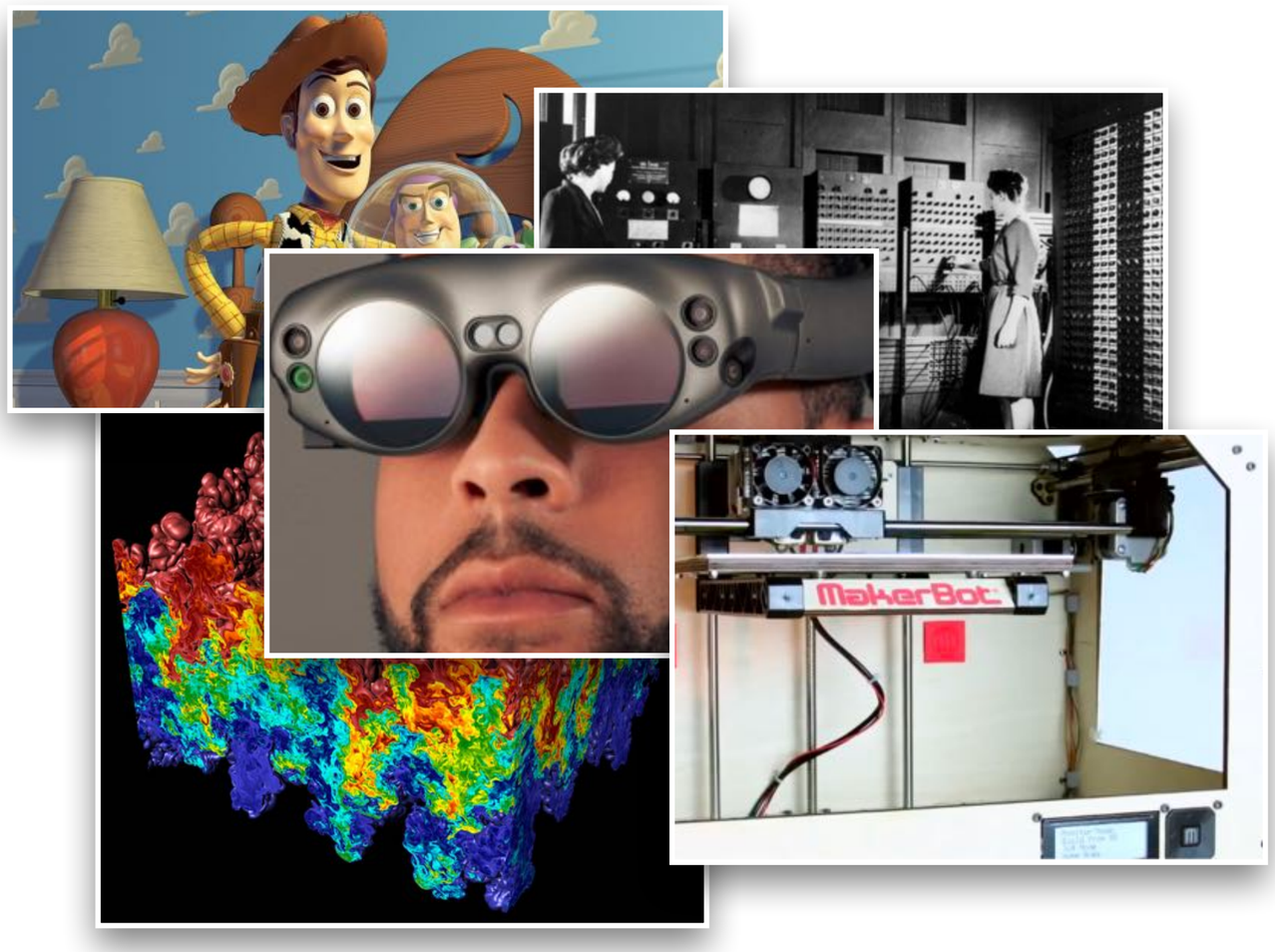
Lecture 1:

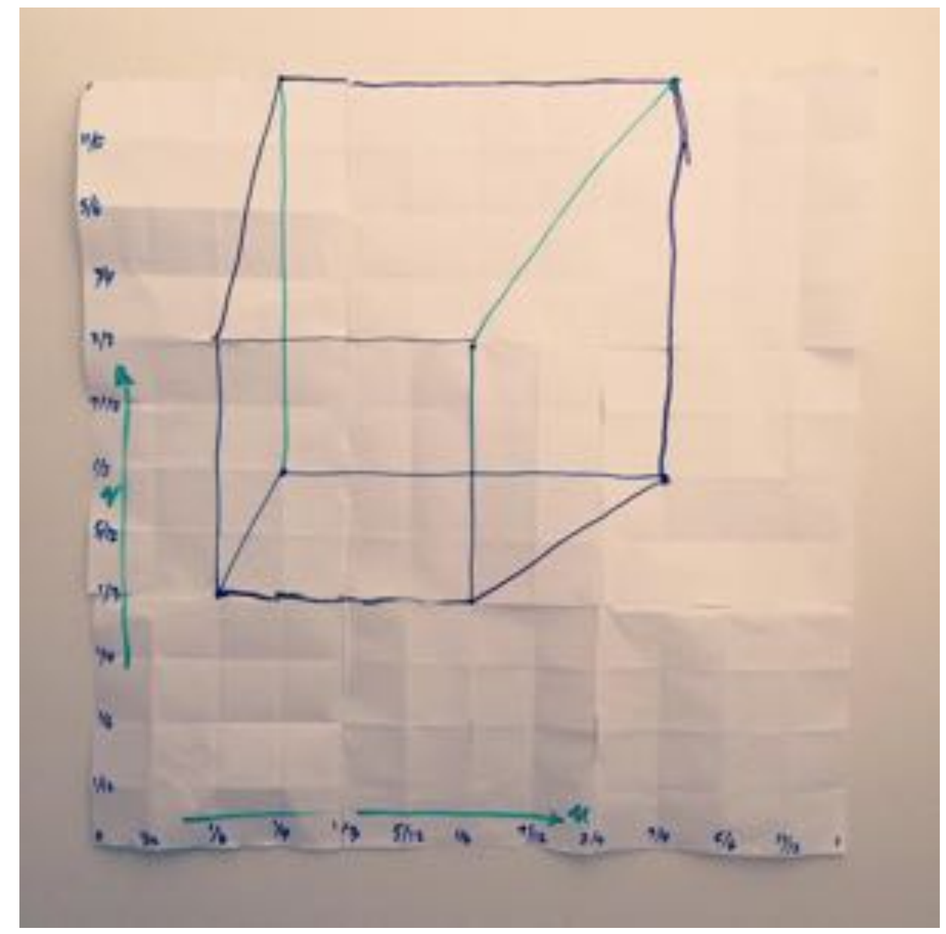
Course Intro: Overview

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**

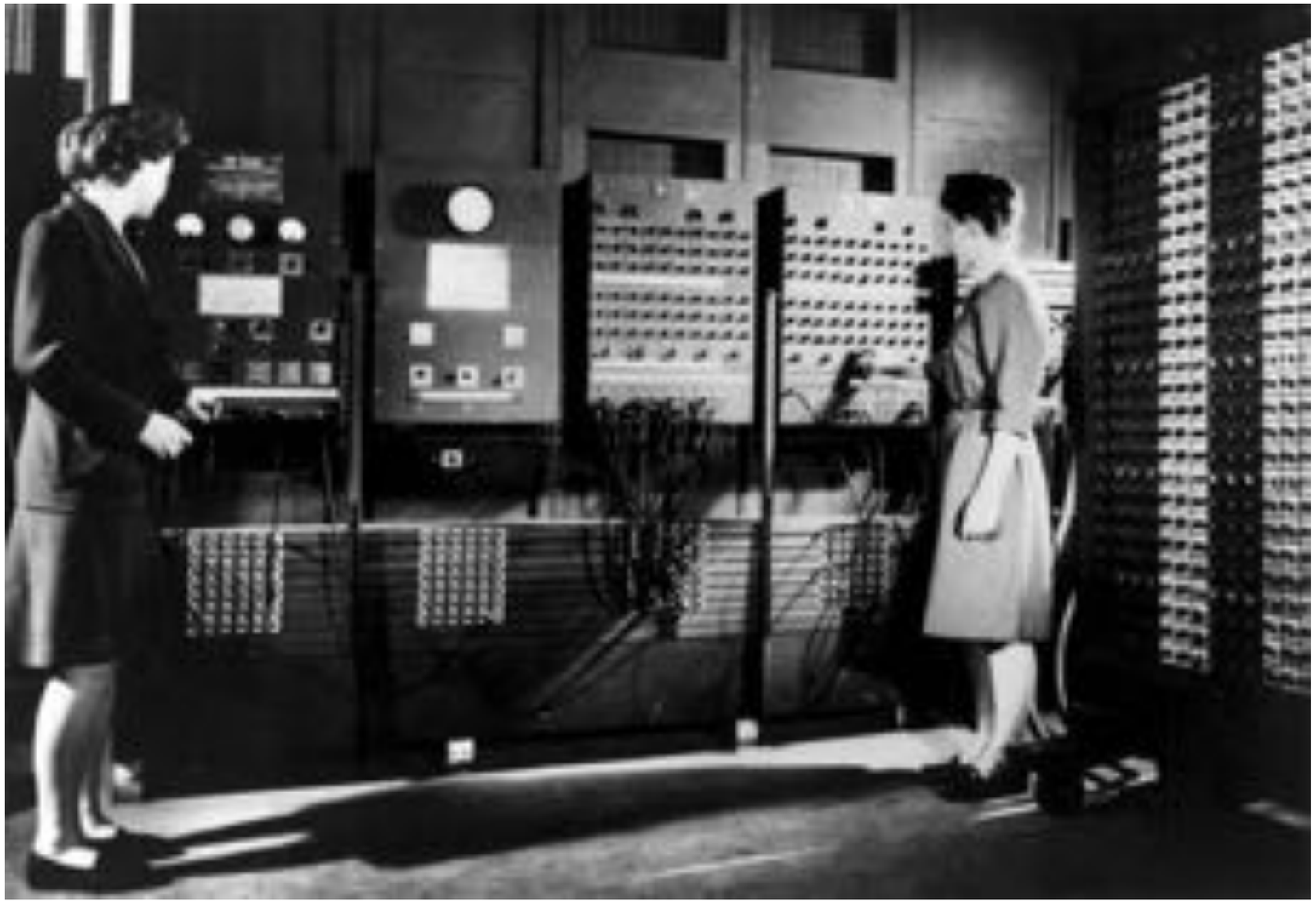




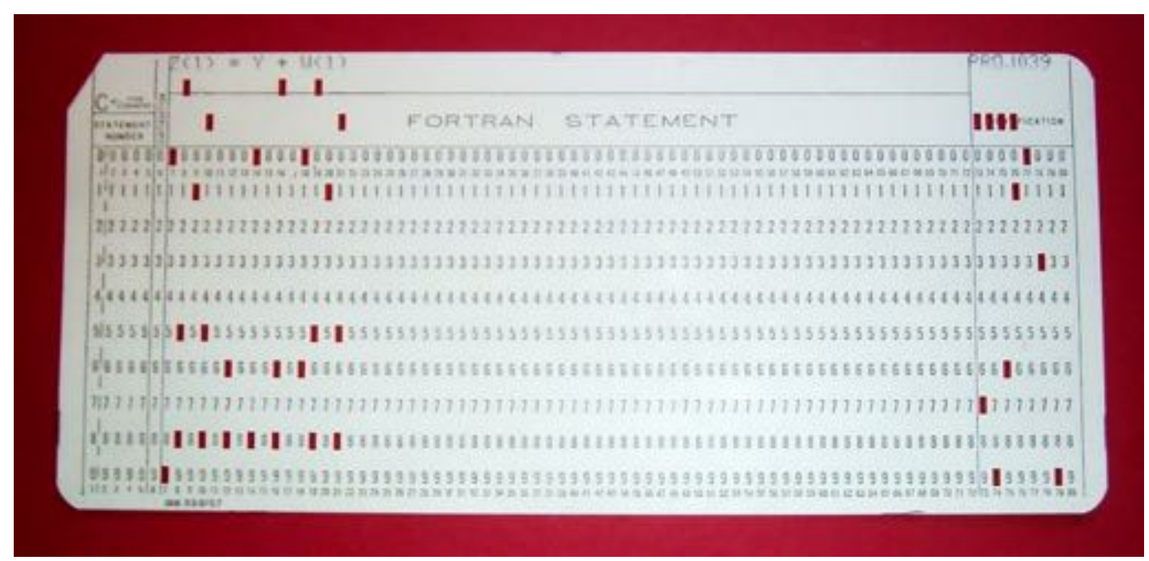
Q: What is computer graphics?

Probably an image like this comes to mind:

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

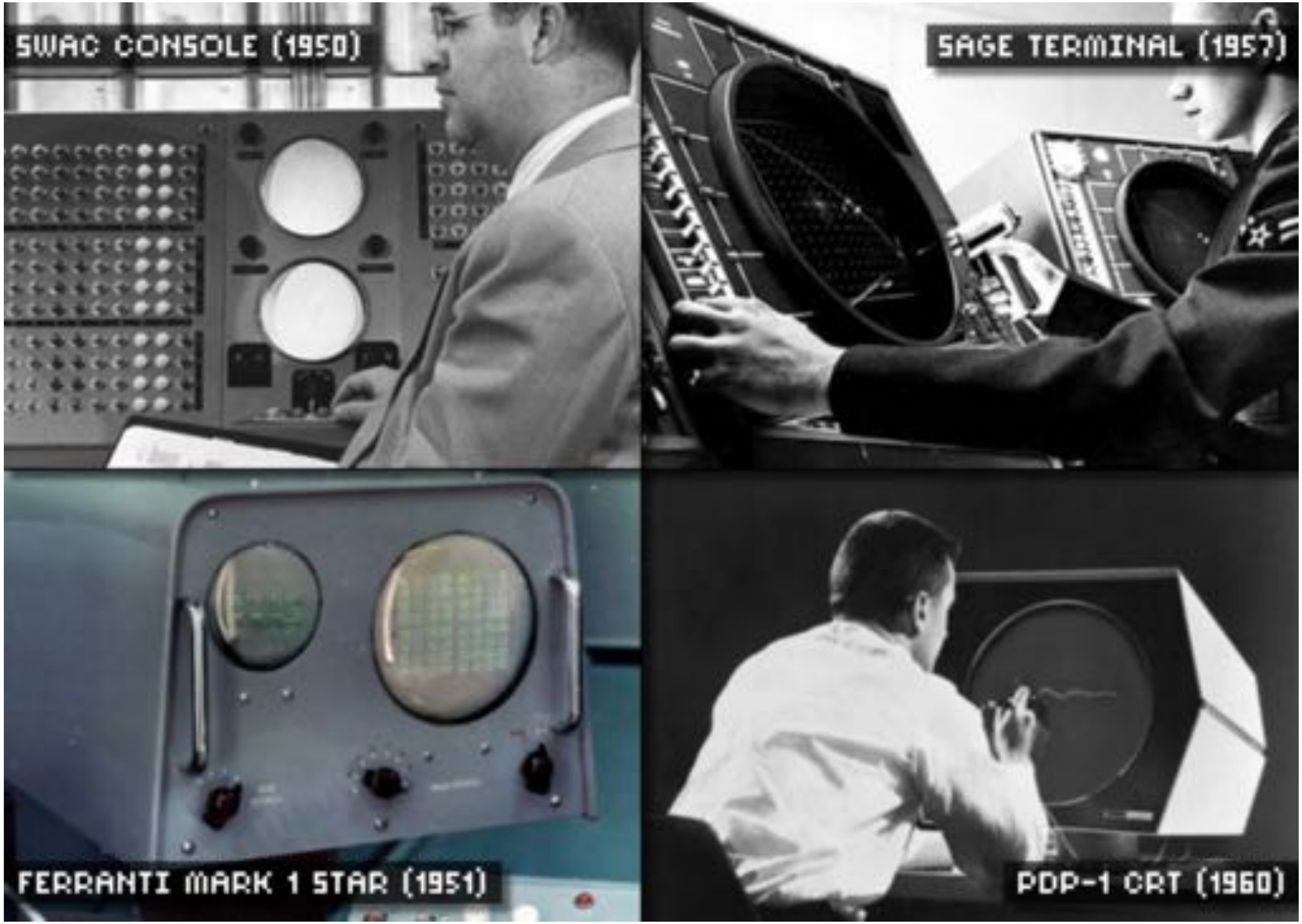


Early computer (ENIAC), 1945



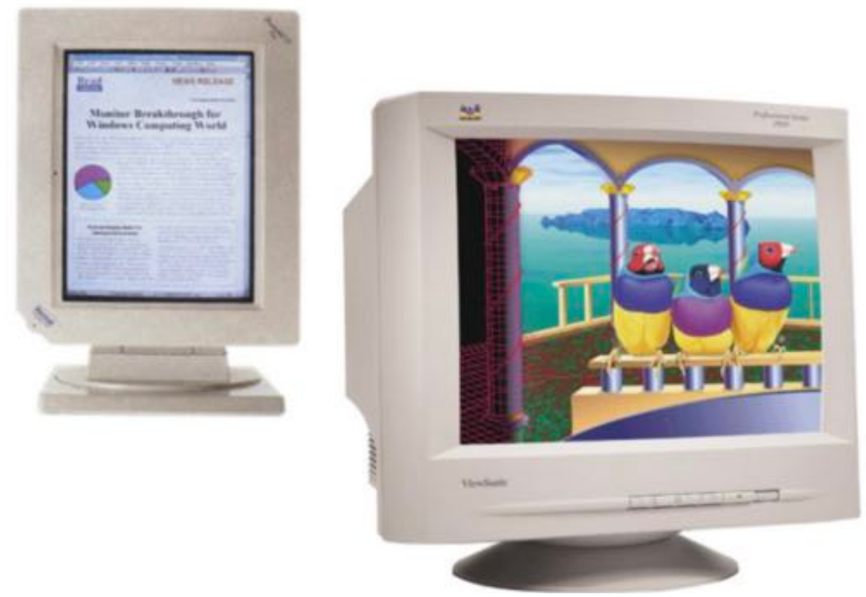
punch card (~120 bytes)

There must be a better way!



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

Sketchpad (Ivan Sutherland, 1963)



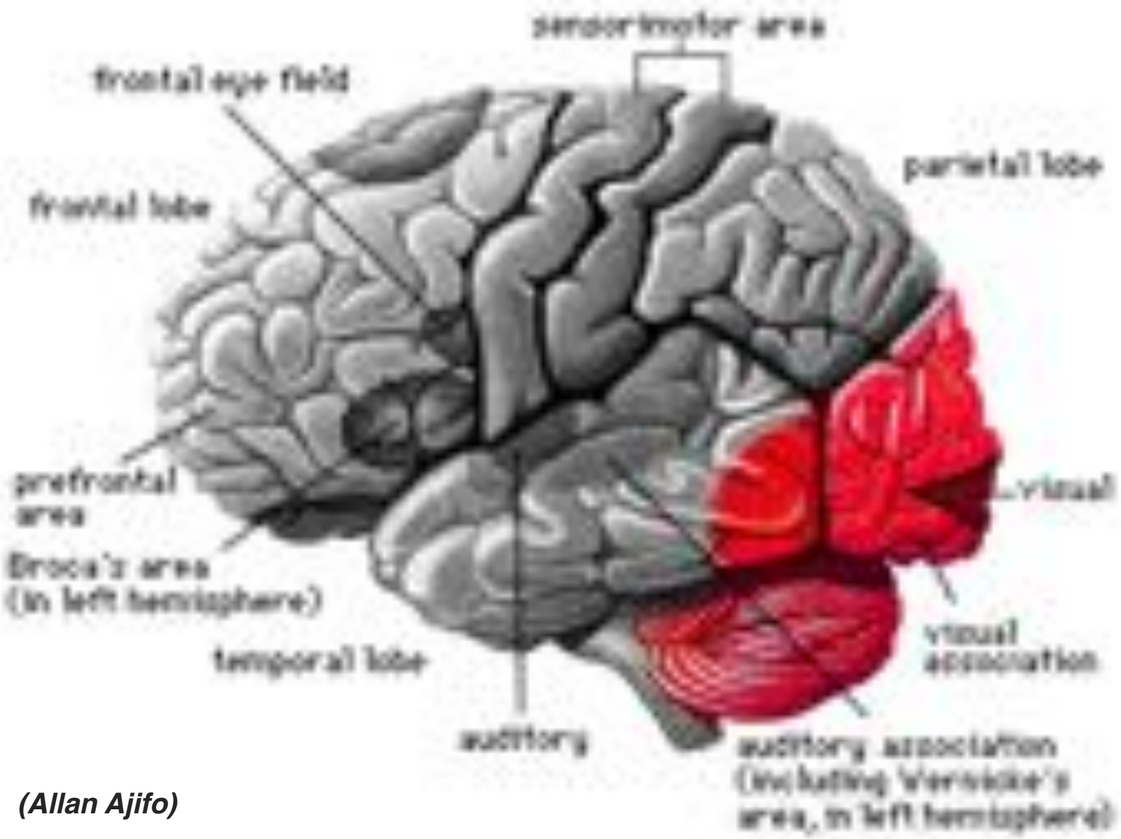
2021: 8k monitor
7680x4320 (~130MB)

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...



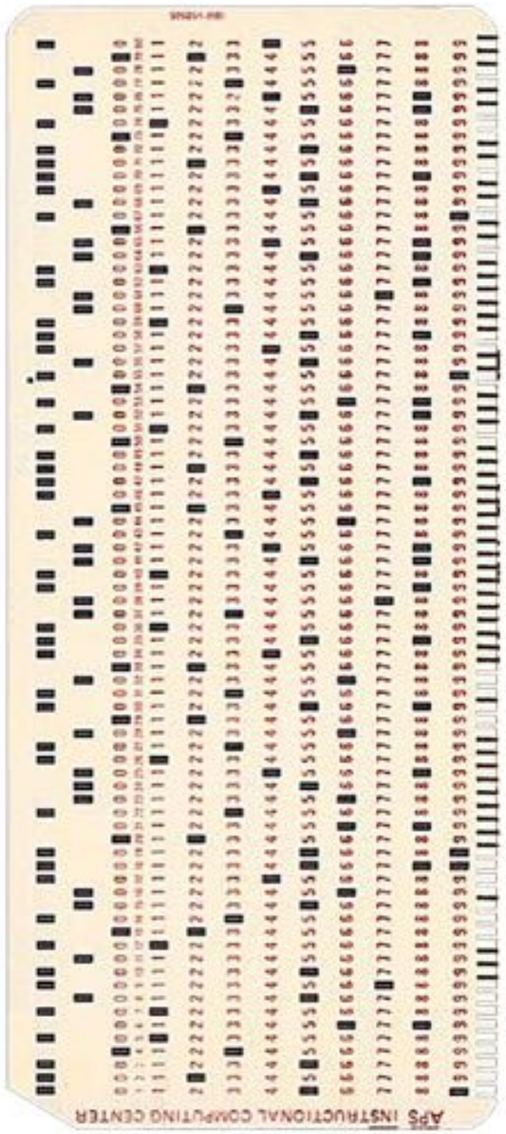
(Allan Ajifo)

(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?

com•put•er graph•ics /kəmˈpyoodərˈgrafiks/ *n.*

The use of computers to synthesize visual information.

Why only visual?

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

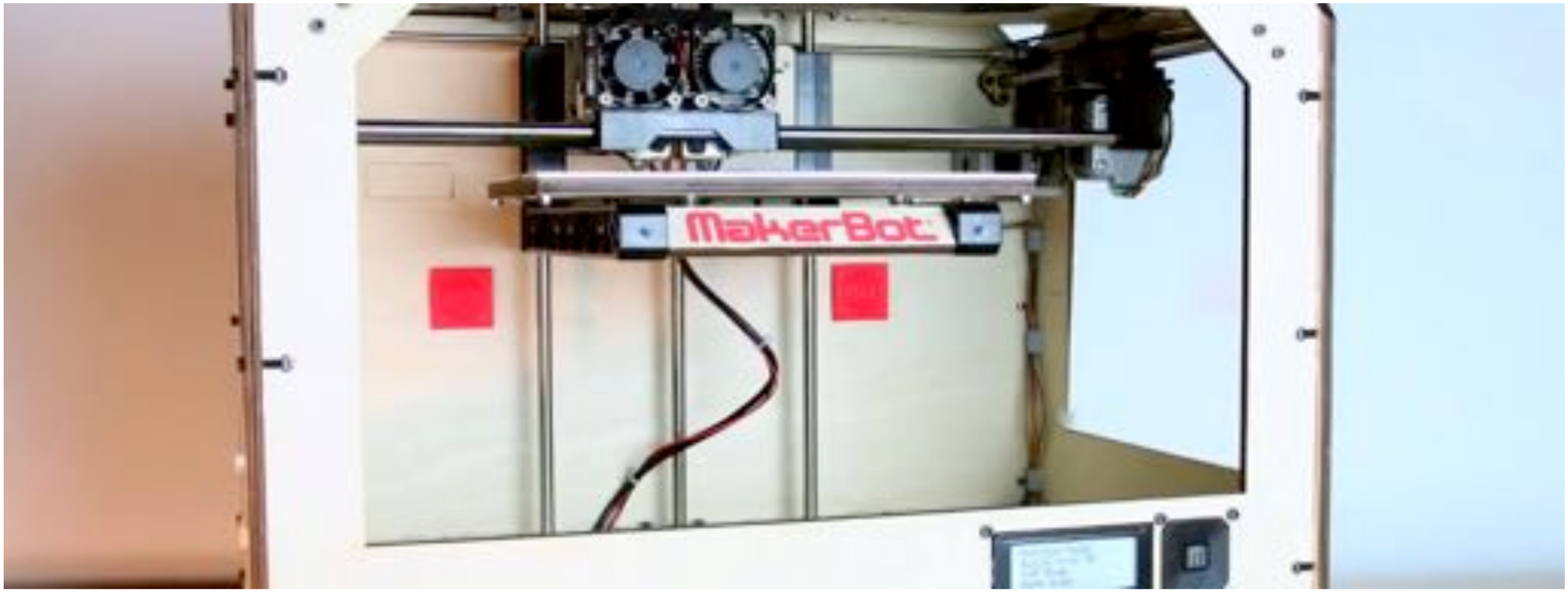
(sound)

(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…

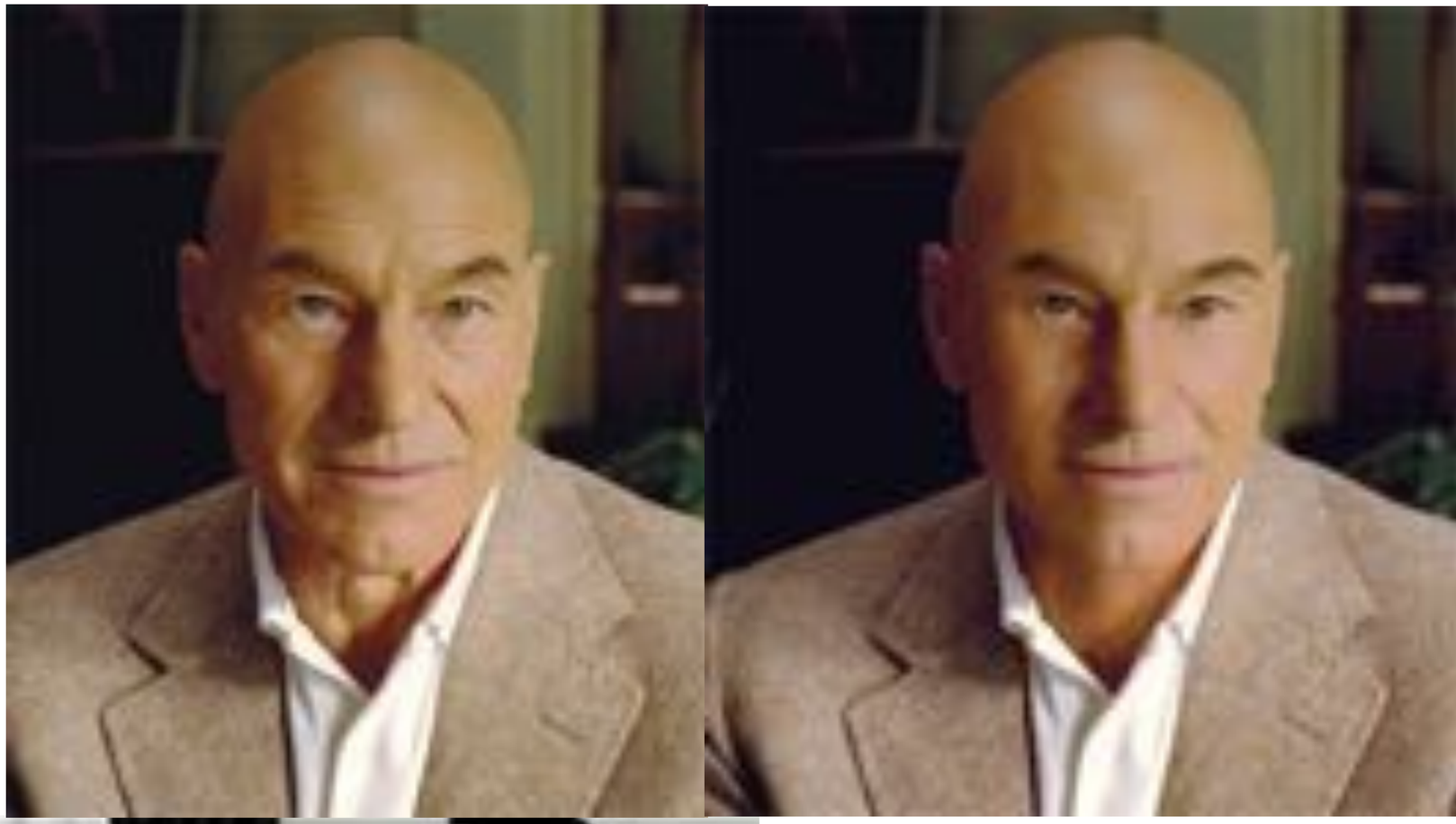
SIGGRAPH 2021 Technical Papers Trailer

Computer graphics is everywhere!

Entertainment (movies, games)

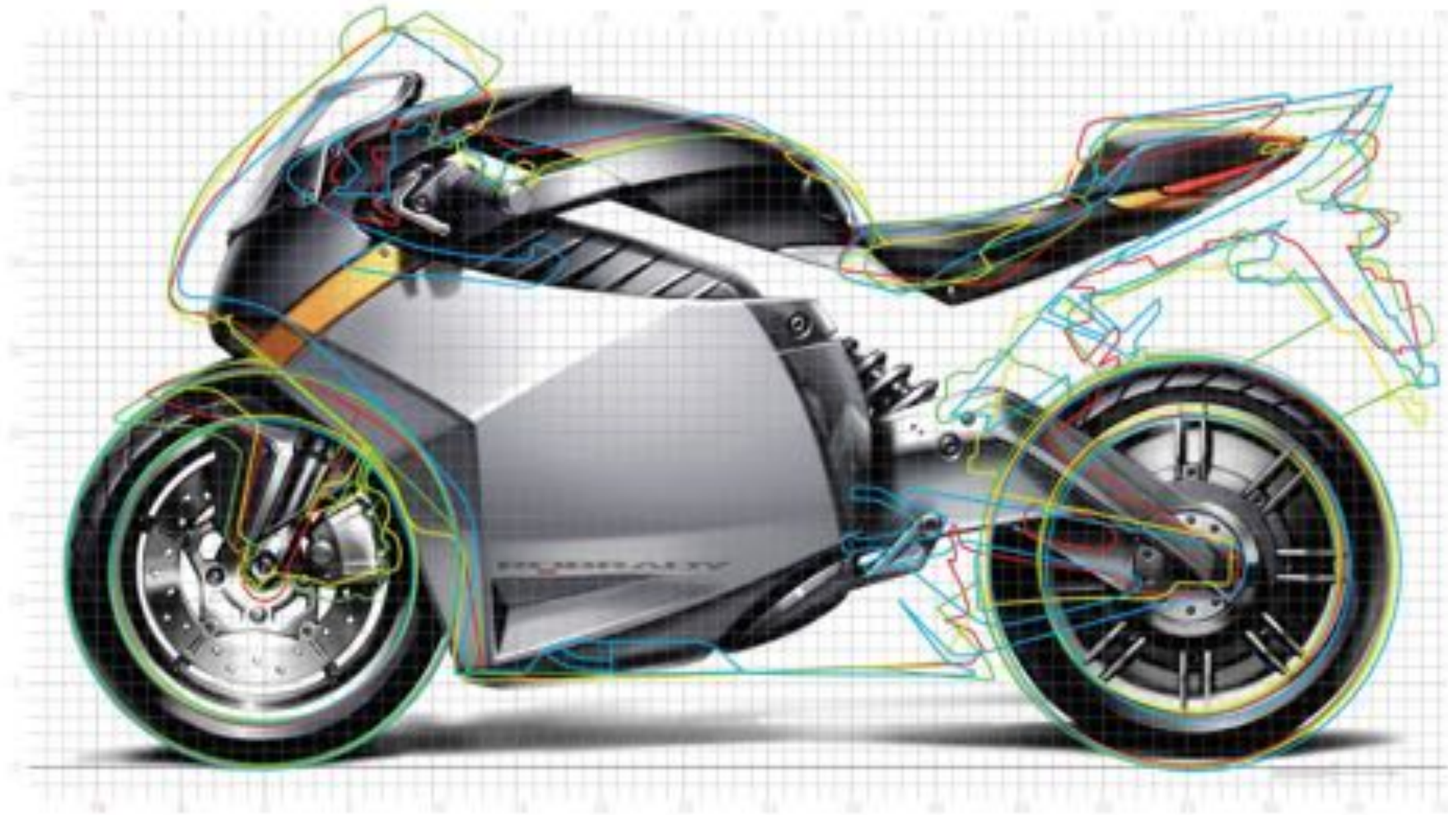
Entertainment

- Not just cartoons!

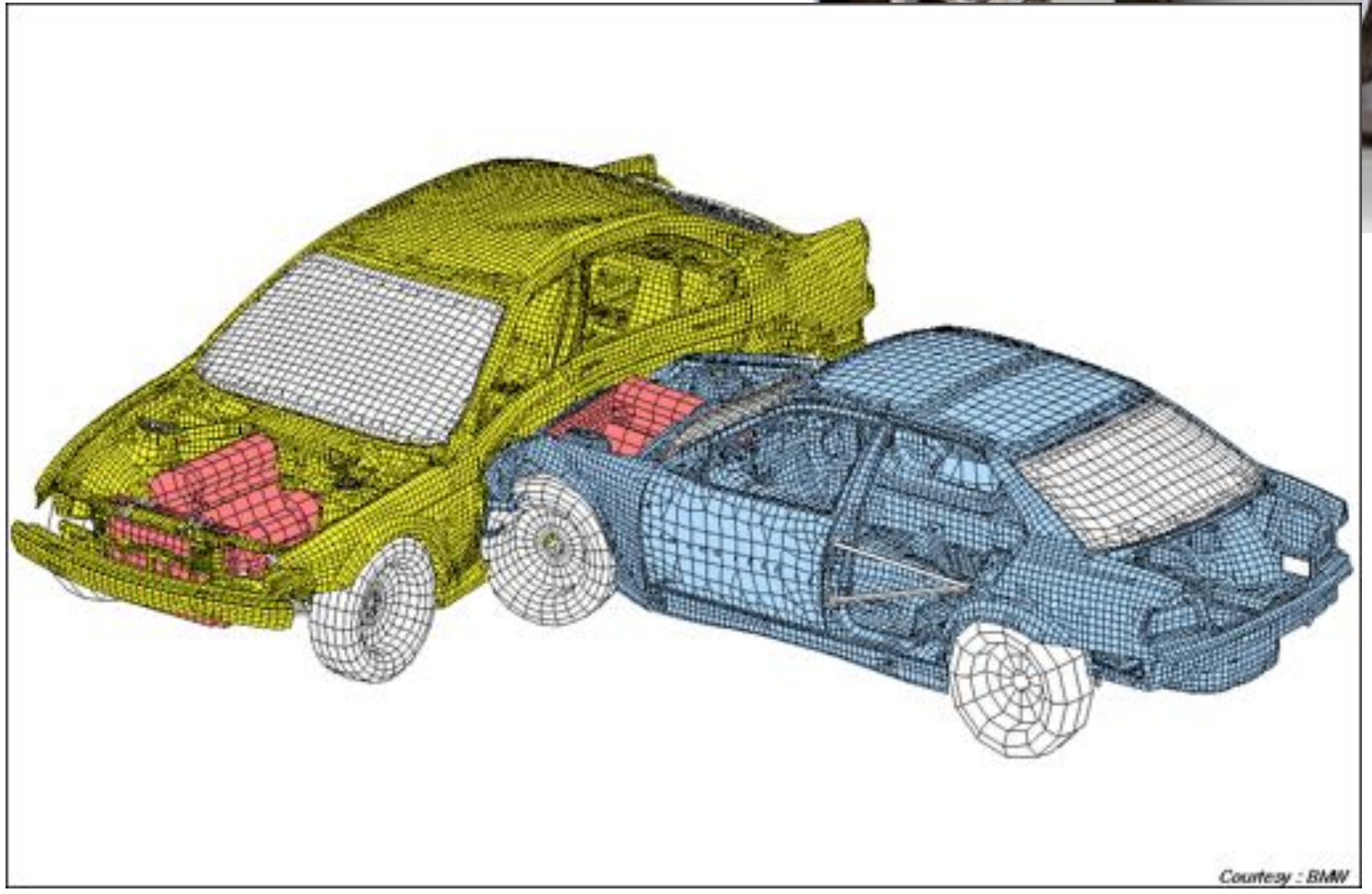


Art and design

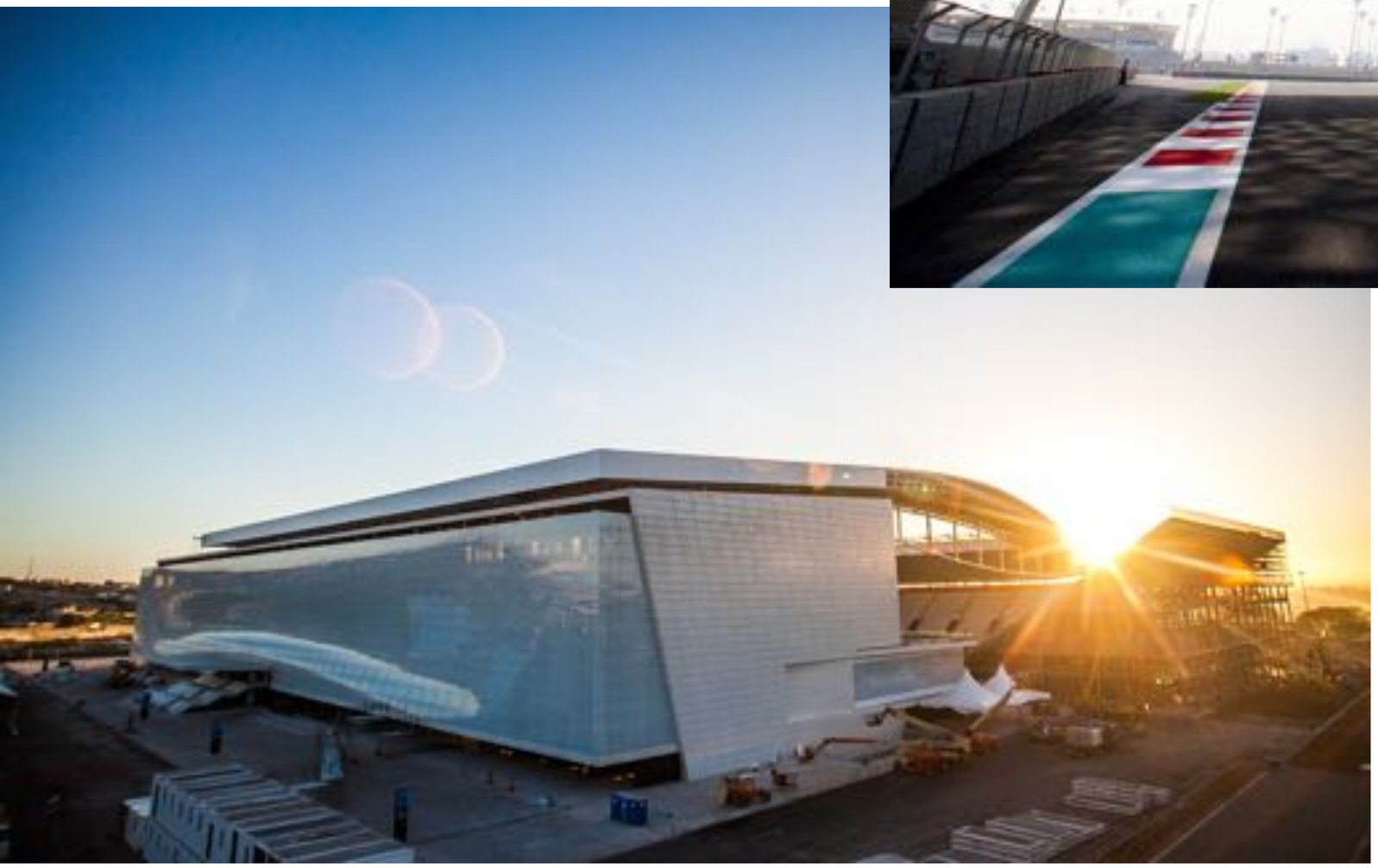
Industrial design



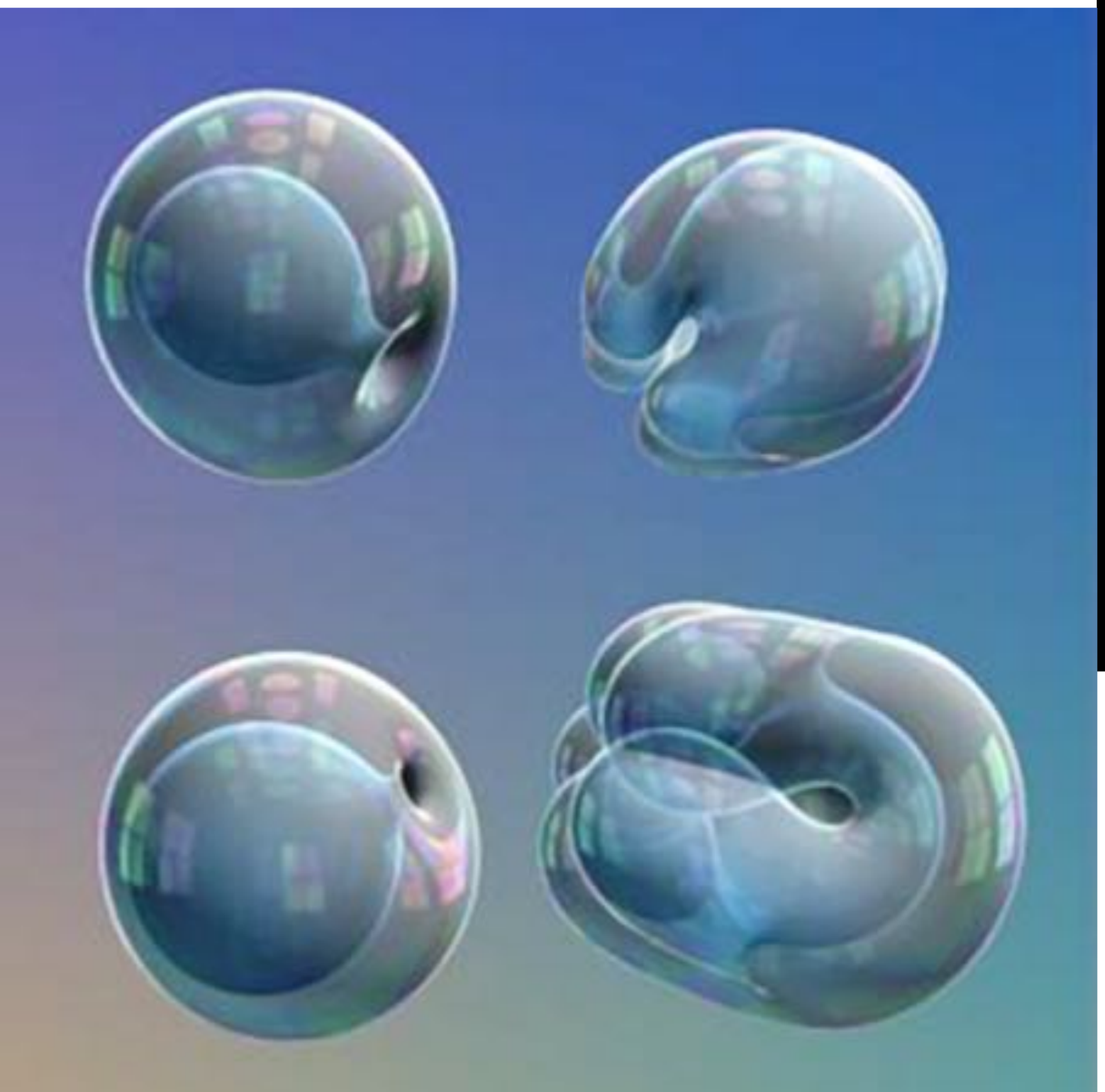
Computer aided engineering (CAE)

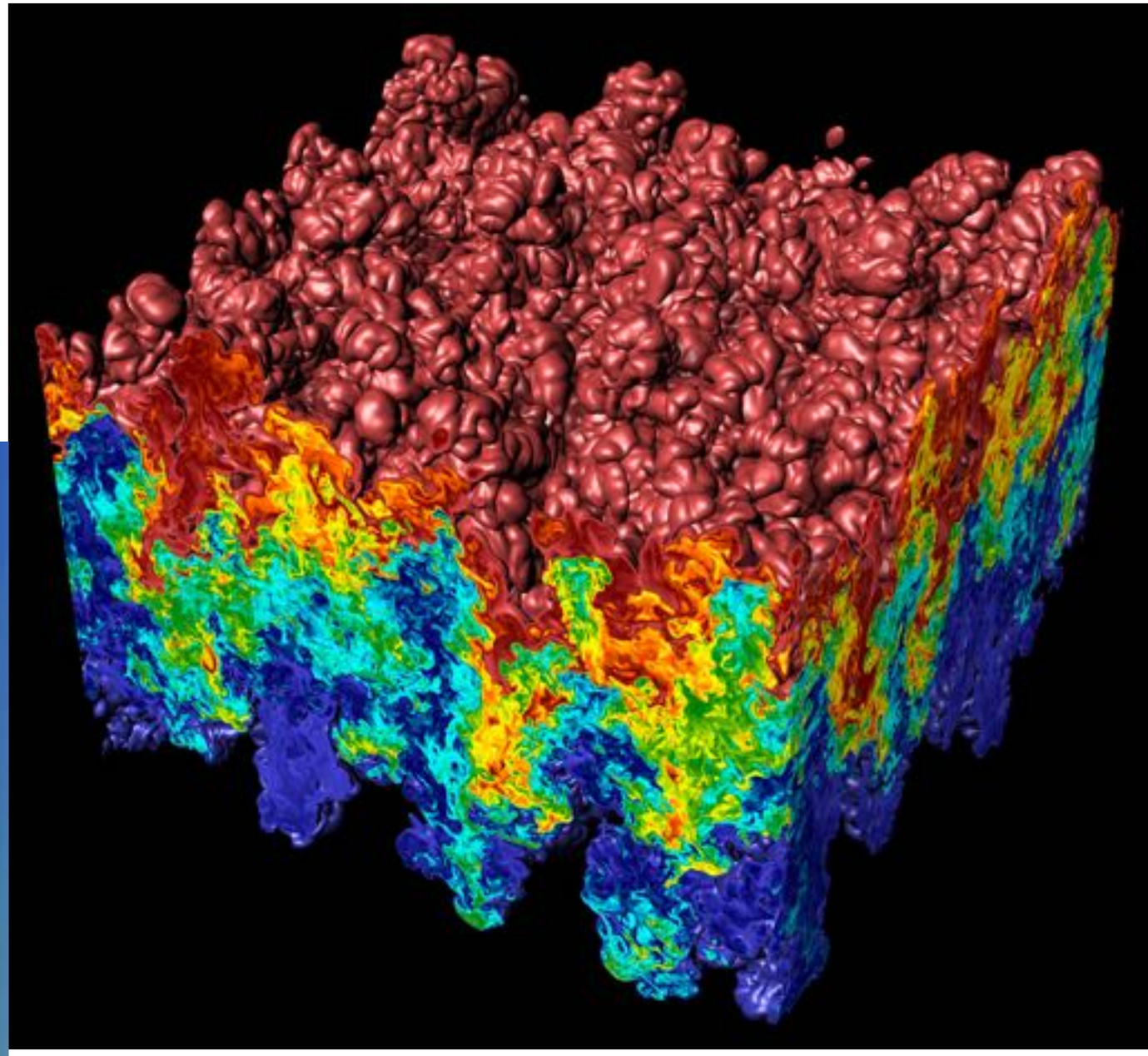


Architecture

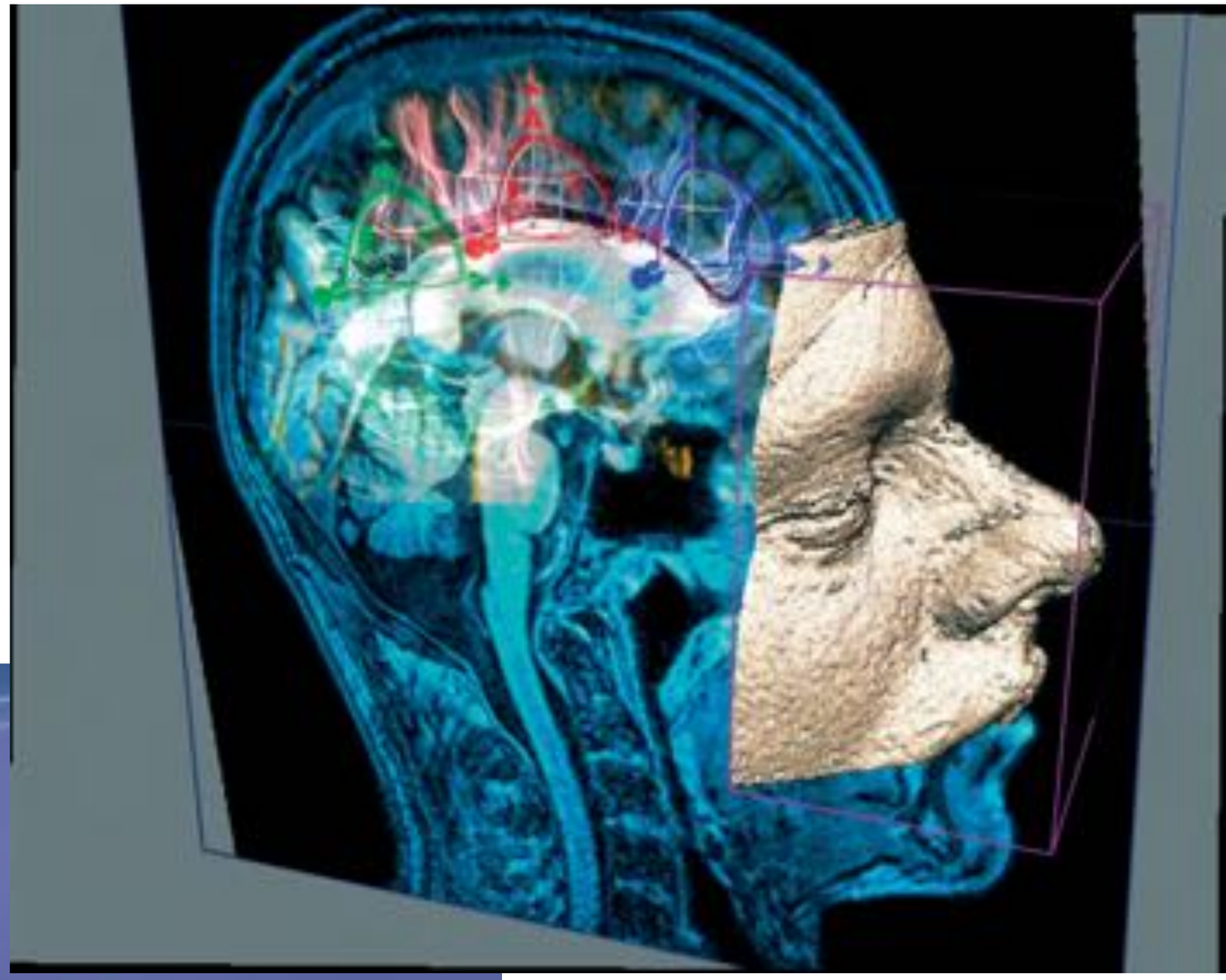


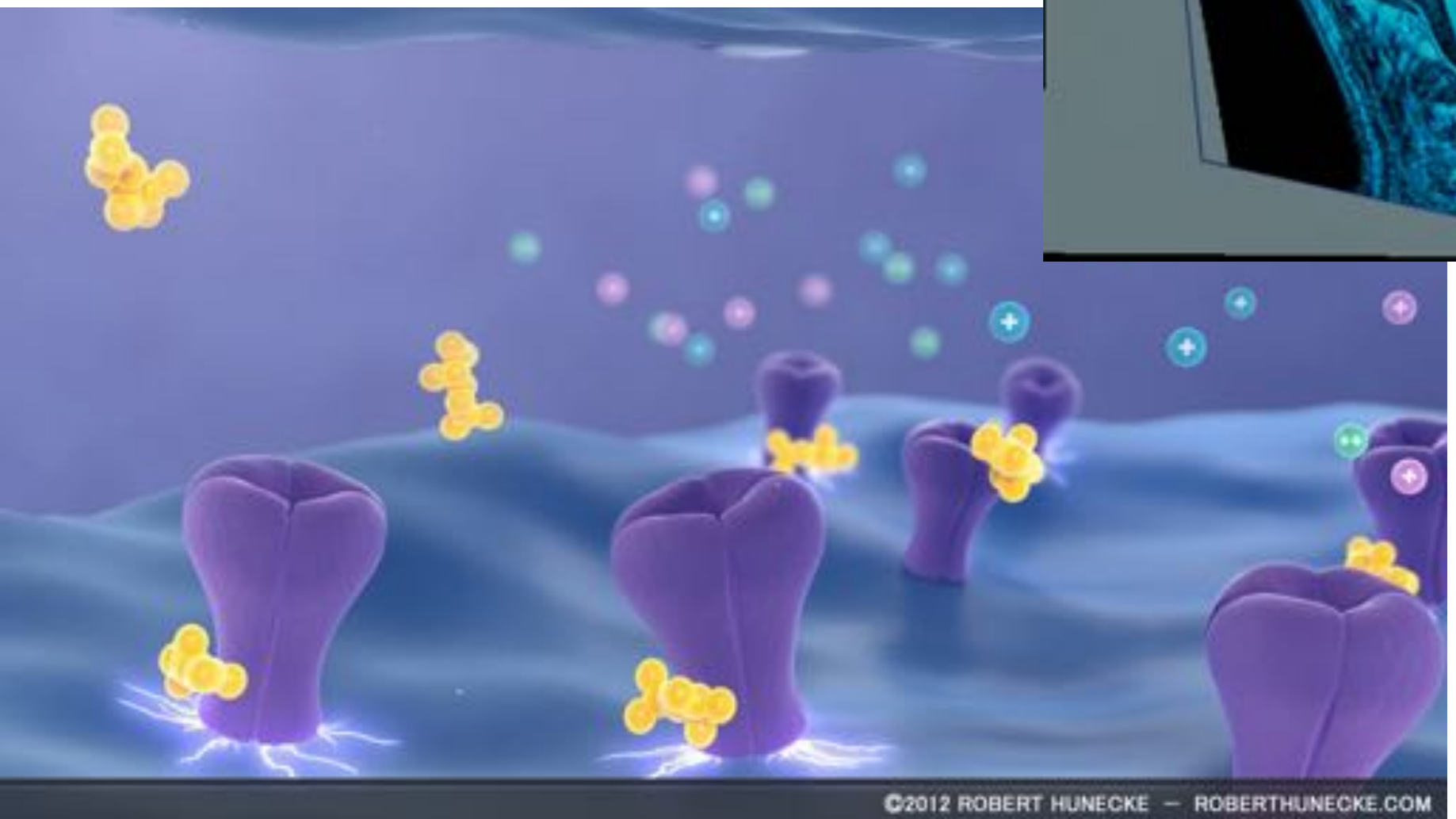
Scientific/mathematical visualization





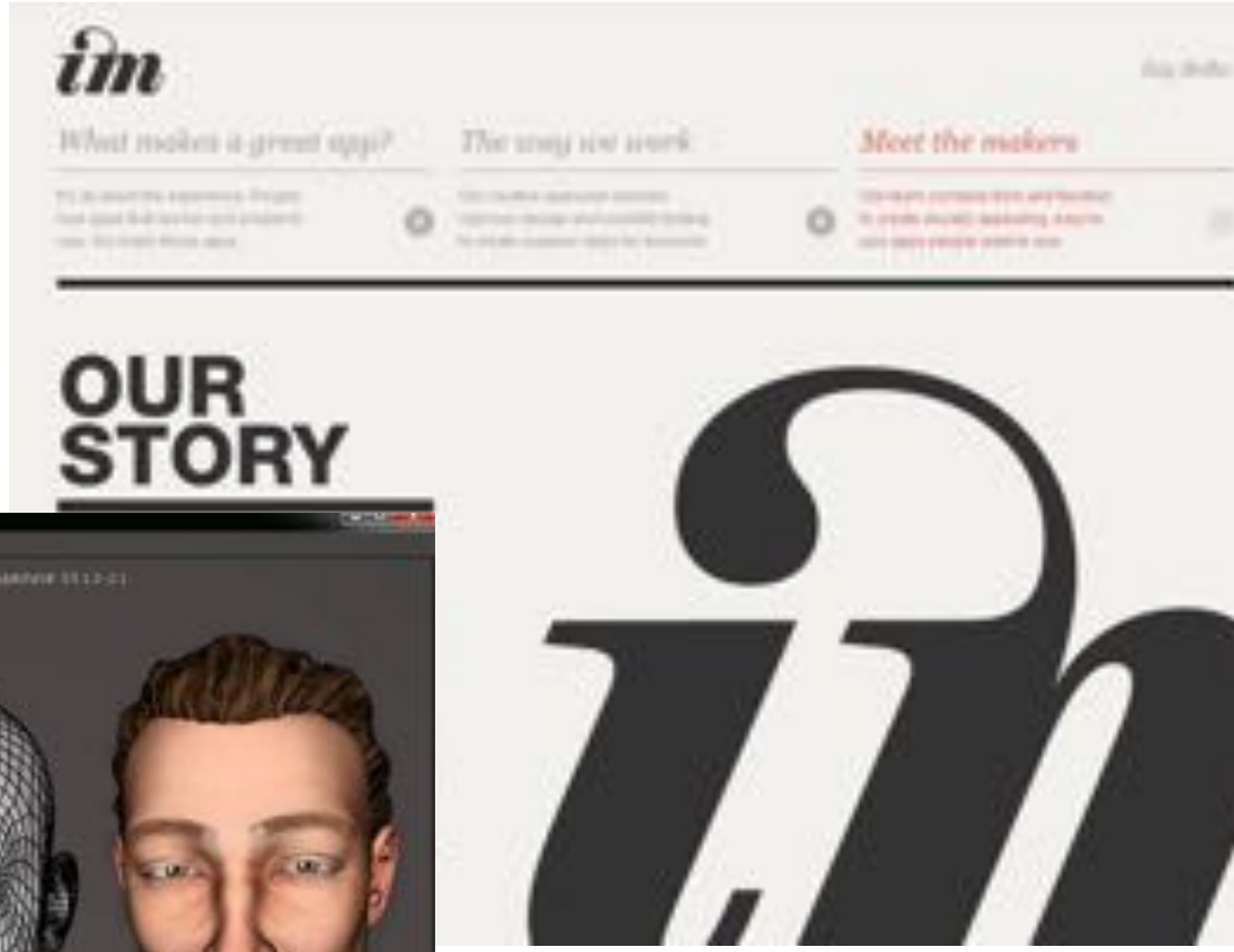
Medical/anatomical visualization

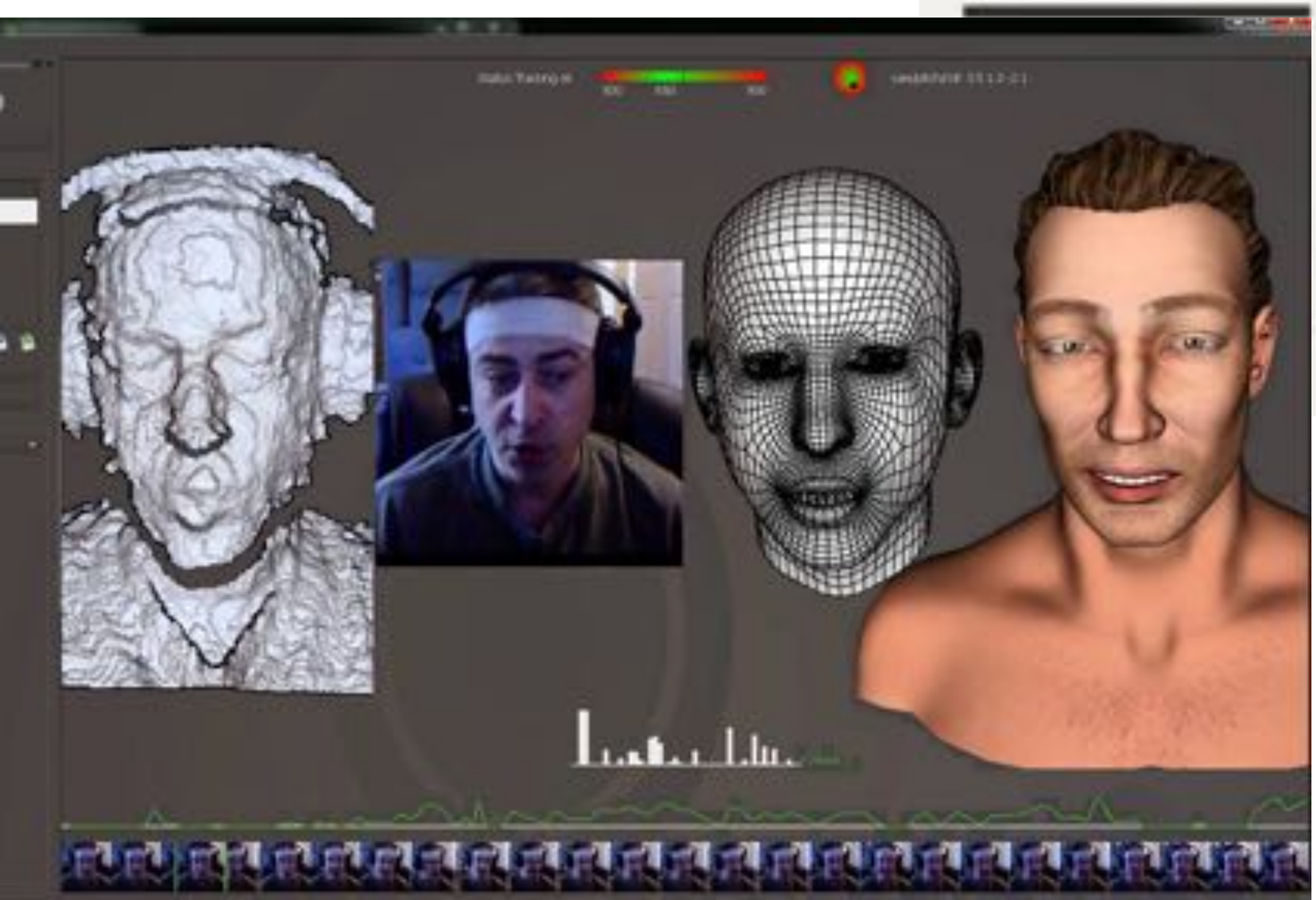




Navigation

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

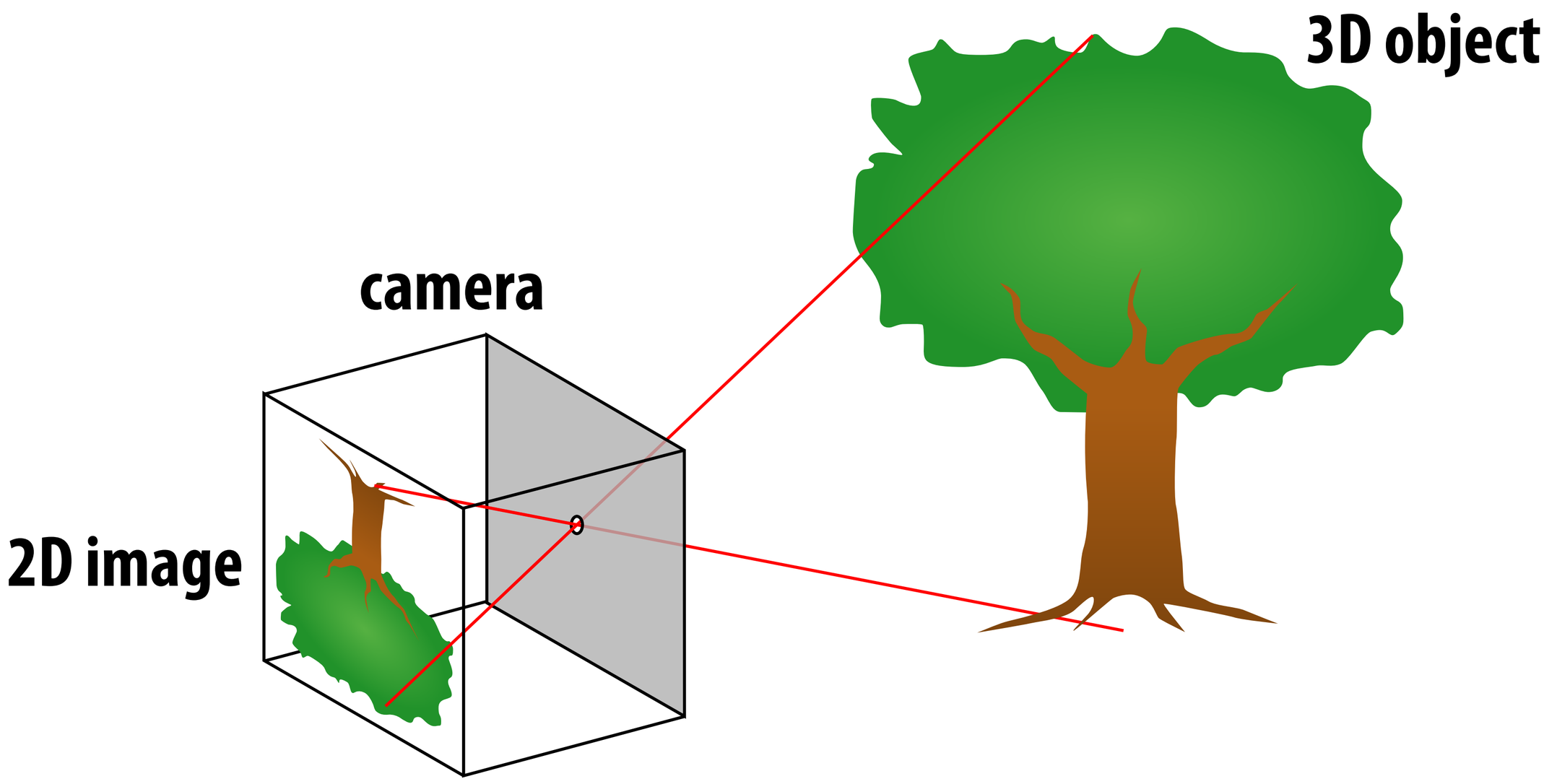
- Now have a digital description of the cube:

```
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?

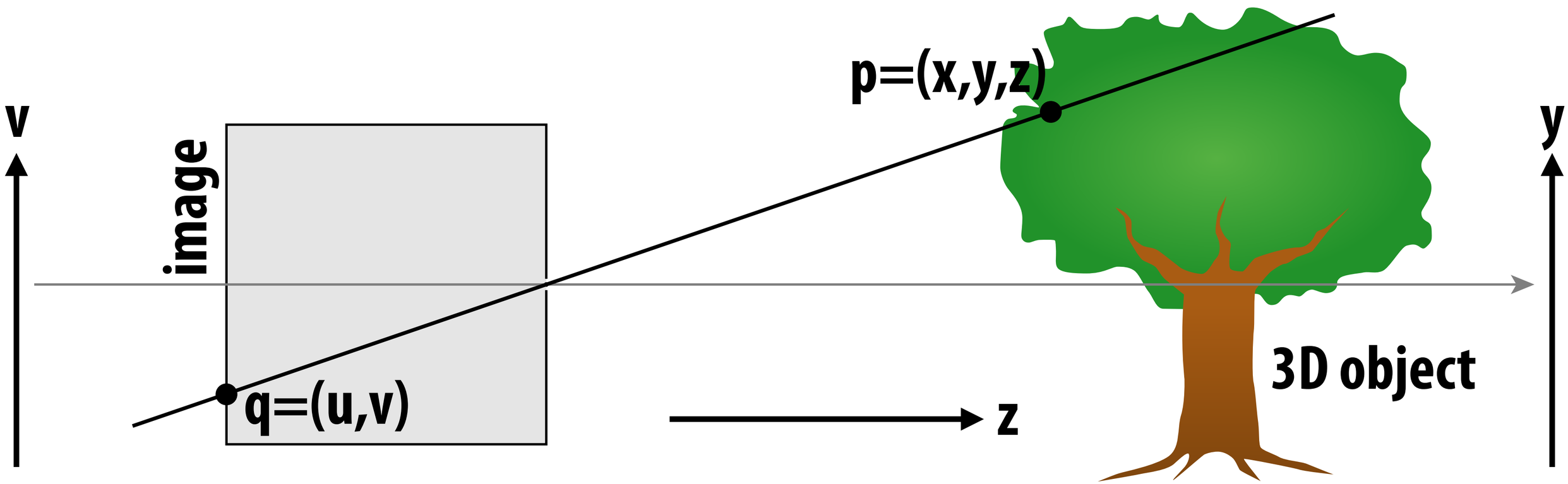
Perspective projection

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



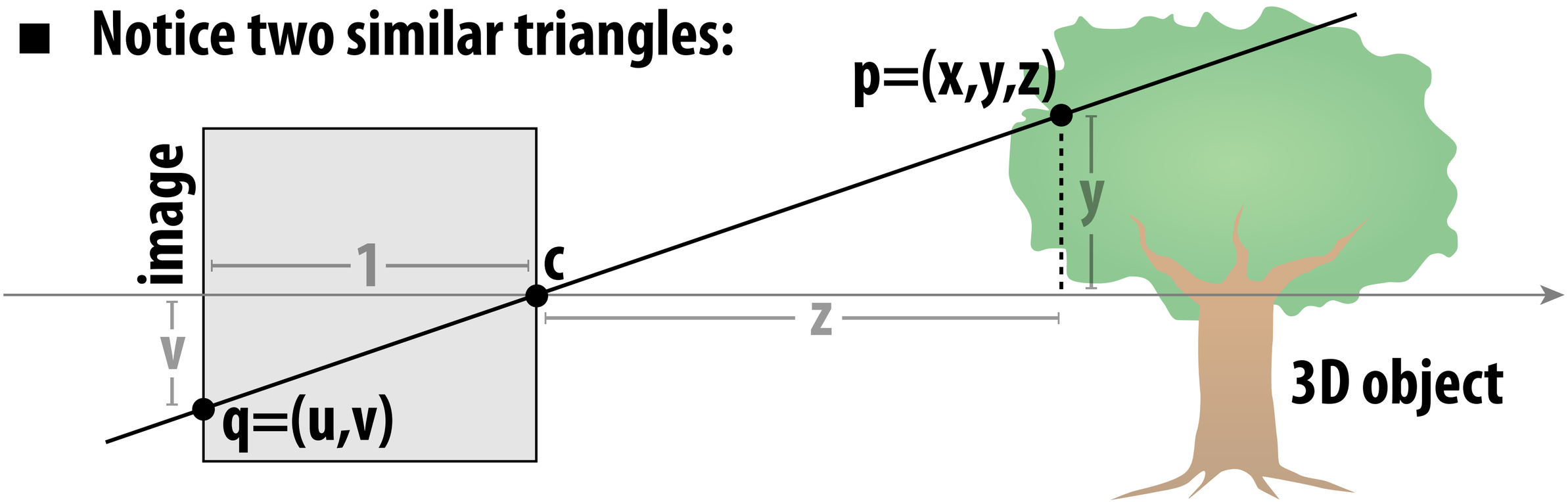
Perspective projection: side view

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



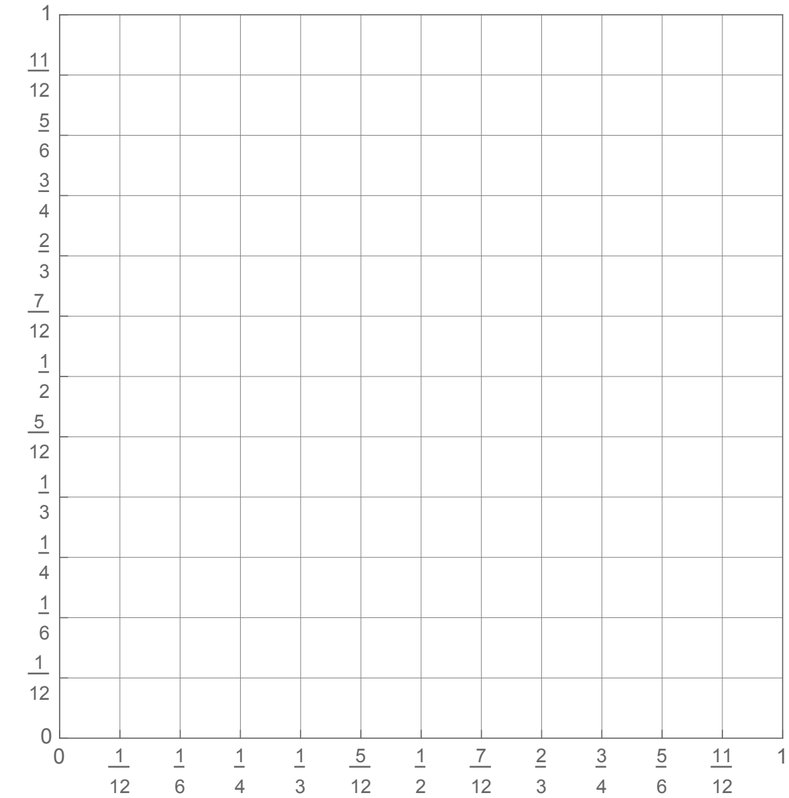
Perspective projection: side view

- 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!



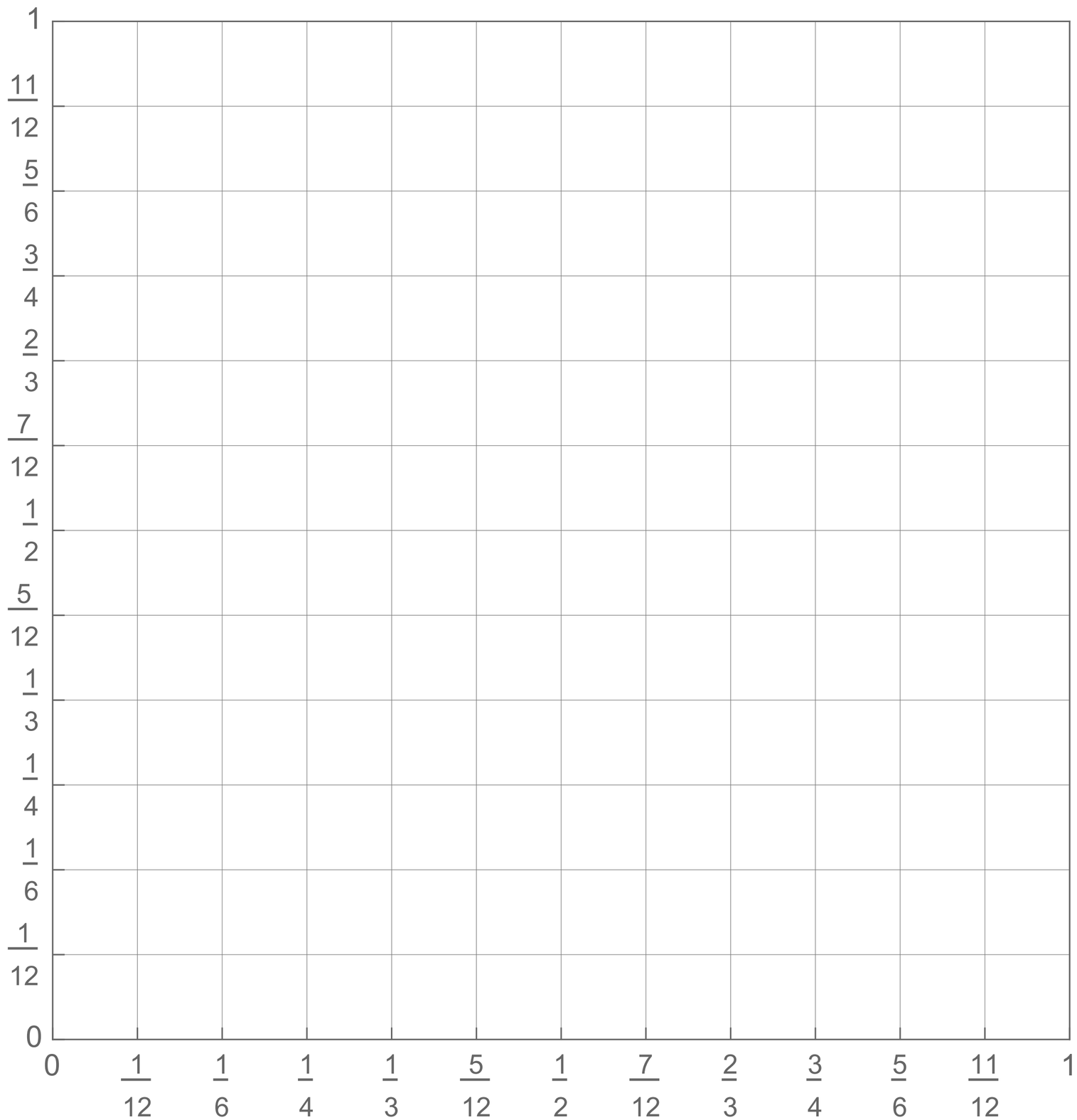
- Repeat the same simple algorithm 12 times
  - Once for each edge
  - Assume camera is at c=(2,3,5)
  - Convert (X,Y,Z) of both endpoints to (u,v):
    1. subtract camera c from vertex (X,Y,Z) to get (x,y,z)
    2. divide (x,y) by z to get (u,v)—write as a fraction
  - Draw line between (u1,v1) and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

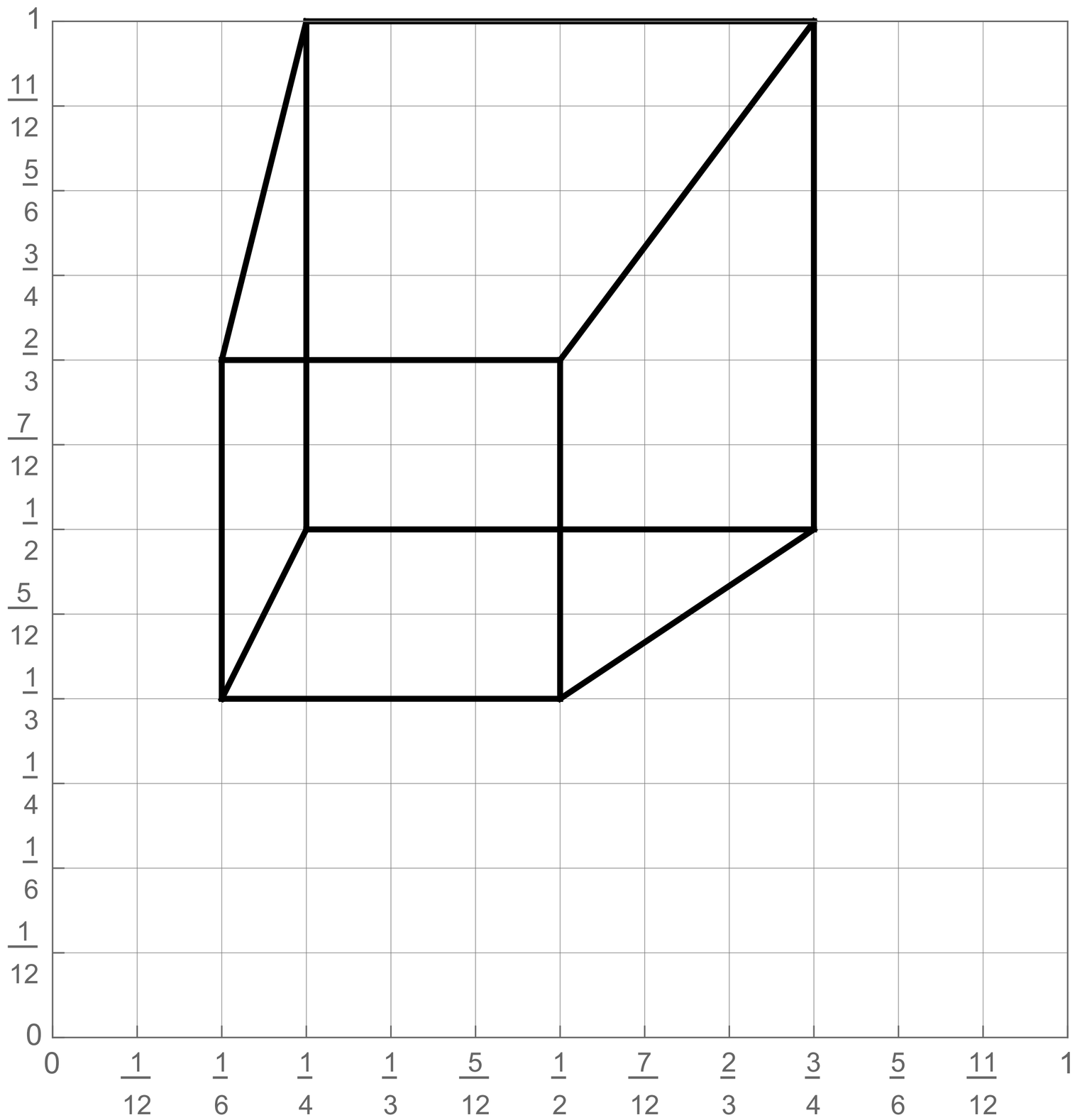
Your Assignment for the next three minutes (write this down!)

- **If your first (preferred) name begins with ….**
  - A you have edge AB
  - B, C, or D you have edge CD
  - E, F, or G you have edge EF
  - H, or Ja you have edge GH
  - Je, Ji, Jo you have edge AC
  - Ju, K, Z you have edge BD
  - L, M you have edge EG
  - N, O, P you have edge FH
  - Q, R, Sa, Sc you have edge AE
  - Se, Sh, T you have edge CG
  - V, W, X you have edge BF
  - Y you have edge DH

ACTIVITY: output on graph paper



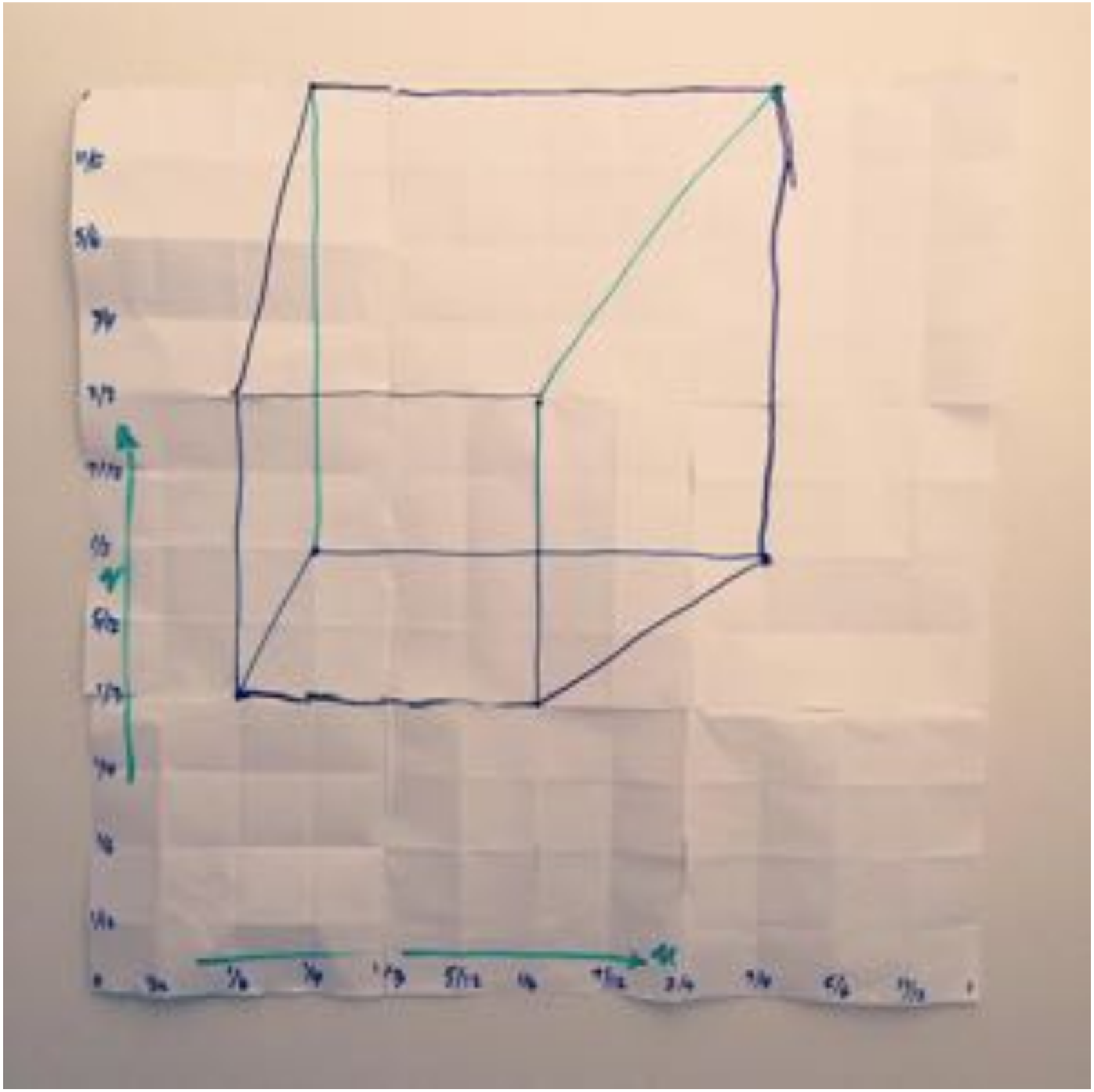
ACTIVITY: How did you do?



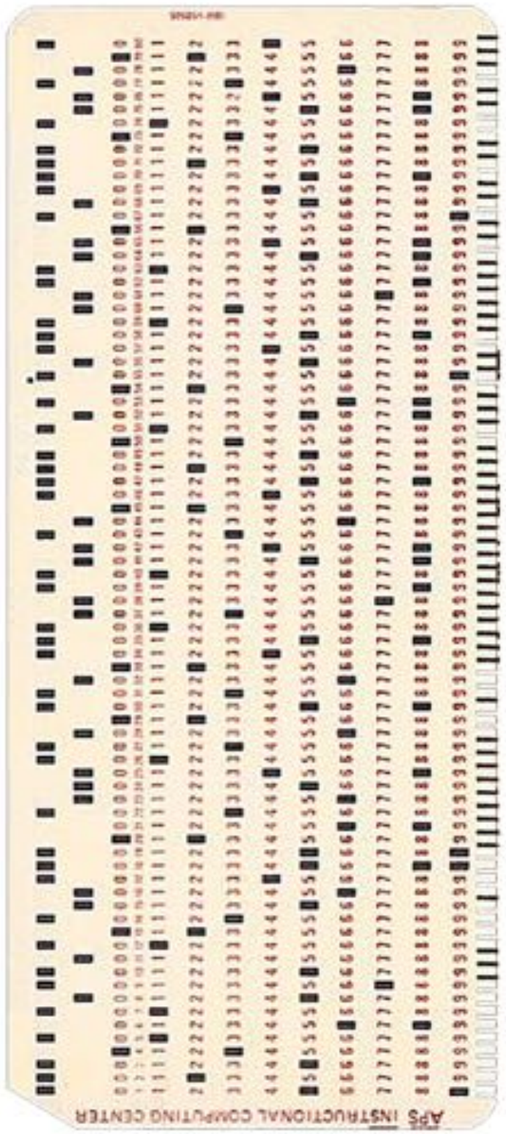
2D coordinates:

```
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.



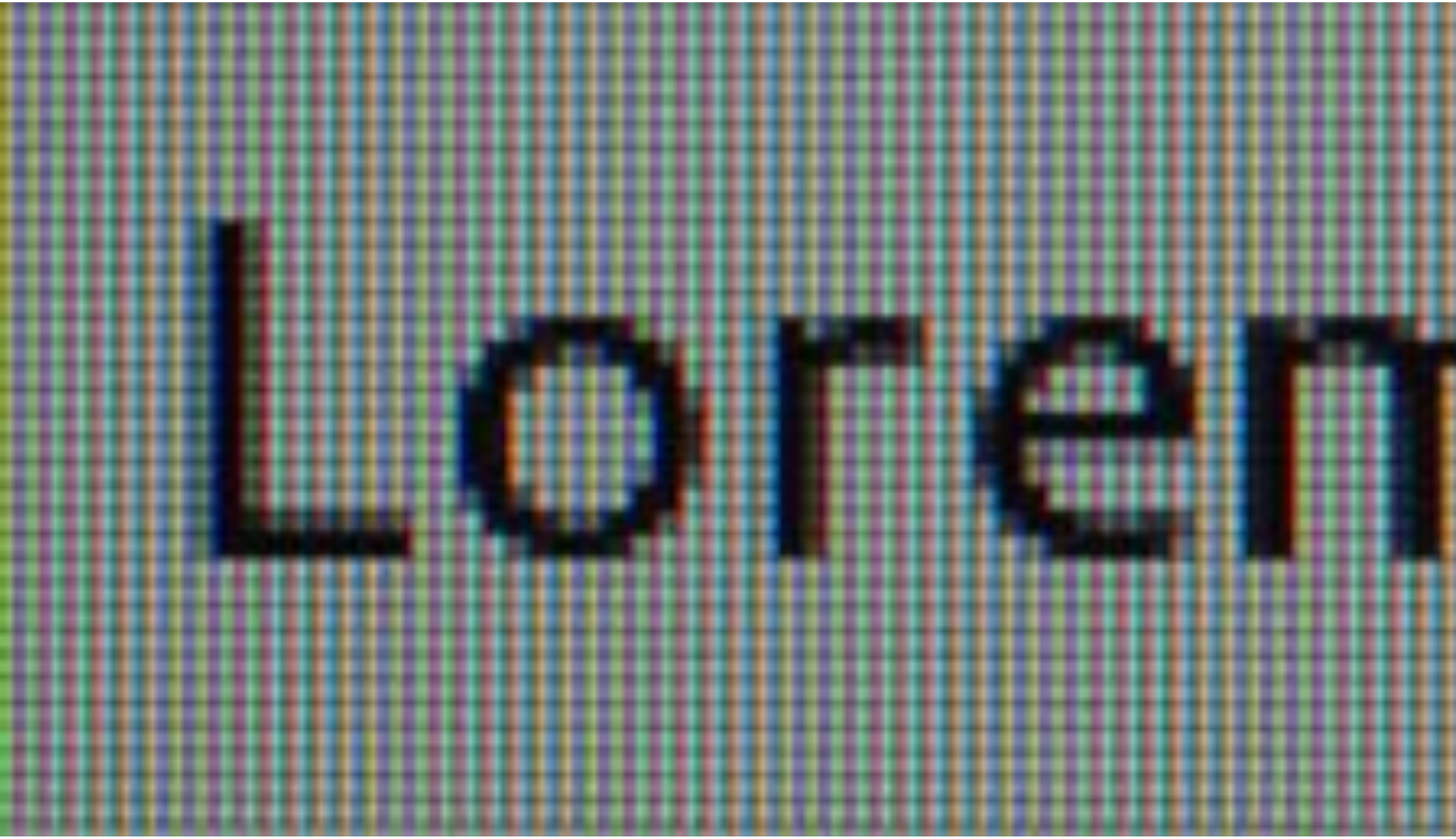
<u>digital</u> information

computation

<u>visual</u> information

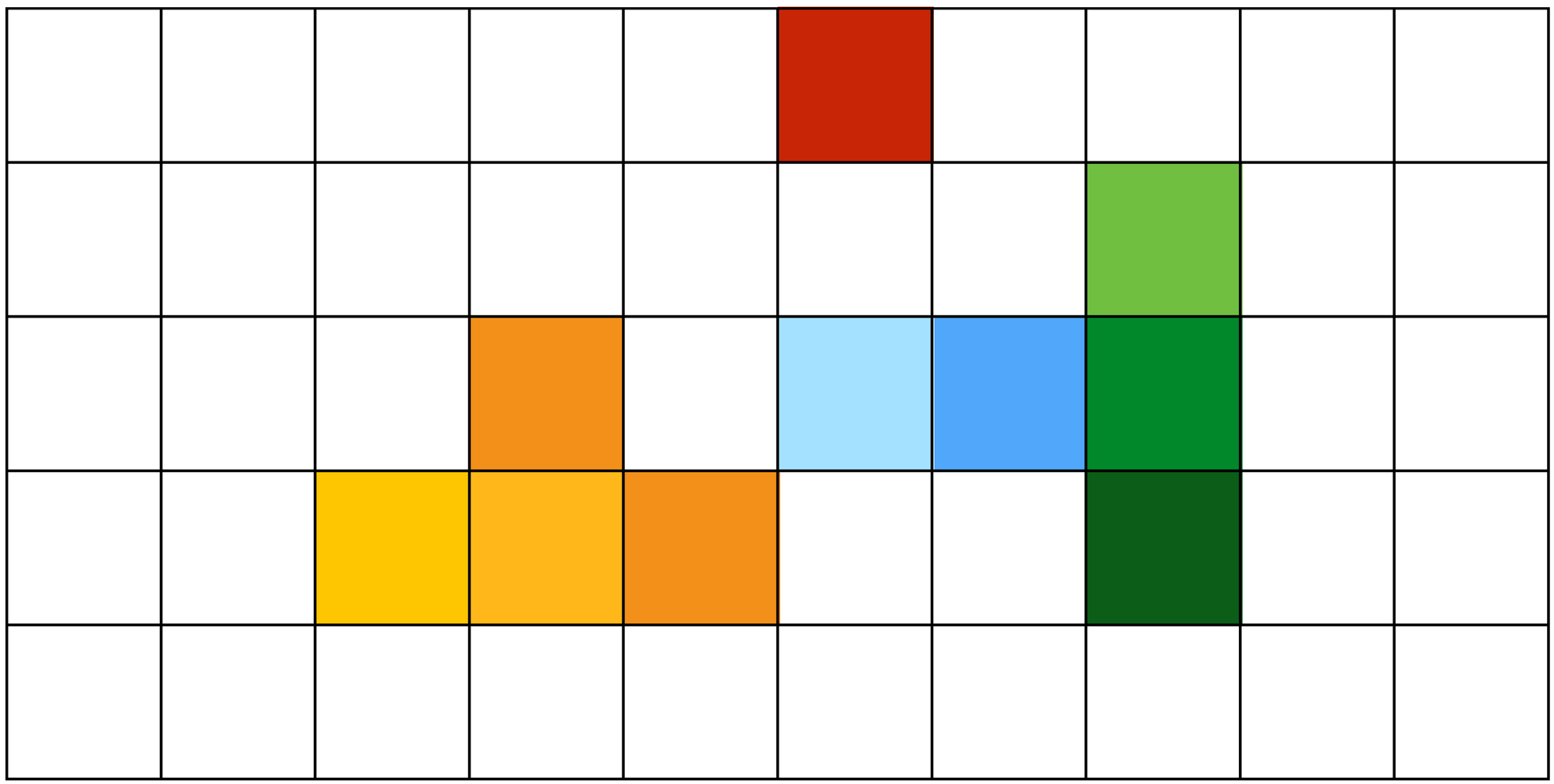
But wait…
How do we draw lines on a computer?

Close up photo of pixels on a modern display



Output for a raster display

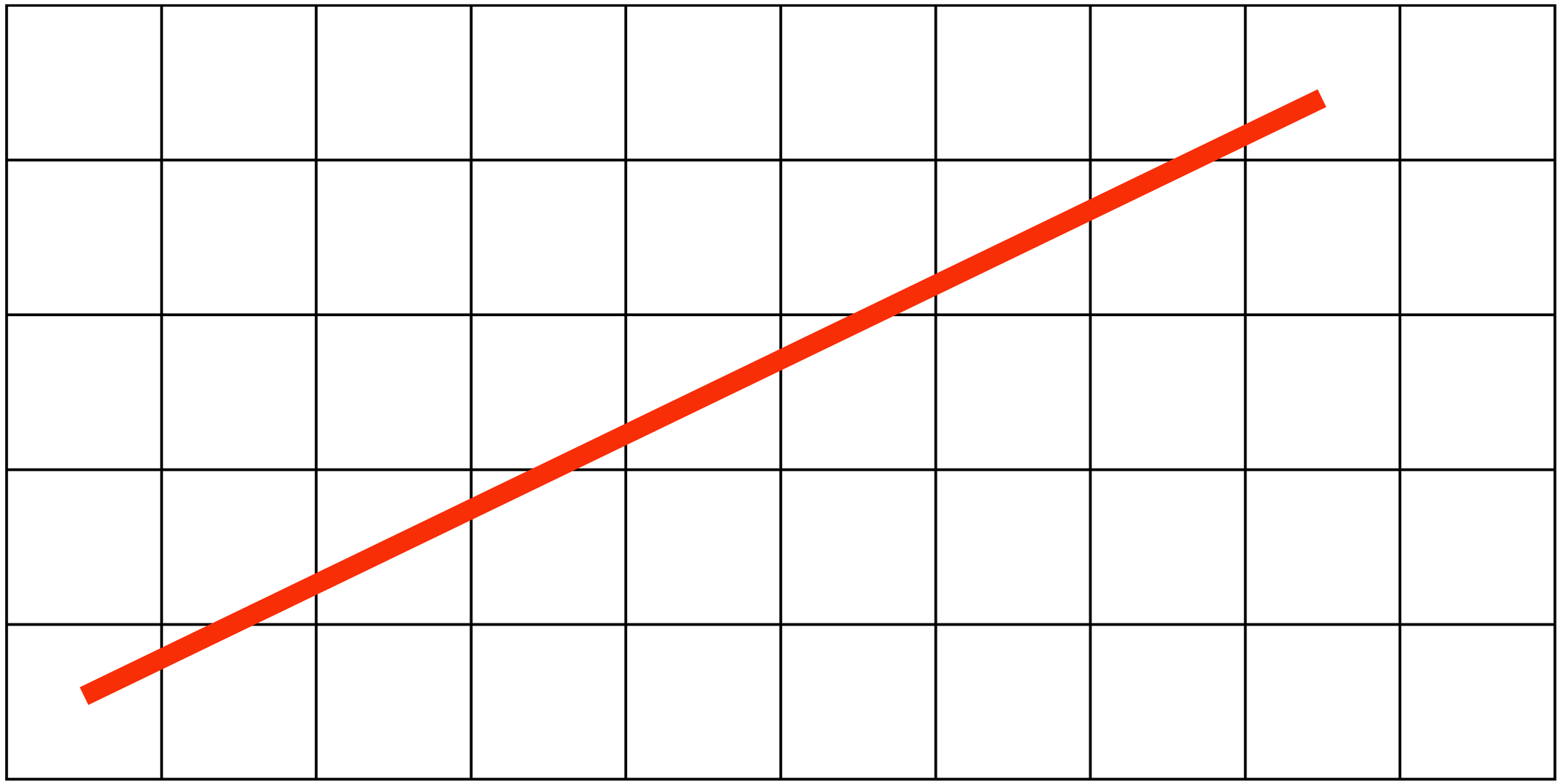
- Common abstraction of a raster display:
  - Image represented as a 2D grid of "pixels" (picture elements) **
  - Each pixel can can take on a unique color value



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

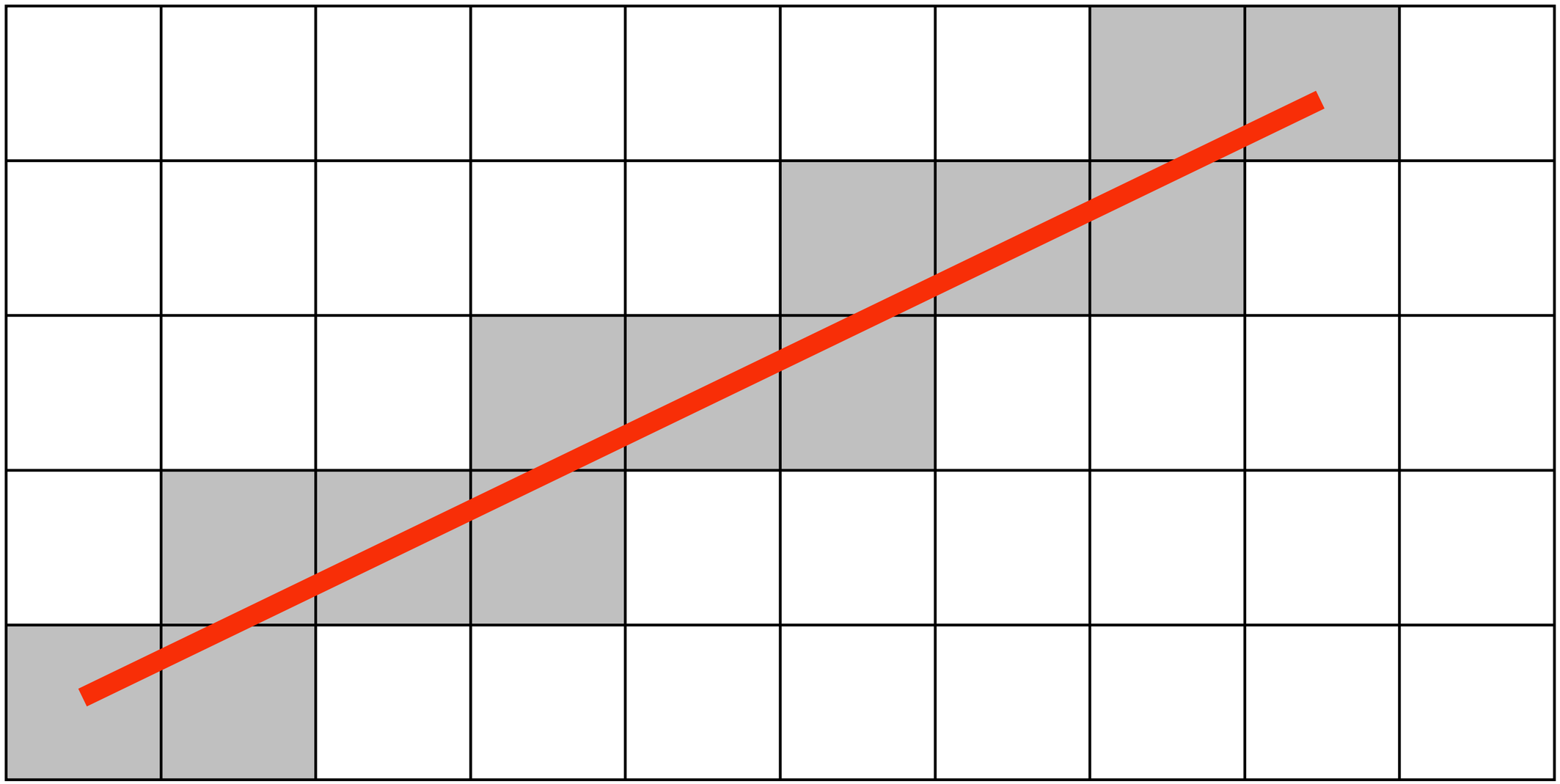
What pixels should we color in to depict a line?

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



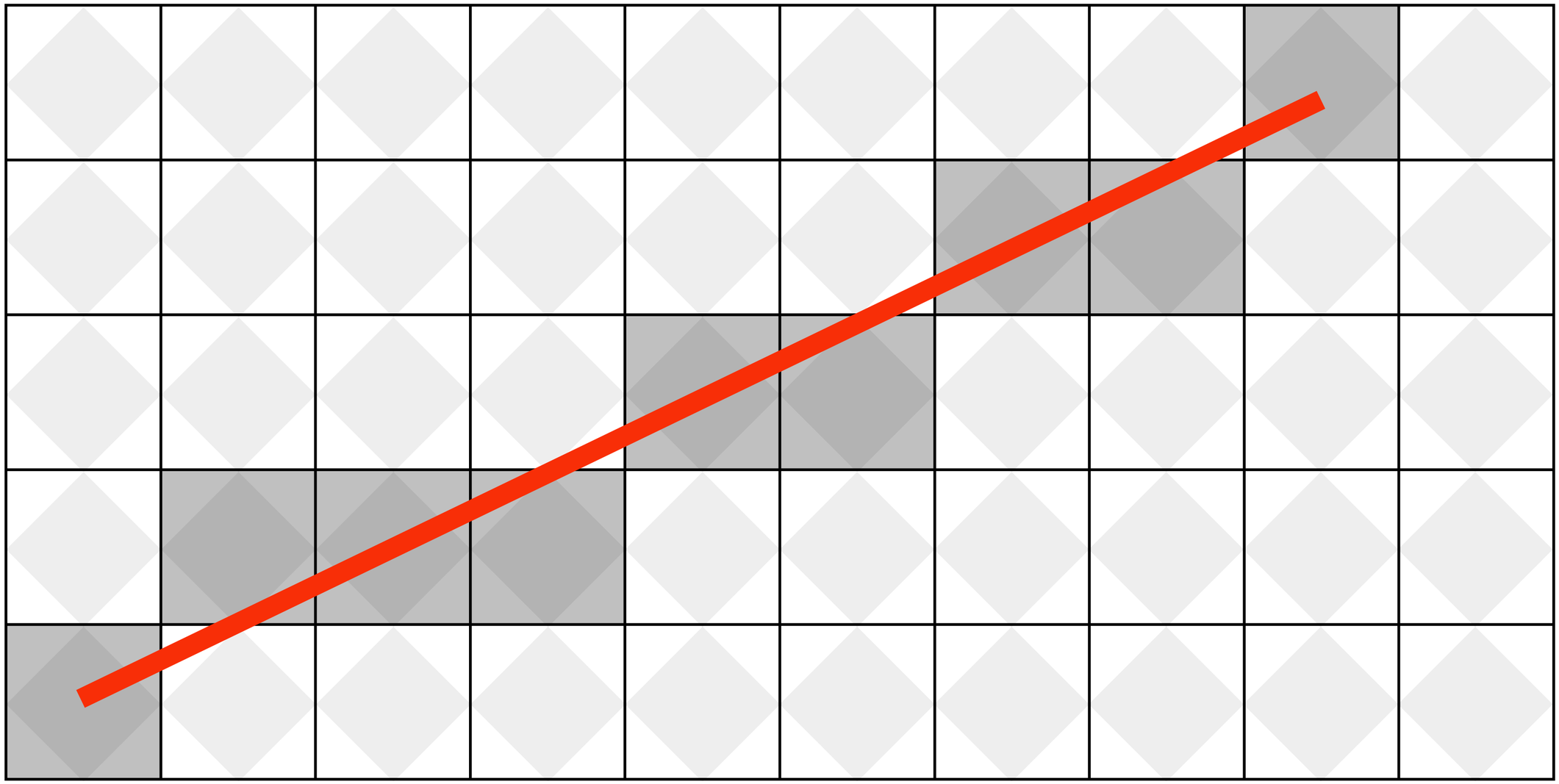
What pixels should we color in to depict a line?

Light up all pixels intersected by the line?



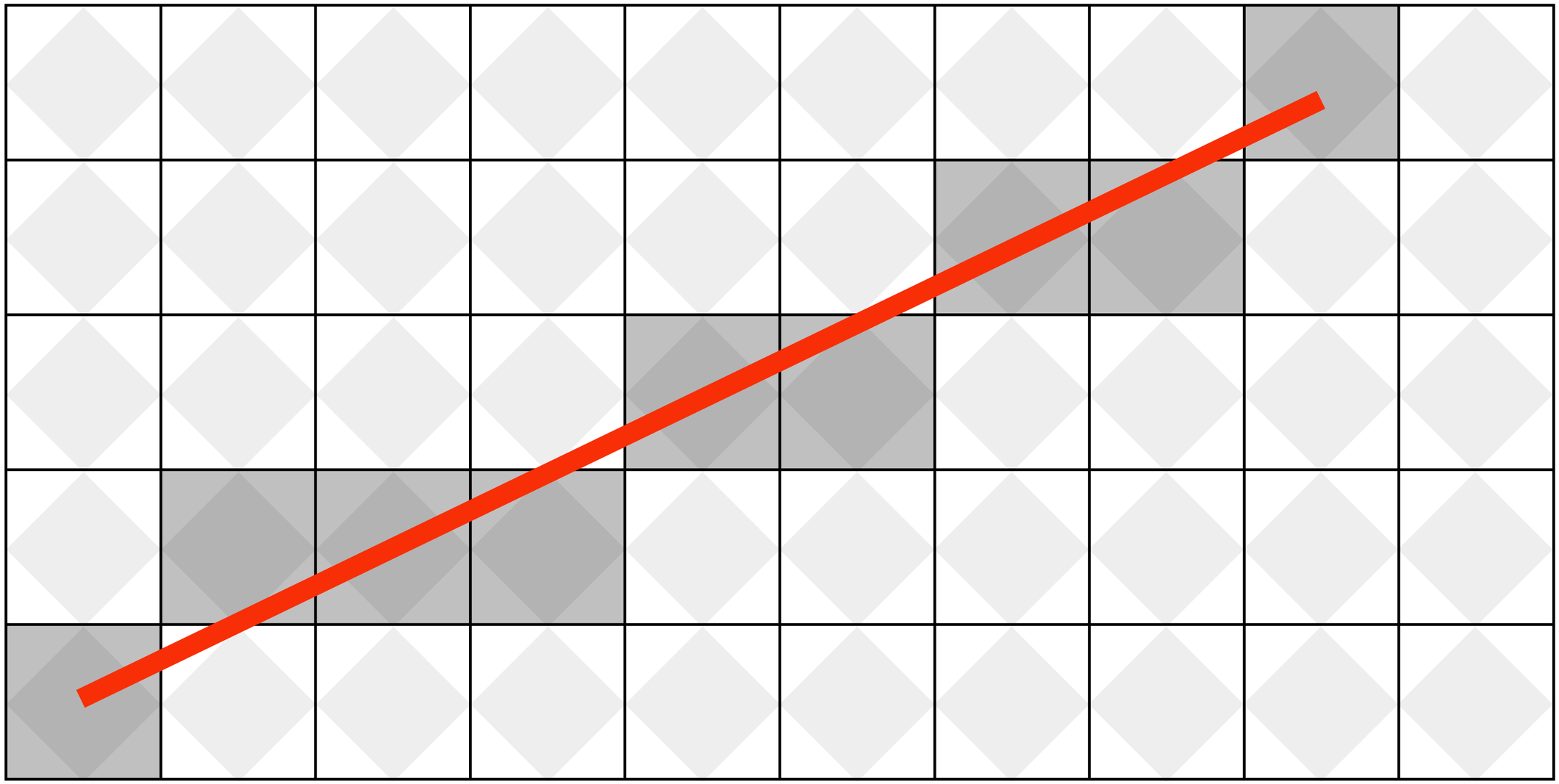
What pixels should we color in to depict a line?

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)



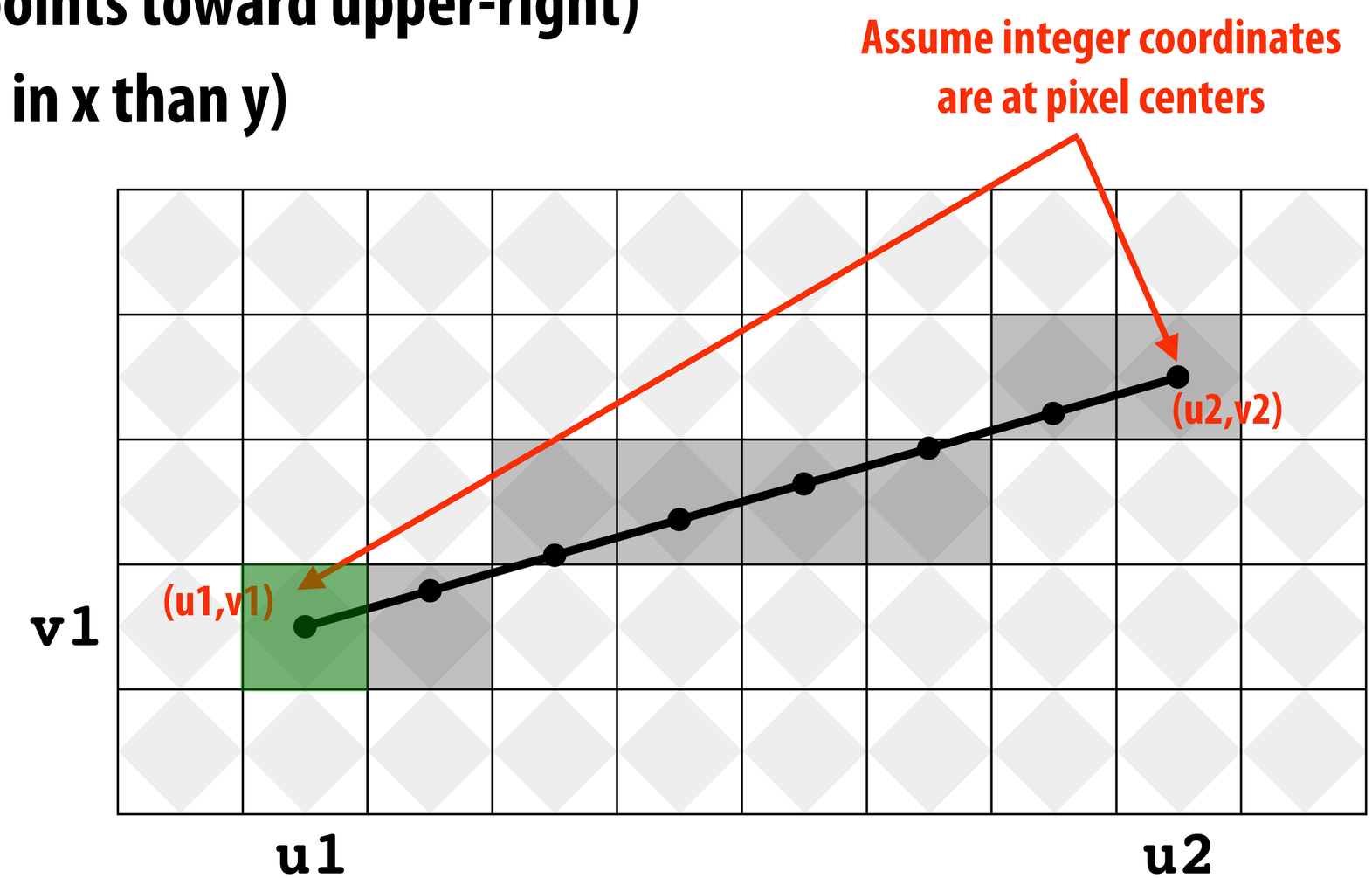
How do we find the pixels satisfying a chosen rasterization rule?

- 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++)
{
  draw(u, round(v))
  v += s;
}
draw(u2, 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

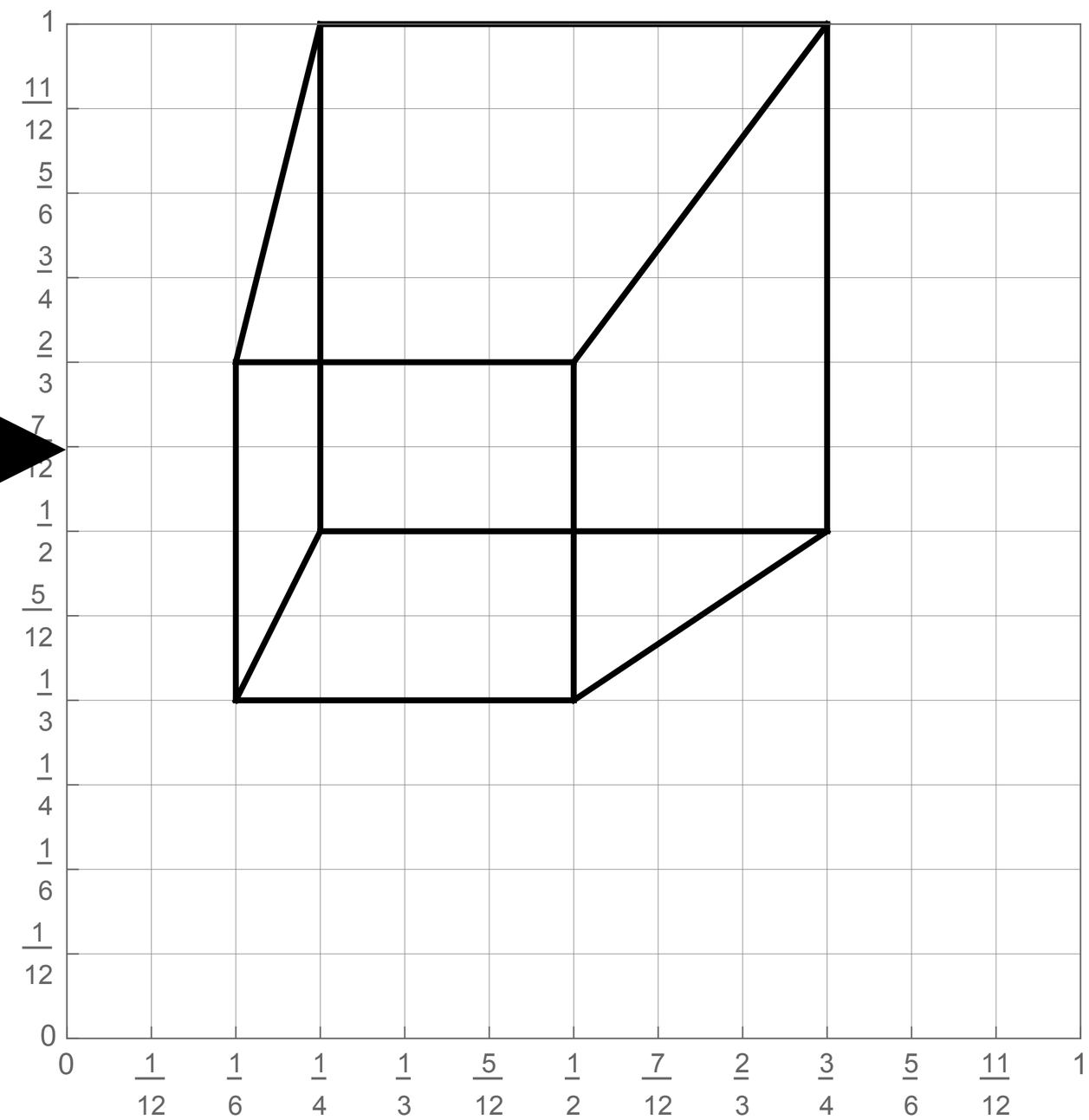
```
VERTICES
A: ( 1, 1, 1 )
B: (-1, 1, 1 )
C: ( 1,-1, 1 )
D: (-1,-1, 1 )
E: ( 1, 1,-1 )
F: (-1, 1,-1 )
G: ( 1,-1,-1 )
H: (-1,-1,-1 )

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.

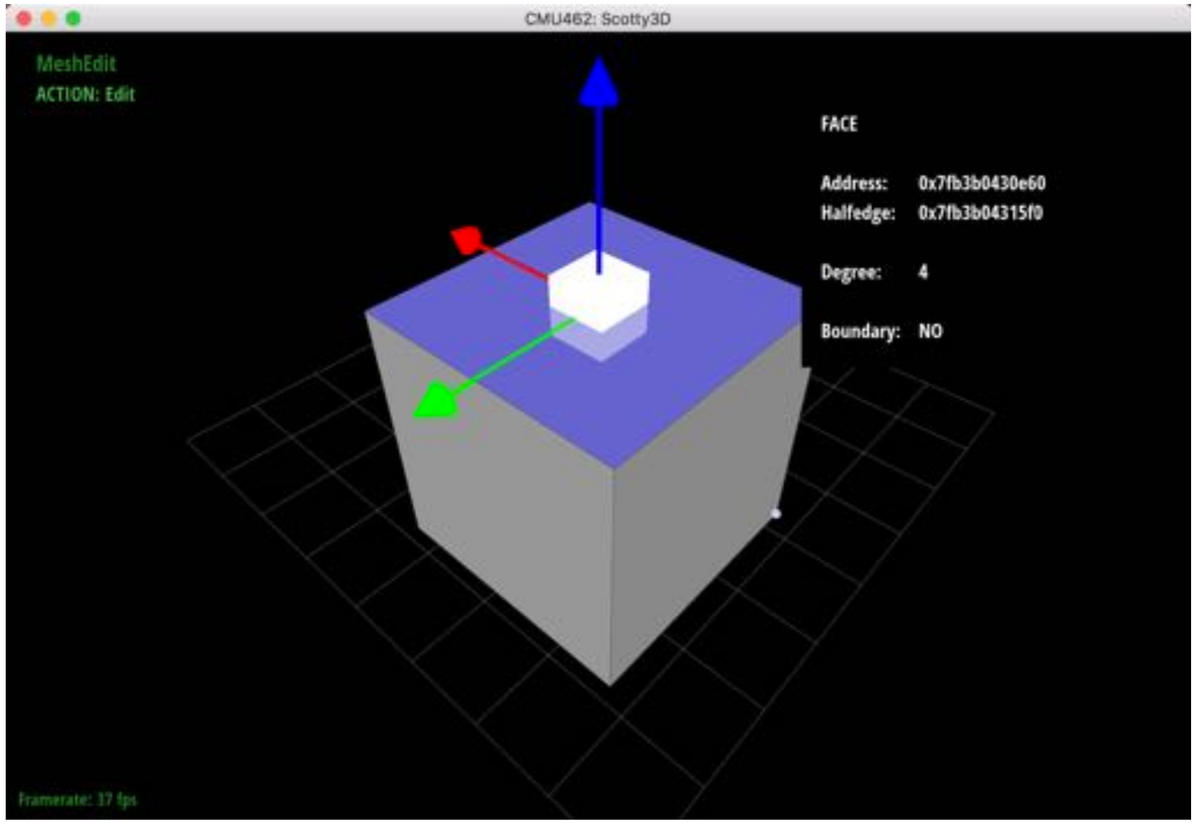
For more realistic pictures, will need a <u>much</u> richer model of the world:

GEOMETRY
MATERIALS
LIGHTS
CAMERAS
MOTION
...

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

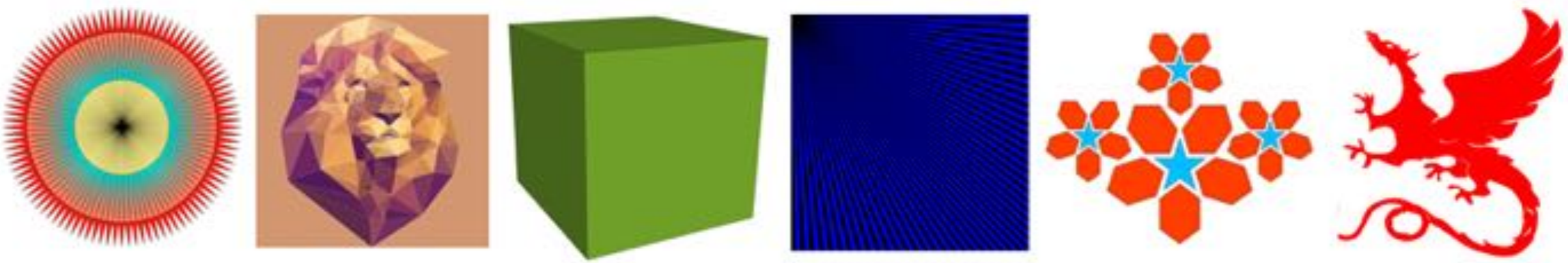
Learn by making/doing!

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

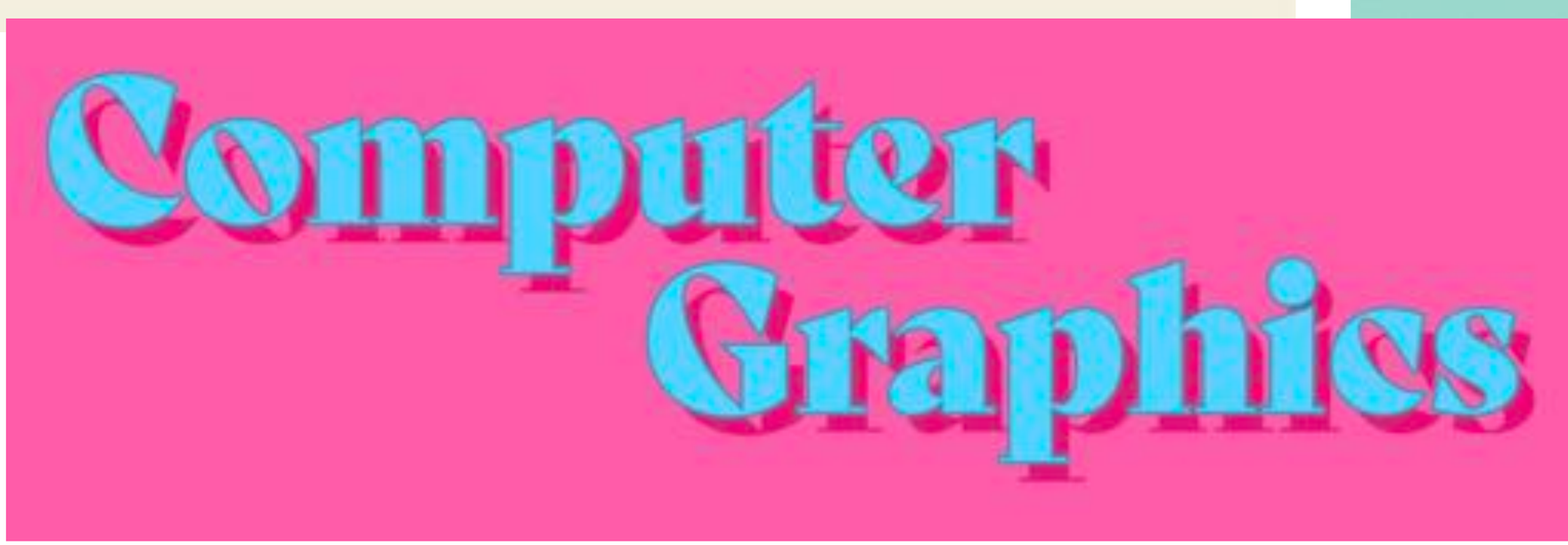


Broken up into four major assignments…

Assignment 1: Rasterization

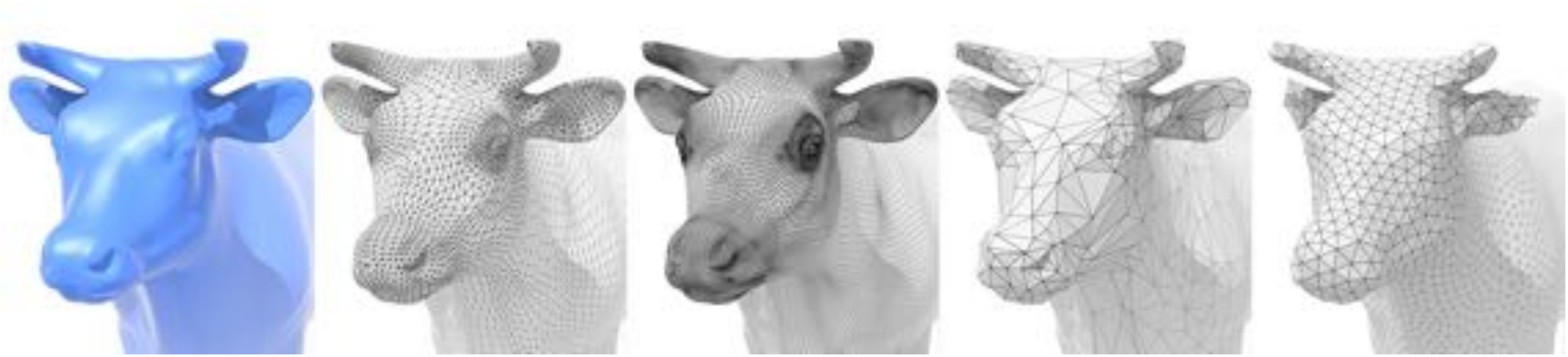


Motivation: display images like these!

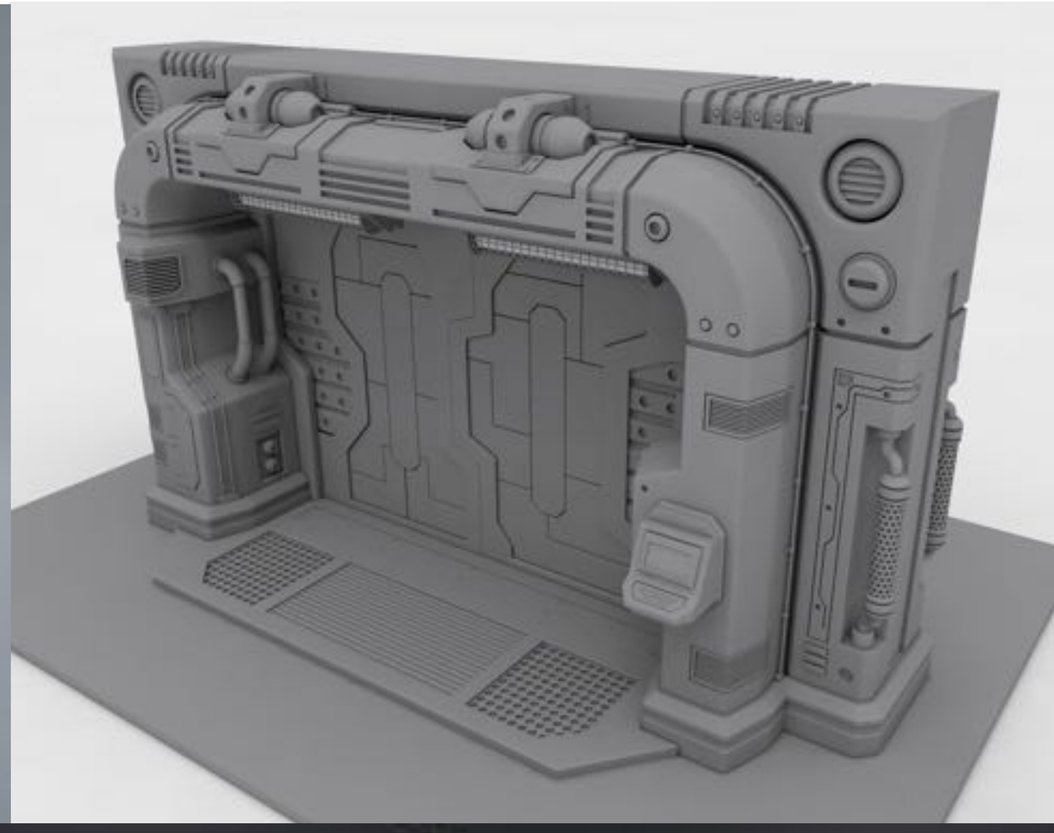


[sources: Charles Williams, @xlavoc on codepen.io]

Assignment 2: Geometric Modeling

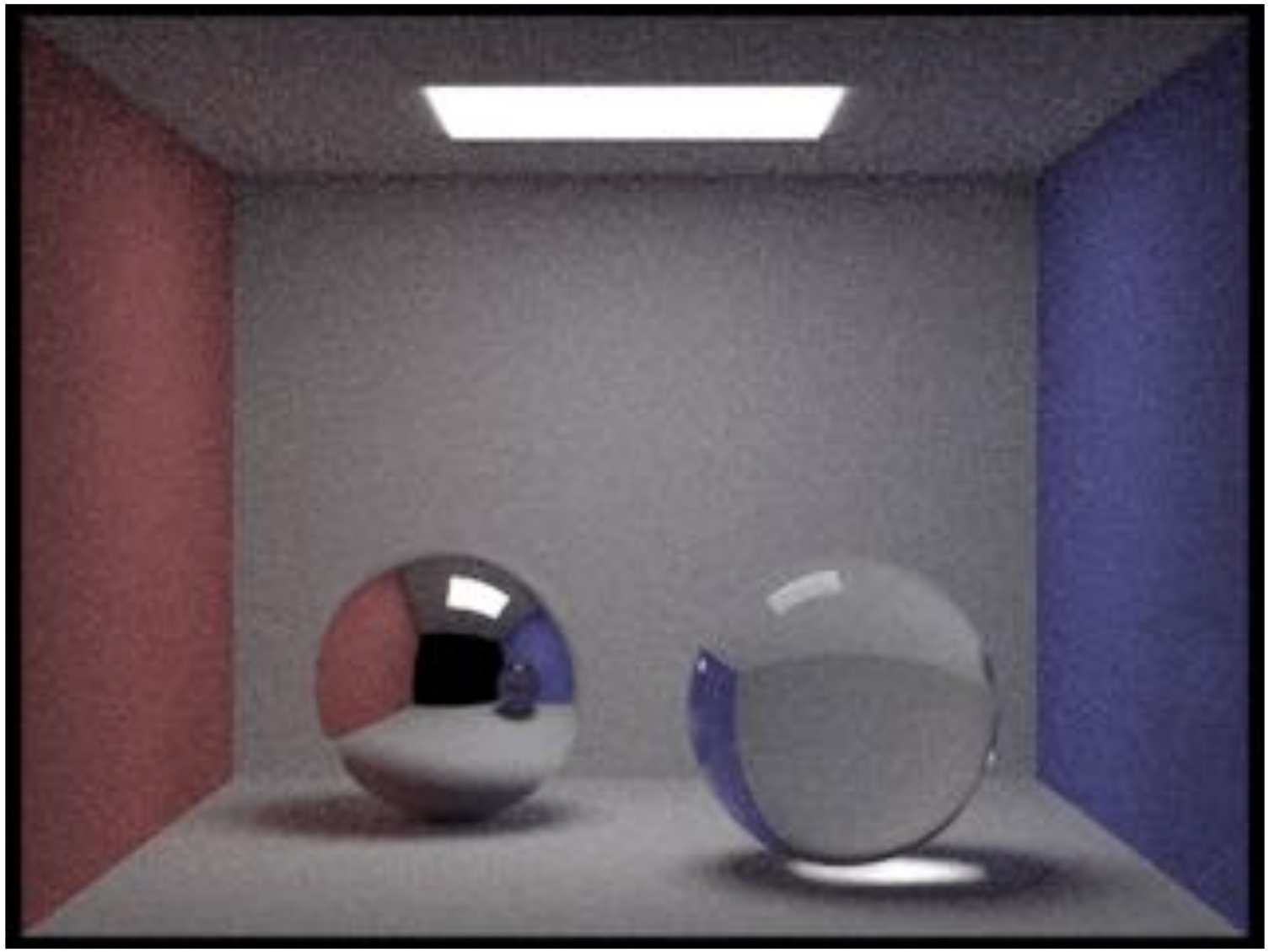


Motivation: create models like these!



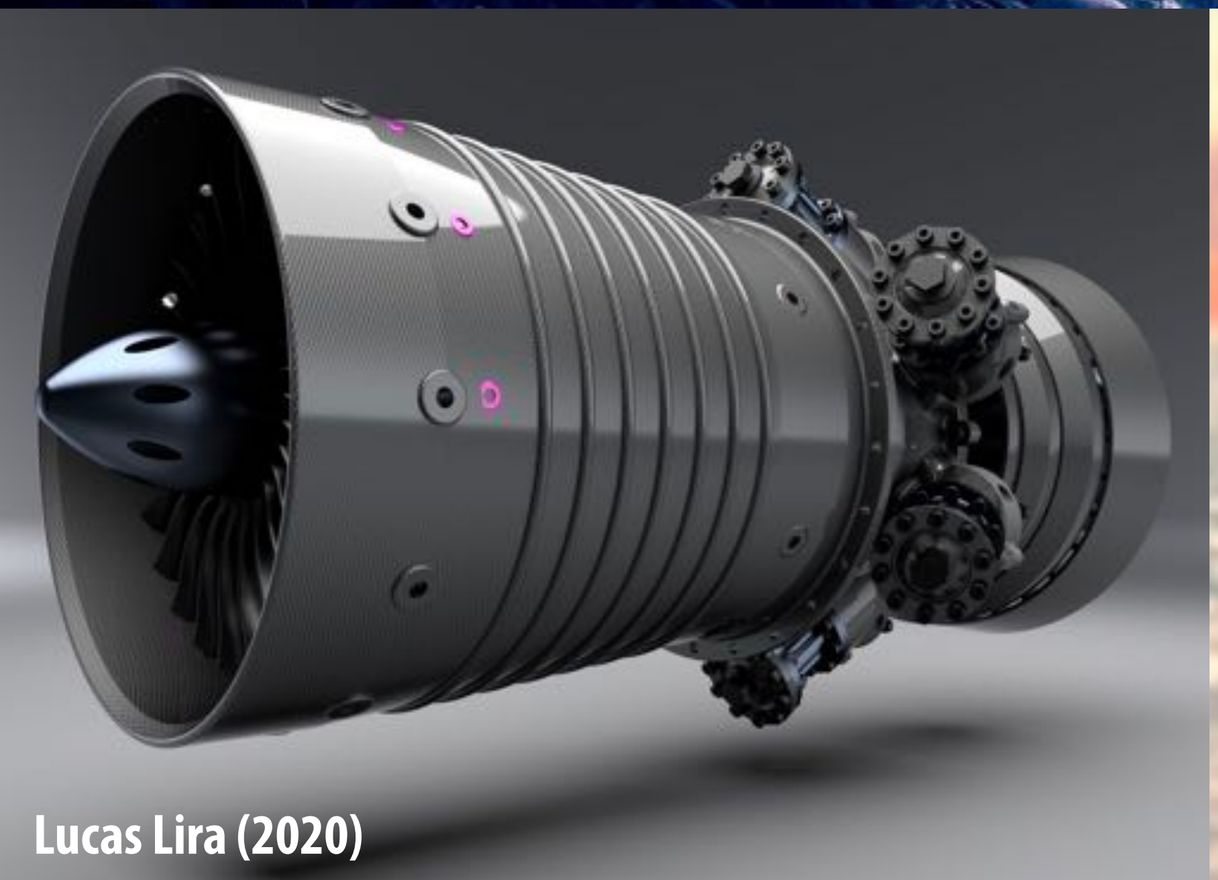
[sources: Richard Yot, 3D-Ace, contrafibbularities,3ddd.ru]

Assignment 3: Photorealistic Rendering



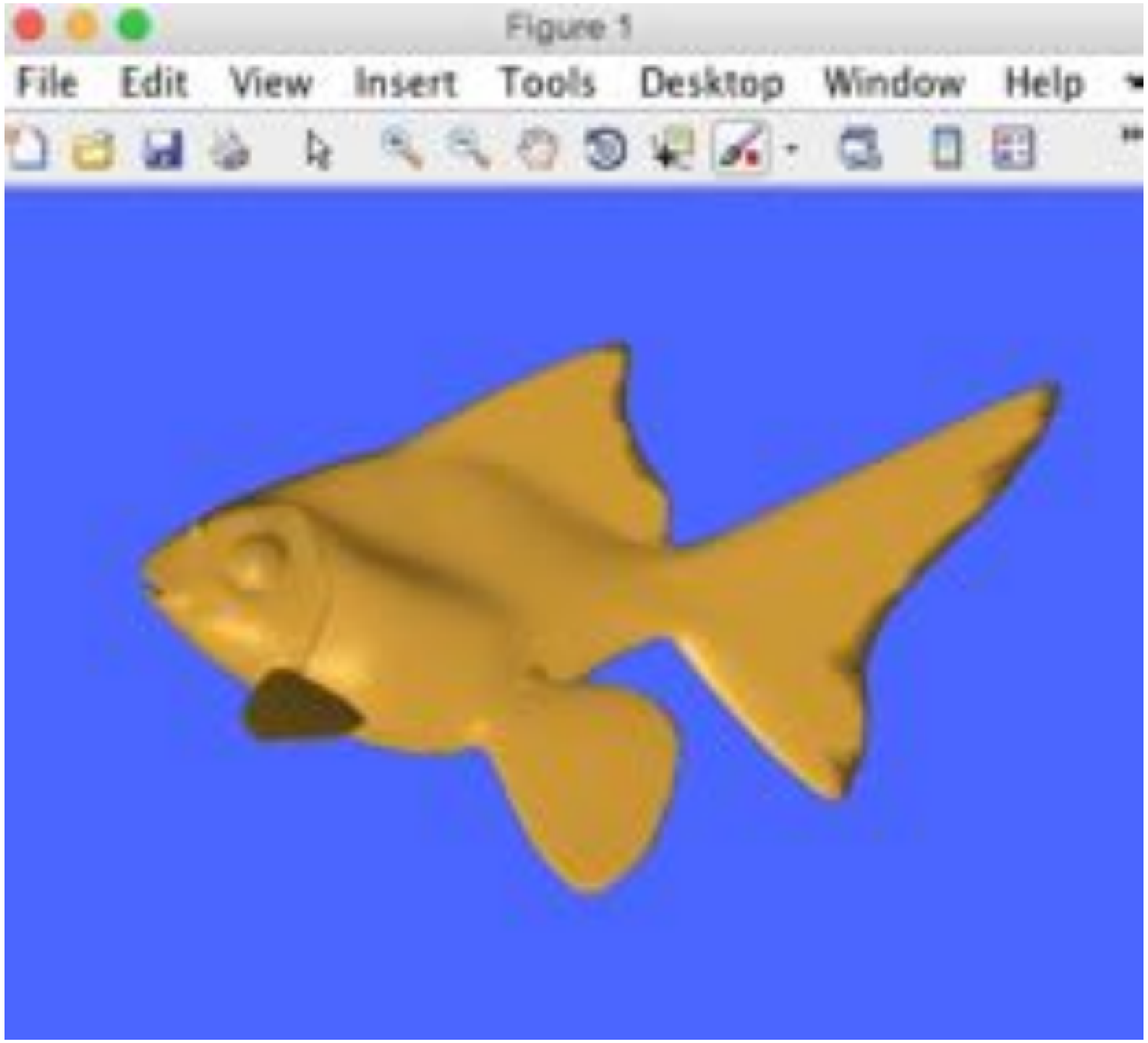
Motivation: render images like these!


WALL-E (Pixar 2009)


Lucas Lira (2020)

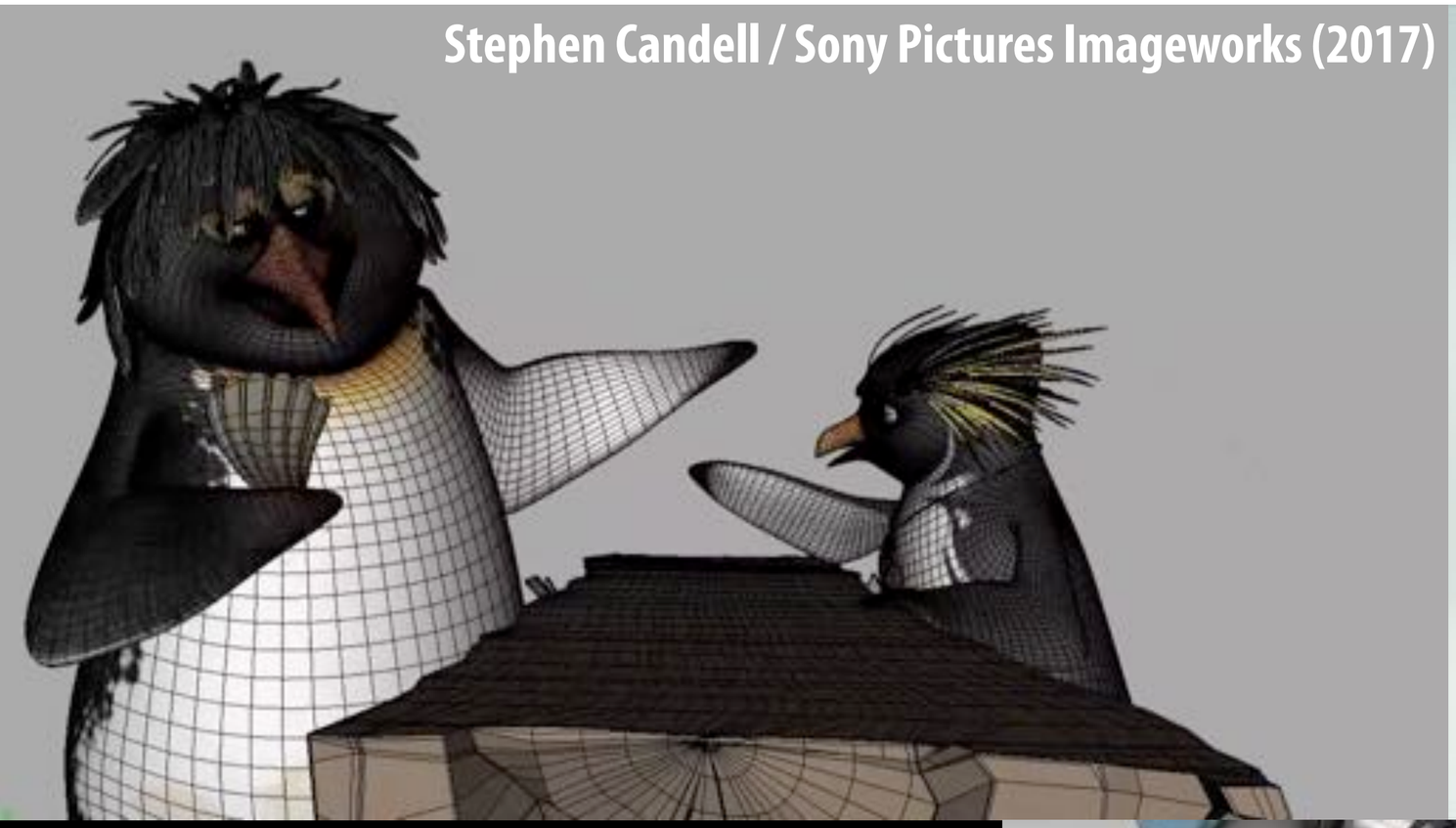

Moana (Disney 2016)

Assignment 4: Animation



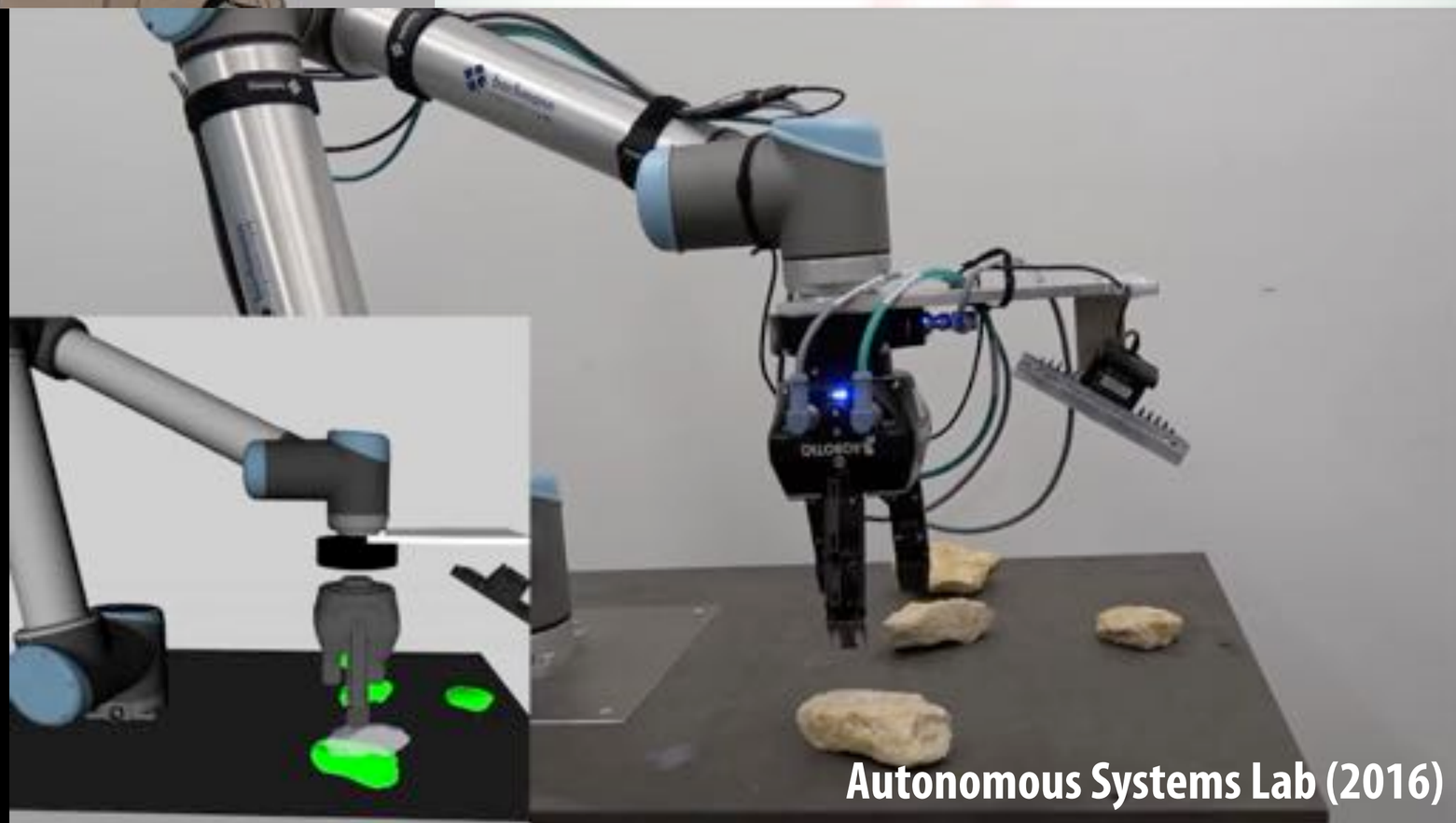
(cribbed from Alec Jacobson)

Motivation: make animations like these!


Stephen Candell / Sony Pictures Imageworks (2017)


Yans Media (2015)


Pixar (2016)


Autonomous Systems Lab (2016)

Gallery of past student projects

https://www.youtube.com/watch?v=yJ5eY3EIImA

A little bit more detail..

Meet our staff!

- Course web page: http://15462.courses.cs.cmu.edu/spring2022/
- Piazza page: https://piazza.com/class/kydbag6zstjxr
- Staff

Alan Lee
[soohyun3 at andrew]
Office hours:
Friday 5-7pm
Location: See Piazza

Sanjay Salem
[svsalem at andrew]
Office hours:
Thursday 6-8
Location: See Piazza

Mia Tang
[xinrant at andrew]
Office hours:
Tuesday 5-7
Location: See Piazza

Daniel Zeng
[dlzeng at andrew]
Office hours:
Wednesday 3-5
Location: See Piazza

Joyce Zhang
[yunyizha at andrew]
Office hours:
Tuesday 5-7
Location: See Piazza

Spring 2022 Schedule

Jan 19	**Course Introduction**
Jan 24	**Math Review Part I (Linear Algebra)** Assignment 0.0 OUT
Jan 26	**Math Review Part II (Vector Calculus)** Assignment 0.0 DUE Assignment 0.5 OUT
Jan 31	**Drawing a Triangle** Assignment 0.5 DUE Assignment 1.0 OUT
Feb 2	**Coordinate Spaces and Transformations**
Feb 7	**3D Rotations and Complex Representations**
Feb 9	**Perspective Projection and Texture Mapping** Assignment 1.0 DUE Assignment 1.5 OUT
Feb 14	**Depth and Transparency**
Feb 16	**Intro to Geometry / Manifolds / Local Operations on Manifolds** Assignment 1.5 DUE Assignment 2.0 OUT
Feb 21	**Midterm Review**
Feb 23	**MIDTERM EXAM**
Feb 28	**Midterm Revisited / Subdivision**
Mar 2	**Geometric Queries** Assignment 2.0 DUE Assignment 2.5 OUT
Mar 7	**SPRING BREAK**
Mar 9	**SPRING BREAK**
Mar 14	**Spatial Data Structures**
Mar 16	**Color / Radiometry** Assignment 2.5 DUE (March 18) Assignment 3.0 OUT (March 18)
Mar 21	**The Rendering Equation**
Mar 23	**A3 PathTracer Specifics**
Mar 28	**Numerical Integration** Assignment 3.0 DUE Assignment 3.5 OUT
Mar 30	**Monte Carlo Ray Tracing**
Apr 4	**Variance Reduction**
Apr 6	**More Variance Reduction** Assignment 3.5 DUE
Apr 11	**Introduction to Animation** Assignment 4.0 OUT
Apr 13	**Dynamics and Time Integration**
Apr 18	**Introduction to Optimization**
Apr 20	**Physically-Based Animation and PDEs** Assignment 4.0 DUE Assignment 4.5 OUT
Apr 25	**Final Review**
Apr 27	**Course WrapUp** Assignment 4.5 DUE (April 29)
TBD	**FINAL EXAM**

Grading and Collaboration Policy

- See the course info website — http://15462.courses.cs.cmu.edu/spring2022/courseinfo

What is a Mini Homework?

- Written assignments to supplement lectures and projects
- Roughly once per week
- Can be done in groups of two or three
- Will typically be released on Monday and due the following Monday
- The first one will be out soon!

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!