



CS334/ECE30834

Fundamentals of Computer Graphics

Fall 2023

Daniel G. Aliaga



Who am I?

- Daniel G. Aliaga

<http://www.cs.purdue.edu/~aliaga> and aliaga@cs.purdue.edu

Associate Professor of CS doing Graphics

Doctorate in Graphics

Master's in Graphics

Bachelors in Graphics

High School Degree doing graphics/robots/science

1980 ([TRS80 Model I](#))

Then: <http://www.youtube.com/watch?v=3yuqdC8ld48>)

<http://thinkingscifi.files.wordpress.com/2012/12/starwars-graphics.png>

Now: <http://www.youtube.com/watch?v=QAEkuVgt6Aw>

- CGVLAB

<http://www.cs.purdue.edu/cgvlab>

My Computer Graphics/Vision/Visualization Research



- Workforce:
 - Graduate students (25+ in CGVLAB)
 - Undergraduate students (0-3 per semester with me)
 - (will have at least 3 this semester)
 - Postdocs and Visiting Professors
- Funding:
 - NSF, MTC, IARPA, Internet2, Microsoft, Google, Adobe, (Intel), and others



- **Inverse Procedural Modeling**

- Facilitate semi-automatic and controllable content creation and edition of large and complex geometric models for use in digital simulation, visualization, entertainment, education, and cultural heritage by converting unstructured data into organized and easily editable procedural representations

- **Urban Modeling and Simulation**

- Collaborations with numerous experts in urban planning, atmospheric/geological sciences, civil engineering, architecture, hydrology, and transportation engineering to capture, simulate, and modify models of urban environments

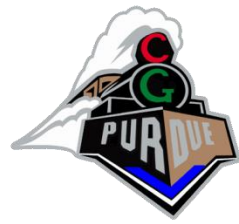
- **Imaging and Reconstruction**

- Develop multiple novel image processing and image-based 3D reconstruction methods



Course Mechanics

- CS334
 - <https://www.cs.purdue.edu/homes/aliaga/cs334-24fall/index.htm>
 - (see course summary + schedule)
- Brightspace
 - For assignments, etc.
- Piazza
 - For communication
- TAs (Ian, Yichen, Ashiqur) + instructor (Daniel)
 - For questions, grading, etc.
 - Office hours (LWSN 3130): Yichen: Tue 4-7pm, Ian: Thur 1:15-4:15pm, Ashiqur: Mon 10:30-12pm



Best way to contact me

- About class general tech questions: use Piazza
- About other stuff or me directly:
 - Email (yes, old fashioned)
 - Mandatory
 - Put CS334 in subject
 - Put CS334 in subject
 - Put CS334 in subject
 - Do NOT put “CS 334” in subject
 - Do NOT only put “Question” in subject, etc...



Exam Question

- Q#1: What must be in subject of an email to me?
 - Answer: CS334
- Q#2: If you want to schedule a meeting with me, what should be in the subject of the email to me?
 - Answer: CS334



Cellphones / Laptops

- NONE
- We are here not elsewhere...
- Unless, you are really really really taking notes



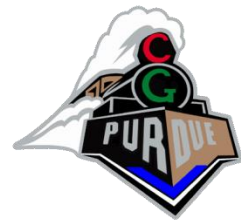
History of Computer Graphics

(some slides courtesy of Marc Levoy)



Early History

- **1940-1941:** first computer-generated image (MIT)
- **1950:** John Whitney Sr. computer assisted graphic artwork
- **1951: Vectorscope computer graphics display on the computer at MIT.**
- The General Motors Research Laboratory also begins the study of computer-aided graphical design applications.
- **1955:** Light pen by Bert Sutherland.
- **1956:** CRT graphics by Bertram Herzog .
- **1957:** IBM 740 created a sequence of points on a CRT
- **1958:** Steven Coons, Ivan Sutherland, and Timothy Johnson started working with the TX-2 computer system to manipulate the drawn pictures. Don Hart and Ed Jacks invented the first computer-aided drawing system at General Motors Research Laboratory and IBM.
- **1960: William Fetter** was first termed “Computer Graphics” for cockpit drawing.



Reprise: Graphics

- First graphics **visual** image:
 - Ben Laposky used an oscilloscope in 1950s

(note: one of my undergrad senior projects was an oscilloscope based graphics engine)



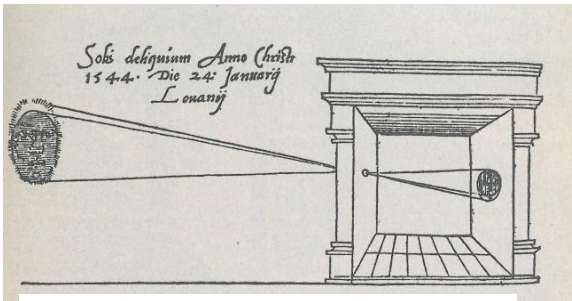
Whirlwind Computer @ MIT



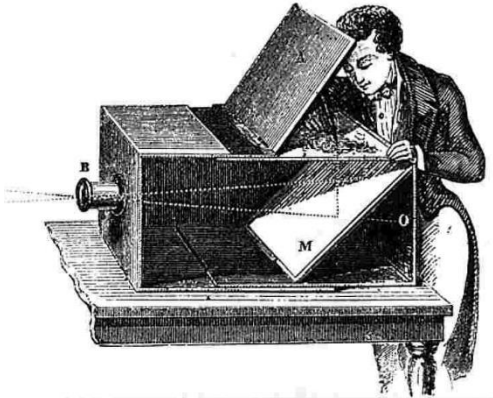
- Video display of real-time data (~1950s)



But “Images” Appeared With Camera too...



- “Camera obscura”: 1545



- “Camera obscura”: 18th century



- Earliest photograph: 1825

Fun History (1908)

ATRIPTHROUGH SEARS, ROEBUCK & CO'S BIG STORE



WOULD YOU LIKE TO SEE how enormous amount of business is handled every day by the nine thousand employees of our great institution? The fifty stereoscopic views we have prepared for this catalogue, and which you will find fully described on this page, are a wonderful revelation of the various methods by which we are able to promptly and accurately handle the orders we receive from nearly six million customers each year. These pictures tell the full story, and you can follow the order right through our house and know just exactly how it is handled by all of the clerks, order fillers, checkers, packers, etc. Every view has a complete description printed on the back with a fully descriptive list of the hundreds of employees shown in these pictures are doing, and the reason why they do it, and fully explains the manner in which it is done. Be sure to read this big list of subjects.

- No. 1. Mr. R. W. Sears seated at his desk.
- No. 2. General View of Our Great Buildings.
- No. 3. Main entrance, Merchandise Building.
- No. 4. Merchandise Building, Largest in the World.
- No. 5. Sunken Garden, Merchandise Building in distance.
- No. 6. Railroad Yards showing hundreds of cars.
- No. 7. Automatic Weighing Machines in Grocery Department.
- No. 8. Watchmaking in Jewelry Department.
- No. 9. Cutting Suits of Clothes by Electricity.
- No. 10. An Able in Tailor Machine Department.
- No. 11. Hair Goods are Packed for Shipment.
- No. 12. A Corner in our Mail Packing Section.
- No. 13. Loading Freight Trains in Class and Freight Train Shed.
- No. 14. Our Long Distance Telephone Switchboard.
- No. 15. Marvellous Automatic Telephone Switchboard.
- No. 16. Portion of Pneumatic Tube Station.
- No. 17. The Great Criminals' Mile Long.
- No. 18. Noon Time on the Street.
- No. 19. Mainframe Administration Building.
- No. 20. Another View of the Administration Building.
- No. 21. Grand Marble Entrance, Administration Building.
- No. 22. Handling Money by the Armfuls.
- No. 23. Preparing Records of our Customers' Orders.
- No. 24. How We Route our Shipments to Customers.
- No. 25. Writing Letters to Customers.
- No. 26. Typewriting Ten Thousand Letters per Day.



SOME VISITORS from foreign countries made a trip through our store the other day. They were shown through all of our great buildings. They saw how our orders were handled on a regular schedule so that nearly every order is shipped within twenty-four hours after it is received. They saw the printing of the great catalogue, where twenty large printing presses, like those used in producing the great magazines of the country, run day and night to supply the millions of catalogues that we send out each year. They saw the immense power house, with its capacity of twelve thousand horse power, with its gigantic dynamo, air compressors, pumps, etc. They saw our beautiful grounds with the Sunken Garden and Creek, LaSalle, and at last when they were leaving, they said, "It's simply wonderful. There is nothing like it in our country, and we never dreamed that such an immense institution as this existed in any part of the world. It is typical of everything American." These views will show you just exactly why they said that.

- No. 27. Keeping a Record of our Orders.
 - No. 28. Where the Money is Counted.
 - No. 29. Street scene at Closing Hour.
 - No. 30. Setting Type for the Great Catalogue.
 - No. 31. Marvellous Type-setting Machines.
 - No. 32. Making Printing Plates by Electricity.
 - No. 33. Sending 437,000 Miles of Paper through the Press.
 - No. 34. Busy Corner in the Press Room.
 - No. 35. A Machine that is almost Human.
 - No. 36. How the Big Catalogue is put together.
 - No. 37. Trimming 2,500 Sheets of Paper at One Stroke.
 - No. 38. Cleanest Boiler Room in the World.
 - No. 39. The Million Dollar Engine Room.
 - No. 40. Largest Switchboard in the World.
 - No. 41. One of our five Great Restaurants.
 - No. 42. Girls at Lunch in Cafeteria.
 - No. 43. Preparing Food for 10,000 Meals.
 - No. 44. Inside the Great Refrigerator.
 - No. 45. The Beautiful Sunken Garden in Summer.
 - No. 46. A Walk through the Garden.
 - No. 47. Green Percecia amid the Flowers.
 - No. 48. School where we Teach New Employees.
 - No. 49. Exciting Drill of our Fire Department.
 - No. 50. A Corner in our own Hospital.
- No. 20L25 10 50 Views, as above described, in miniature case. Price... 30c.**
Do not add postage extra, 12 cents.
No. 20L25 18 50 Views, same as above, but with our best, handwood stereoscope. Price... 45c.
Do not add postage extra, 12 cents.

No. 20L2750 New Comic Views. The funniest, most original and laugh provoking collection of stereoscopic pictures ever made.

No. 20L2751 Great Cities of America. Showing the beautiful parks, public buildings, and magnificent structures.

No. 20L2752 Picturesque America. Presenting the most interesting and beautiful portions of our great American Continent.

No. 20L2753 Yellowstone National Park, the wonderland of the world. Showing the boiling springs and the wonderful formations of this picturesque region.

No. 20L2754 Sportsman Adventures. Actual photographs of hunting and fishing scenes. These views bring back pleasant memories of the past and anticipate the delightful days to come.

No. 20L2755 Holy Land; through ancient Palestine. Showing the sacred localities of this land of Bible history.

No. 20L2756 Tours of Europe. The picturesque scenery of France, Germany and Holland; a wonderful collection of views.

Price on above views Nos. 20L2750 to 20L2764 inclusive, per dozen, all different... \$9.35
Per 100 assorted views... 100.00

GENUINE PHOTOGRAPHIC VIEWS

32c PER DOZEN FOR THESE PHOTOGRAPHIC VIEWS. These are genuine photographic views printed from negatives upon regular photographic paper, mounted on good cards and handled in the exact same quality sold by canvassers at \$1.00 per dozen.

EXTRA HIGH GRADE VIEWS, 48c PER DOZEN. The best photographic stereoscopic views that can be made, the exact same style sold everywhere by canvassers at \$2.00 per dozen. Every one of these views is made from an original retouched negative, printed on the finest quality of photographic paper, highly polished, and mounted on the best quality of card stock.

No. 20L2770 High Grade Comic Views. A superb collection of the most laugh provoking and comical scenes, all photographic direct from life.

No. 20L2771 Dimples of American Cities. Showing the public buildings, beautiful parks and magnificent palaces.

No. 20L2772 Picturesque Scenery of America. Illustrating the most beautiful and interesting portions of the United States.

No. 20L2773 Yellowstone National Park, the world's wonderland. Views of spouting geysers, boiling springs, and the strangest rock formations in the world.

No. 20L2774 Yosemite Valley. Showing the giant red wood trees, the Yosemite Falls, the Sentinels, and other natural beauties of this region.

No. 20L2775 Sportsman Series. Actual photographs of hunting and fishing adventures. They bring to mind pleasant days spent in the woods and every man's memories of long dead campfires.

Price on above views Nos. 20L2770 to 20L2782 inclusive, per dozen, all different... \$9.35
Per 100 assorted views... 100.00

No. 20L2776 Palestine. Showing the ancient cities and the sacred localities of the Holy Land.

No. 20L2777 Sweden and Norway. The picturesque beauty of this northern land where the sun illuminates the landscape at the midnight hour.

No. 20L2778 Travels across Europe. Showing the wonderful mountain scenery and picturesque landscape of the old world countries.

No. 20L2779 Ancient Egypt, Greece and Rome. Ruins of colossal statues, temples and monuments built centuries ago.

No. 20L2780 Oriental Realms. China and Japan, in the wealth and splendor of their oriental glory.

No. 20L2781 Jap-Russian War Views. Taken during the terrific conflict between the little brown men and the Russian Empire.

No. 20L2782 Miscellaneous Views. A superb collection of scientific, Mexican and many other lands. Price... \$9.35
Per 100 assorted views... 100.00

STANDARD HARDWOOD STEREOSCOPE.

24c

A GOOD STEREOSCOPE—EXTRA LARGE LENSES.

No. 20L2500 This Standard Hardwood Stereoscope is a well made and first class instrument in every respect. It is usually sold by other dealers at from 75c to \$1.00. The lenses are extra large, measuring 1 1/2-1 3/4 inches, and the frame is made from carefully selected hardwood, put together so as to prevent warping, and the hood is made of tripleply hardwood veneer, neatly varnished.

Price, each... \$0.24
Per dozen... 2.75
If by mail, postage extra, each, 10 cents.

A surprisingly good instrument for those who desire an inexpensive stereoscope.

SPECIAL ALUMINUM STEREOSCOPE.

36c

A BARGAIN IN ALUMINUM STEREOSCOPES.

No. 20L2502 This big value Aluminum Stereoscope thoroughly high grade instrument and is a universe of merit with canvas cover. The very low price is due to the fact that we have contracted for an enormous quantity of these goods, thus enabling the manufacturer to reduce his cost to the lowest possible figure. The lenses are of the clearest optical glass, made extra large, and mounted to the frame. The hood is made of aluminum, finished with dark red velvet. The frame is made of carefully selected hardwood, and fitted with patent folding handle.

Price, per dozen, \$4.25; each, 36c.
If by mail, postage extra, each, 10 cents.

IMPROVED ALUMINUM STEREOSCOPE.

49c

ALUMINUM LENS LOCKS—ENGRAVED HOOD.

No. 20L2503 This Elegant Frosted Aluminum Stereoscope is the finest stereoscope that can be produced. The beautiful frosted aluminum hood is richly engraved and bound with dark red velvet. The frame is made of cherry wood, varnished by hand, and provided with patent folding handle. The lenses are made from the finest quality of clear optical glass and are firmly held in place by the patent aluminum lens locks, which makes it impossible for them to ever get out of adjustment at any time.

Price, each... \$0.49
Per dozen... 5.64
If by mail, postage extra, each, 10 cents.



Ivan Sutherland (1963) - SKETCHPAD

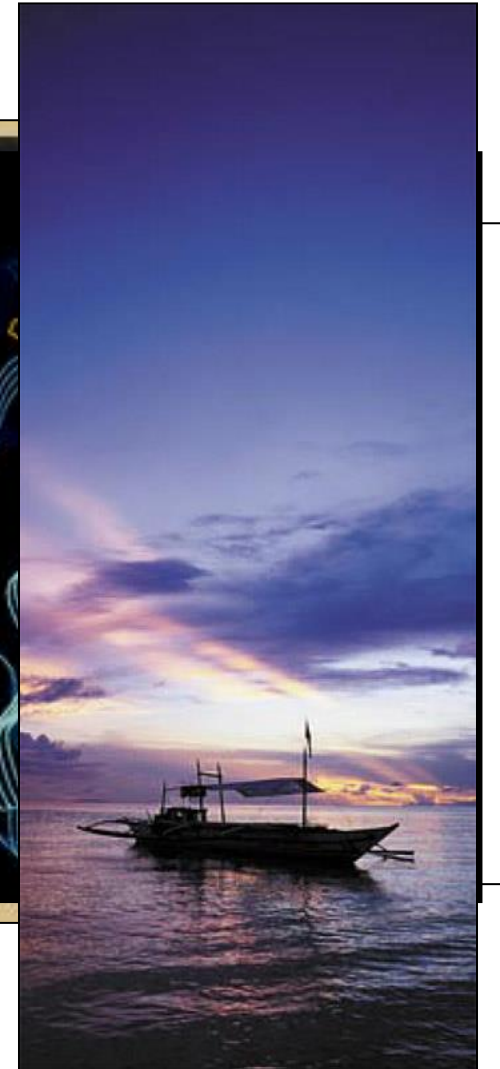
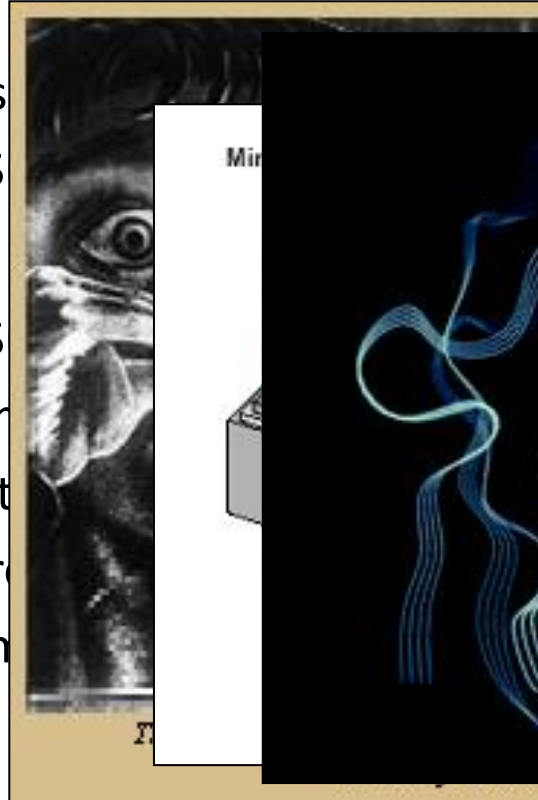


- pop-up menus
- constraint-based drawing
- hierarchical modeling



Display hardware

- vector displays
 - 1963 – modified oscilloscope
 - 1974 – Evans and Sutherland
- raster displays
 - 1975 – Evans and Sutherland
 - 1980s – cheap frame buffers
 - 1990s – liquid-crystal displays
 - 2000s – micro-mirrors
 - 2010s – high dynamic range
- other
 - stereo, head-mounted displays
 - autostereoscopic displays





Input hardware

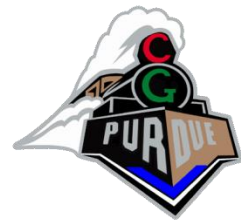
- 2D
 - light pen, tablet, mouse, joystick, track ball, touch panel, etc.
 - 1970s & 80s - CCD analog image sensor + frame grabber



Input hardware

- 2D

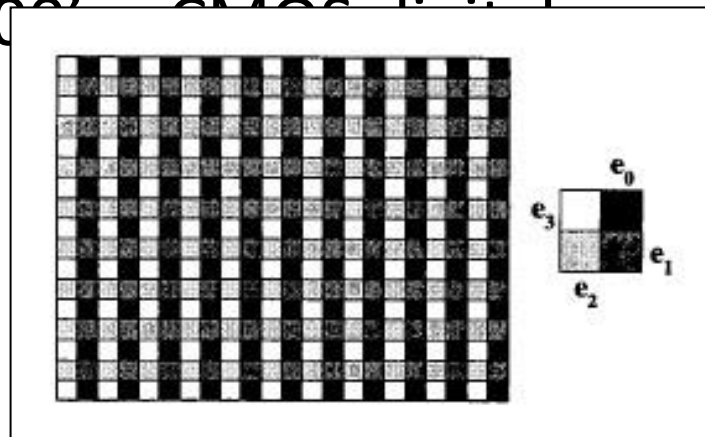




Input hardware

- 2D

- light pen, tablet, mouse, joystick, track ball, touch panel, etc.
- 1970s & 80s - CCD analog image sensor + frame grabber
- 1990s & 2000s - CMOS digital image sensor + in-camera processing

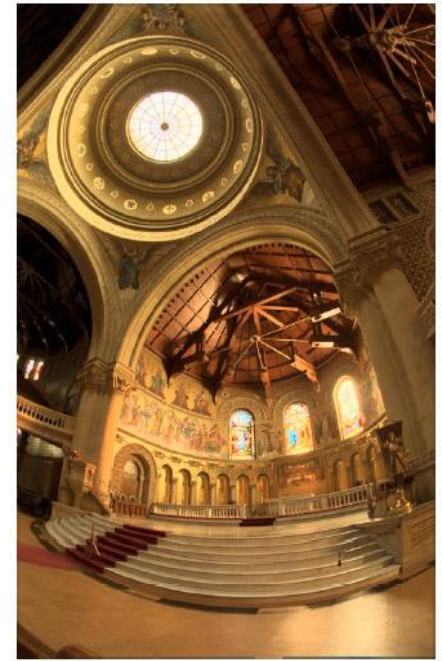


[Nayar00]

→ high-dynamic range (HDR) imaging



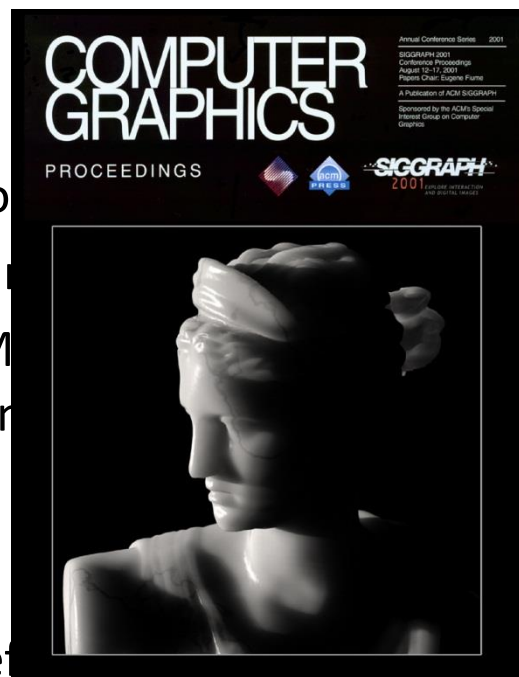
- negative film = 130:1 (7 stops)
- paper prints = 46:1
- [Debevec97] = 250,000:1 (18 stops)





Input hardware

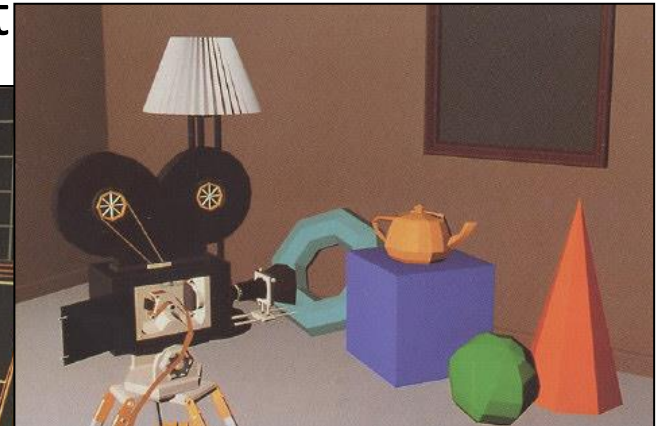
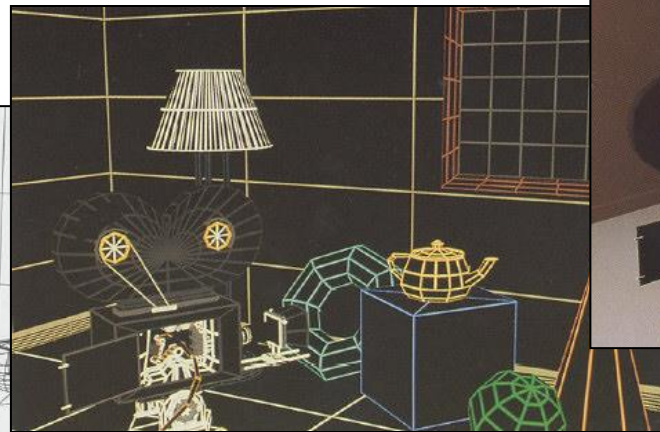
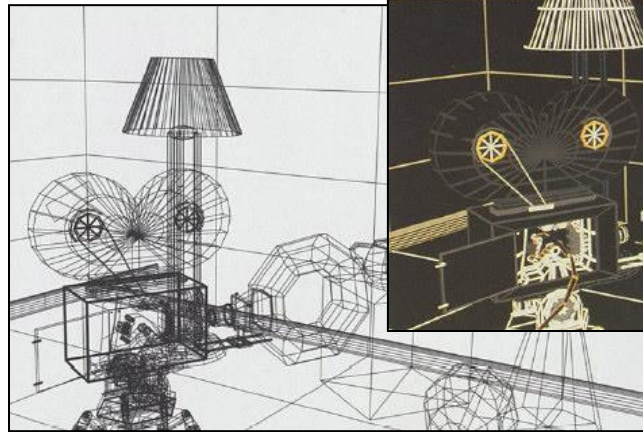
- 2D
 - light pen, tablet, mo
 - 1970s & 80s - CCD a
 - 1990s & 2000's - CM
 - high-dynamic ran
- 3D
 - 1980s - 3D trackers
 - 1990s - active range
- 4D and higher
 - multiple cameras
 - multi-arm gantries

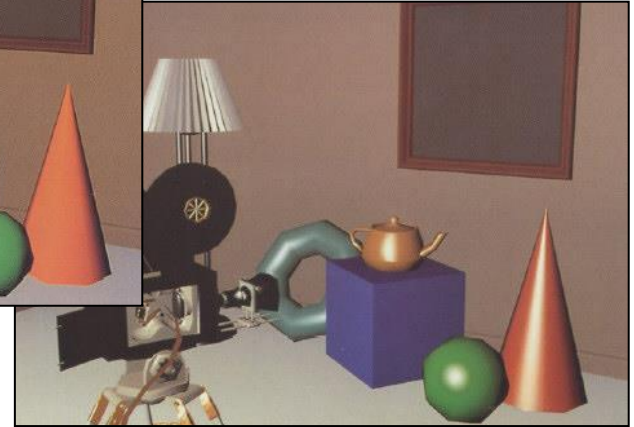
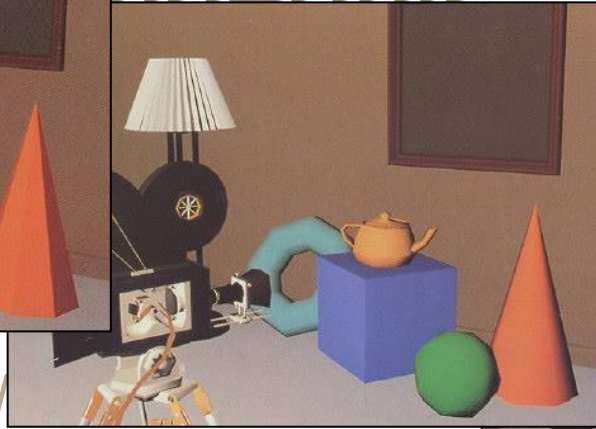
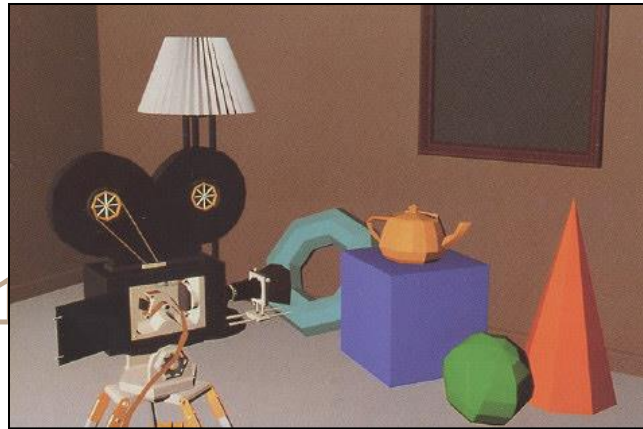




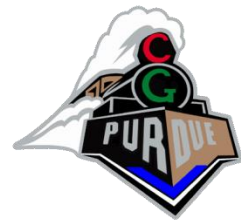
Rendering

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

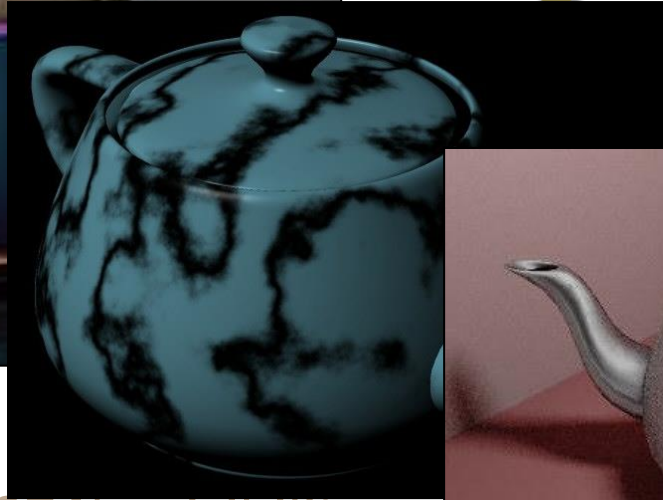




- - Warnock (1969), visibility algorithms
 - Sutherland (1974) - visibility = sorting
- 1970s - raster graphics
 - Gouraud (1971) - diffuse lighting
 - Phong (1974) - specular lighting
 - Blinn (1974) - curved surfaces, texture
 - Crow (1977) - anti-aliasing



ering



algorithms

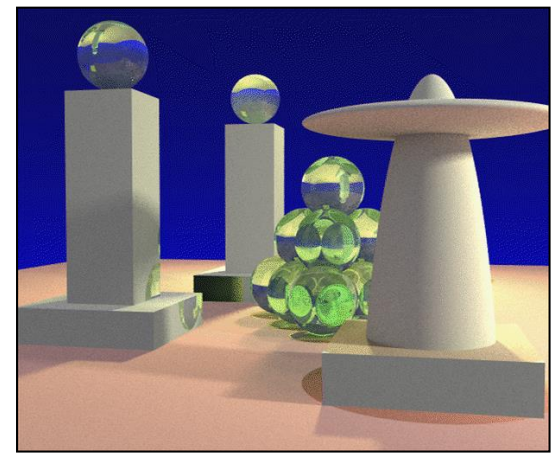
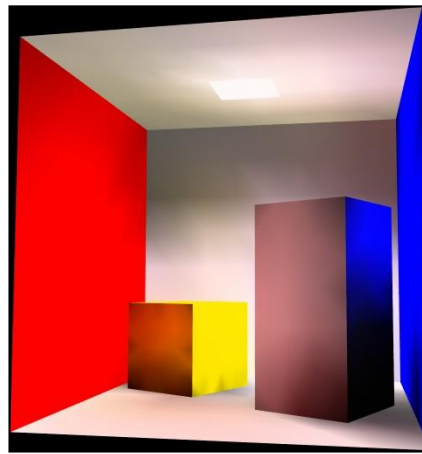
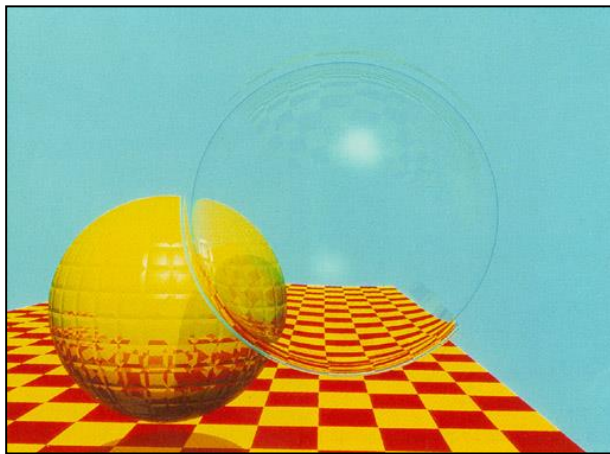
– Sutherland (1974) - visibility = s

- 1970s - raster graphics
 - Gouraud (1971) - diffuse lighting
 - Phong (1974) - specular lighting
 - Blinn (1974) - curved surfaces, texture
 - Catmull (1974) - Z-buffer hidden-surface algorithm
 - Crow (1977) - anti-aliasing

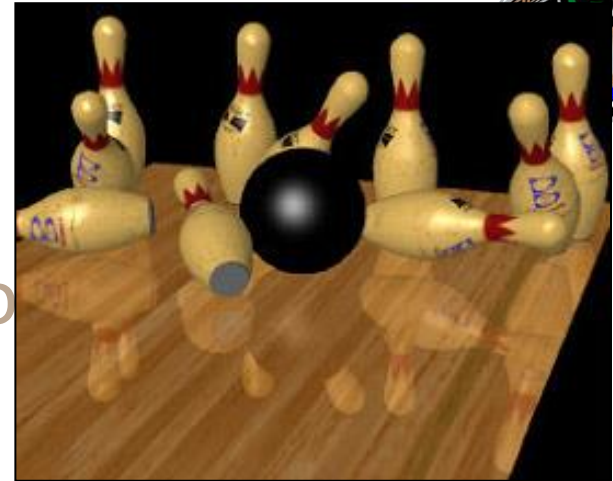


Rendering

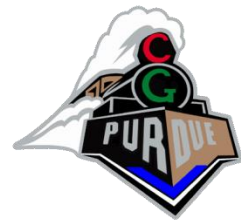
- early 1980s - global illumination
 - Whitted (1980) - ray tracing
 - Goral, Torrance et al. (1984), Cohen (1985) - radiosity
 - Kajiya (1986) - the rendering equation



→ shaders

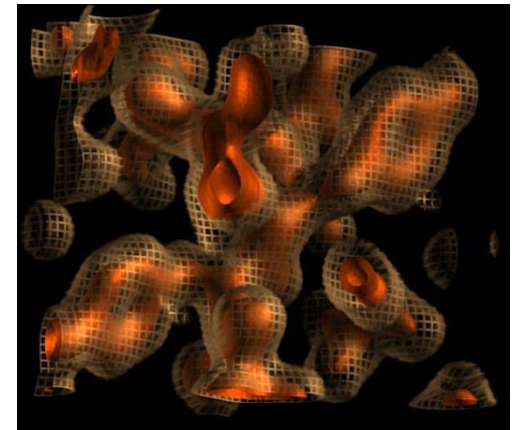
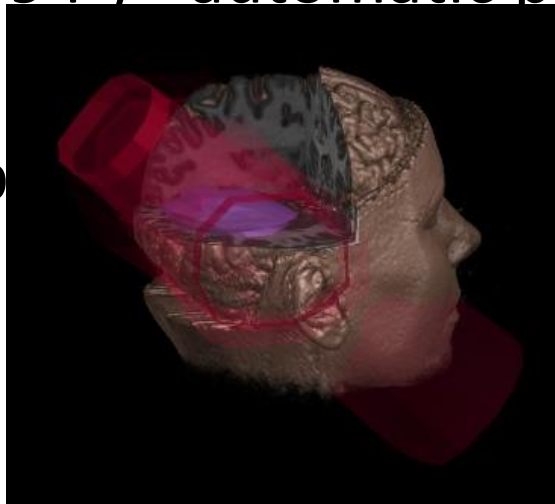
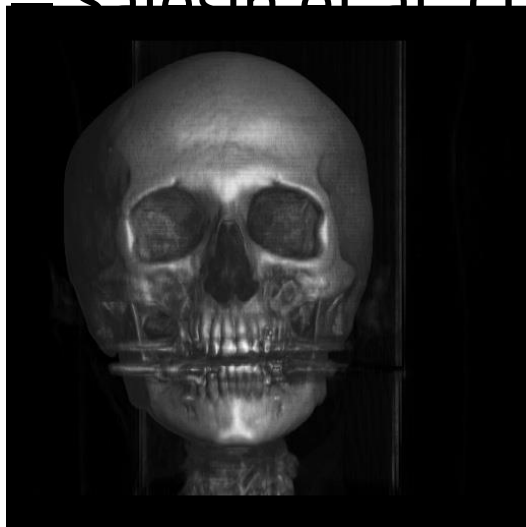


- e - b o
 - Goral, Torrance and Whitted (1984) - radiosity
 - Kajiya (1986) - the rendering equation
- late 1980s - photorealism
 - Cook (1984) - shade trees
 - Perlin (1985) - shading languages
 - Hanrahan and Lawson (1990) - RenderMan



Rendering

- 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





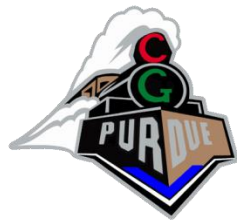
Rendering

- early 1990s - non-photorealistic rendering
 - Drebin et al. (1988), Levoy (1988) - volume rendering
 - Haeberli (1990) - impressionistic paint programs
 - Salesin et al. (1994-) - automatic





Sampling of Computer Graphics Today



Faces a while ago...

- <https://www.youtube.com/watch?v=-CbyAk3Sn9I>



Faces no too long ago...

- <https://www.youtube.com/watch?v=Qevnfvplbpw>



Faces today!

- <https://thispersondoesnotexist.com/>
- (courtesy of Deep Learning & NVIDIA)



Even Presidents!

- <https://www.youtube.com/watch?v=Jd38tSubiR4>



Mona Lisa

- <https://www.youtube.com/watch?v=Uun5B1hHmds>



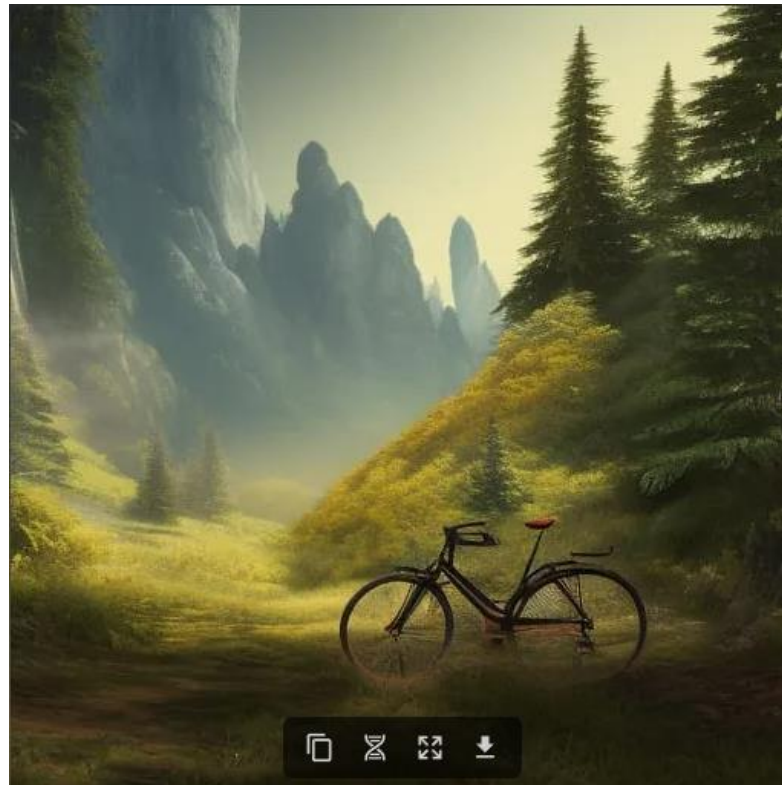
Games, of course

- <https://www.youtube.com/watch?v=6kqe2ICmTxc>

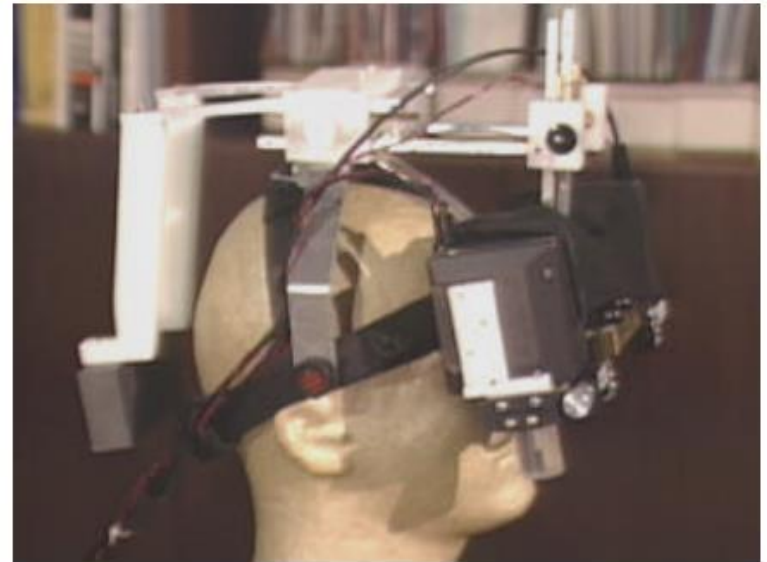


AI Based

- Diffusion based generation (creator.nightcafe.studio)
- I wrote “Mountain with trees and a bicycle”
- I got:



Augmented Reality



Augmented Reality



Microsoft
HoloLens

SLASH GEAR Windows 10



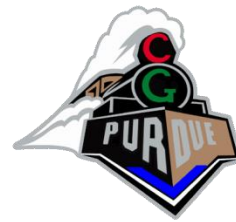
Virtual Reality





3D Displays

- Simple
 - <https://www.youtube.com/watch?v=bBQQEcfkHoE>



3D Displays

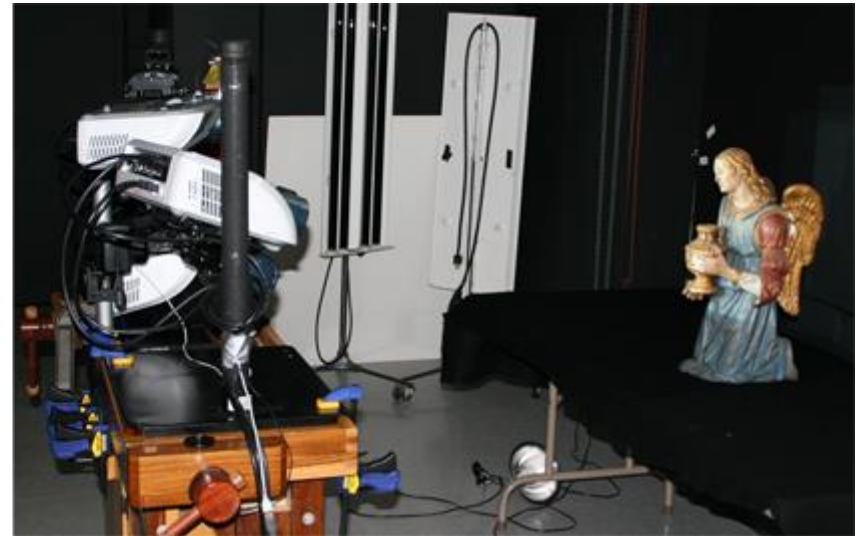
- Complex

- <https://www.youtube.com/watch?v=YKCUGQ-u08c>

- <https://www.youtube.com/watch?v=CfHw8NA75Xc>

(careful with Hollywood tricks...)

Projection Based Displays



Projection Based Displays



Dynamic Projection Based Displays



- <https://www.youtube.com/watch?v=Ki8UXSJmrJE>
- <https://www.youtube.com/watch?v=j9JXtTj0mzE>



And More!

- <https://www.nvidia.com/en-us/research/ai-playground/>



Books for your enjoyment

(I have a copy of these books if you wish to preview)

- “Interactive Computer Graphics”
 - Angel and Shreiner, pub: Addison Wesley
- “3D Computer Graphics”
 - Watt, pub: Addison Wesley
- “Real-time Rendering”
 - Moller and Haines, pub: AK Peters
- “3D Game Engine Design”
 - Eberly, pub: Morgan Kaufmann
- “Level of Detail for 3D Graphics”
 - Luebke, Reddy, Cohen, Varshney, Watson, and Huebner, pub: Morgan Kaufmann
- **“Computer Graphics: Principles and Practice, 3rd edition**
 - Hughes, van Dam, McGuire, Sklar, Foley, Feiner, and Akeley