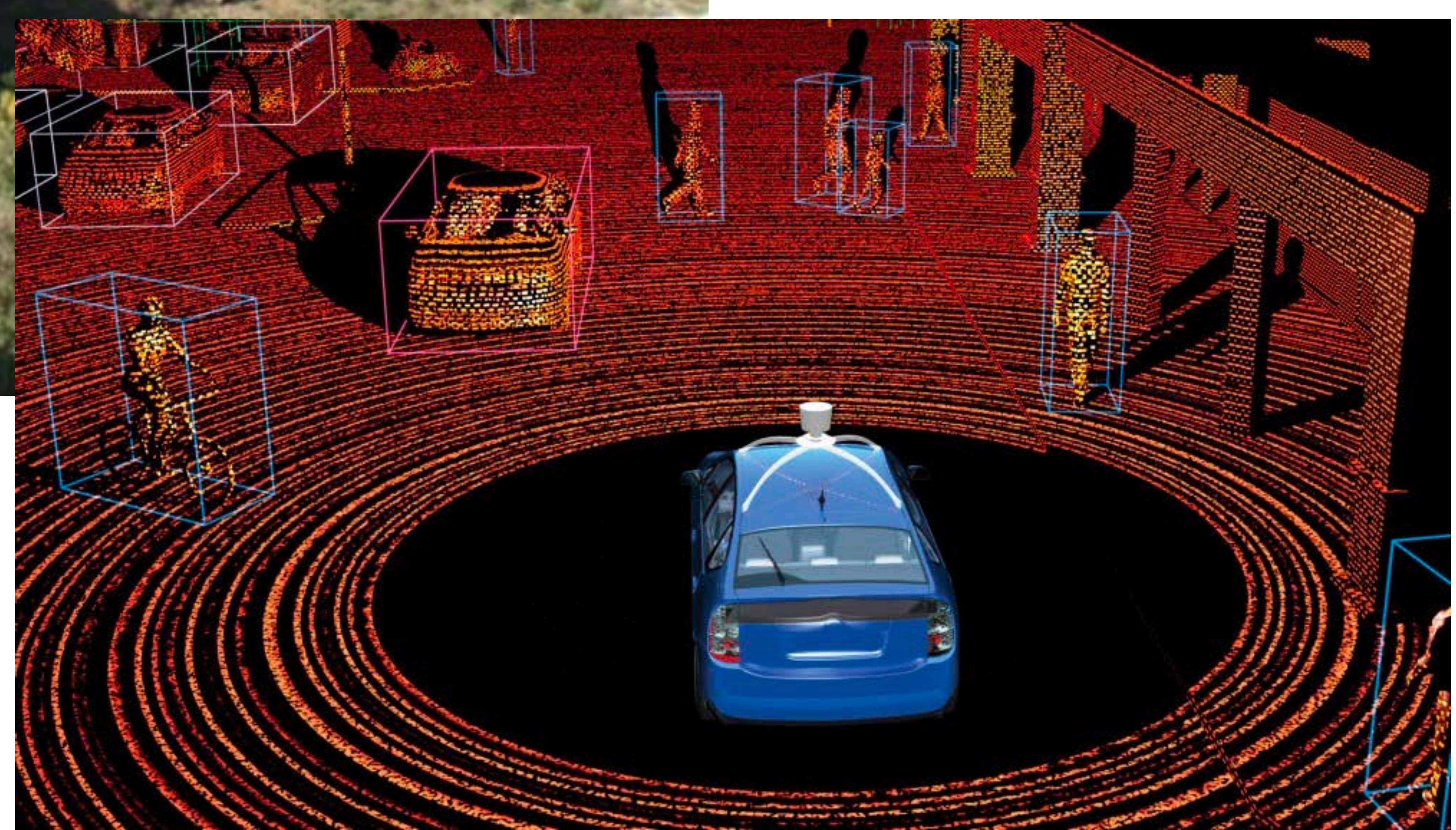
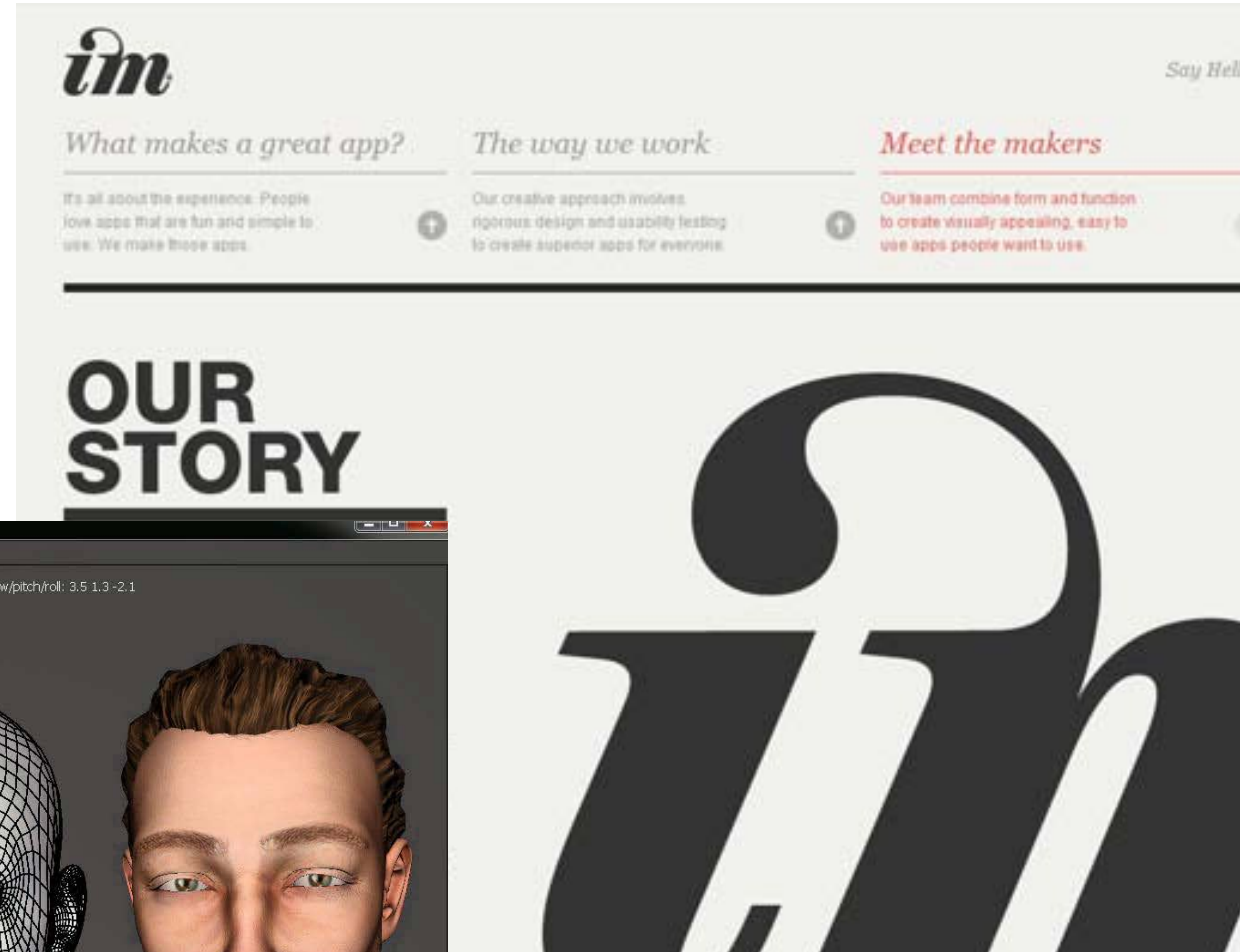
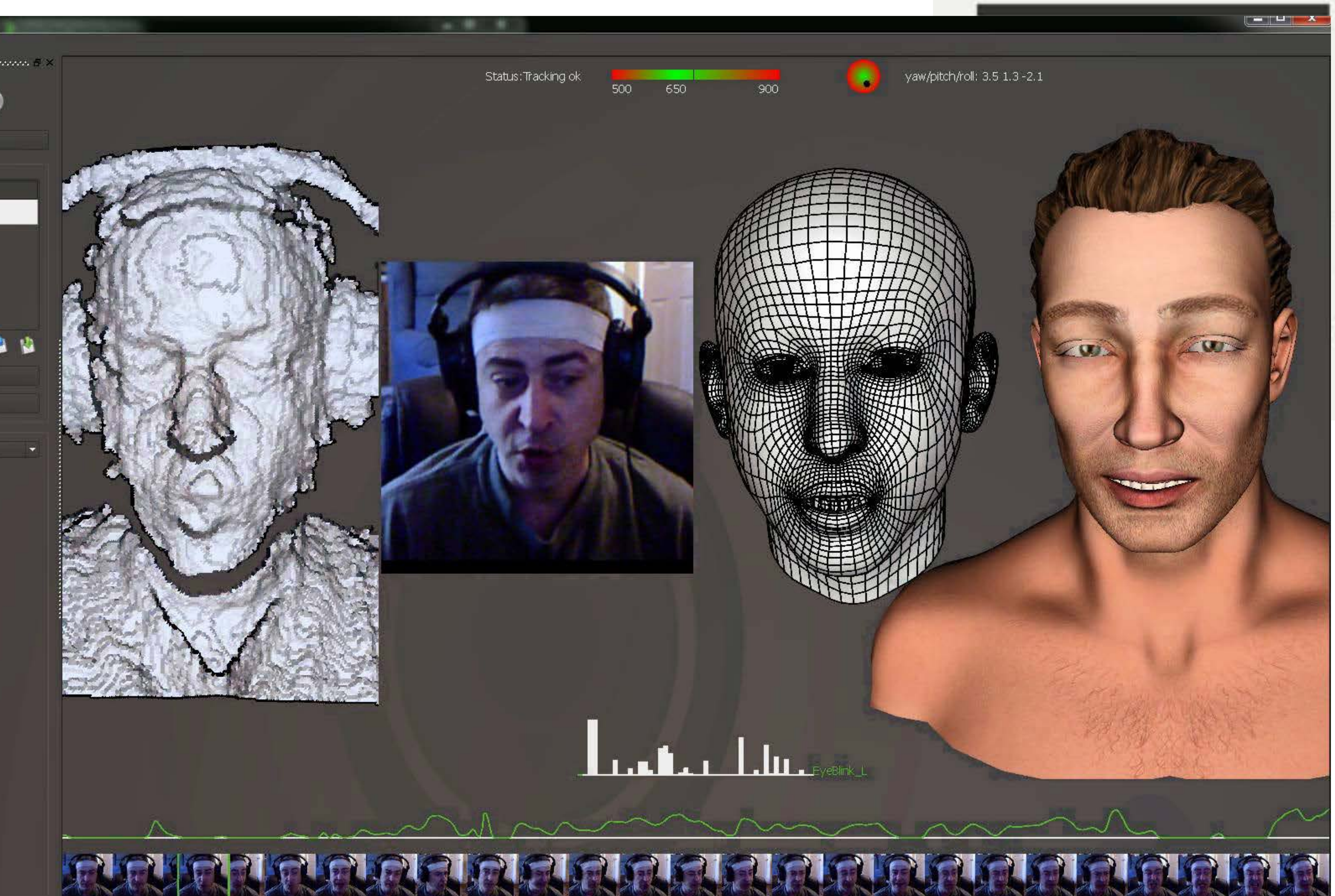
Directions
empire state building new york
Empire State Building



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

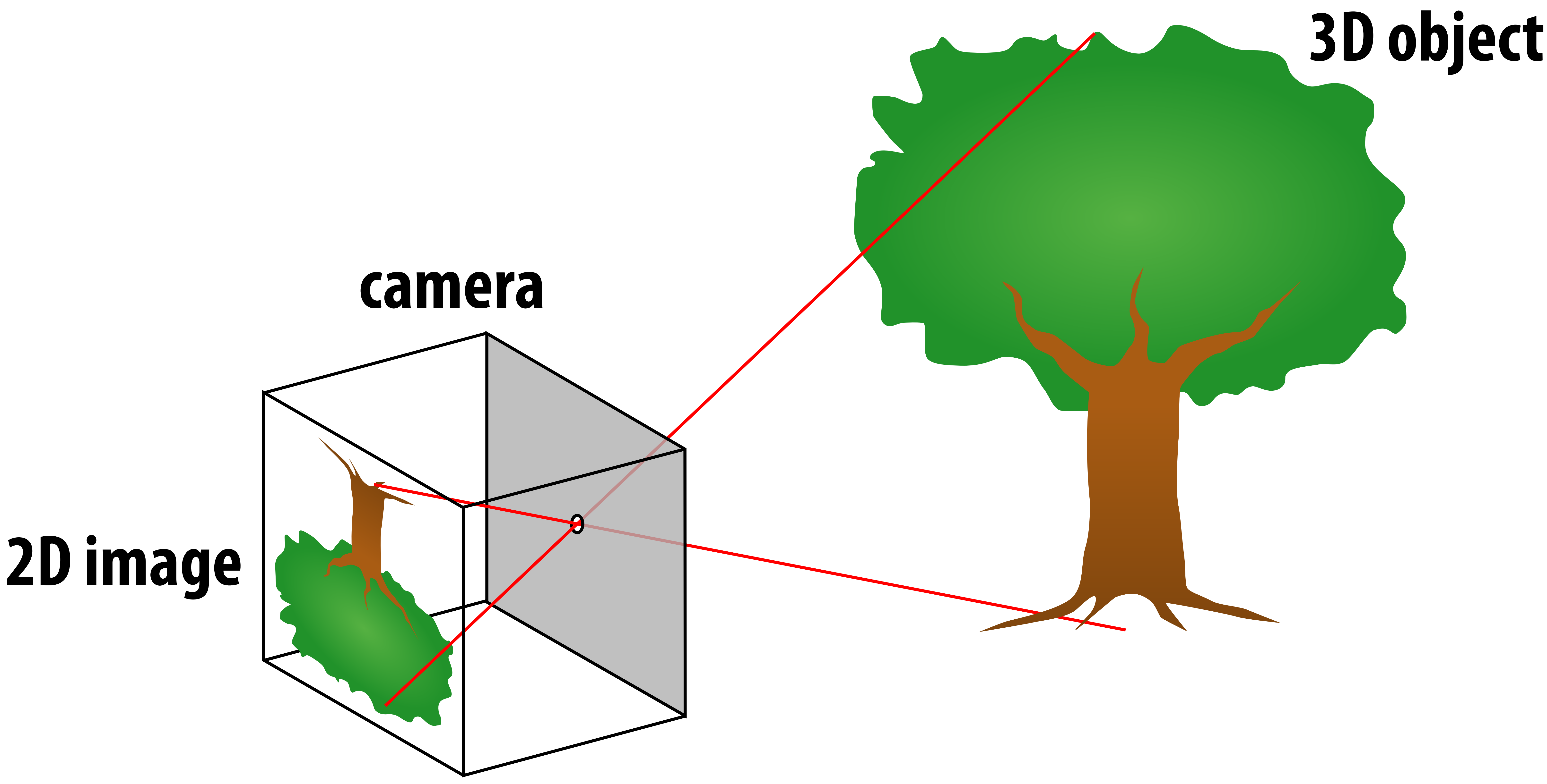
- **Now have a digital description of the cube:**

```
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?**

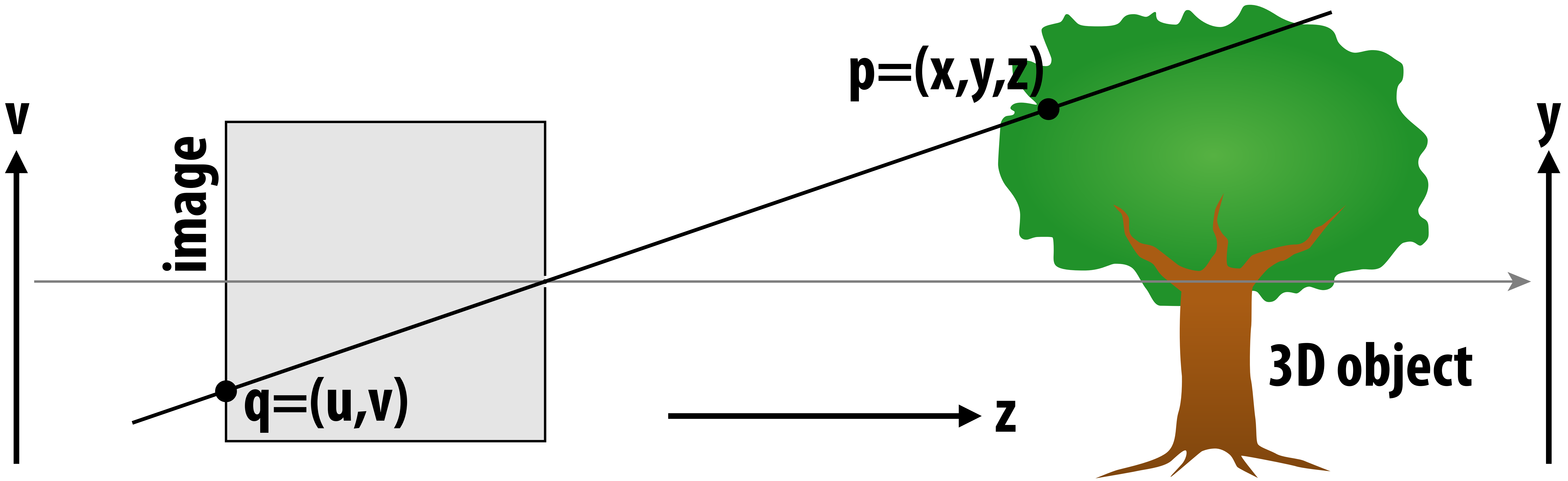
Perspective projection

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



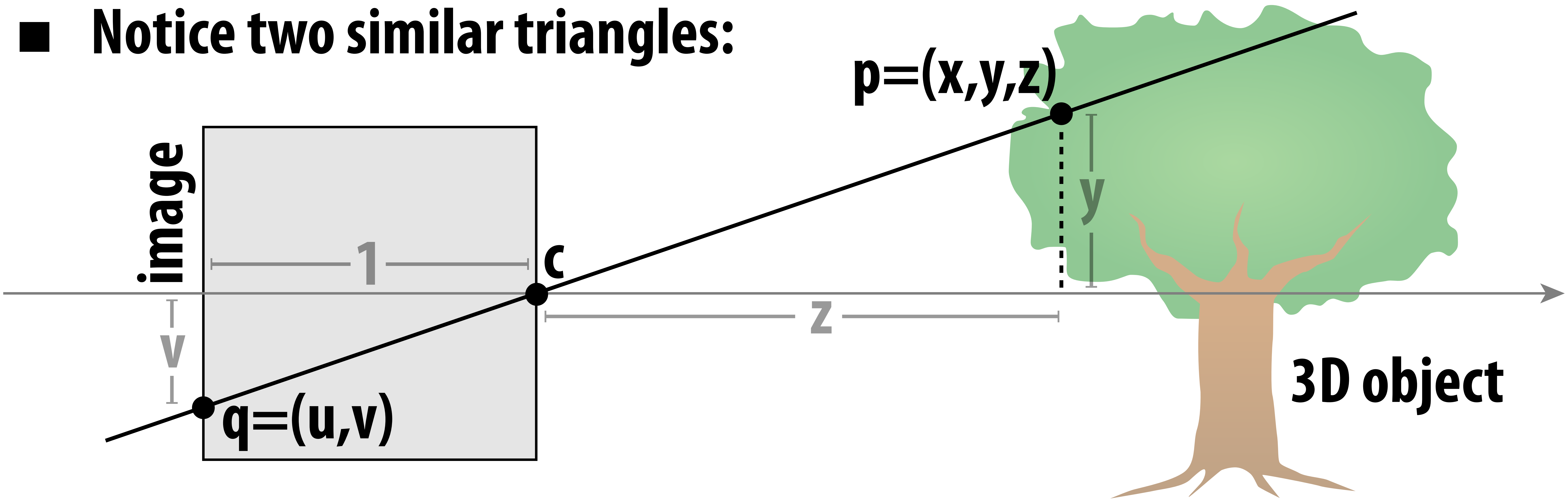
Perspective projection: side view

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



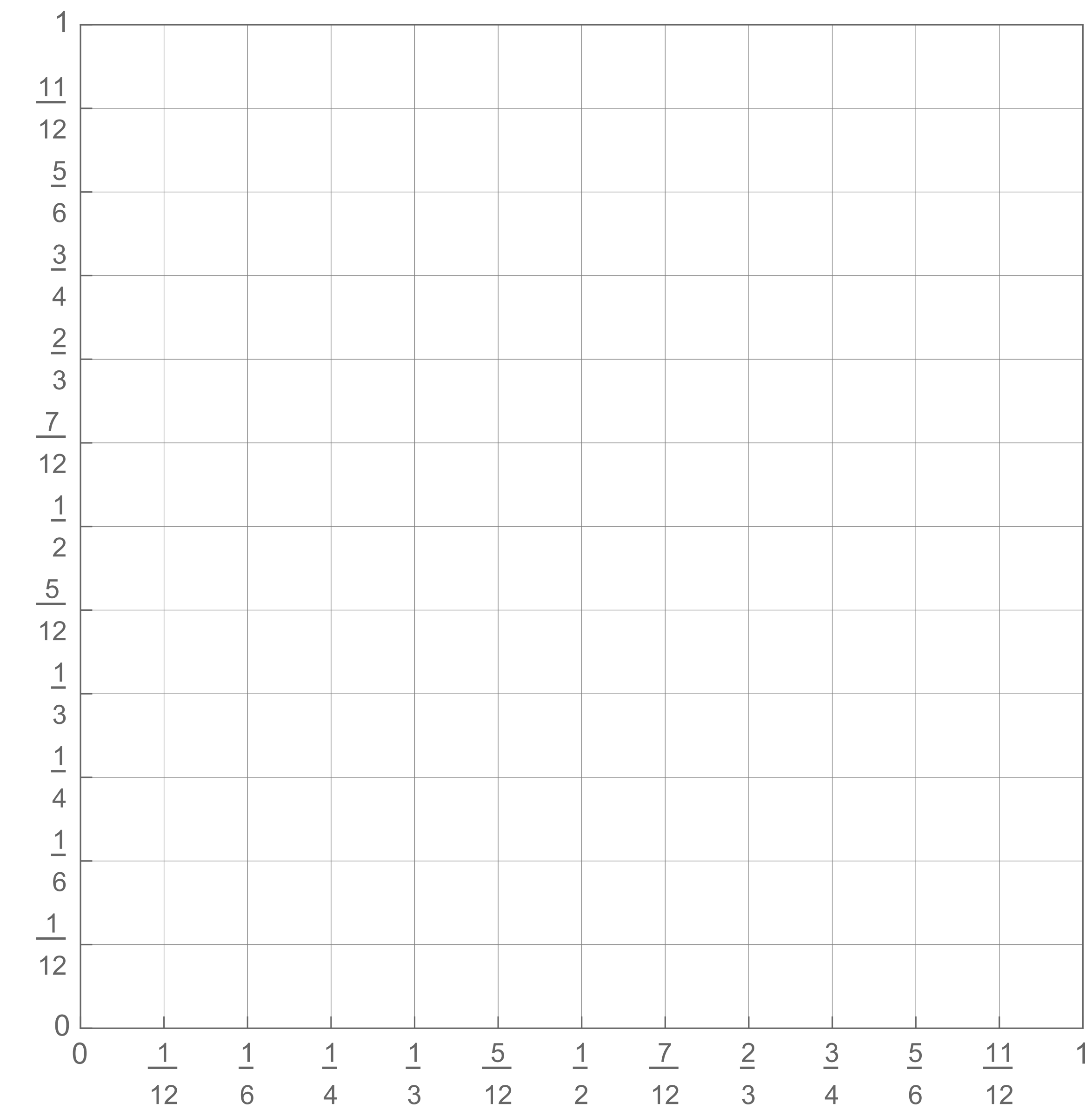
Perspective projection: side view

- 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

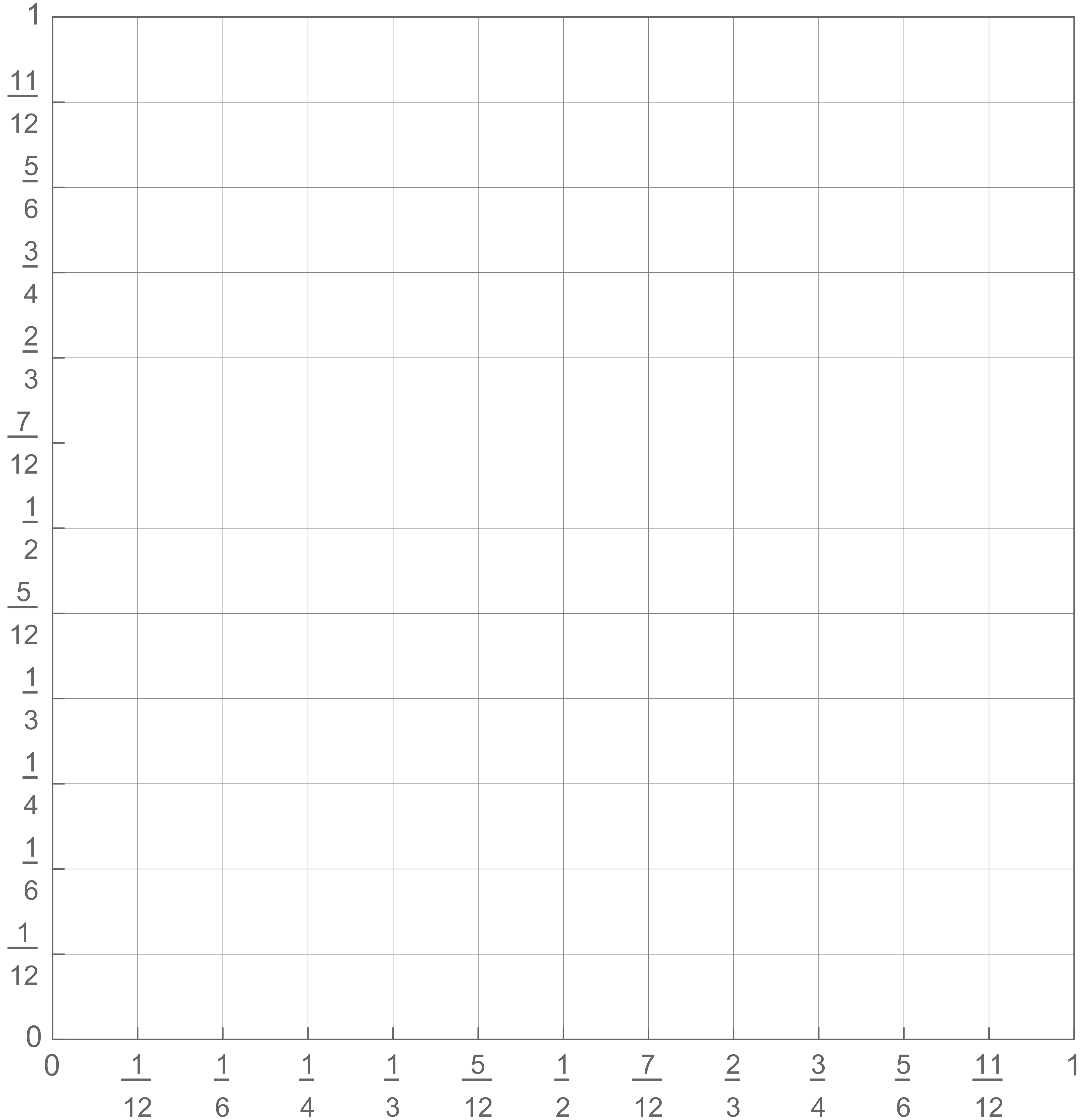
ACTIVITY: now draw it!



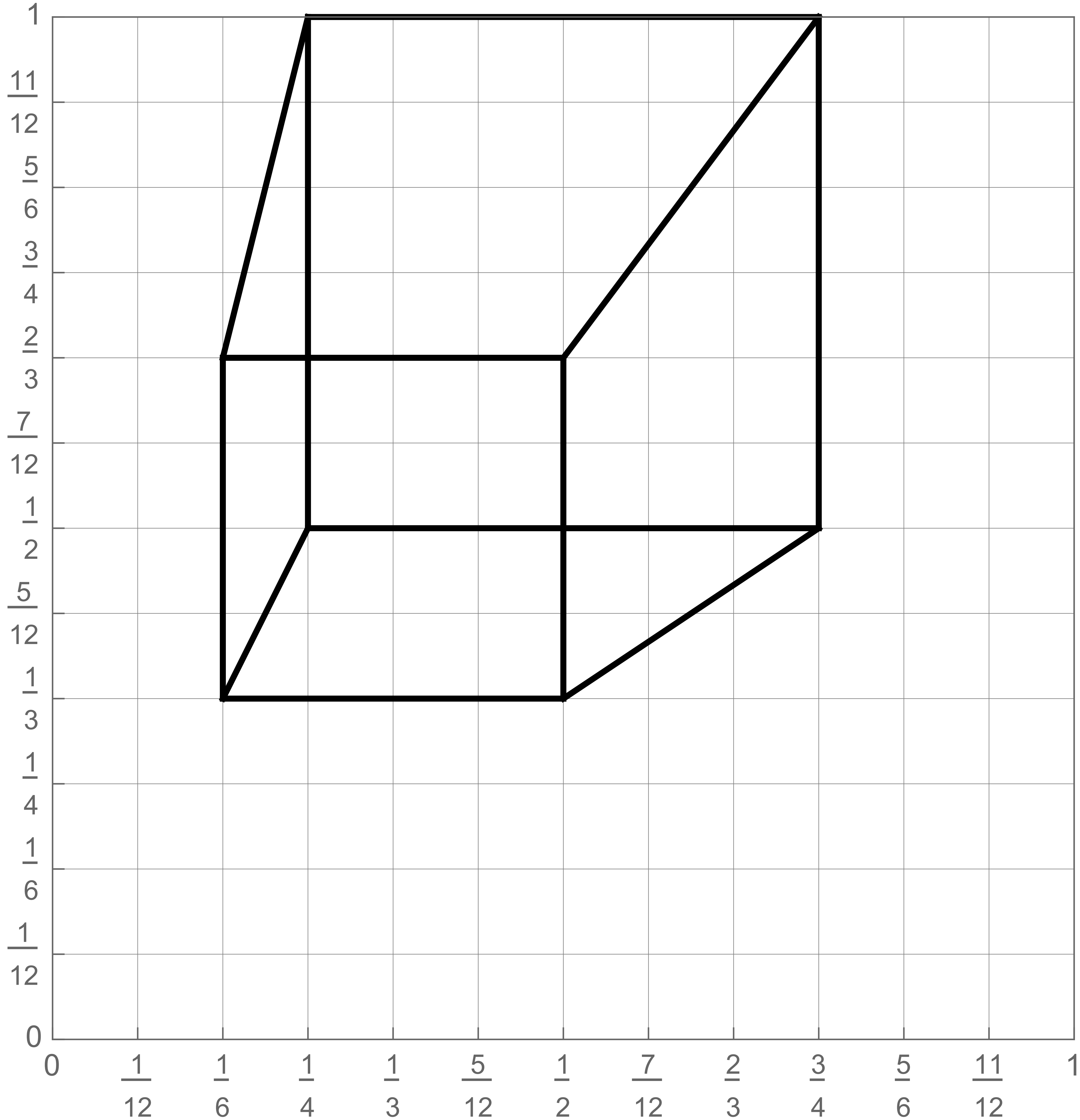
- **Repeat the same simple algorithm 12 times**
  - **Once for each edge**
  - **Assume camera is at c=(2,3,5)**
  - **Convert (X,Y,Z) of both endpoints to (u,v):**
    1. **subtract camera c from vertex (X,Y,Z) to get (x,y,z)**
    2. **divide (x,y) by z to get (u,v)—*write as a fraction***
  - **Draw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



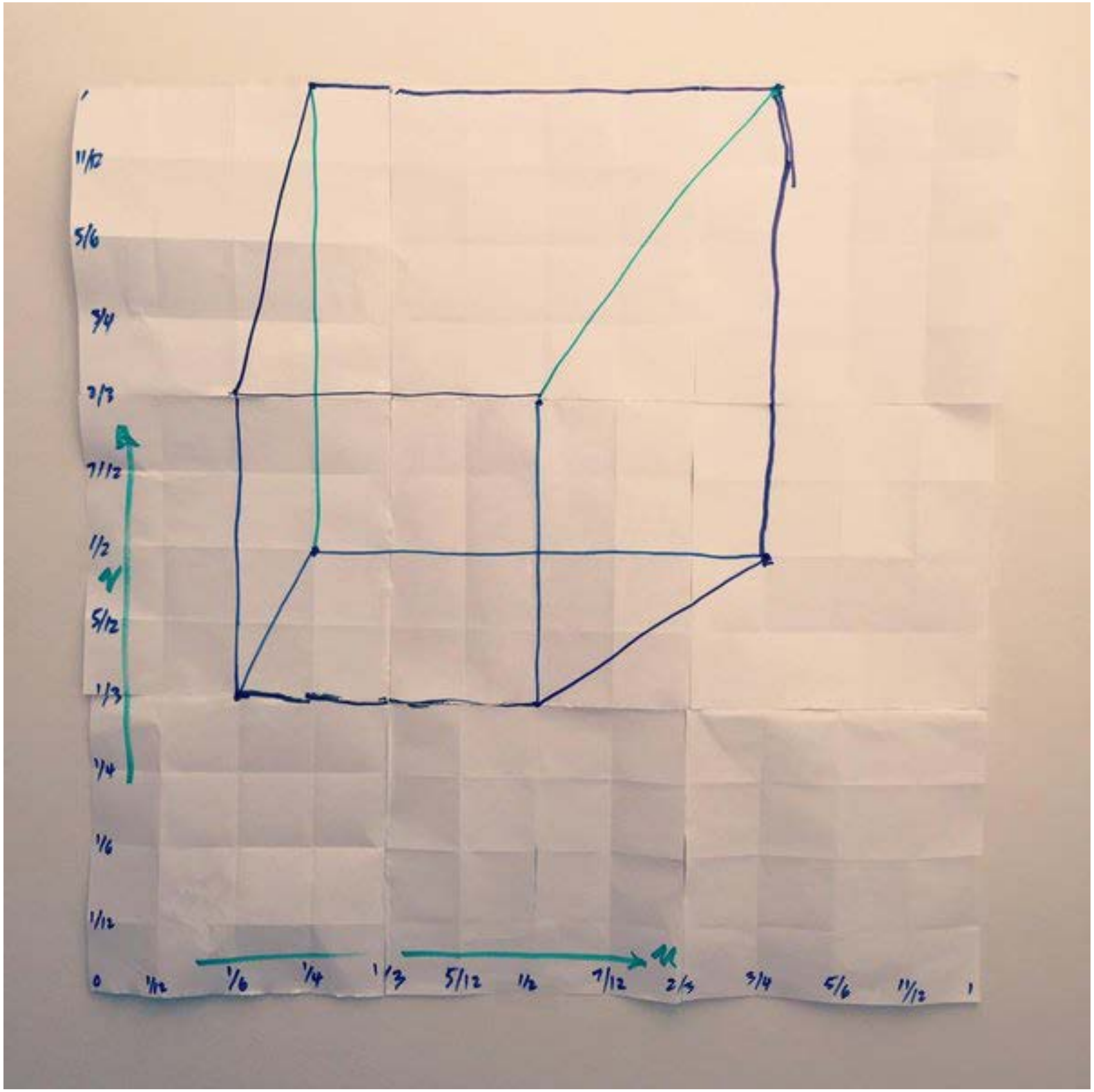
ACTIVITY: How did you do?



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 digital information into purely visual information, using a completely algorithmic procedure.

digital information

computation →

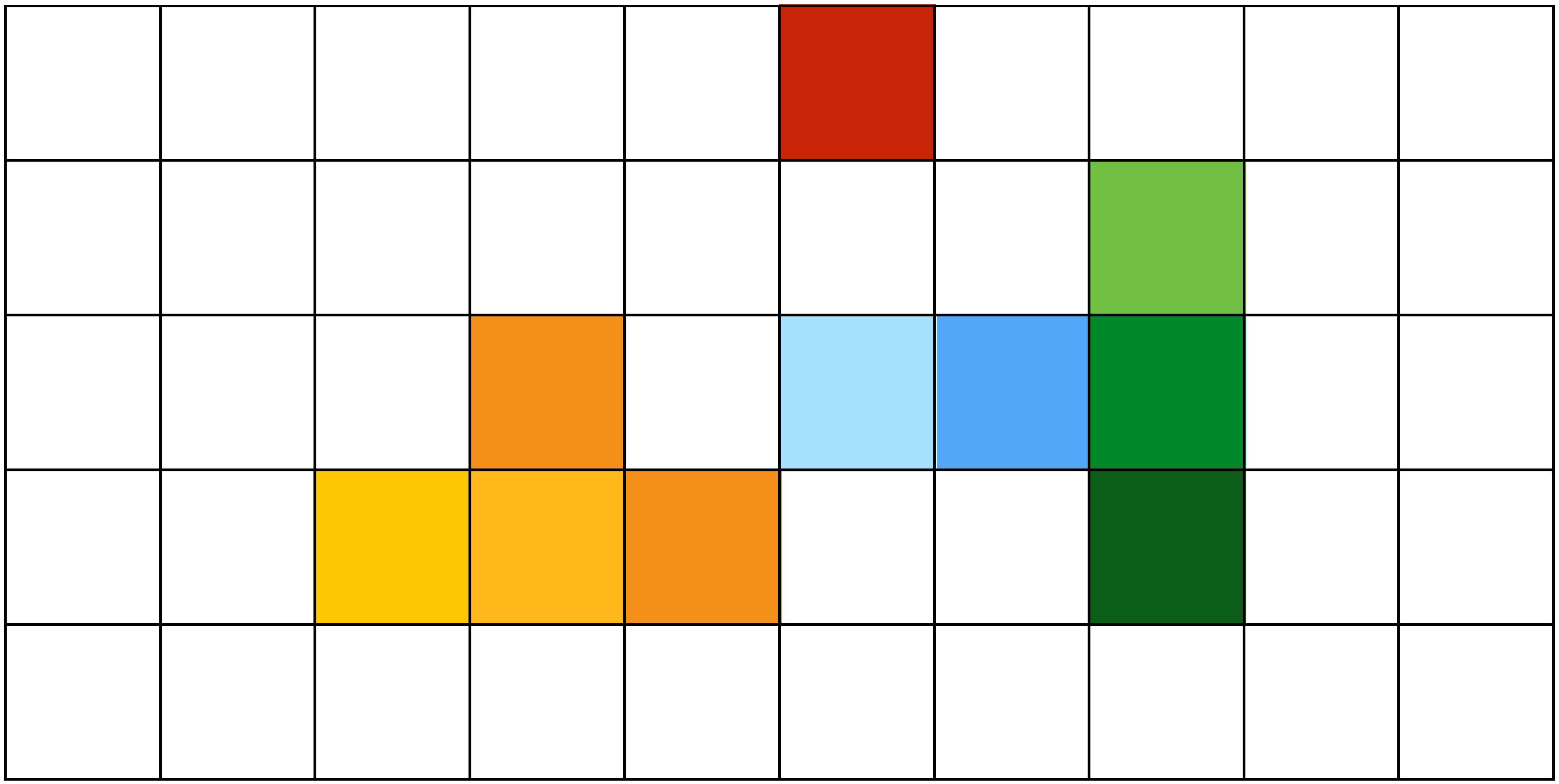
visual information

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

Close up photo of pixels on a modern display

Output for a raster display

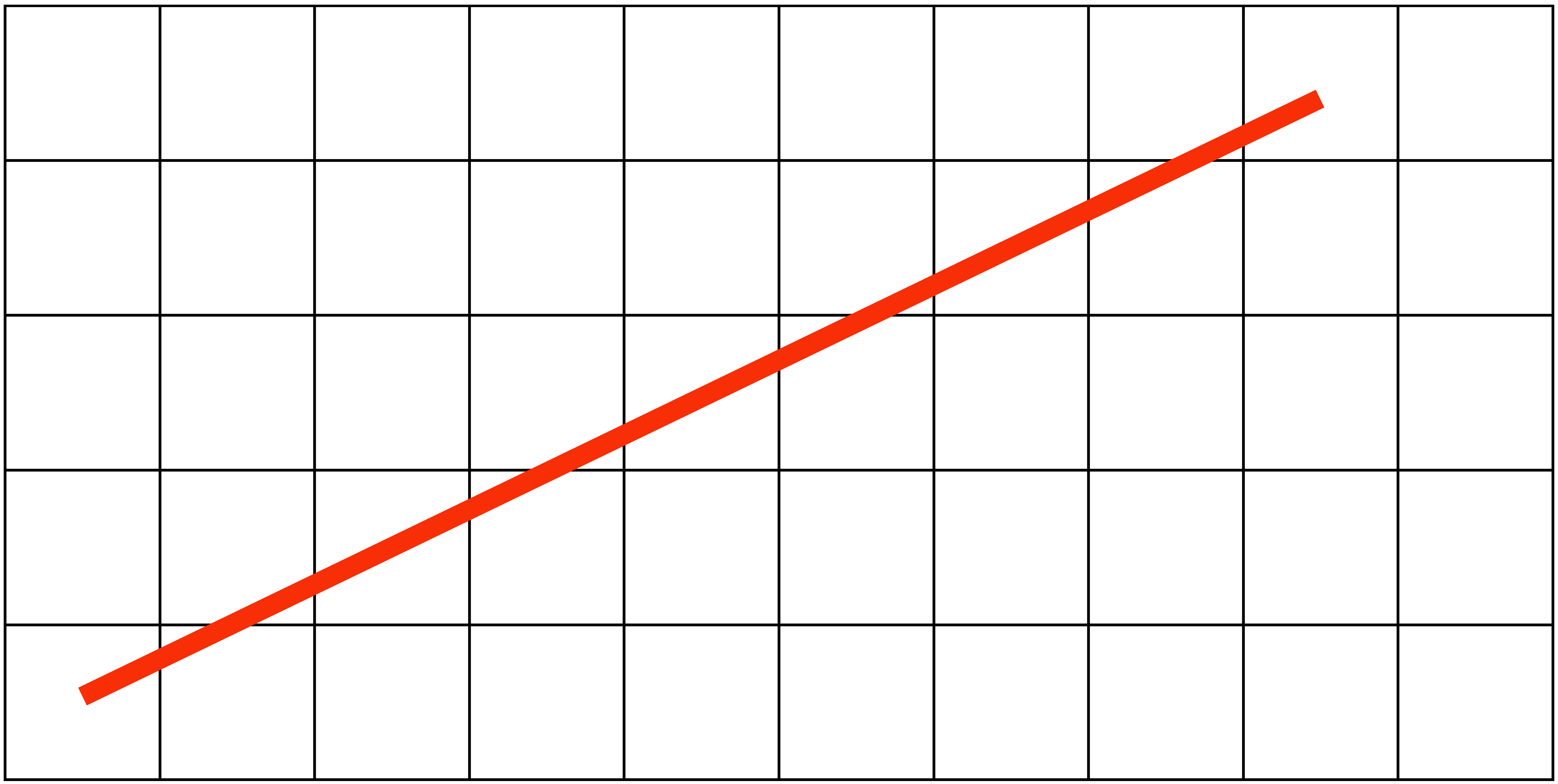
- **Common abstraction of a raster display:**
  - **Image represented as a 2D grid of "pixels" (picture elements) ****
  - **Each pixel can can take on a unique color value**



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

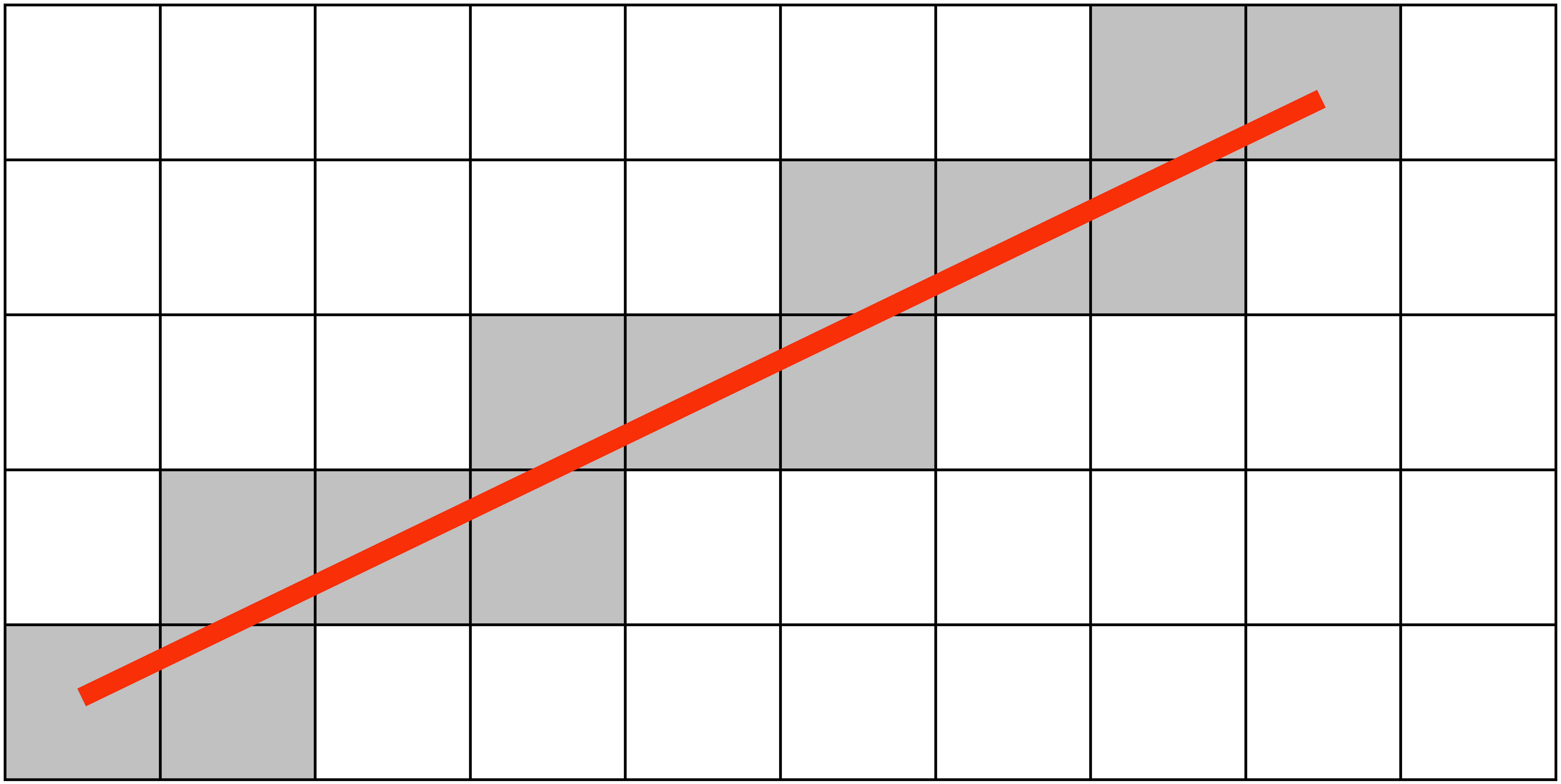
What pixels should we color in to depict a line?

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



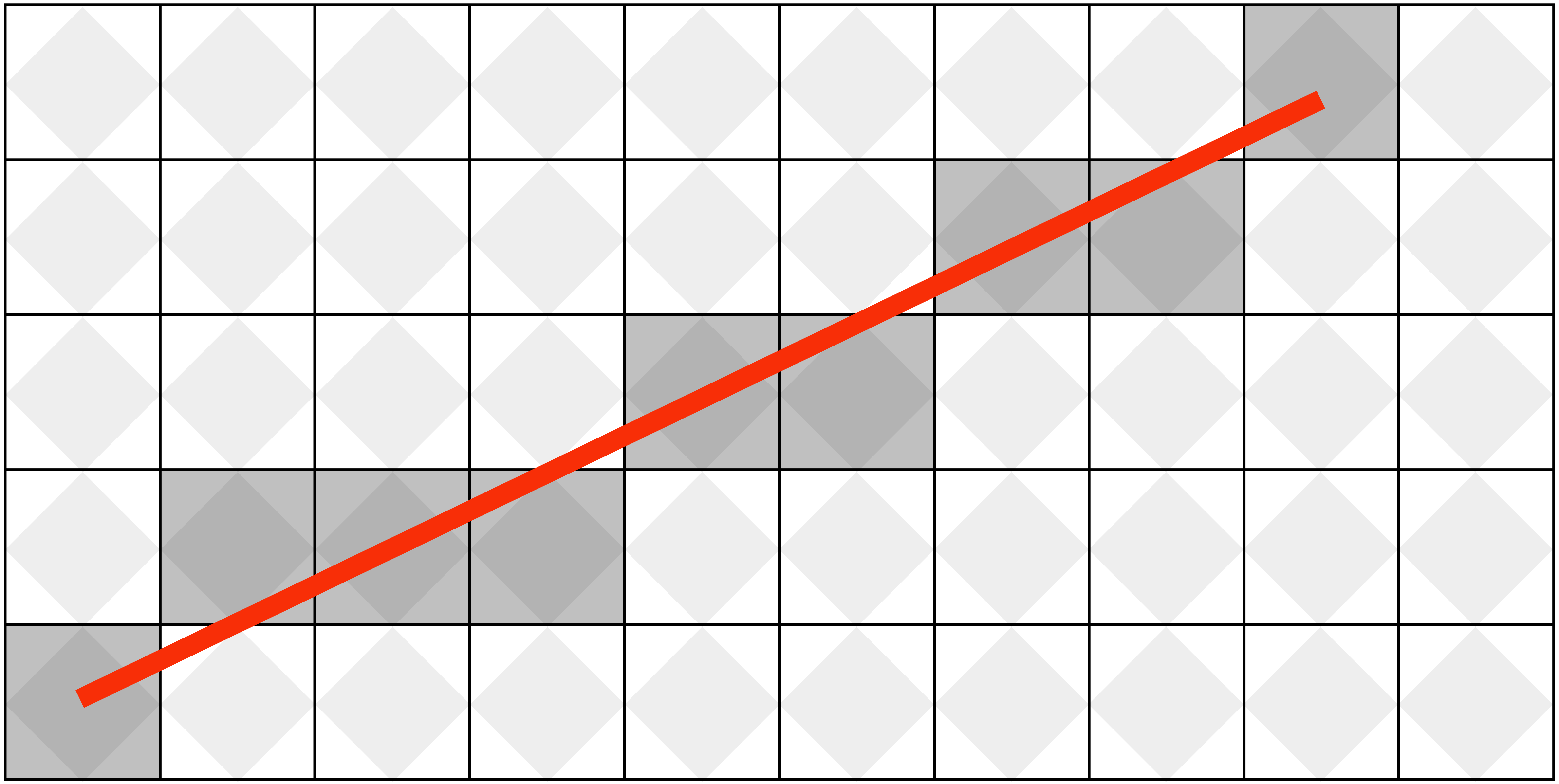
What pixels should we color in to depict a line?

Light up all pixels intersected by the line?



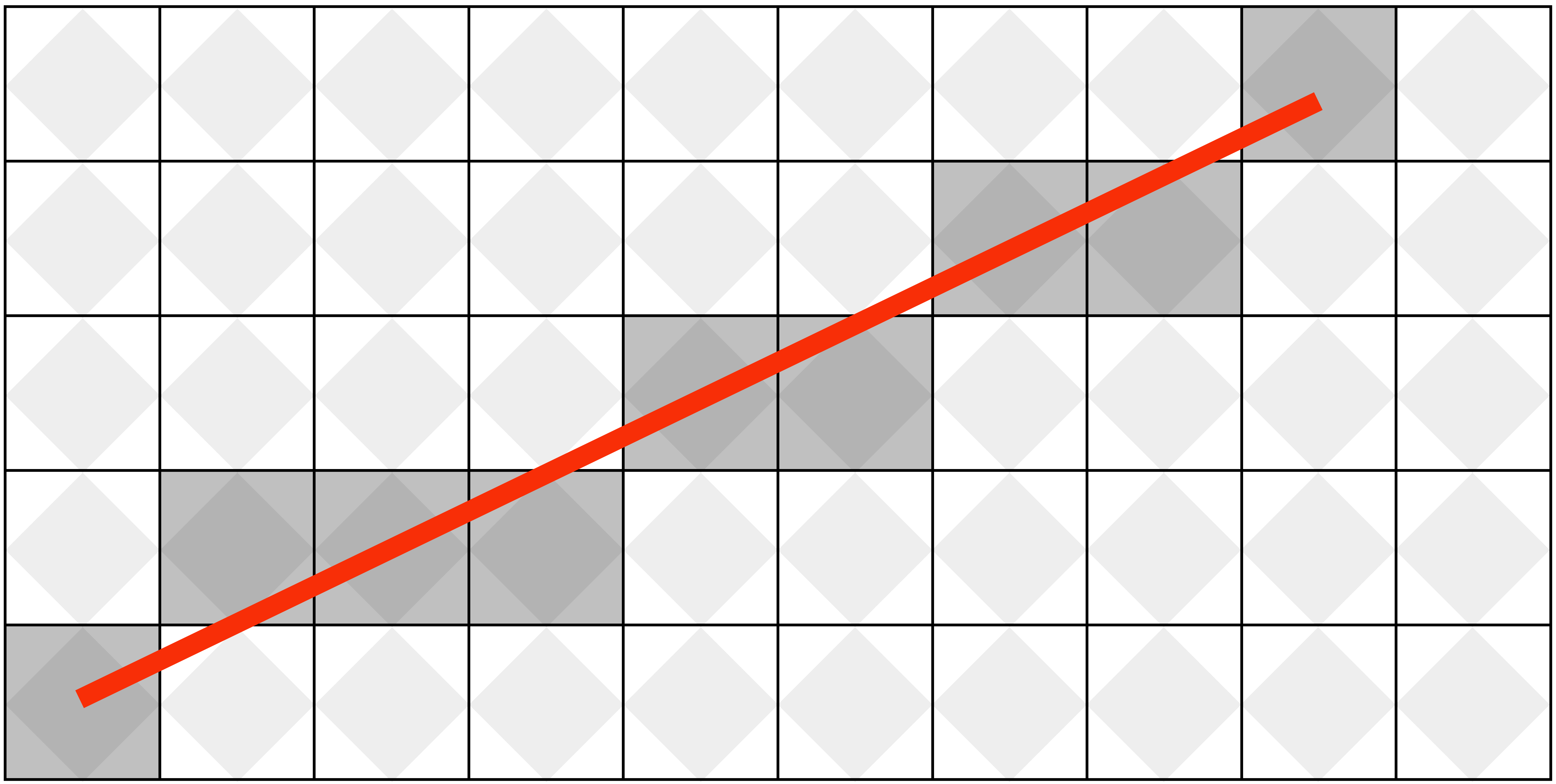
What pixels should we color in to depict a line?

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)



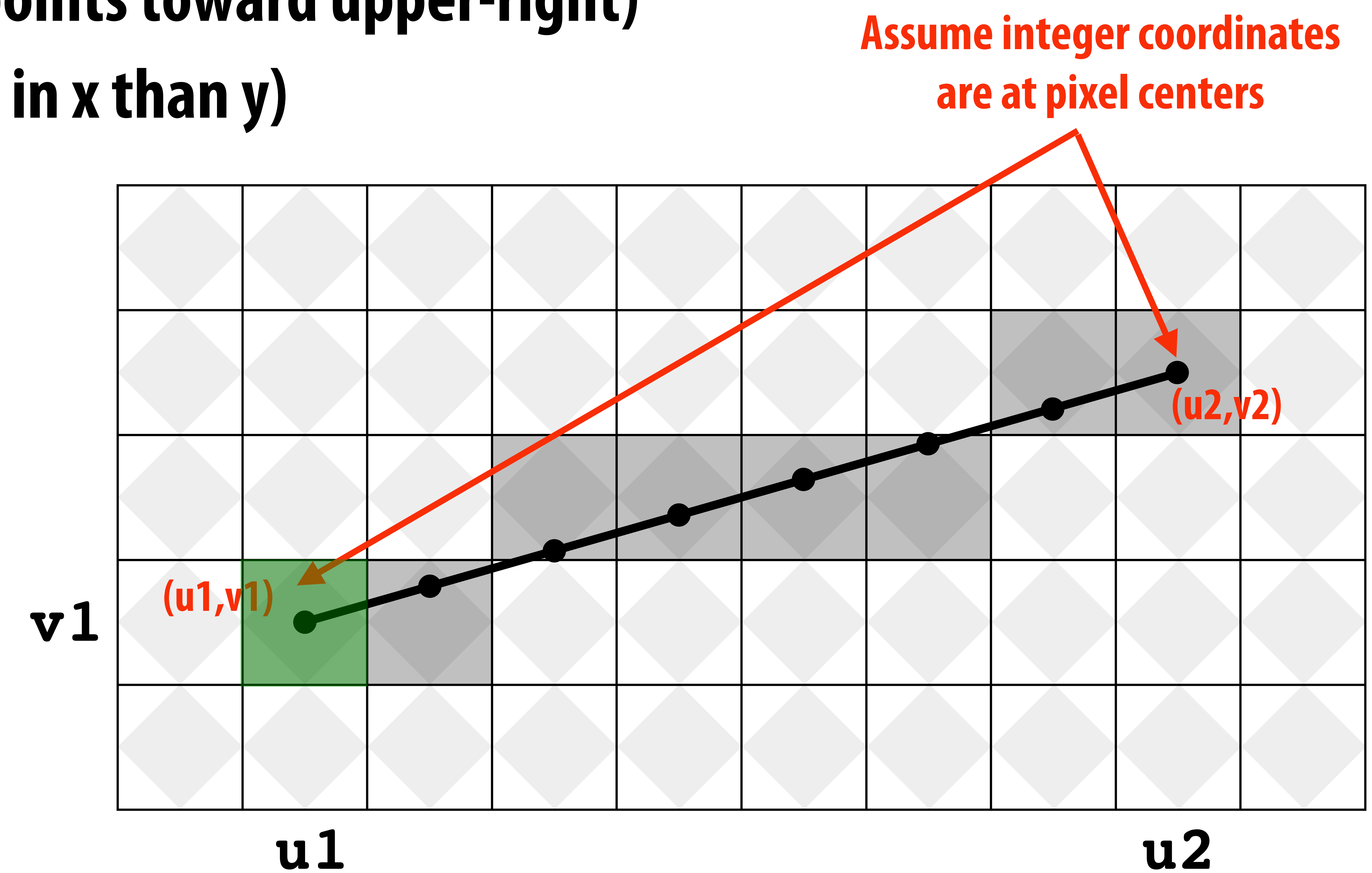
How do we find the pixels satisfying a chosen rasterization rule?

- **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… not how lines are drawn in modern software/hardware!

We now have our first complete graphics algorithm!

Digital information

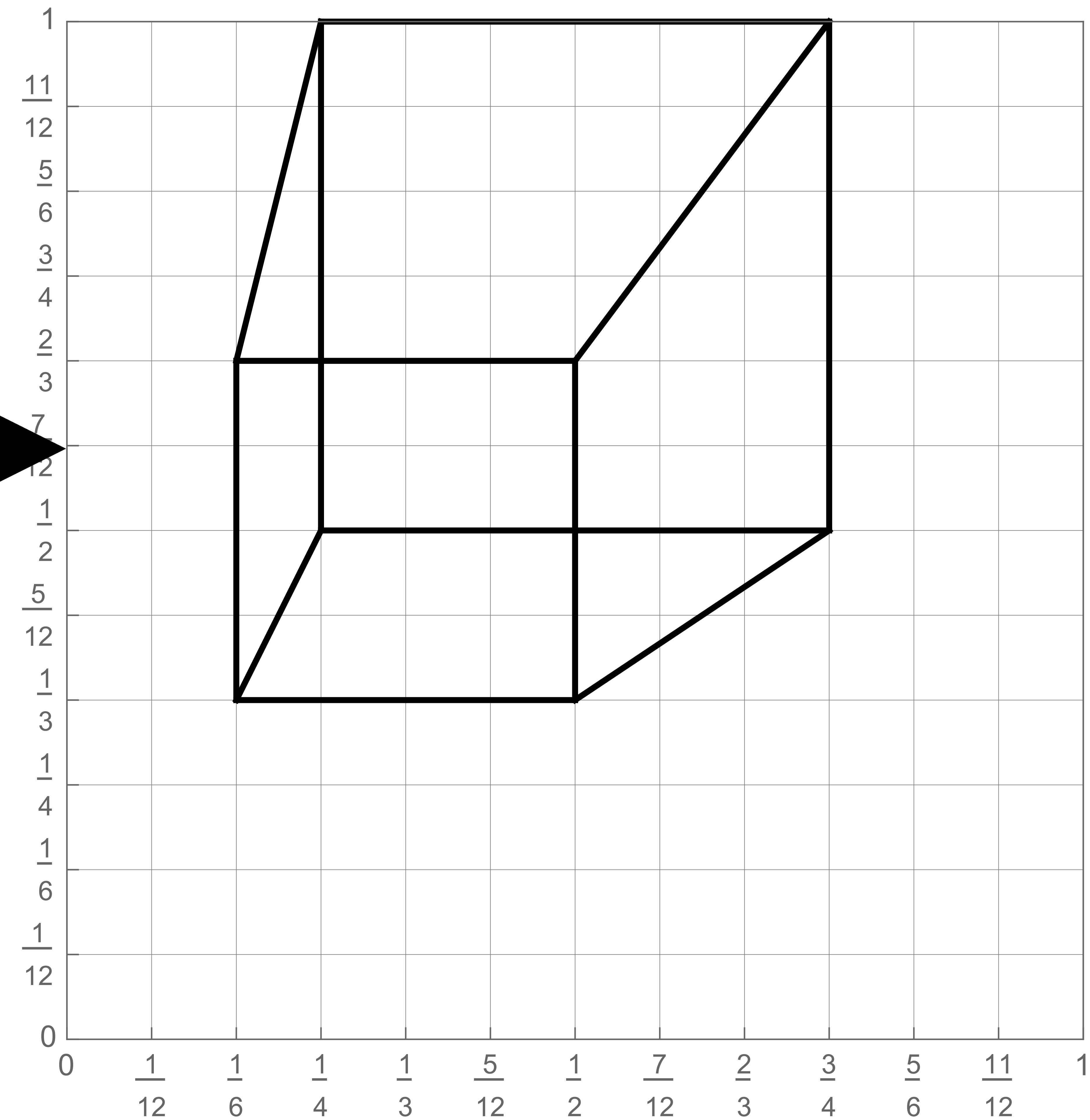
```
VERTICES
A: ( 1, 1, 1 )
B: (-1, 1, 1 )
C: ( 1,-1, 1 )
D: (-1,-1, 1 )
E: ( 1, 1,-1 )
F: (-1, 1,-1 )
G: ( 1,-1,-1 )
H: (-1,-1,-1 )

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 *much* richer model of the world:

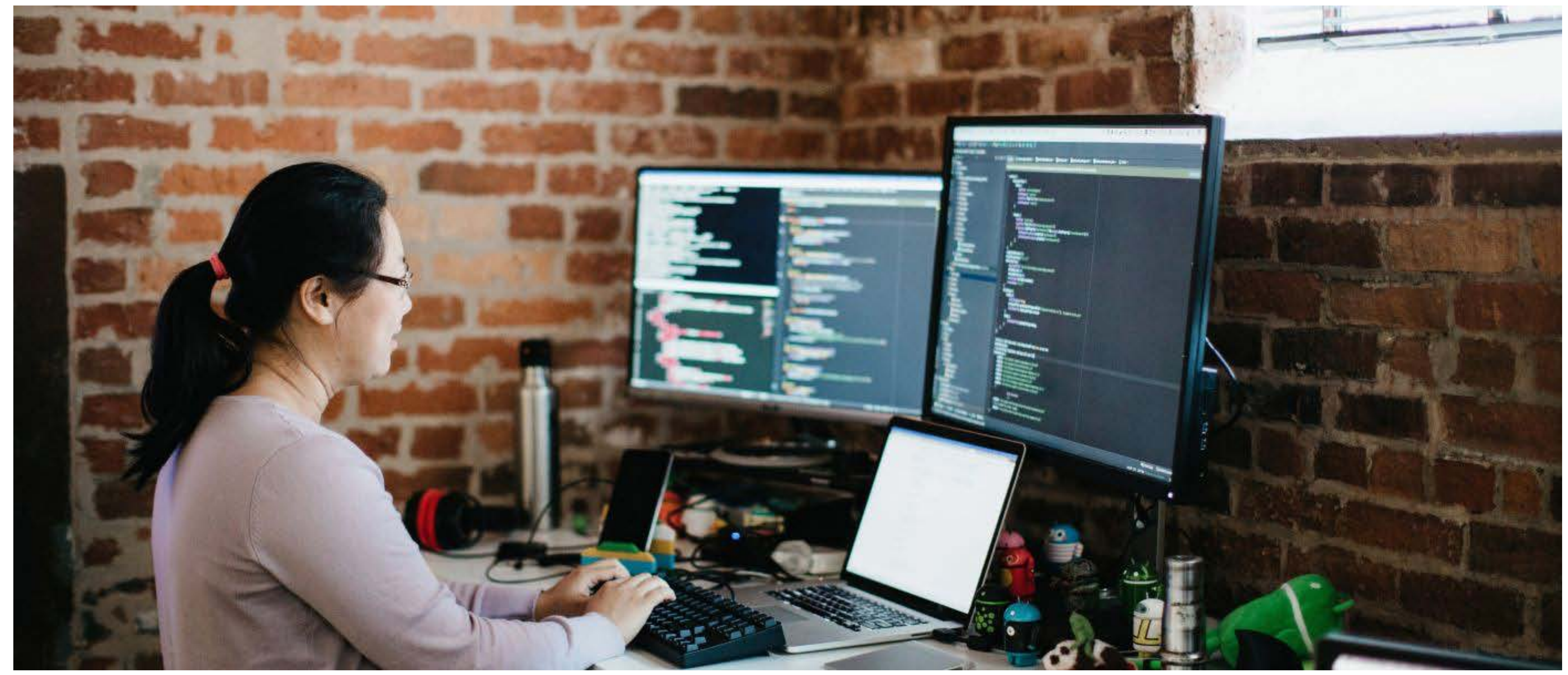
GEOMETRY
MATERIALS
LIGHTS
CAMERAS
MOTION
...

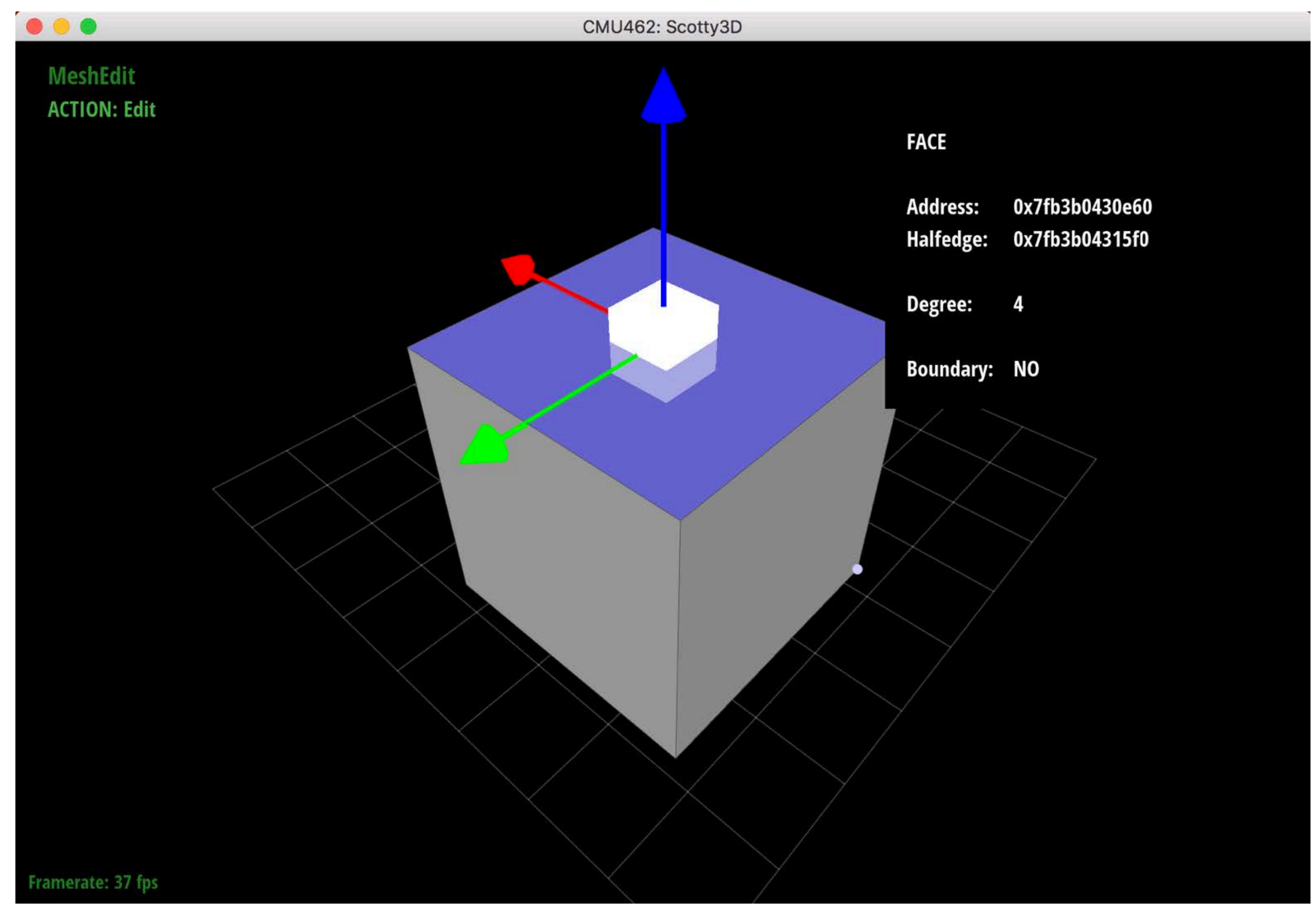
Will see all of this (and more!) as our course progresses.

Learn by making/doing!

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

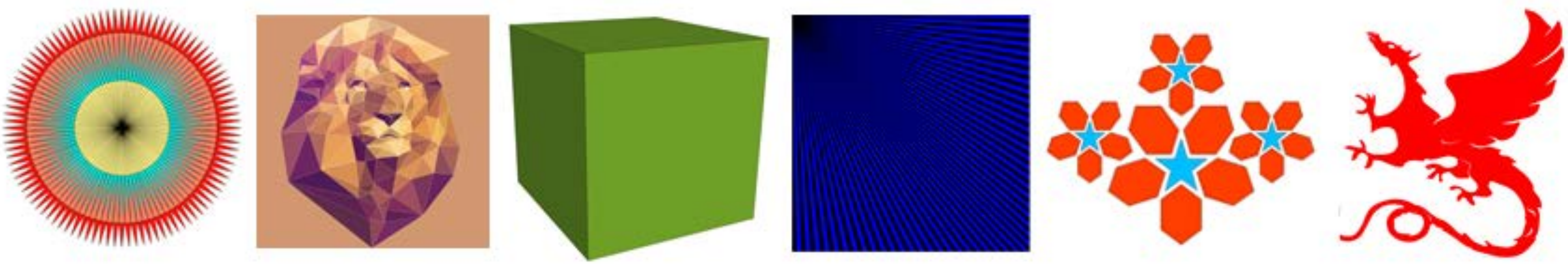
Scotty3D



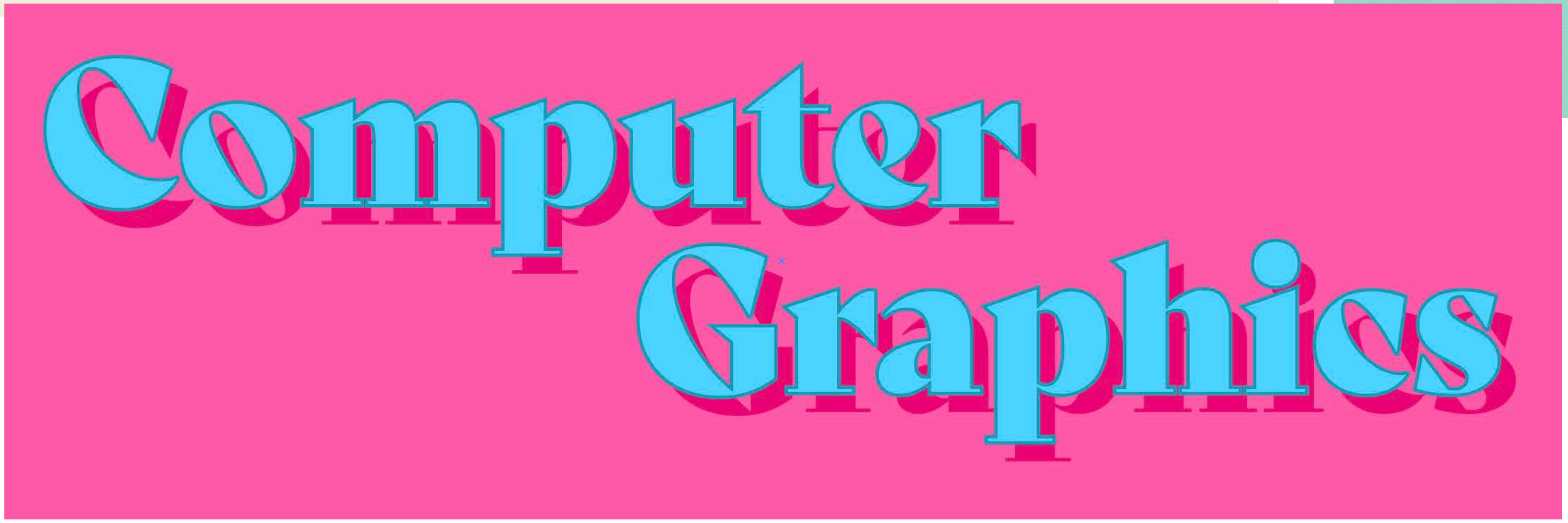


Broken up into four major assignments…

Assignment 1: Rasterization

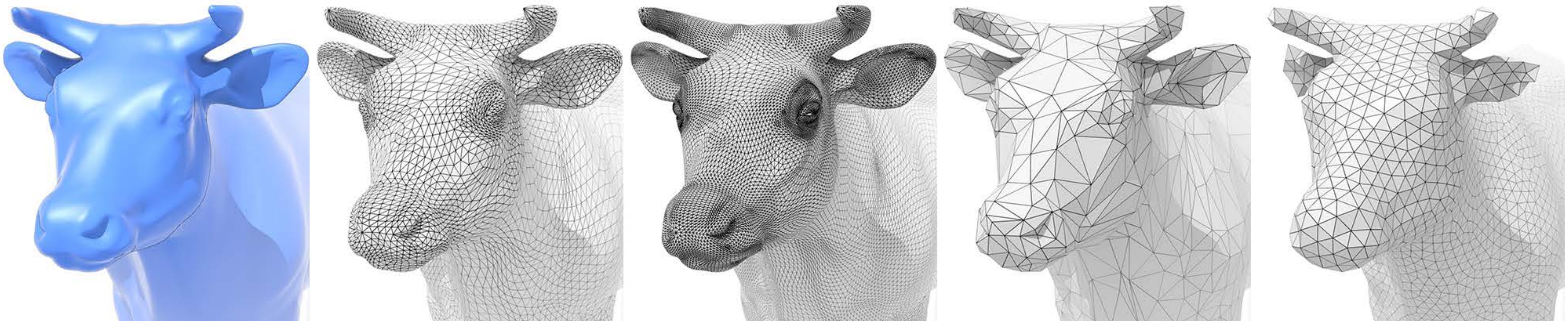


Motivation: display images like these!

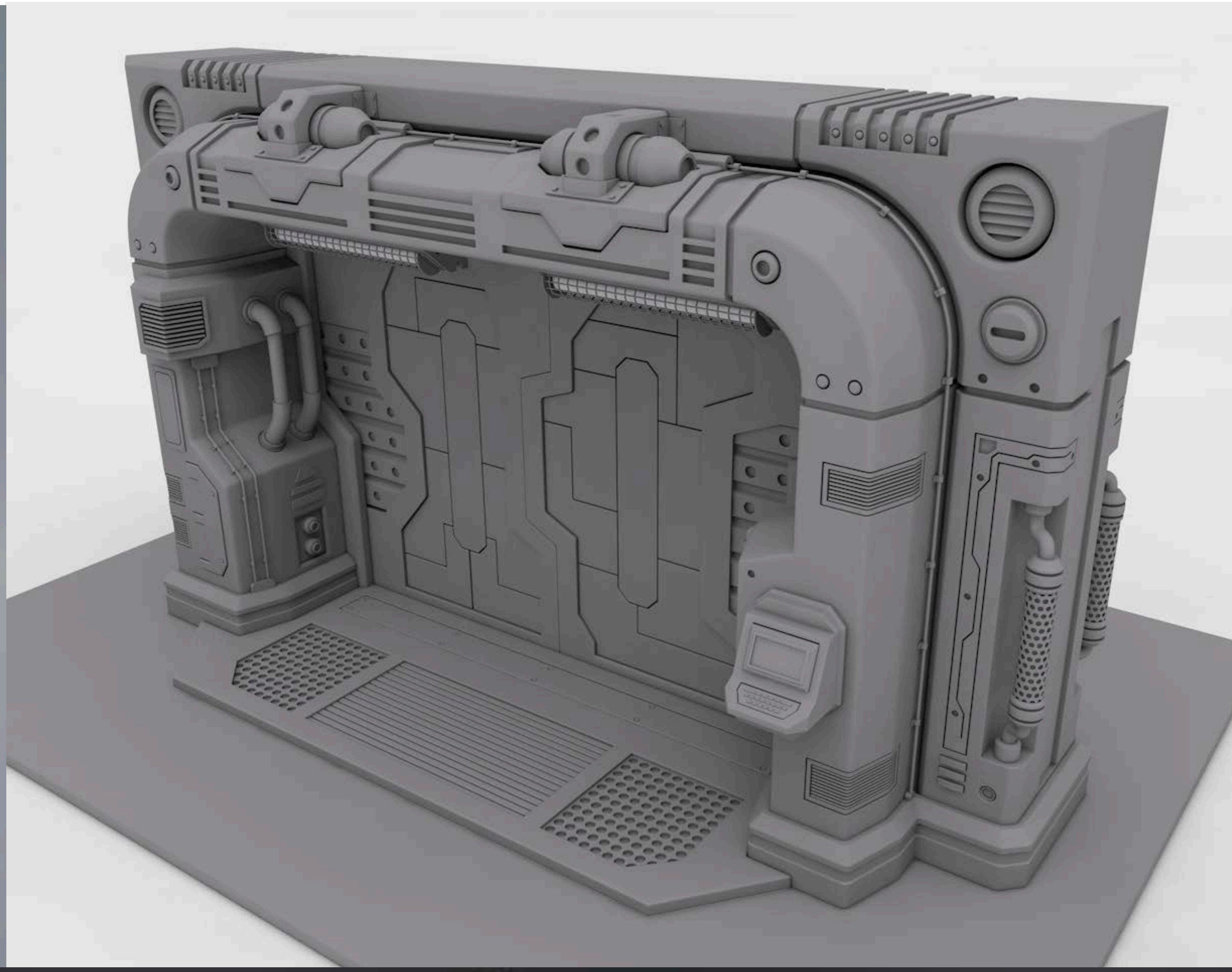


[sources: Charles Williams, @xlavoc on codepen.io]

Assignment 2: Geometric Modeling

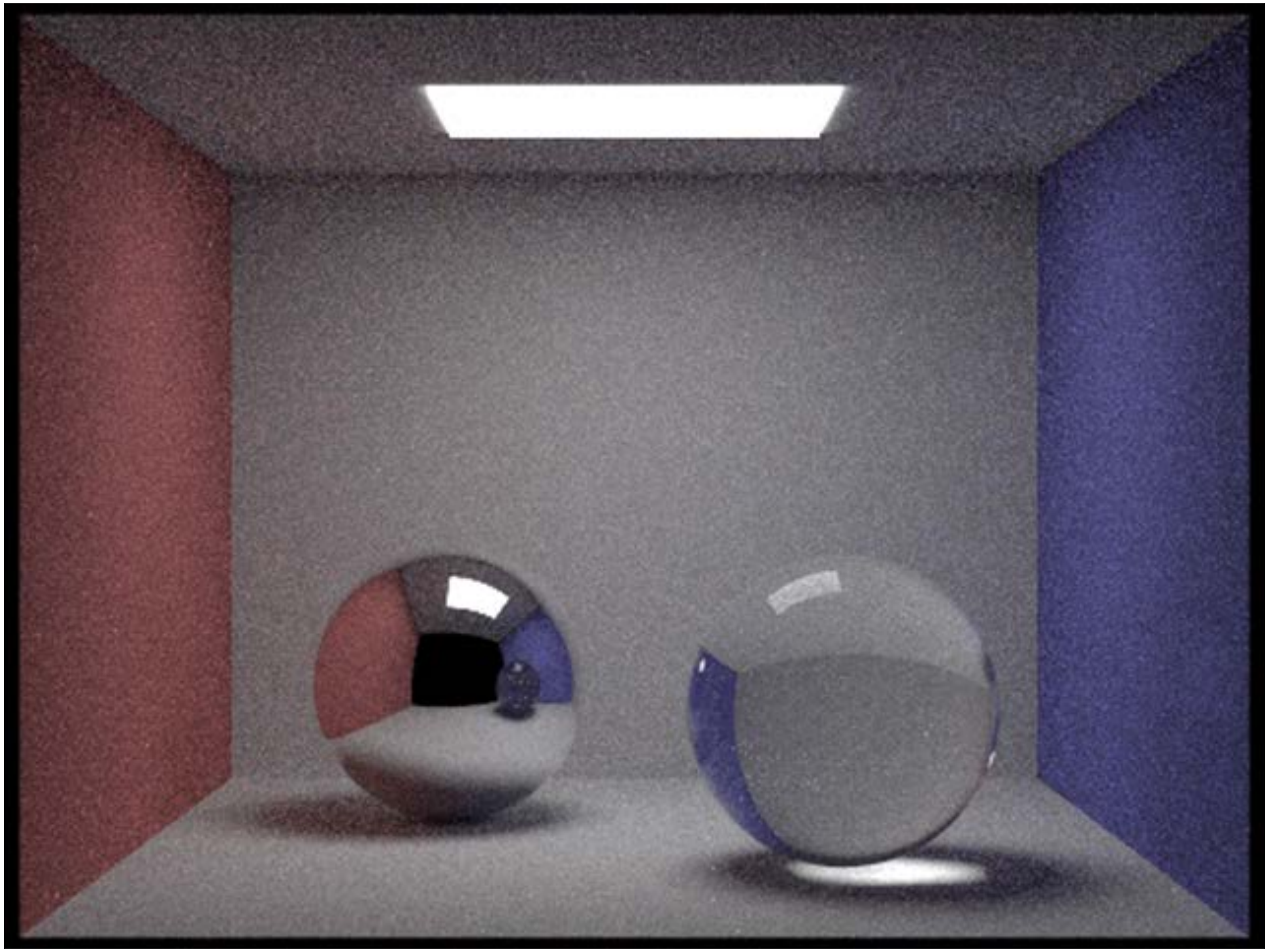


Motivation: create models like these!



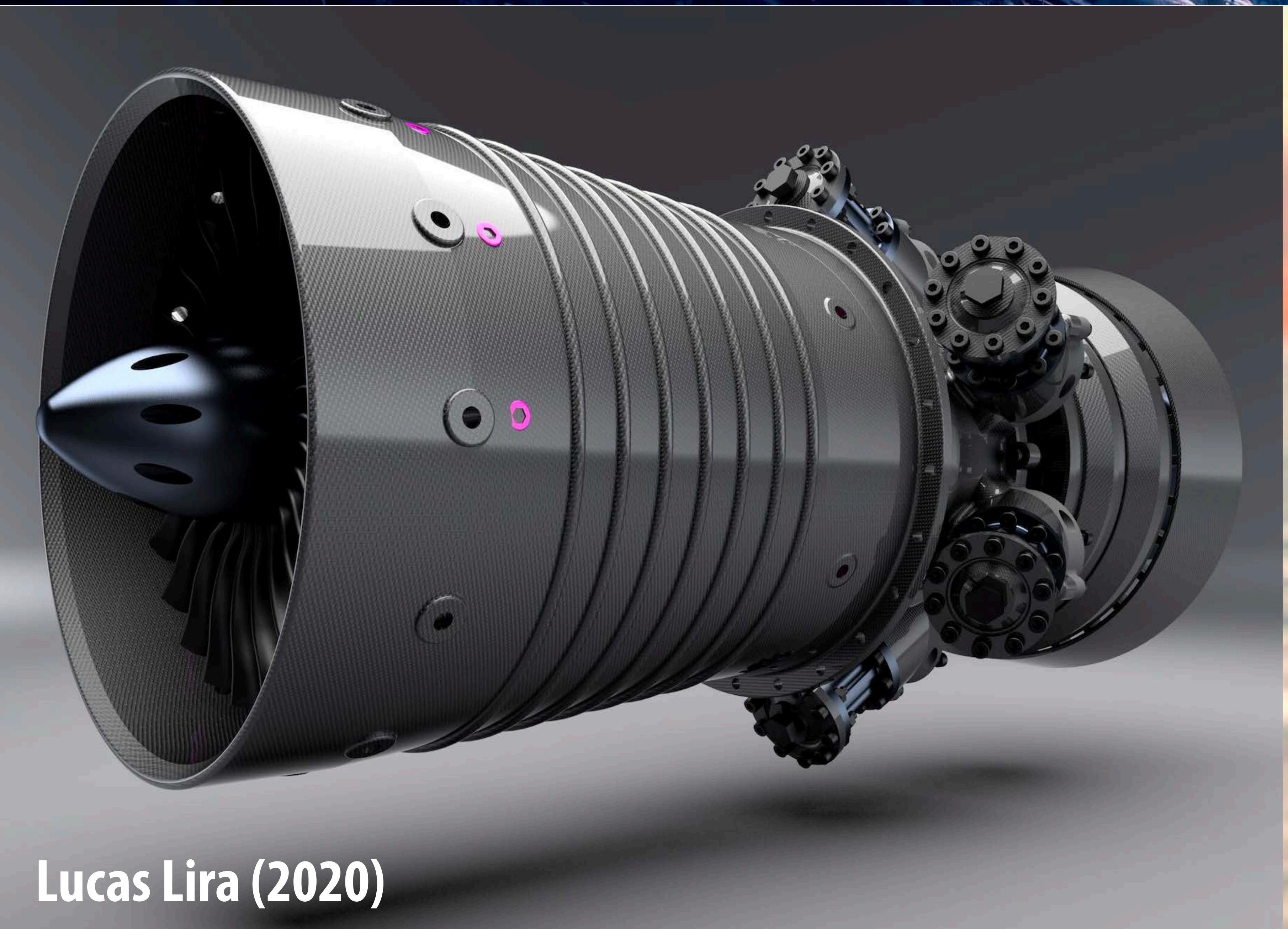
[sources: Richard Yot, 3D-Ace, contrafibbularities,3ddd.ru]

Assignment 3: Photorealistic Rendering



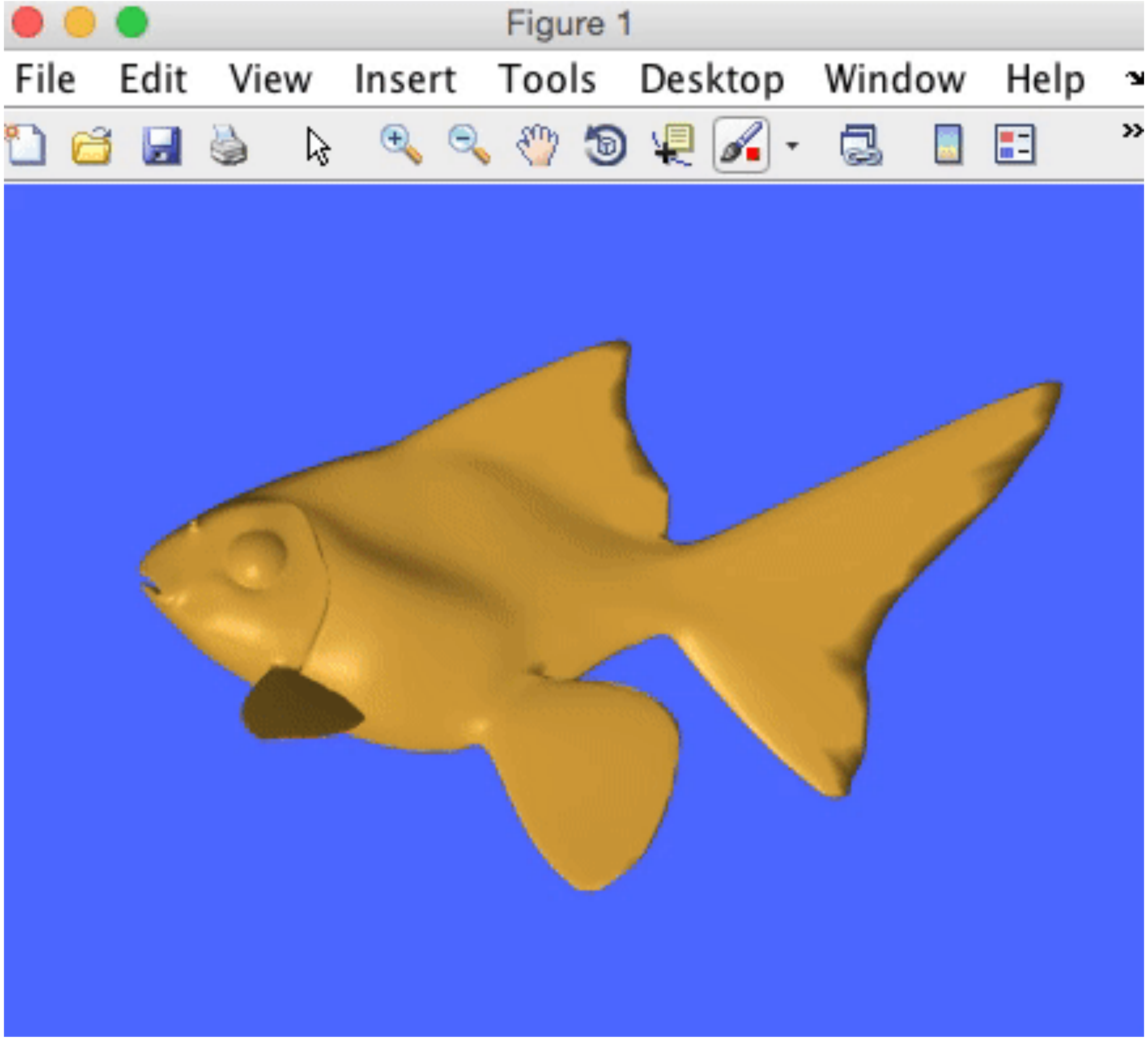
Motivation: render images like these!


WALL-E (Pixar 2009)


Lucas Lira (2020)

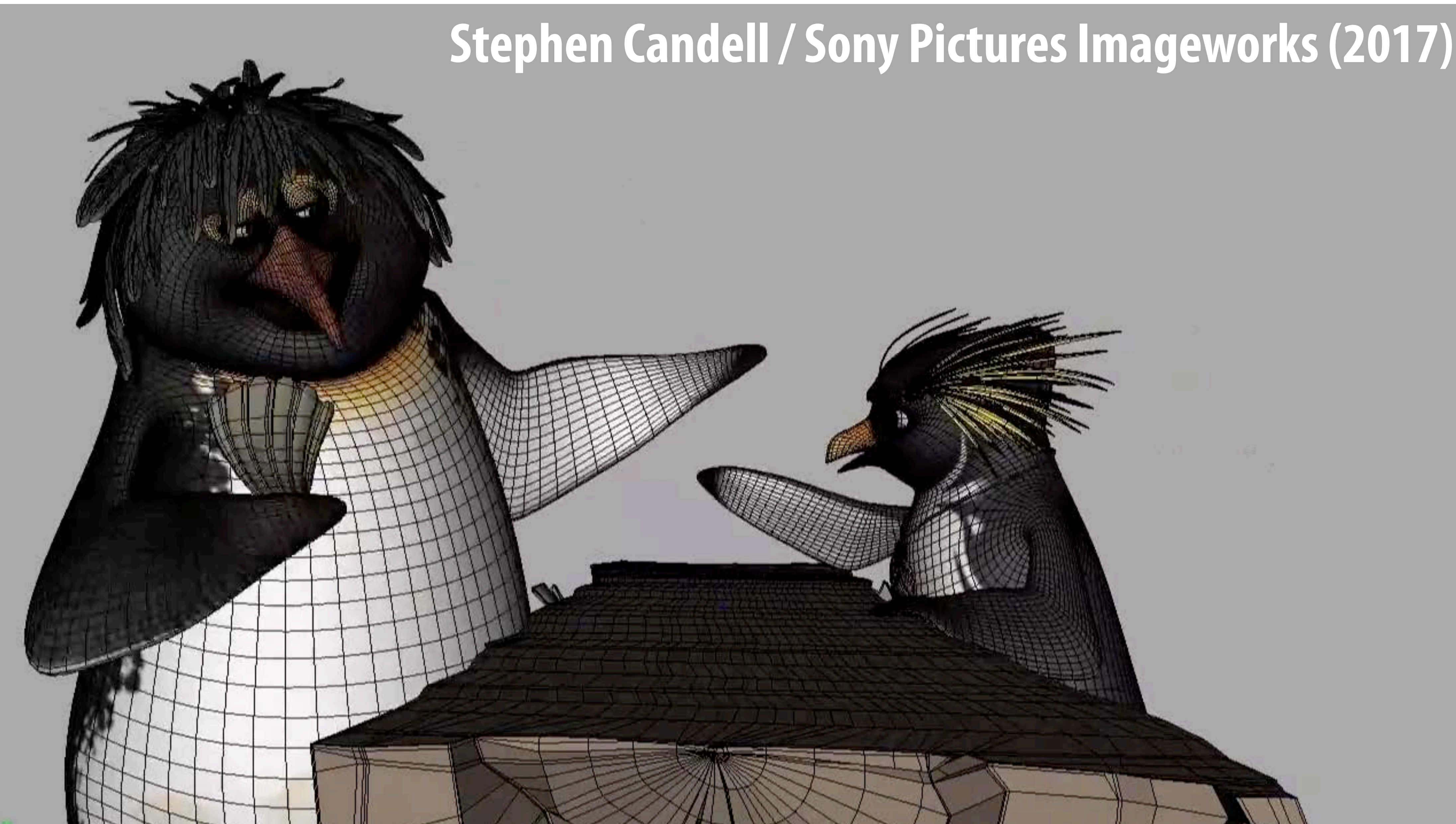

Moana (Disney 2016)

Assignment 4: Animation



(cribbed from Alec Jacobson)

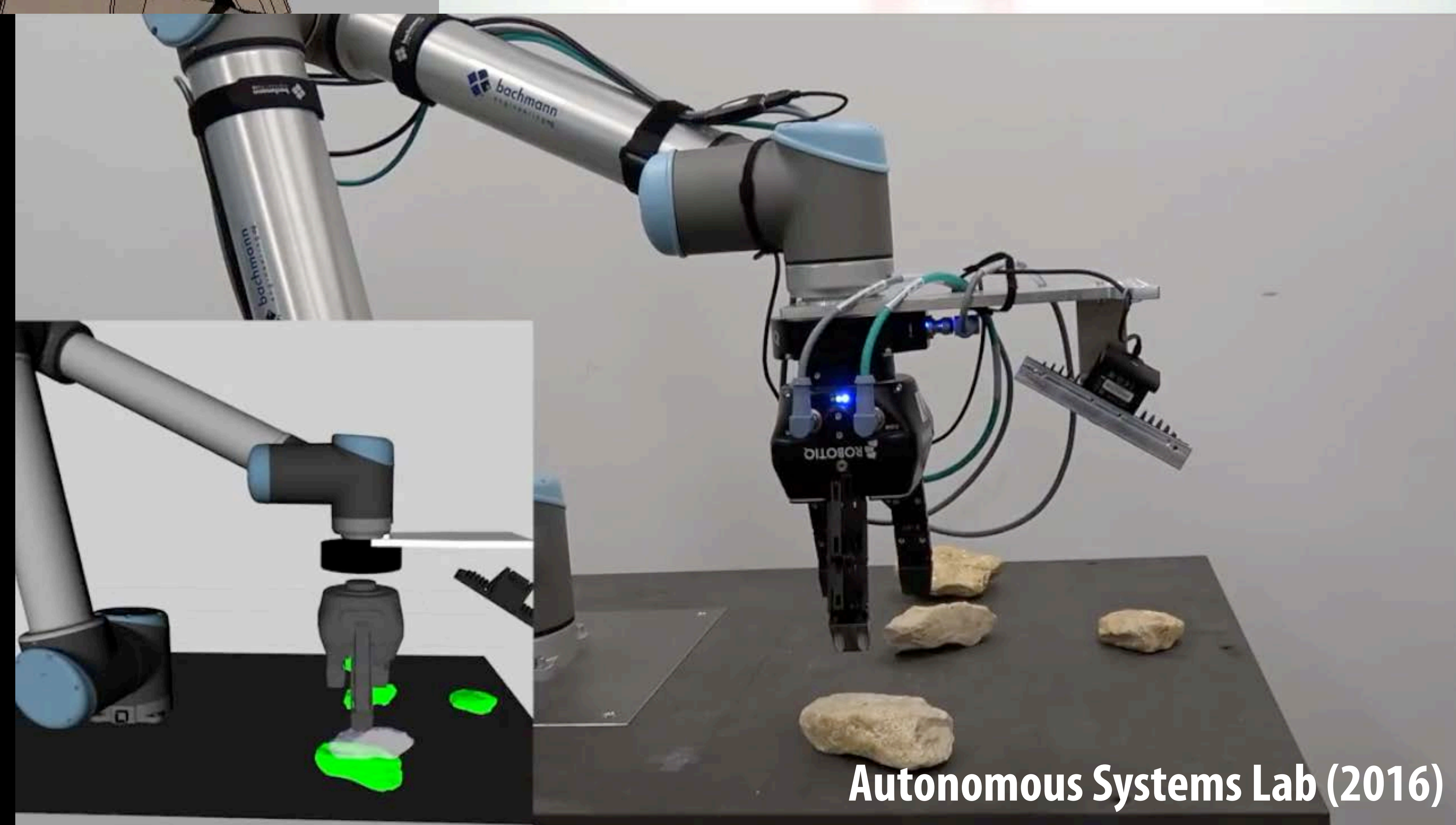
Motivation: make animations like these!



Stephen Candell / Sony Pictures Imageworks (2017)

Yans Media (2015)

Pixar (2016)



Autonomous Systems Lab (2016)

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!