Lecture 1:

Course Intro:

Welcome to Computer Graphics!

Computer Graphics
CMU 15-462/15-662, Fall 2016

Hi!

Stelian Coros

Se-Joon Chung

Keenan Crane

Joey Jia

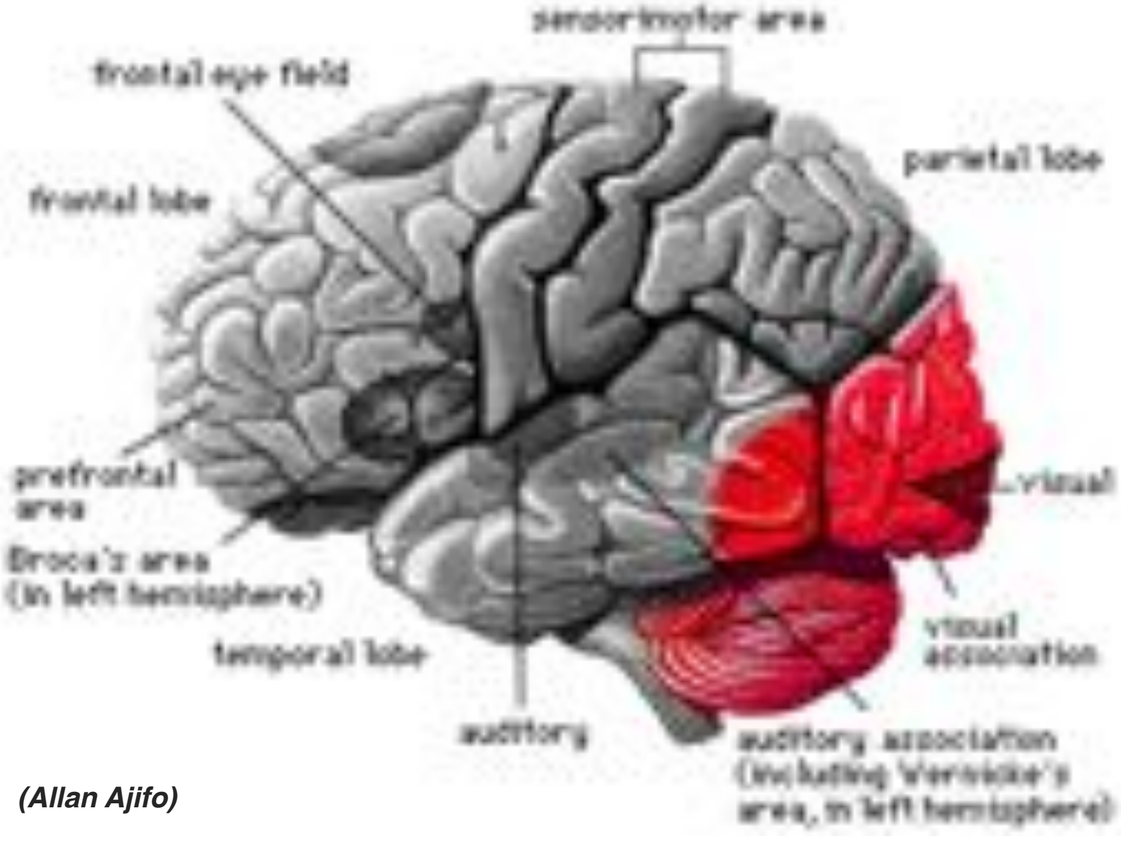
Zachary Shearer

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!

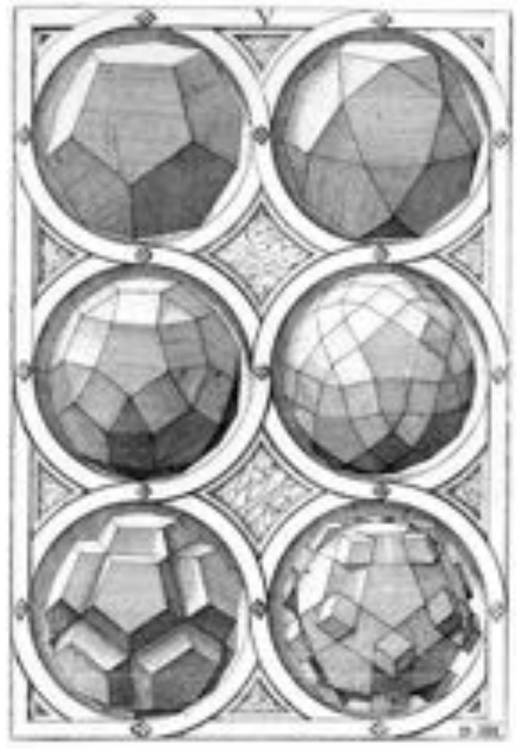
History of visual depiction

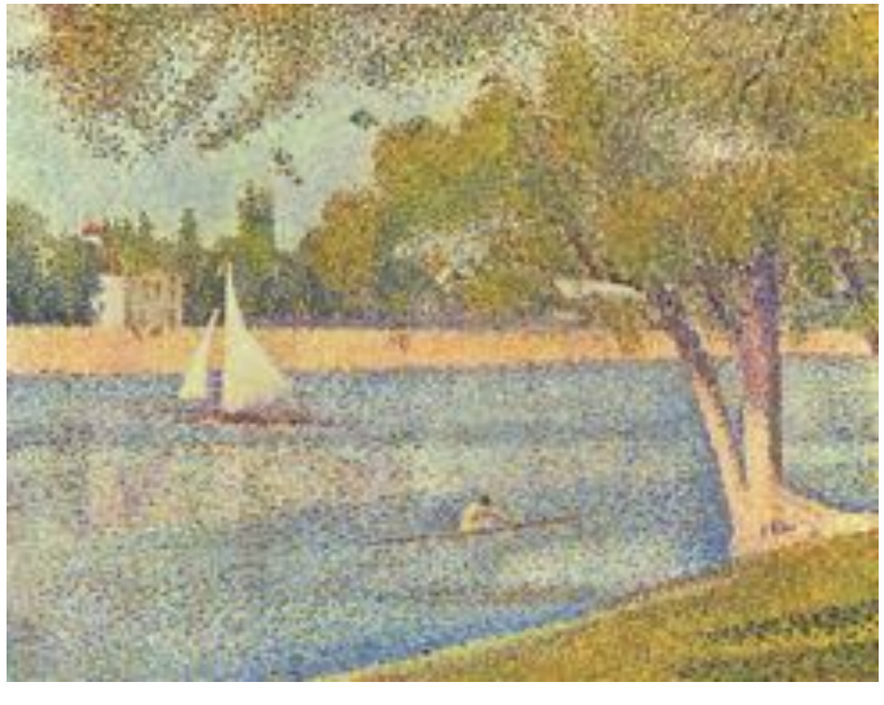
- **Humans have *always* been visual creatures!**

Indonesian cave painting (~38,000 BCE)

Visual technology: painting / illustration

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





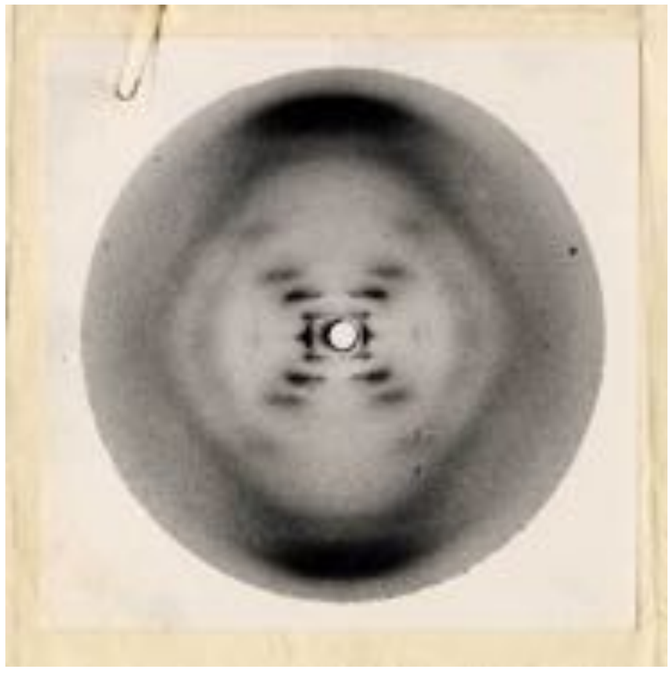
Visual technology: carving / sculpture

Visual technology: photography / imaging

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

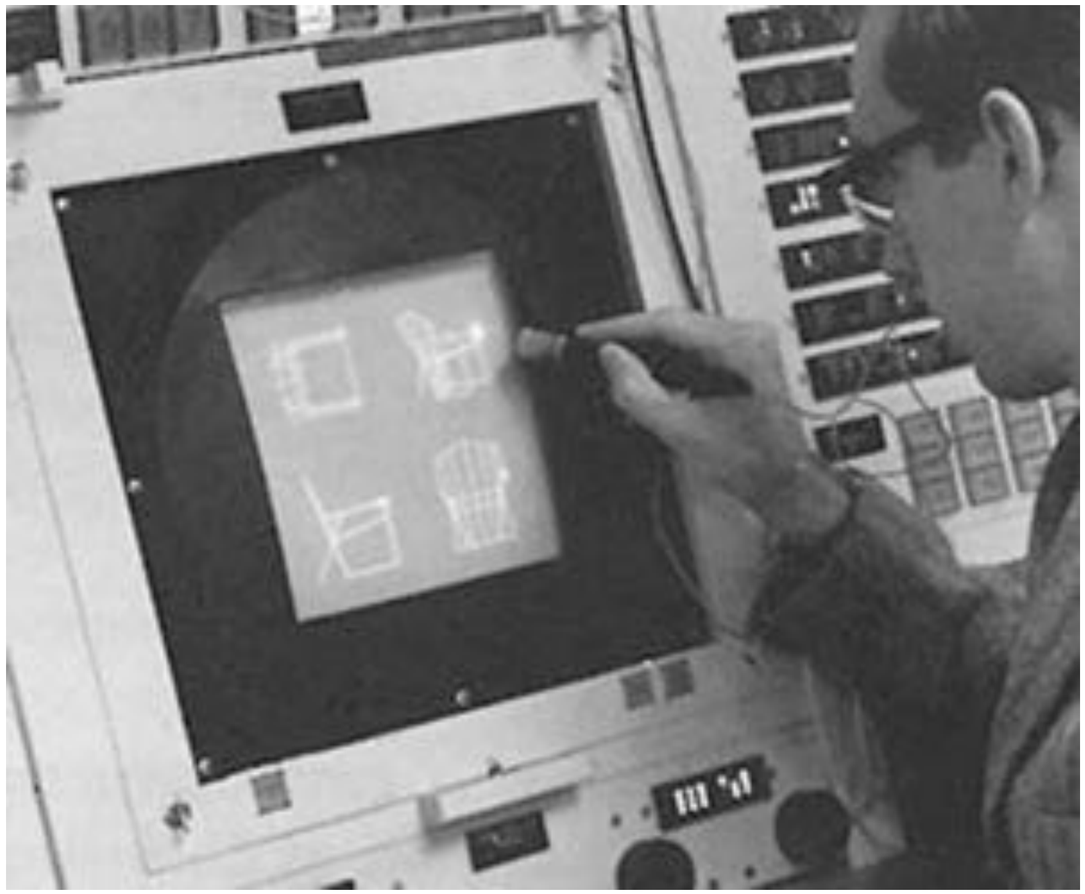
Joseph Niépce, "View from the Window at Le Gras" (1826)

Visual technology: photography / imaging



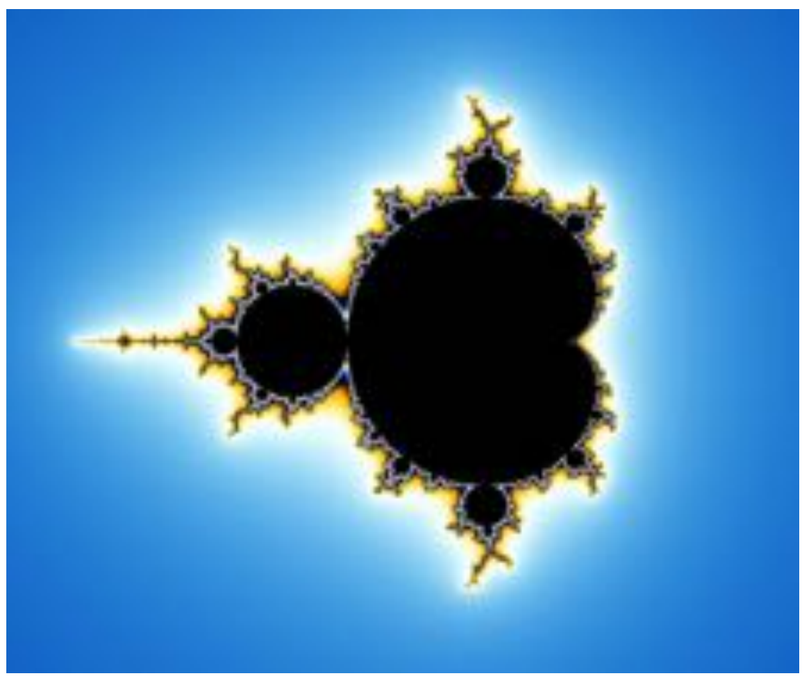
Visual technology: digital imagery

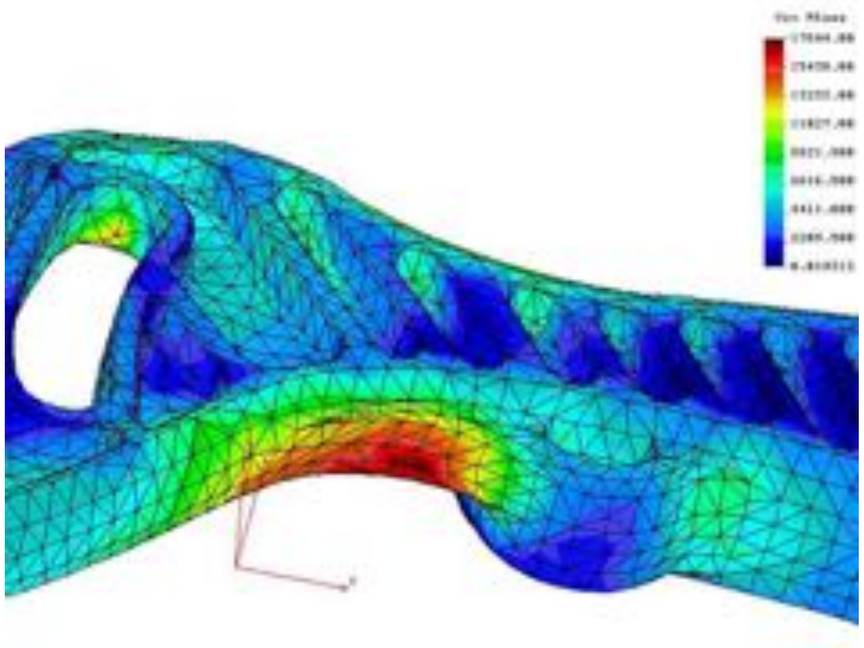
- Intersection of visual depiction & computation



Ivan Sutherland, “Sketchpad” (1963)

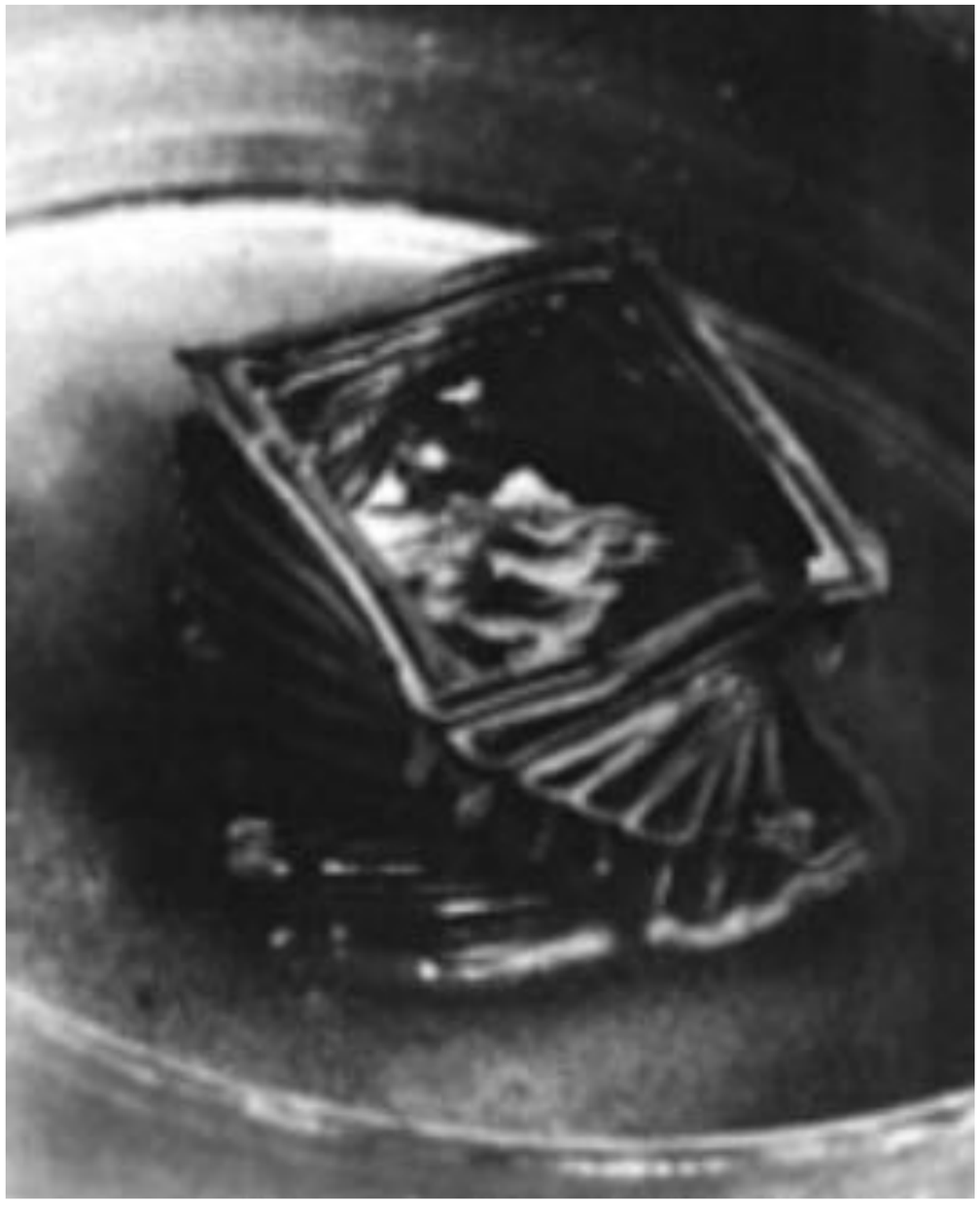
Visual technology: digital imagery

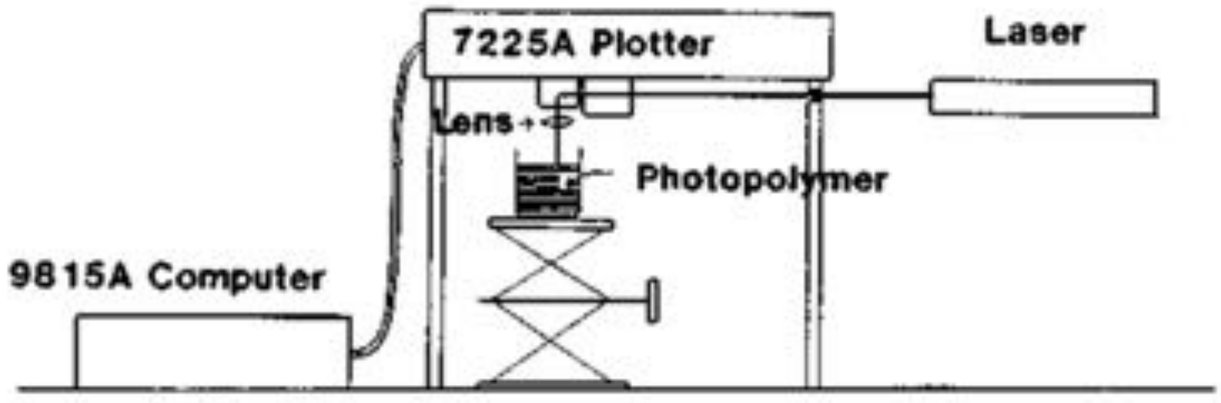




Visual technology: 3D fabrication

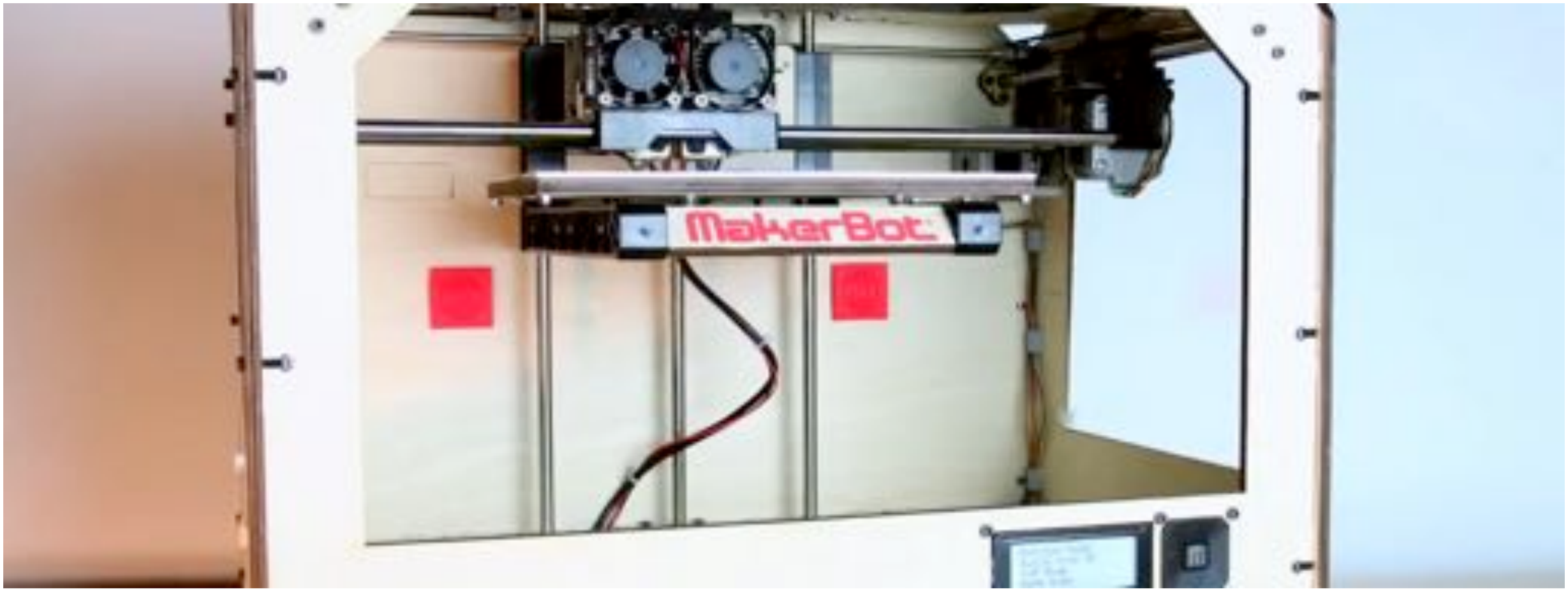
- Create *physical* realization of digital shape





A.J. Herbert / 3M (1979)

Visual technology: 3D fabrication



Technologies for visual depiction

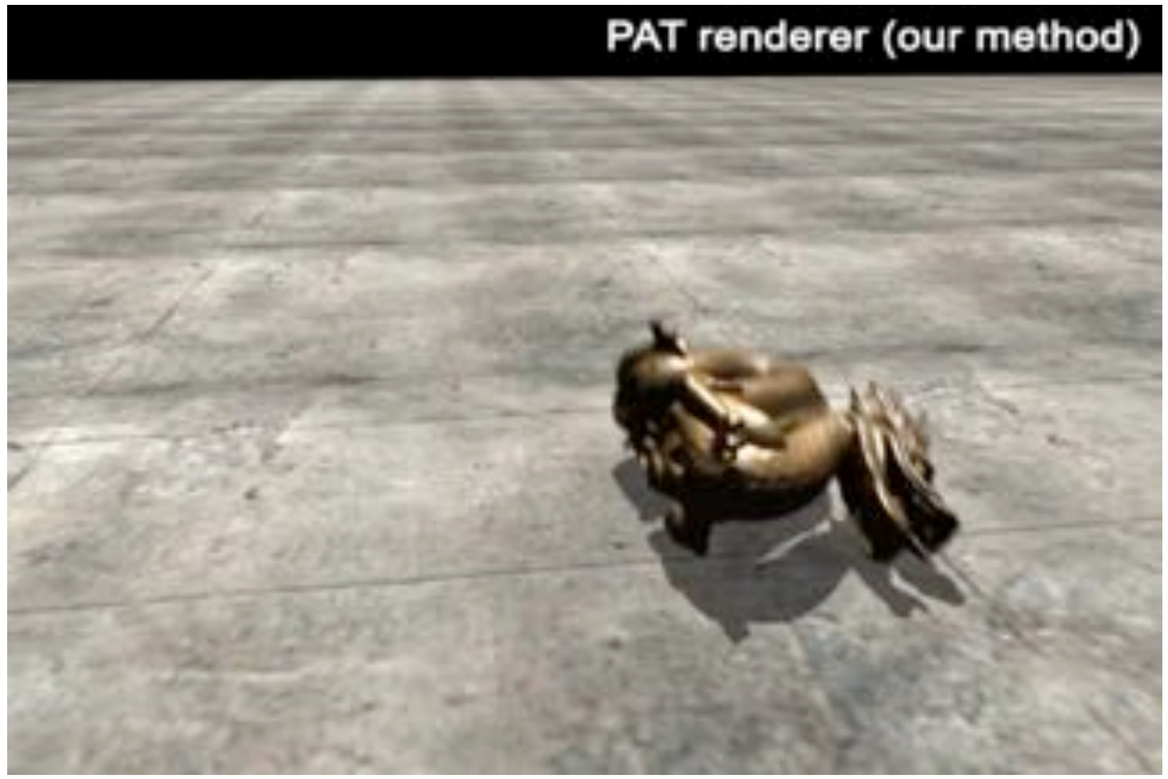
- Drawing/painting/illustration (~40,000 BCE)
- Sculpture (~40,000 BCE)
- Photography (~1826)
- *Digital Imagery (~1963)*
- *3D Fabrication (~1979)*

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.

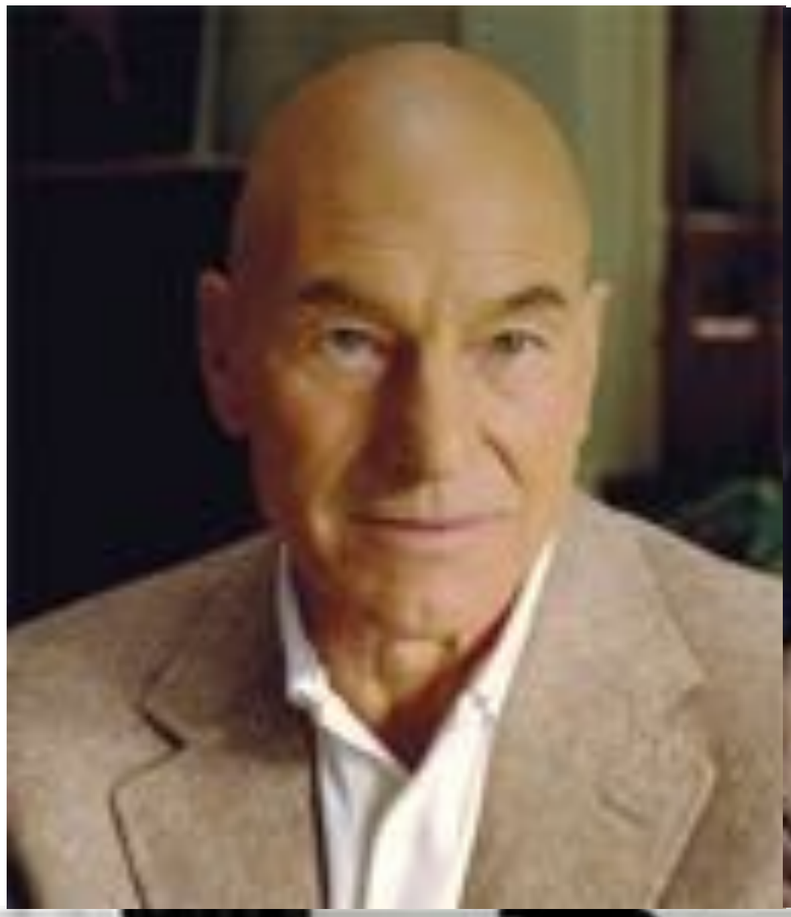
(…What about taste? *Smell?!*)

Computer graphics is *everywhere!*

Entertainment (movies, games)

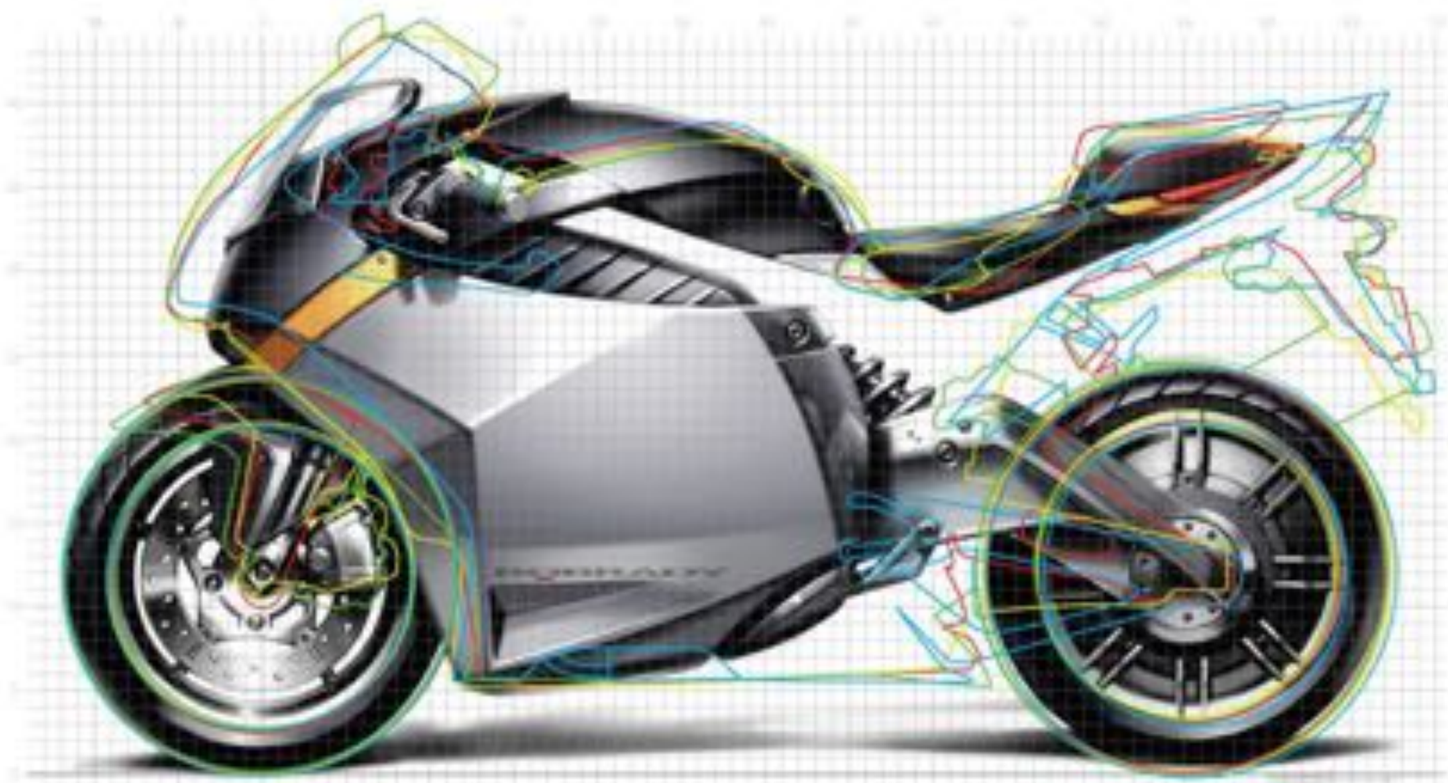
Entertainment

- Not just cartoons!

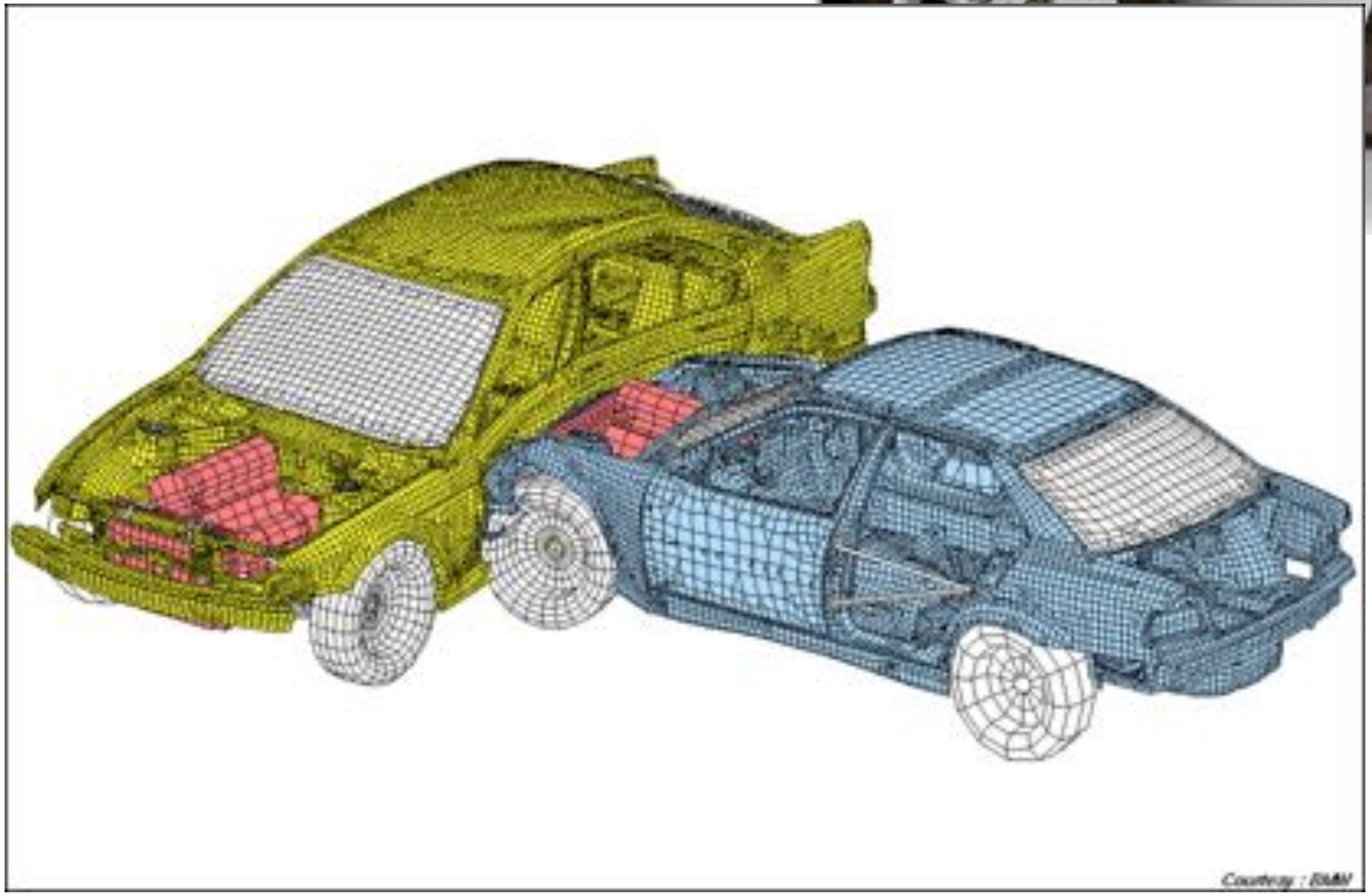


Art and design

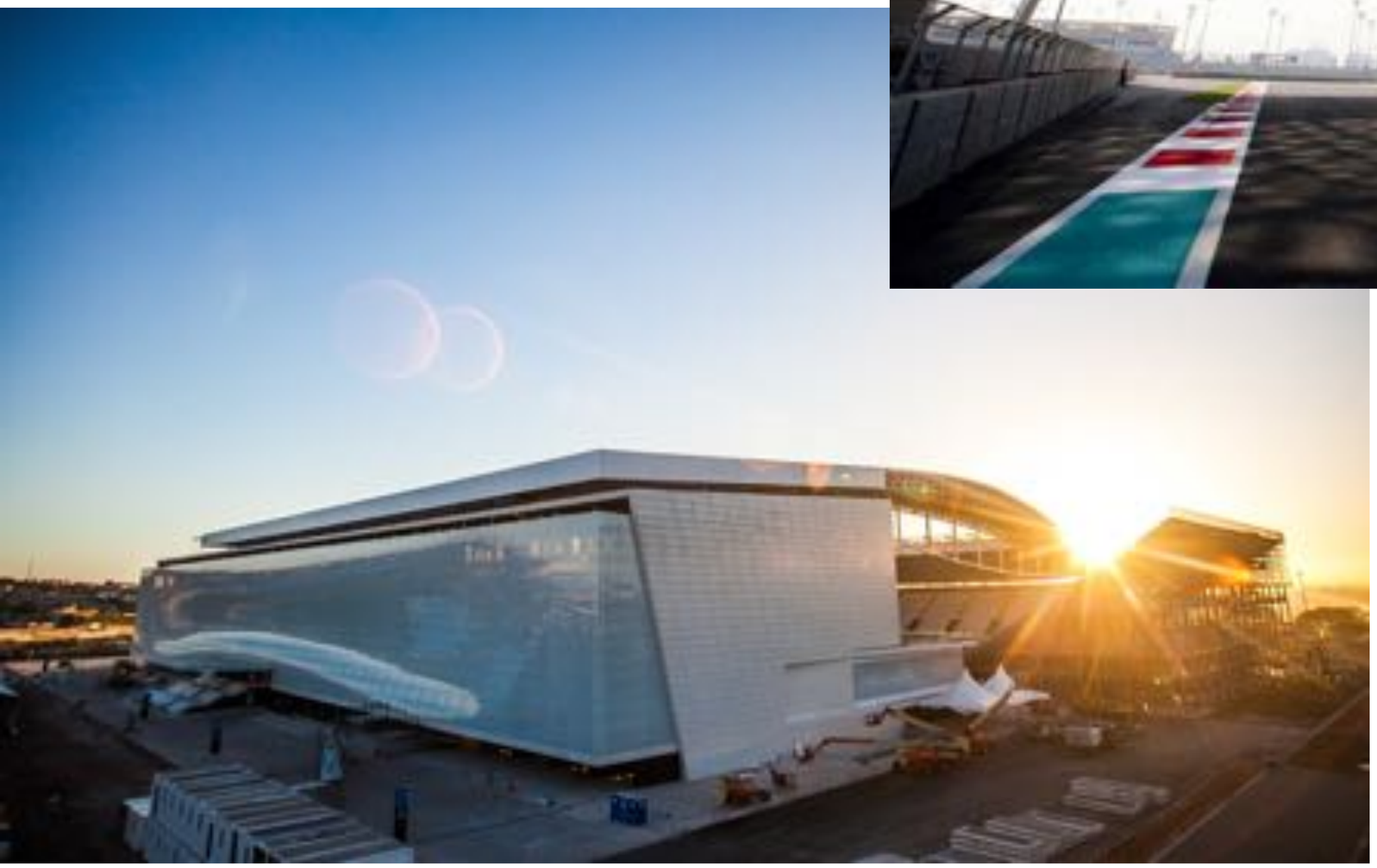
Industrial design



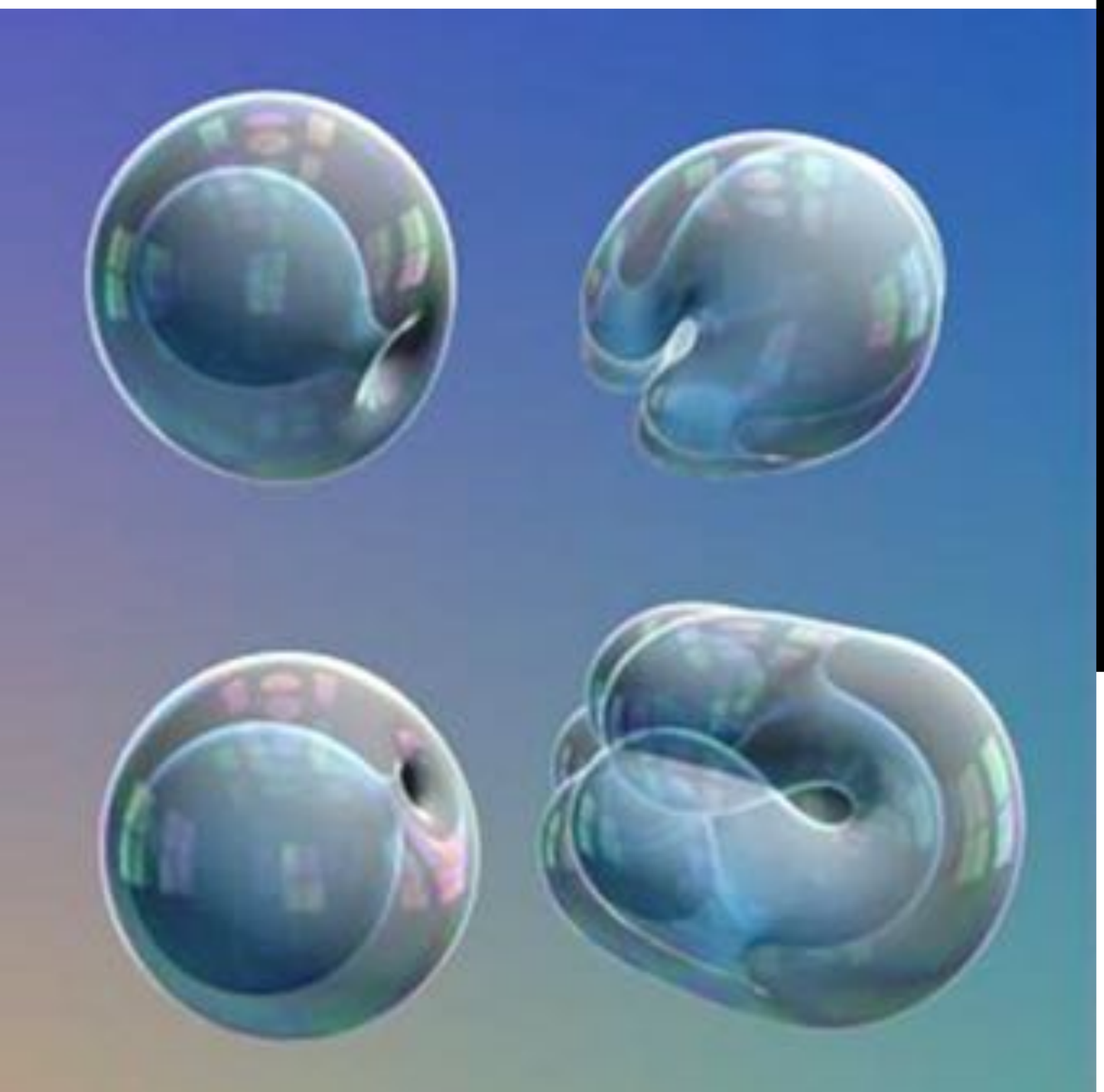
Computer aided engineering (CAE)

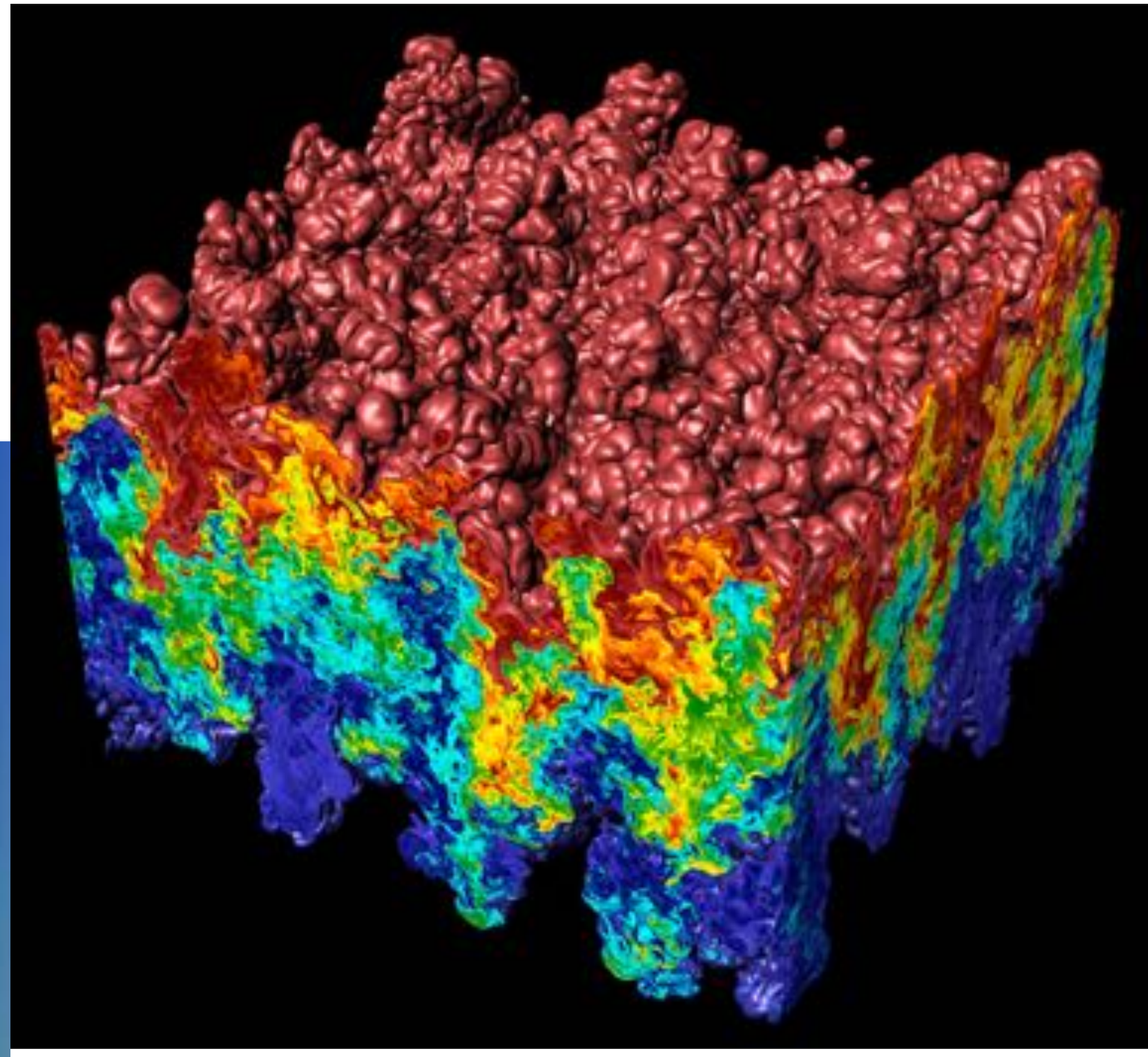


Architecture

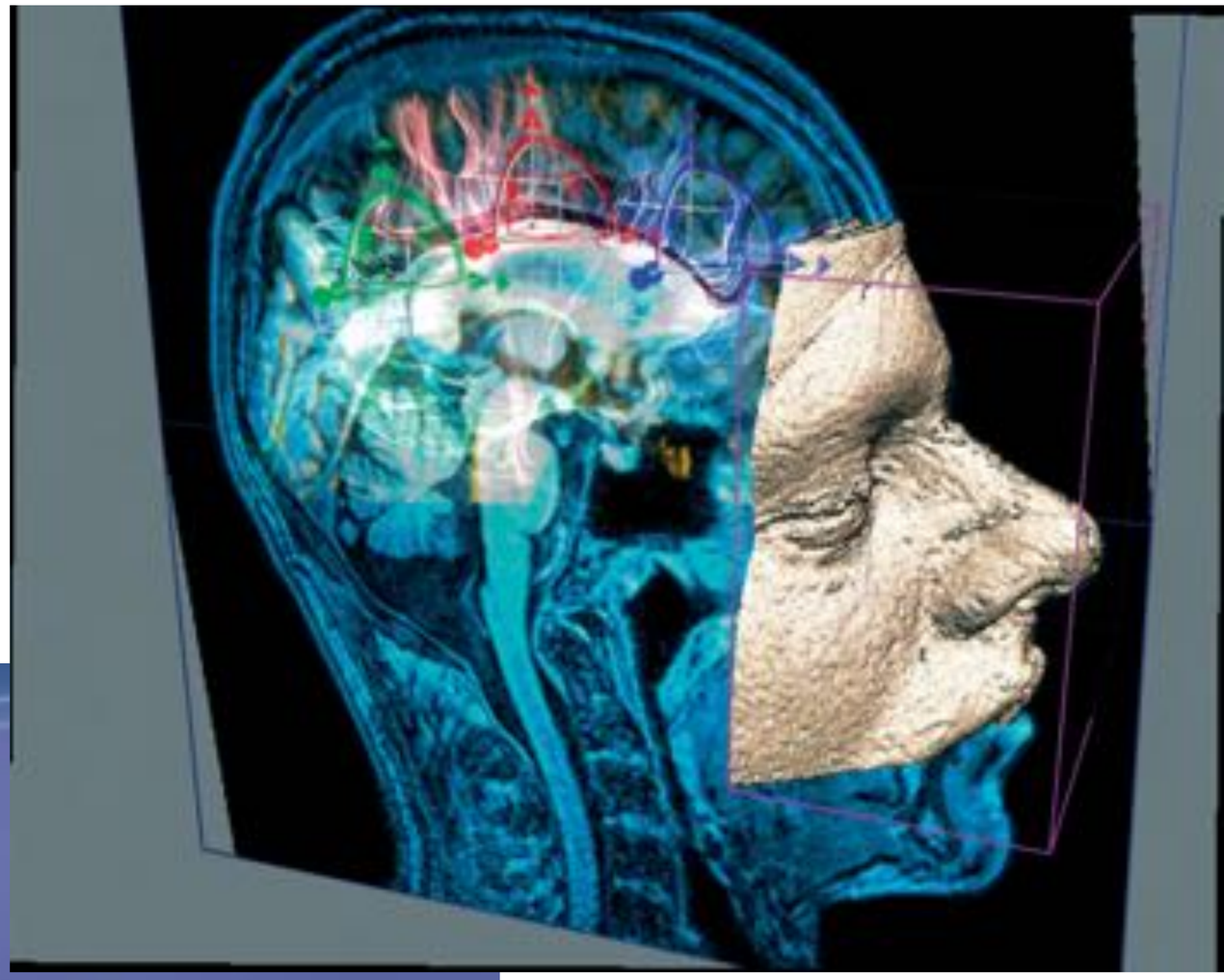


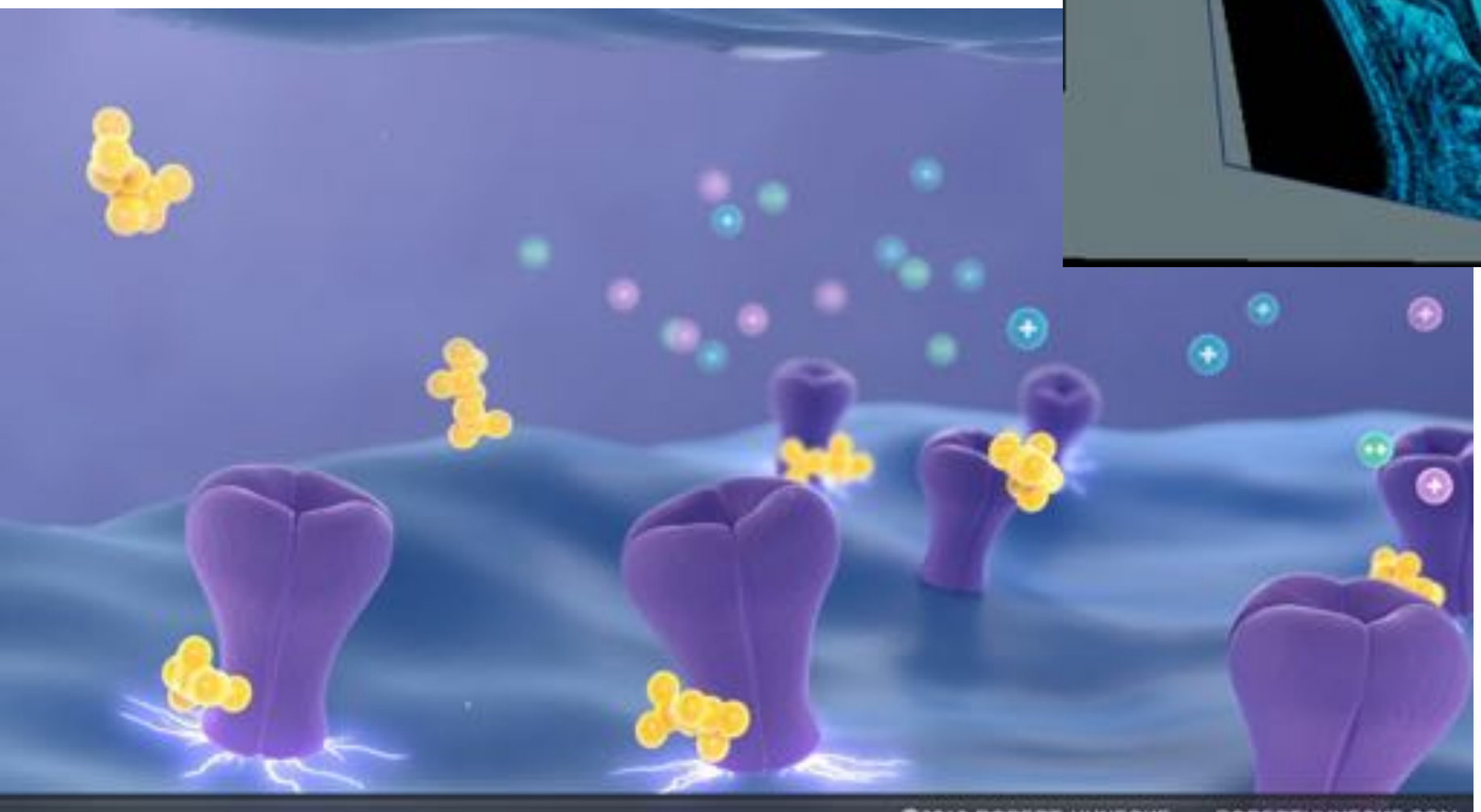
Scientific/mathematical visualization





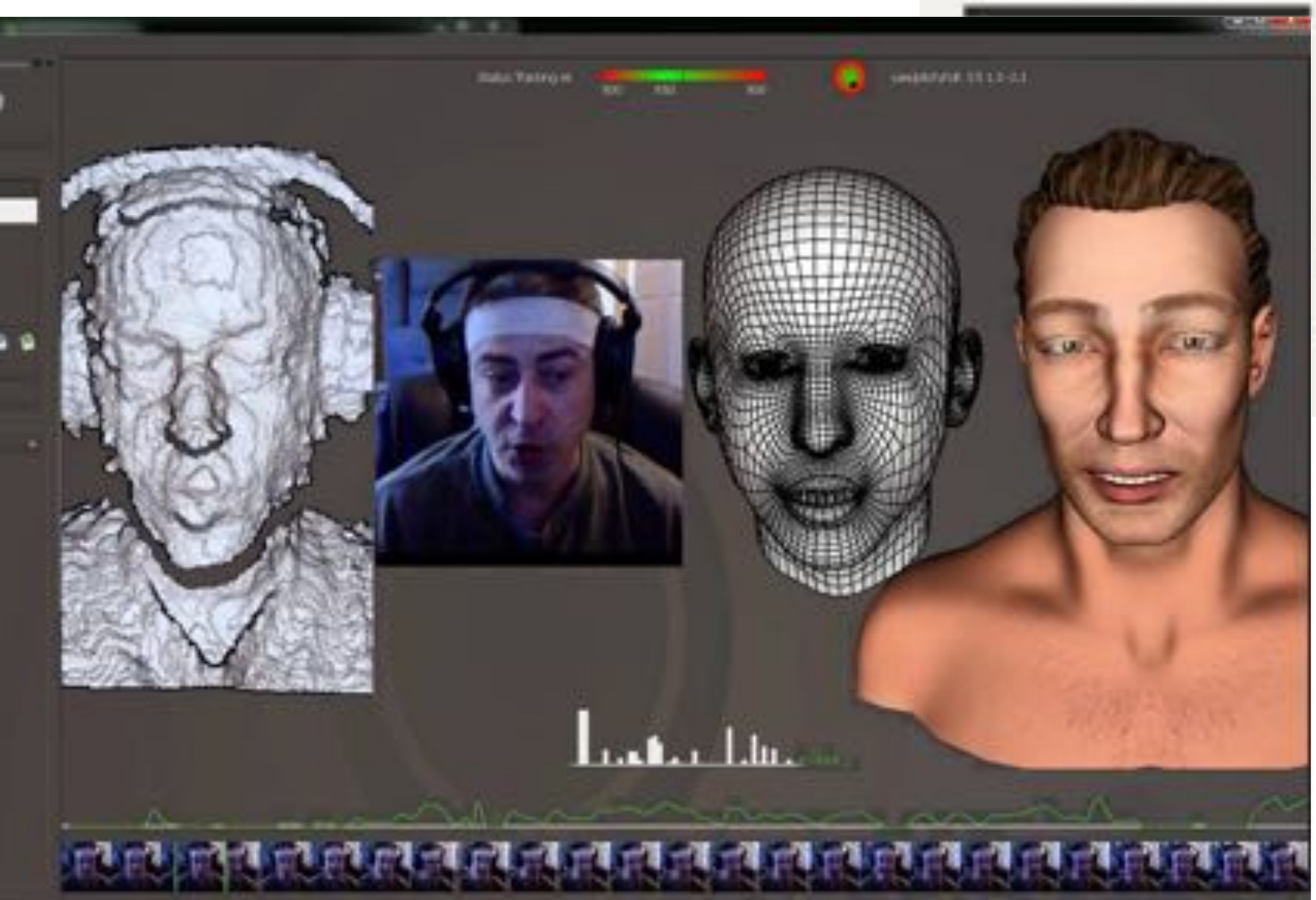
Medical/anatomical visualization

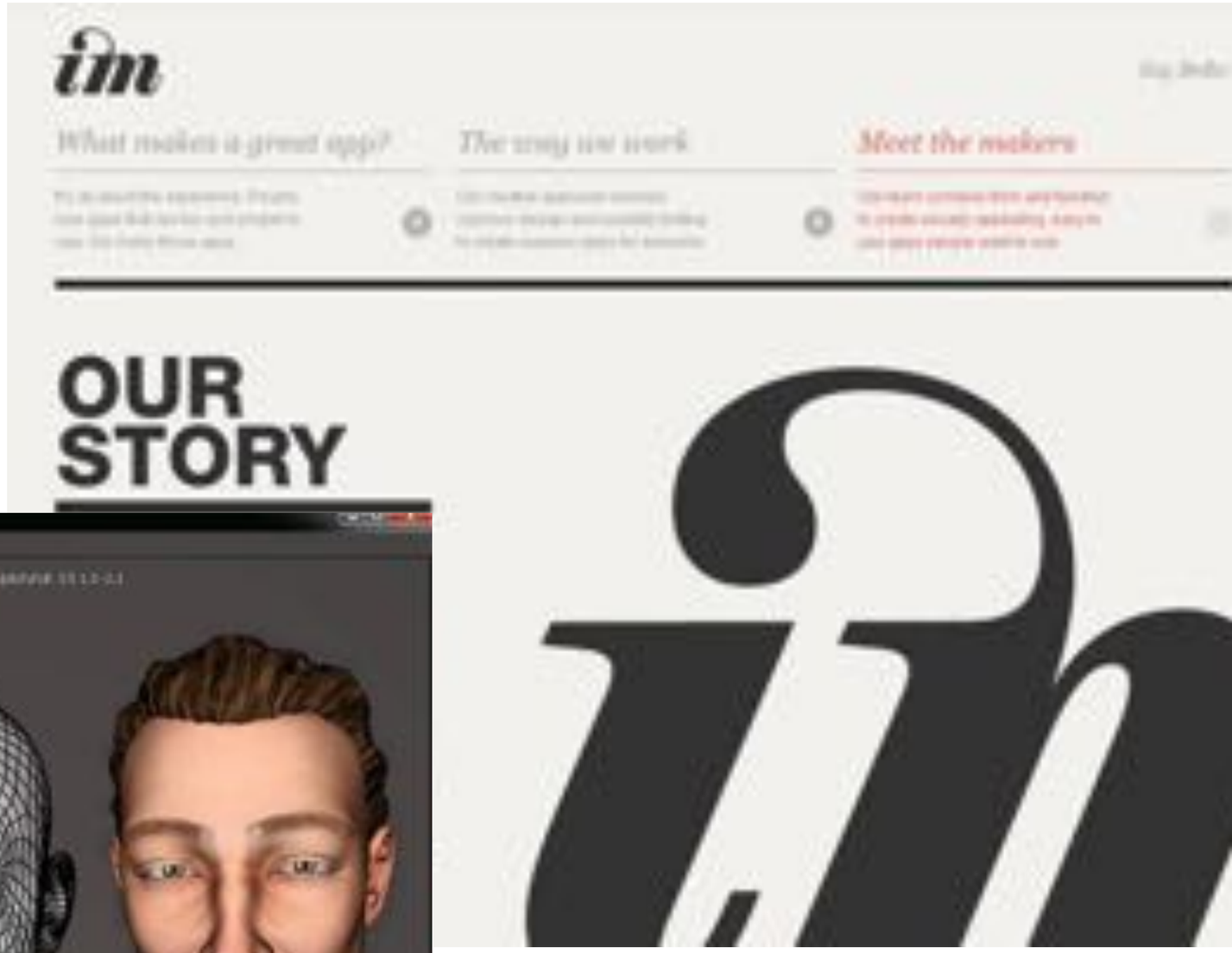




Navigation

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:

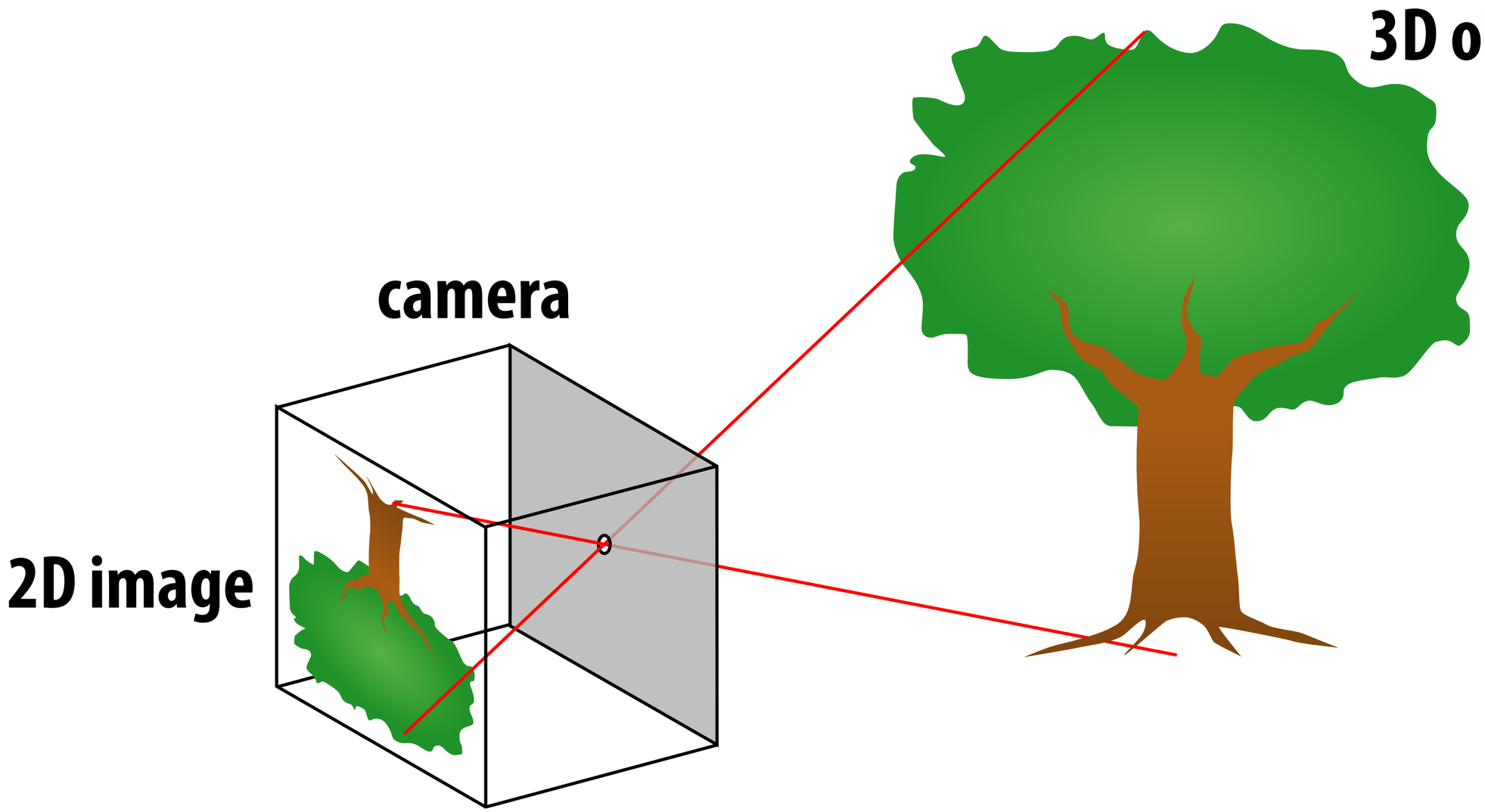
```
VERTICES                                          EDGES
A: ( 1, 1, 1 )    E: ( 1, 1,-1 )
B: (-1, 1, 1 )    F: (-1, 1,-1 )                  AB, CD, EF, GH,
C: ( 1,-1, 1 )    G: ( 1,-1,-1 )                  AC, BD, EG, FH,
D: (-1,-1, 1 )    H: (-1,-1,-1 )                  AE, CG, BF, DH
```

- 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?

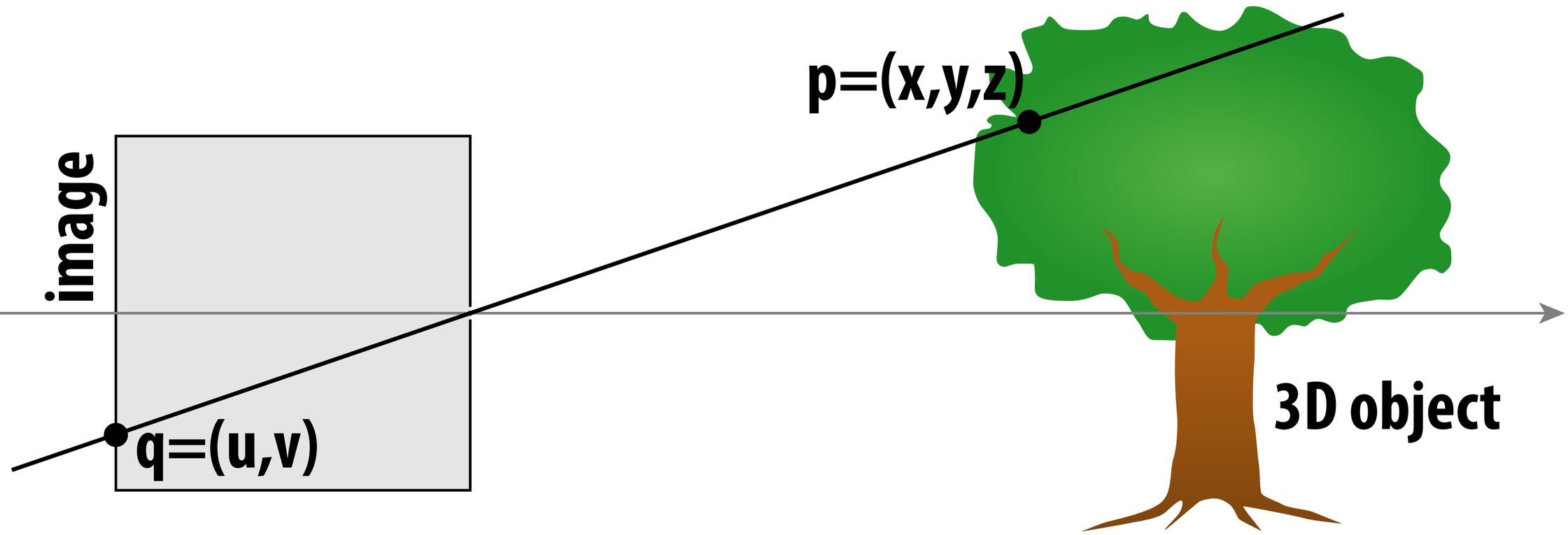
Perspective projection

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



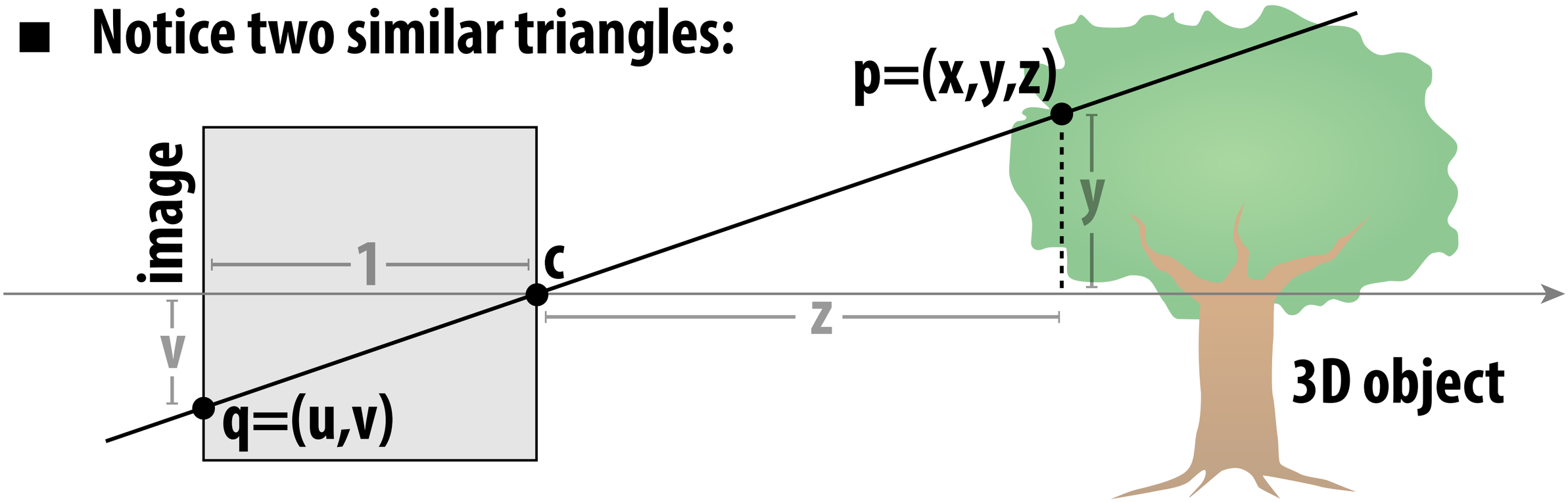
Perspective projection: side view

- 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

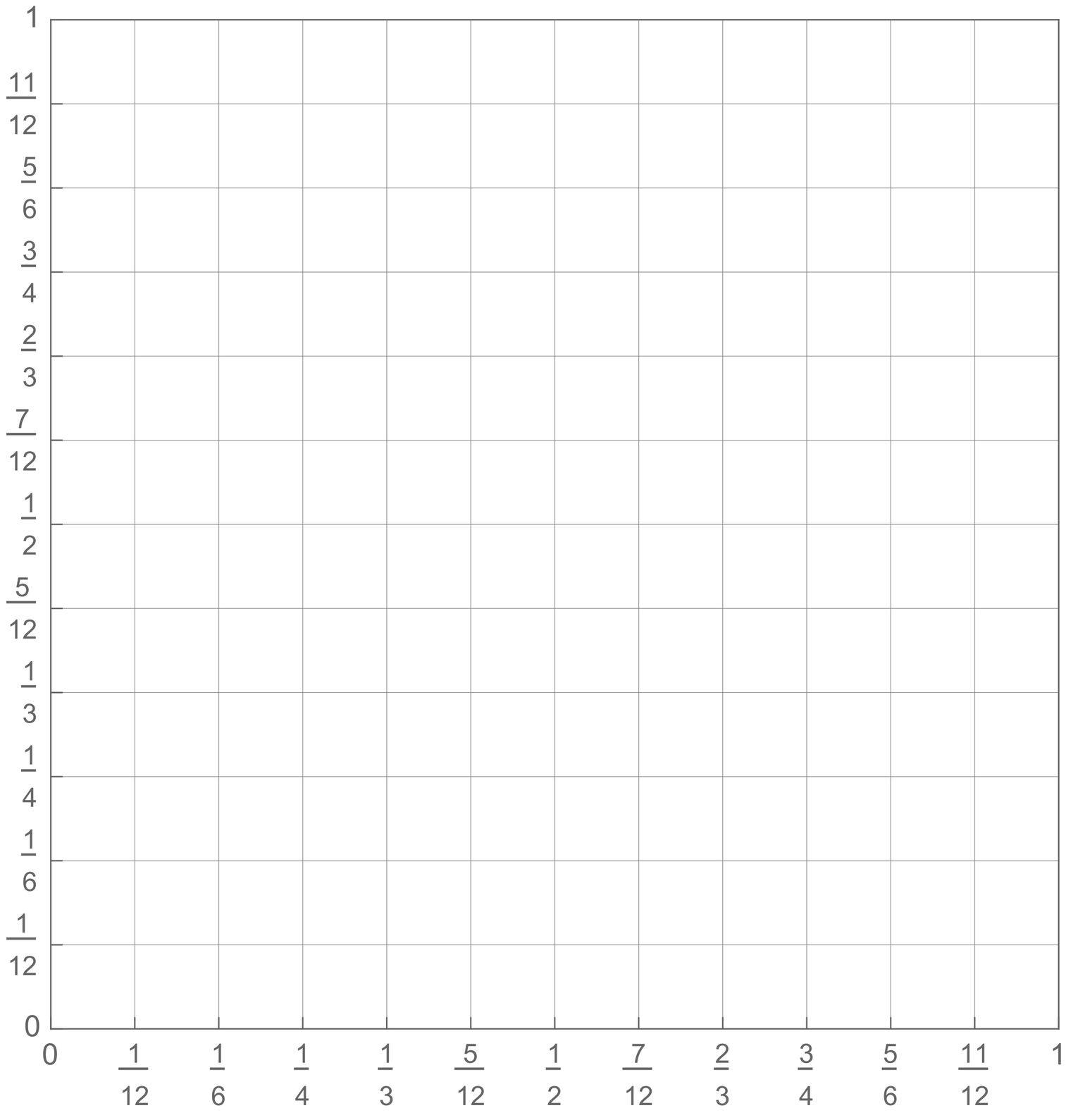
ACTIVITY: now draw it!

- 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)

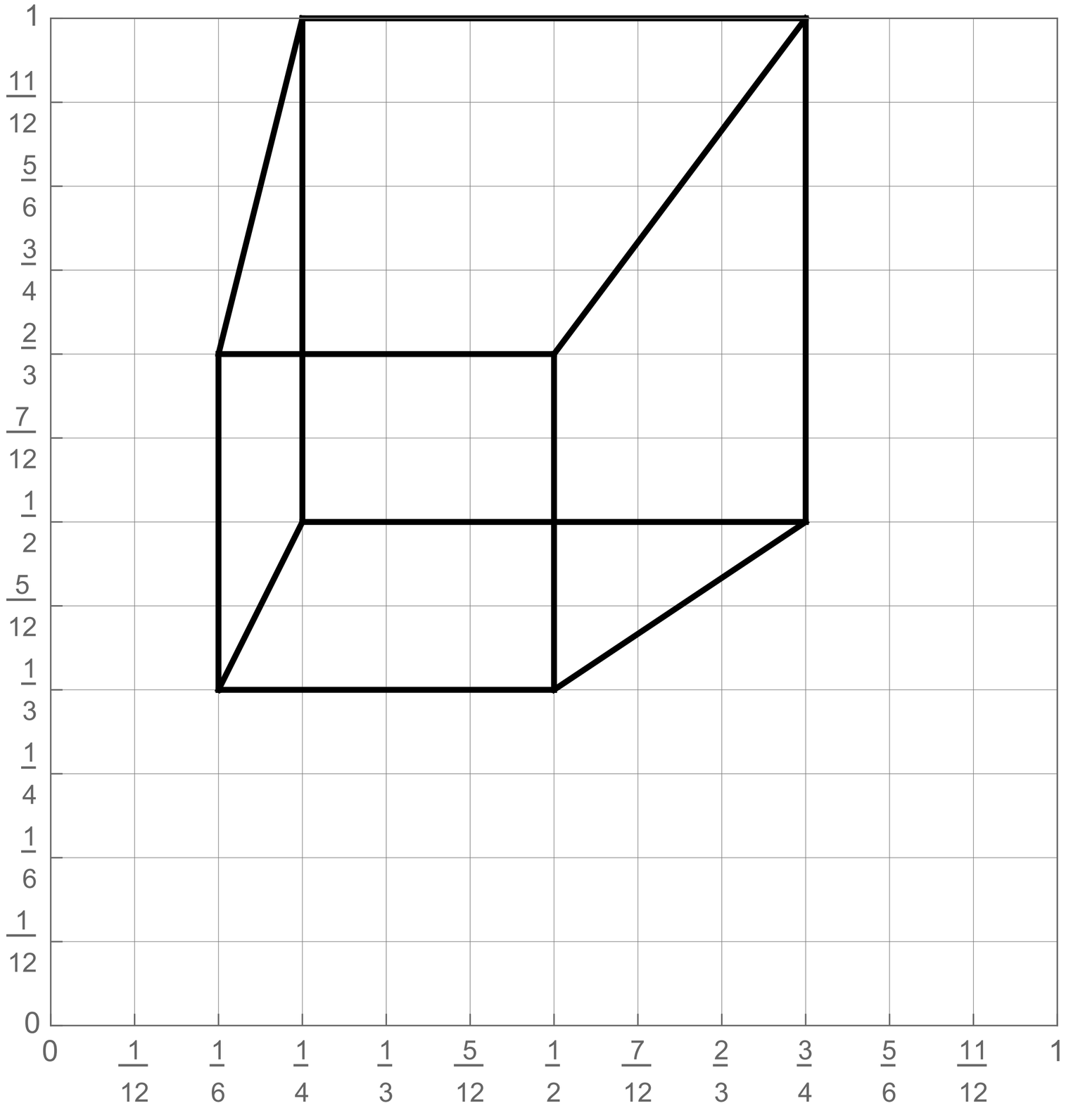
```
VERTICES                                          EDGES
A: ( 1, 1, 1 )    E: ( 1, 1,-1 )

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



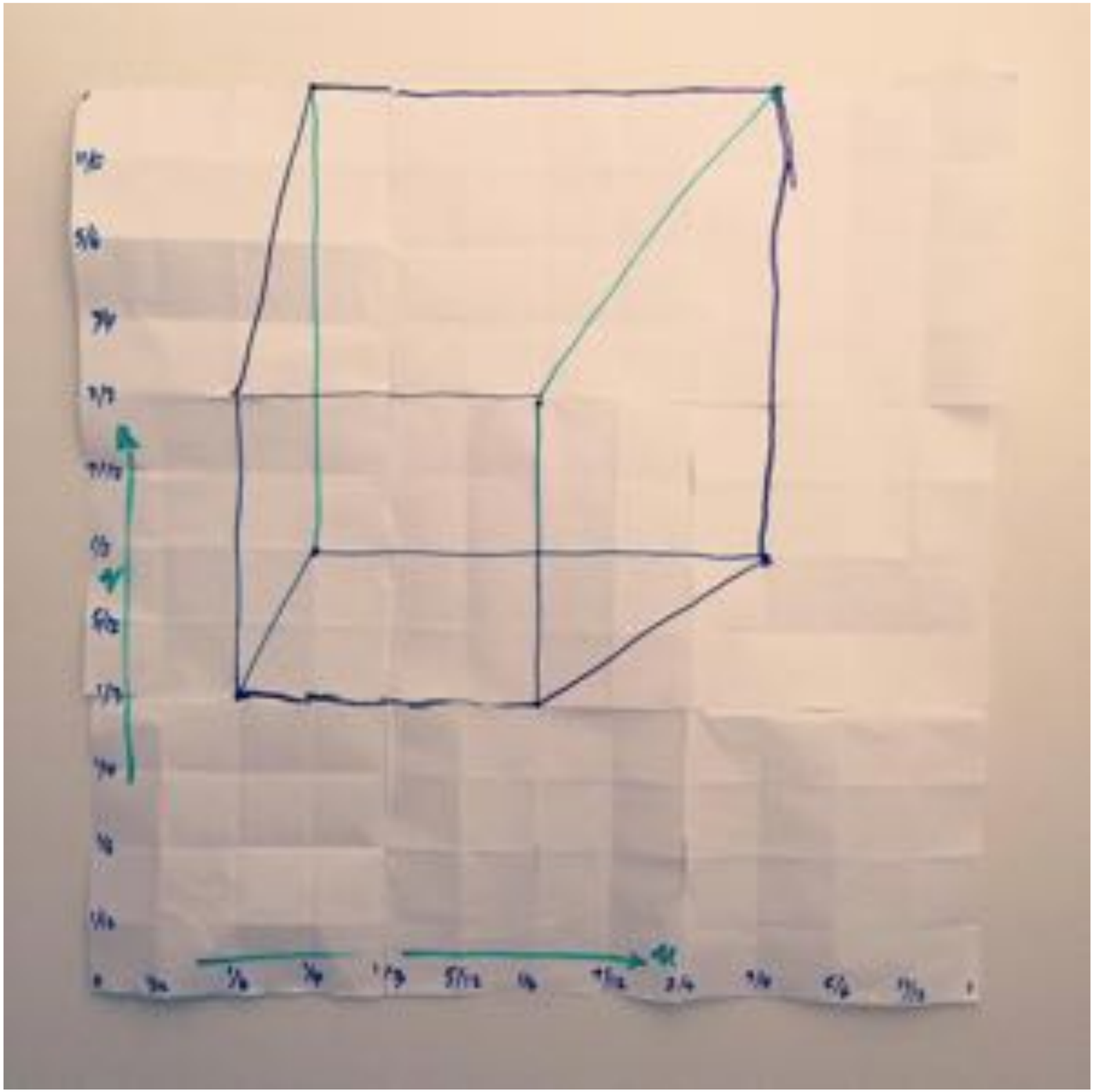
ACTIVITY: How did we do?



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: Last year's result

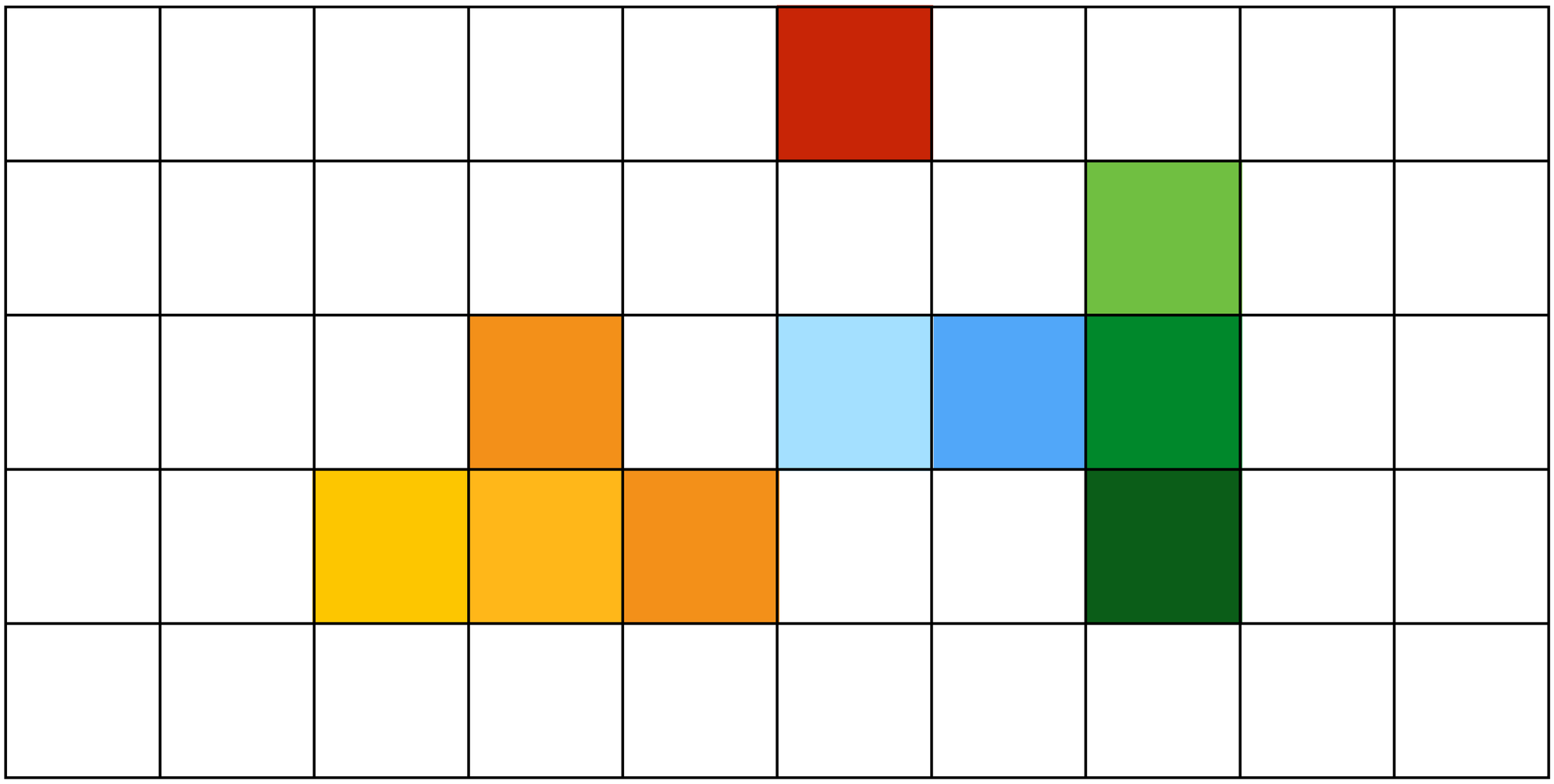


But wait…

How do we draw lines on a computer?

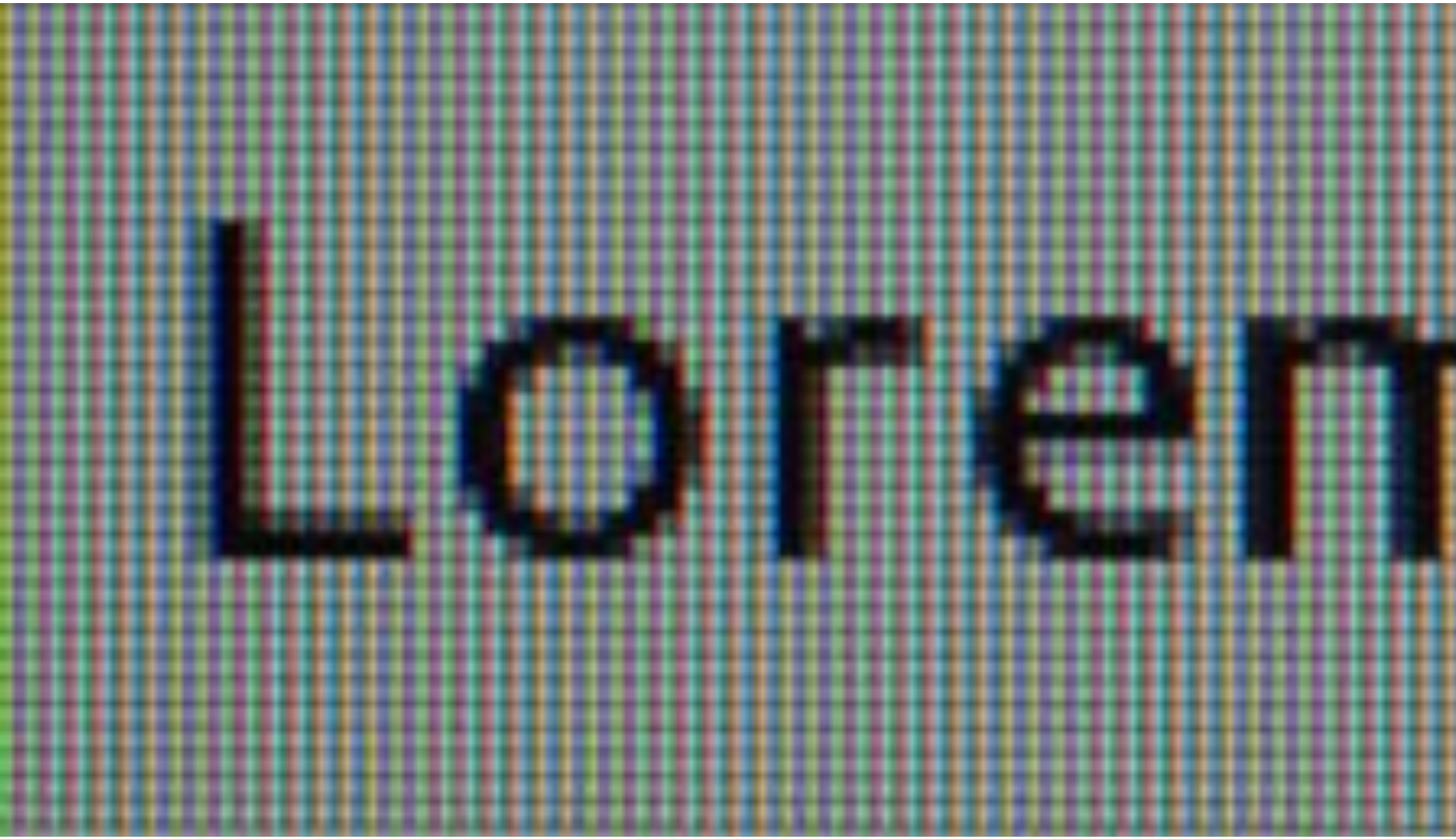
Output for a raster display

- 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



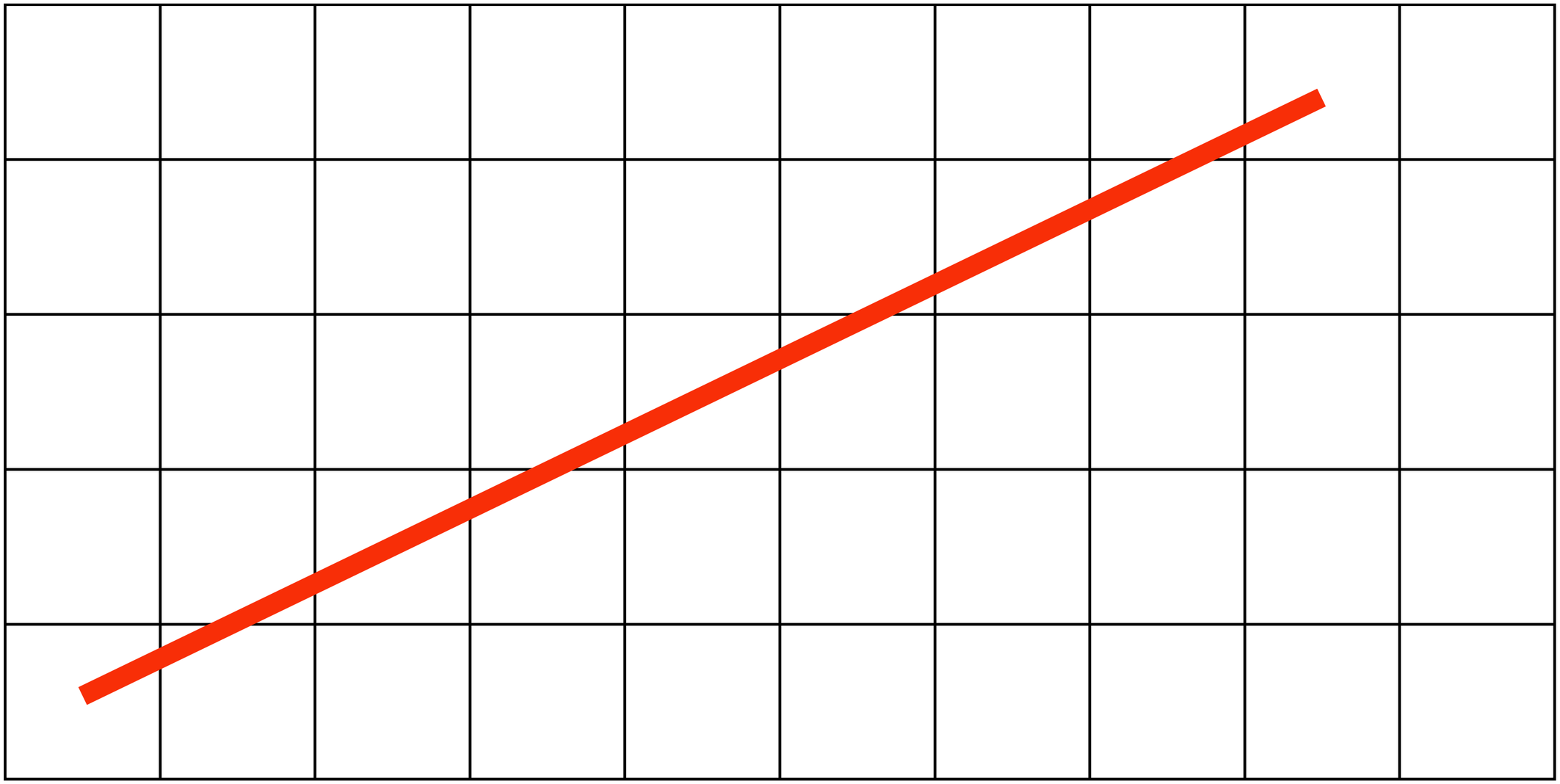
** We will strongly challenge this notion of a pixel "as a little square" soon enough.
But let's go with it for now. ;-)

Close up photo of pixels on a modern display



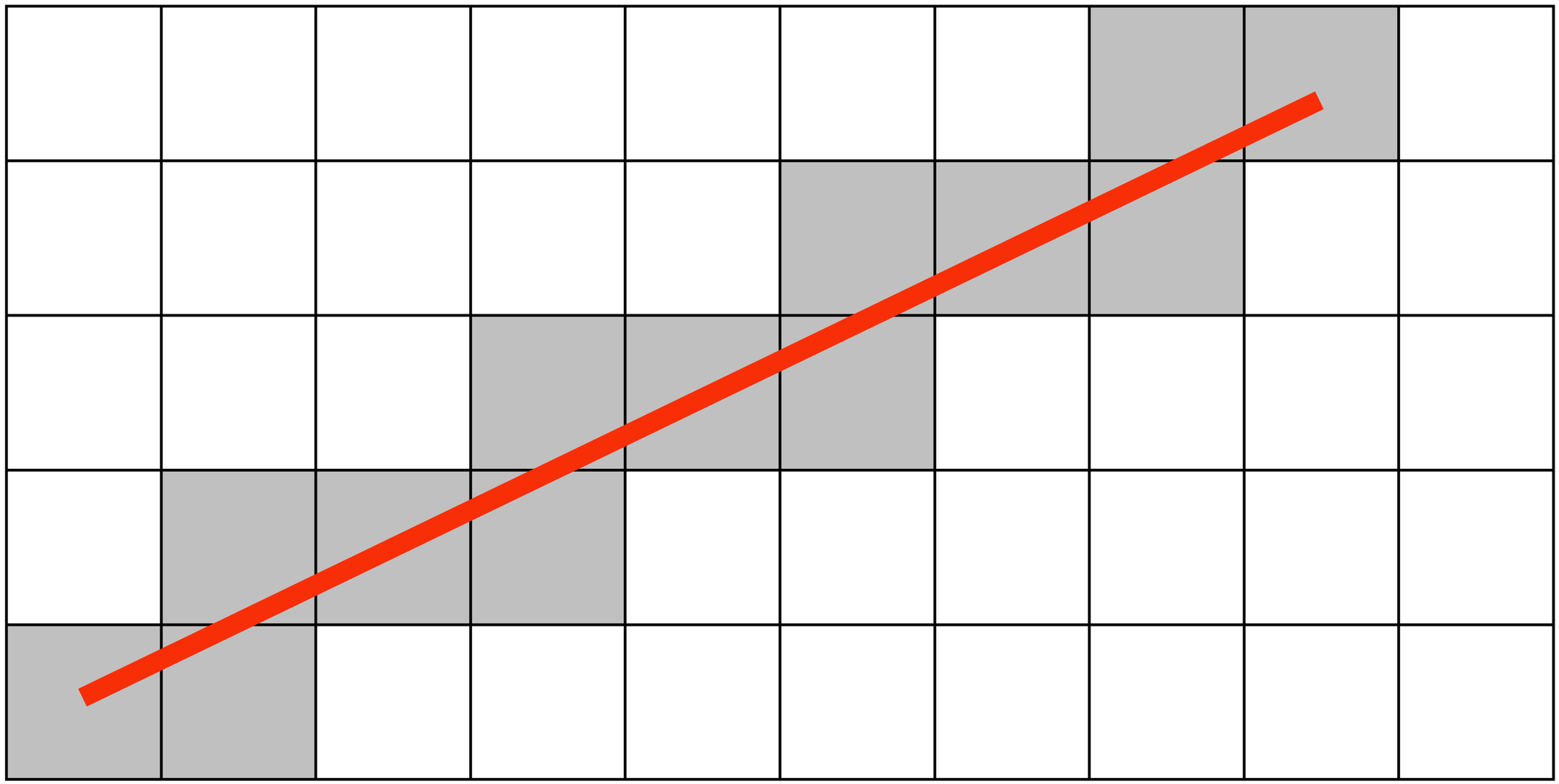
What pixels should we color in to depict a line?

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



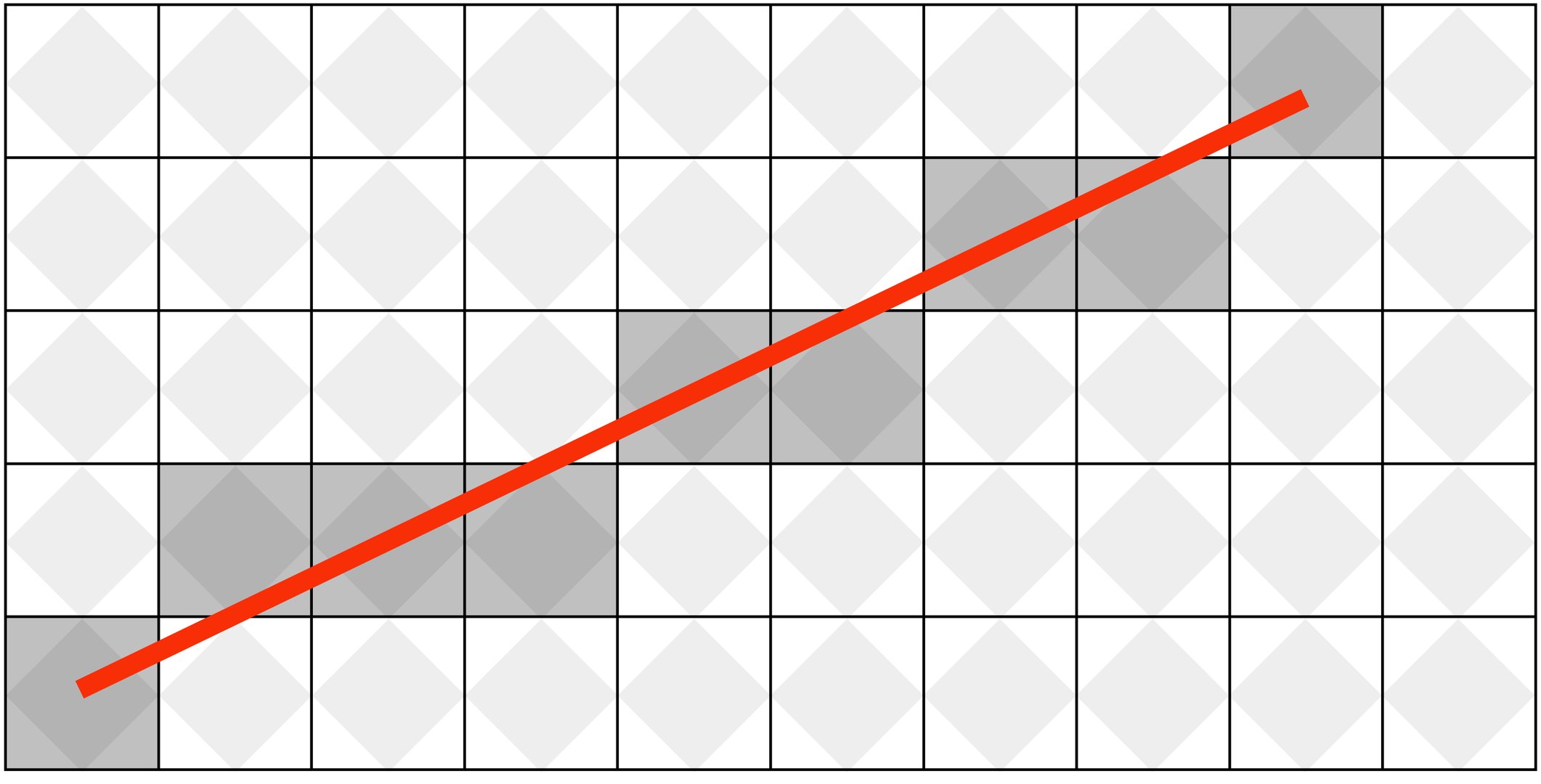
What pixels should we color in to depict a line?

Light up all pixels intersected by the line?



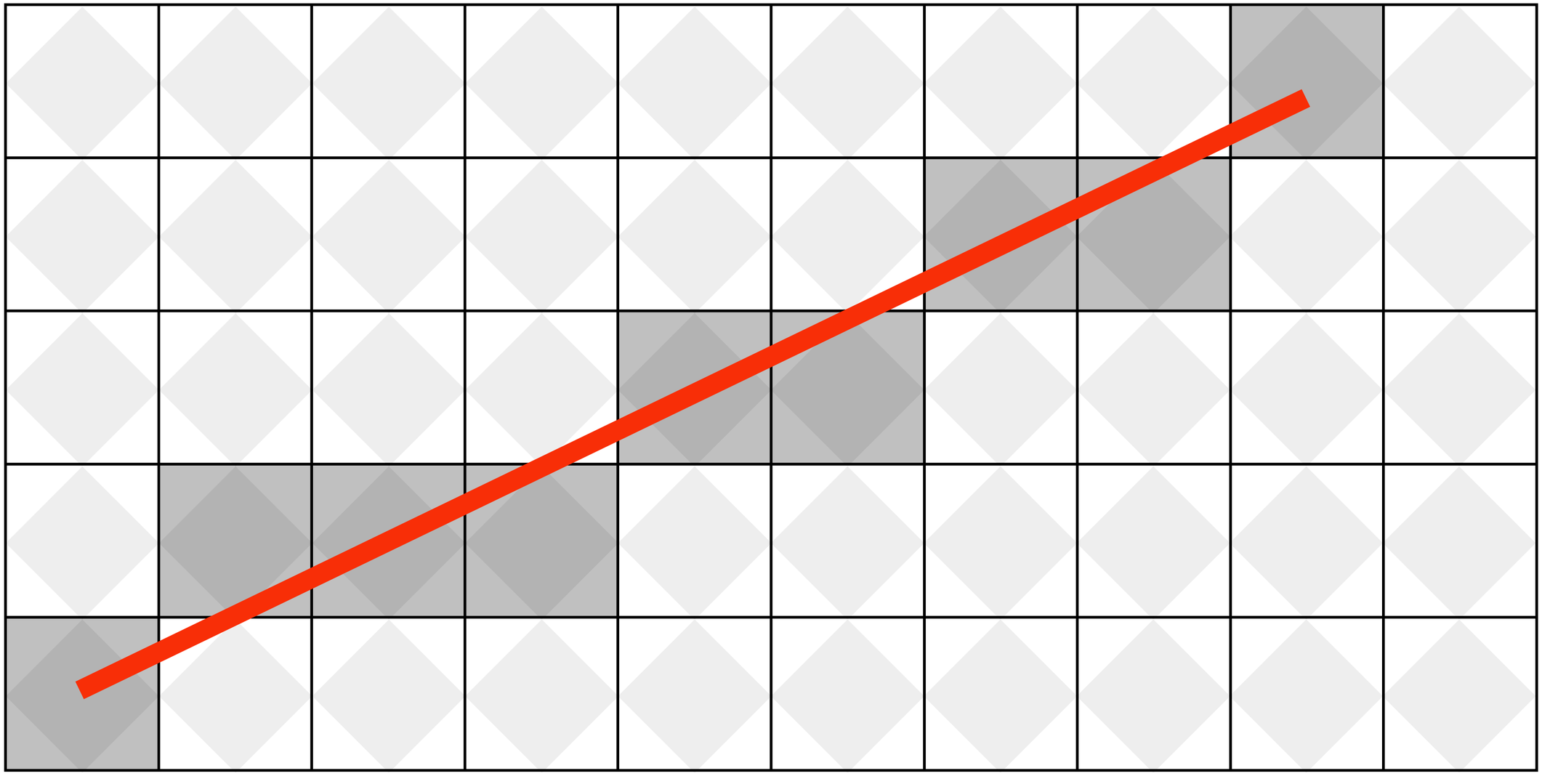
What pixels should we color in to depict a line?

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)



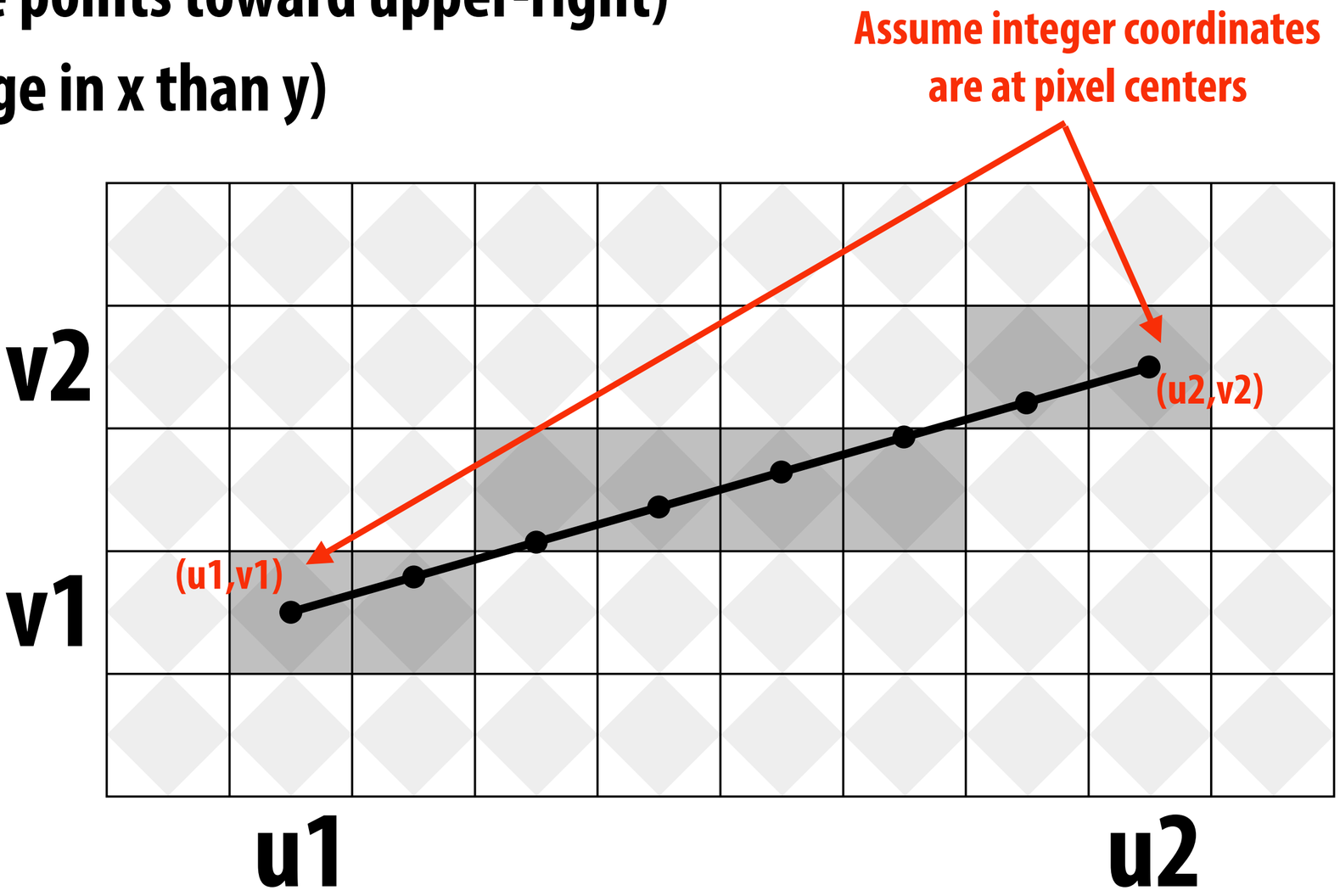
How do we find the pixels satisfying a chosen rasterization rule?

- 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

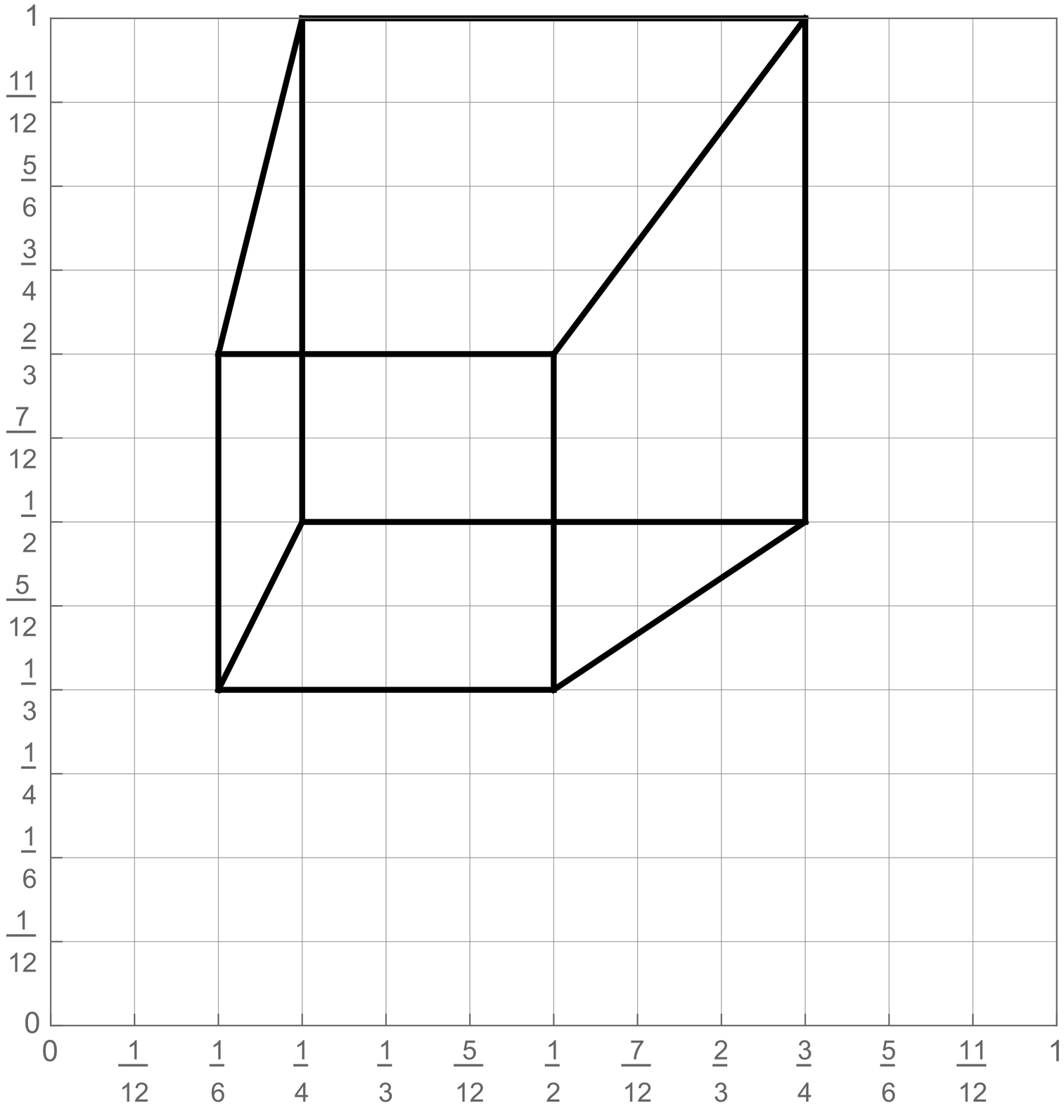
- Let's say a line is represented with integer endpoints: (u1,v1), (u2,v2)
- Slope of line: s = (v2-v1) / (u2-u1)
- Consider a very easy special case:
  - u1 < u2, v1 < v2 (line points toward upper-right)
  - 0 < s < 1 (more change in x than y)

```
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:

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

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 2015]

Complex 3D surfaces

Platonic noid

Modeling material properties

[Wann Jensen 2001]

[Jakob 2014]

[Zhao 2013]

Realistic lighting environments

Up, (Pixar 2009)

Realistic lighting environments

Toy Story 3 (Pixar 2010)

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)

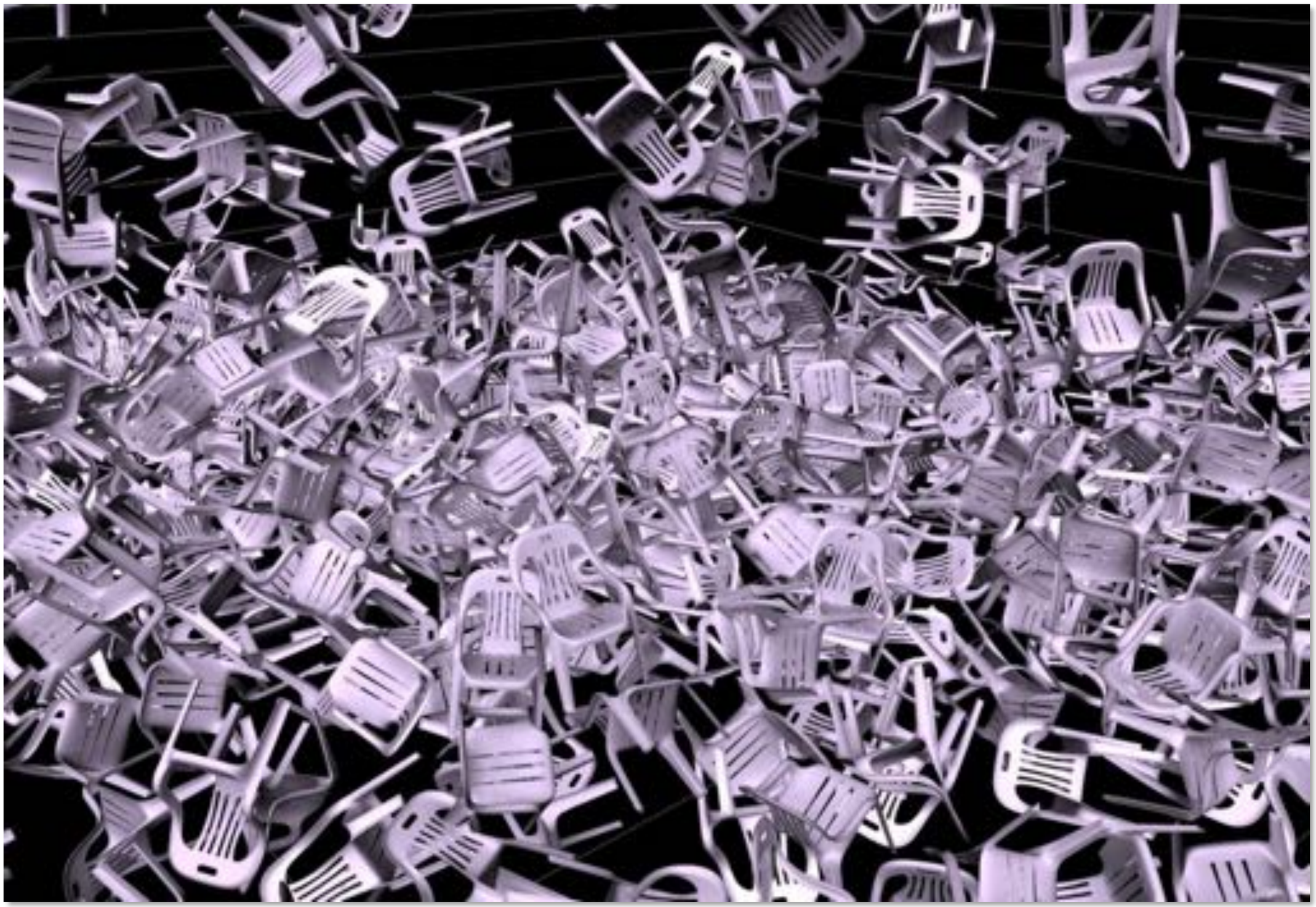
So is this.

[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]

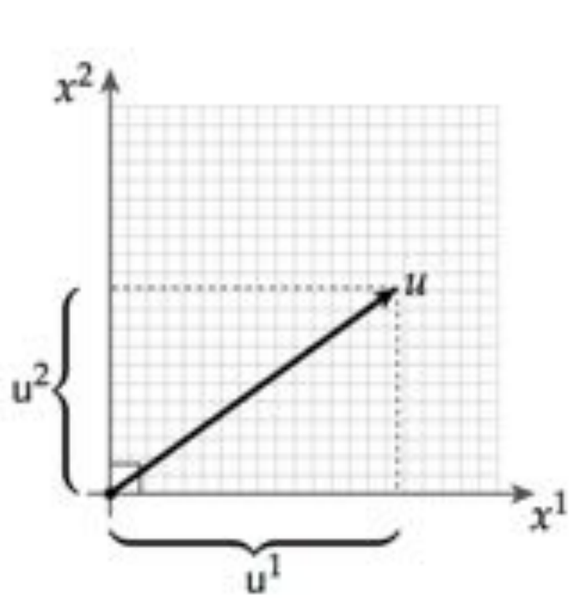
Course Logistics

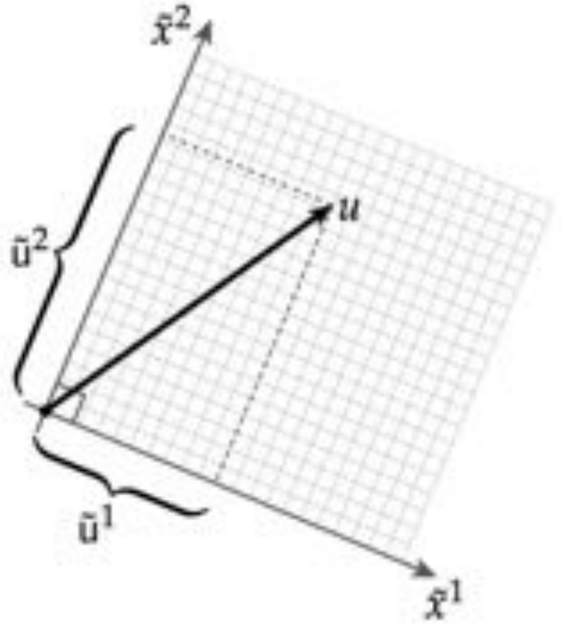
About this course

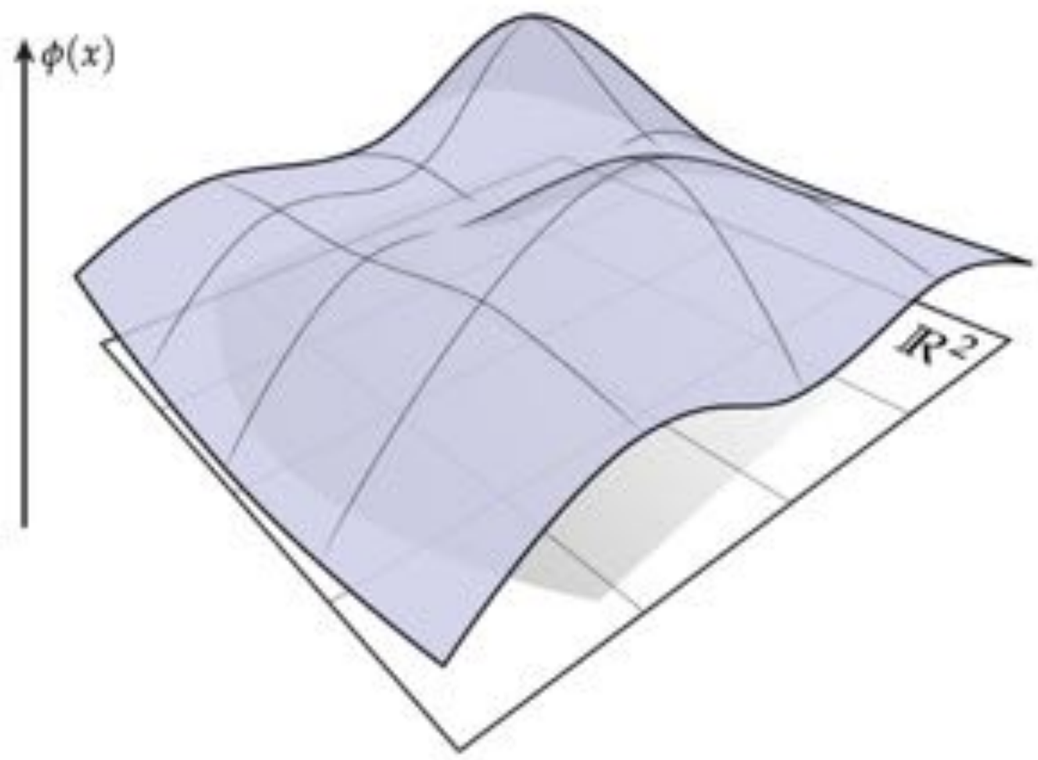
- A broad overview of major topics and techniques in computer graphics: geometry, rendering, animation, imaging

- Outline:
  - Focus on fundamental data structures and algorithms that are reused across all areas of graphics
  - Assignments on:
    - Rasterization
    - Geometric Modeling
    - Photorealistic Rendering
    - Animation
    - Choose Your Own Adventure!

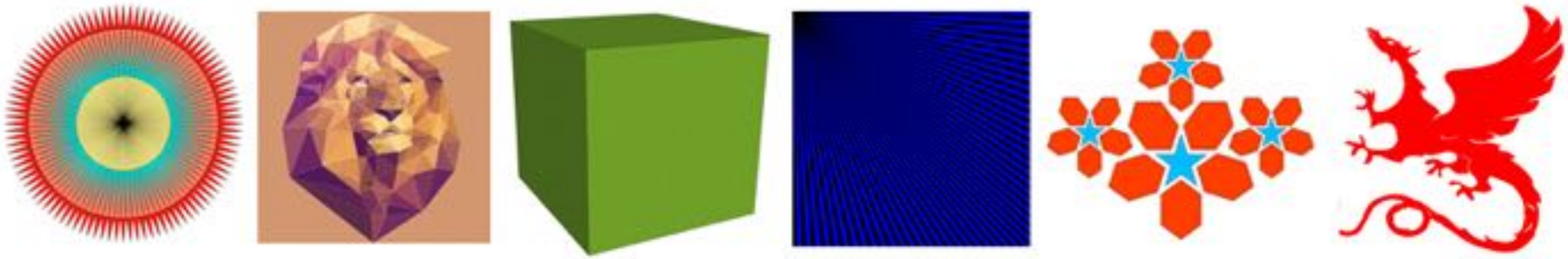
Assignment 0: Math (P)Review



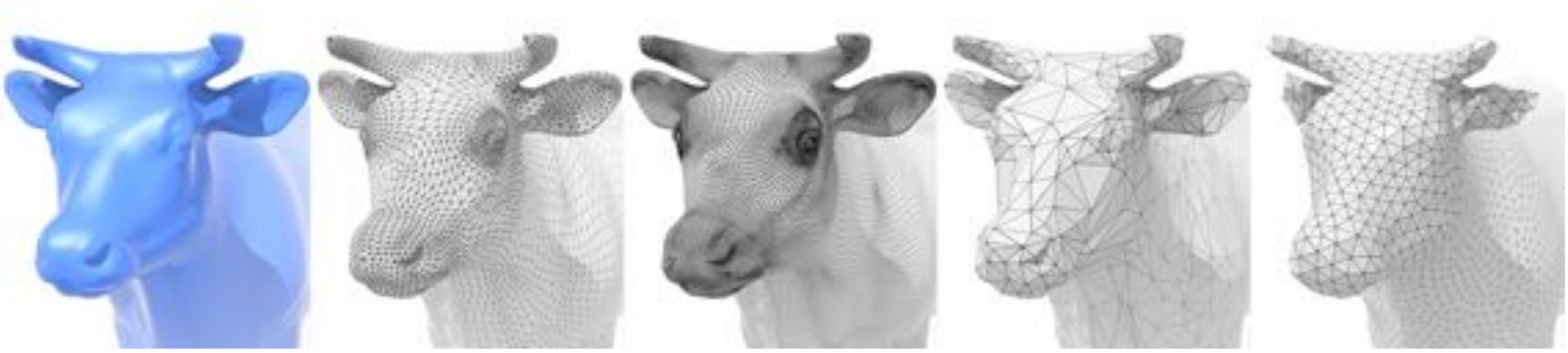




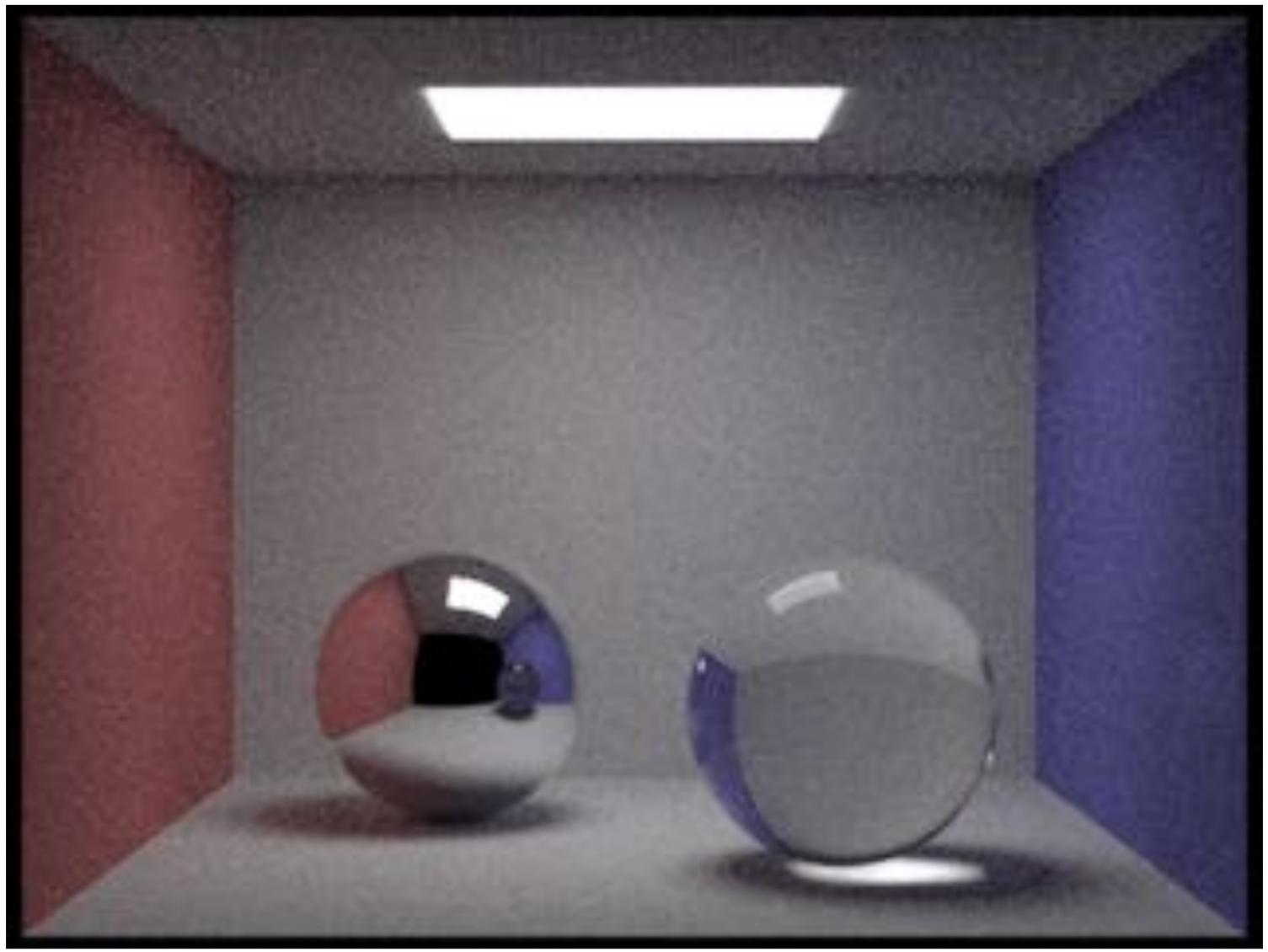
Assignment 1: Rasterization



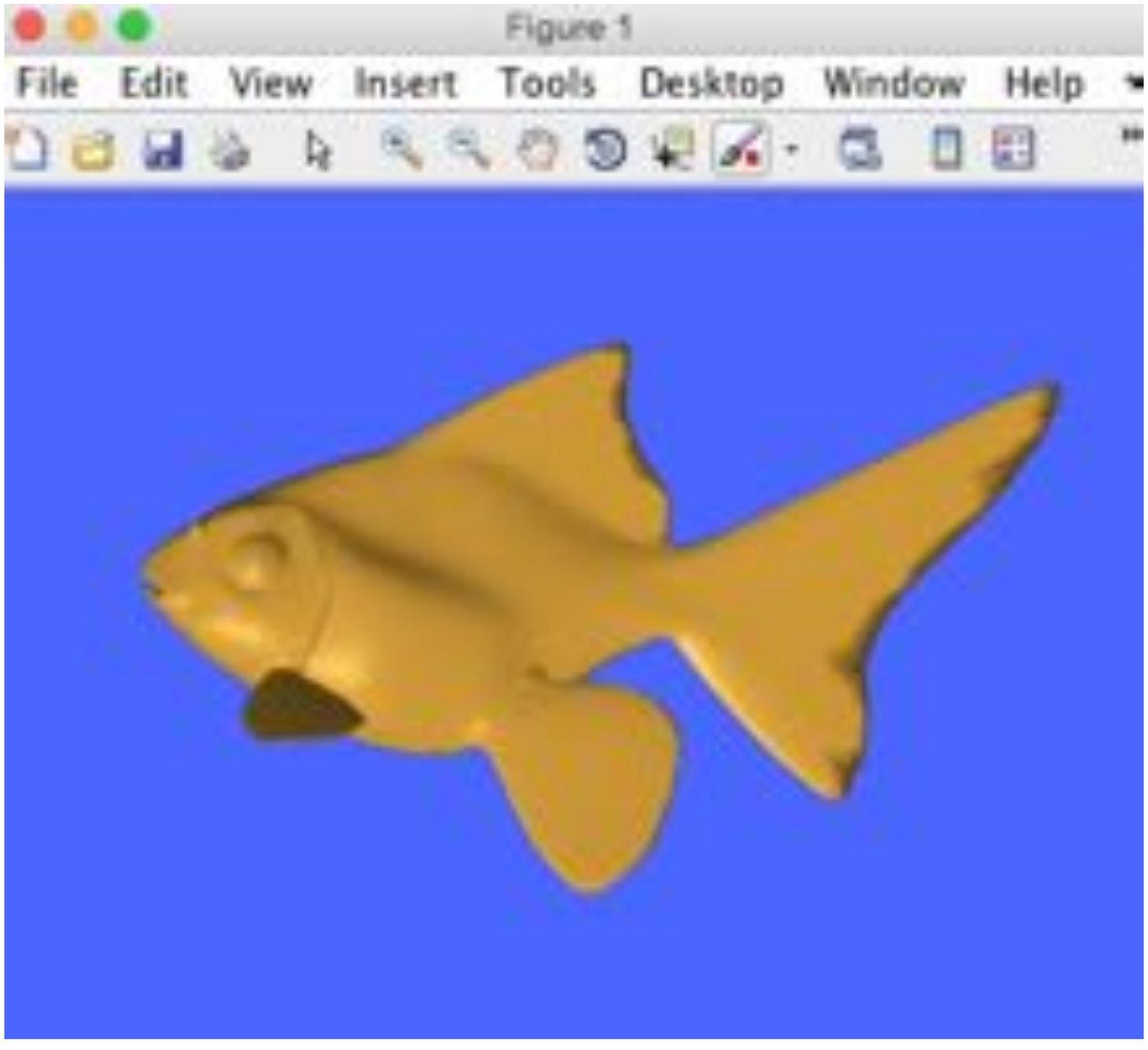
Assignment 2: Geometric Modeling



Assignment 3: Photorealistic Rendering



Assignment 4: Animation



(cribbed from Alec Jacobson)

Assignment 5: Choose Your Own Adventure

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

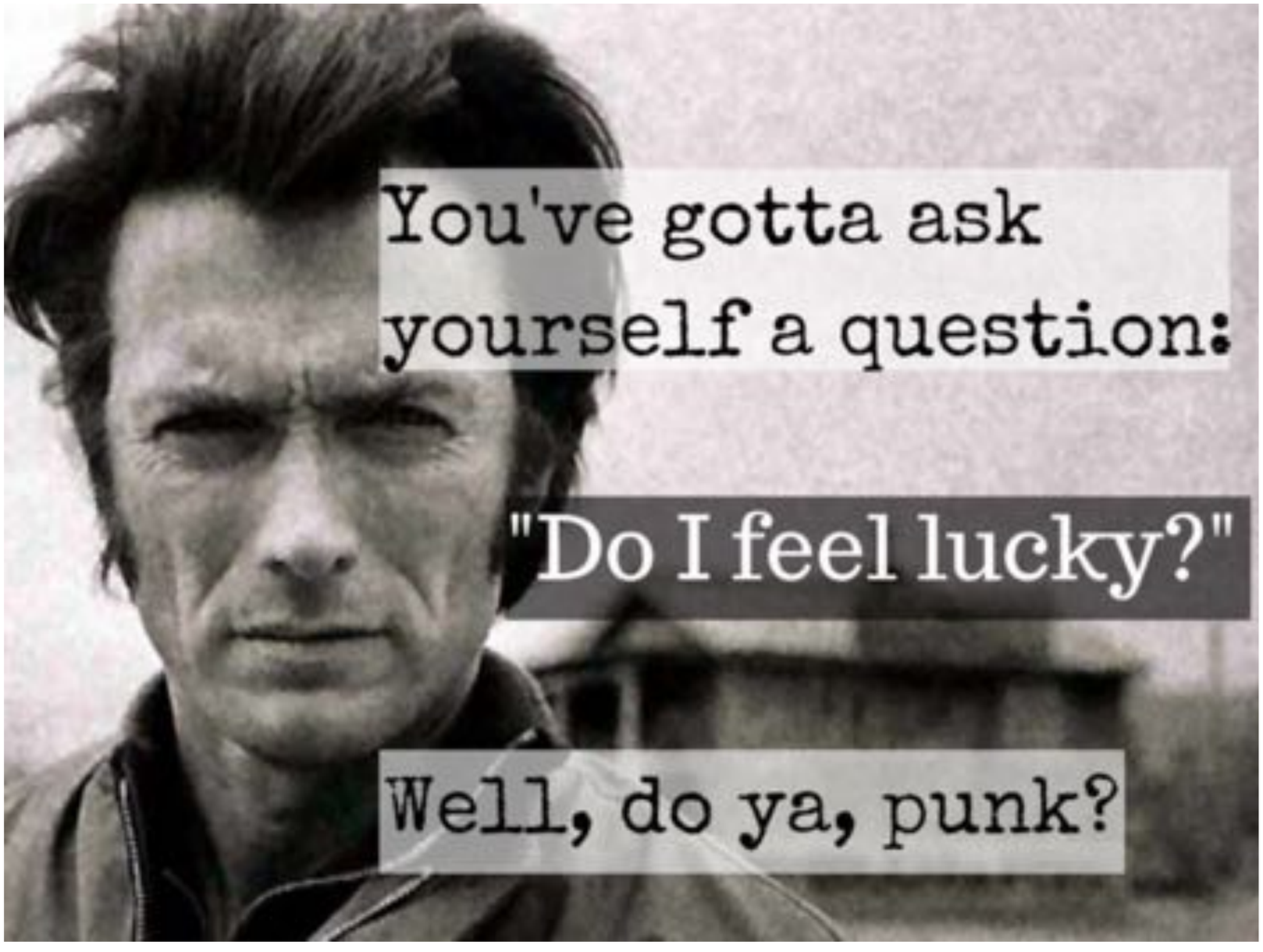
- (5%) Warm-up Math (P)Review
  - Written exercises on basic linear algebra and vector calc. (individually)
- (60%) Five programming assignments
  - Four programming assignments (individually)
  - One "go further" final assignment (in pairs)
- (7%) Take-home quizzes
  - One per lecture, graded on effort
  - 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

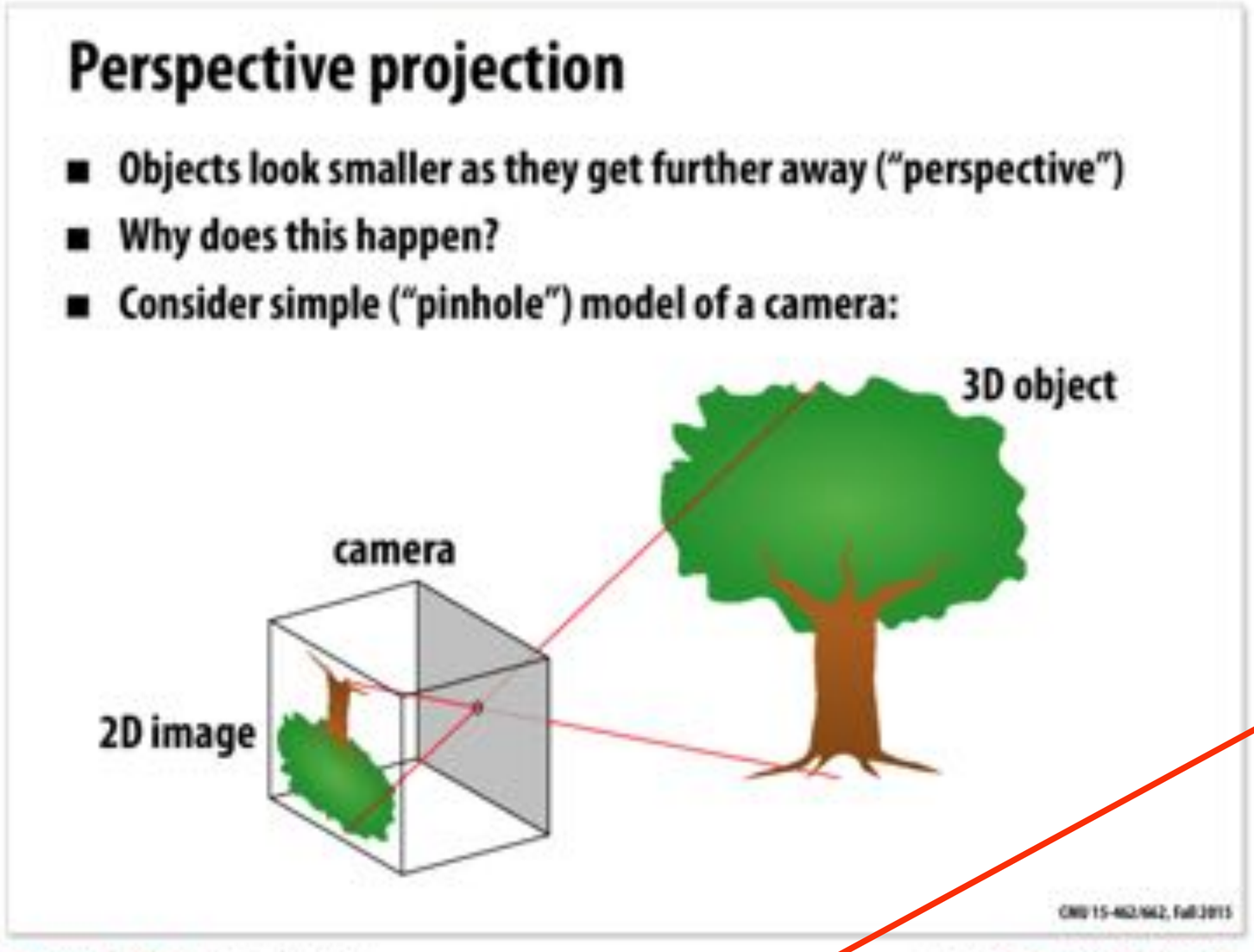
Cheating Policy



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.

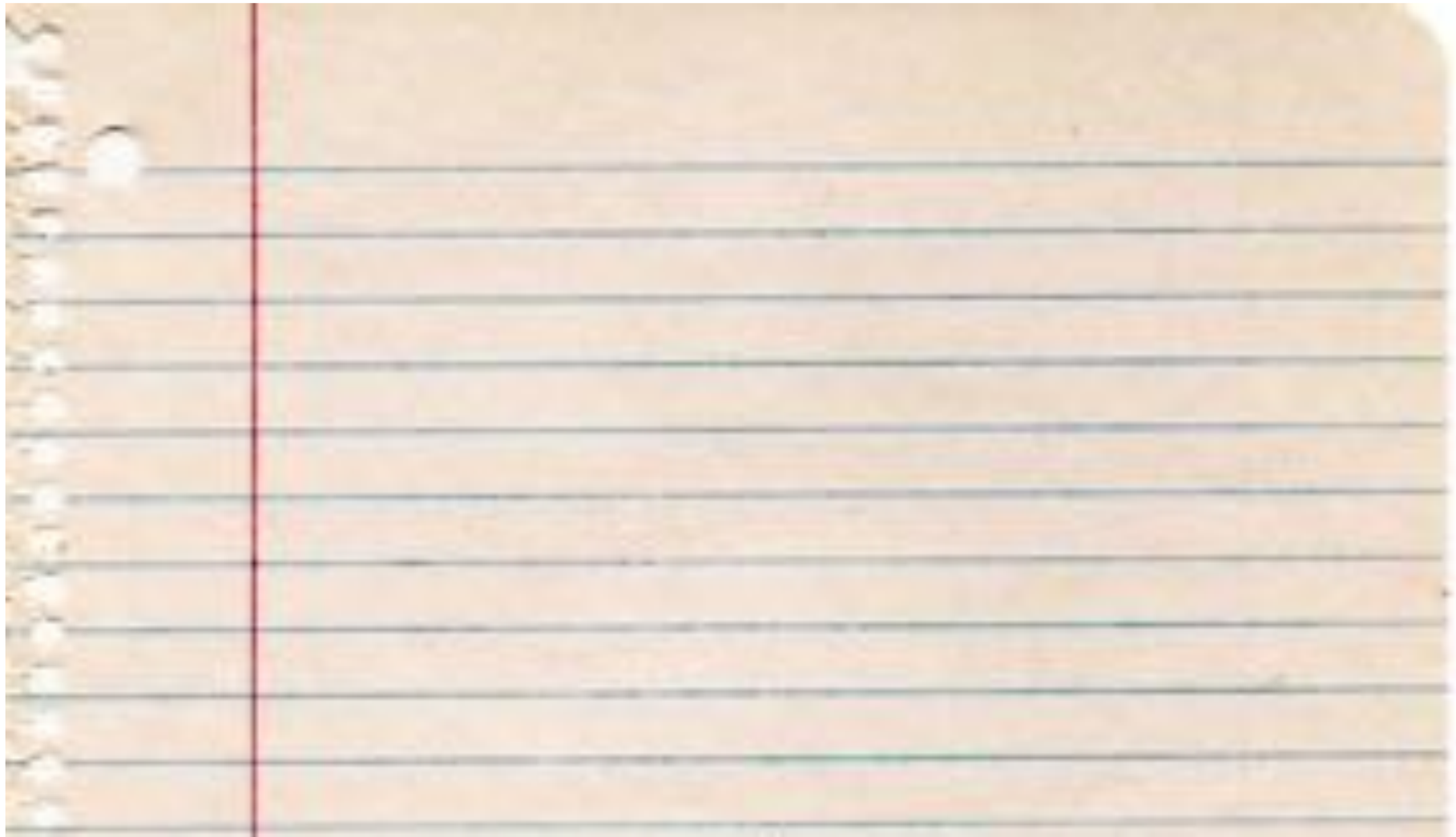
Slide comments and discussion

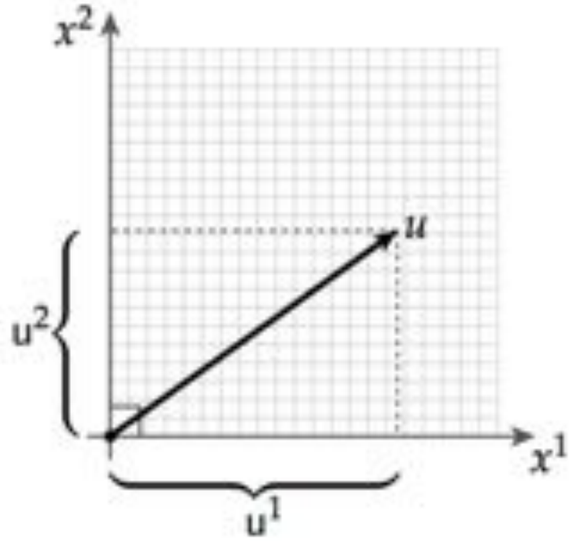
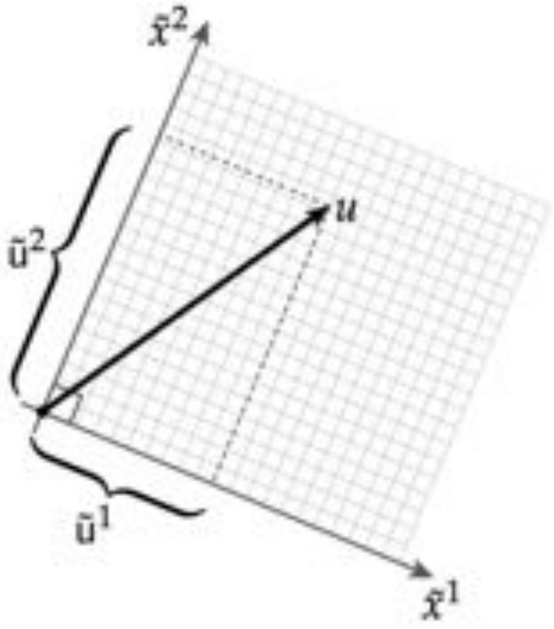
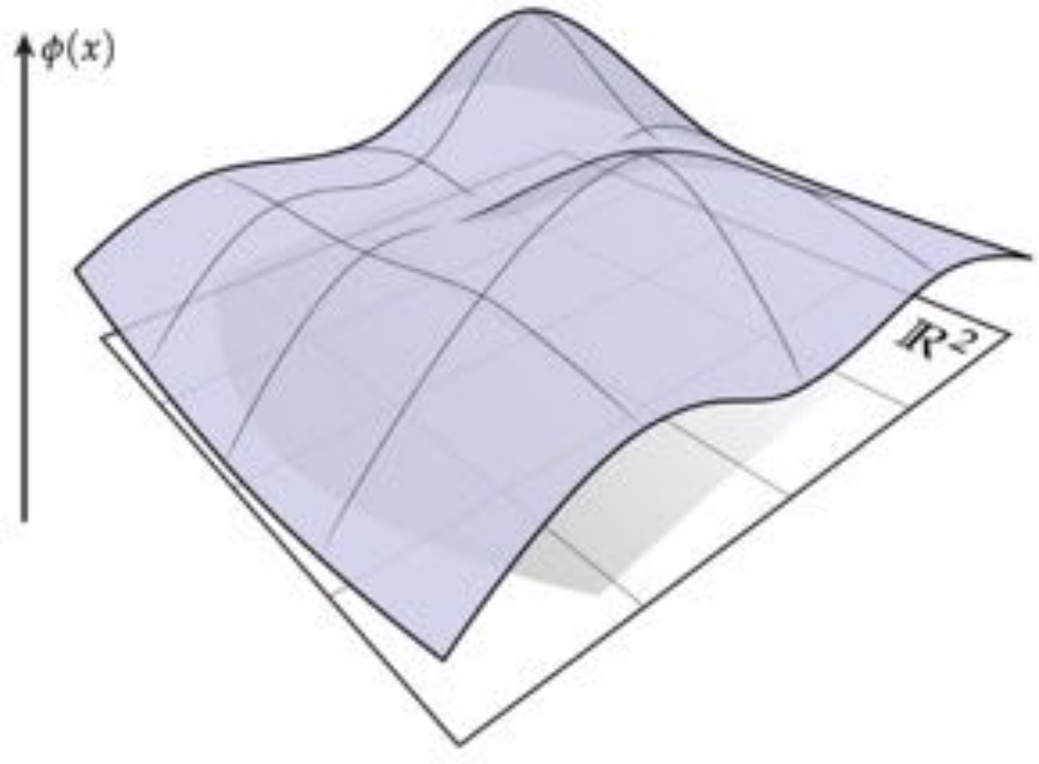
Our philosophy

- 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!