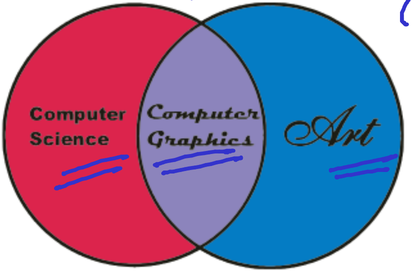
What is Computer Graphics?

No. of frames

- **Def:** Synthesizing and displaying image/video using computer
- Synthesizing Image is termed as Rendering Image

{ ① Rendering + ② Displaying



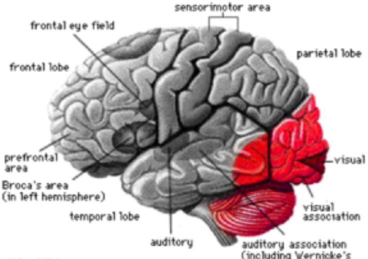
Why Computer Graphics?

Human → Eye, Nose, Ear, Skin, Tongue.

- About 30% of brain dedicated to visual processing.

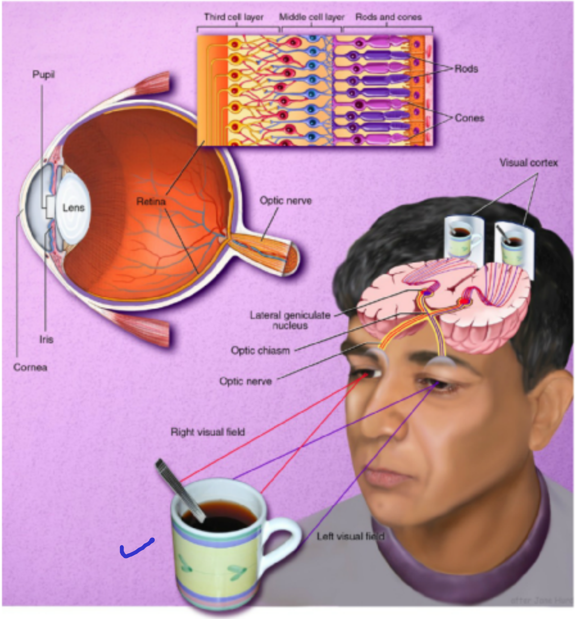
visual data.

- Eyes are highest-bandwidth port into the head!



(Allan Ajifo)

(Petar Milošević)

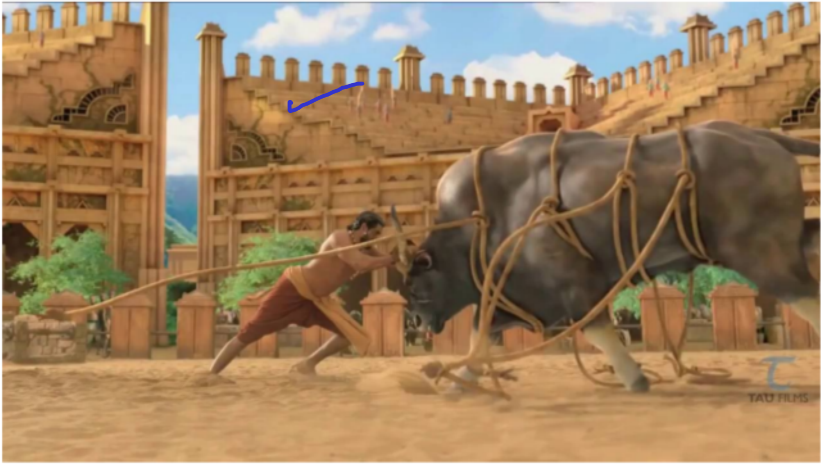


Third cell layer
Middle cell layer
Rods and cones
Rods
Cones
Pupil
Lens
Retina
Optic nerve
Visual cortex
Lateral geniculate nucleus
Optic chiasm
Optic nerve
Iris
Cornea
Right visual field
Left visual field

Why Computer Graphics? (cont.)

→ computer generated images.

- The CGI can cost from a fifth up to a half of the overall budget, that is to say between 40 and over 100 million dollars.



MOVIES

Figure 1: Robot 2.0 (2018)

MOVIES (cont.)

Figure 2: Avengers(2018)

MOVIES (cont.)

Figure 3: Avatar(2009)

Figure 4: Jurrasic Park(1993)

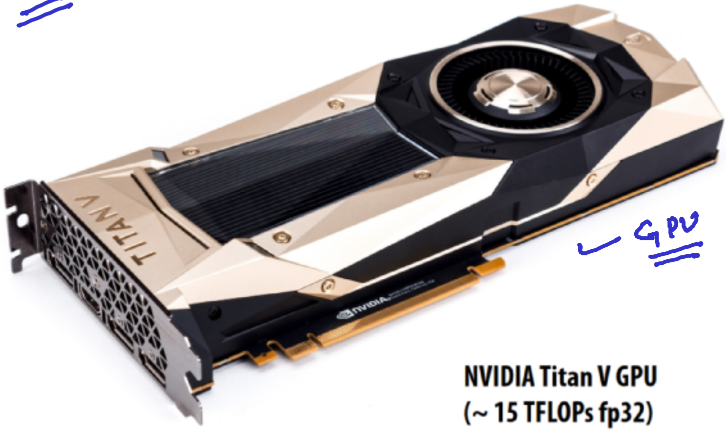
Games

Figure 5: PUBG

Games (cont.)

Figure 6: Call Of Duty

- For graphics intensive tasks such as video games and video editing, GPU is useful



GPU

NVIDIA Titan V GPU
(~ 15 TFLOPs fp32)

Augmented Reality

vs virtual Reality

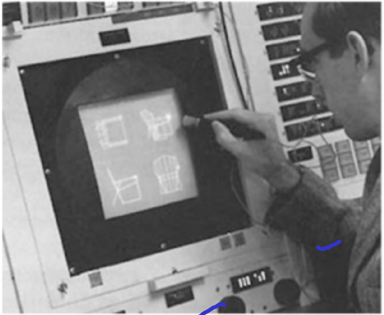
- AR superimposes a computer-generated image on a user's view of the real world, thus providing a composite view.
- By looking through the screens of mobile devices, such as smartphones and tablets, we can see things that are not really there.

Figure 7: Microsoft Hololens augmented reality headset concept

Virtual Reality

Digital Illustrations

Graphical User Interfaces



Ivan Sutherland, "Sketchpad" (1963)

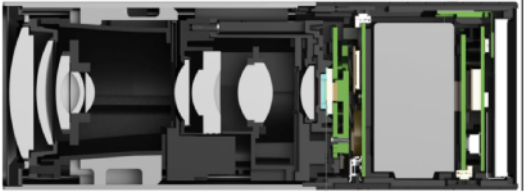
Doug Engelbart
Mouse

Modern graphical user interfaces

- 2D drawing and animation are ubiquitous in computing. Typography, icons, images, transitions, transparency, ... (all rendered at high frame rate for rich experience)

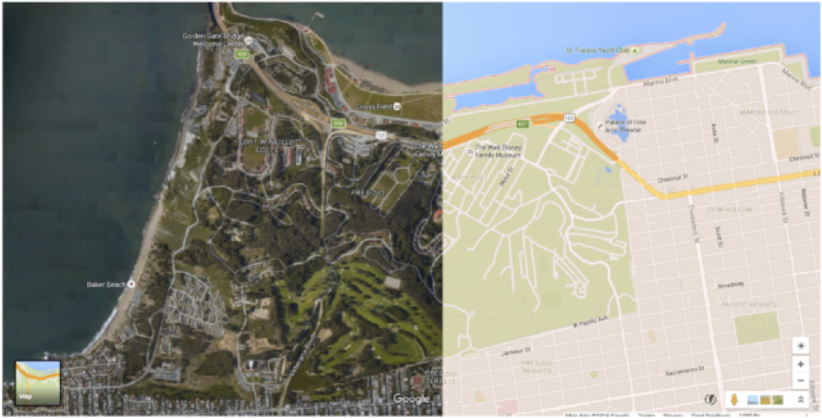
Computational cameras

- Panaromic stitching, HDR photos, light field cameras, ...



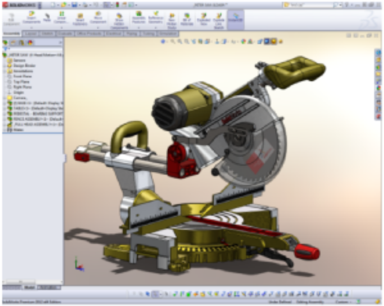
Imaging for mapping

- Maps, satellite imagery, street-level imaging,...

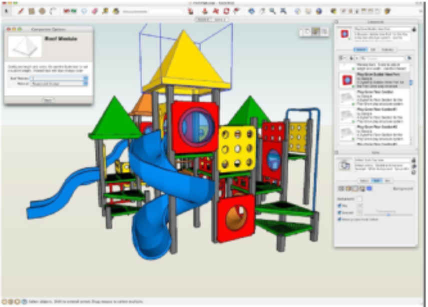


Computer aided design (CAD)

- For mechanical, architectural, electronic, optical, ...



SolidWorks



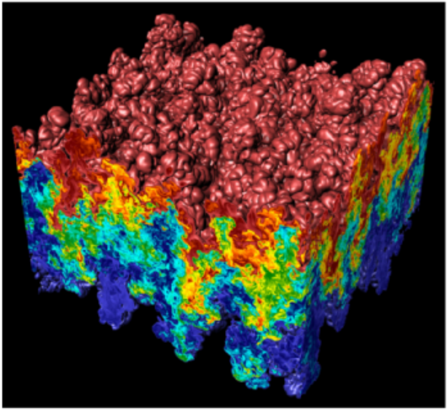
SketchUp

Architectural design

Figure 9: Bilbao Guggenheim, Frank Gehry

Visualization

- Science, engineering, medicine, journalism, ...



Simulation

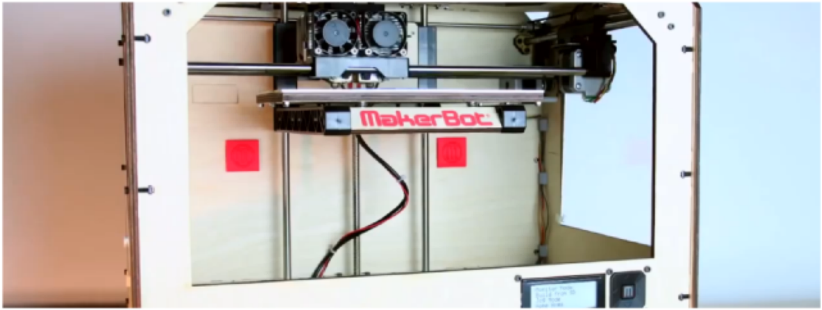
Driving simulator
Toyota Higashifuji Technical Center

da Vinci surgical robot
Intuitive Surgical

Simulation for training models

Figure 10: autonomous driving simulator

3D Fabrication



DeepFakes

- The porn industry replaces the faces in the porn videos by celebrity faces to have better business by using a software called DeepFakes which creates the fake face which are hard to differentiate.

(a)

(b)

Figure 11: Deepfakes examples

Generative Adverserial Networks

https://thispersondoesnotexist.com/

Foundations of Computer Graphics

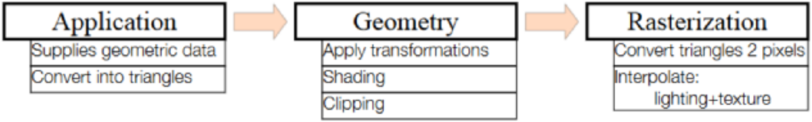
- All these applications demand sophisticated theory and systems
- Science and mathematics
  - Physics of light, color, optics
  - Math of curves, surfaces, geometry, perspective, ...
  - Sampling
- Systems
  - Parallel, heterogeneous processing
  - Graphics-specific programming systems
  - Input/output devices
- Art and psychology
  - Perception: color, stereo, motion, image quality, ...
  - Art and design: composition, form, lighting, ...

Computer Graphics vs DIP vs Computer Vision

- Digital Image Processing takes images as input and outputs processed image or feature/information in the image
- Computer Graphics deals with generating or synthesising images, but does not consider camera captured images
- Computer Vision deals with analyzing images to get information about the scene which was imaged.
  - Computer Vision is often seen as part of Image Processing (High level Image Processing)

Pipeline

- Geometry + Transformations
- Cameras and viewing
- Lighting and shading
- Rasterization
- Texturing



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?

Modeling the cube

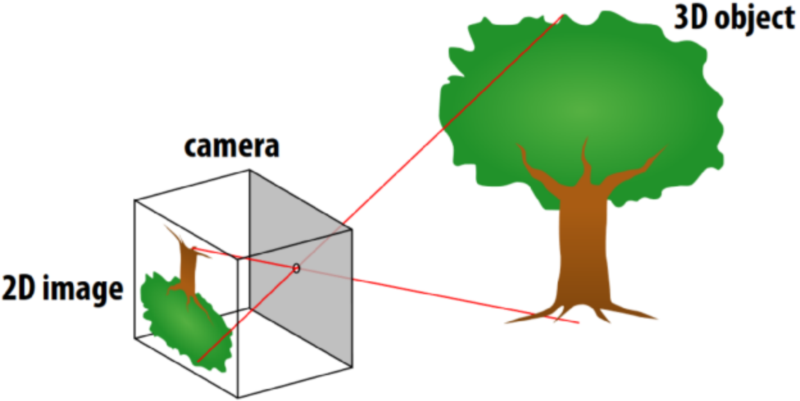
- Suppose our cube is...
  - centered at the origin (0,0,0)
  - has dimensions 2 x 2 x 2
- QUESTION: What are the coordinates of the cube vertices?
  A: (1, 1, 1) E: (1, 1,-1)
  B: (-1, 1, 1) F: (-1, 1,-1)
  C: (1,-1, 1) G: (1,-1,-1)
  D: (-1,-1, 1) H: (-1,-1,-1)
- QUESTION: What about the edges?
  AB, CD, EF, GH,
  AC, BD, EG, FH,
  AE, CG, BF, DH

Drawing the cube

- Now have a digital description 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)
  Edges
  AB, CD, EF, GH,
  AC, BD, EG, FH,
  AE, CG, BF, DH
- How do we draw this 3D cube as a 2D (flat) image?
- Basic strategy:
  1. Project 3D vertices to 2D points in the image
  2. Connect 2D points with straight lines

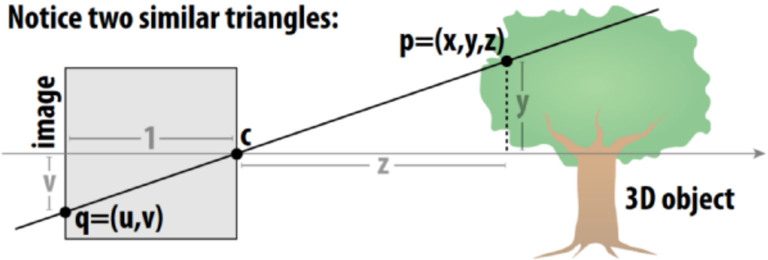
Perspective projection

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



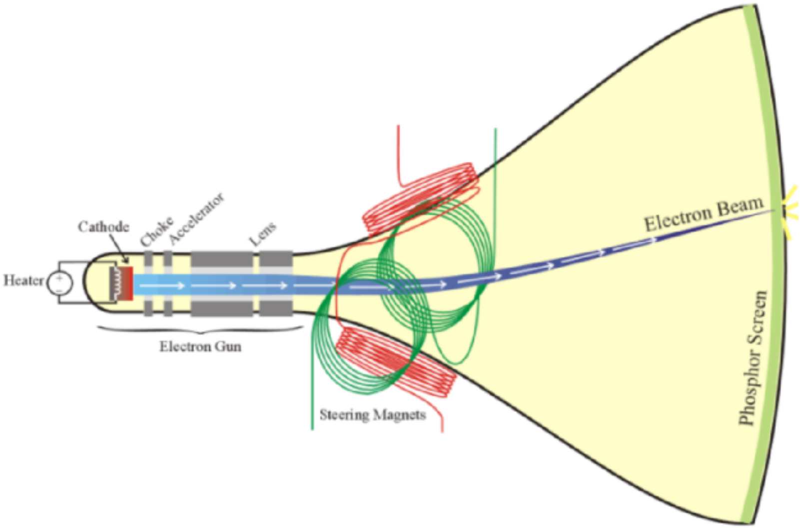
Perspective projection: side view

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



- Assume camera has unit size, coordinates relative to pinhole c
- Then $\frac{v}{1} = \frac{y}{z}$, similarly $u = \frac{x}{z}$

Displays: Cathod Ray Tube(CRT)

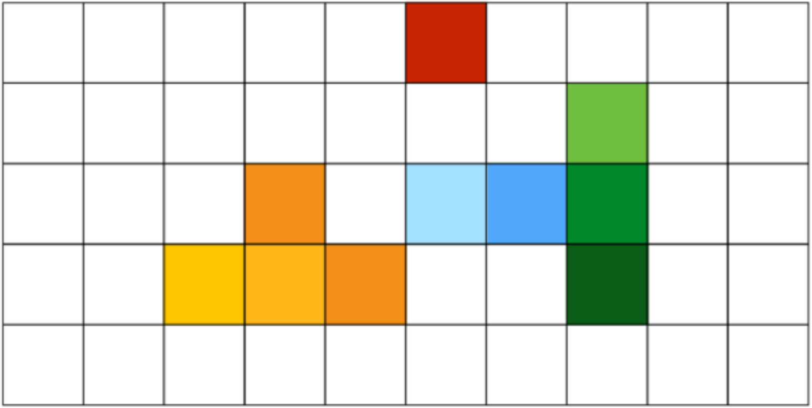


Frame buffer: memory for a raster display

image = "2D array of colors"

Output for a raster display

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



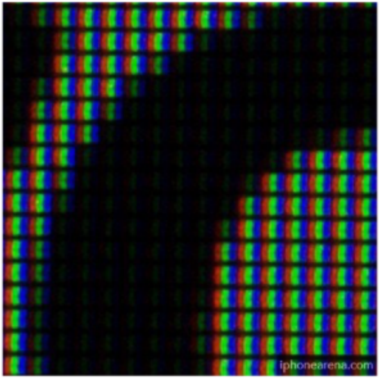
Flat panel displays

Low-Res LCD Display

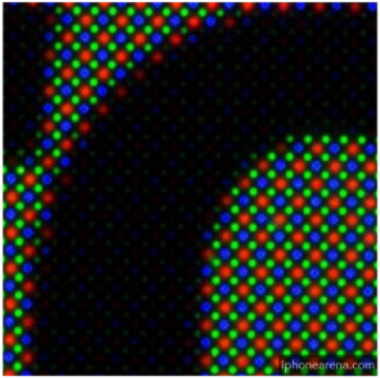
High resolution color LCD, OLED, ...

Close up photo of pixels on a modern display

LCD screen pixels (closeup)



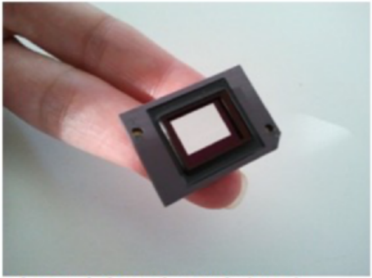
iPhone 6S



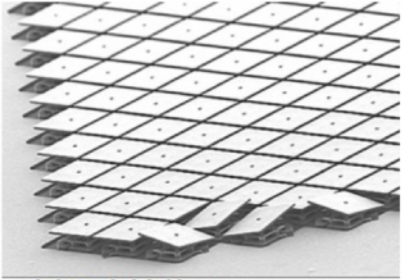
Galaxy S5

DMD projection display

- Array of micro-mirror pixels
- DMD = Digital micro-mirror device



DIGITAL MICRO MIRROR DEVICE **(DMD)**
(**SLM** - Spatial Light Modulator)

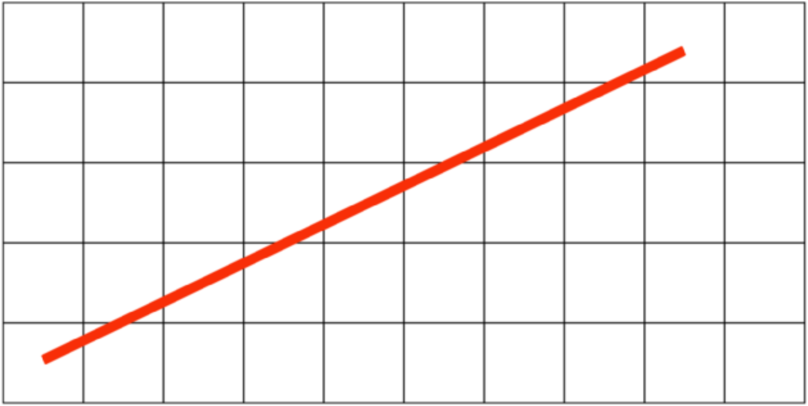


MICRO MIRRORS CLOSE UP

[Y.K. Rabinowitz; EKB Technologies

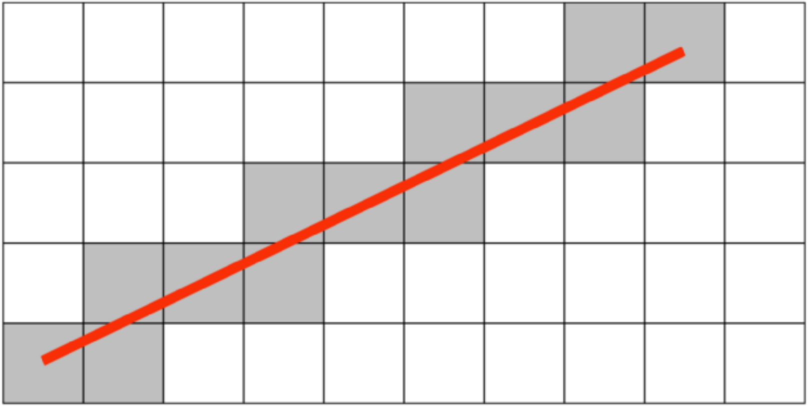
What pixels should we color in to depict a line?

- "Rasterization": process of converting a continuous object (a line, a polygon, etc.) to a discrete representation on a "raster" grid (pixel grid)



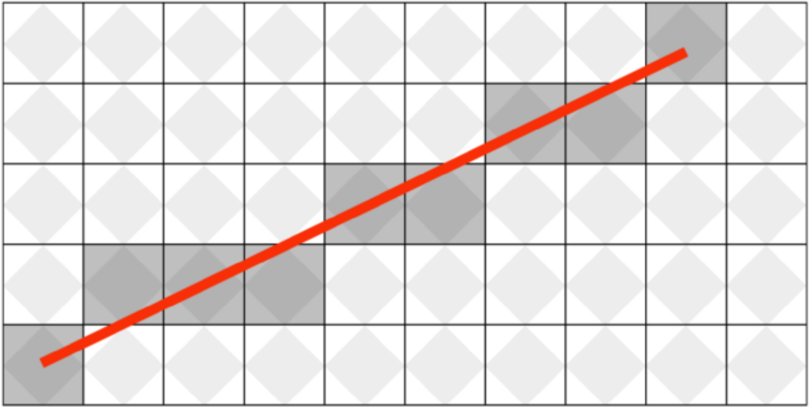
What pixels should we color in to depict a line? (cont.)

Light up all pixels intersected by the line?



What pixels should we color in to depict a line? (cont.)

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

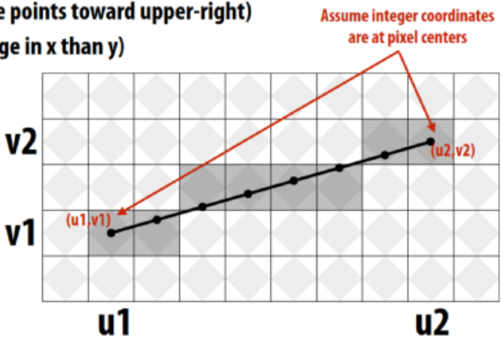


- Could check every single pixel in the image to see if it meets the condition...
  - $O(n^2)$ pixels in image vs. at most O(n) "lit up" pixels
  - must be able to do better! (e.g., seek algorithm that does work proportional to number of pixels in the drawing of the line)

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) )
}
```



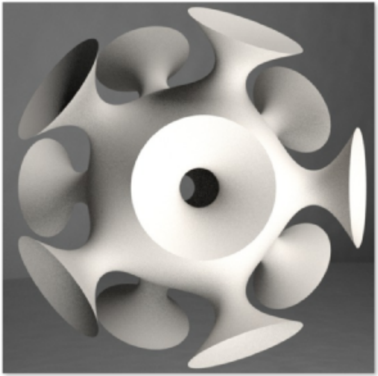
- Common optimization: rewrite algorithm to use only integer arithmetic (Bresenham algorithm)

Realistic rendering

- To render more realistic pictures (or animations) we need a much richer model of the world.
  - surfaces
  - motion
  - materials
  - lights
  - cameras

2D shapes

Complex 3D surfaces



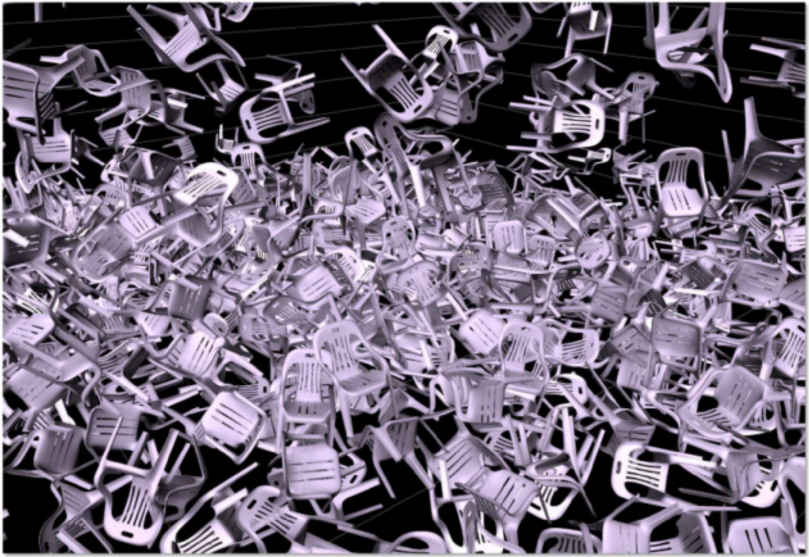
Platonic noid

Modeling material properties

Realistic lighting environments

Simulation of motion

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



History of Computer Graphics

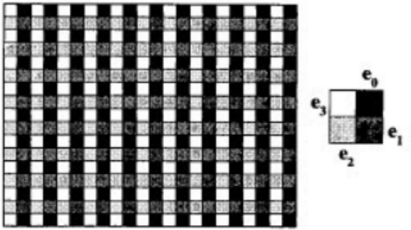
- Ivan Sutherland (1963) - SKETCHPAD
  - pop-up menus
  - constraint-based drawing
  - hierarchical modeling

Display hardware

- vector displays
  - 1963 – modified oscilloscope
  - 1974 – Evans and Sutherland Picture System
- raster displays
  - 1975 – Evans and Sutherland frame buffer
  - 1980s – cheap frame buffers bit-mapped personal computers
  - 1990s – liquid-crystal displays laptops
  - 2000s – micro-mirror projectors digital cinema
- other
  - stereo, head-mounted displays
  - autostereoscopic displays
  - tactile, haptic, sound

Input hardware

- 2D
  - light pen, tablet, mouse, joystick, track ball, touch panel, etc.
  - 1970s 80s - CCD analog image sensor + frame grabber
  - 1990s 2000's - CMOS digital sensor + in-camera processing
    - high-X imaging (dynamic range, resolution, depth of field,. . .)

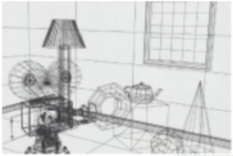


Input Hardware

- 3D
  - 3D trackers
  - multiple cameras
  - active rangefinders
- data gloves
- voice

Rendering

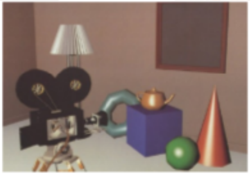
- 1960s - the visibility problem
  - Roberts (1963), Appel (1967) - hidden-line algorithms
  - Warnock (1969), Watkins (1970) - hidden-surface algorithms
  - Sutherland (1974) - visibility = sorting



Rendering (cont.)

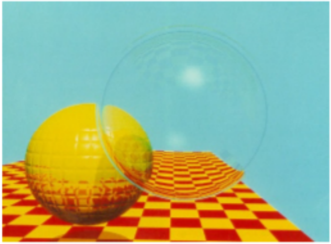
- 1970s - raster graphics
  - Gouraud (1971) - diffuse lighting
  - Phong (1974) - specular lighting
  - Blinn (1974) - curved surfaces, texture
  - Crow (1977) - anti-aliasing

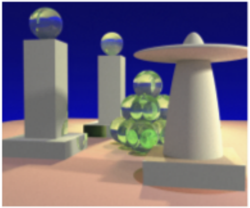




Rendering (cont.)

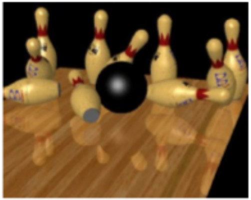
- early 1980s - global illumination
  - Whitted (1980) - ray tracing
  - Goral, Torrance et al. (1984), Cohen (1985) - radiosity
  - Kajiya (1986) - the rendering equation





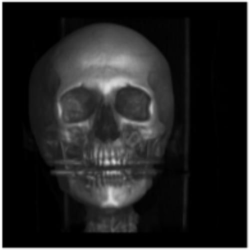
- late 1980s - photorealism
  - Cook (1984) - shade trees
  - Perlin (1985) - shading languages
  - Hanrahan and Lawson (1990) - RenderMan

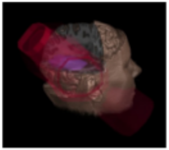


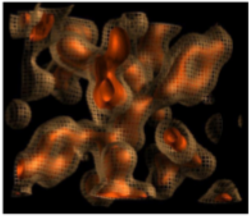


Rendering (cont.)

- early 1990s - non-photorealistic rendering
  - Drebin et al. (1988), Levoy (1988) - volume rendering
  - Haeberli (1990) - impressionistic paint programs
  - Salesin et al. (1994-) - automatic pen-and-ink illustration
  - Meier (1996) - painterly rendering







Computer Graphics 2010s

- CG has been nearly ubiquitous in video generation
- Pre-rendered graphics are nearly scientifically photorealistic
- Real-time graphics on a suitably high-end system may simulate photorealism to the untrained eye.
- Texture mapping has matured into a multistage process with many layers
- Experiments into the processing power required to provide graphics in real time at ultra-high-resolution modes like 4K Ultra HD are beginning.

2019 Turing Award for CG Pioneers

(a) Edwin E. Catmull(US – 2019), former president of Pixar and Disney Animation Studios For fundamental contributions to 3D computer graphics and the impact of computer-generated imagery (CGI) in filmmaking and other applications.

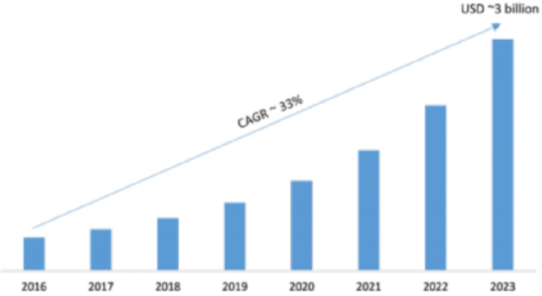
(b) Stanford computer scientist and engineer Patrick M. “Pat” Hanrahan is co-recipient of the 2019 Turing Award.

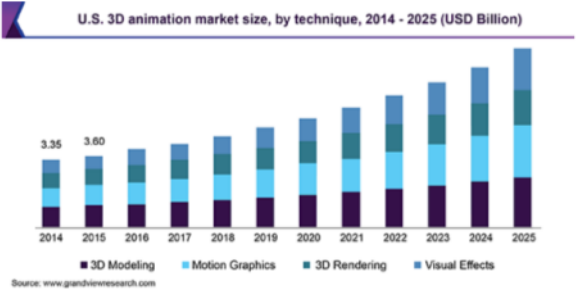
Computer Graphics in Industry

- Key players profiled in the global computer graphics market include
  - Advanced Micro Devices (AMD), Inc.
  - ARM Ltd.
  - Intel Corporation
  - Imagination Technologies Limited
  - Nvidia Corporation
  - Sony Corporation
  - Adobe Systems Ltd.
  - Siemens PLM Software
  - Autodesk Inc.
  - Microsoft Corporation
  - Dassault Systemes SA.

- Other significant players in the global computer graphics market include Matrox, Mentor Graphics, Inc., and 3D PLM-related software providers including, PTC, SAP PLM, and Oracle PLM
- The global computer graphics market is projected to reach the value of US $ 308.6 Bn by 2030.
- The computer graphics market is projected to expand at a CAGR of 6% from 2020 to 2030.

Computer Graphics in Industry (cont.)





Acknowledgements

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Thank You! :)