Lecture 1:

Course Intro:
Welcome to Computer Graphics!

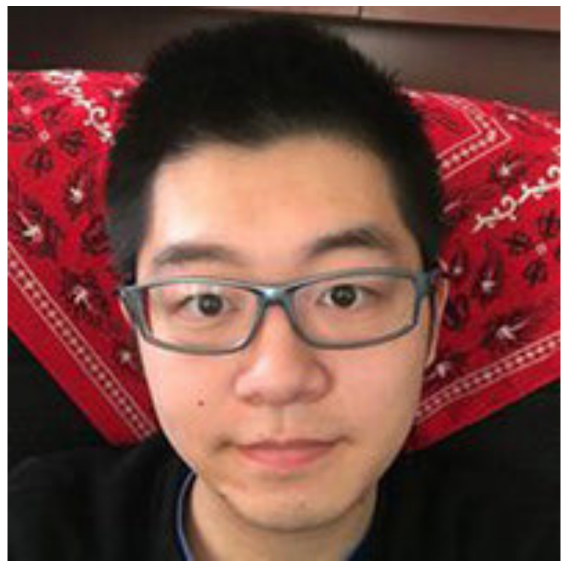
Computer Graphics
CMU 15-462/662, Fall 2017

Hi!

Keenan Crane

Nick Sharp

Eric Fang



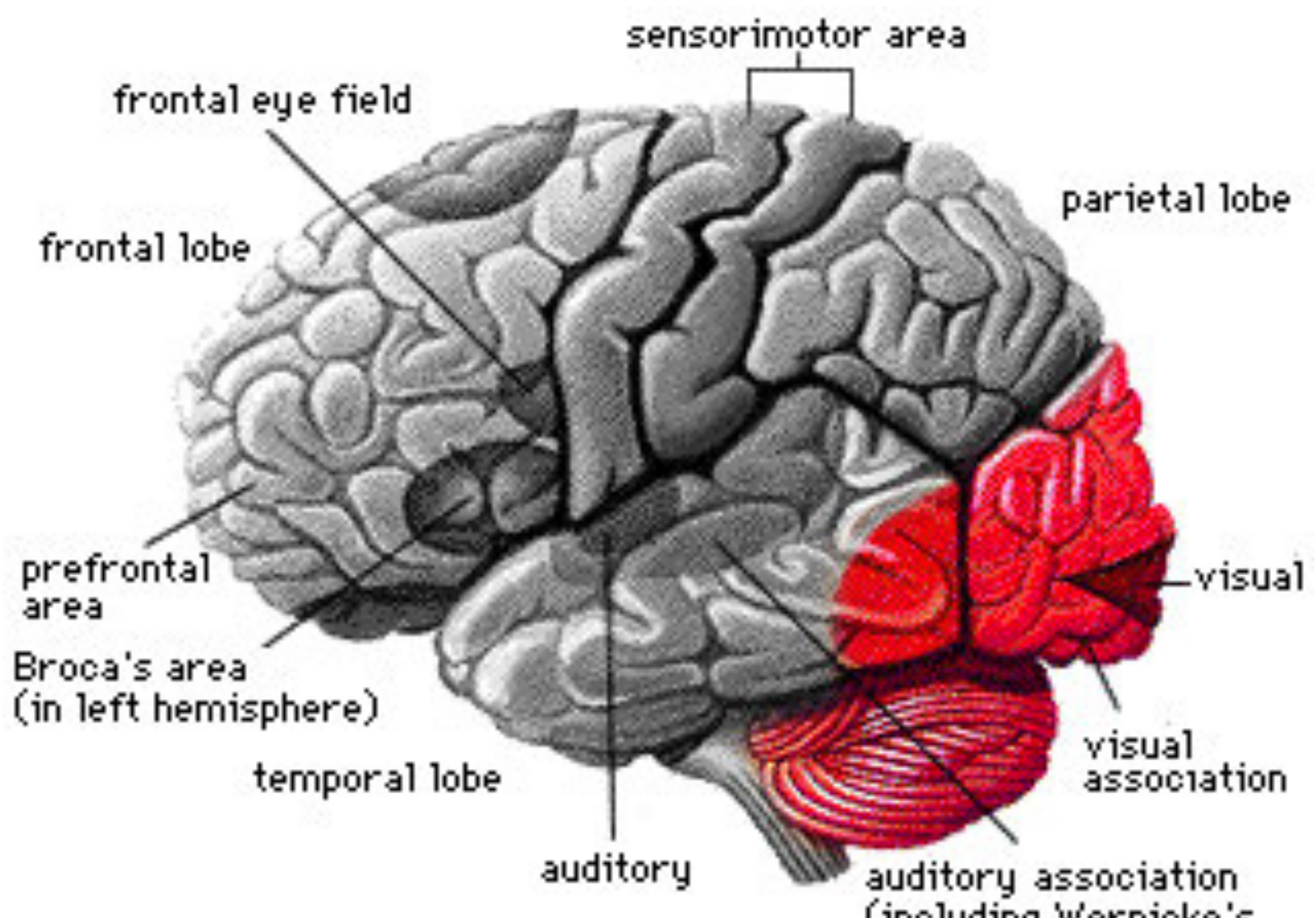
Connor Lin

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!

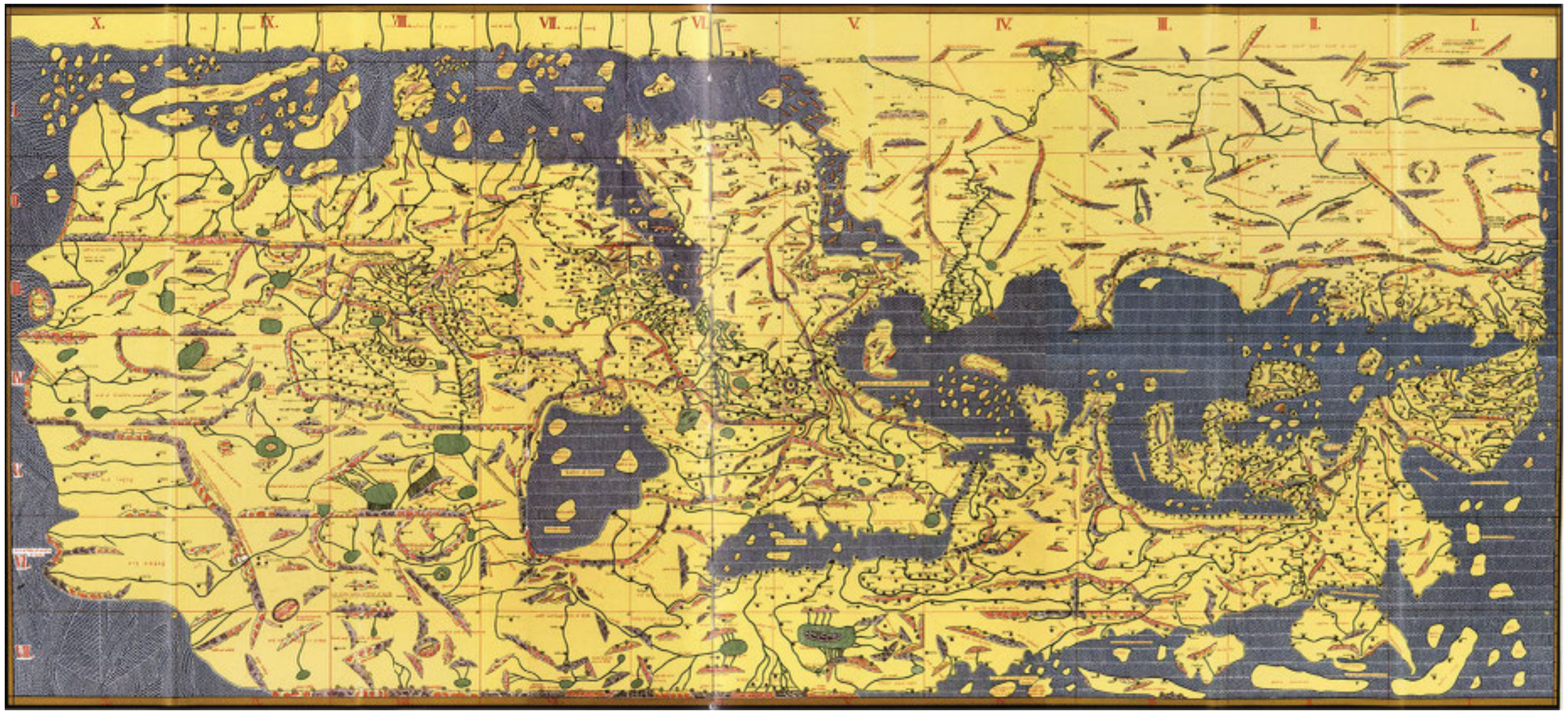
History of visual depiction

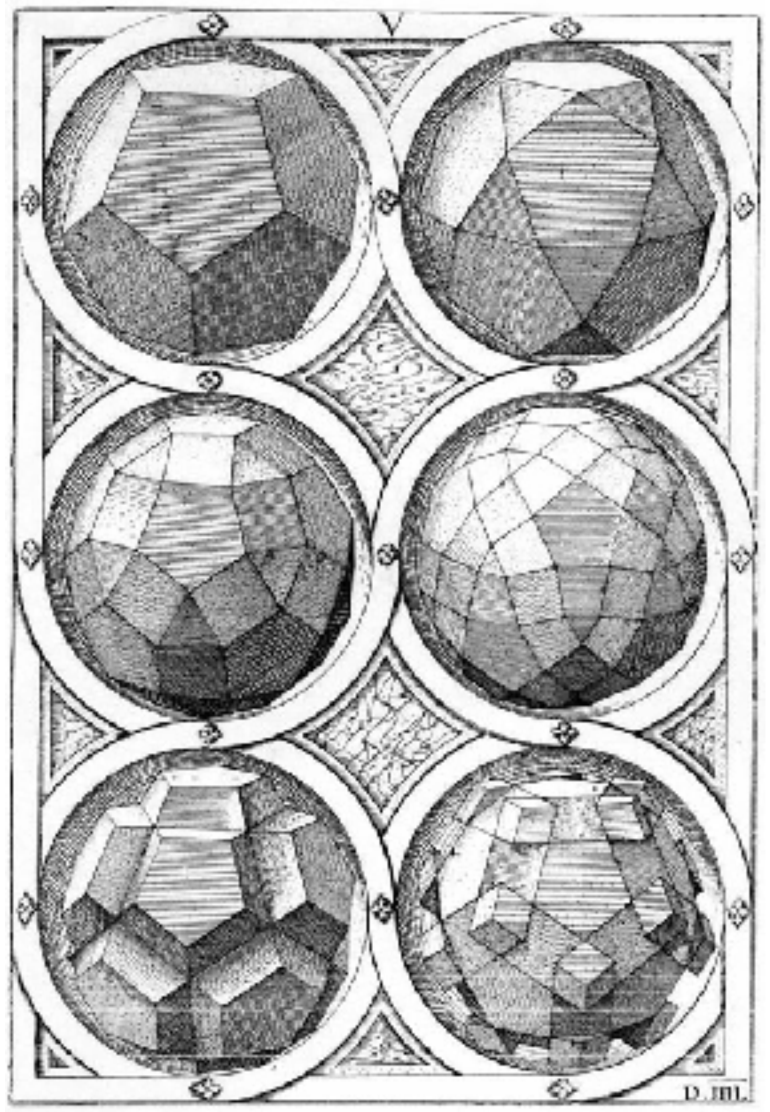
- Humans have *always* been visual creatures!

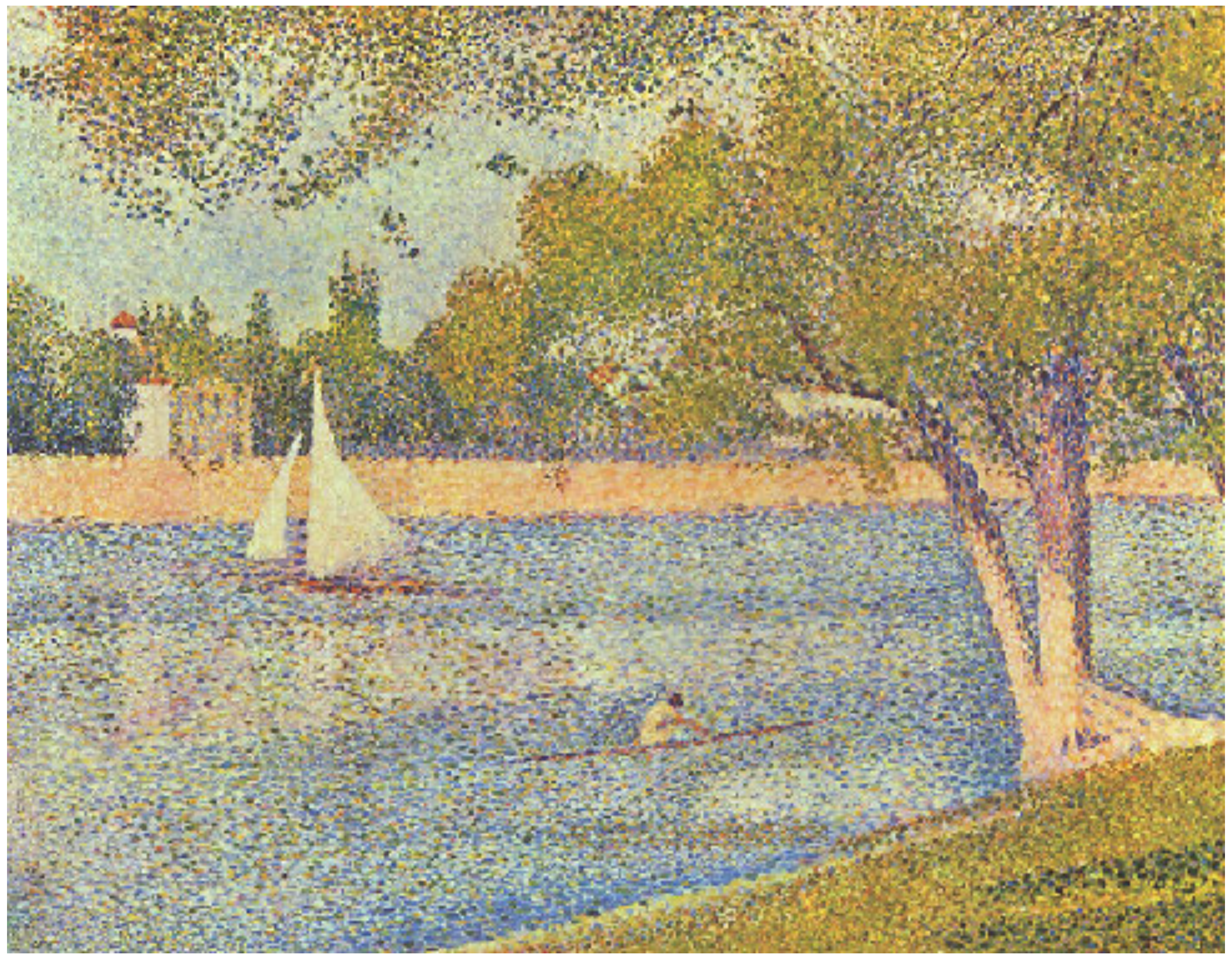
Indonesian cave painting (~38,000 BCE)

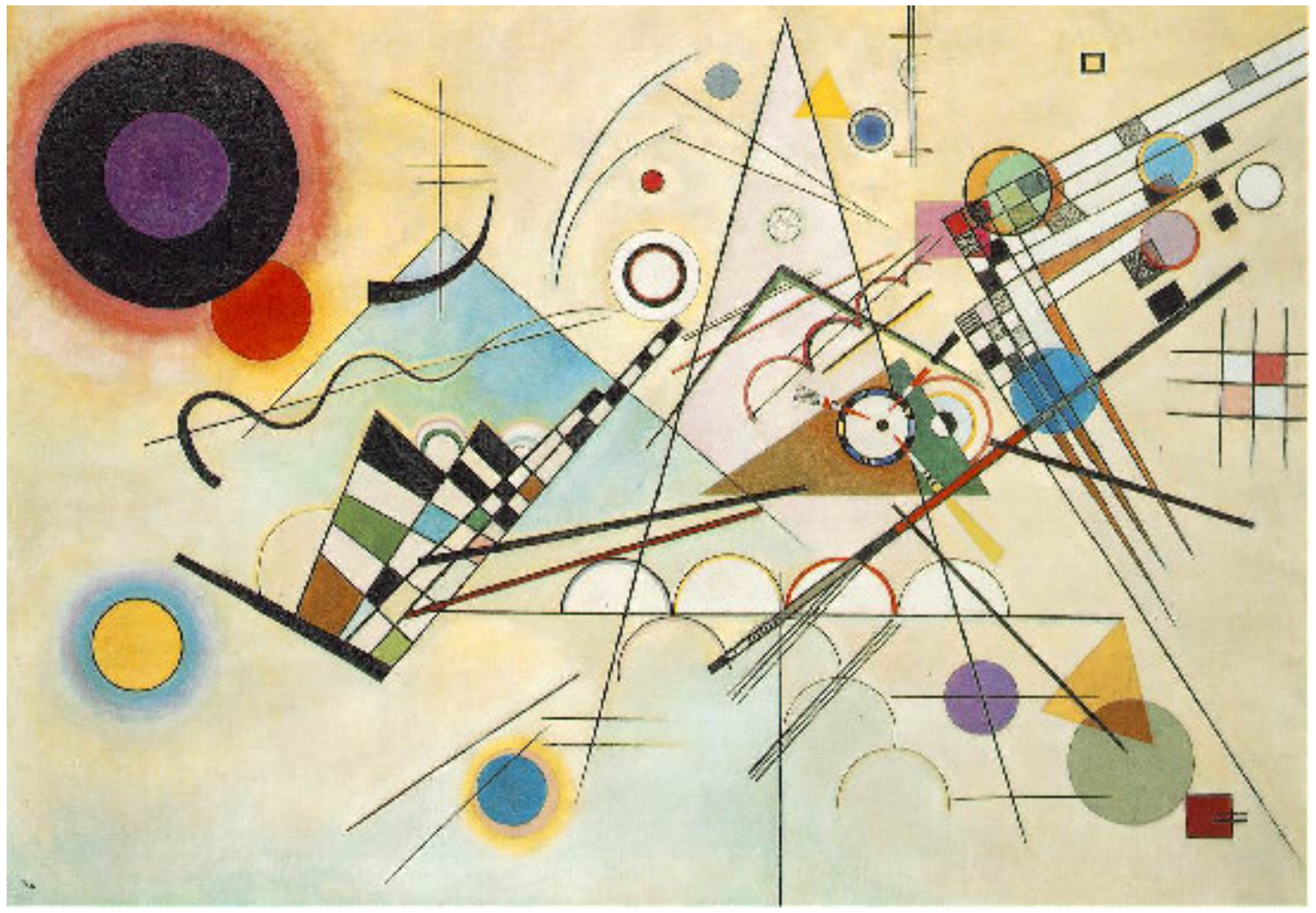
Visual technology: painting / illustration

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









Visual technology: carving / sculpture



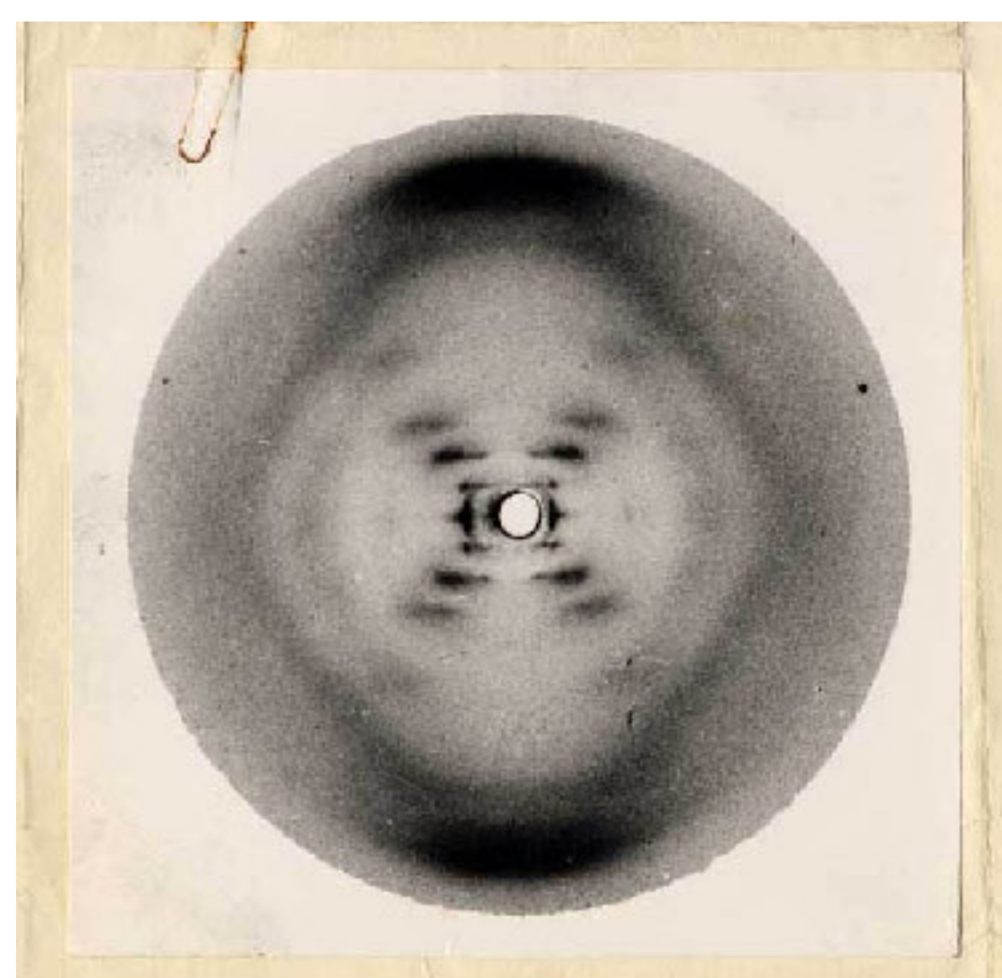


Visual technology: photography / imaging

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

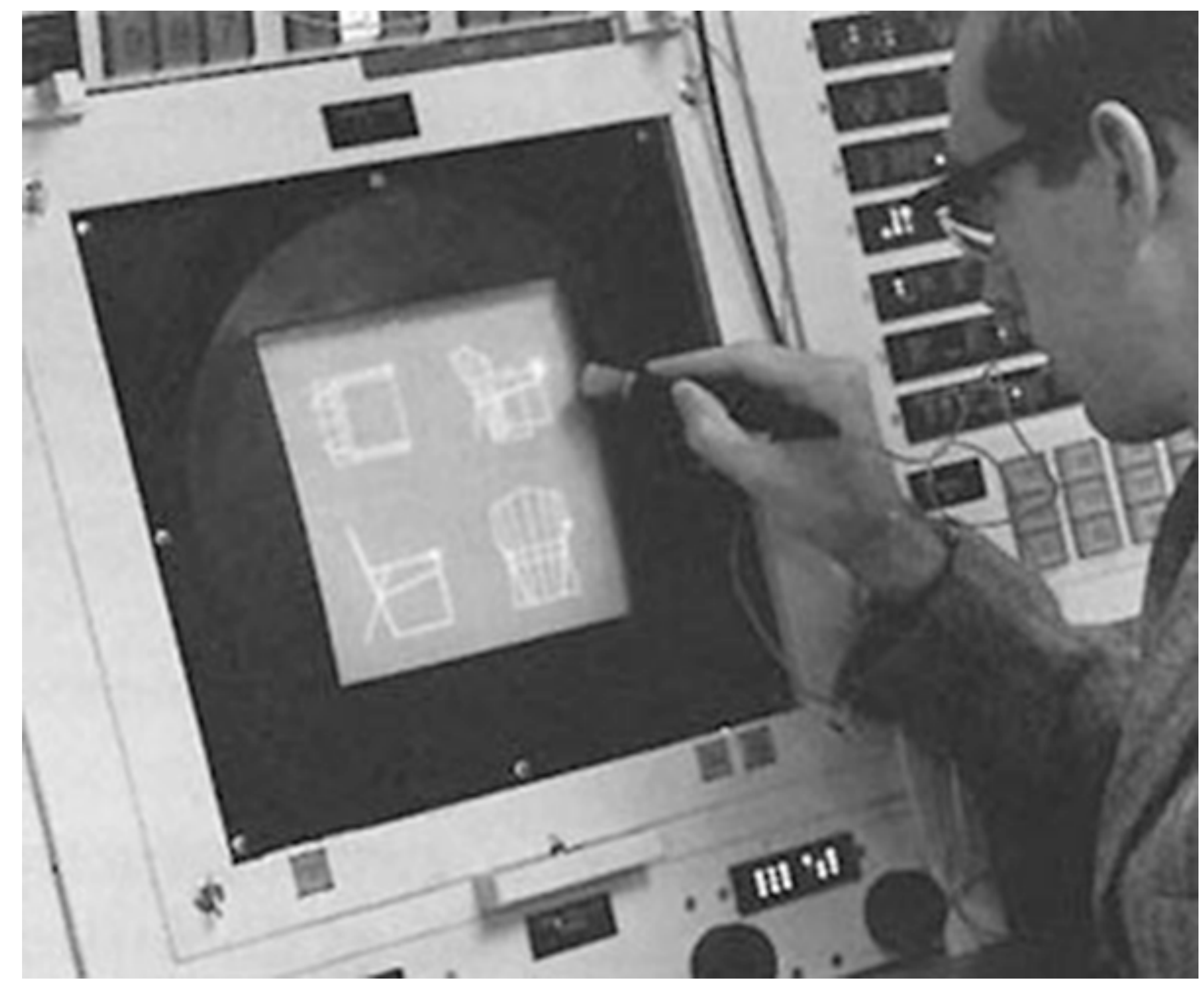
Joseph Niépce, “View from the Window at Le Gras” (1826)

Visual technology: photography / imaging



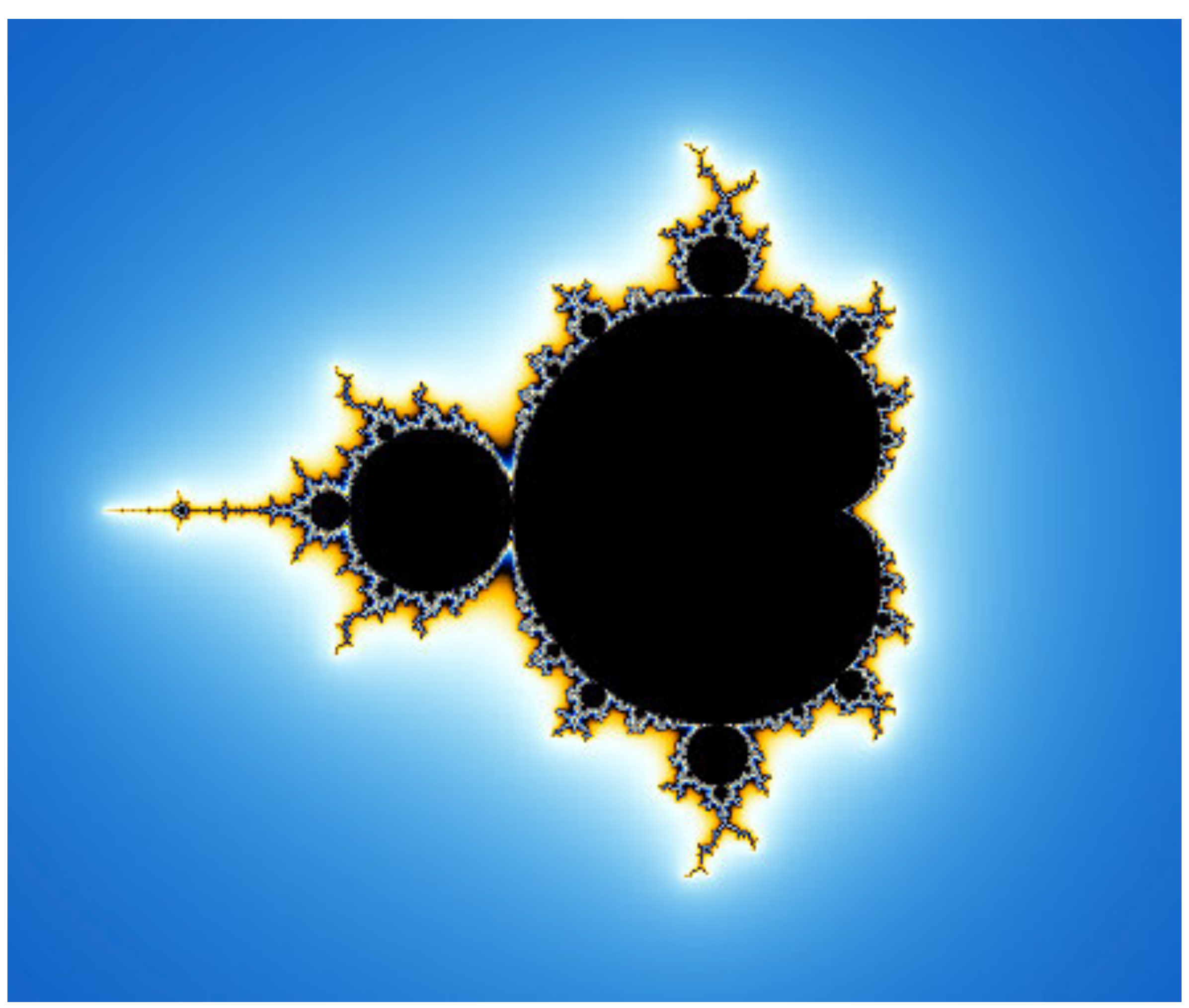
Visual technology: digital imagery

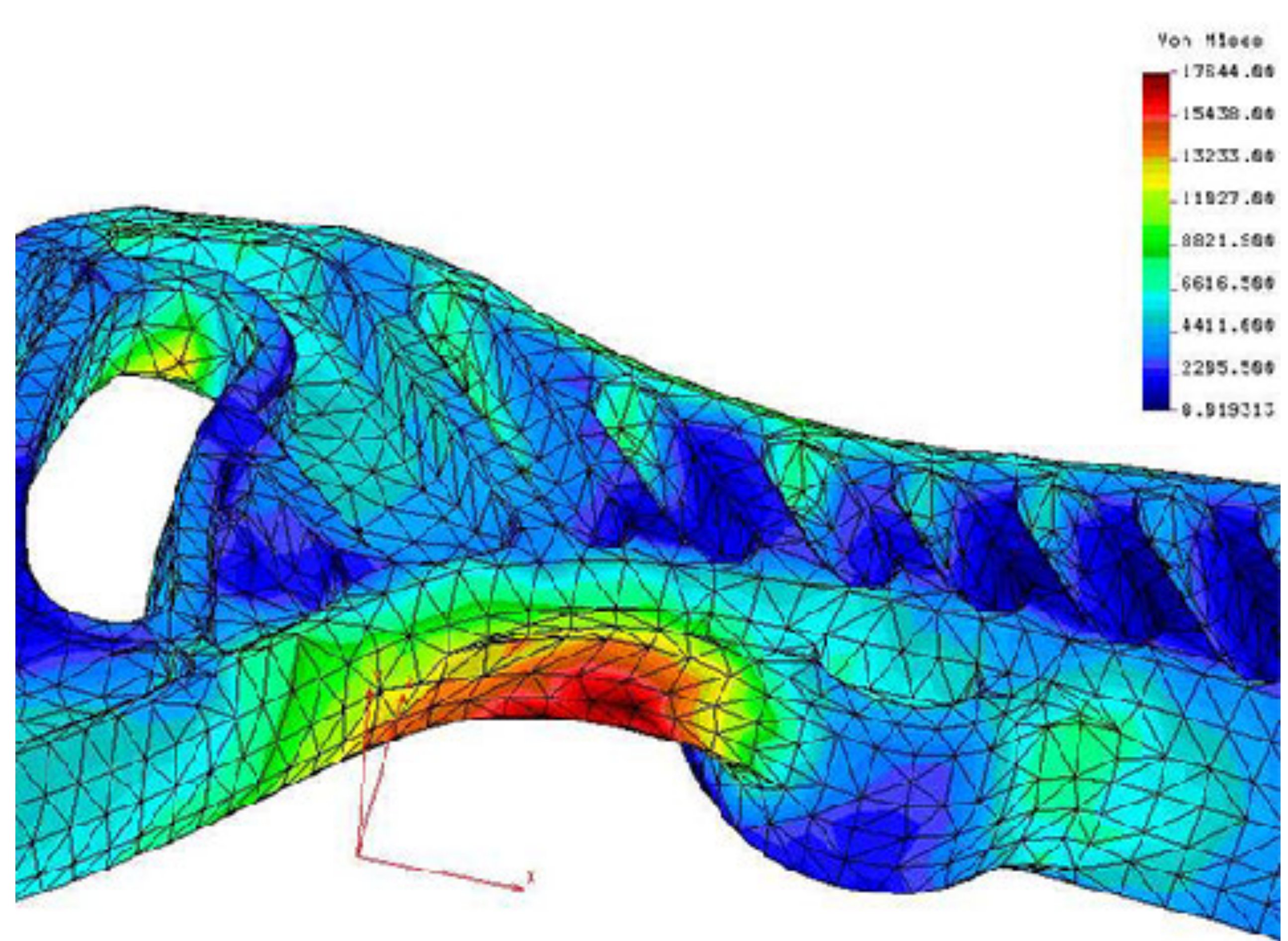
- **Intersection of visual depiction & computation**

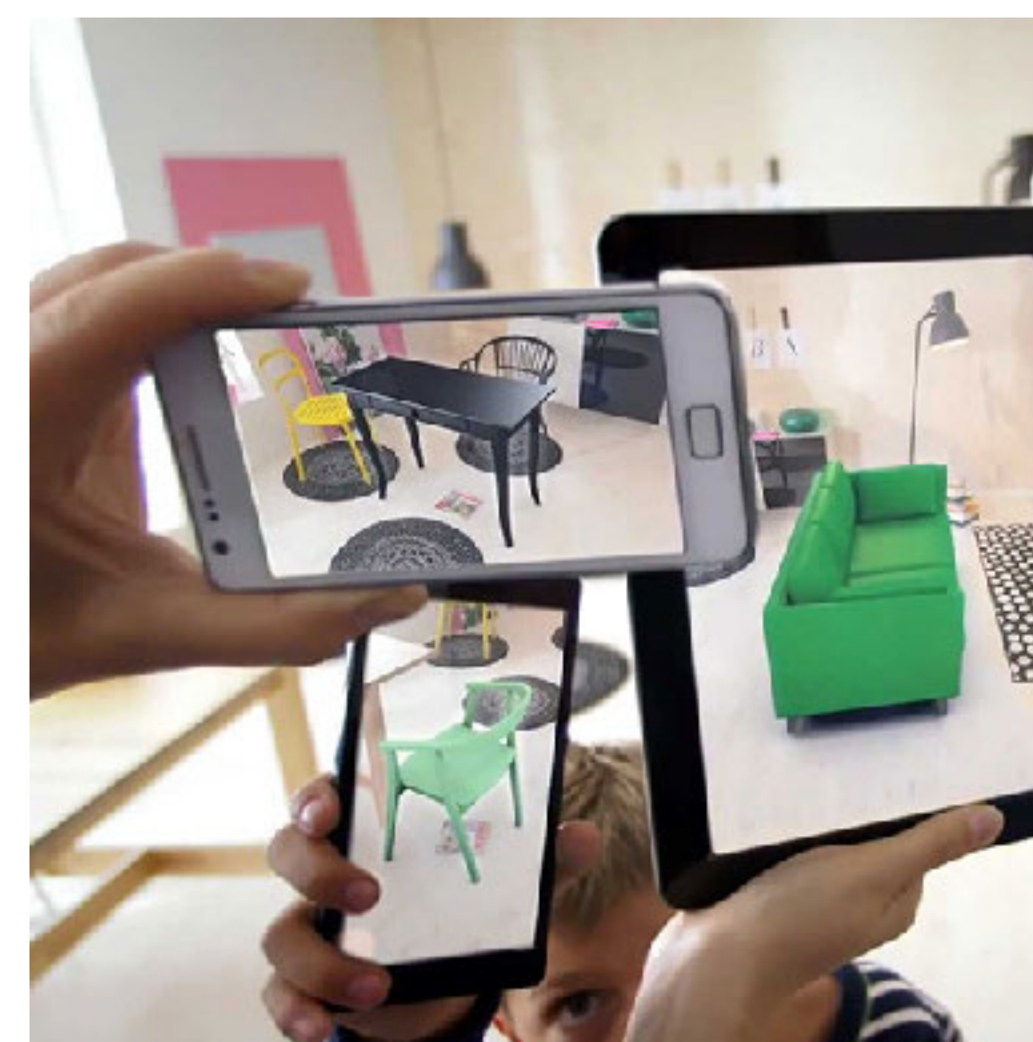


Ivan Sutherland, "Sketchpad" (1963)

Visual technology: digital imagery

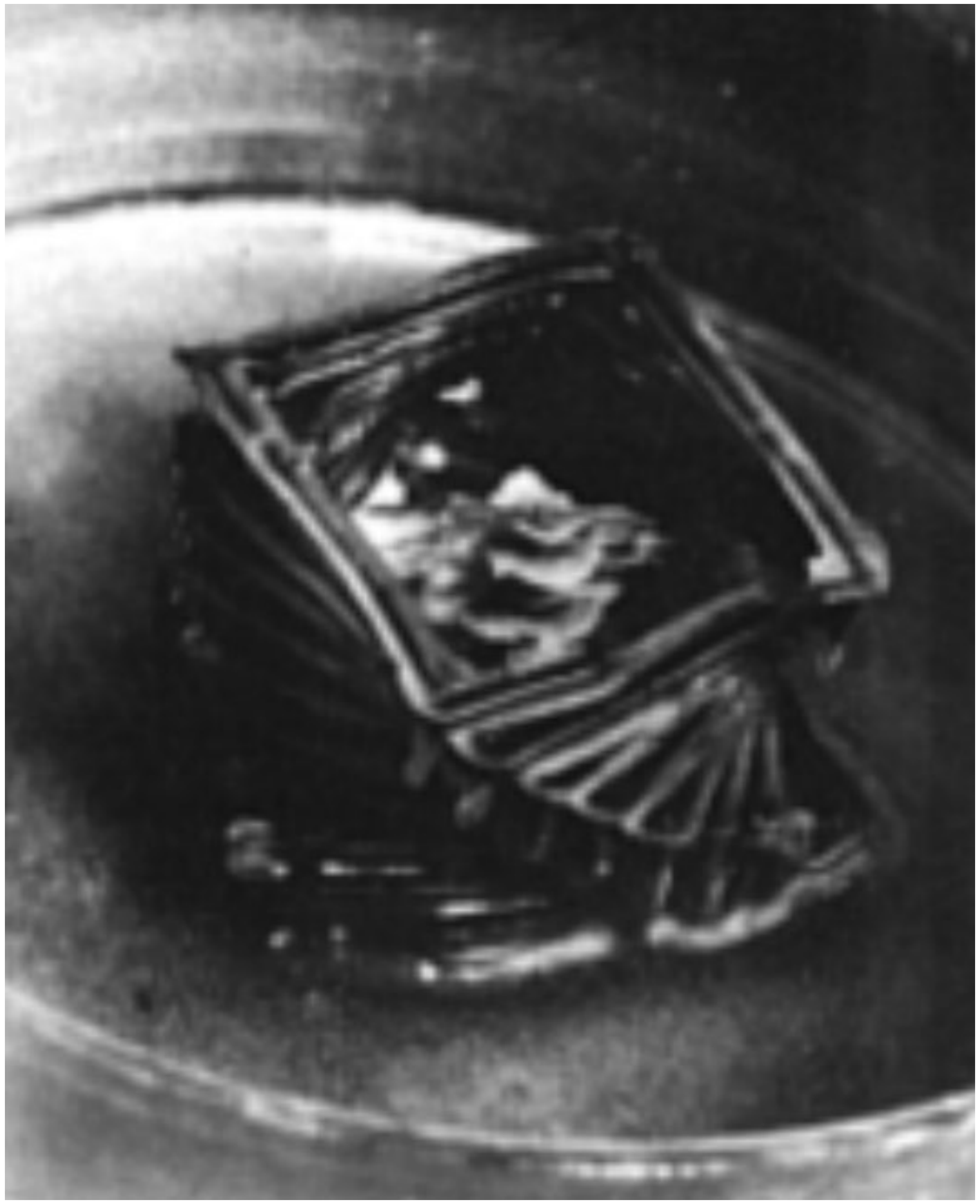


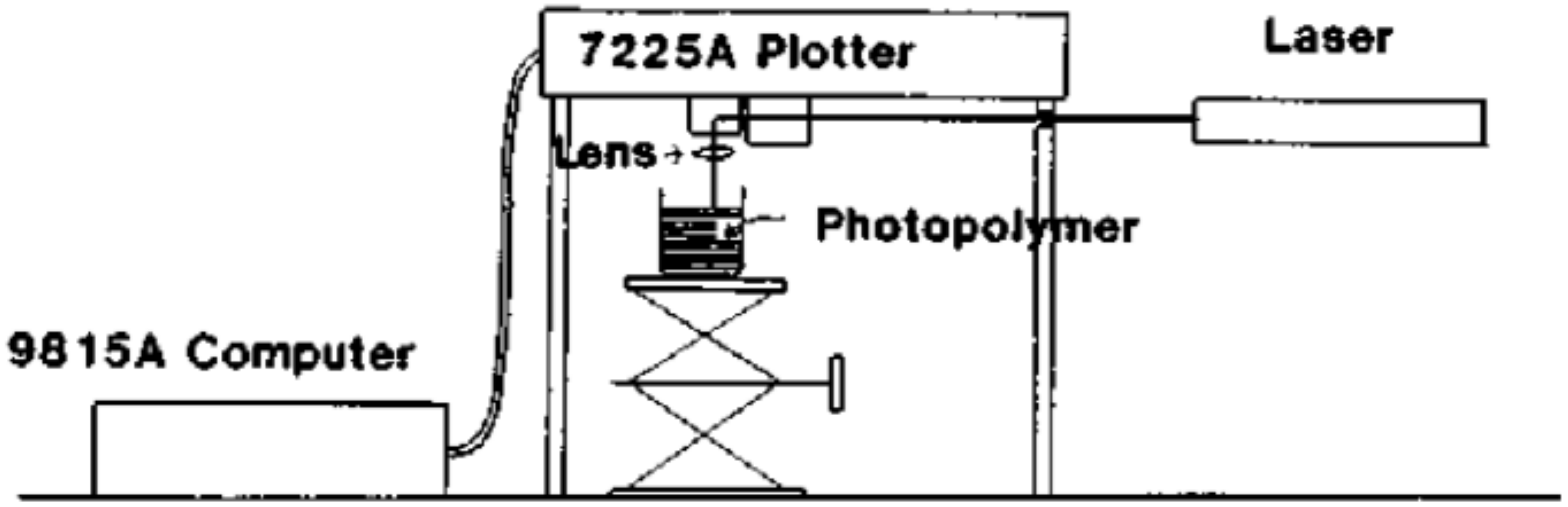




Visual technology: 3D fabrication

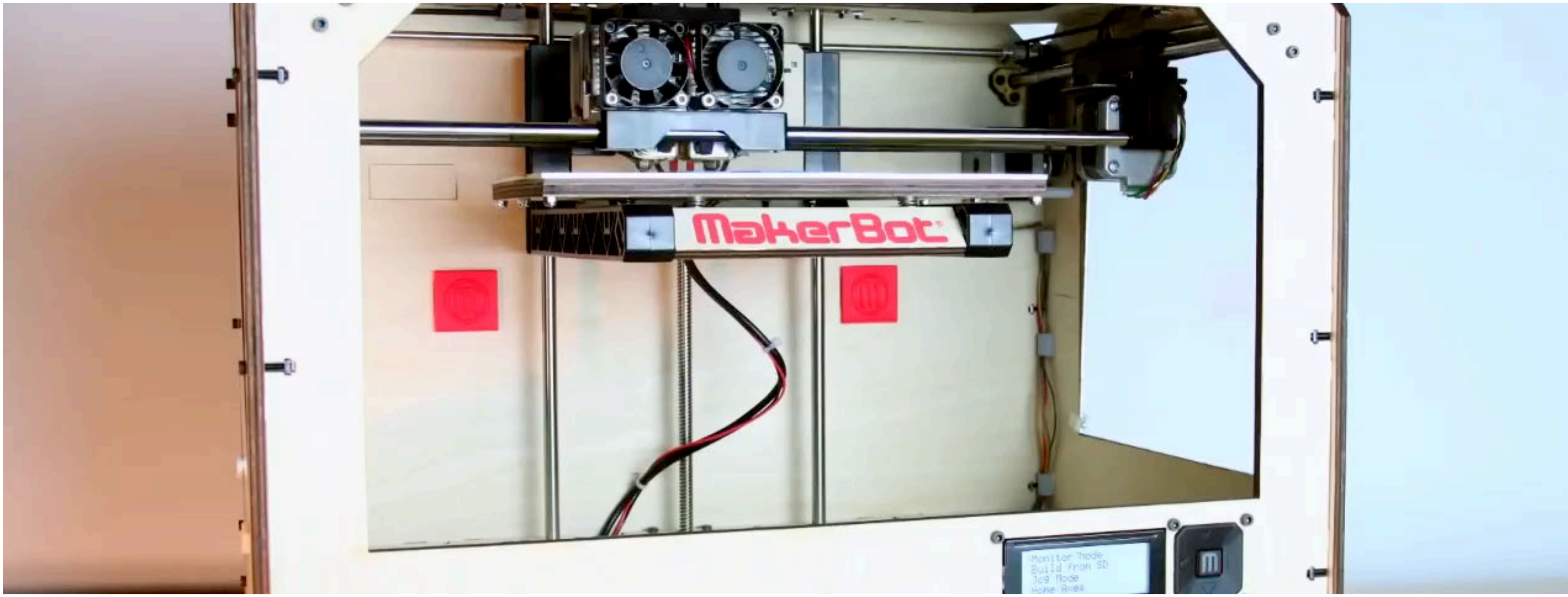
- Create *physical* realization of digital shape

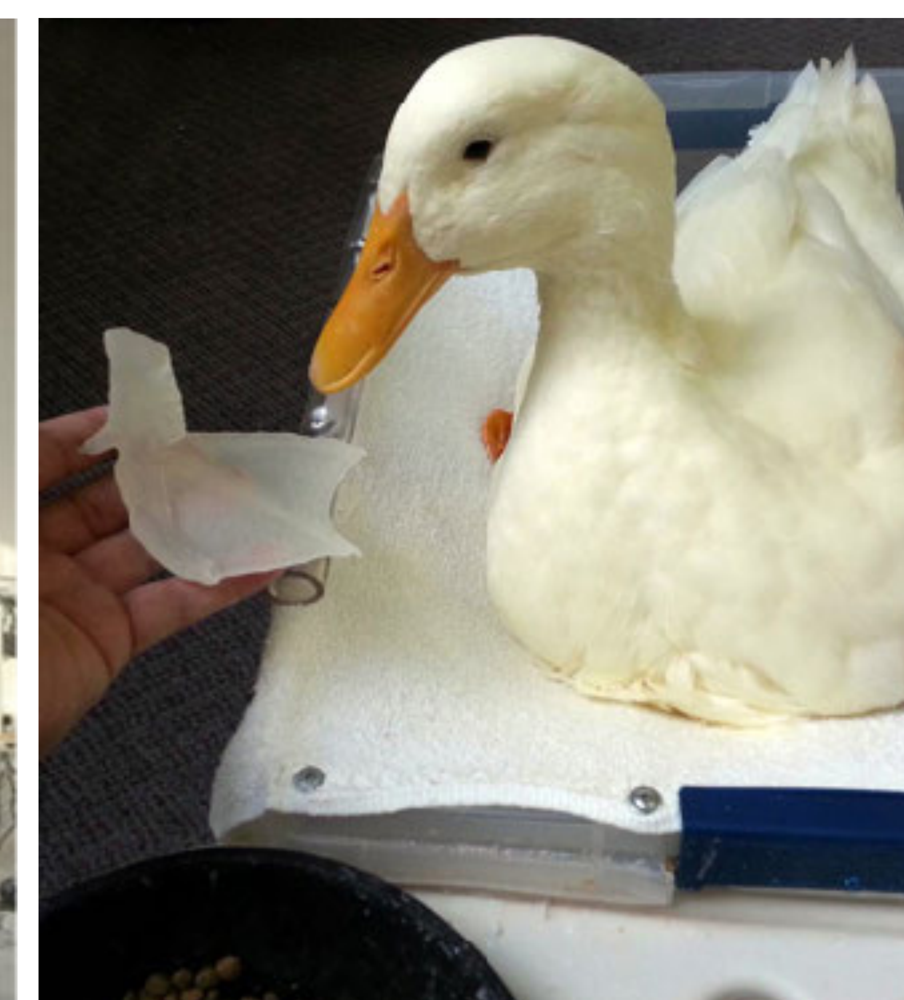




A.J. Herbert / 3M (1979)

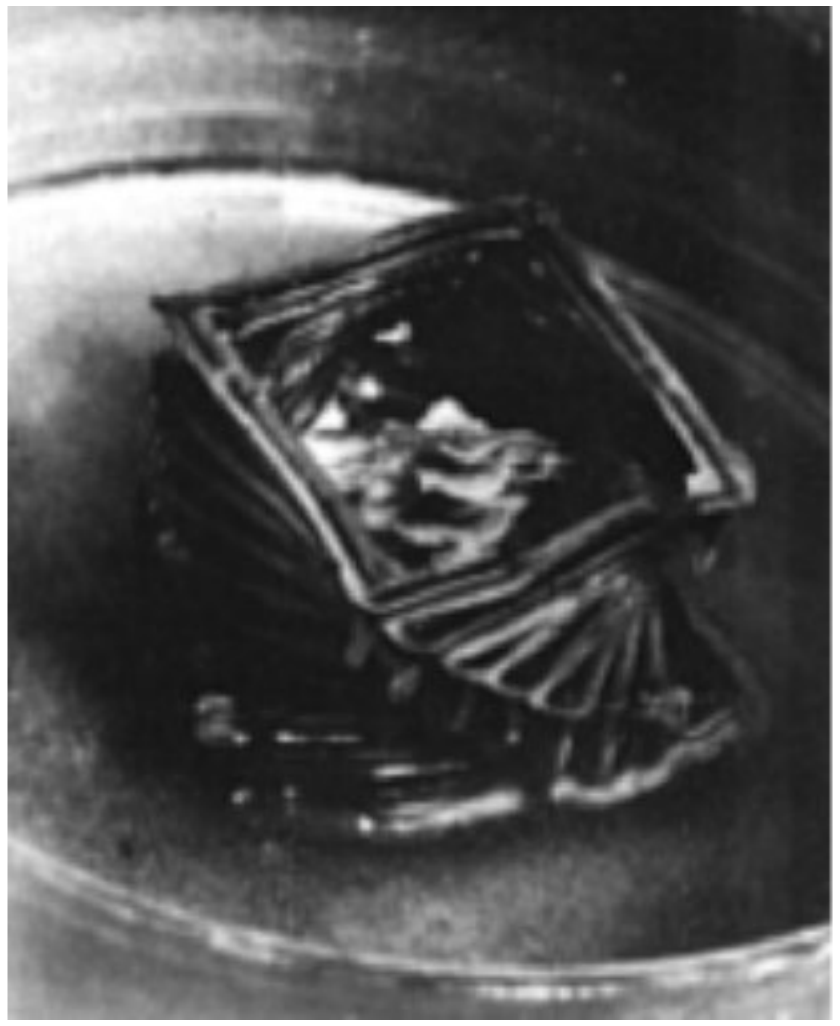
Visual technology: 3D fabrication





Technologies for visual depiction

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

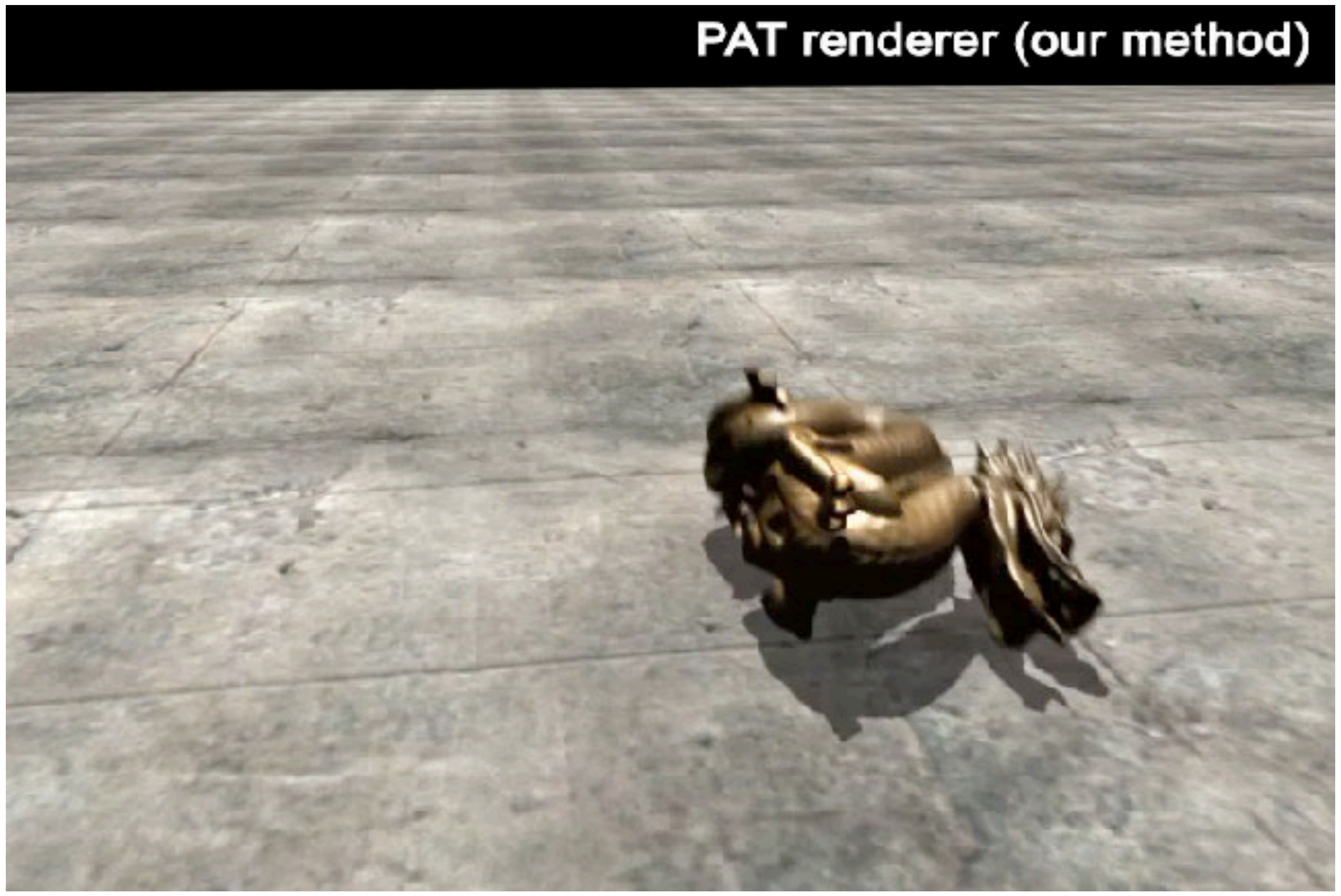


Definition of Graphics, Revisited

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.

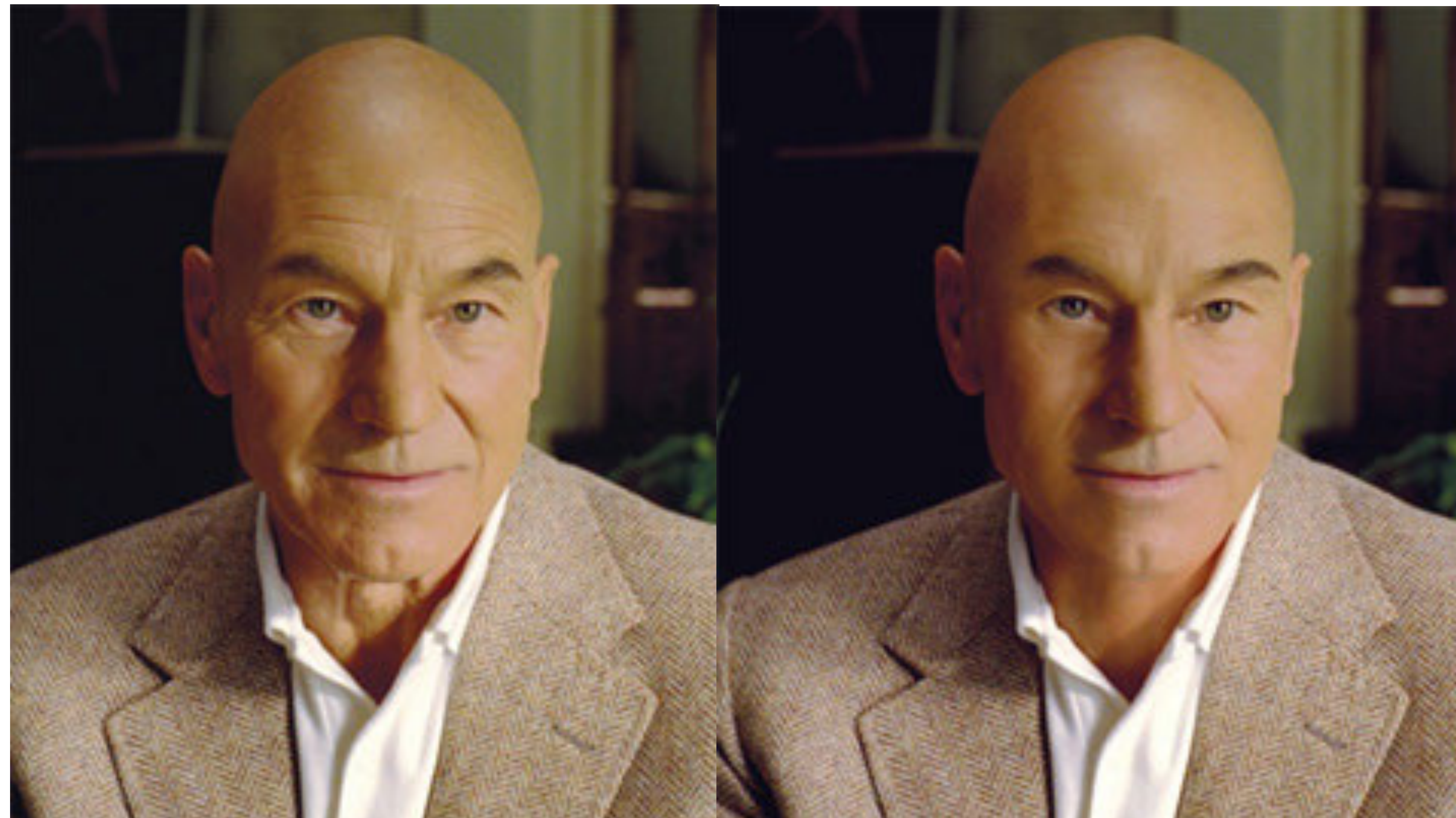
(…What about taste? *Smell?!*)

Computer graphics is *everywhere!*

Entertainment (movies, games)

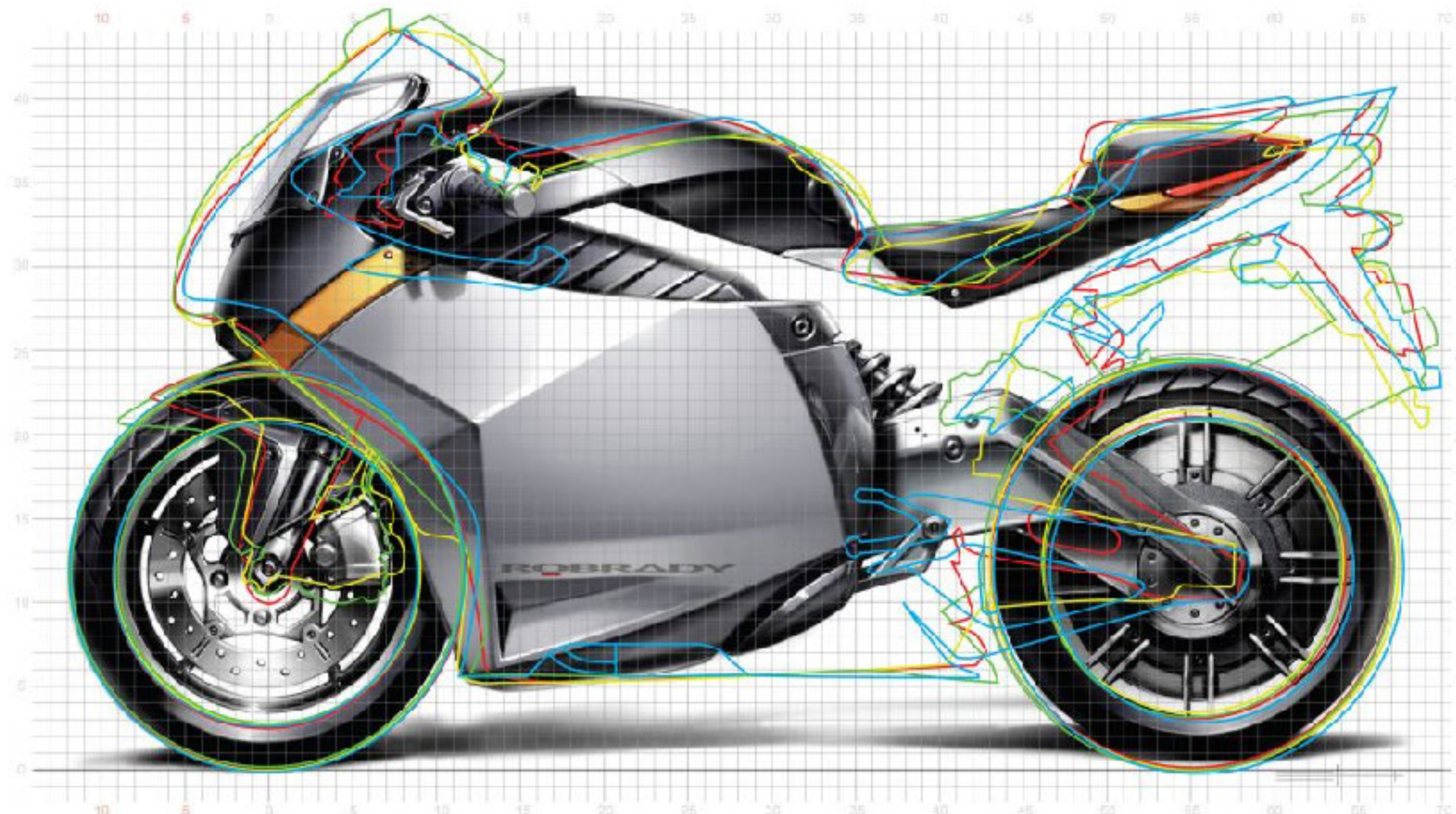
Entertainment

- **Not just cartoons!**

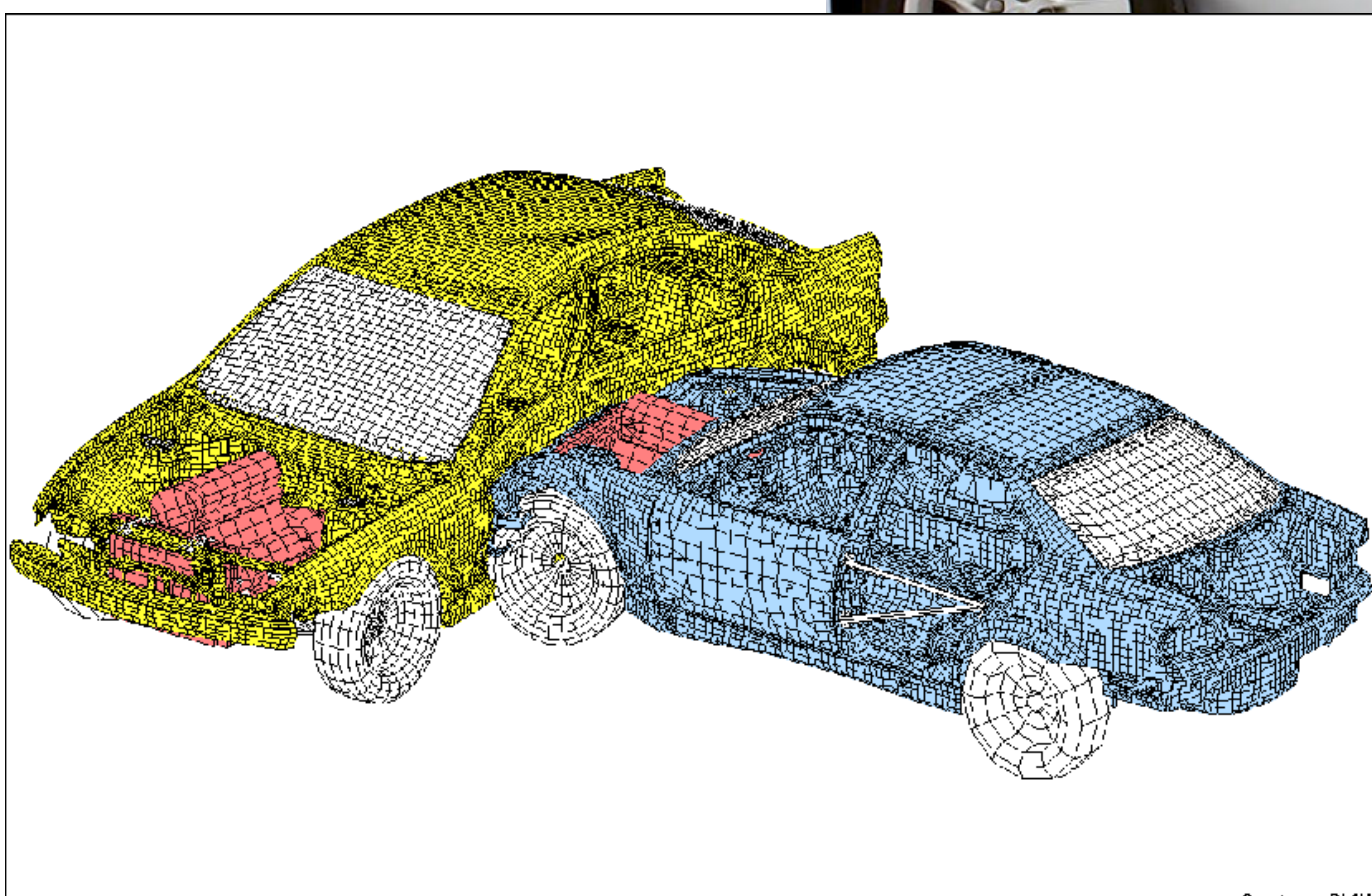


Art and design

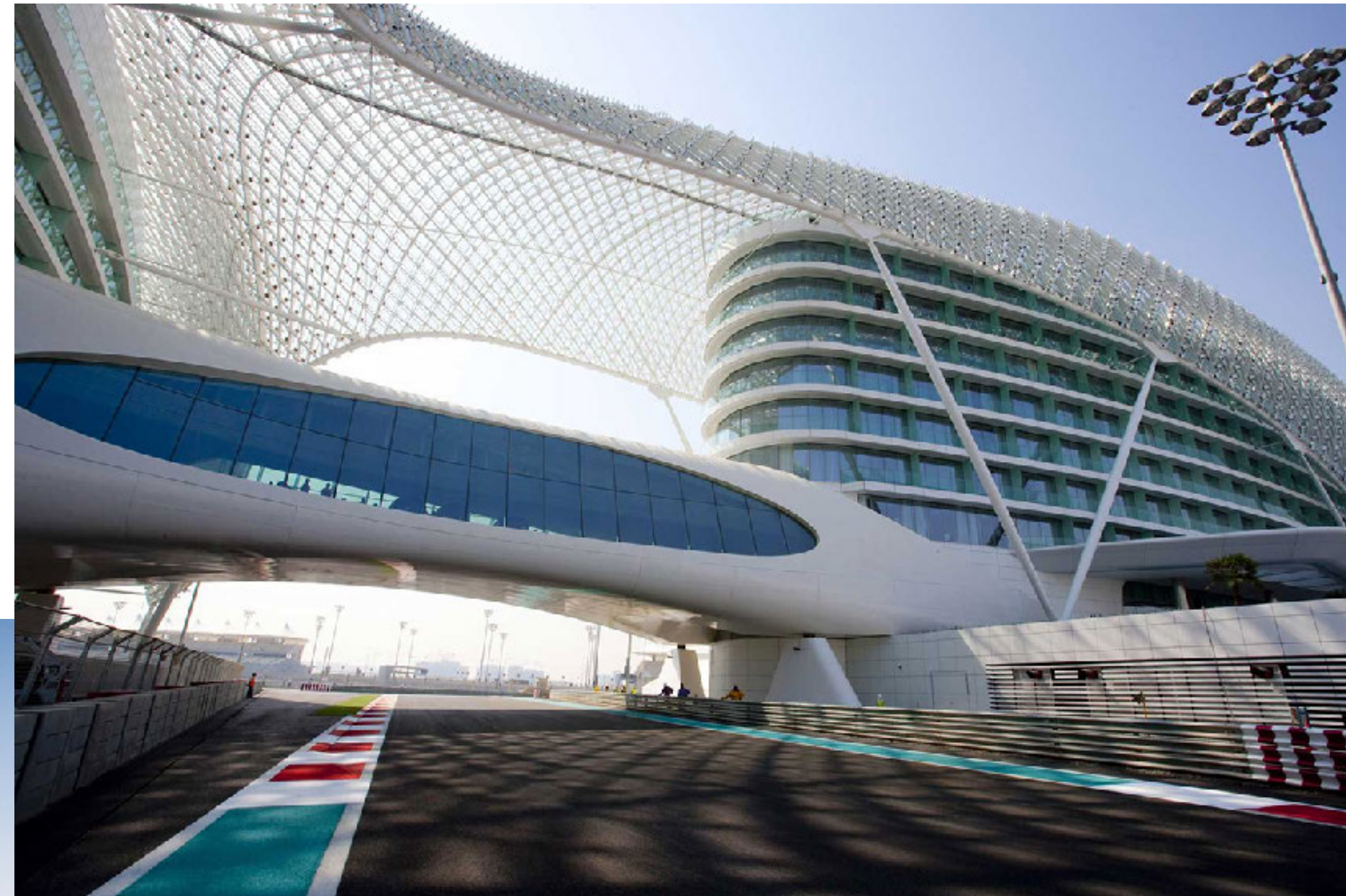
Industrial design

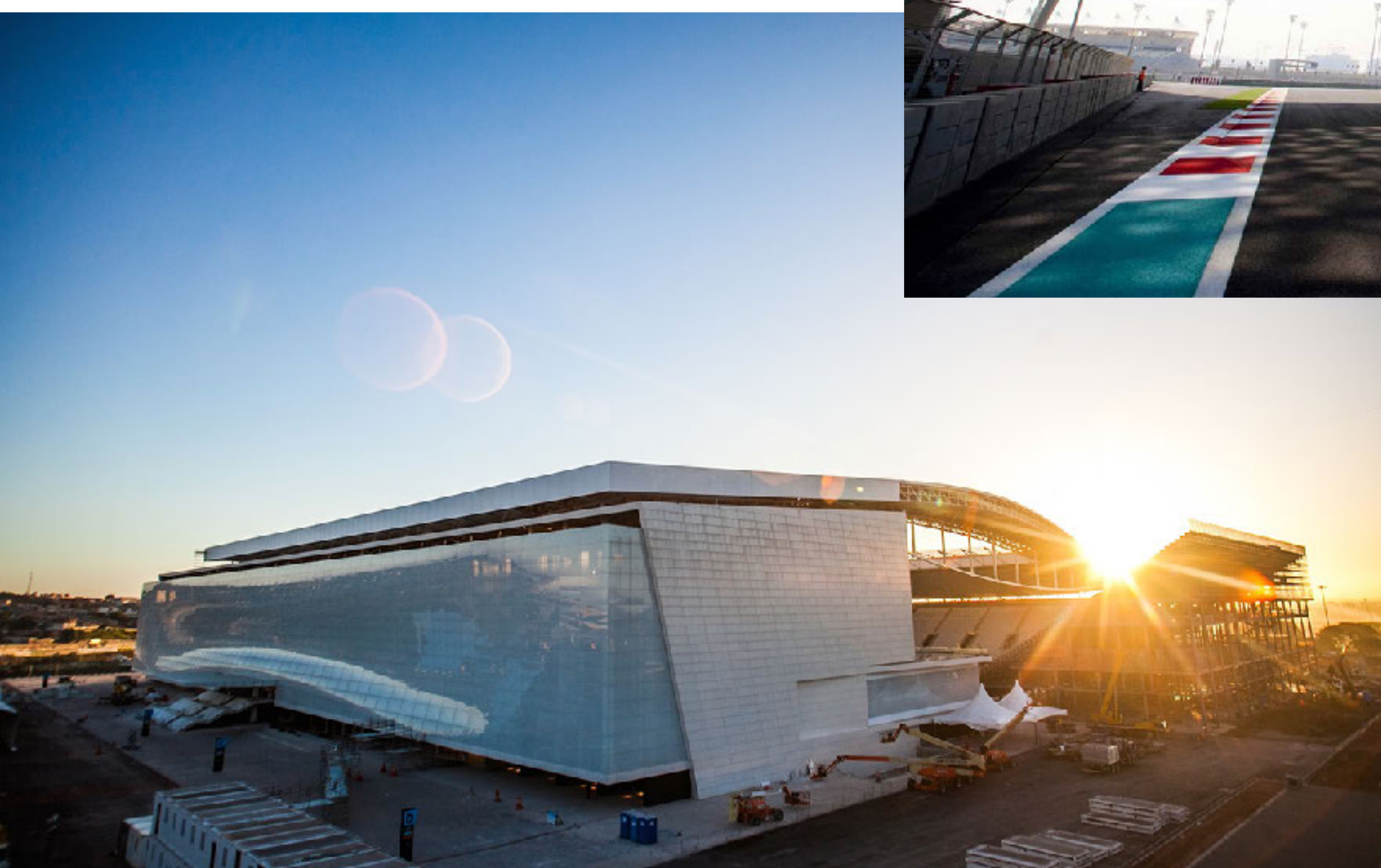


Computer aided engineering (CAE)

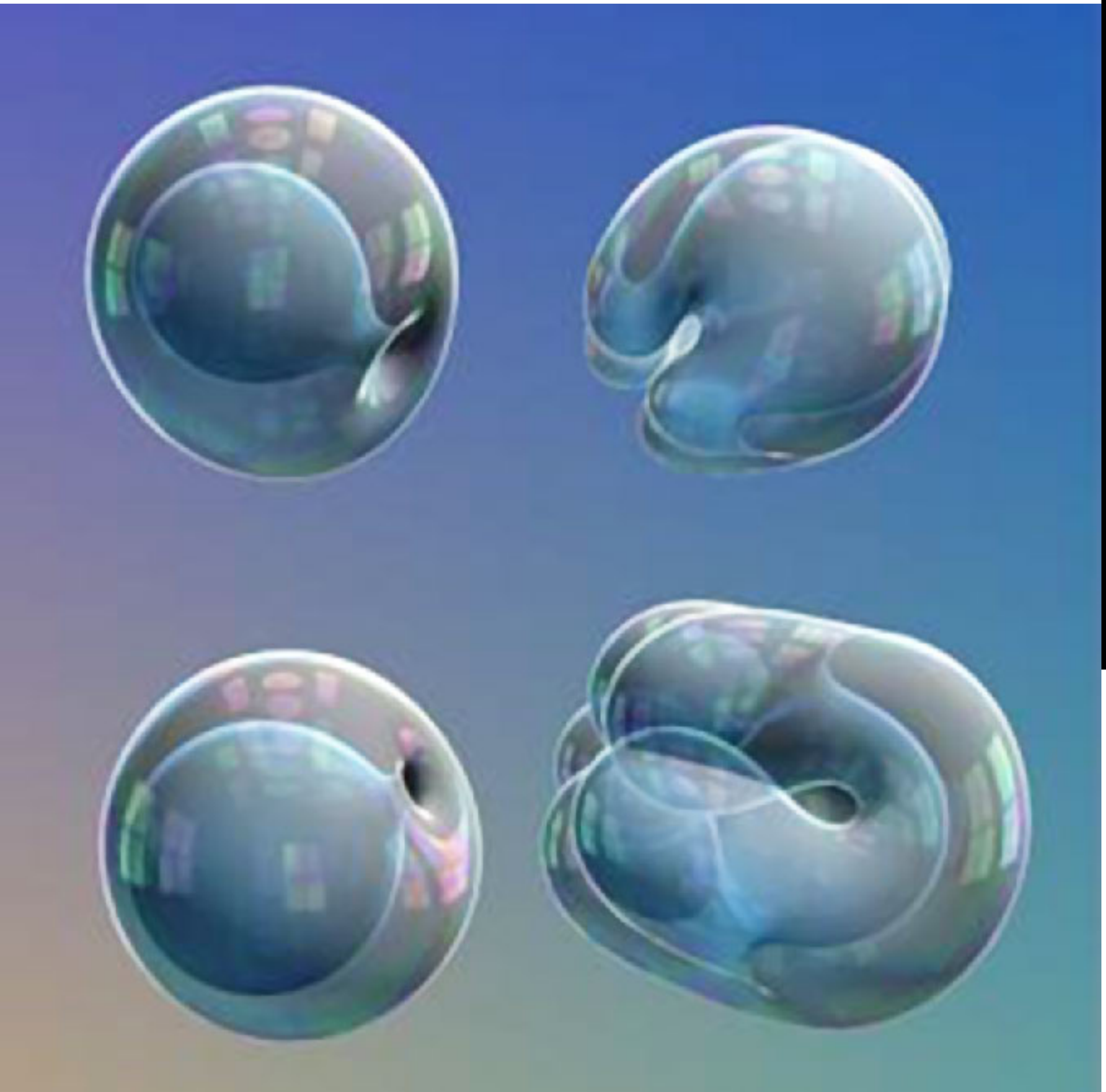


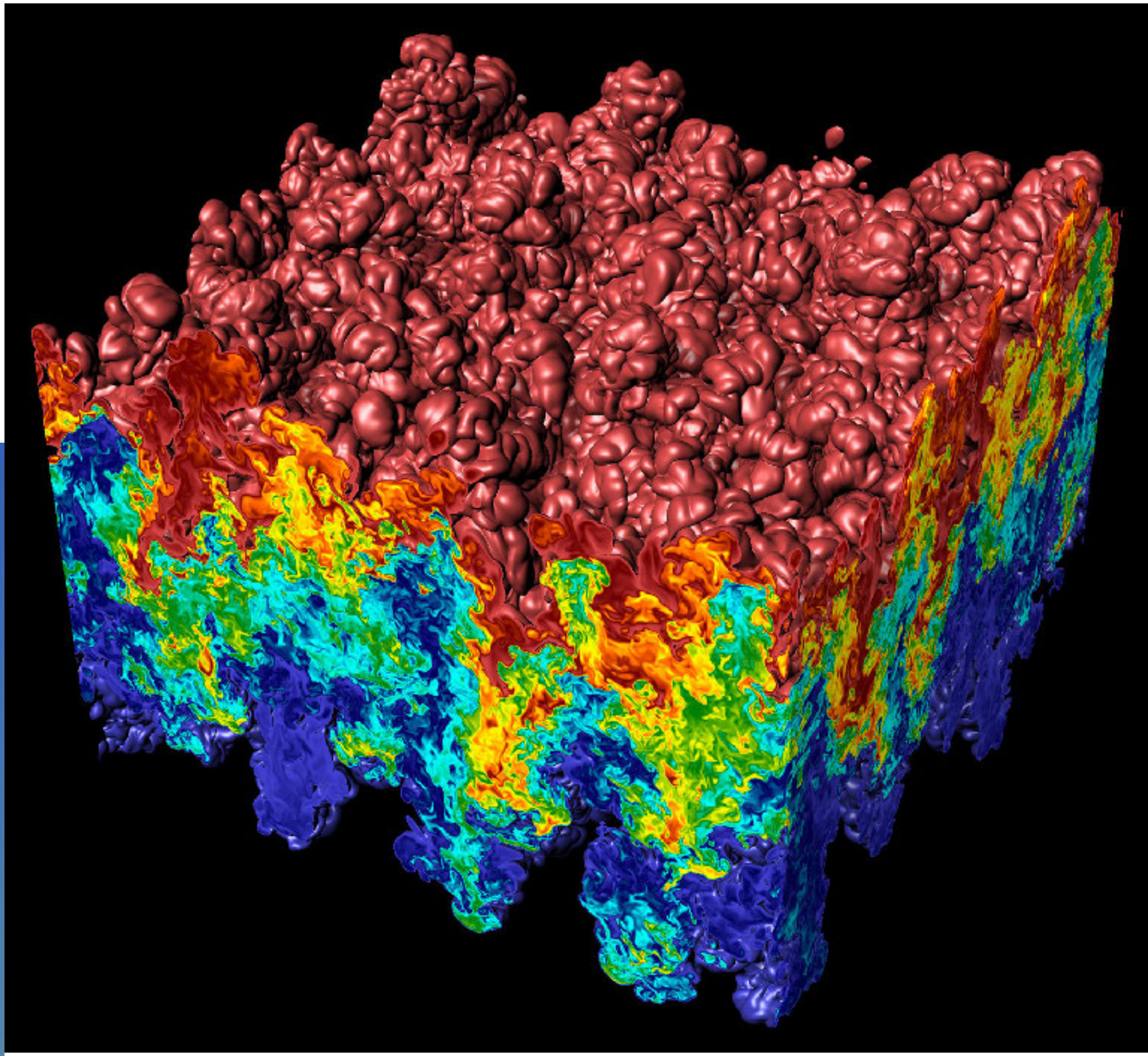
Architecture



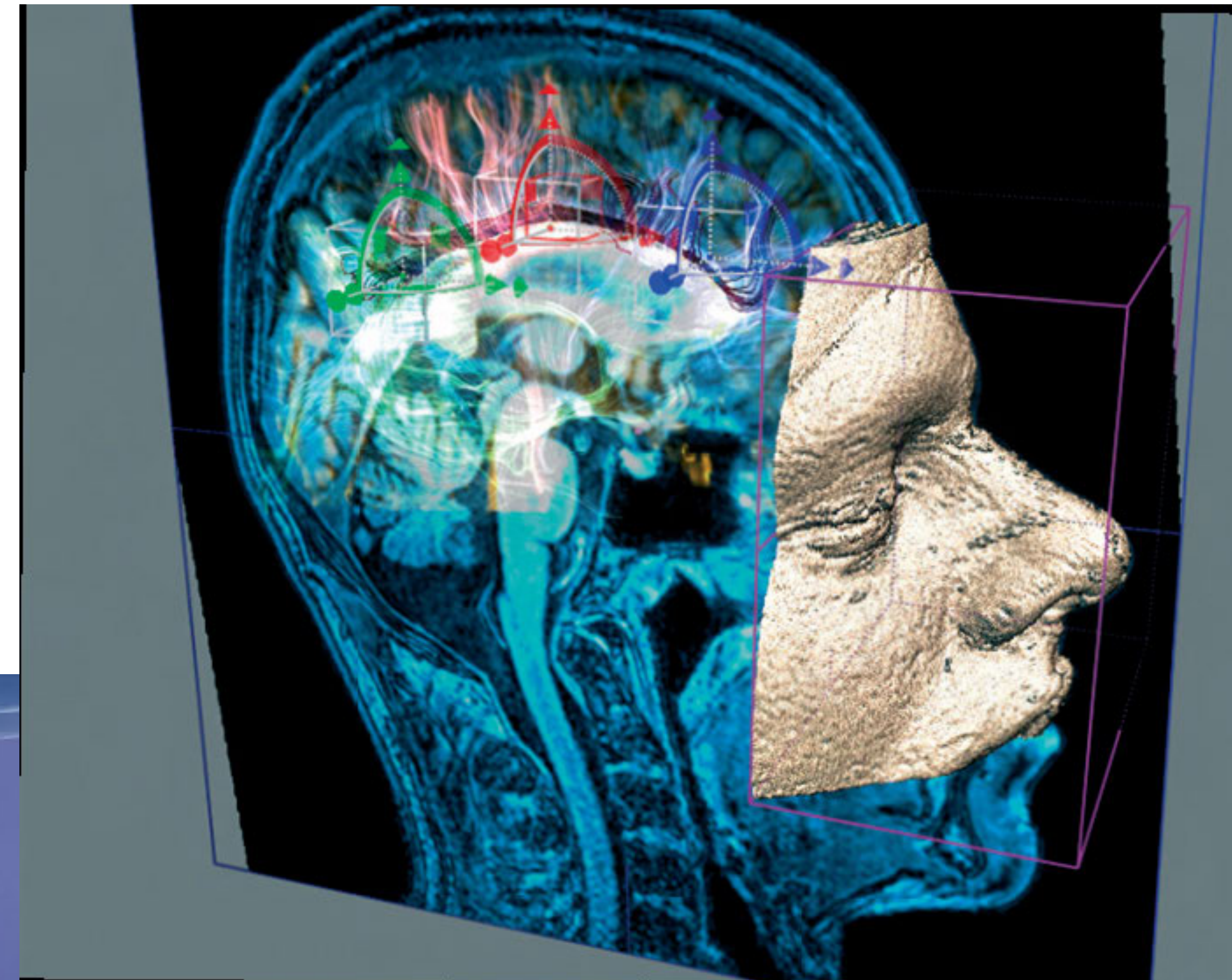


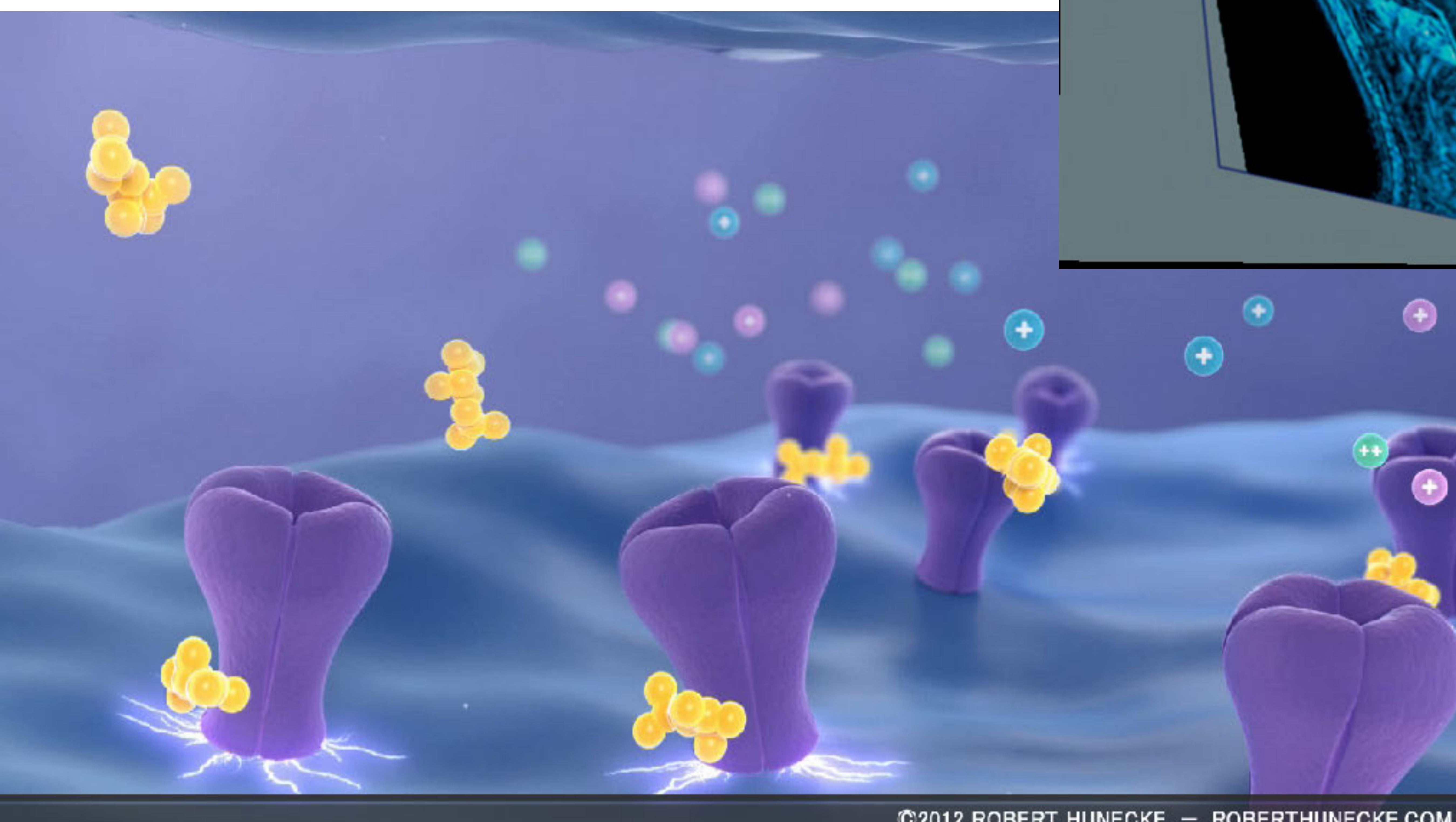
Scientific/mathematical visualization



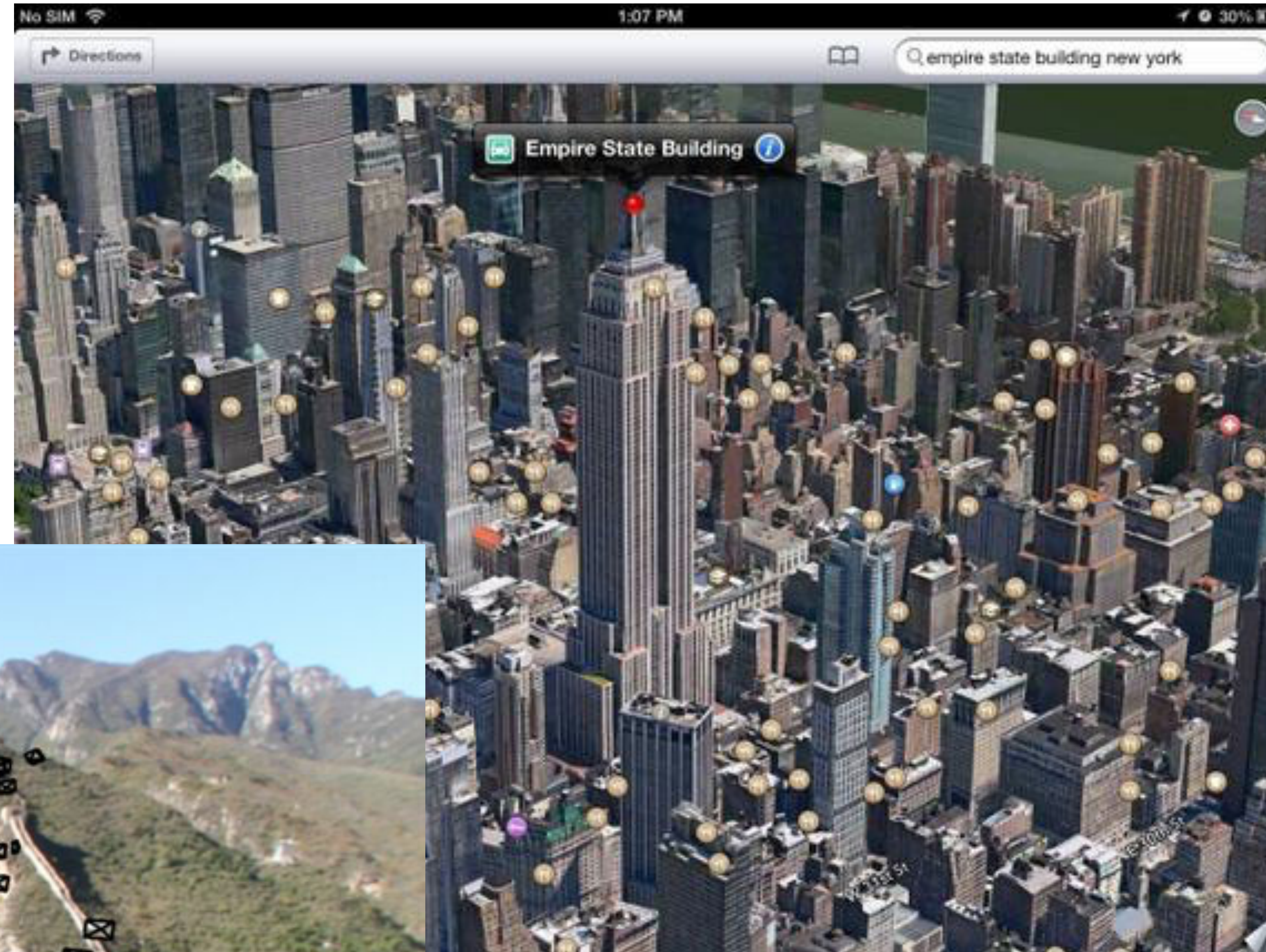


Medical/anatomical visualization



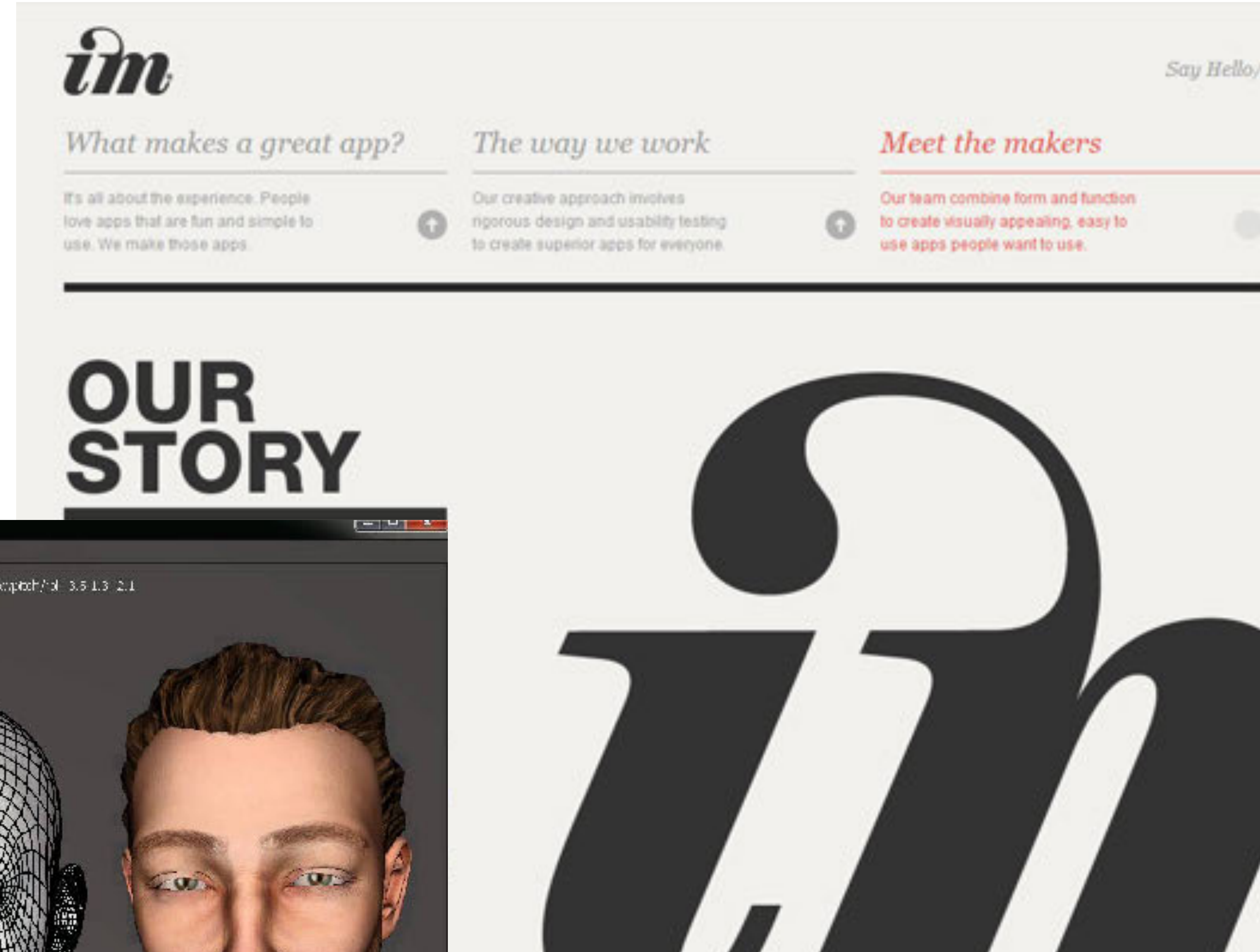


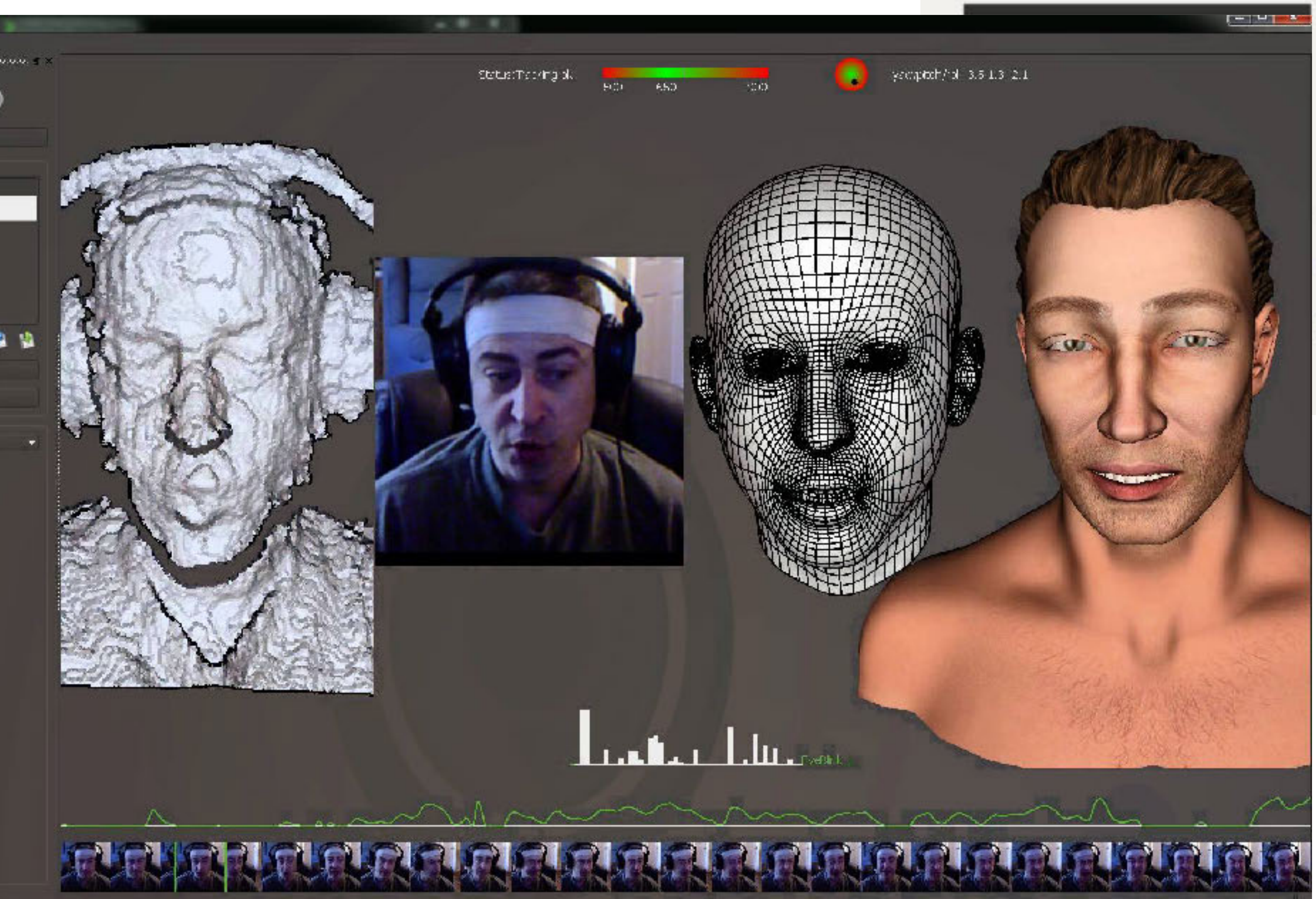
Navigation



No SIM
1:07 PM
30%
Directions
empire state building new york
Empire State Building

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

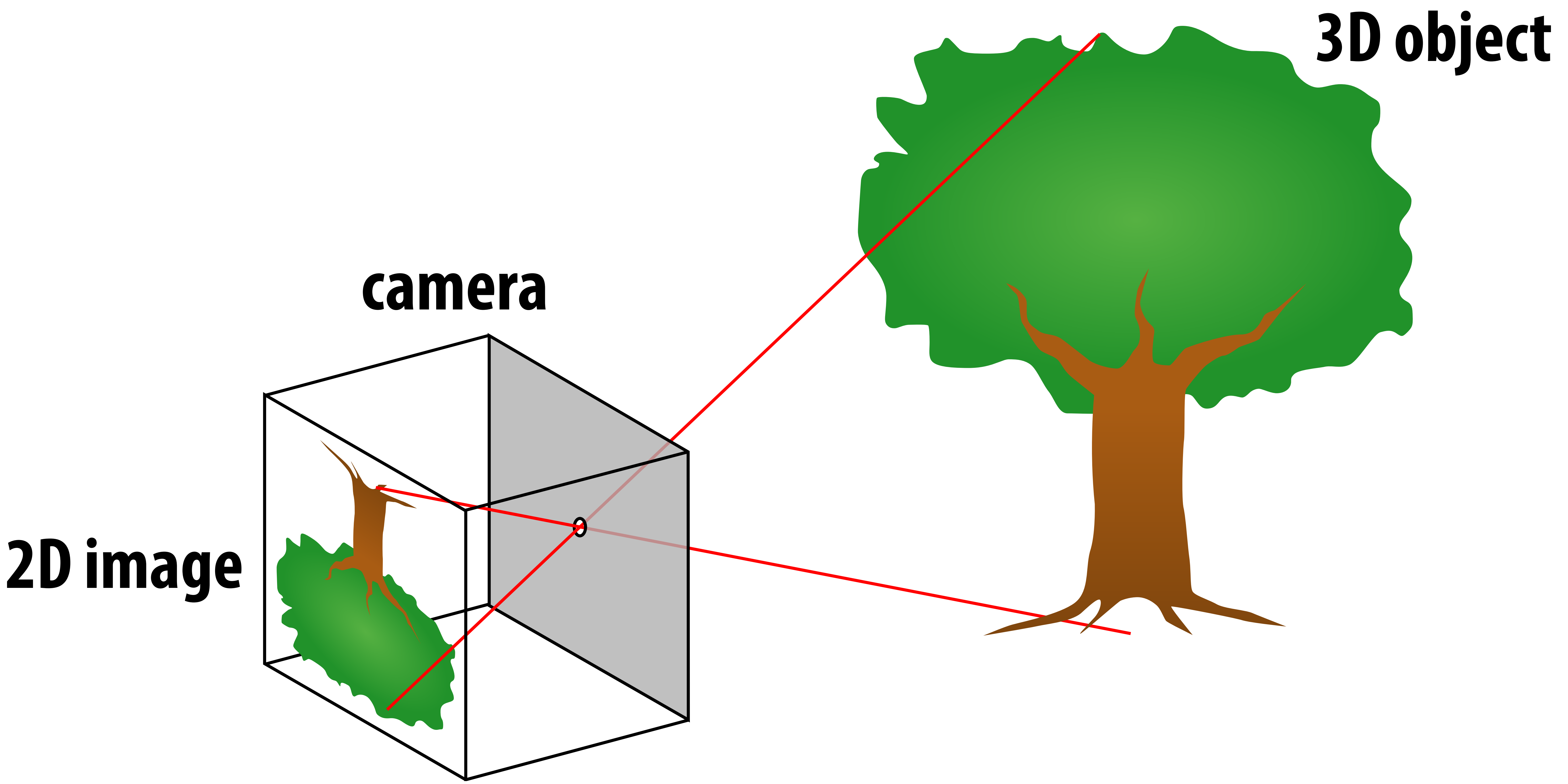
- Now have a digital description of the cube:

```
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?

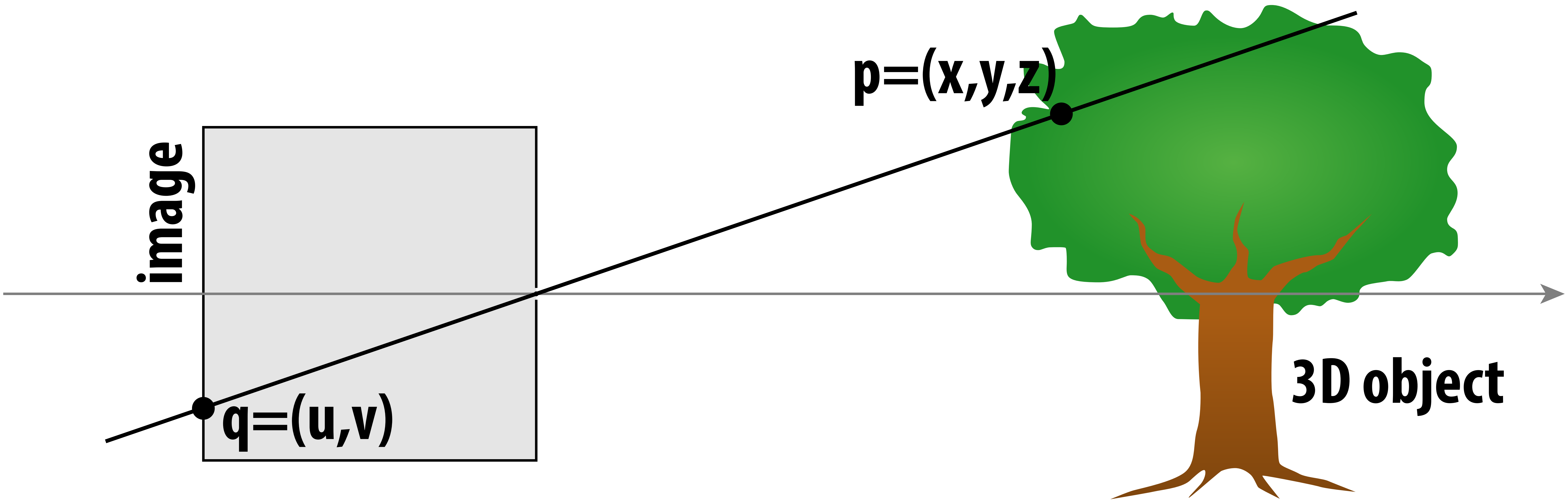
Perspective projection

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



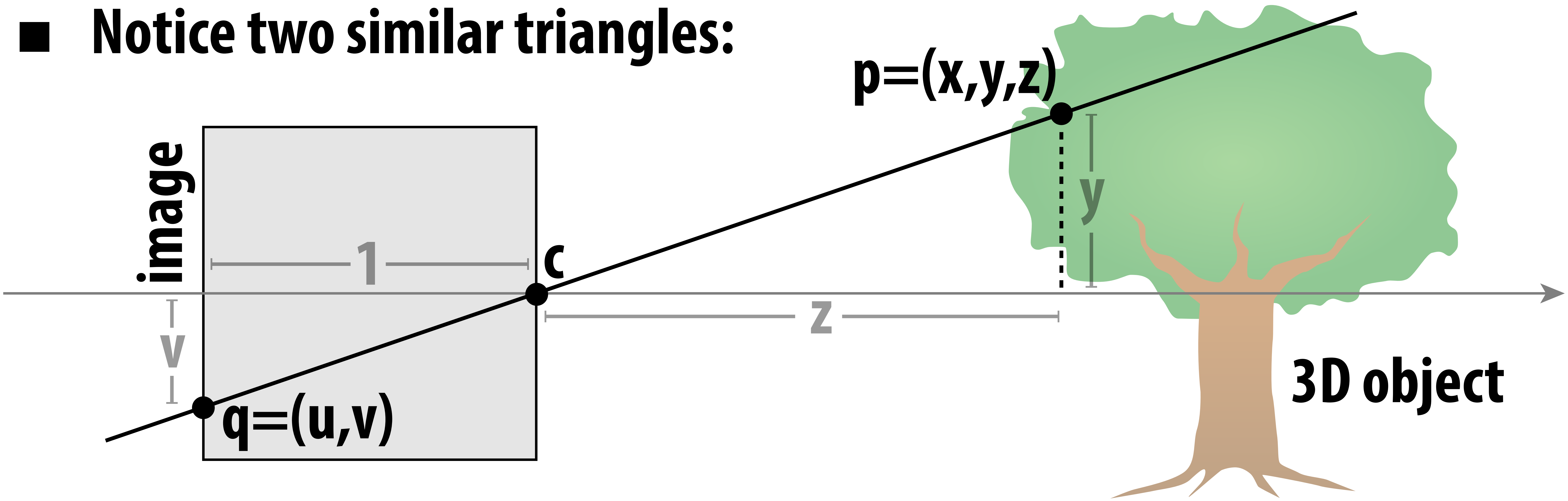
Perspective projection: side view

- 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:



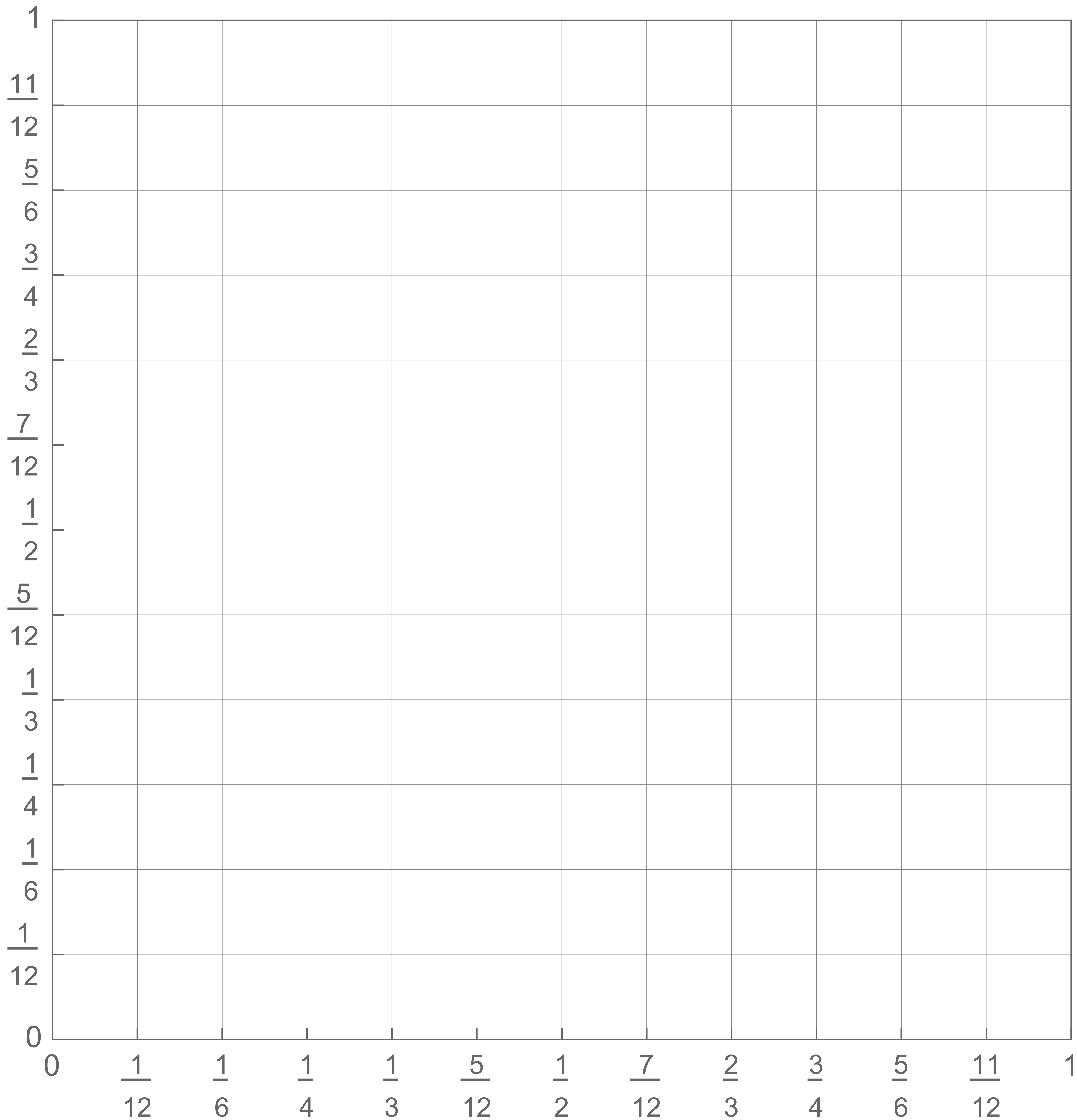
- Assume camera has unit size, origin is at pinhole c
- Then v/1 = y/z, i.e., vertical coordinate is just the slope y/z
- Likewise, horizontal coordinate is u=x/z

ACTIVITY: now draw it!

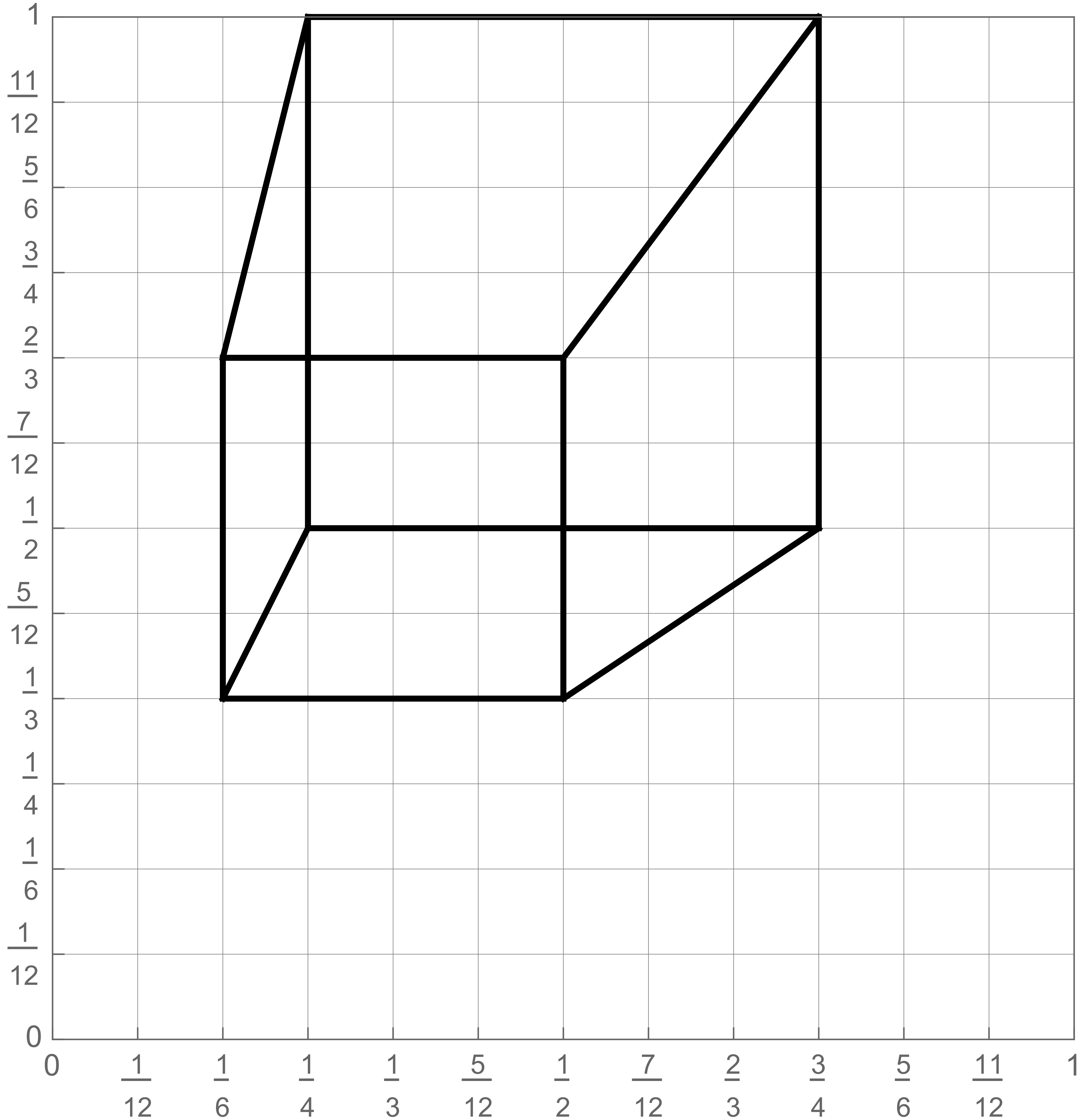
- **Need 12 volunteers**
  - each person will draw one cube edge
  - assume camera is at c=(2,3,5)
  - convert (X,Y,Z) of both endpoints to (u,v):
    1. subtract camera c from vertex (X,Y,Z) to get (x,y,z)
    2. divide (x,y) by z to get (u,v)—*write as a fraction*
  - draw line between (u1,v1) and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



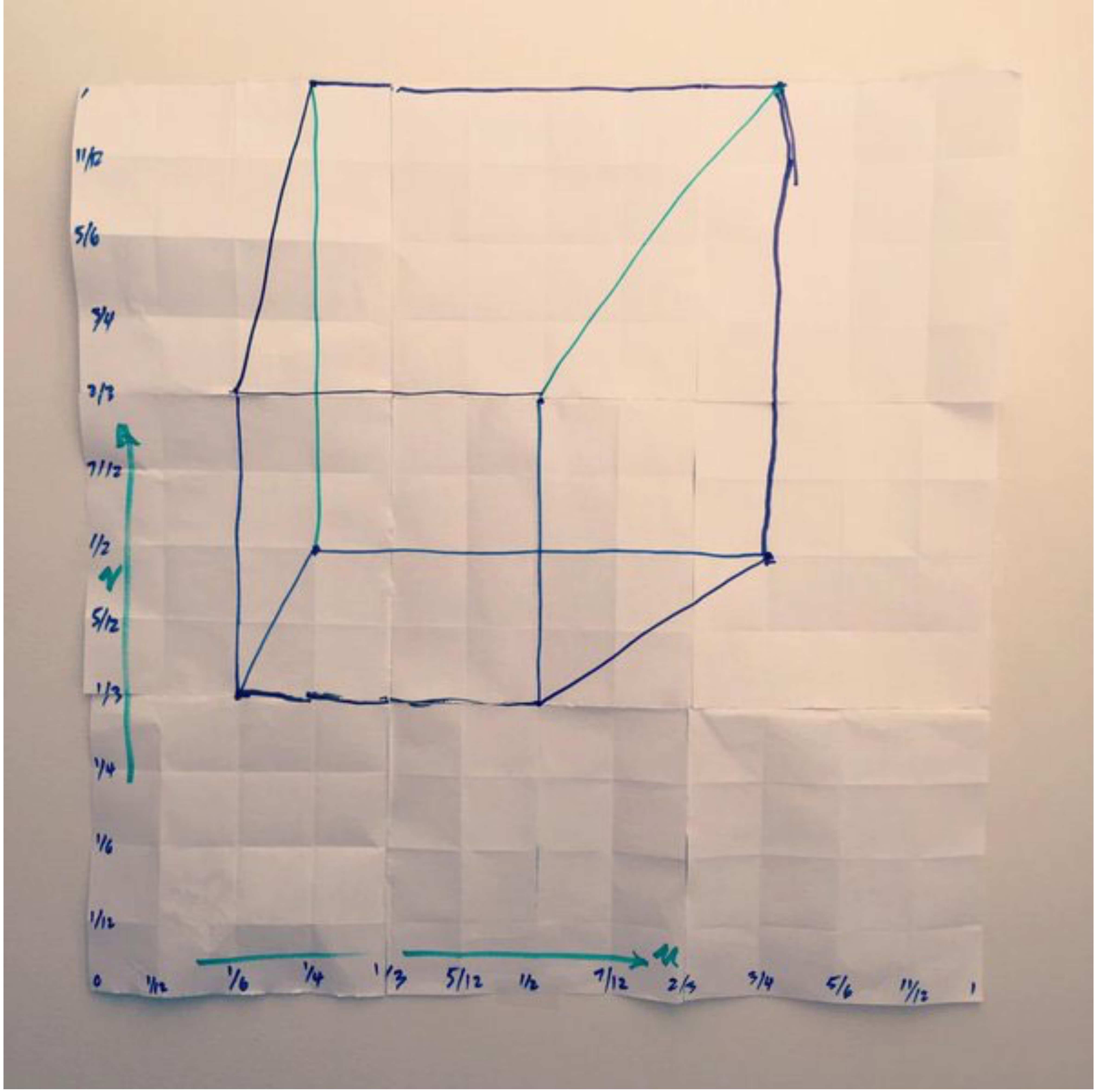
ACTIVITY: How did we do?



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

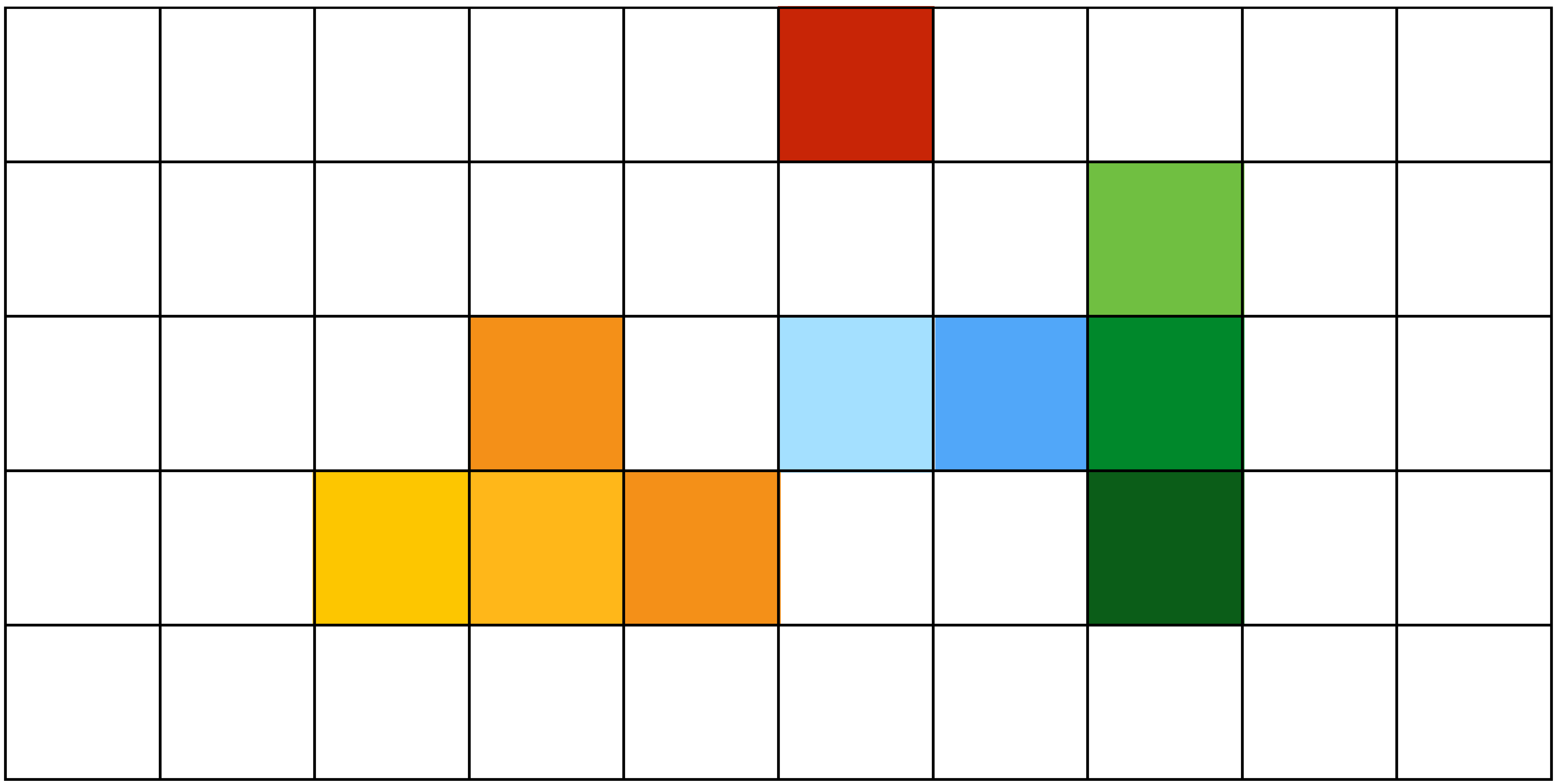


But wait…
How do we draw lines on a computer?

Close up photo of pixels on a modern display

Output for a raster display

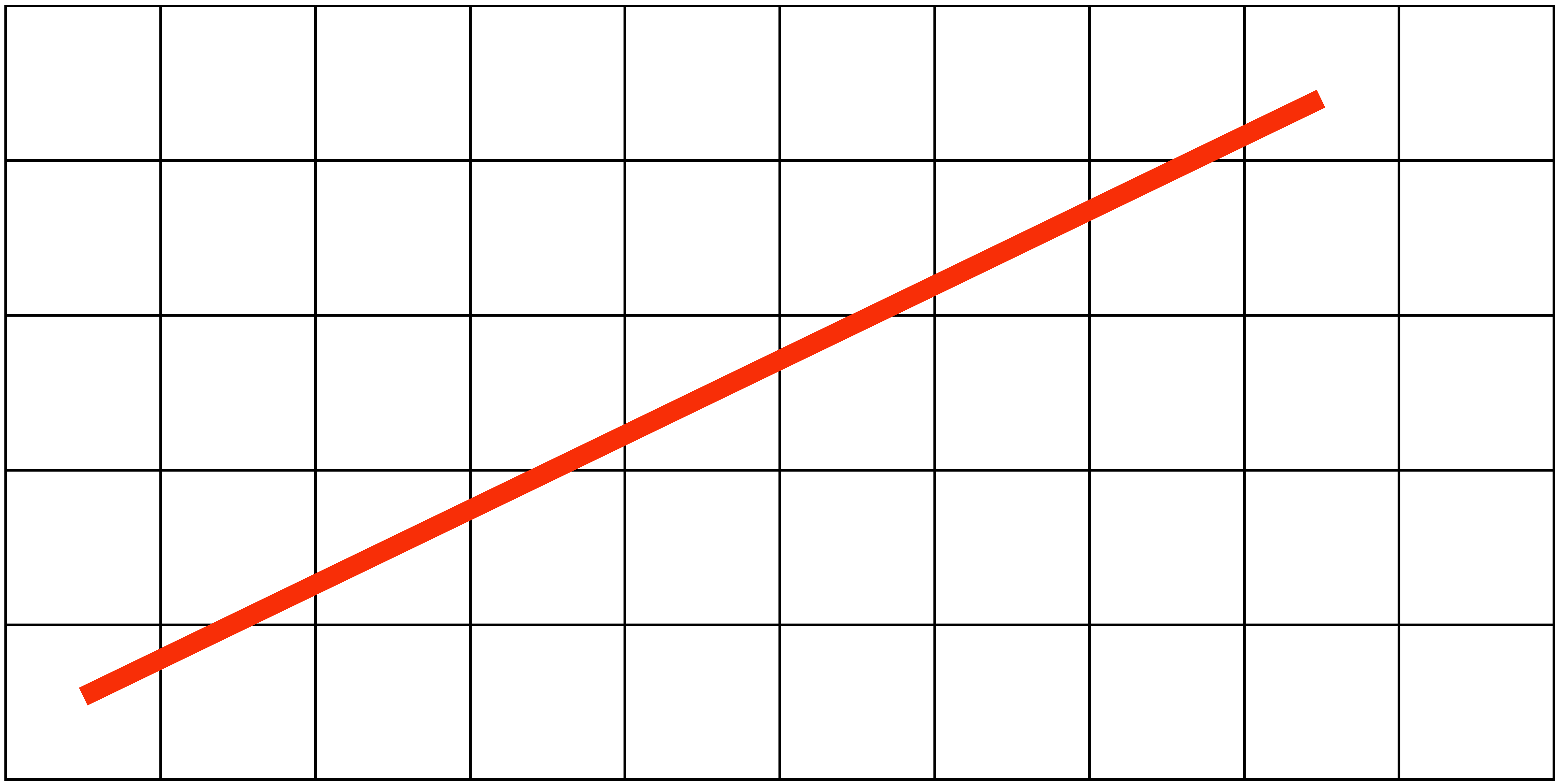
- Common abstraction of a raster display:
  - Image represented as a 2D grid of "pixels" (picture elements) **
  - Each pixel can can take on a unique color value



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

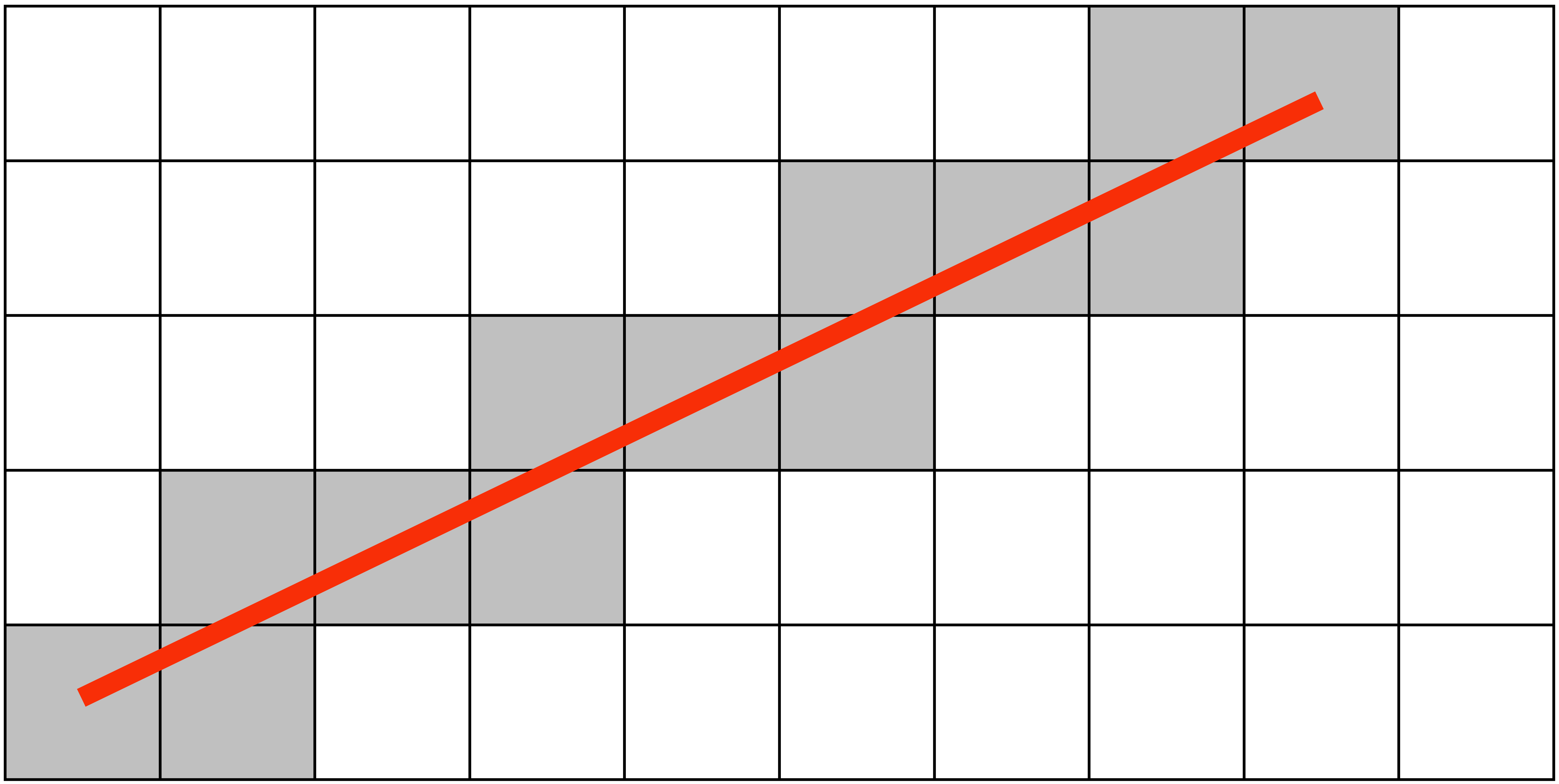
What pixels should we color in to depict a line?

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



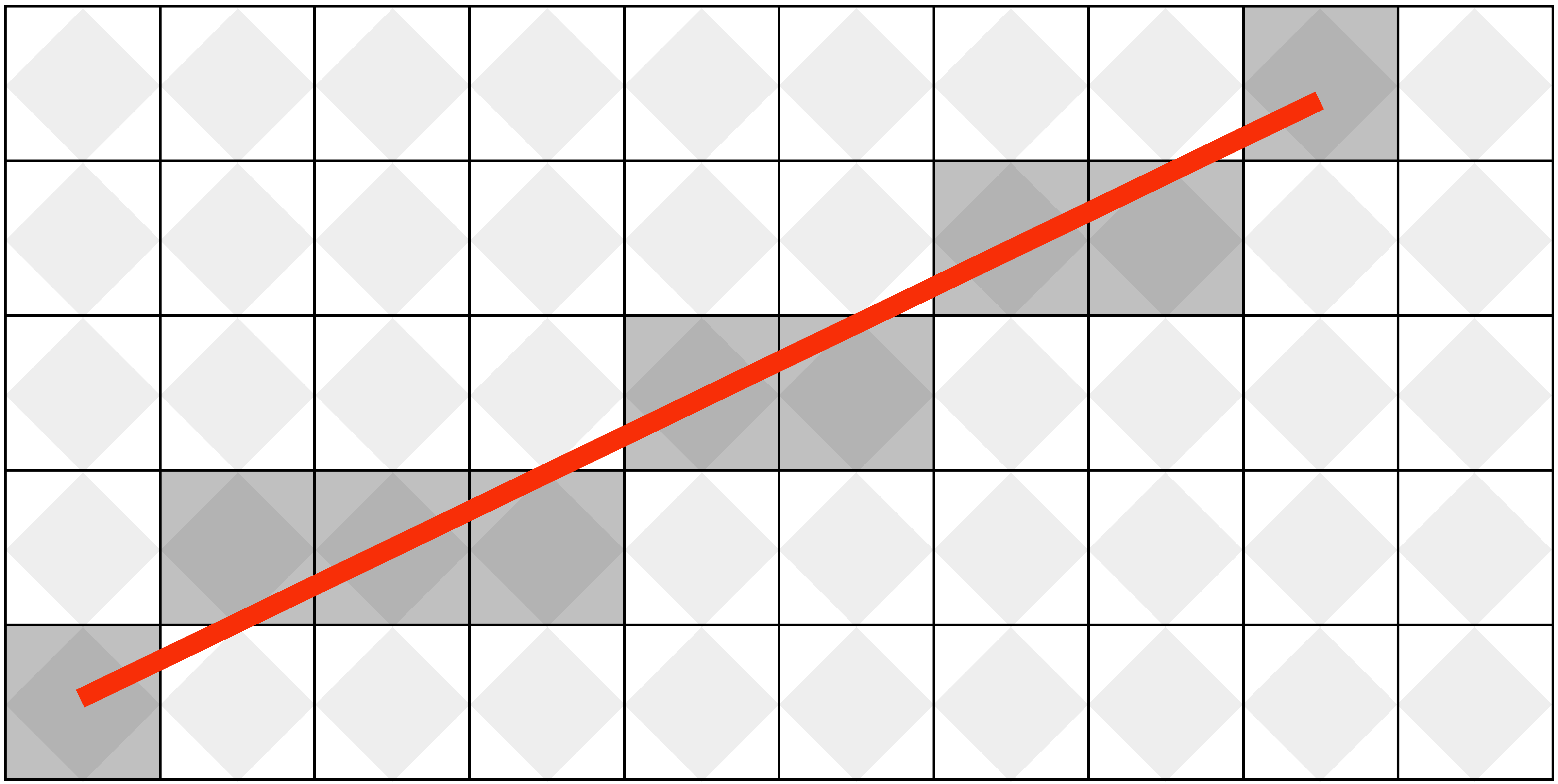
What pixels should we color in to depict a line?

Light up all pixels intersected by the line?



What pixels should we color in to depict a line?

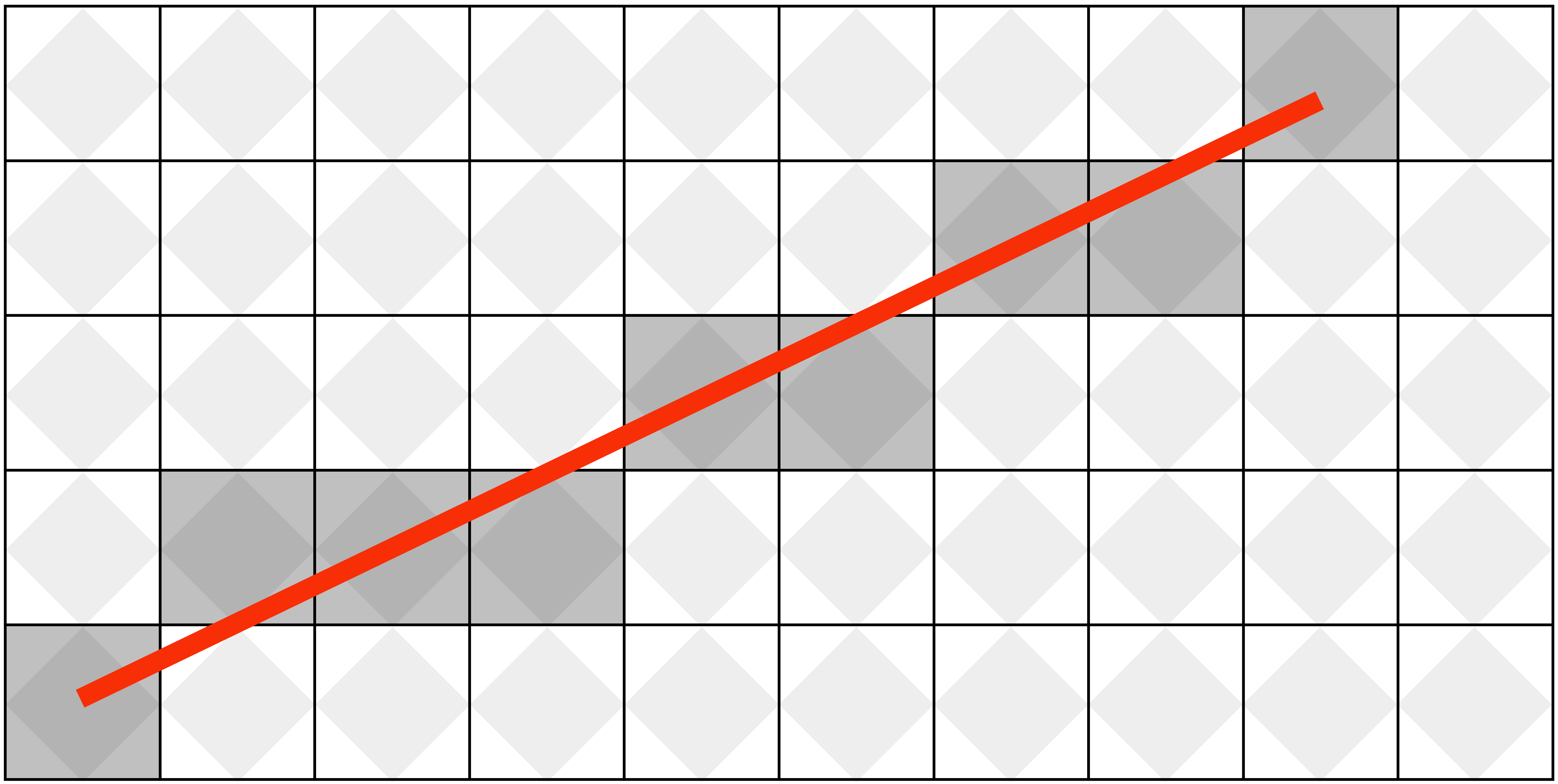
Diamond rule (used by modern GPUs):
light up pixel if line passes through associated diamond



What pixels should we color in to depict a line?

Is there a right answer?

(consider a drawing a “line” with thickness)



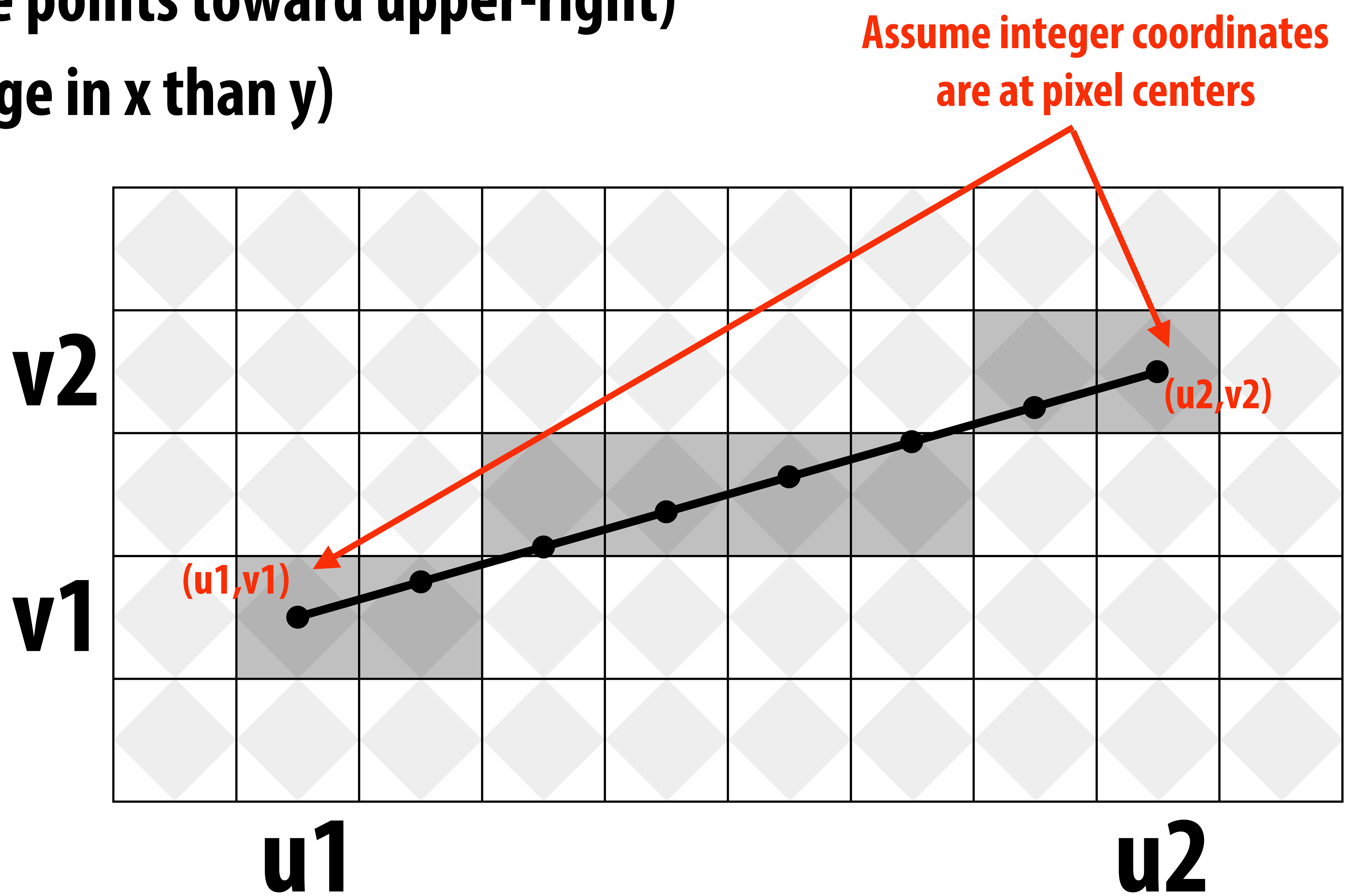
How do we find the pixels satisfying a chosen rasterization rule?

- 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

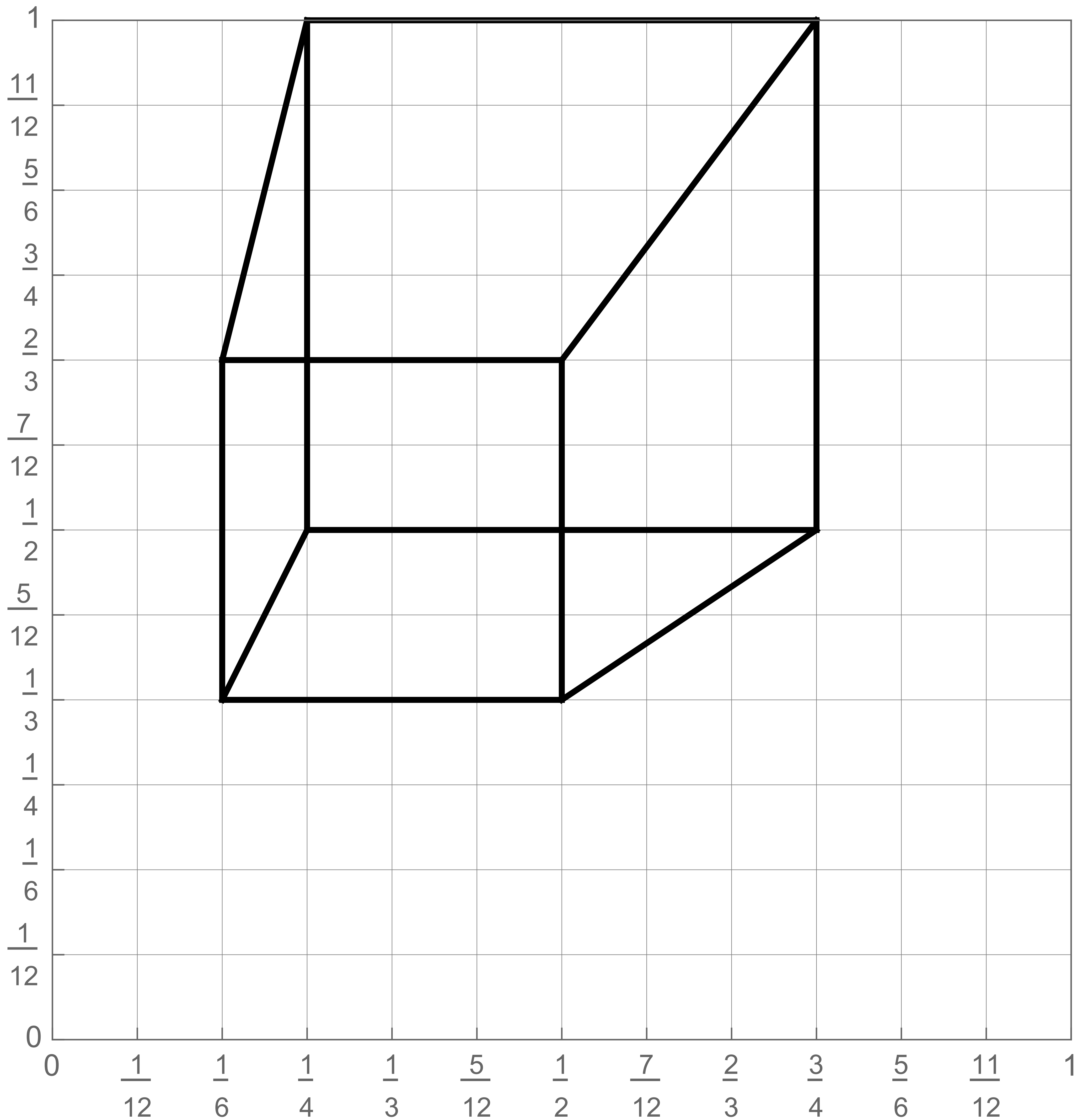
- Let's say a line is represented with integer endpoints: (u1,v1), (u2,v2)
- Slope of line: s = (v2-v1) / (u2-u1)
- Consider a very easy special case:
  - u1 < u2, v1 < v2 (line points toward upper-right)
  - 0 < s < 1 (more change in x than y)

```
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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D: 3/4, 1
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

Up, (Pixar 2009)

Realistic lighting environments

Realistic lighting environments

Big Hero 6 (Disney 2014)

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

Unreal Engine Kite Demo (Epic Games 2015)

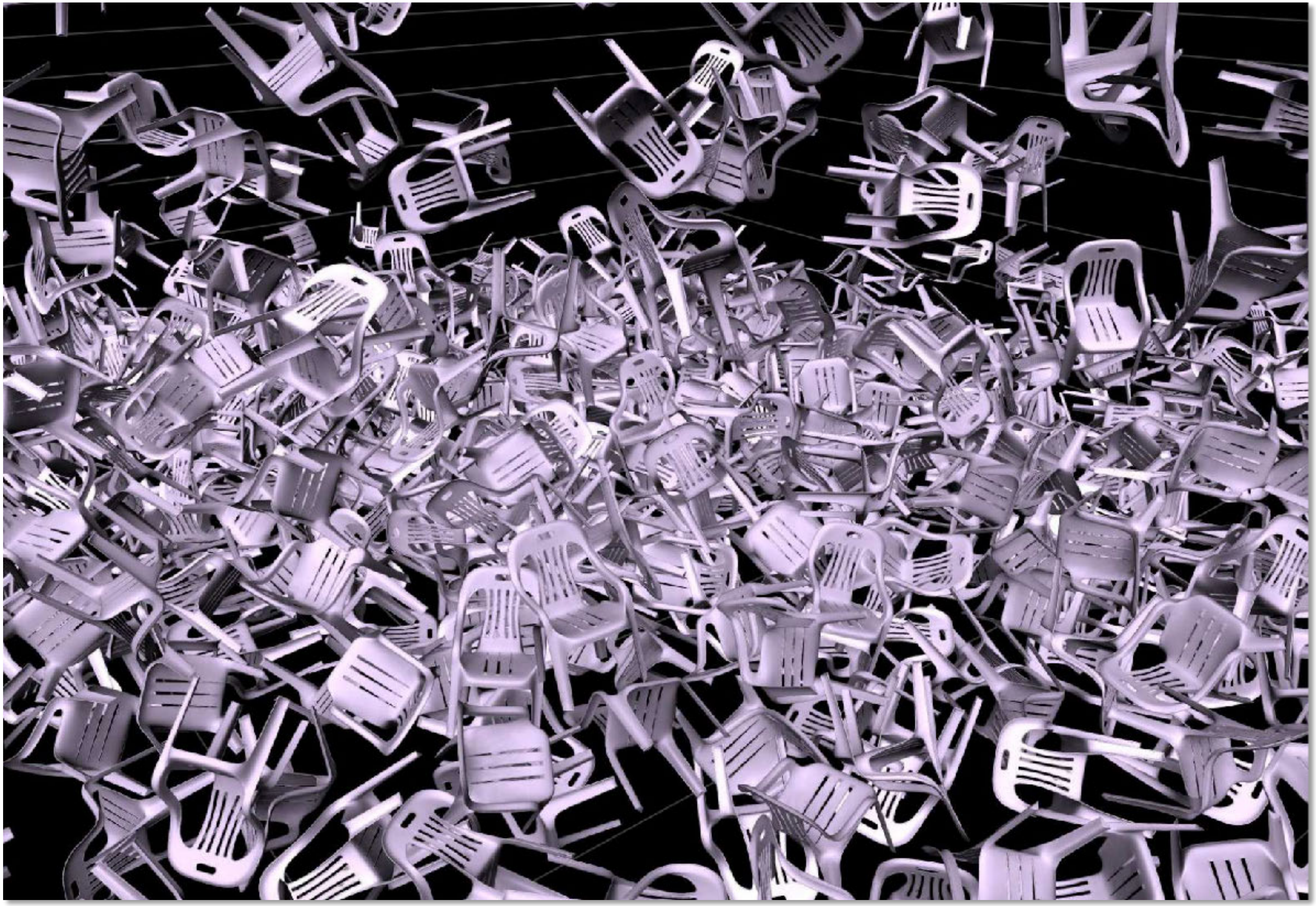
So is this.

[Mirror's Edge 2008]

Animation: modeling motion

https://www.youtube.com/watch?v=wYfYtV_2ezs

Physically-based simulation of motion



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

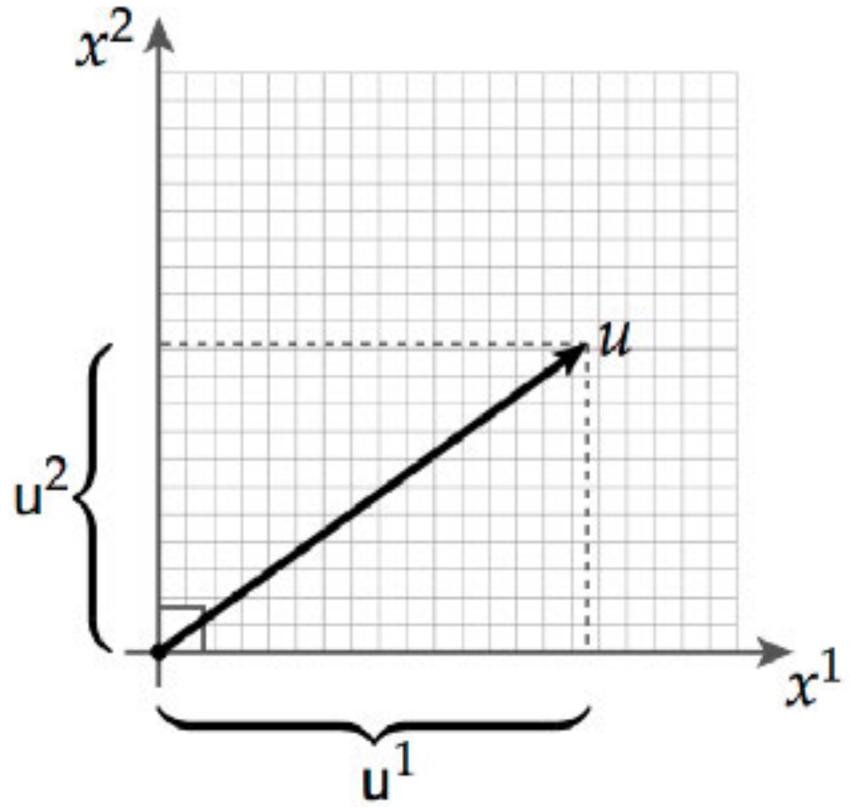
[James 2004]

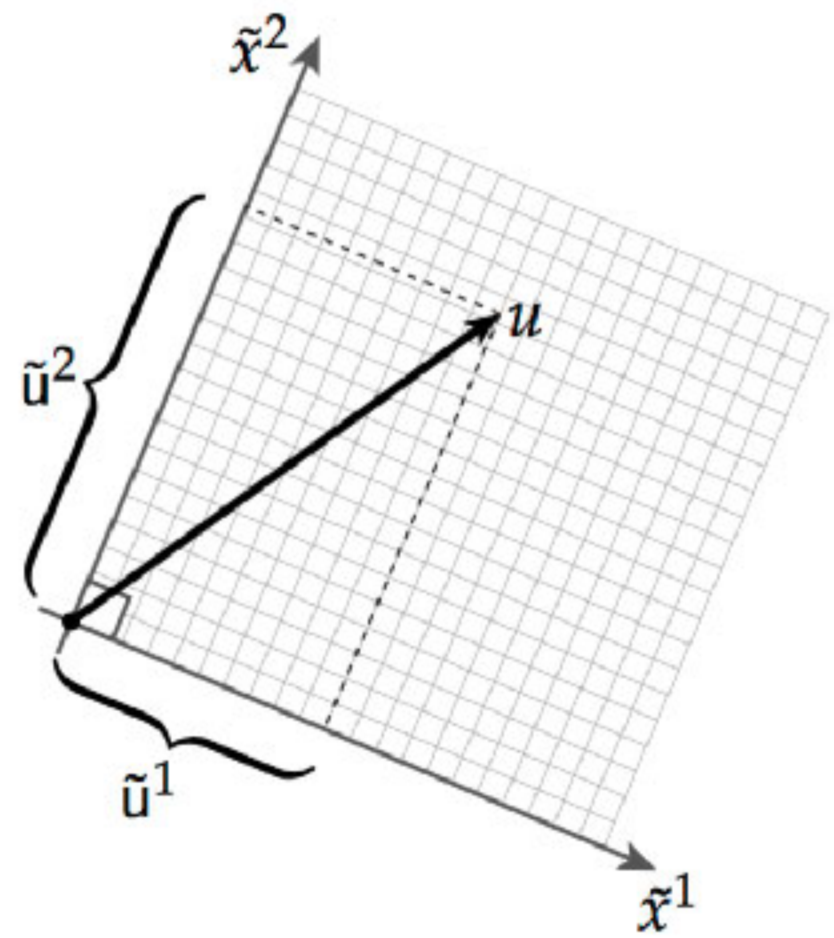
Course Logistics

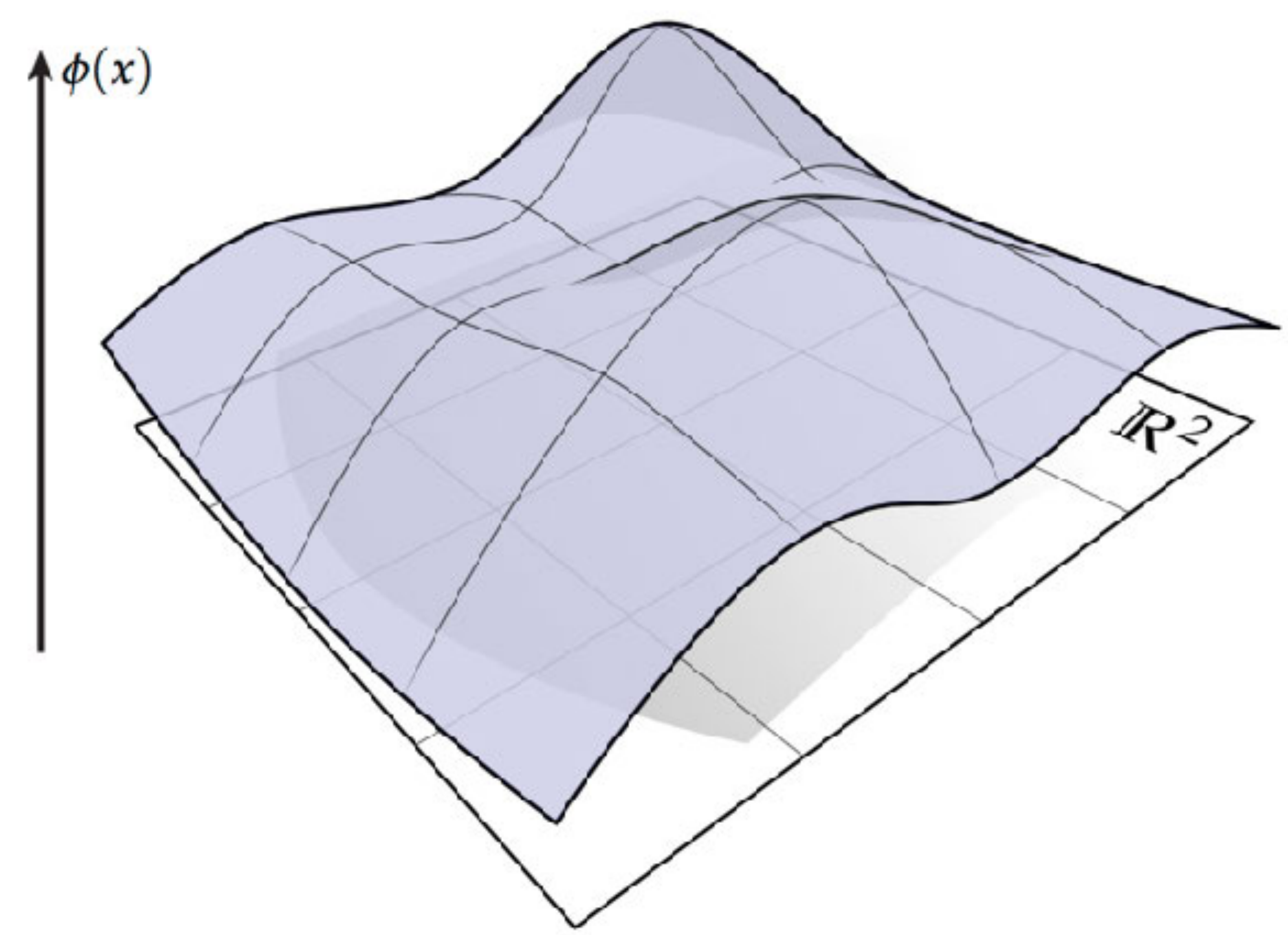
About this course

- 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
  - Weekly out-of-class quizzes
  - In-class midterm/final

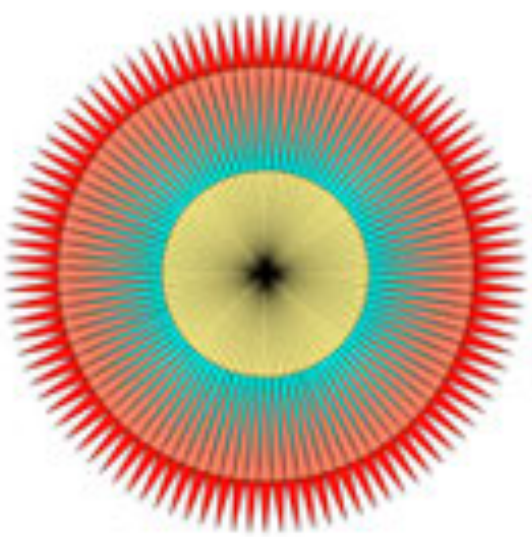
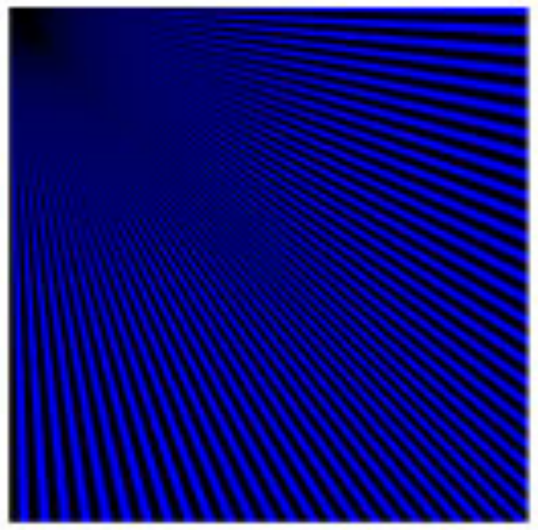
Assignment 0: Math (P)Review



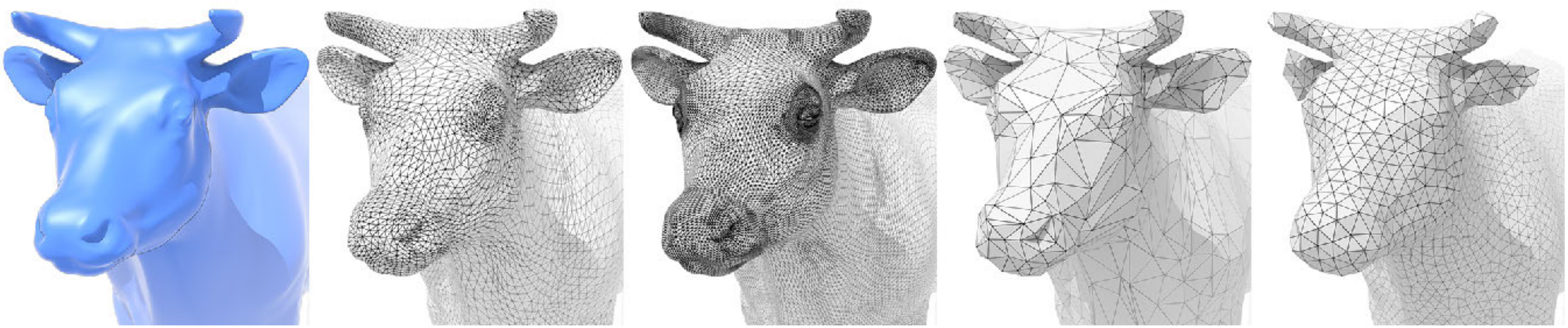




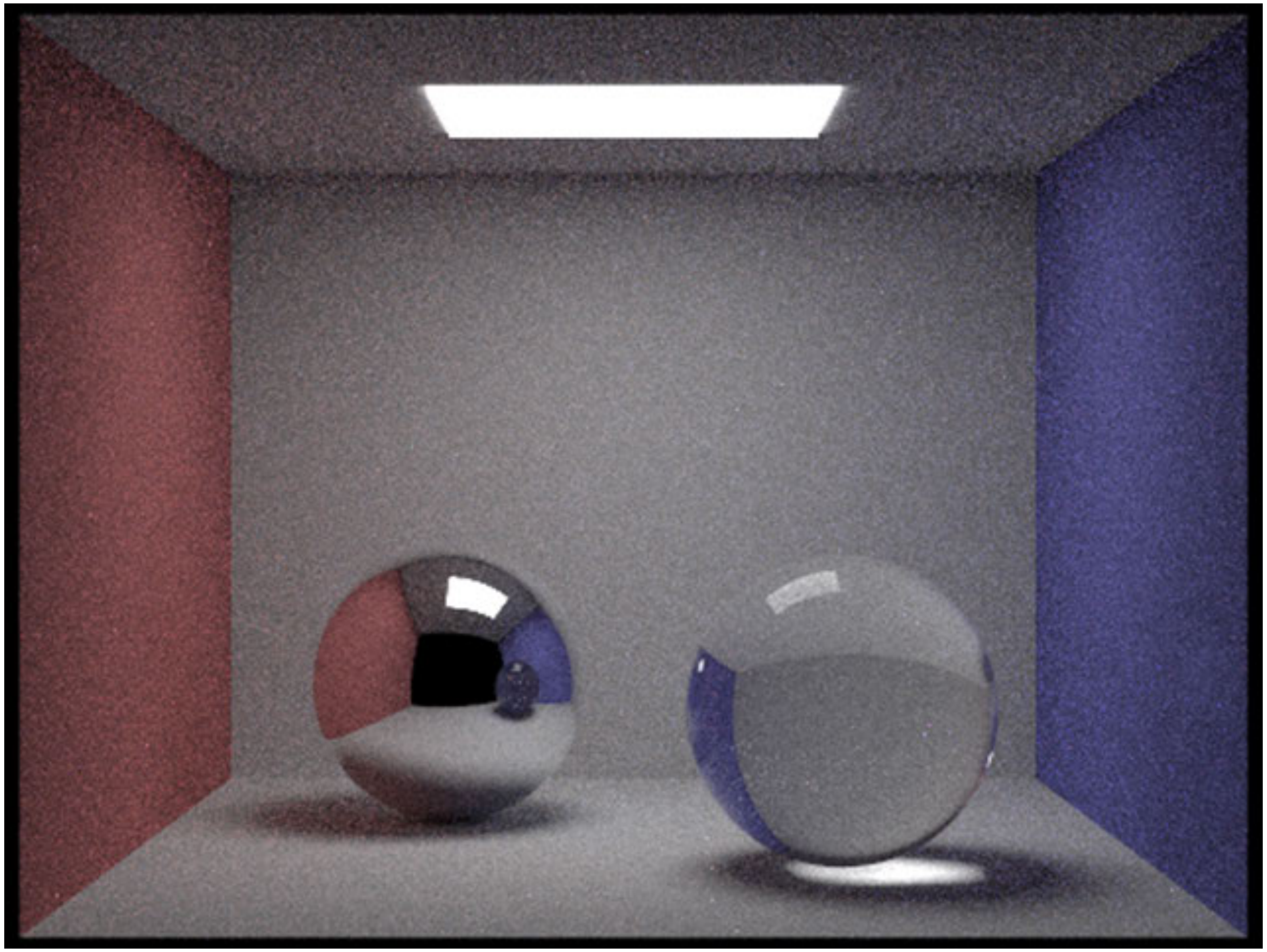
Assignment 1: Rasterization

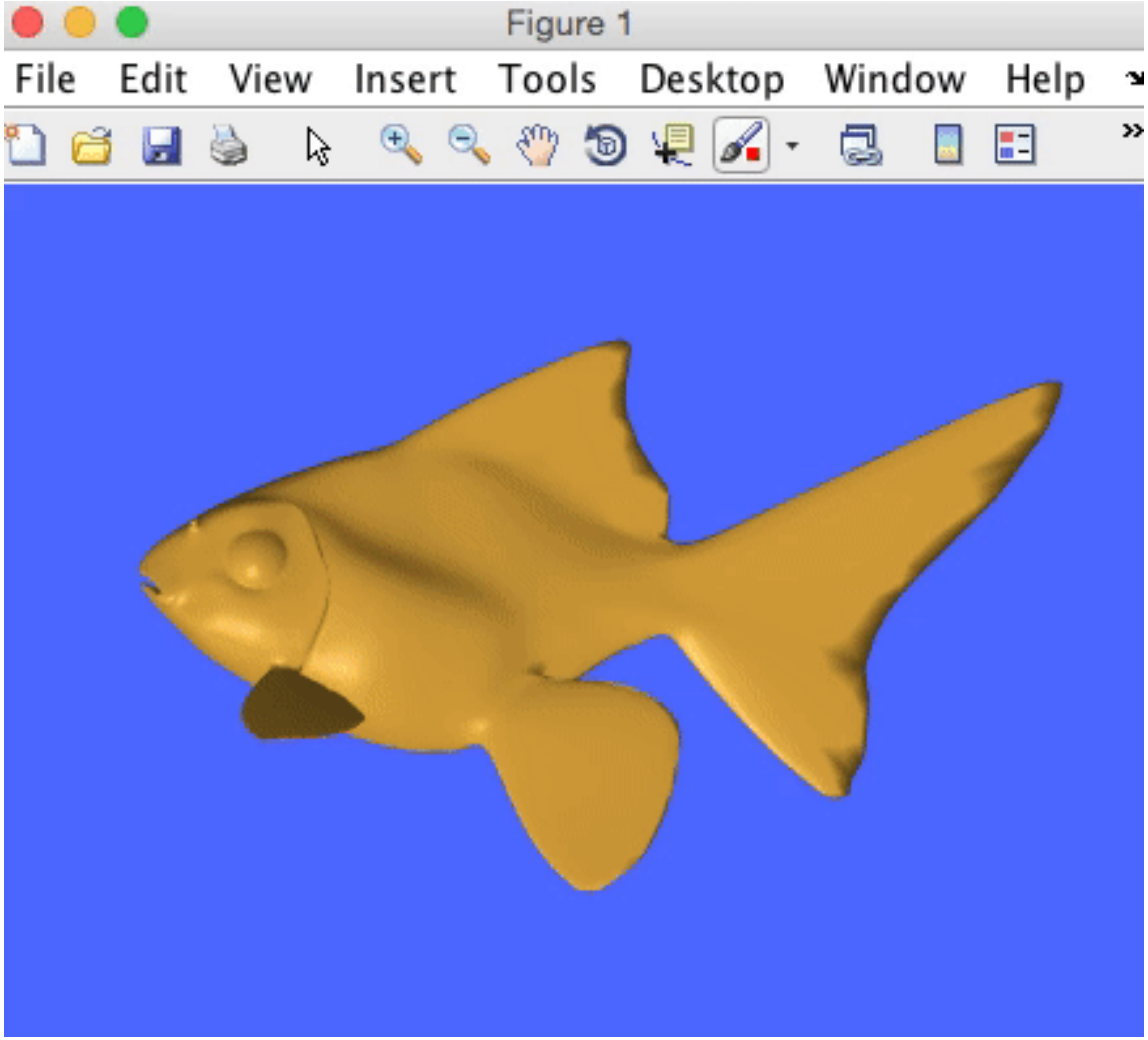
Assignment 2: Geometric Modeling



Assignment 3: Photorealistic Rendering



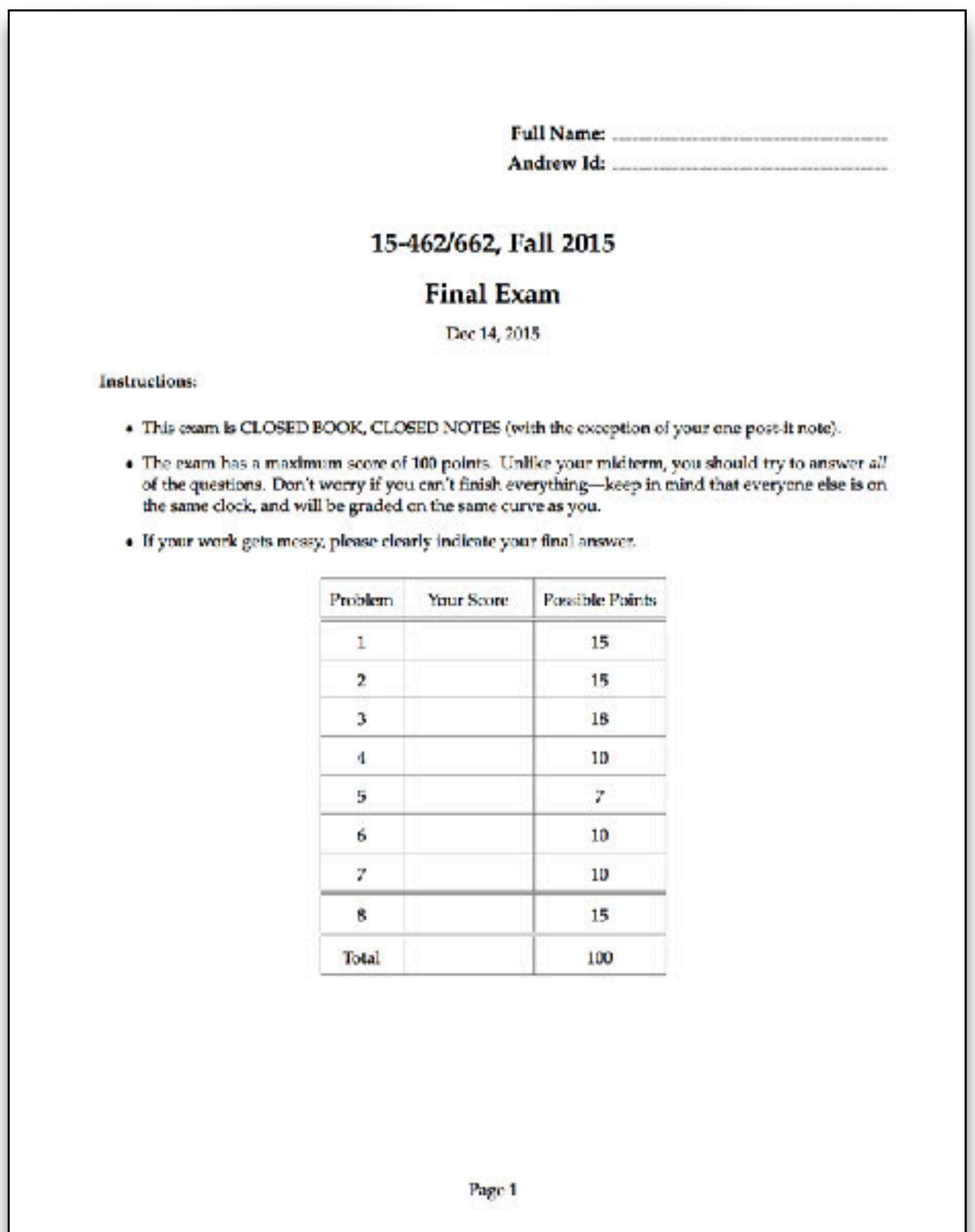
Assignment 4: Animation



(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

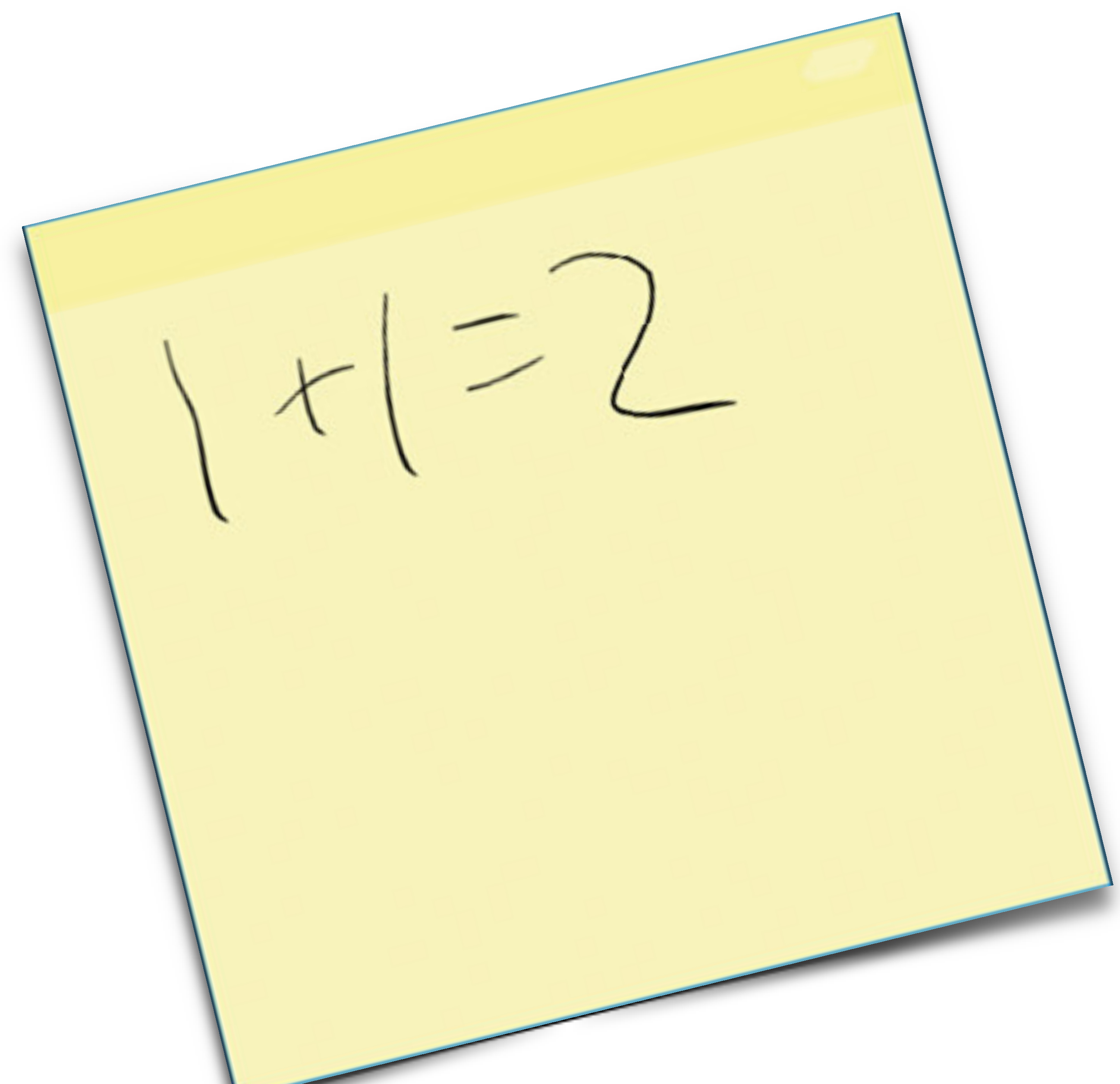
Dec 14, 2015

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.

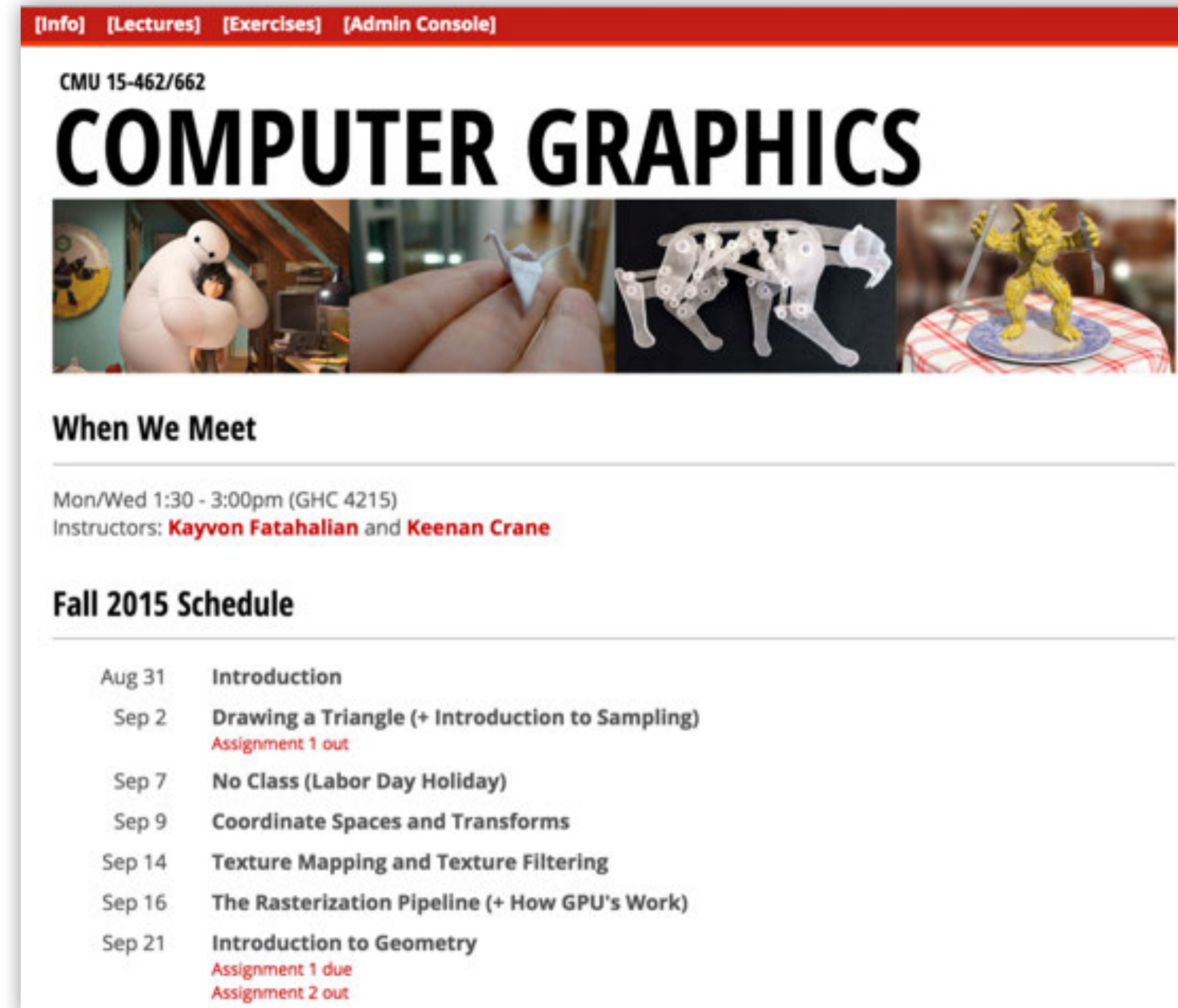
Problem	Your Score	Possible Points
1		15
2		15
3		18
4		10
5		7
6		10
7		10
8		15
Total		100

Page 1



Getting started

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



- Sign up for the course on Piazza
  - http://piazza.com/cmu/fall2016/15462

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

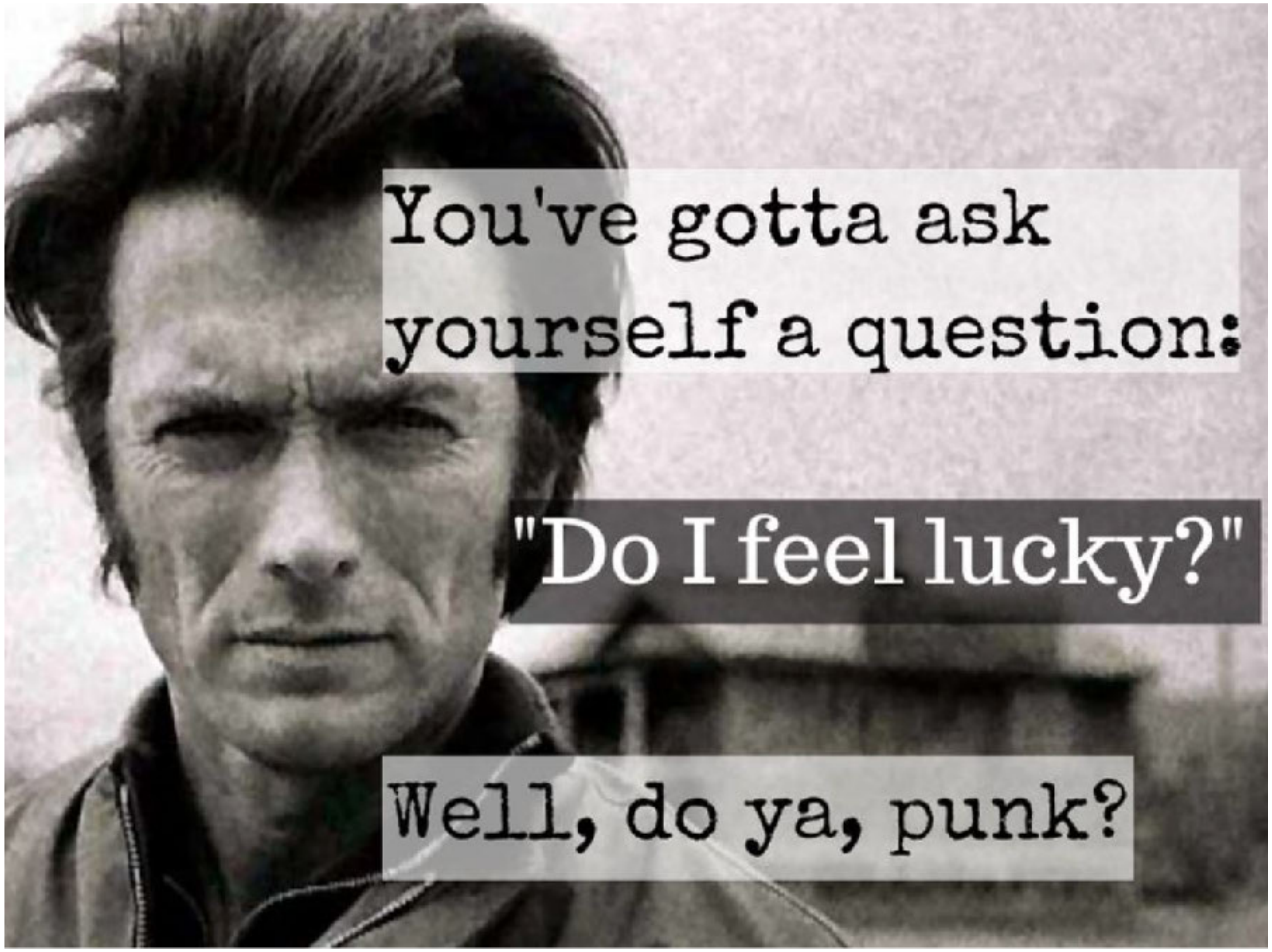
Assignments / Grading

- (5%) 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
- (7%) Take-home quizzes
  - One per lecture
  - Must be turned in BY YOU at the beginning of the next lecture
- (25%) Midterm / final
  - Both cover cumulative material seen so far
- (3%) Class participation
  - In-class/website comments, other contributions to class

Late hand-in policy

- **Programming assignments**
  - Five late day points for the semester
  - First four programming assignments only
  - No more late points? 10% penalty per day
  - No assignments will be accepted more than 3 days past the deadline
- **Daily Quizzes**
  - You can skip up to 6 with no penalty

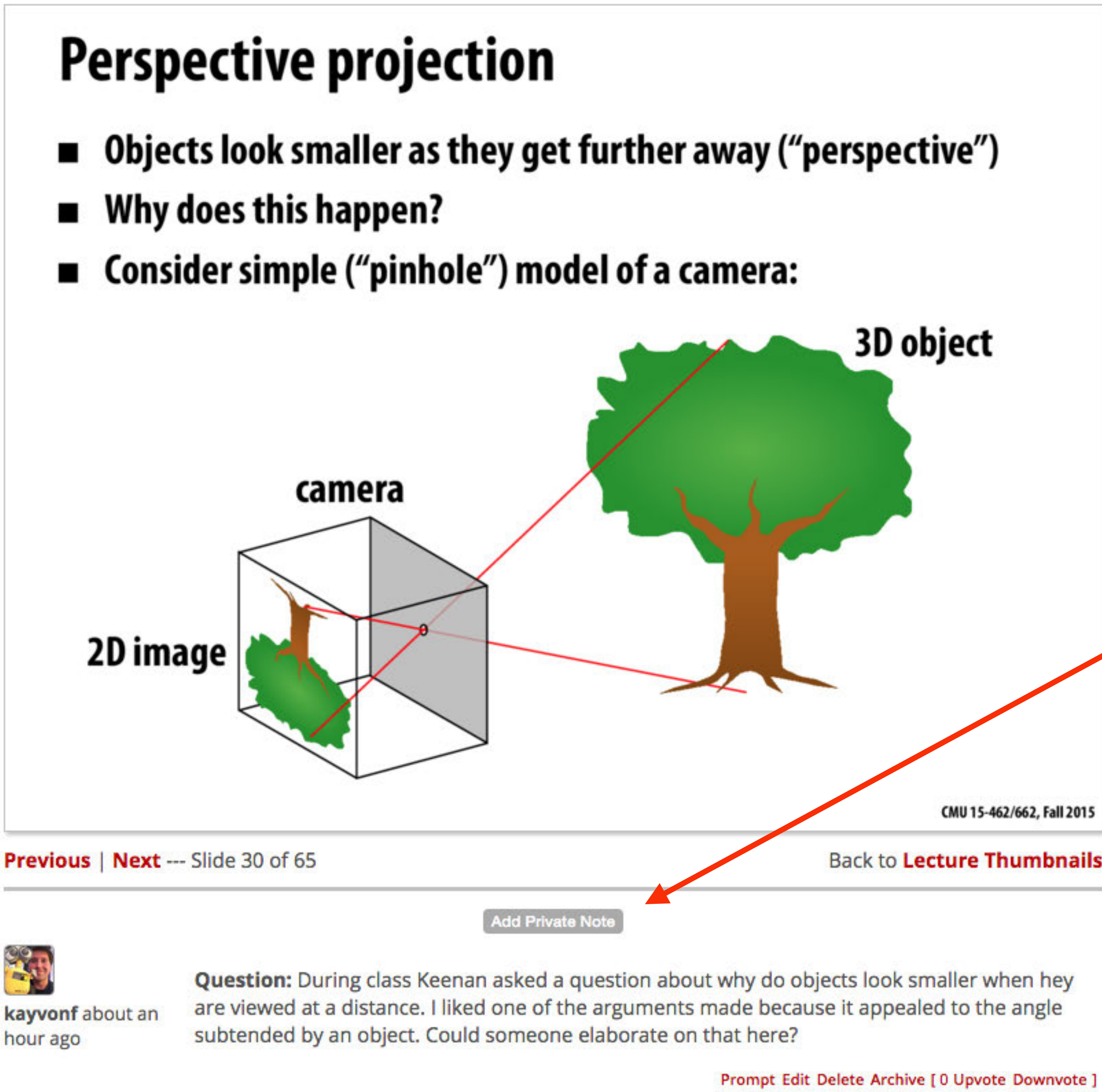
Cheating Policy



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.

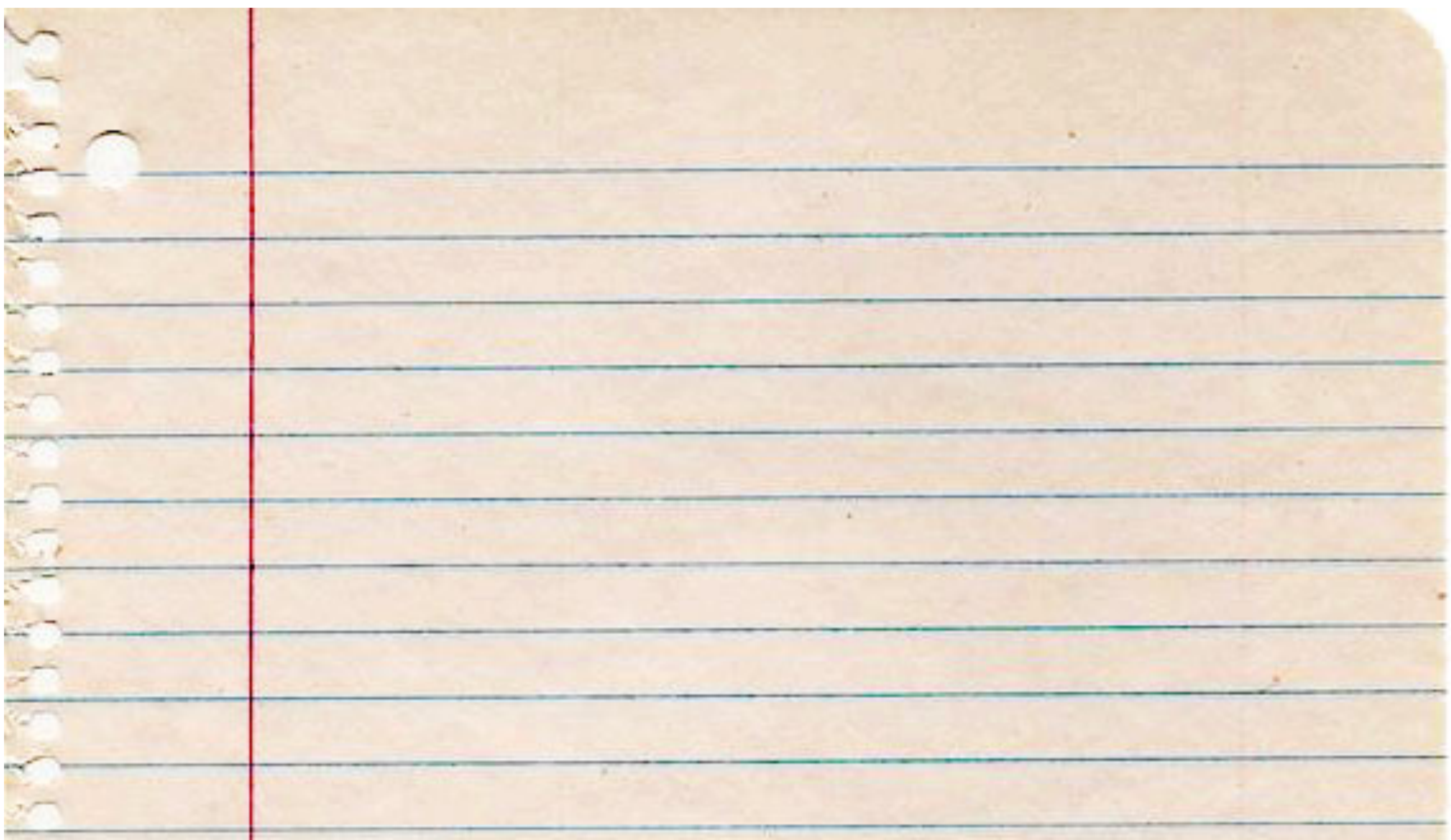
Slide comments and discussion

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)

QUIZ[0]

- This one is easy: write one thing you want to learn from this course and/or one reason you decided to take the course.
- Write answer on physical paper.
- Must be turned in BY YOU in-class at the START of the next lecture.



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!