Lecture 1:

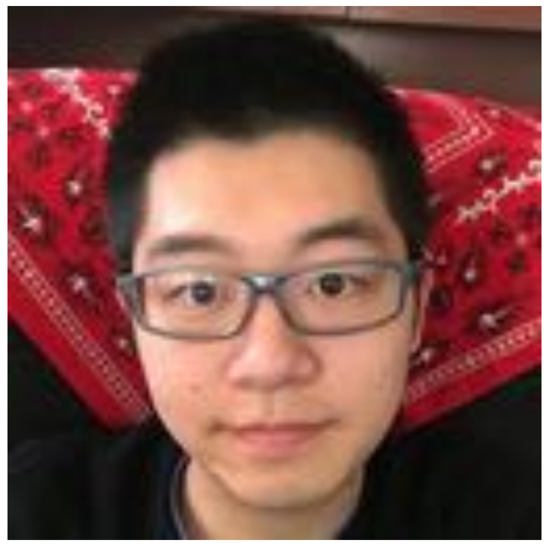
Course Intro:
Welcome to Computer Graphics!

Computer Graphics
CMU 15-462/662, Spring 2019

Hi!

Nancy Pollard

Adrian Biagioli



Connor Lin

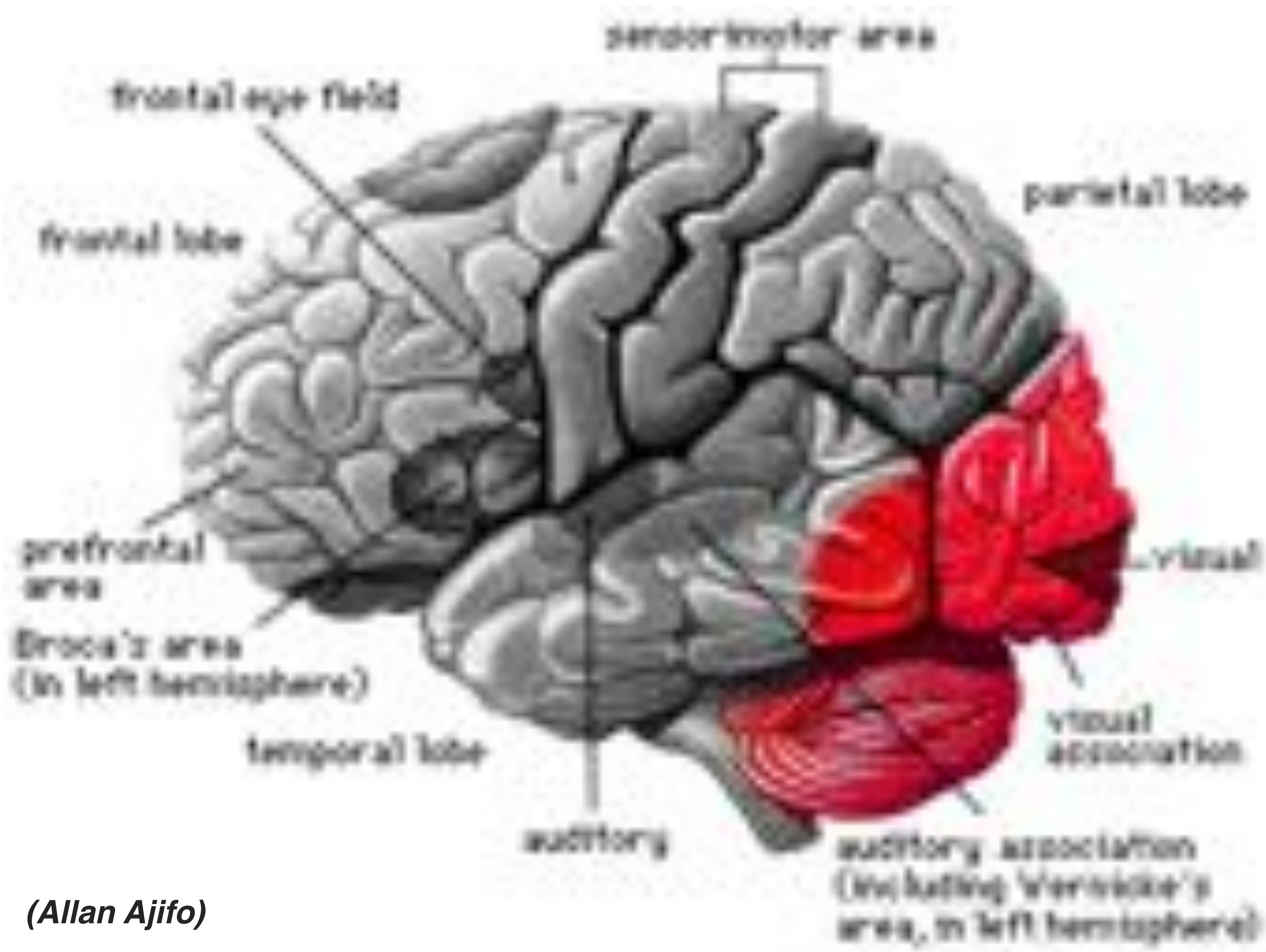
Yuqiao Zeng

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?

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



(Allan Ajifo)


(Petar Milošević)

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

Humans are visual creatures!

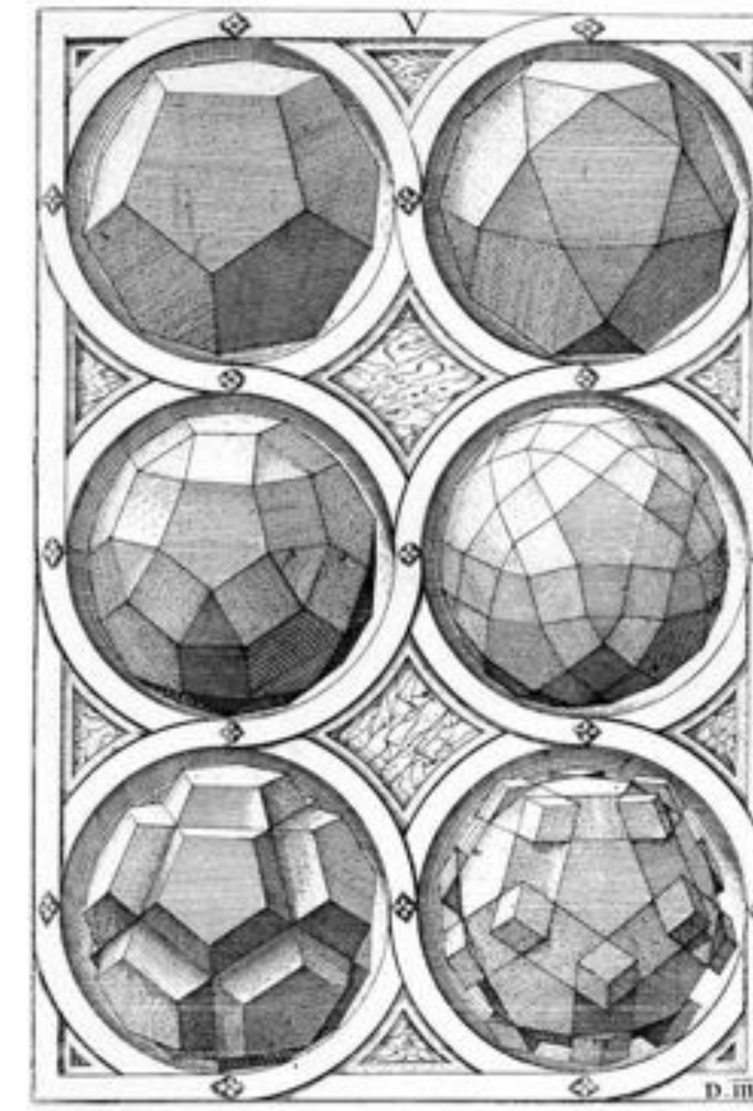
History of visual depiction

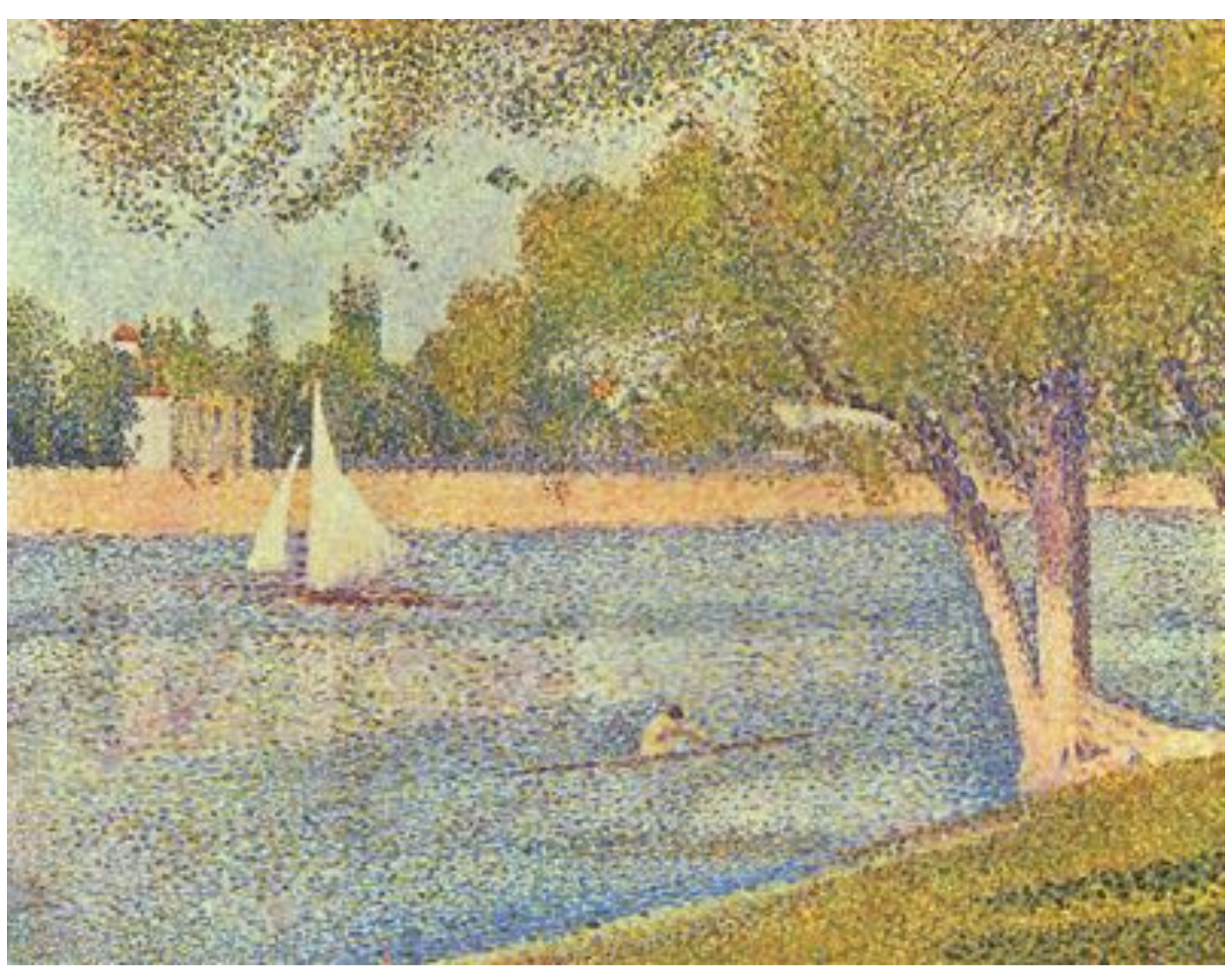
- Humans have always been visual creatures!

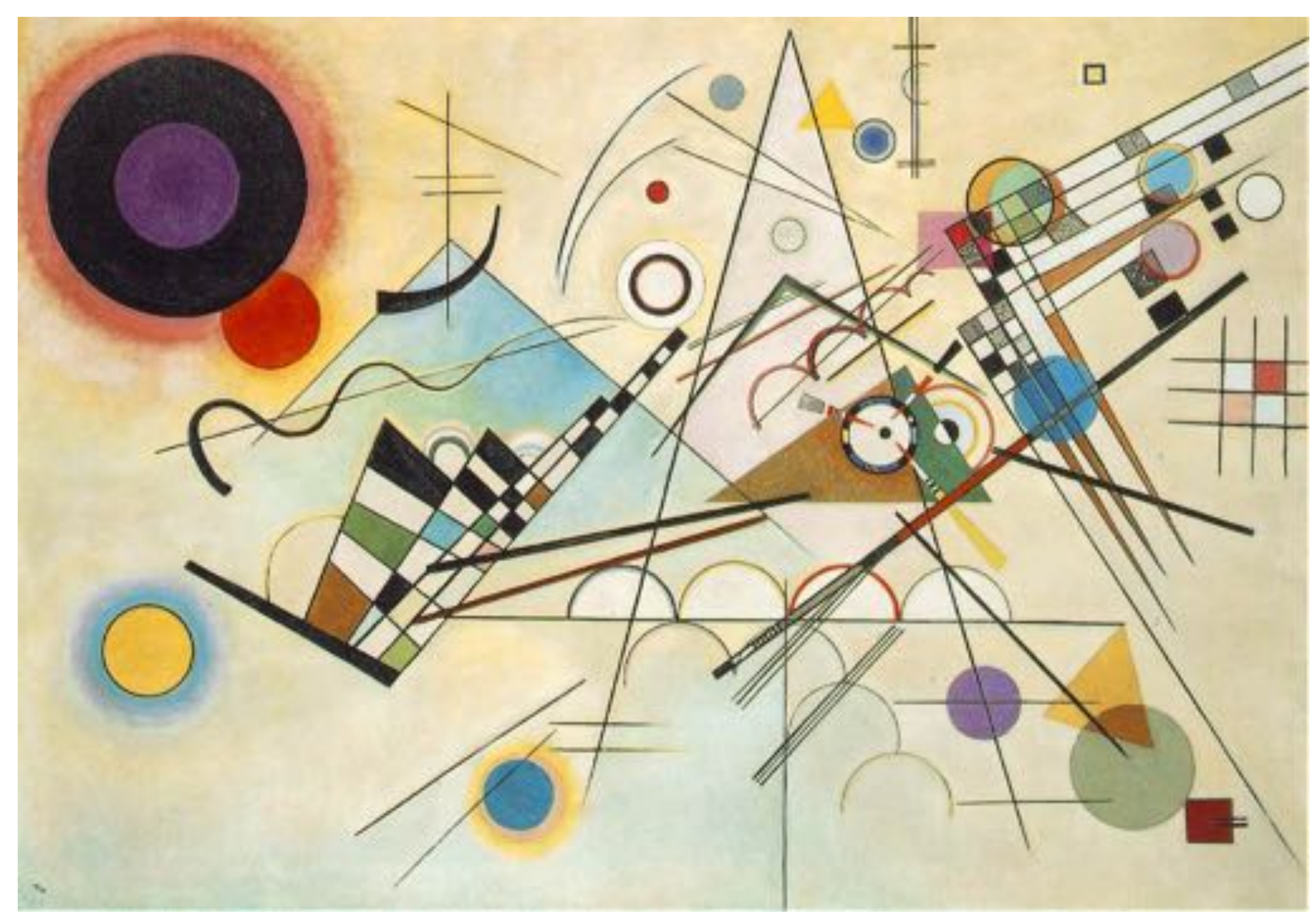
Indonesian cave painting (~38,000 BCE)

Visual technology: painting / illustration

- **Not purely representational: ideas, feelings, data, ...**







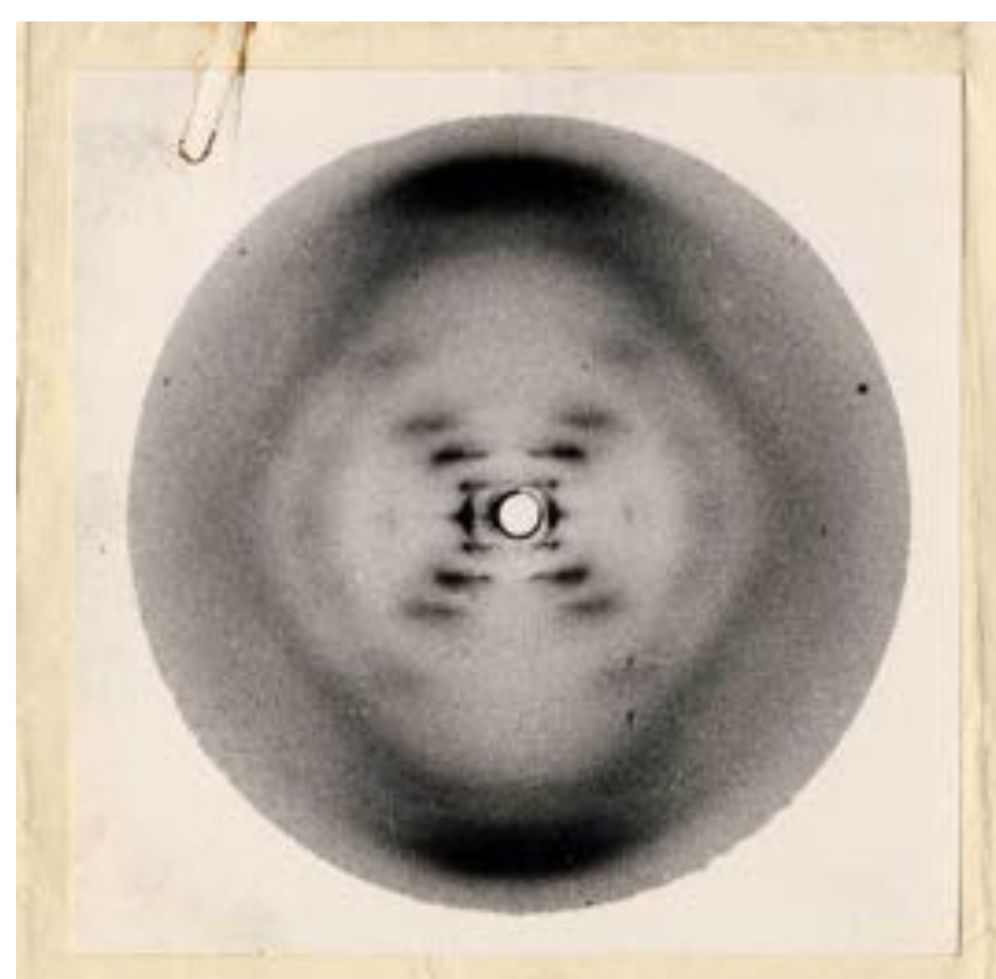
Visual technology: carving / sculpture

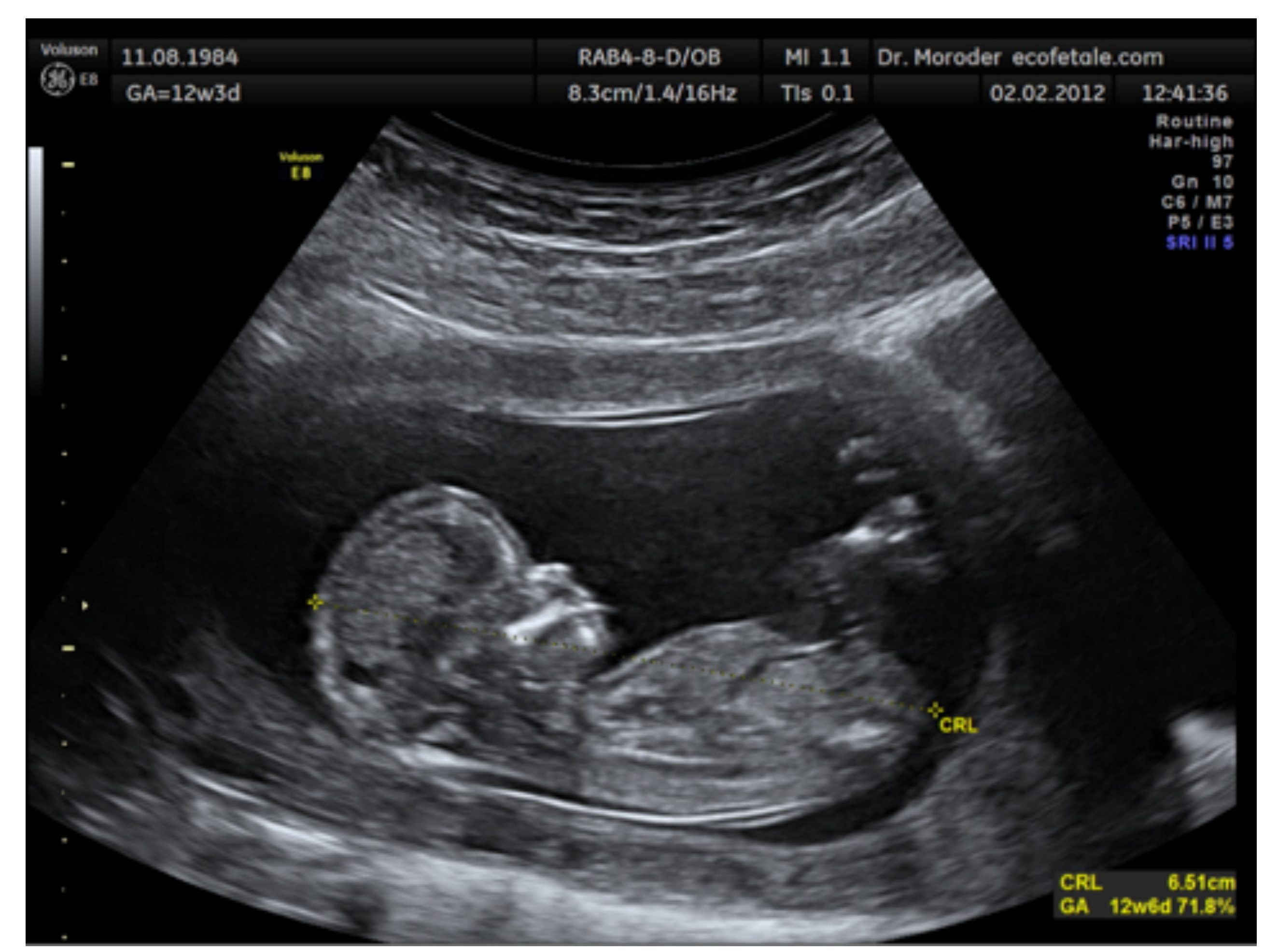
Visual technology: photography / imaging

- **Processing of visual data no longer happening in the head!**

Joseph Niépce, “View from the Window at Le Gras” (1826)

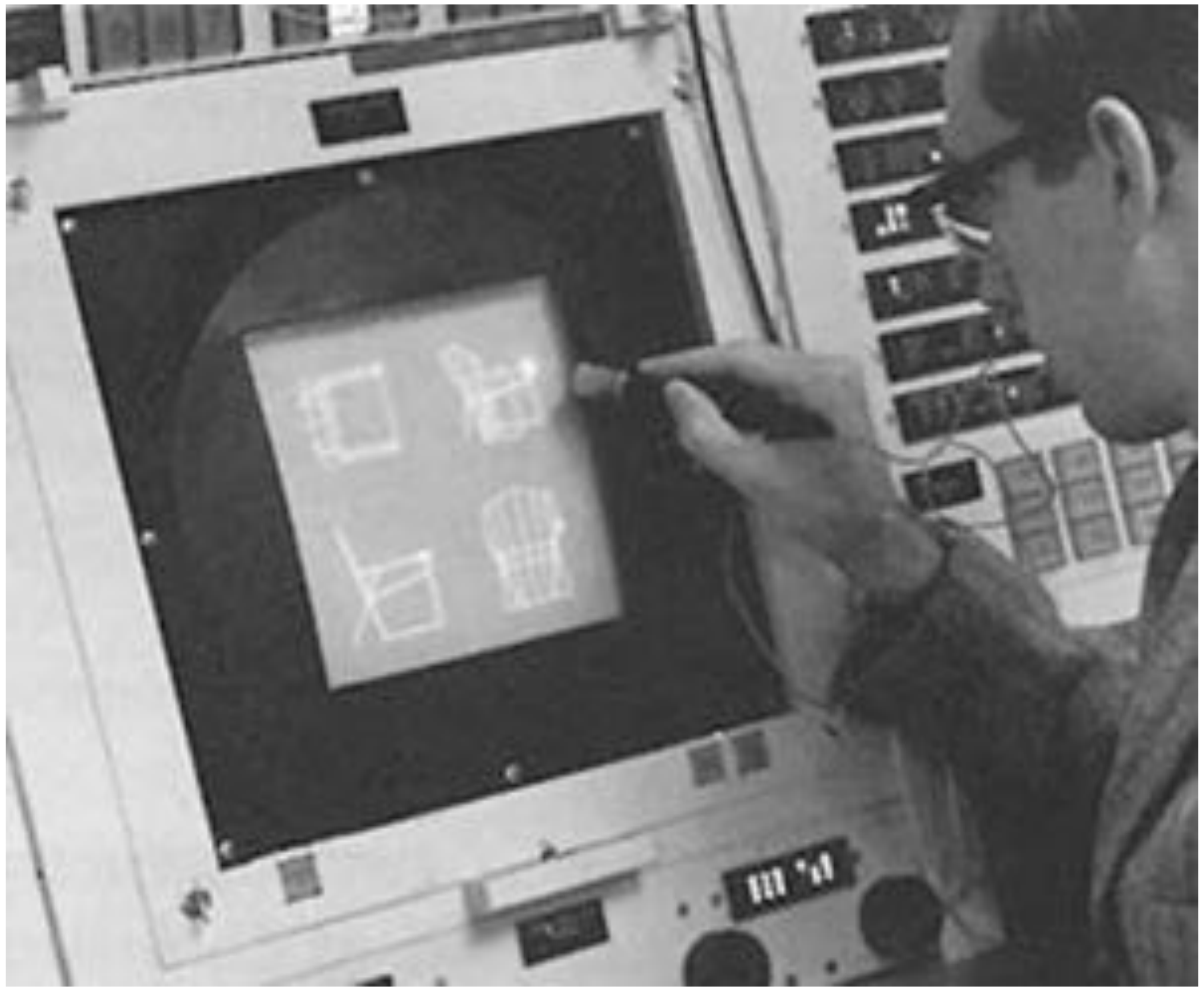
Visual technology: photography / imaging





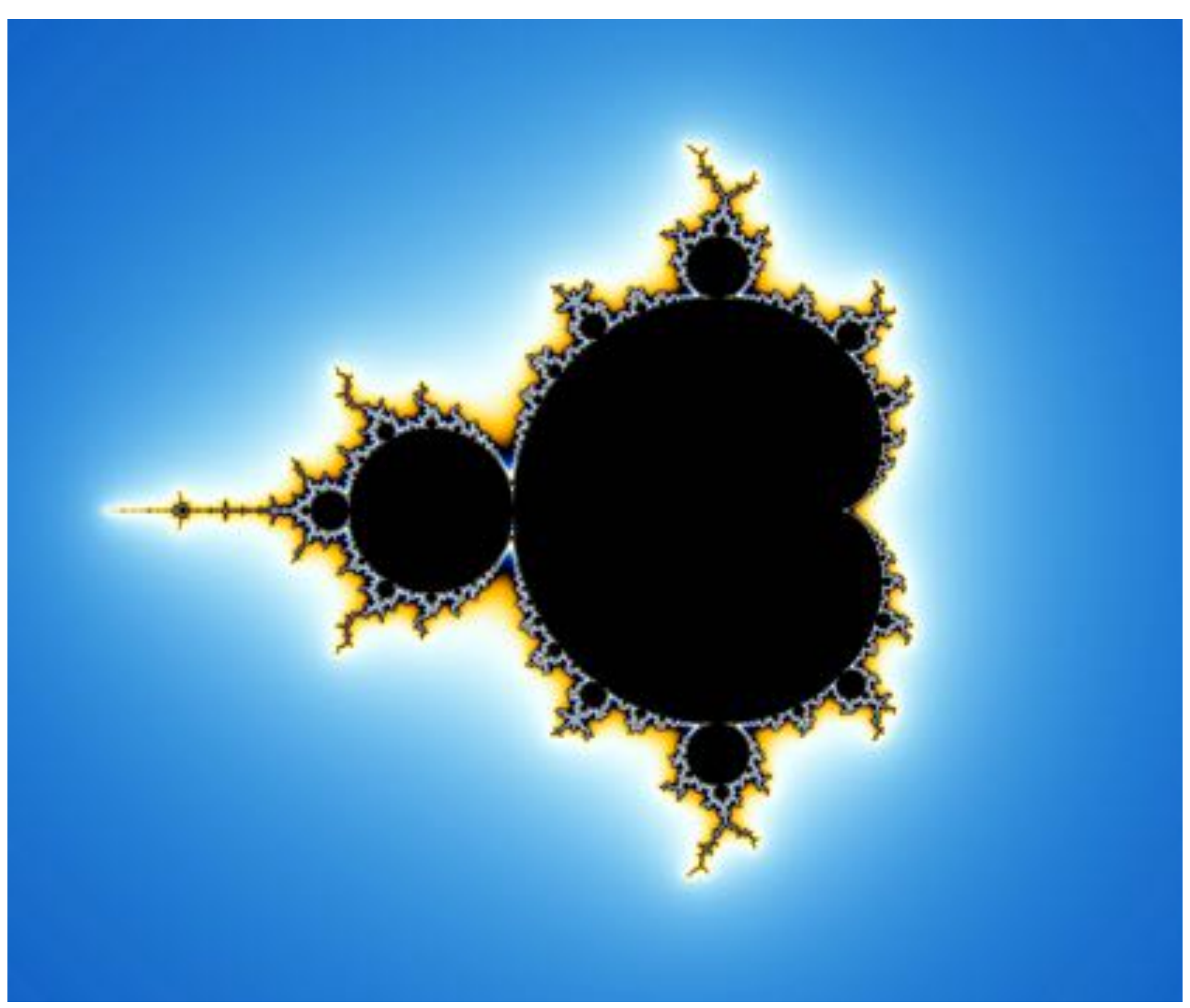
Visual technology: digital imagery

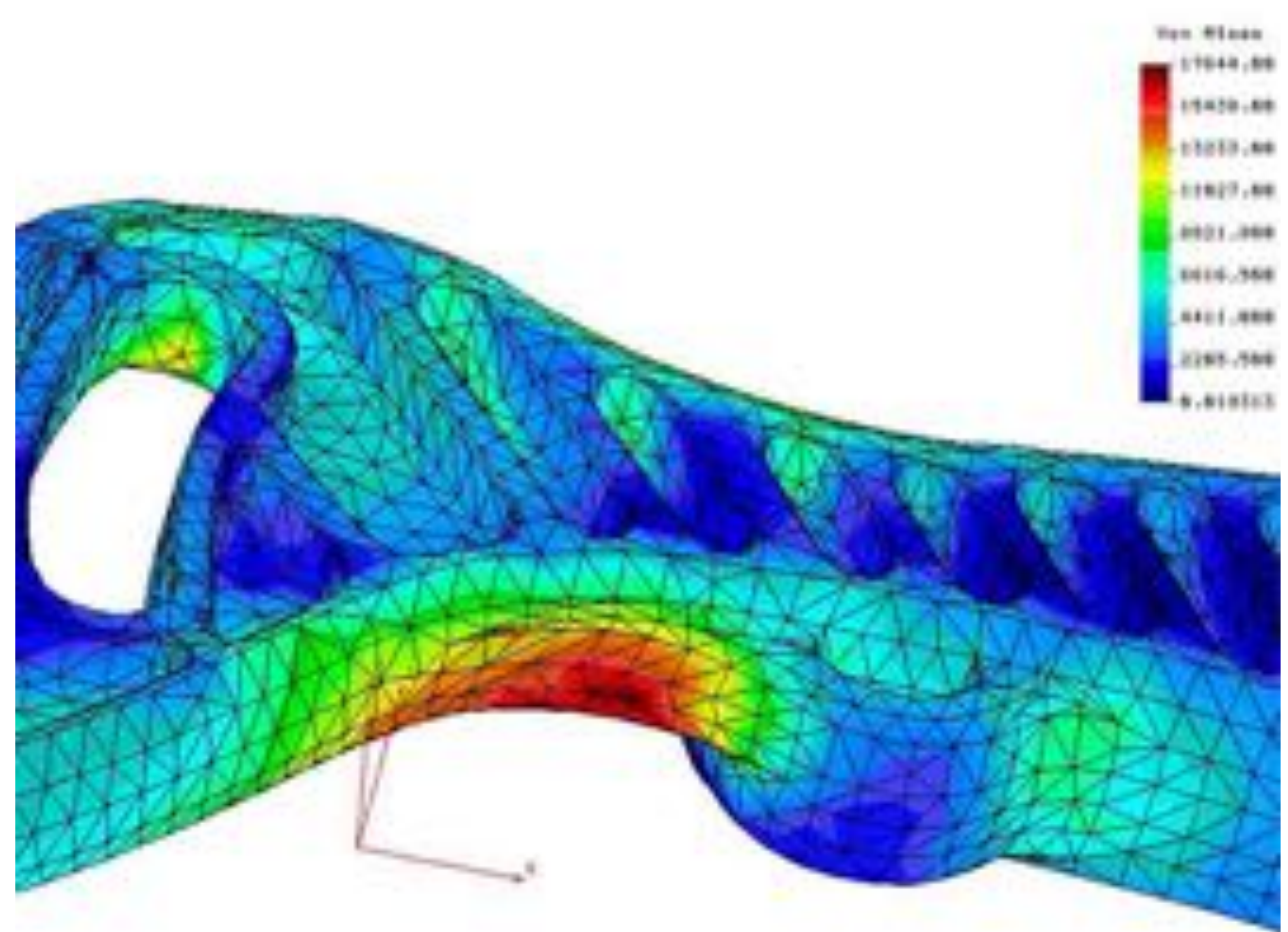
- **Intersection of visual depiction & computation**



Ivan Sutherland, "Sketchpad" (1963)

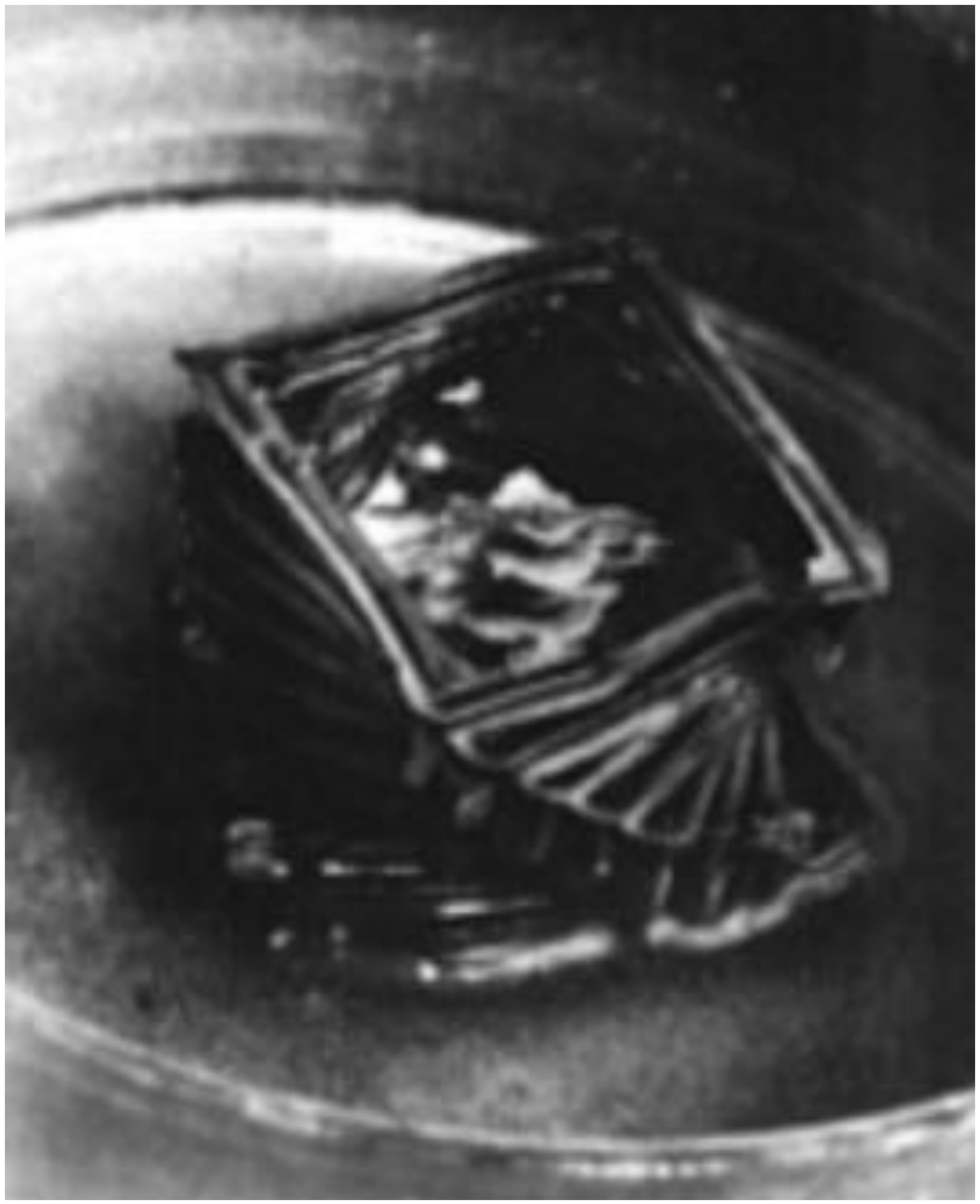
Visual technology: digital imagery

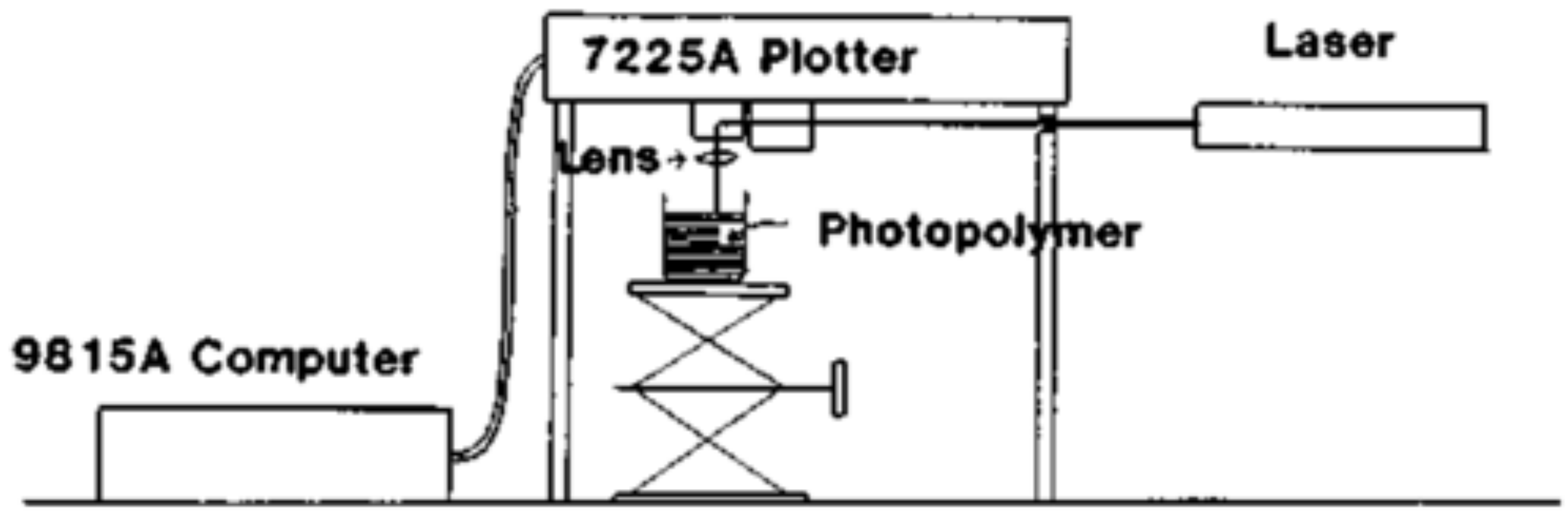




Visual technology: 3D fabrication

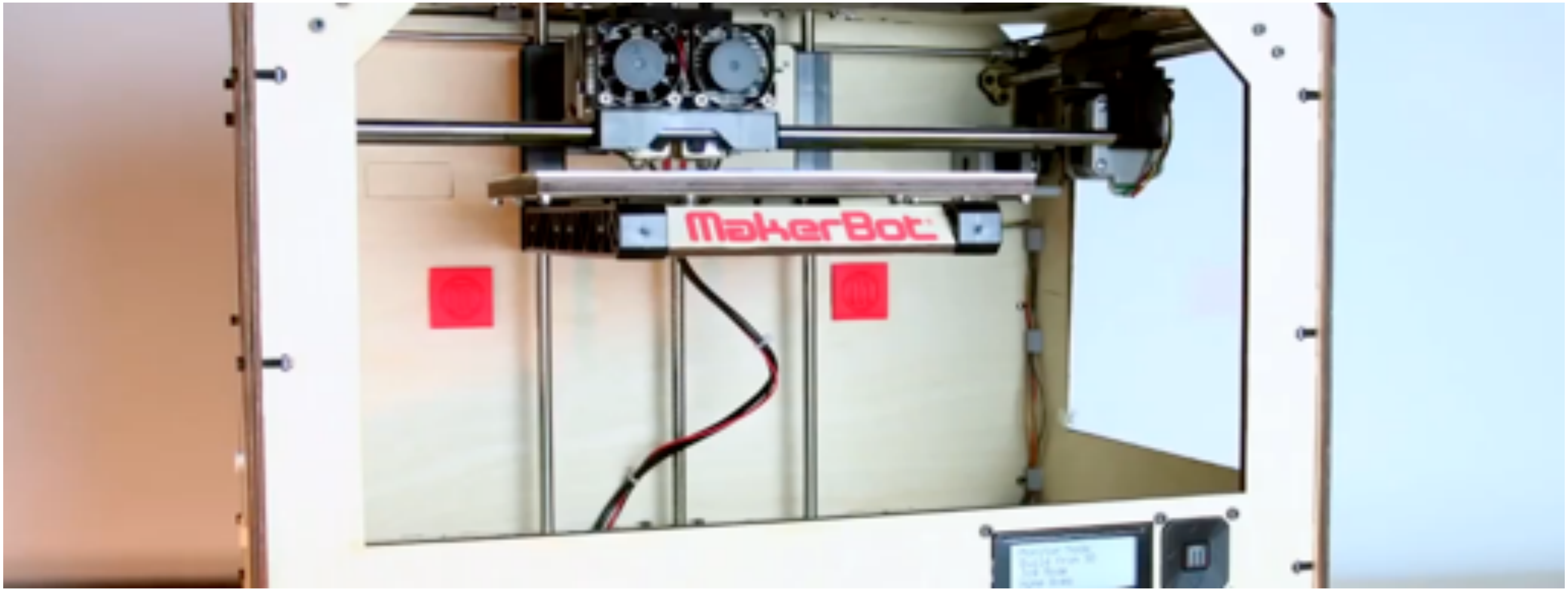
- **Create physical realization of digital shape**

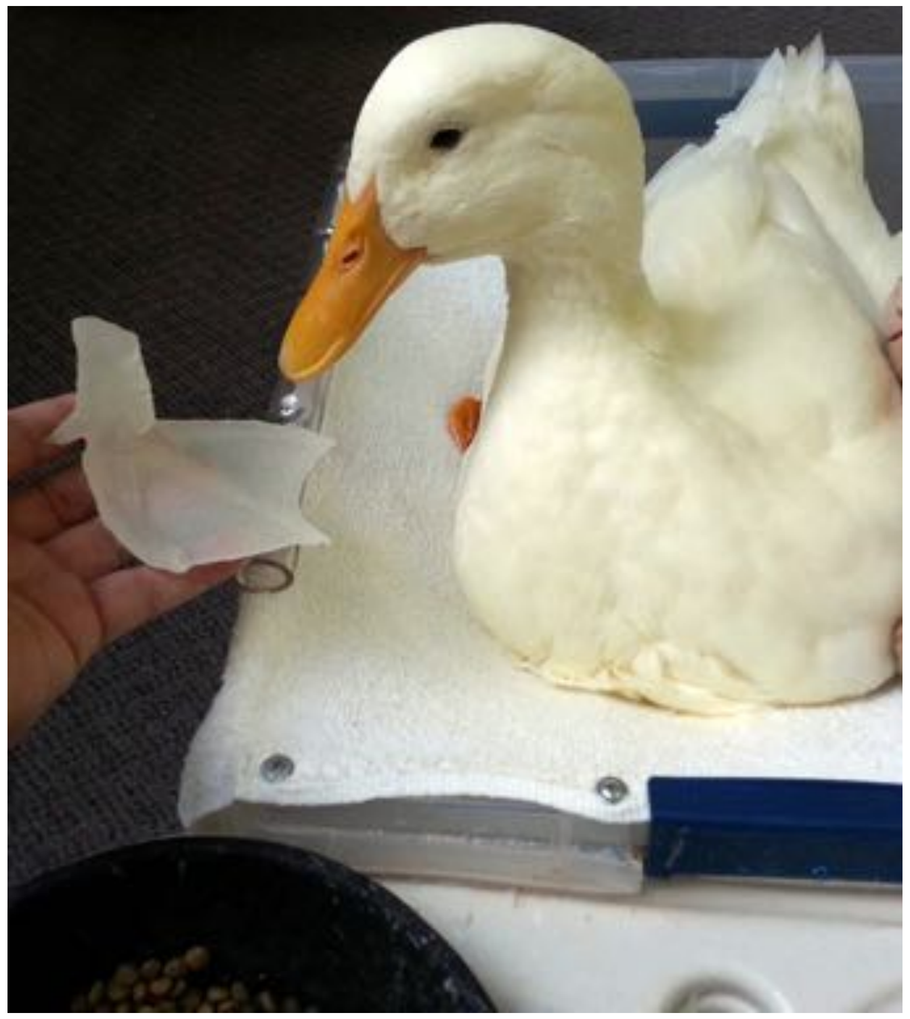




A.J. Herbert / 3M (1979)

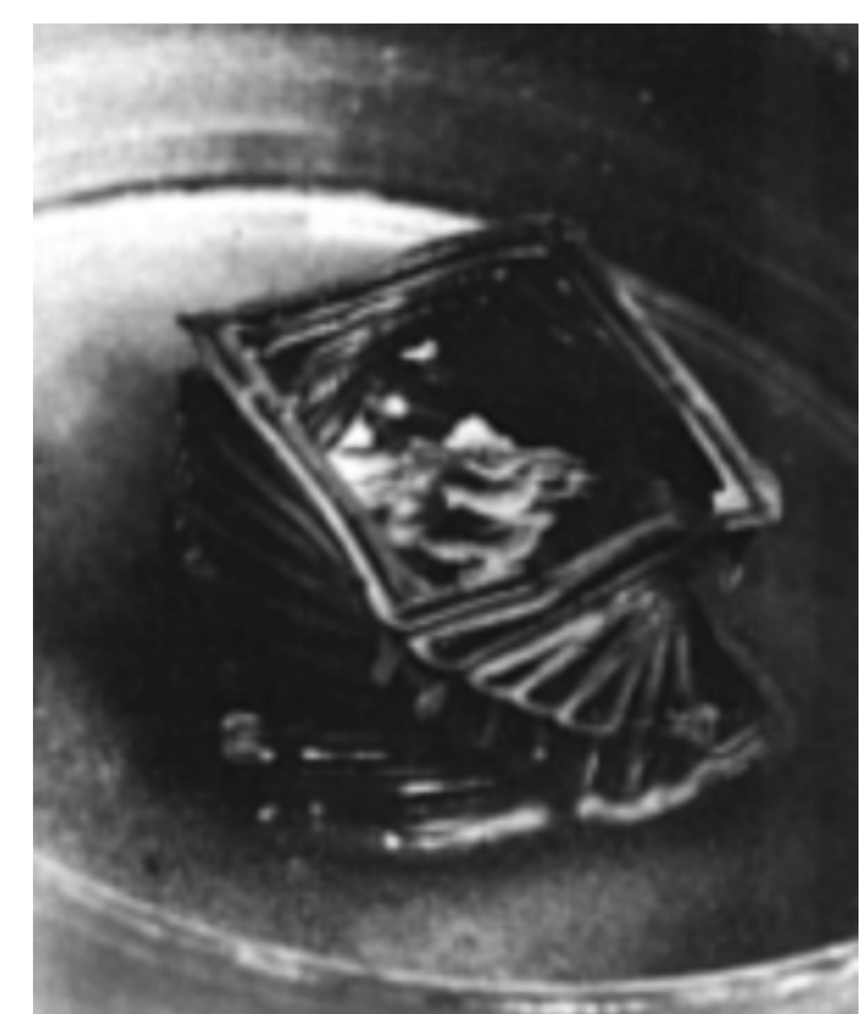
Visual technology: 3D fabrication





Technologies for visual depiction

- Drawing/painting/illustration (~40,000 BCE)
- Sculpture (~40,000 BCE)
- Photography (~1826)
- Digital Imagery (~1963)
- 3D Fabrication (~1979)



Definition of Graphics, Revisited

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

Why only visual?

Graphics as Synthesis of 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?!)

Computer graphics is everywhere!

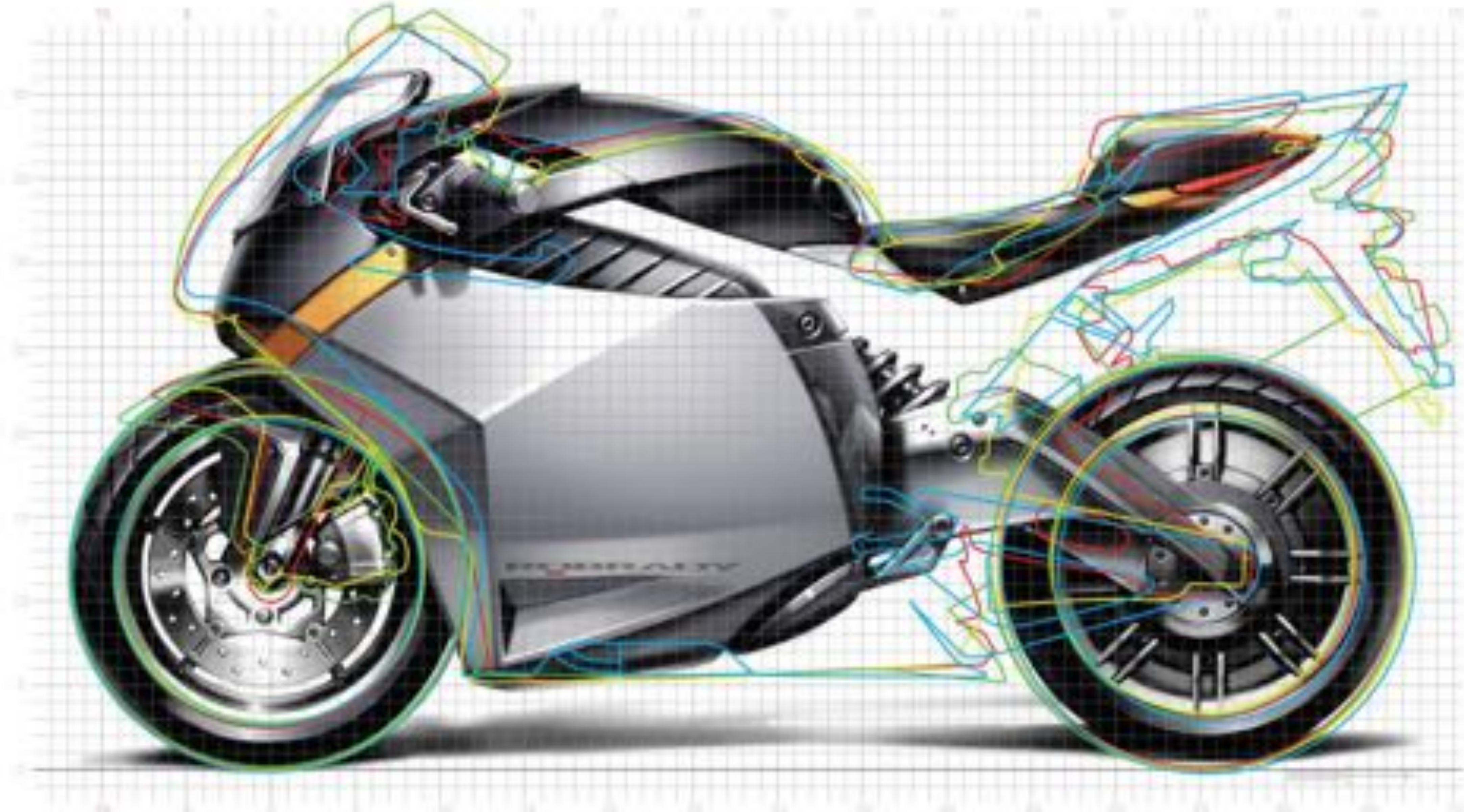
Entertainment (movies, games)

Entertainment

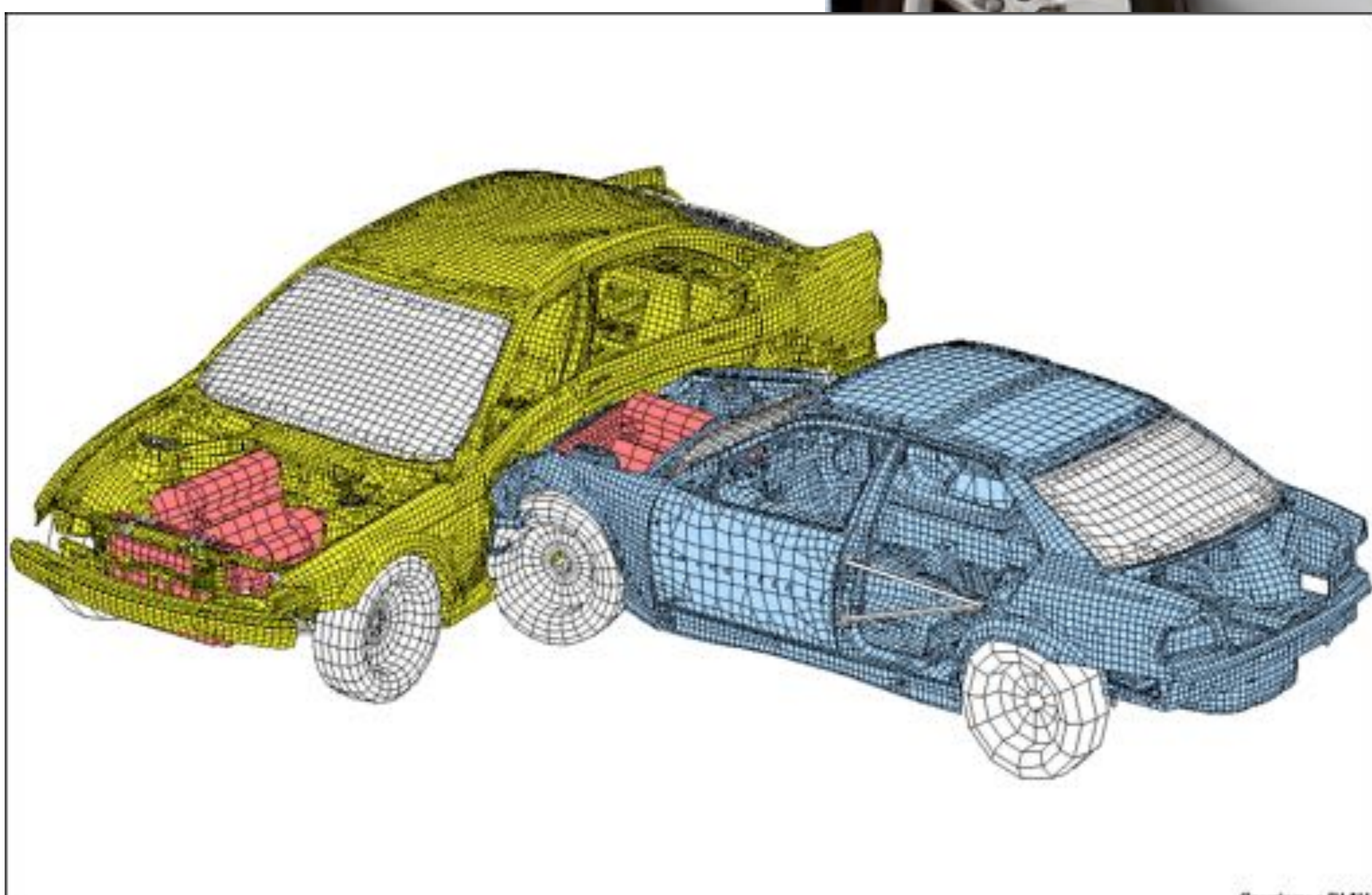
- **Not just cartoons!**

Art and design

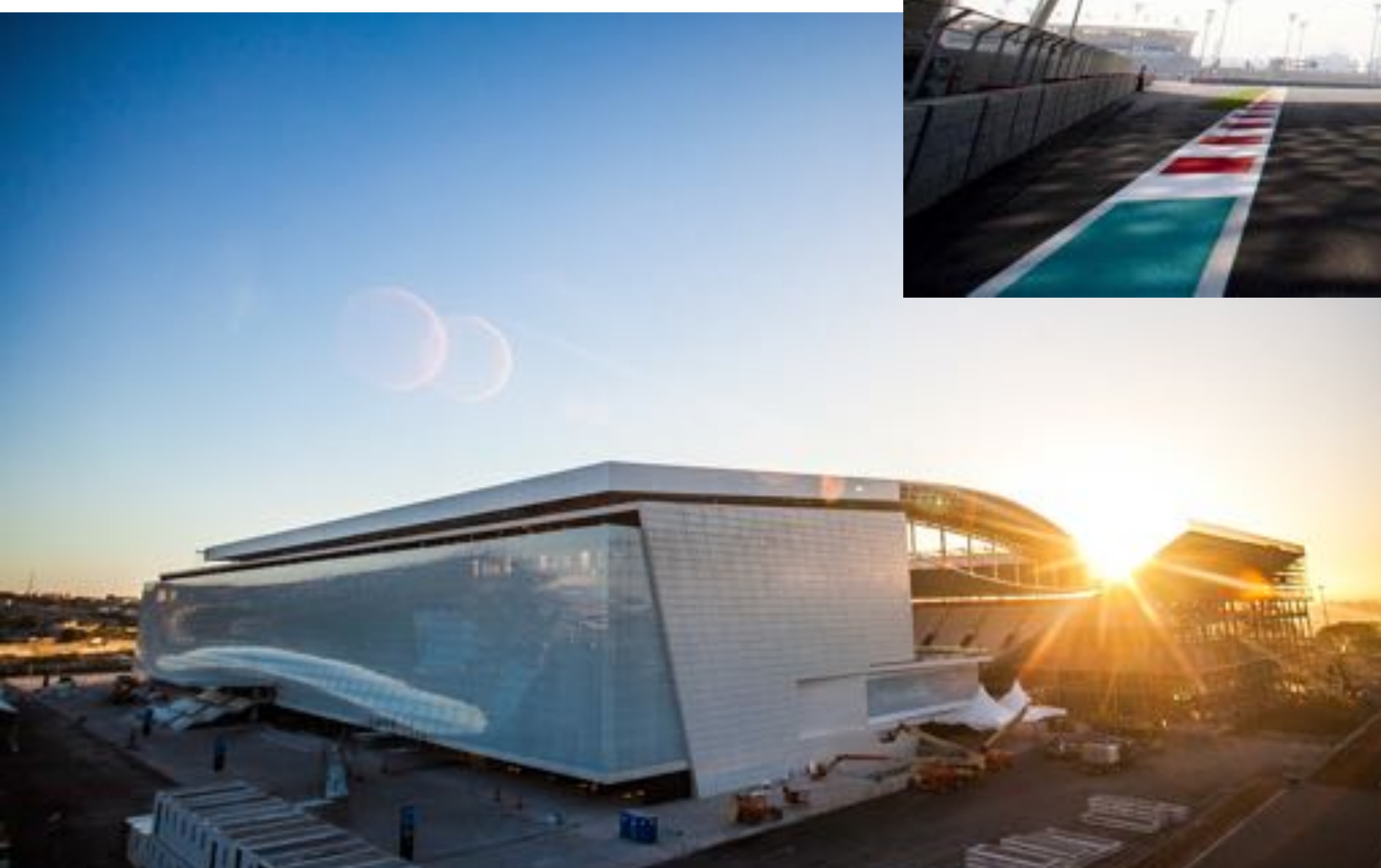
Industrial design



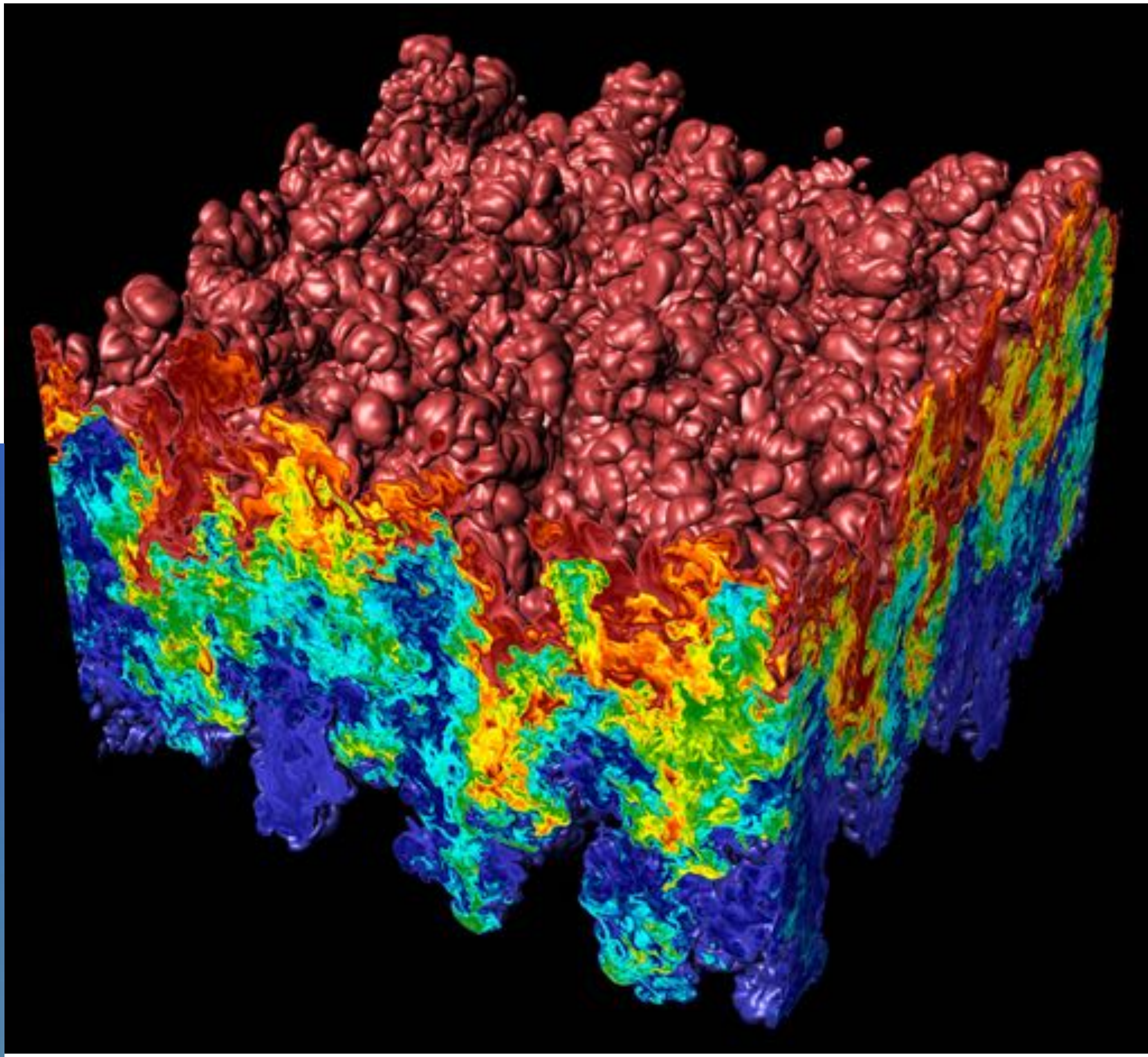
Computer aided engineering (CAE)

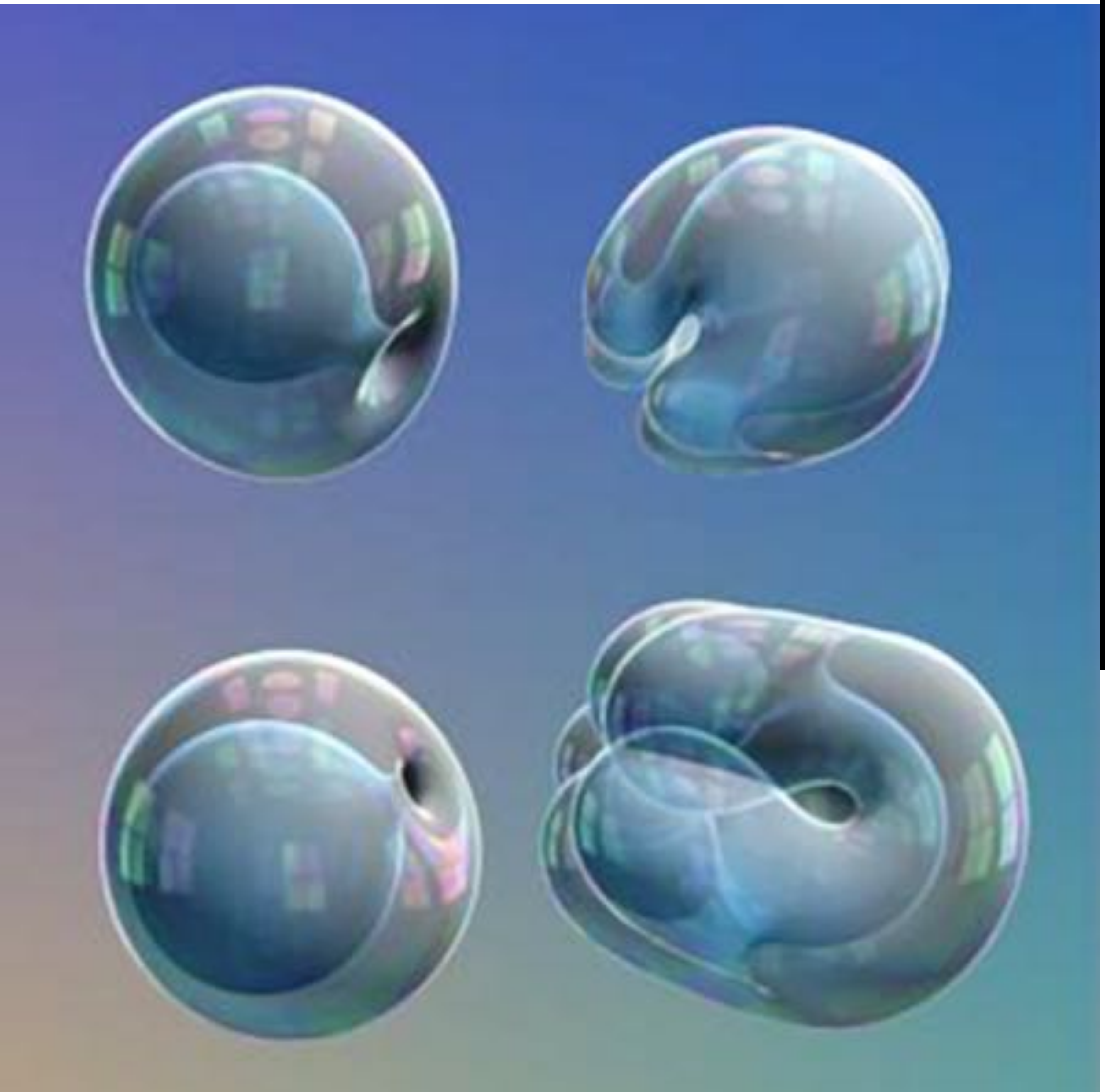


Architecture

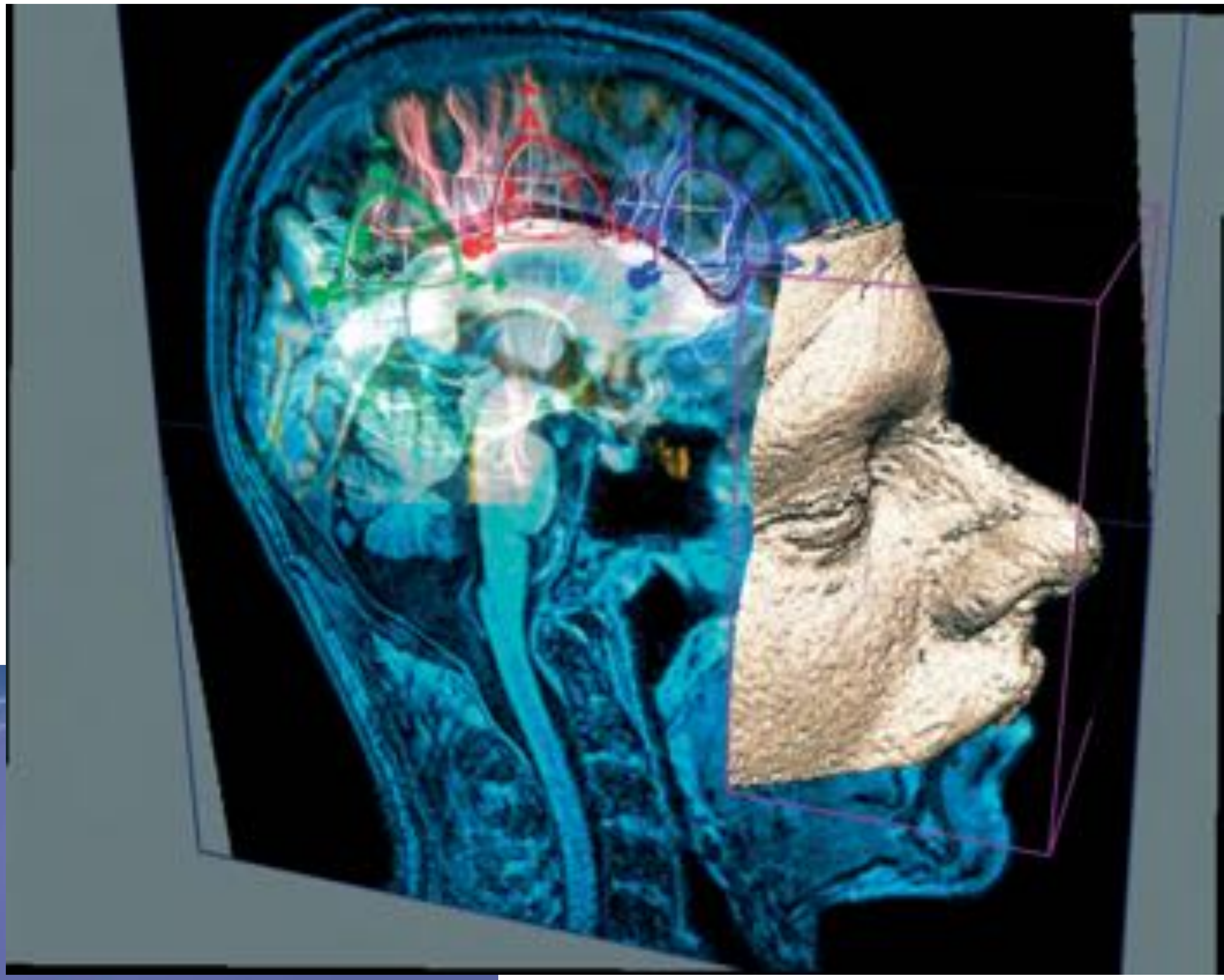


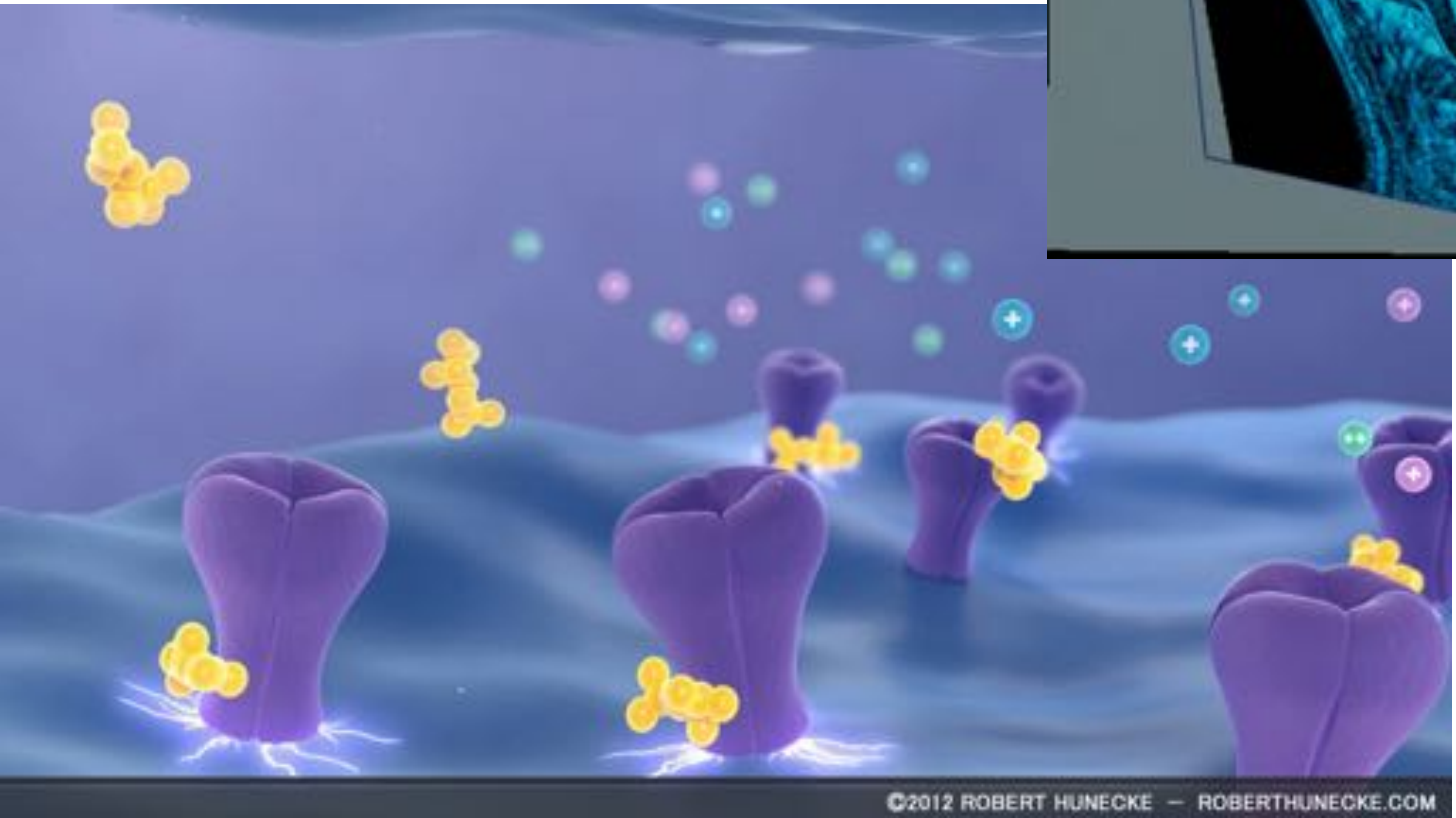
Scientific/mathematical visualization





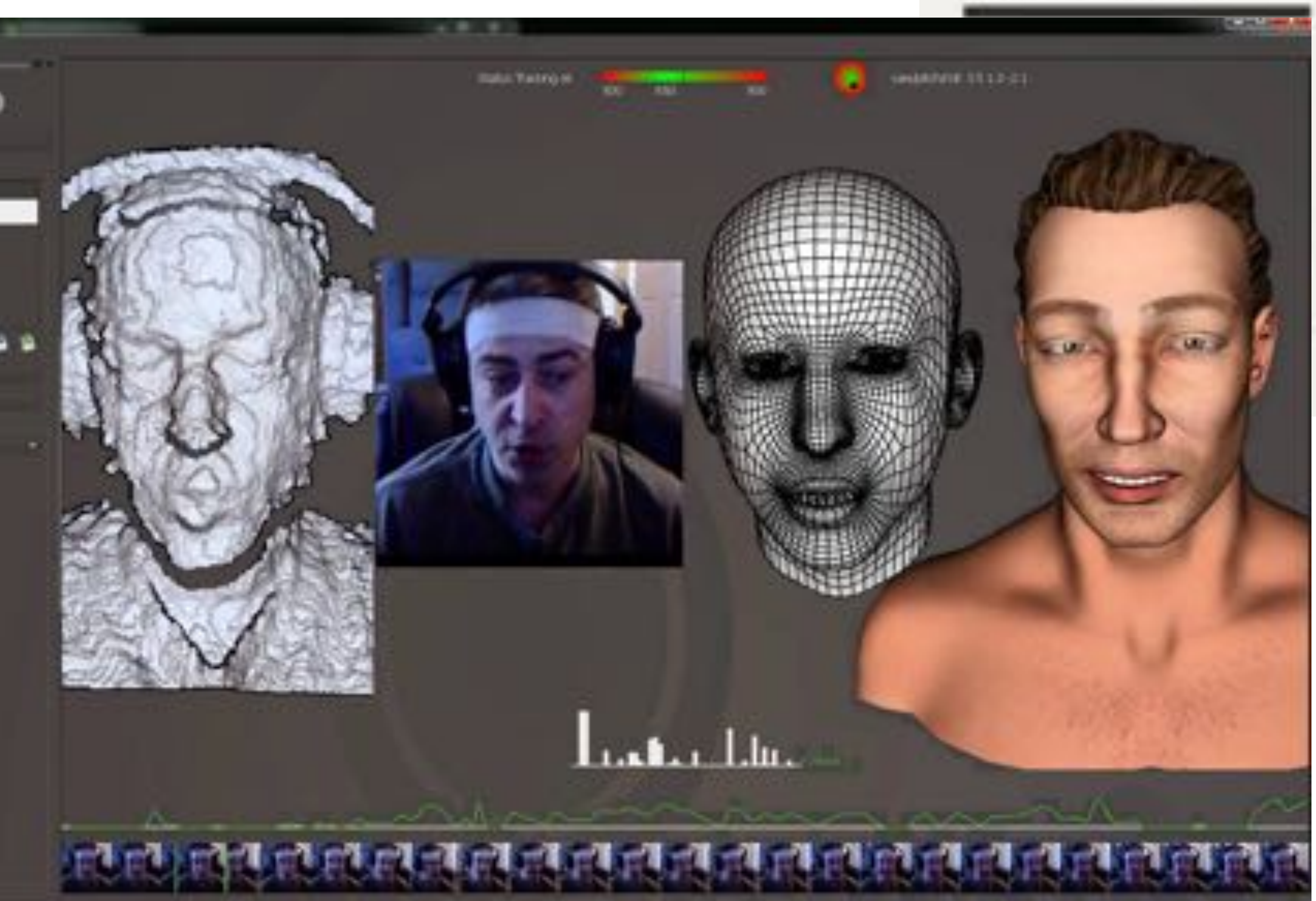
Medical/anatomical visualization





Navigation

Communication



Foundations of computer graphics

- All these applications demand sophisticated theory & systems
- Theory
  - geometric representations
  - sampling theory
  - integration and optimization
  - radiometry
  - perception and color
- 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

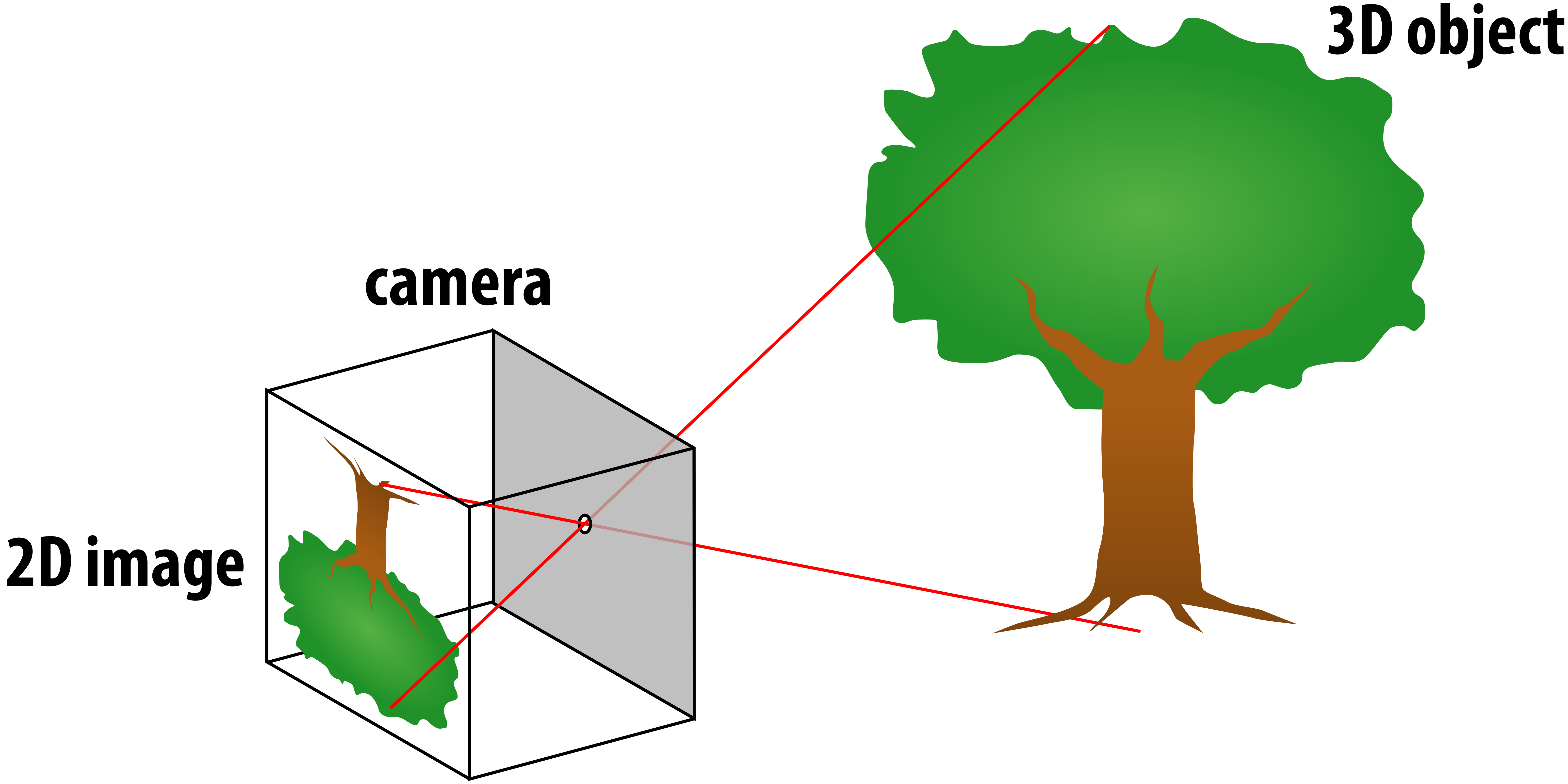
- **Now have a digital description of the cube:**

```
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?**

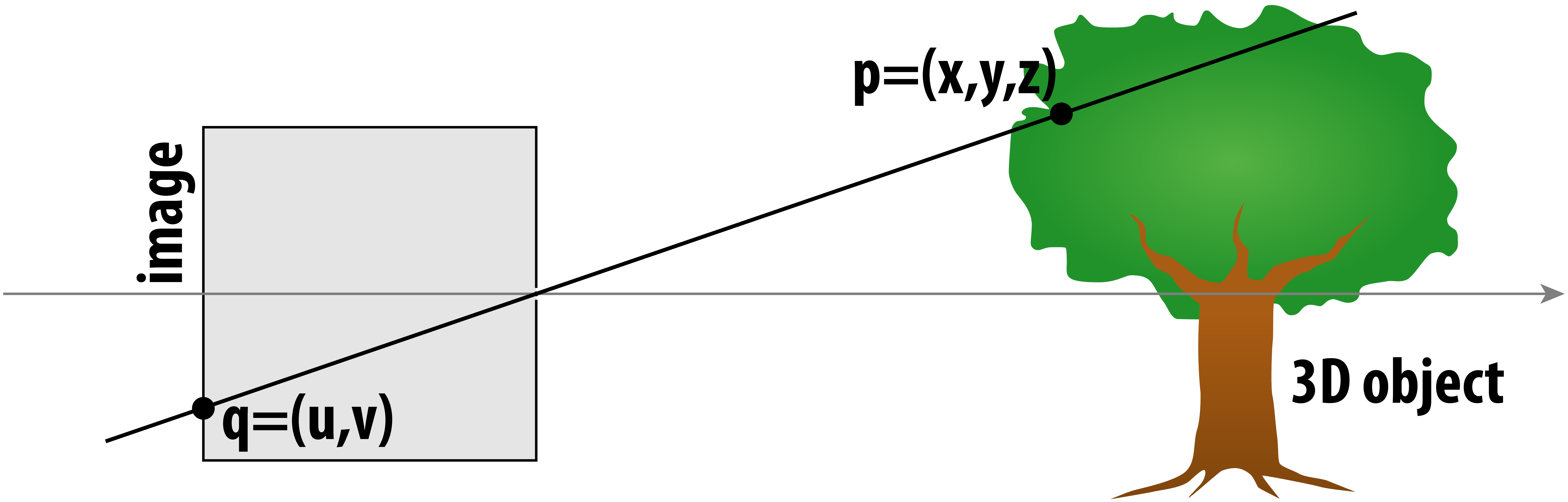
Perspective projection

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



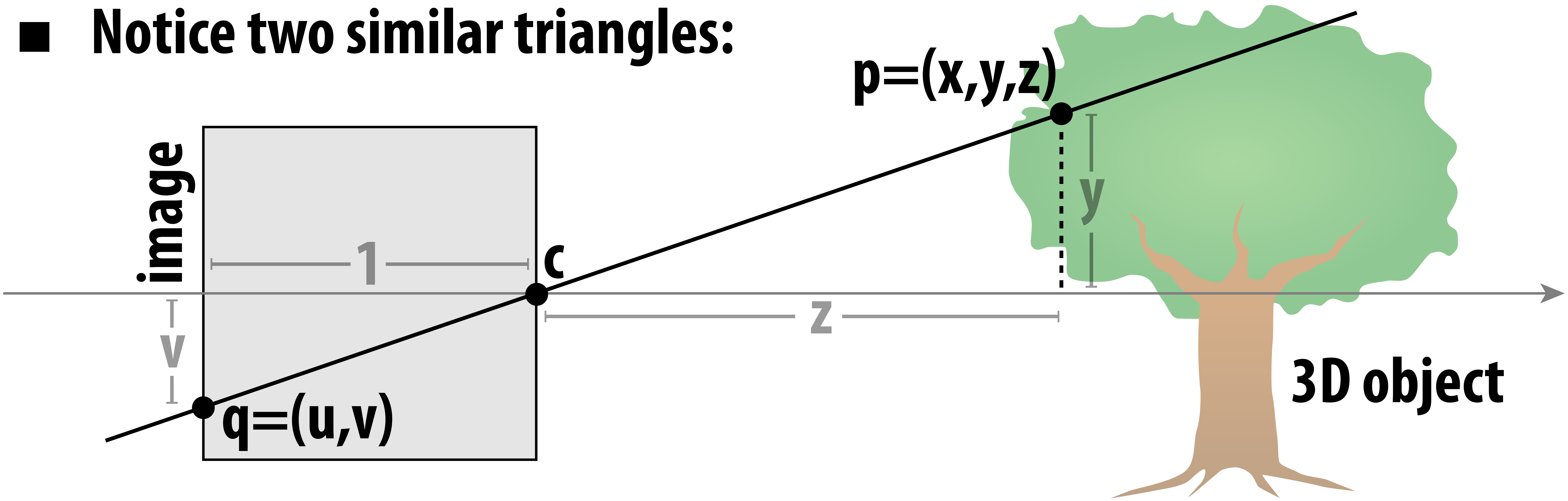
Perspective projection: side view

- 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:



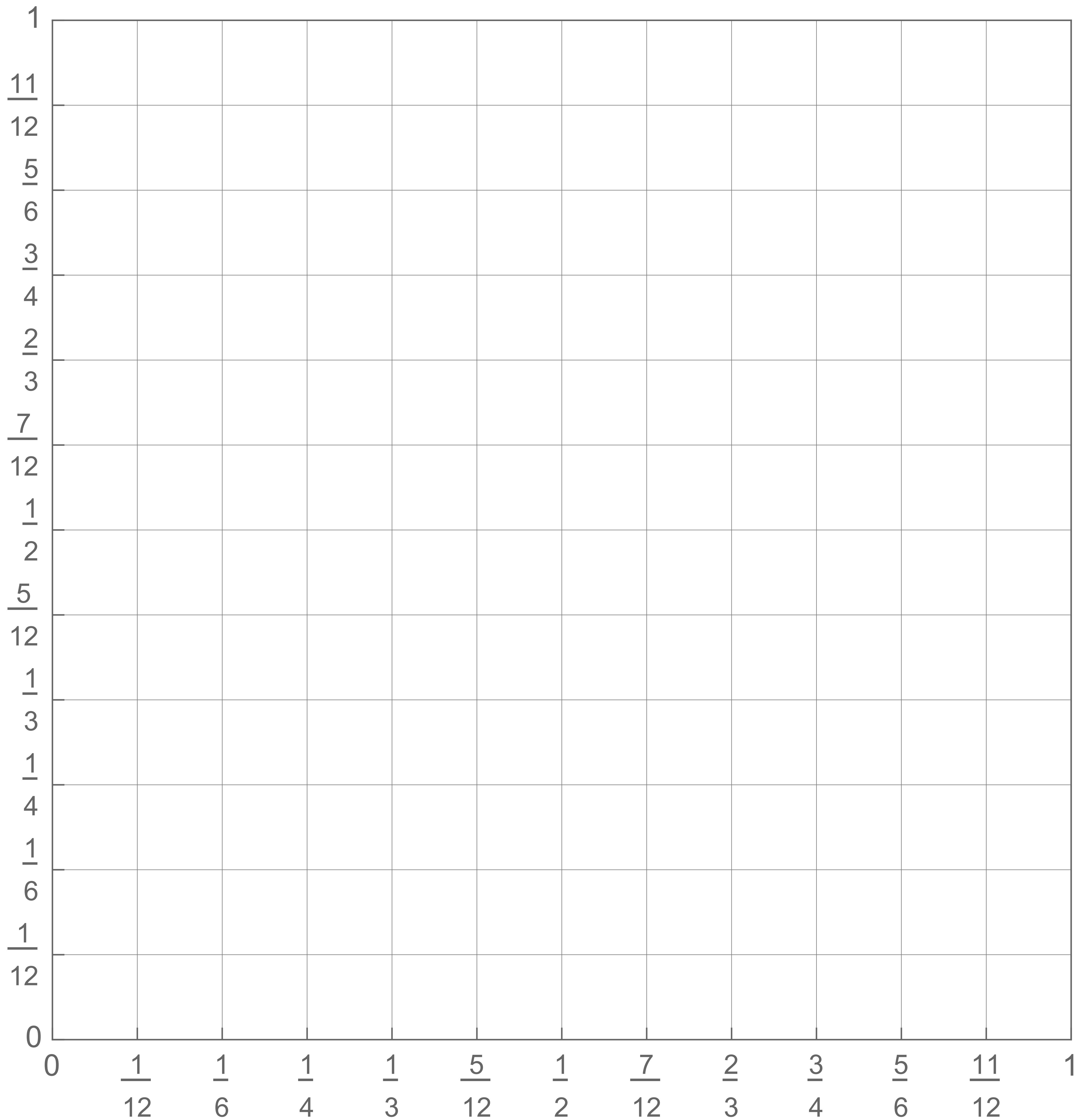
- Assume camera has unit size, origin is at pinhole c
- Then v/1 = y/z, i.e., vertical coordinate is just the slope y/z
- Likewise, horizontal coordinate is u=x/z

ACTIVITY: now draw it!

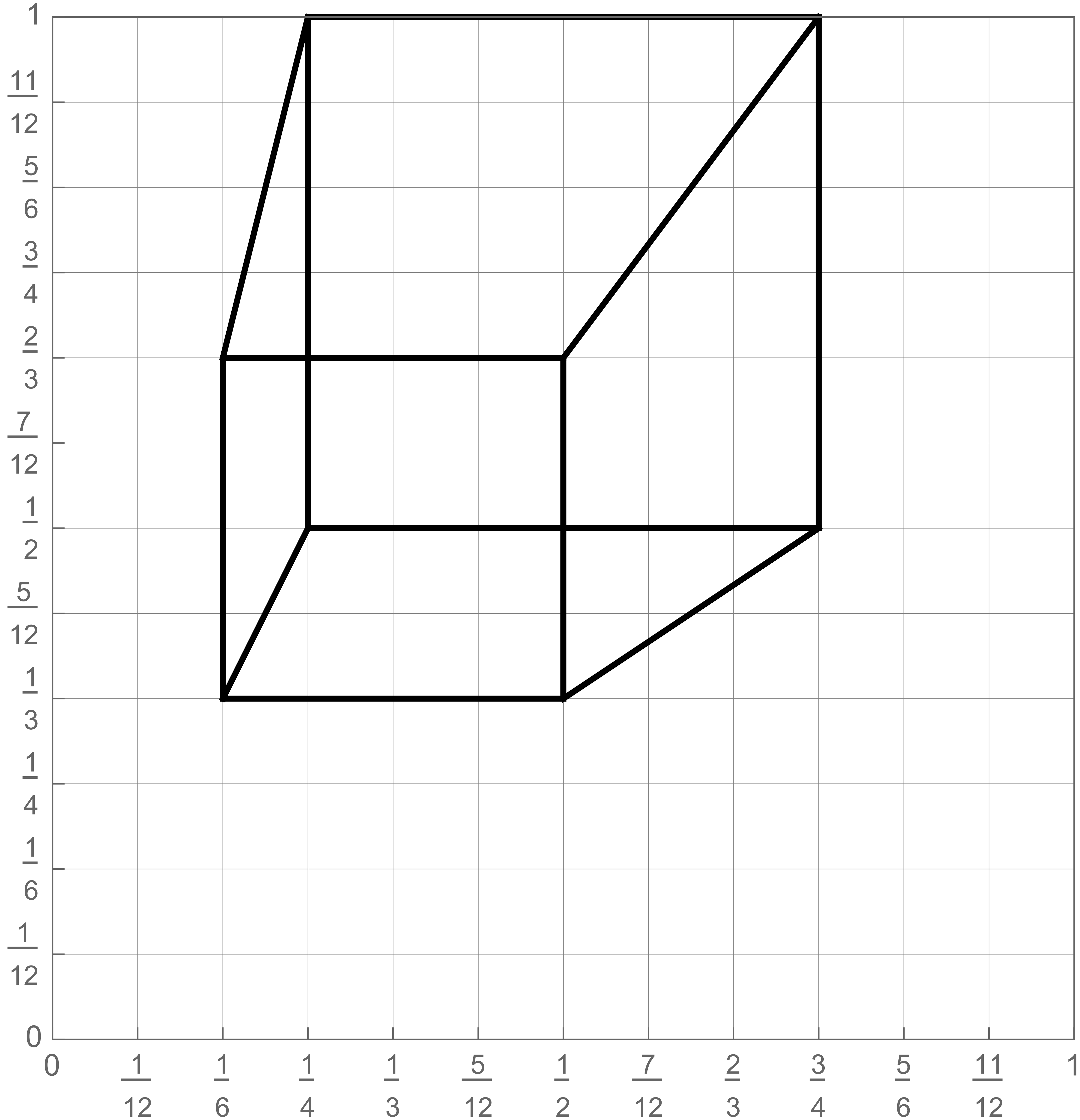
- **Need 12 volunteers**
  - each person will draw one cube edge
  - assume camera is at c=(2,3,5)
  - convert (X,Y,Z) of both endpoints to (u,v):
    1. subtract camera c from vertex (X,Y,Z) to get (x,y,z)
    2. divide (x,y) by z to get (u,v)—write as a fraction
  - draw line between (u1,v1) and (u2,v2)

```
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



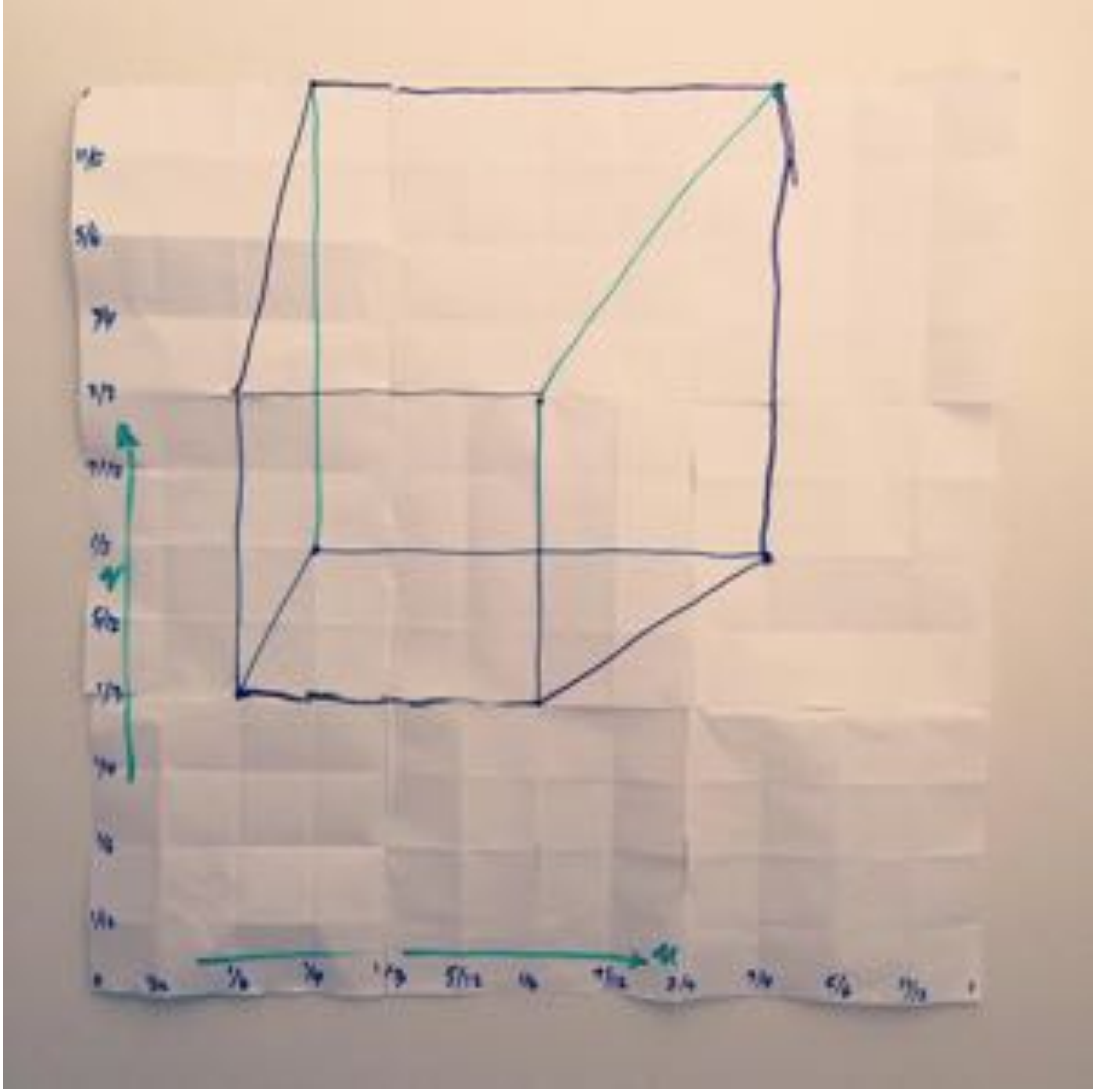
ACTIVITY: How did we do?



2D coordinates:

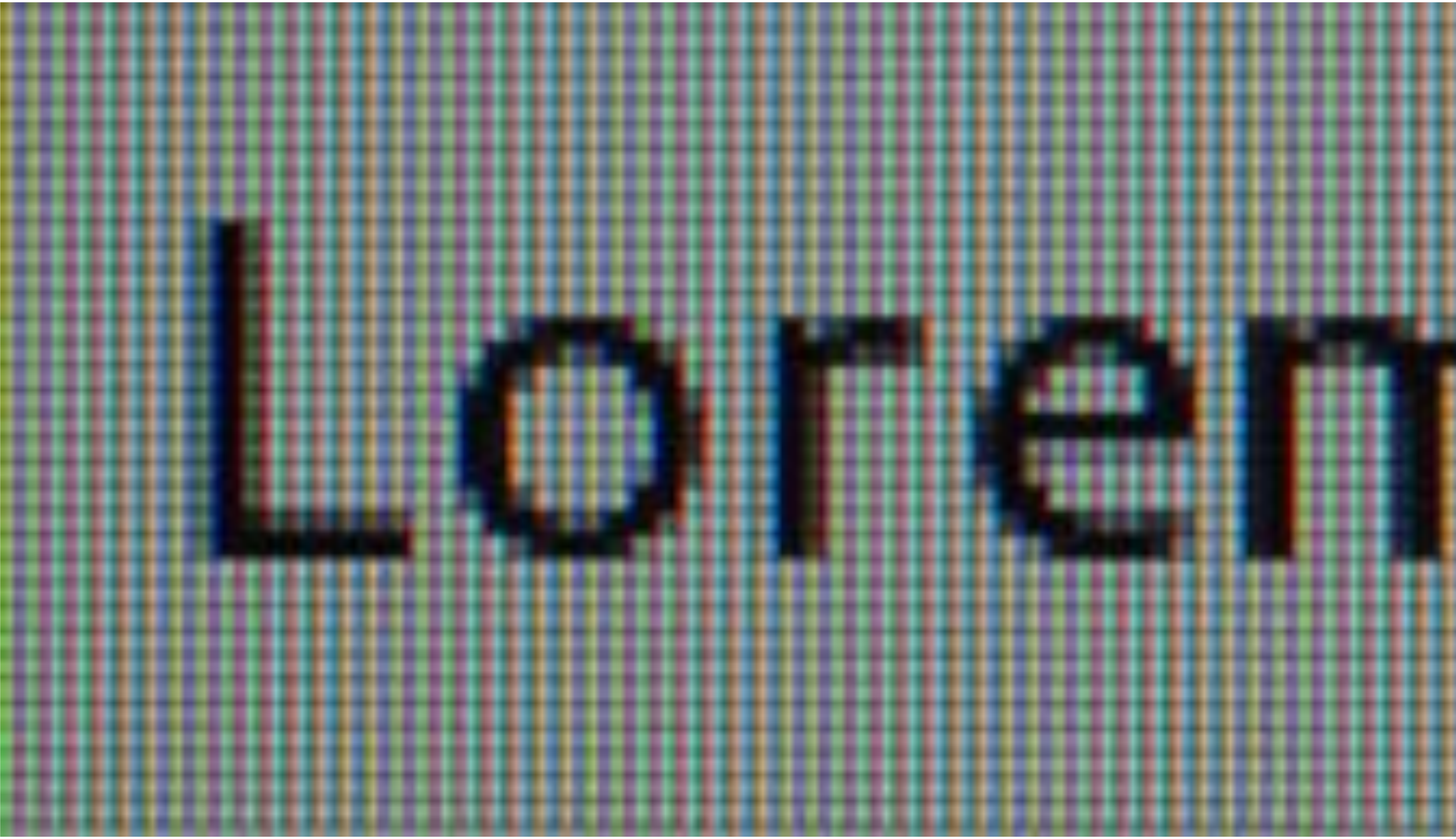
```
A: 1/4, 1/2
B: 3/4, 1/2
C: 1/4, 1
D: 3/4, 1
E: 1/6, 1/3
F: 1/2, 1/3
G: 1/6, 2/3
H: 1/2, 2/3
```

ACTIVITY: Previous year's result



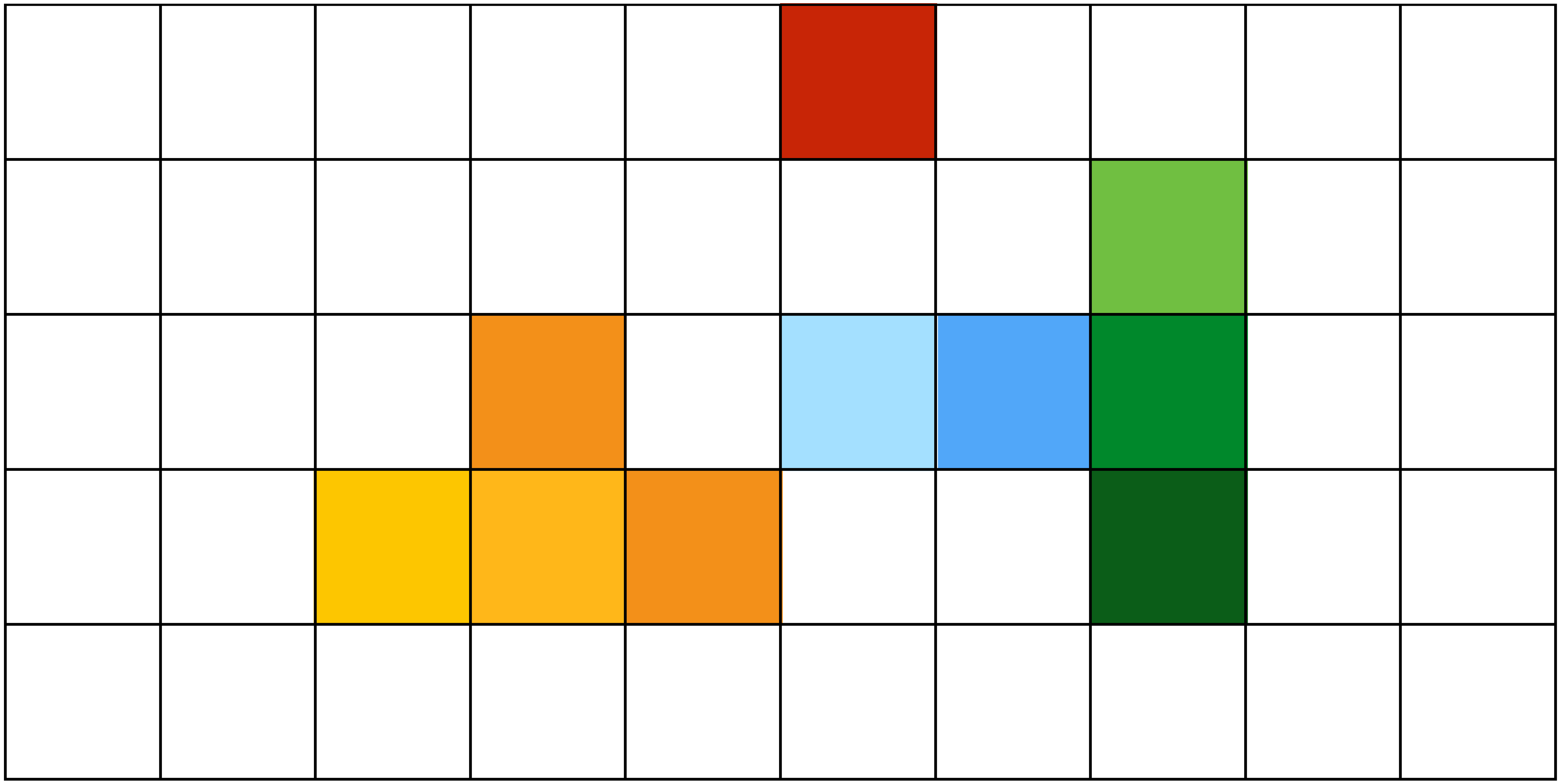
But wait…
How do we draw lines on a computer?

Close up photo of pixels on a modern display



Output for a raster display

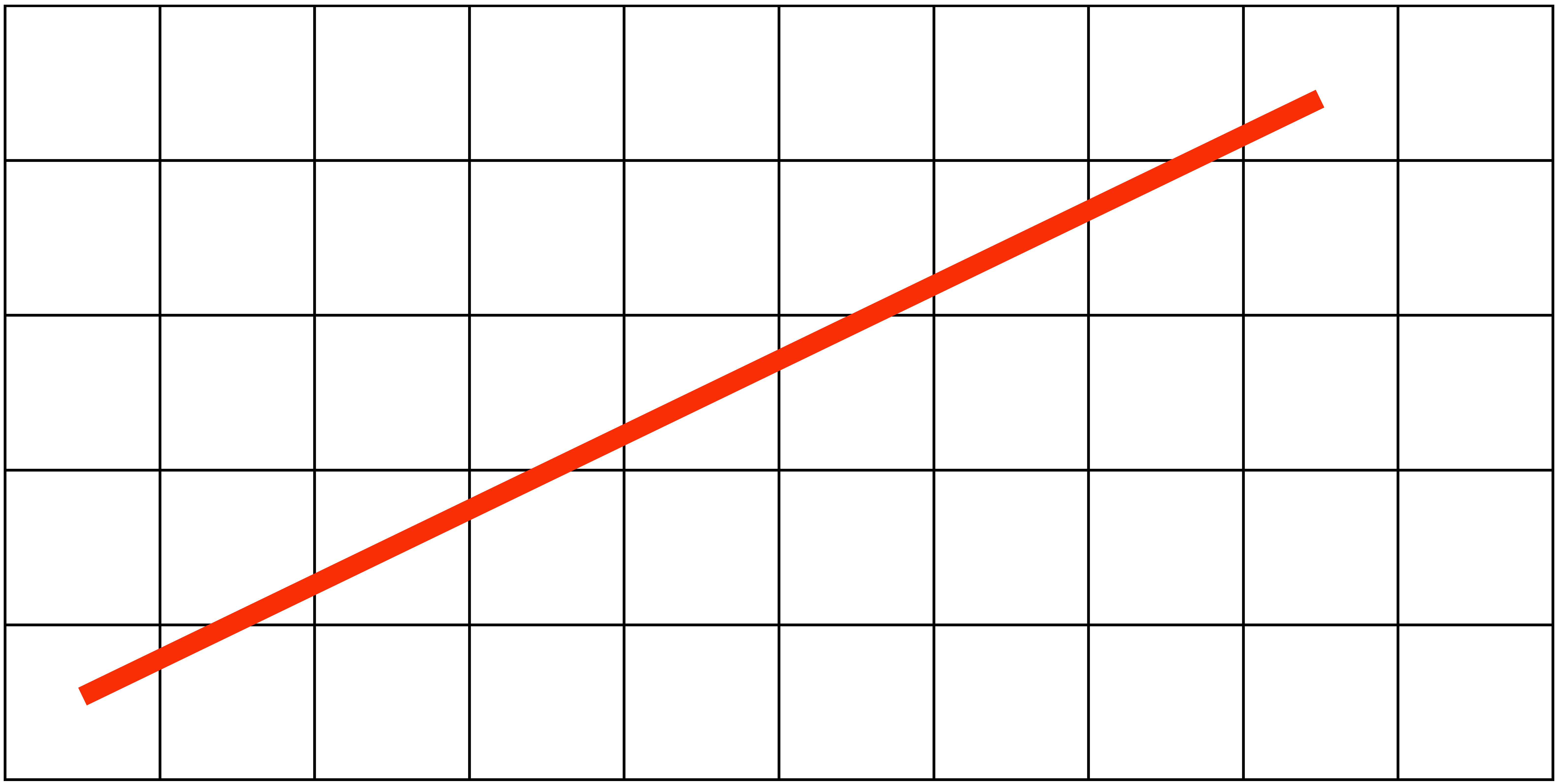
- Common abstraction of a raster display:
  - Image represented as a 2D grid of "pixels" (picture elements) **
  - Each pixel can can take on a unique color value



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

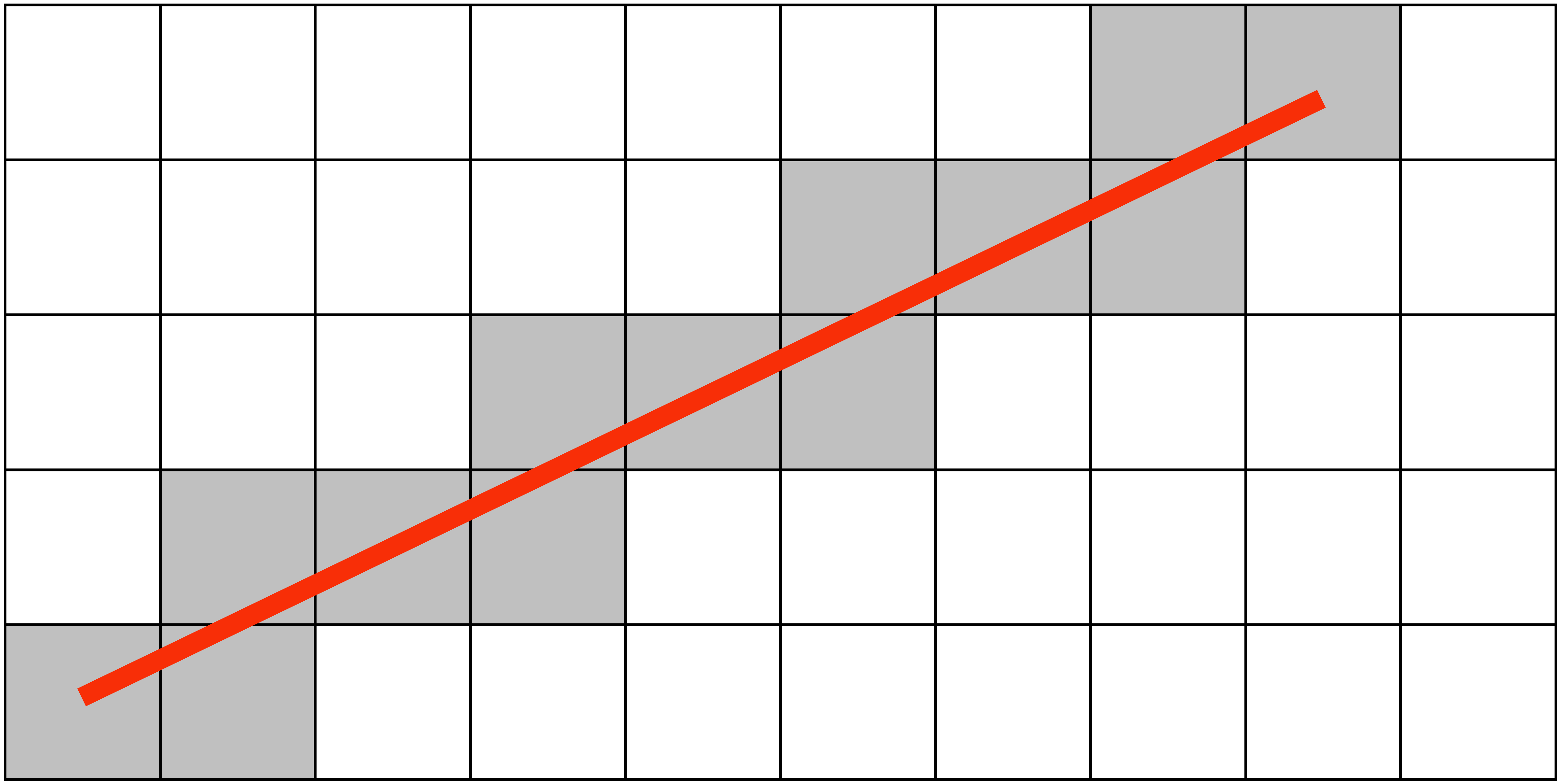
What pixels should we color in to depict a line?

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



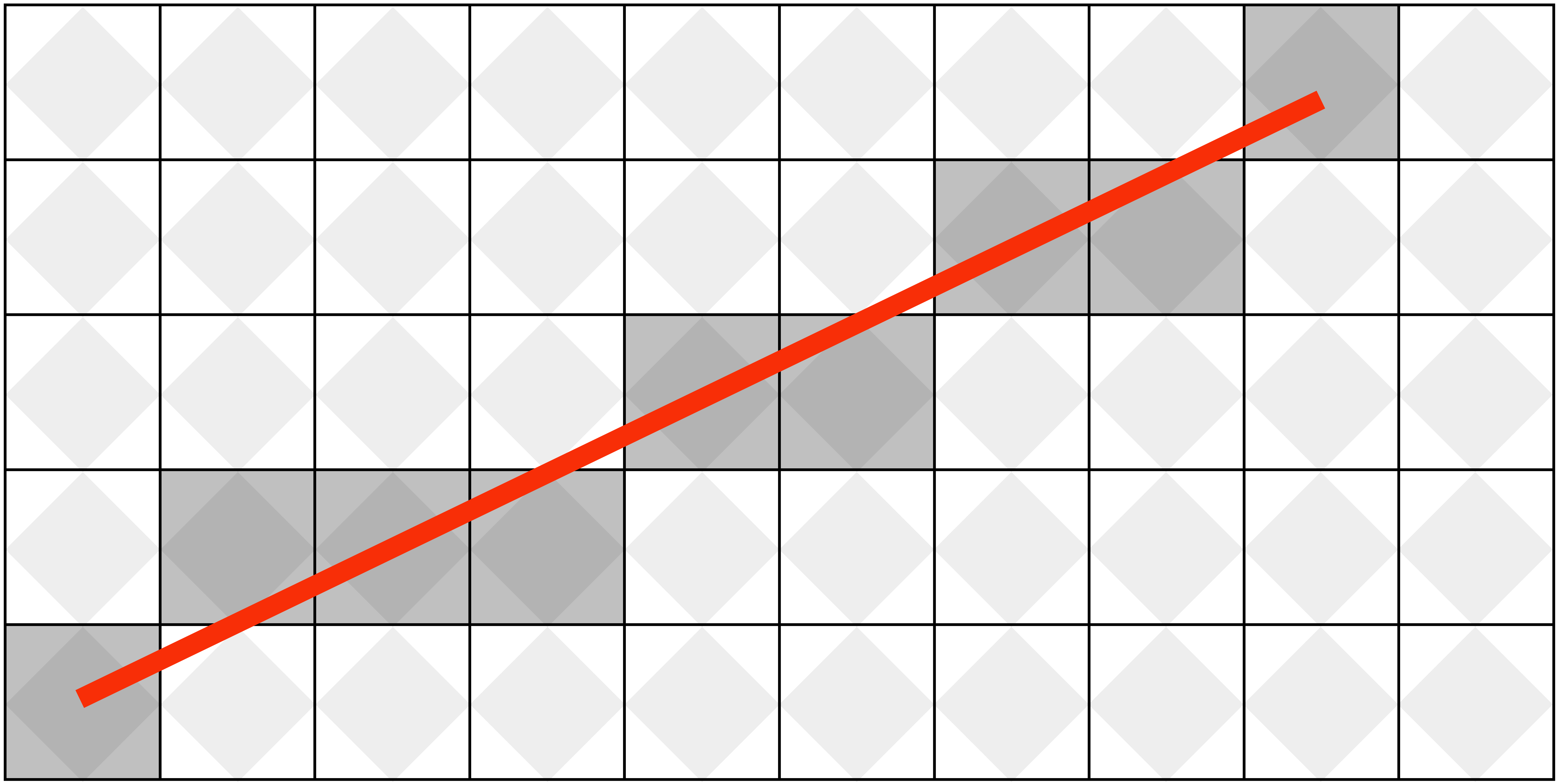
What pixels should we color in to depict a line?

Light up all pixels intersected by the line?



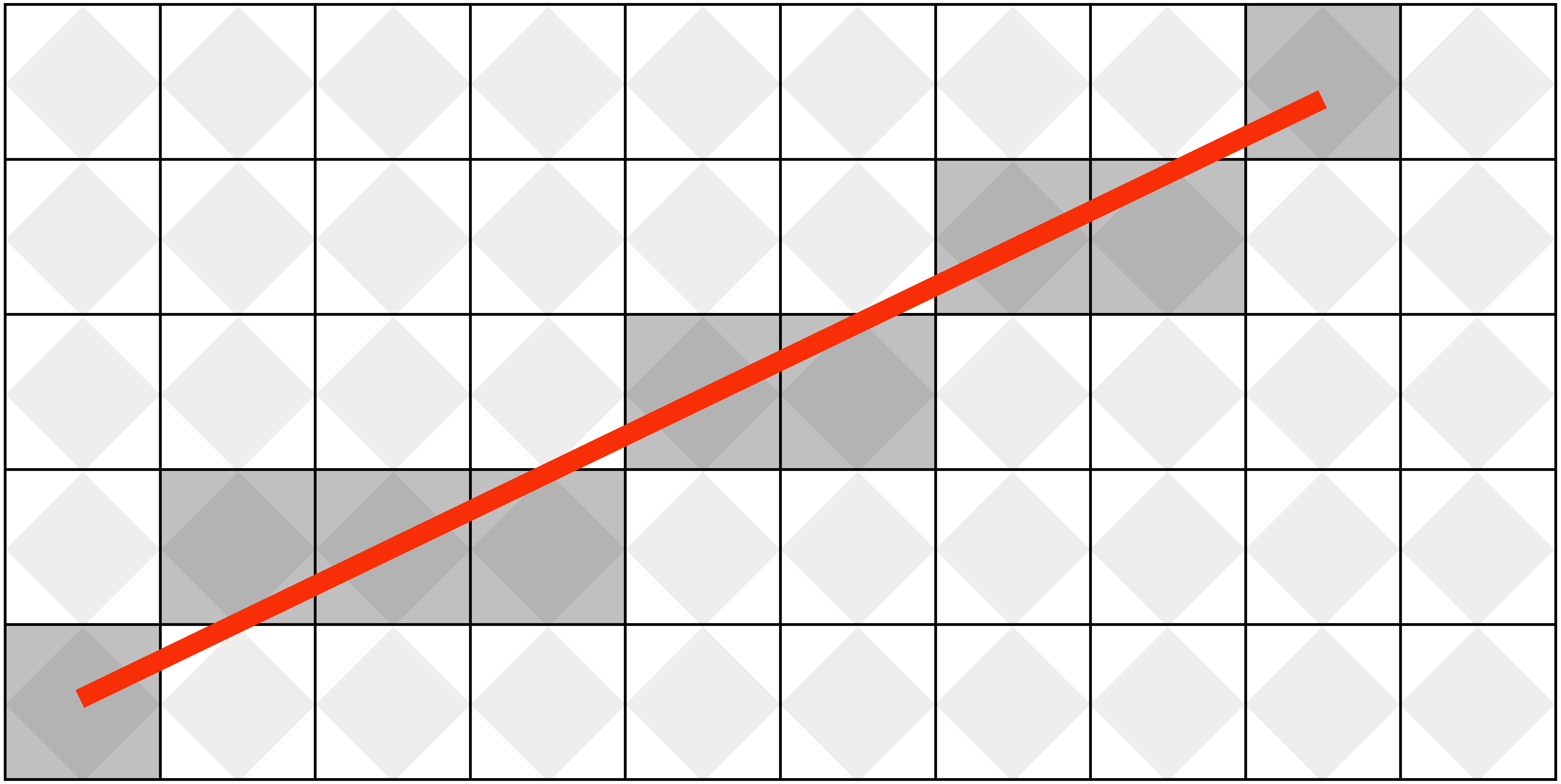
What pixels should we color in to depict a line?

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)



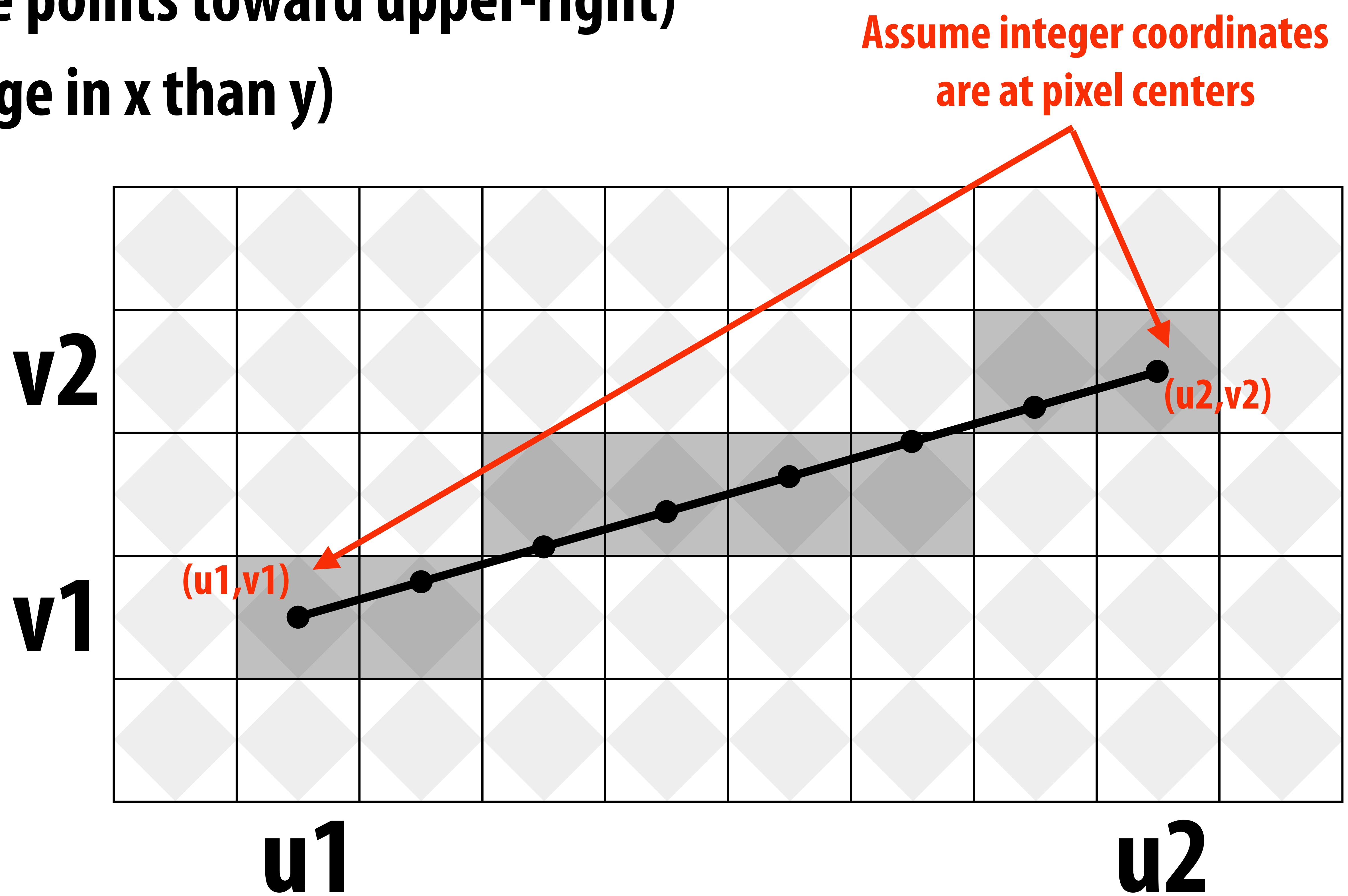
How do we find the pixels satisfying a chosen rasterization rule?

- 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

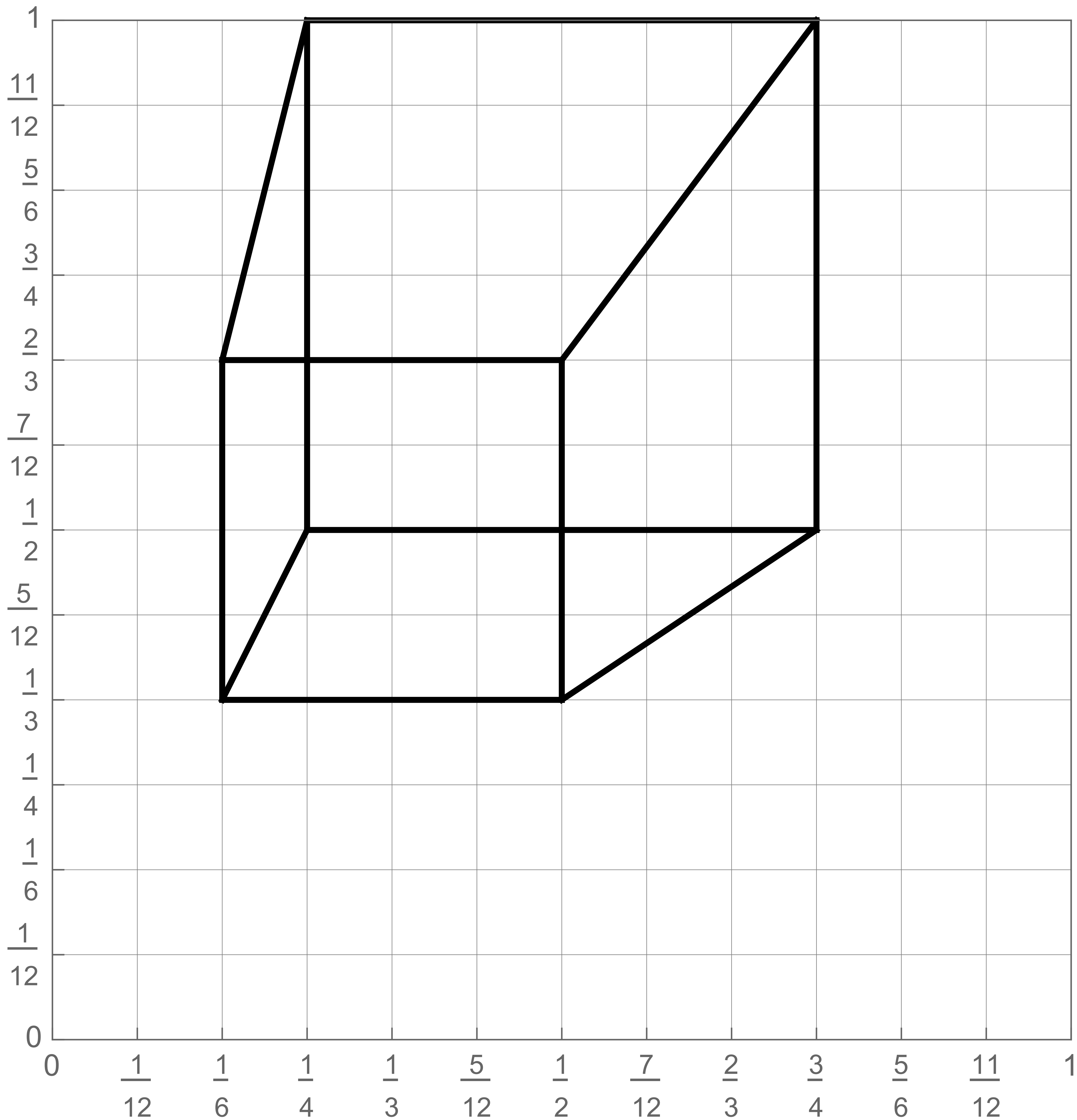
- Let's say a line is represented with integer endpoints: (u1,v1), (u2,v2)
- Slope of line: s = (v2-v1) / (u2-u1)
- Consider a very easy special case:
  - u1 < u2, v1 < v2 (line points toward upper-right)
  - 0 < s < 1 (more change in x than y)

```
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)

Our line drawing!



2D coordinates:

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C: 1/4, 1
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E: 1/6, 1/3
F: 1/2, 1/3
G: 1/6, 2/3
H: 1/2, 2/3
```

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 2017]

Complex 3D surfaces

Modeling material properties


[Wann Jensen 2001]


[Jakob 2014]


[Zhao 2013]

Realistic lighting environments

Realistic lighting environments

Realistic lighting environments

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

Unreal Engine Kite Demo (Epic Games 2015)

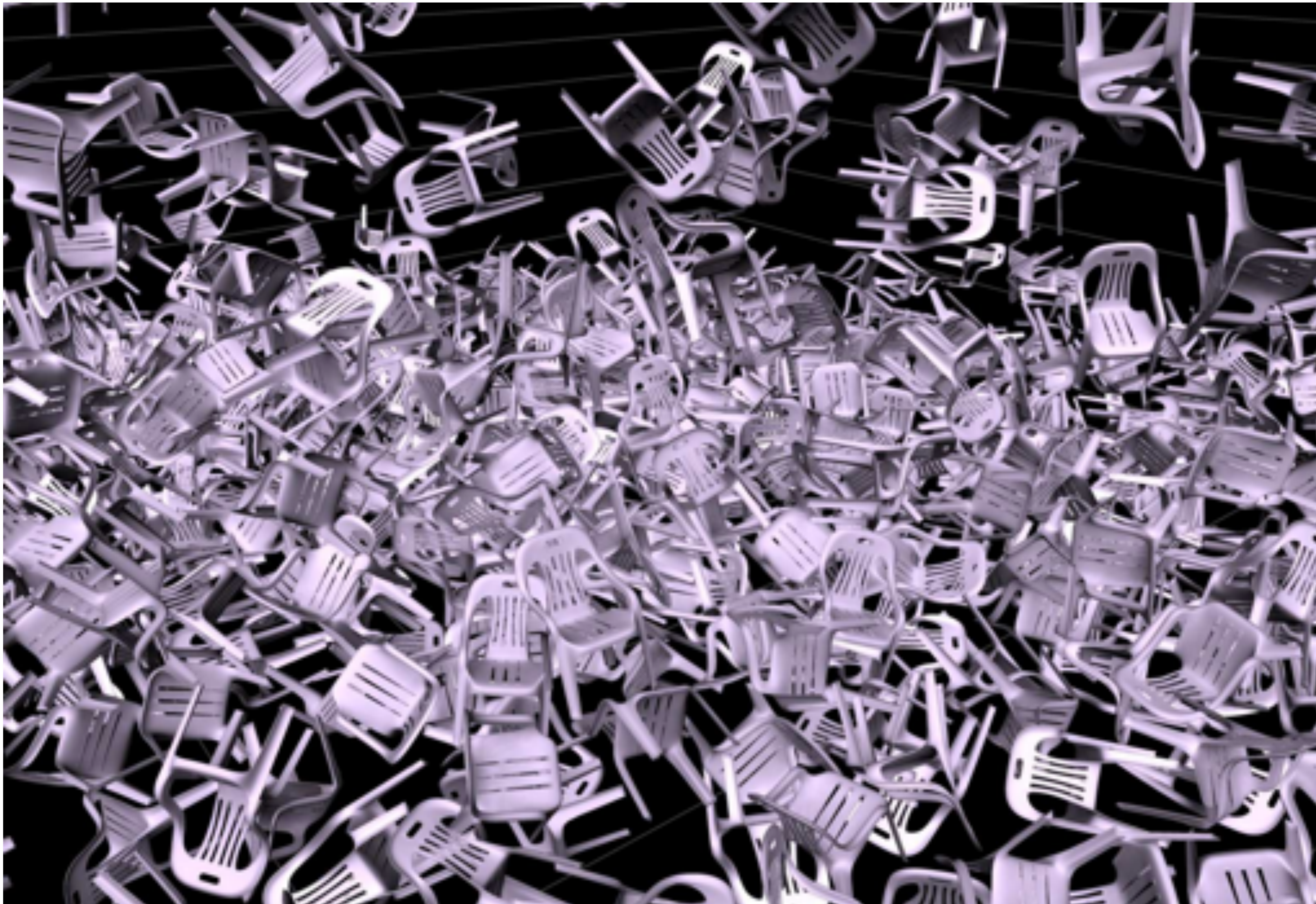
So is this.

[Mirror's Edge 2008]

Animation: modeling motion

https://www.youtube.com/watch?v=6G3O60o5U7w

Physically-based simulation of motion



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

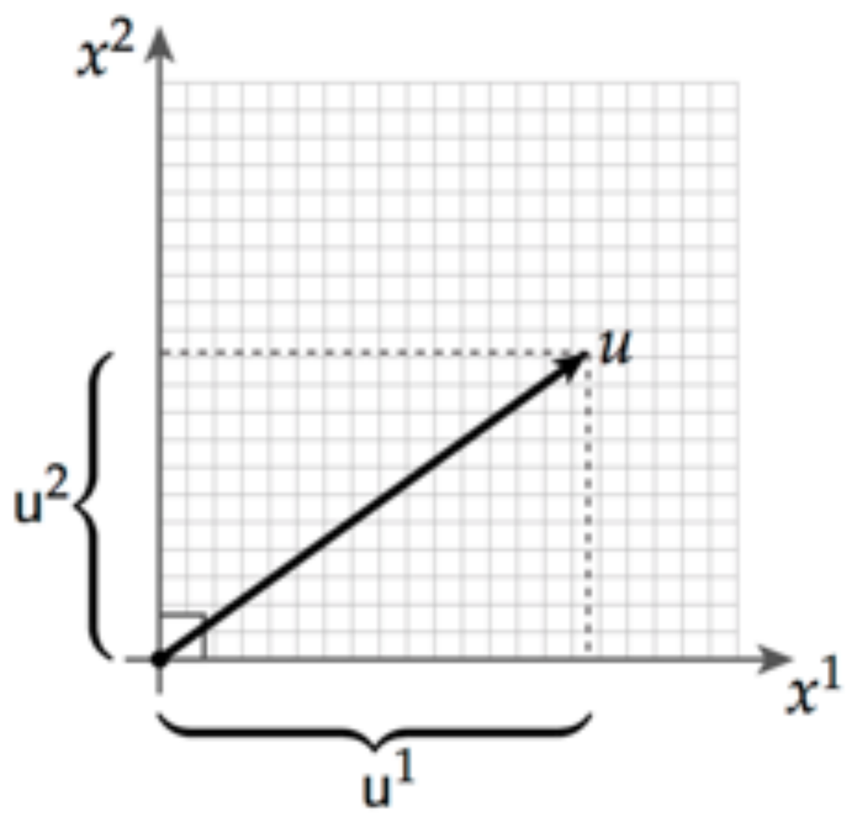
[James 2004]

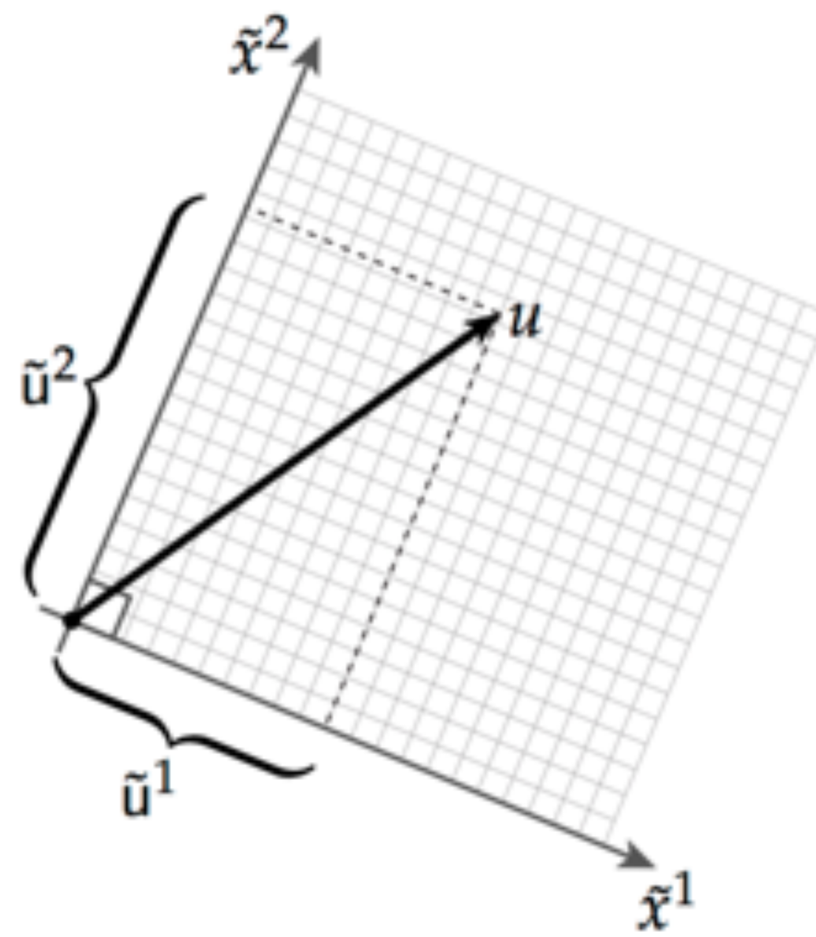
Course Logistics

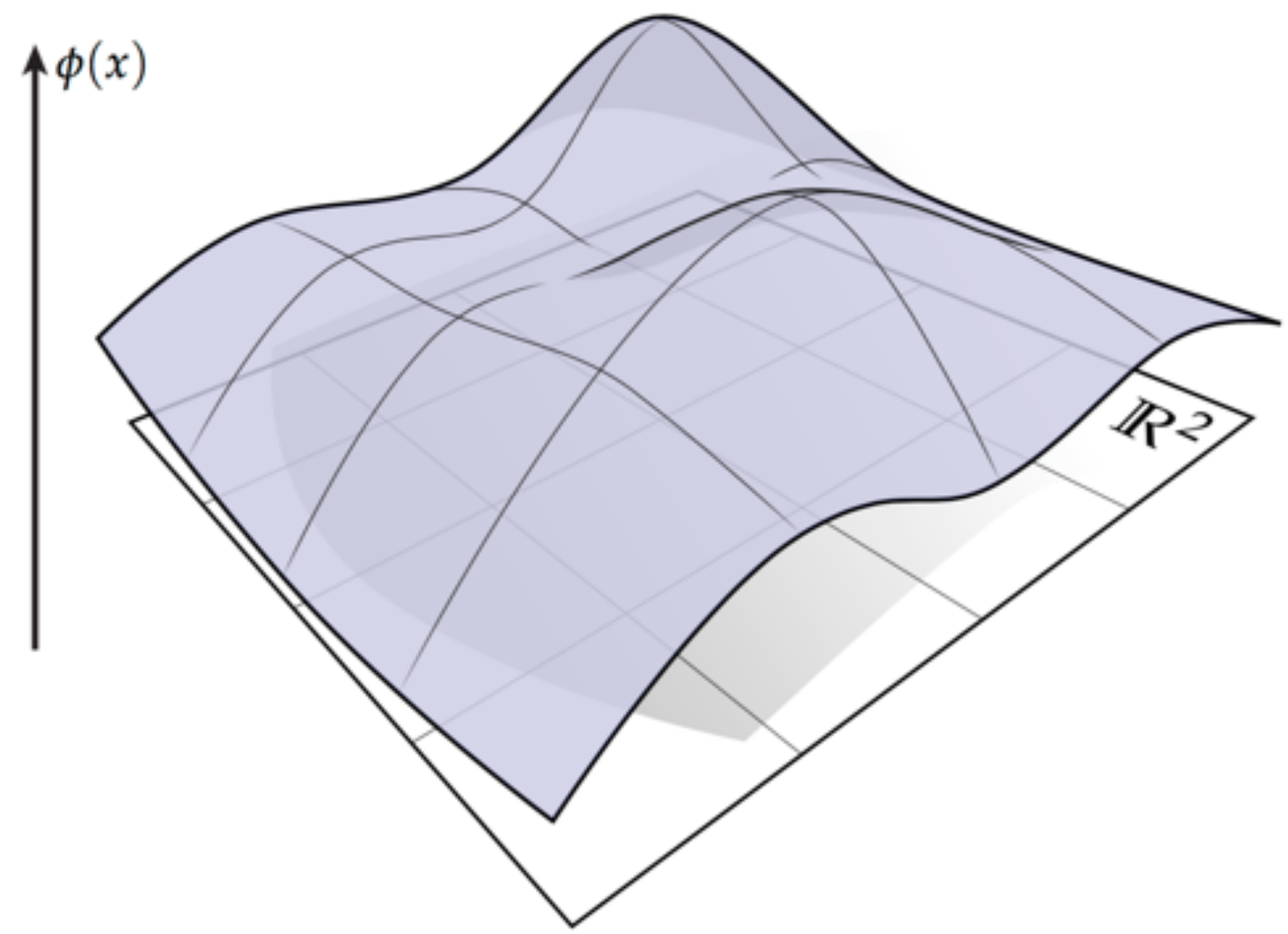
About this course

- A broad overview of major topics and techniques in computer graphics: geometry, rendering, animation, imaging
- Outline:
  - Focus on fundamental data structures and algorithms that are reused across all areas of graphics
  - Assignments on:
    - Rasterization
    - Geometric Modeling
    - Photorealistic Rendering
    - Animation
  - In-class midterm/final

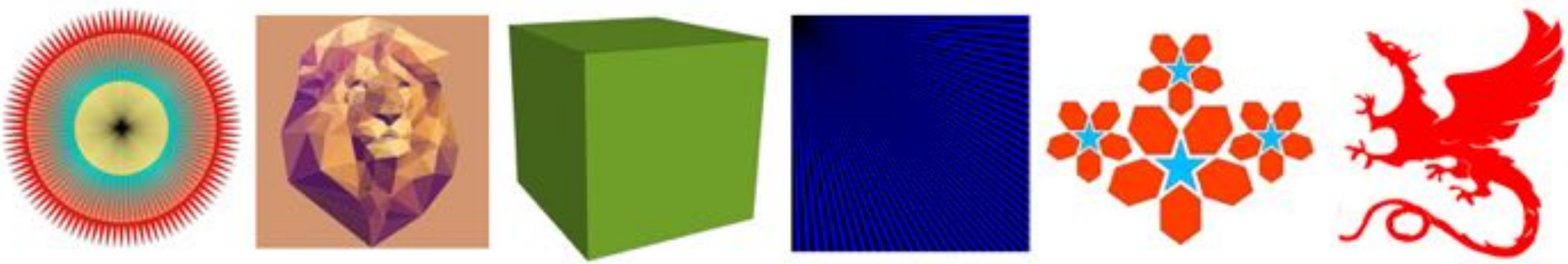
Assignment 0: Math (P)Review





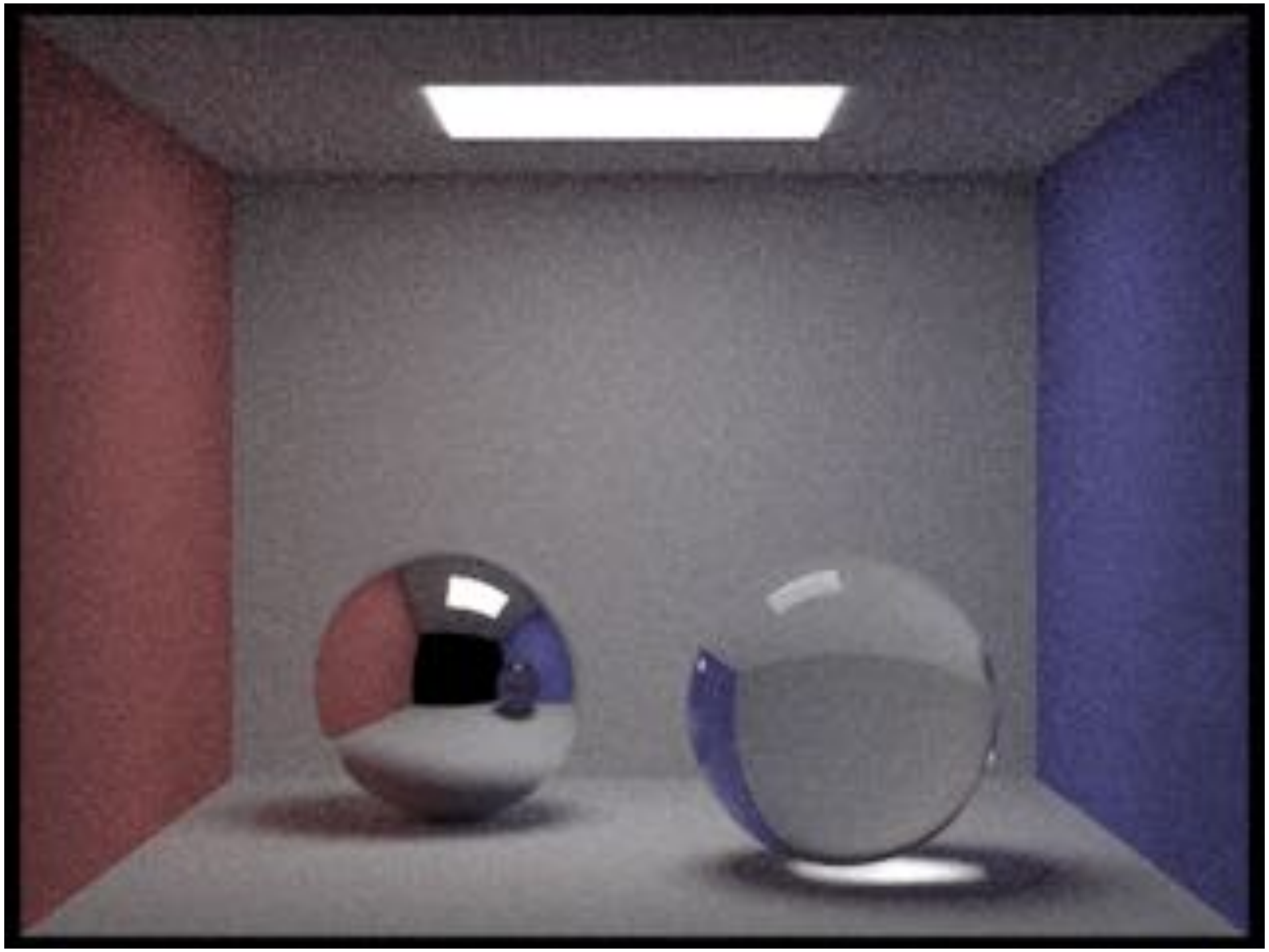


Assignment 1: Rasterization

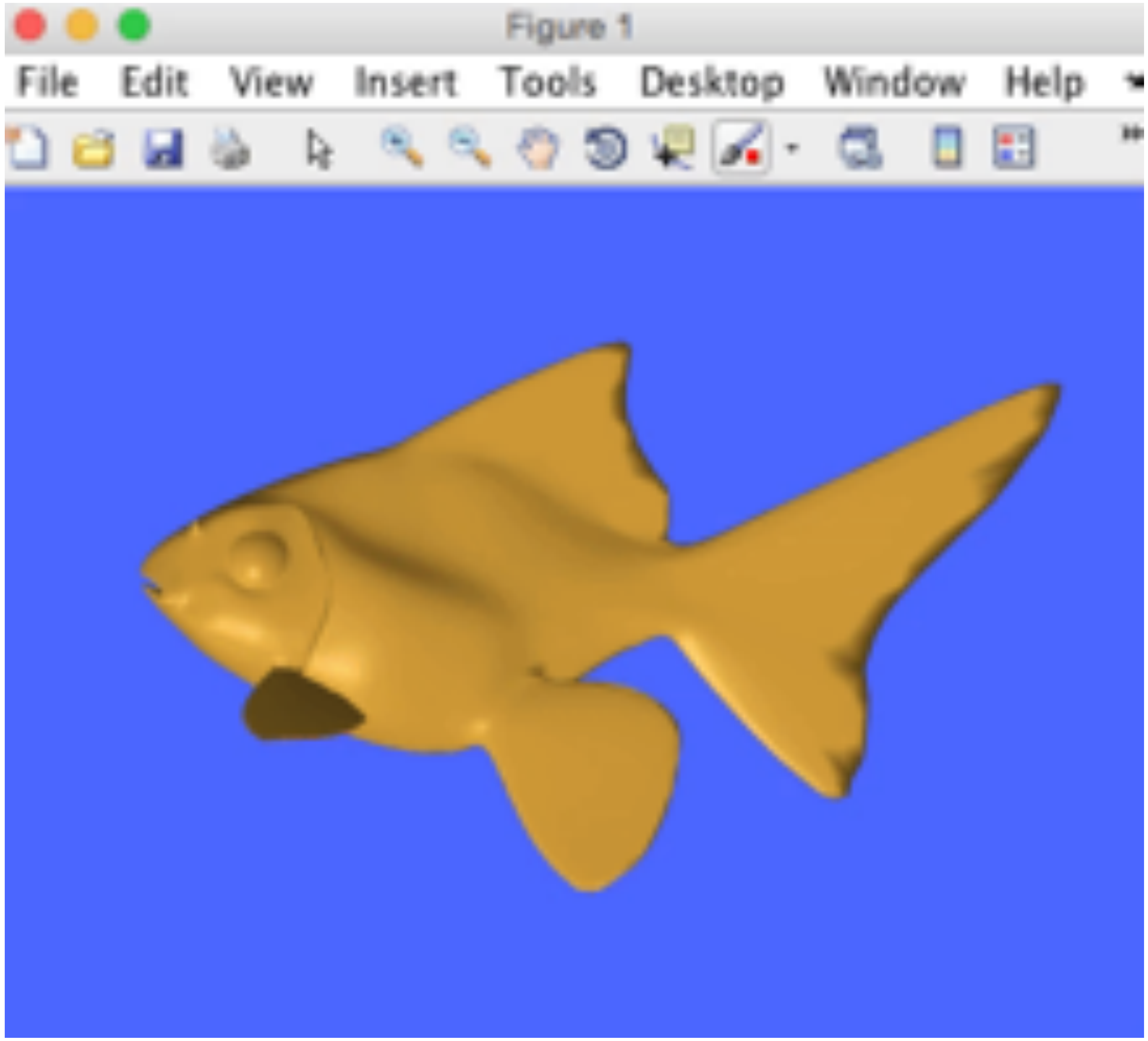


Assignment 2: Geometric Modeling

Assignment 3: Photorealistic Rendering



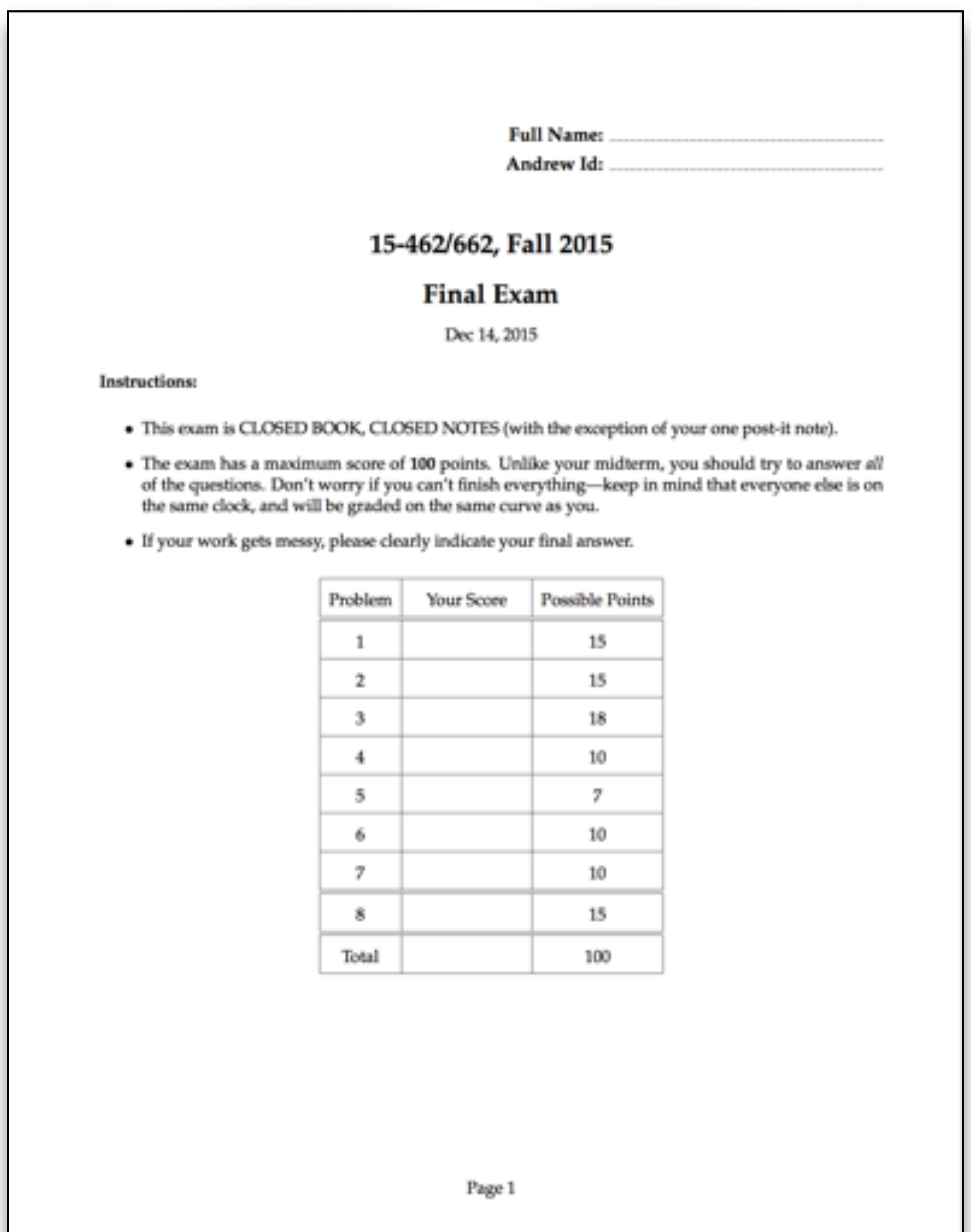
Assignment 4: Animation



(cribbed from Alec Jacobson)

Midterm / Final

- Both cover cumulative material seen so far
- In-class, proctored exam
- Can bring one sticky note (both sides) w/ any information on it



Full Name: ....

Andrew Id: ....

15-462/662, Fall 2015

Final Exam

Dec 14, 2015

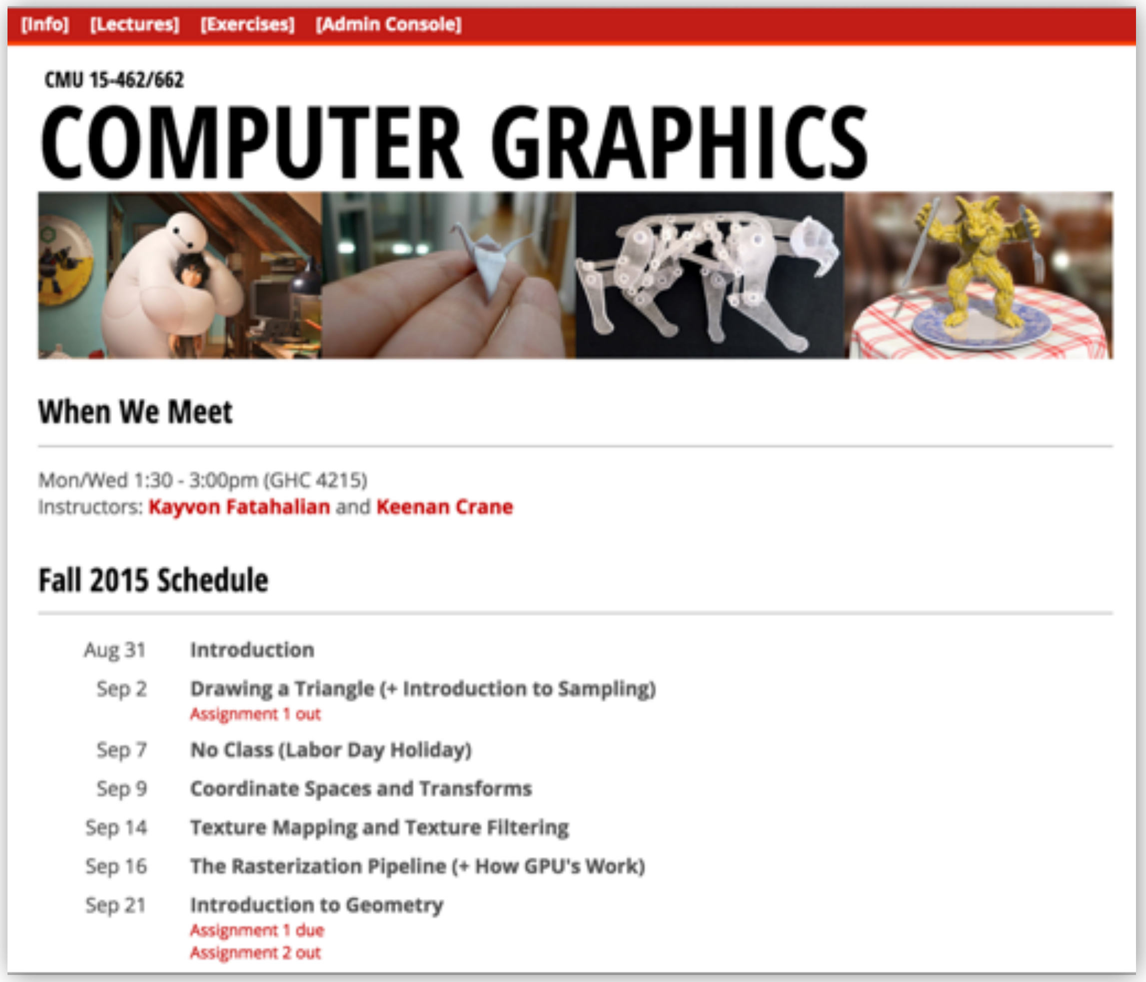
Instructions:

- This exam is CLOSED BOOK, CLOSED NOTES (with the exception of your one post-it note).
- The exam has a maximum score of **100** points. Unlike your midterm, you should try to answer *all* of the questions. Don't worry if you can't finish everything—keep in mind that everyone else is on the same clock, and will be graded on the same curve as you.
- If your work gets messy, please clearly indicate your final answer.

Problem	Your Score	Possible Points
1		15
2		15
3		18
4		10
5		7
6		10
7		10
8		15
Total		100

Page 1

Getting started



- Create an account on the course web site:
  - http://15462.courses.cs.cmu.edu/spring2019/home

- Sign up for the course on Piazza
  - https://piazza.com/class/jqv79wkbxqz743

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

Assignments / Grading

- **(10%) Warm-up Math (P)Review**
  - Written exercises on basic linear algebra and vector calc. (individually)

- **(60%) Four programming assignments**
  - Four programming assignments
  - Each worth 15% of overall course grade

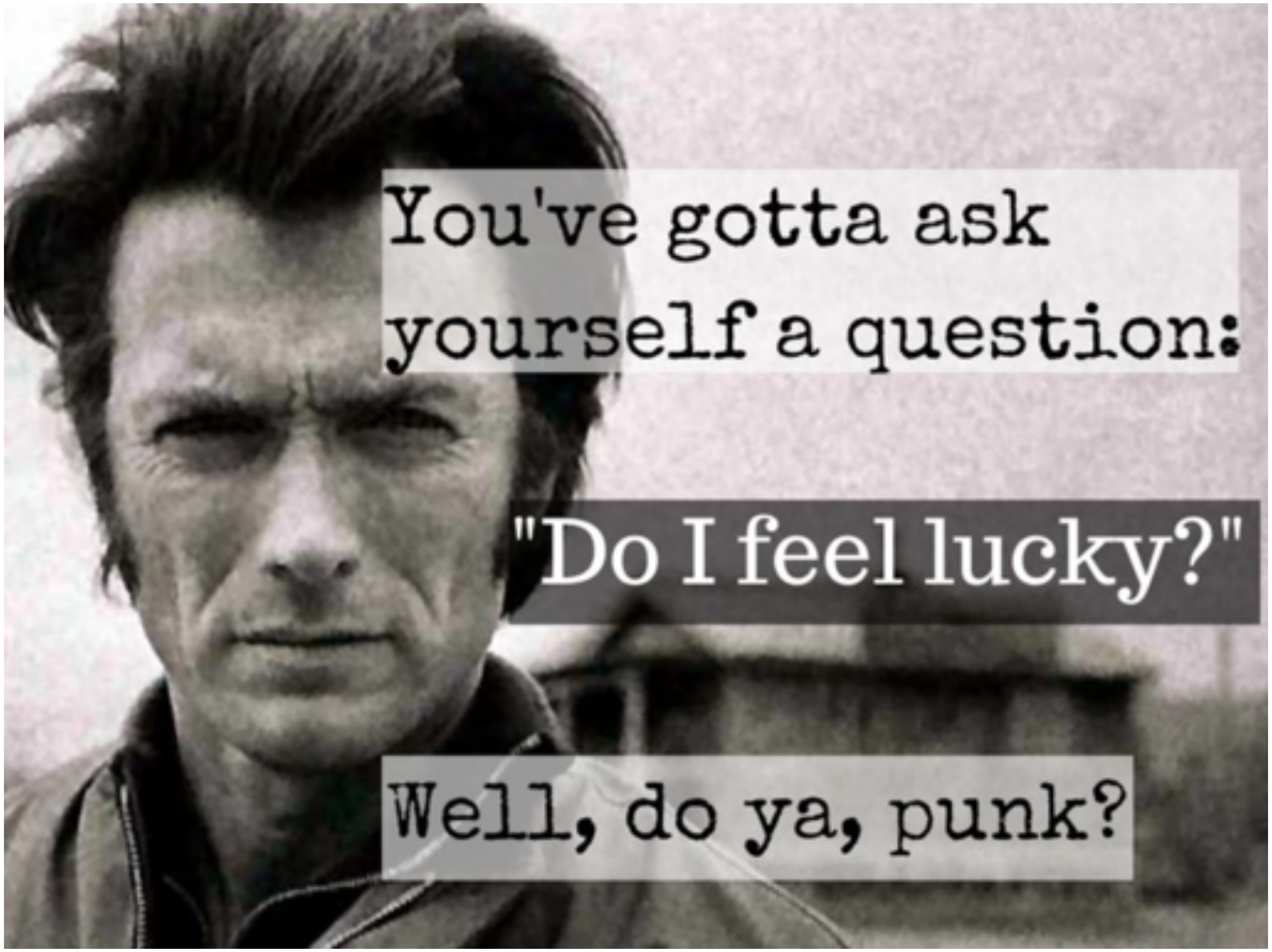
- **(25%) Midterm / final**
  - Both cover cumulative material seen so far

- **(5%) Class participation**
  - In-class/website comments, other contributions to class

Late hand-in policy

- **Programming assignments**
  - Five late day points for the semester
  - First three programming assignments only
  - No more late points? 10% penalty per day
  - No assignments will be accepted more than 3 days past the deadline

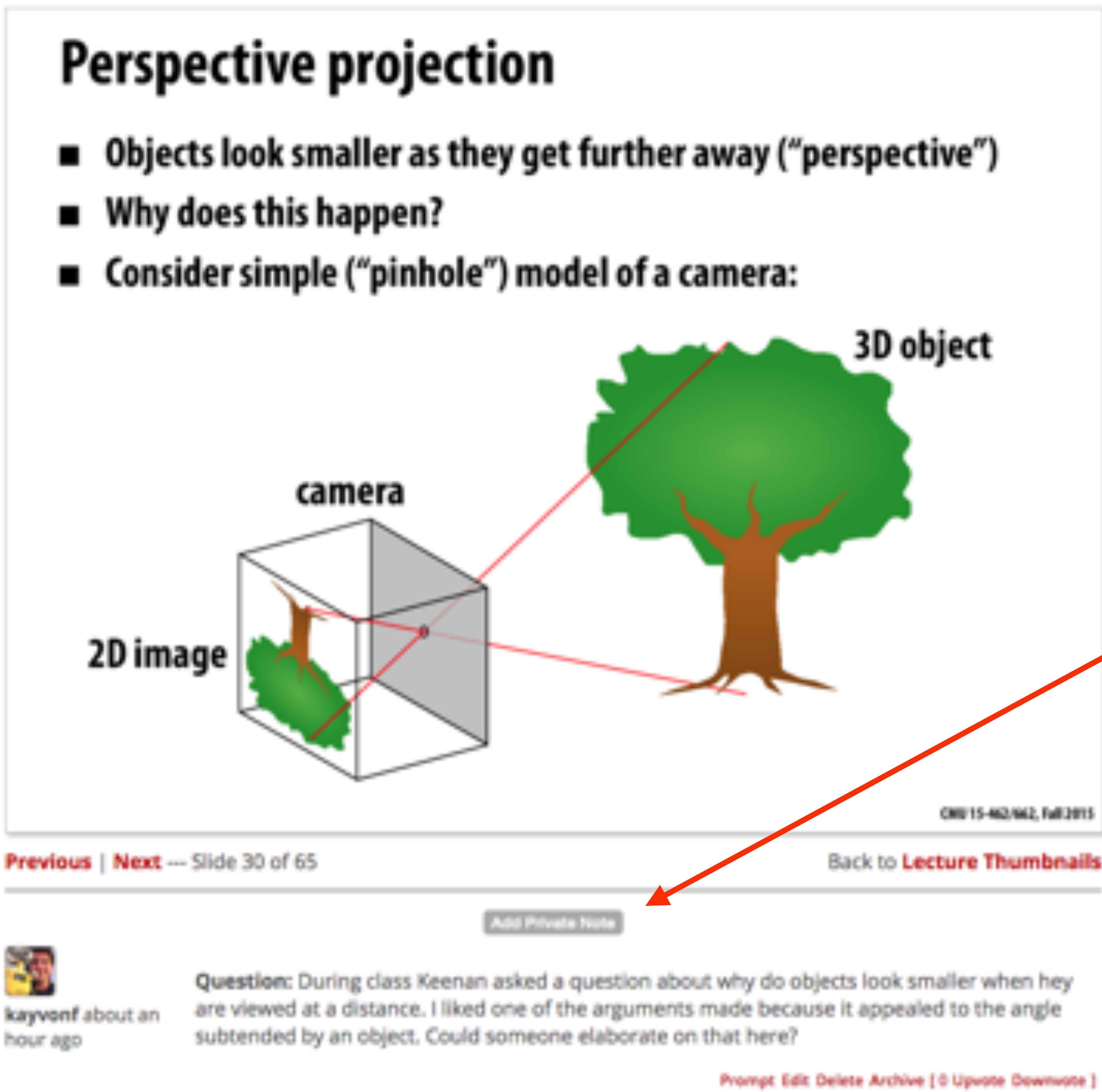
Cheating Policy



Let's keep it simple: if you are caught cheating, you will get a zero for the entire course (not just the assignment).

The course web site

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



"Add private note" button: You can add notes to yourself about this slide here.

Slide comments and discussion

Our philosophy

- We want a very active class: come to class, participate in the class, contribute to the web site
- Challenging assignments (with tons of “going further” opportunities: see what you can do!)
- Challenging exams (see what you can do!)
- Very reasonable grading (at least the instructors think so)

See you next time!

- Next time, we'll do a math review & preview
  - Linear algebra, vector calculus
  - Help make the rest of the course easier!