Computer Graphics

Lecture - 02

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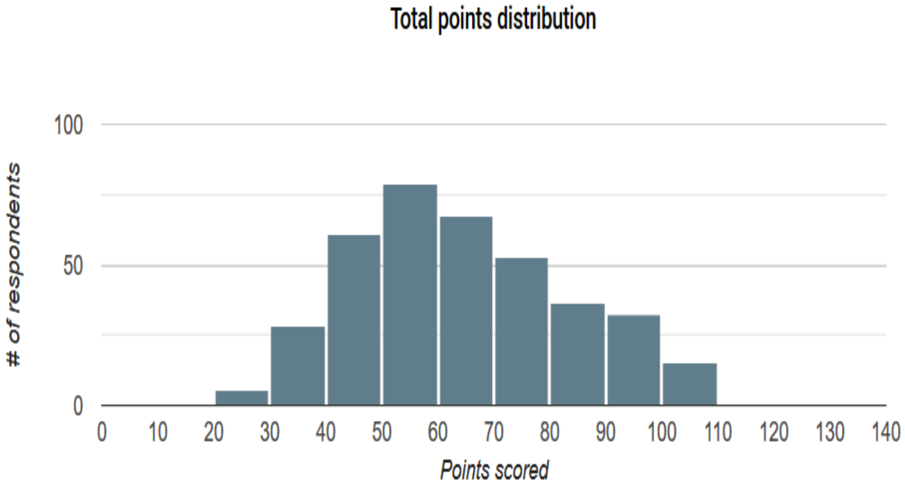
Average	Median	Range
63.54 / 130 points	62 / 130 points	27 - 108 points



Computer Graphics

Interactive Computer Graphics

Enabling Modern Computer Graphics

- Hardware Revolution
  - GPU
  - Processor
- Graphic Subsystems
- Input Devices
- Software Improvements

Rendering

- Rendering Methods
  - Wire-frame Model
  - Polygonal Modeling
  - Scanline Rendering
  - Rasterization
  - Ray Tracing

Computer Graphics - 01

- Computer graphics, or CG as it is often simply called, is the use of computers to generate images.
- This is as opposed to the capture of images from the real-world with, say, a camera, or the realization by hand of an artist's imagination on a drawing medium.
- Computer graphics generally means creation, storage and manipulation of models and images
- Such models come from diverse and expanding set of fields including physical, mathematical, artistic, biological, and even conceptual (abstract) structures

Computer Graphics - 02

- William Fetter coined term "computer graphics" in 1960 to describe new design methods he was pursuing at Boeing, as presented in 1 at page 5
- Created a series of widely reproduced images on "pen plotter" exploring cockpit design, using 3D model of human body.

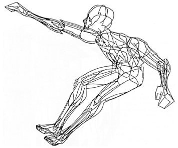


Figure: Boeing Computer Graphics Models and Simulation

Computer Graphics - 03

- "Perhaps the best way to define computer graphics is to find out what it is not. It is not a machine. It is not a computer, nor a group of computer programs. It is not the know-how of a graphic designer, a programmer, a writer, a motion picture specialist, or a reproduction specialist. Computer graphics is all these – a consciously managed and documented technology directed toward communicating information accurately and descriptively." Computer Graphics, by William A. Fetter, 1966

Interactive Computer Graphics - 01

- User controls content, structure, and appearance of objects and their displayed images via rapid visual feedback
- Basic components of an interactive graphics system
  - input (e.g., mouse, tablet and stylus, multi-touch...)
  - processing (and storage)
  - display/output (e.g., screen, paper-based printer, video recorder...)

Interactive Computer Graphics - 02

- First truly interactive graphics system, **Sketchpad** presented in 2 at page 12, pioneered at MIT by Ivan Sutherland for his 1963 Ph.D. thesis
- Used TX-2 transistorized "mainframe" at Lincoln Lab

- Almost all key elements of interactive graphics system are expressed in first paragraph of Sutherland's 1963 Ph.D. thesis, Sketchpad, A Man-Machine Graphical Communication System:

- The Sketchpad system uses drawing as a novel communication medium for a computer. The system contains input, output, and computation programs which enable it to interpret information drawn directly on a computer display. Sketchpad has shown the most usefulness as an aid to the understanding of processes, such as the motion of linkages, which can be described with pictures. Sketchpad also makes it easy to draw highly repetitive or highly accurate drawings and to change drawings previously drawn with it. . .


PRODUCTION
DIRECTOR
CAMERA

- Today, we still use non-interactive batch mode for final production-quality video and film (special effects – FX). Rendering a single frame of Cars 2 (a 24 fps movie) averaged 11.5 hours on a 12,500-core render farm!

Figure: Render Farm

Enabling Modern Computer Graphics - 01

1. **Hardware revolution**
   - Moore's Law: every 12-18 months, computer power improves by factor of 2 in price / performance as feature size shrinks
   - Significant advances in commodity graphics chips every 6 months vs. several years for general purpose CPUs
     - For more information on NVIDIA GeForce Desktop GPUs `https://www.geforce.com/hardware/desktop-gpus`


PRODUCTION
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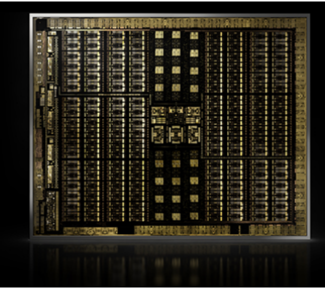
NVIDIA TURING

GeForce RTX™ graphics cards are powered by the Turing GPU architecture and the all-new RTX platform. This gives you up to 6X the performance of previous-generation graphics cards and brings the power of real-time ray tracing and AI to games.

UP TO
6X
FASTER PERFORMANCE

REAL-TIME
RAY TRACING
IN GAMES

POWERFUL
AI
ENHANCED GRAPHICS



Enabling Modern Computer Graphics - 02

- Newest processors are 64-bit, 2, 4, 6, 8, or 10 core
  - Intel Core i7 – consumer, up to 6 cores hyper-threaded to provide 12 threads
  - Intel Sandy Bridge EP– industrial, 8 cores HT, 16 threads

Enabling Modern Computer Graphics - 03

2. **Graphic subsystems**
   - Offloads graphics processing from CPU to chip designed for doing graphics operations quickly
   - nVidia GeForce™, ATI Radeon™
   - GPUs used for special purpose computation, also bunched together to make supercomputers
   - GPU has led to development of other dedicated subsystems
     - Physics: nVidia PhysX PPU (Physics Processing Unit), standard on many NVIDIA GPUs
   - Hardware show and tell: Dept's new NVIDIA GeForce GTX 460s
     - 1.35 GHz clock, 1GB memory, 37.8 billion pixels/second fill rate
     - Old cards: GeForce 7300 GT: 350 MHz clock, 256 MB memory, 2.8 billion fill rate

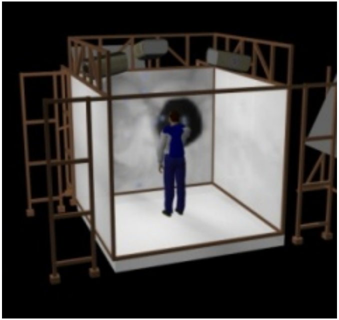
Enabling Modern Computer Graphics - 04

3. **Input Devices**
   - Mouse, tablet & stylus, multi-touch, force feedback, and other game controllers (e.g., Wii), scanner, digital camera (images, computer vision), etc.
   - Whole body as interaction device: `http://www.xbox.com/kinect`
   - Many form factors
     - Cell Phones/PDAs (smartphones), laptop/desktops/tablets,
     - Microsoft PPI display


PERCEPTIVE PIXEL

Brown's Old Cave

- 3D immersive virtual reality systems such as Brown's new Cave being built at 180 George Street
- Old Cave - as presented in 3 at page 20:
  - 4 1024 x 786 projectors on 8' x 8' walls (8-10 pixels per inch)
  - Too low resolution and brightness for many applications, and got worse (brightness, contrast deteriorated over time)



Brown's New Cave

- New Cave as planned - as presented in 4 at page 21:
  - 69 projectors onto cylindrically curved screen 8' radius
  - 140 million pixels
  - Powered by a 69 gpu cluster
  - No right angles, up to 40 pixels per inch (can't see individual pixels at normal viewing distance)

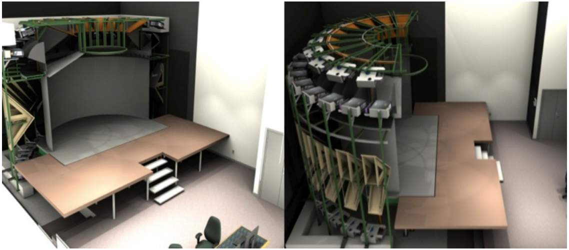


Figure: Brown's New Cave

Enabling Modern Computer Graphics - 05

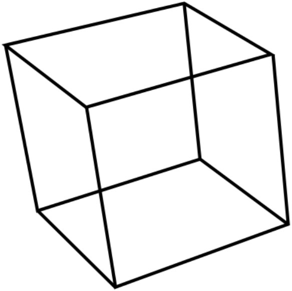
4. **Software Improvements**
   - Algorithms and data structures
     - Modeling of materials
     - Rendering of natural phenomena
     - “Acceleration data structures” for ray tracing
   - Parallelization
     - Most operations are embarrassingly parallel: changing value of one pixel is often independent of other pixels
   - Distributed and Cloud computing
     - Send operations into ‘cloud’, get back results, don’t care how
     - Rendering even available as internet service!

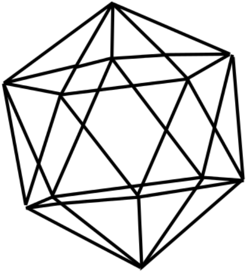
Rendering

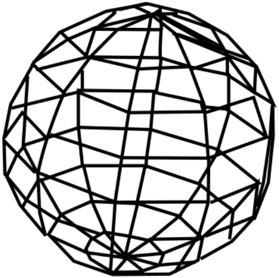
- **Rendering** converts a model into an image either by simulating light transport to get photo-realistic images, or by applying an art style as in non-photorealistic rendering.
- The two basic operations in realistic rendering are
  - transport (how much light gets from one place to another)
  - scattering (how surfaces interact with light)
- This step is usually performed using 3D computer graphics software or a 3D graphics API.
- Altering the scene into a suitable form for rendering also involves **3D projection**, which displays a three-dimensional image in two dimensions.

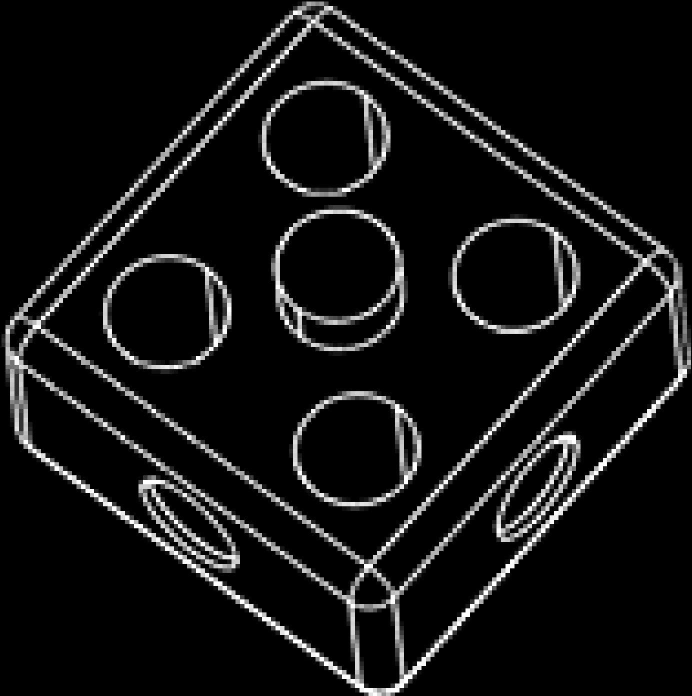
Wire-frame Model

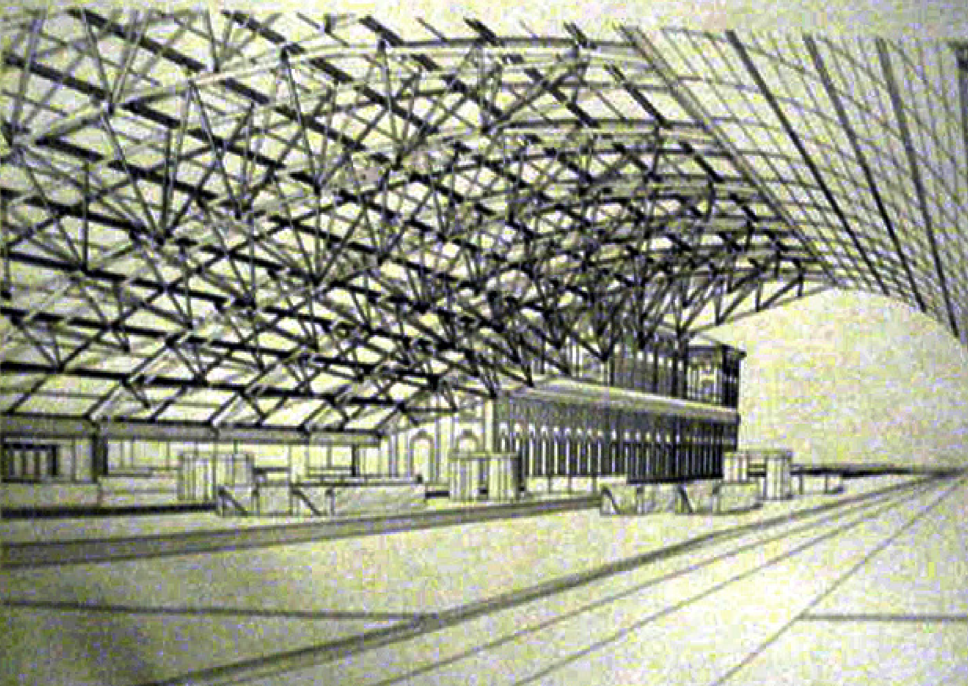
- A wire-frame model is a visual presentation of a 3-dimensional (3D) or physical object used in 3D computer graphics.
- It is created by specifying each edge of the physical object where two mathematically continuous smooth surfaces meet, or by connecting an object's constituent vertices using straight lines or curves.
- The object is projected into screen space by drawing lines at the location of each edge.
- The term wire frame comes from designers using metal wire to represent the three-dimensional shape of solid objects.











Copertura - stazione Trastevere - Prospettiva Wireframe Hasan Isawi 2005

Basic Idea and Example

- Wireframing is one of the methods used in geometric modelling systems. A wireframe model represents the shape of a solid object with its characteristic lines and points.
- An object is specified by two tables: (1) Vertex Table, and, (2) Edge Table.
- Vertex: In geometry, Point where two or more curves or lines or edges meet
- Edge: In geometry, an edge is a particular type of line segment joining two vertices in a polygon.

Vertex Table

The vertex table consists of three-dimensional coordinate values for each vertex with reference to the origin.

Vertex	X	Y	Z
1	1	1	1
2	1	-1	1
3	-1	-1	1
4	-1	1	1
5	1	1	-1
6	1	-1	-1
7	-1	-1	-1
8	-1	1	-1

Edge Table

Edge table specifies the start and end vertices for each edge.

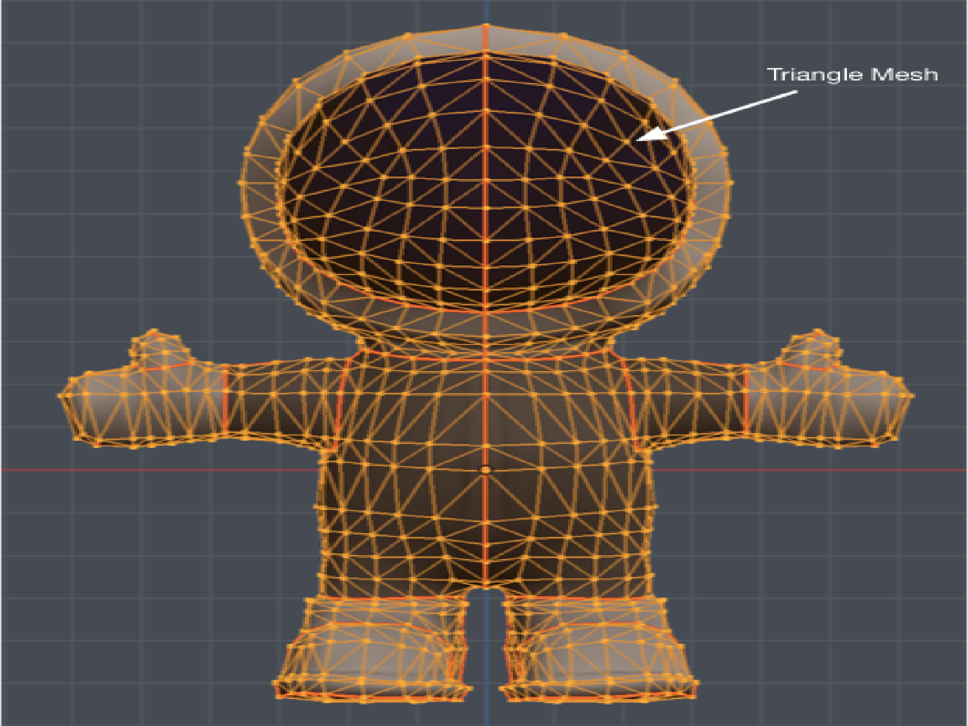
Edge	Start Vertex	End Vertex
1	1	2
2	2	3
3	3	4
4	4	1
5	5	6
6	6	7
7	7	8
8	8	5
9	1	5
10	2	6
11	3	7
12	4	8

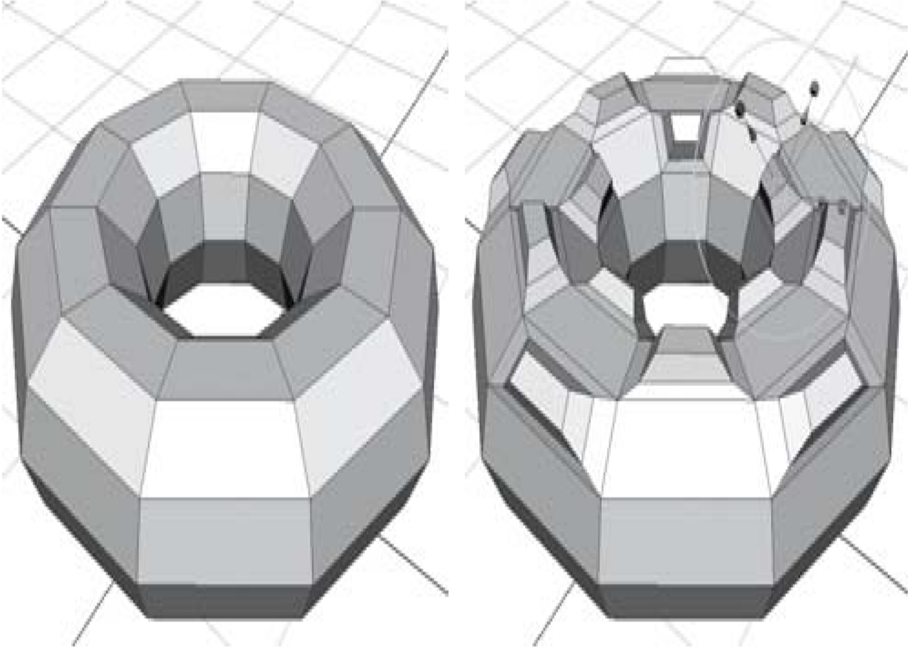
Wireframe

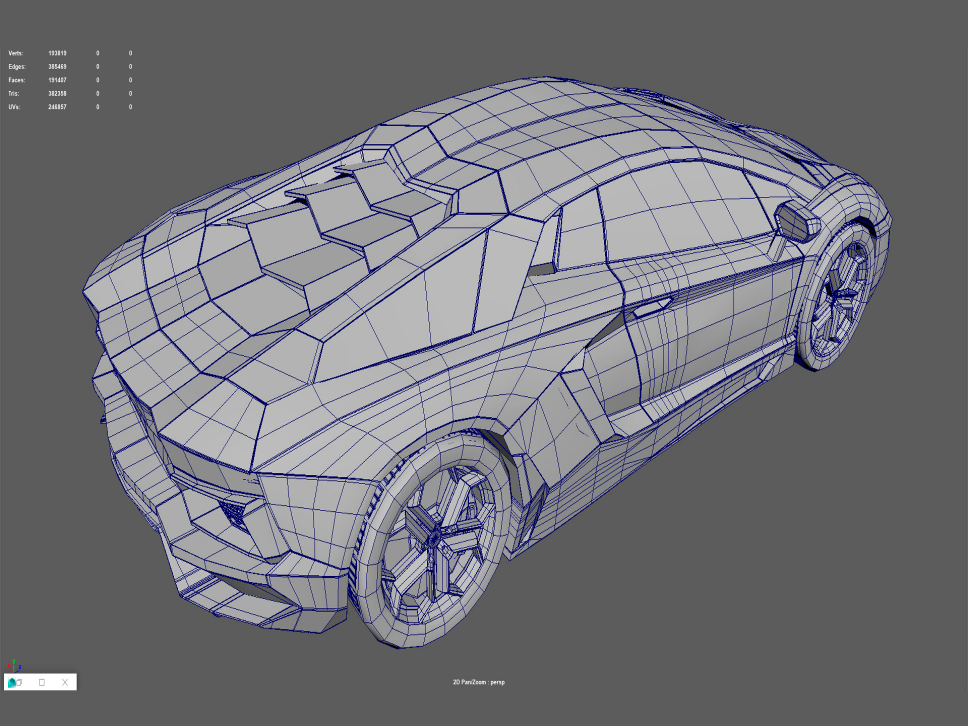
- A naive interpretation could create a wire-frame representation by simply drawing straight lines between the screen coordinates of the appropriate vertices using the edge list.
- Unlike representations designed for more detailed rendering, face information is not specified (it must be calculated if required for solid rendering).
- Appropriate calculations have to be performed to transform the 3D coordinates of the vertices into 2D screen coordinates.

Polygonal Modeling

- In 3D computer graphics, Polygonal modeling is an approach for modeling objects by representing or approximating their surfaces using polygons.
- Polygonal modeling is well suited to scanline rendering and is therefore the method of choice for real-time computer graphics.

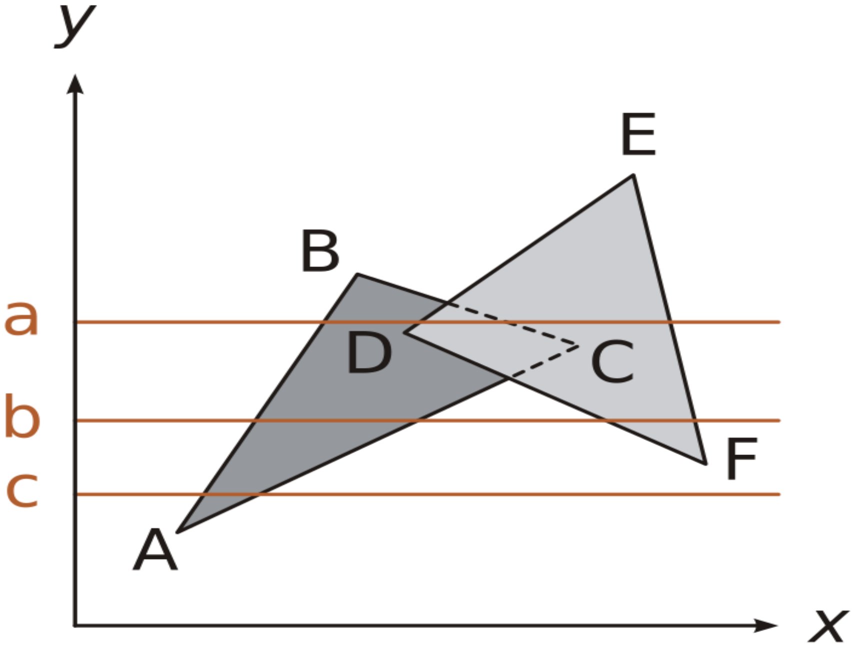

Triangle Mesh




Verts: 193819 0 0
Edges: 385469 0 0
Faces: 191407 0 0
Tris: 382358 0 0
UVs: 246857 0 0
2D Pan/Zoom : persp

Scanline Rendering

- Algorithm for visible surface determination that works on a row-by-row basis rather than a polygon-by-polygon or pixel-by-pixel basis.
- All of the polygons to be rendered are first sorted by the top y coordinate at which they first appear, then each row or scan line of the image is computed using the intersection of a scanline with the polygons on the front of the sorted list, while the sorted list is updated to discard no-longer-visible polygons as the active scan line is advanced down the picture.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C
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F
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A
x

Rasterization - 01

- Real-time computer graphics have long used it to display three-dimensional objects on a two-dimensional screen
- It's fast, and the results have gotten very good
- Objects on the screen are created from a mesh of virtual triangles, or polygons, that create 3D models of objects
- In this virtual mesh, the corners of each triangle — known as vertices — intersect with the vertices of other triangles of different sizes and shapes
- A lot of information is associated with each vertex, including its position in space, as well as information about color, texture and its "normal," which is used to determine the way the surface of an object is facing.

Rasterization - 02

- Computers then convert the triangles of the 3D models into pixels, or dots, on a 2D screen. Each pixel can be assigned an initial color value from the data stored in the triangle vertices.
- Further pixel processing or “shading,” including changing pixel color based on how lights in the scene hit the pixel, and applying one or more textures to the pixel, combine to generate the final color applied to a pixel.
- This is computationally intensive. There can be millions of polygons used for all the object models in a scene, and roughly 8 million pixels in a 4K display. And each frame, or image, displayed on a screen is typically refreshed 30 to 90 times each second on the display.

Rasterization - 03

- Additionally, memory buffers, a bit of temporary space set aside to speed things along, are used to render upcoming frames in advance before they're displayed on screen.
- A depth or "z-buffer" is also used to store pixel depth information to ensure front-most objects at a pixel's x-y screen location are displayed on-screen, and objects behind the front-most object remain hidden.
- This is why modern, graphically rich computer games rely on powerful GPUs.

Ray Tracing - 01

- Ray tracing is different. In the real-world, the 3D objects we see are illuminated by light sources, and photons can bounce from one object to another before reaching the viewer's eyes.
- Light may be blocked by some objects, creating shadows.
- Or light may reflect from one object to another, such as when we see the images of one object reflected in the surface of another.
- And then there are refractions — when light changes as it passes through transparent or semi-transparent objects, like glass or water.

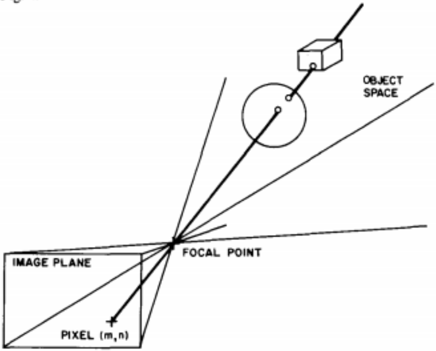
Ray Tracing - 02

- Ray tracing captures those effects by working back from our eye (or view camera) — a technique that was first described by IBM's Arthur Appel, in 1969, in "Some Techniques for Shading Machine Renderings of Solids." It traces the path of a light ray through each pixel on a 2D viewing surface out into a 3D model of the scene.
- The next major breakthrough came a decade later.
- In a 1979 paper, "An Improved Illumination Model for Shaded Display," Turner Whitted, now with NVIDIA Research, showed how to capture

Since a sphere can serve as its own bounding volume, initial experiments with the shading processor used spheres as test objects. For nonspherical objects, additional intersection processors must be specified whenever a ray does intersect the bounding sphere for that object. For polygonal surfaces the algorithm solves for the point of intersection of the ray and the plane of the polygon and then checks to see if the point is on the interior of the polygon. If the surface consists of bicubic patches, bounding spheres are generated for each patch. If the bounding sphere is pierced by the ray, then the patch is subdivided using a method described by Catmull and Clark [10], and bounding spheres are produced for each subpatch. The subdivision process is repeated until either no bounding spheres are intersected (i.e., the patch is not intersected by the ray) or the intersected bounding sphere is smaller than a predetermined minimum. This scheme was selected for simplicity rather than efficiency.

The visible surface algorithm also contains the mech-

Fig. 4.



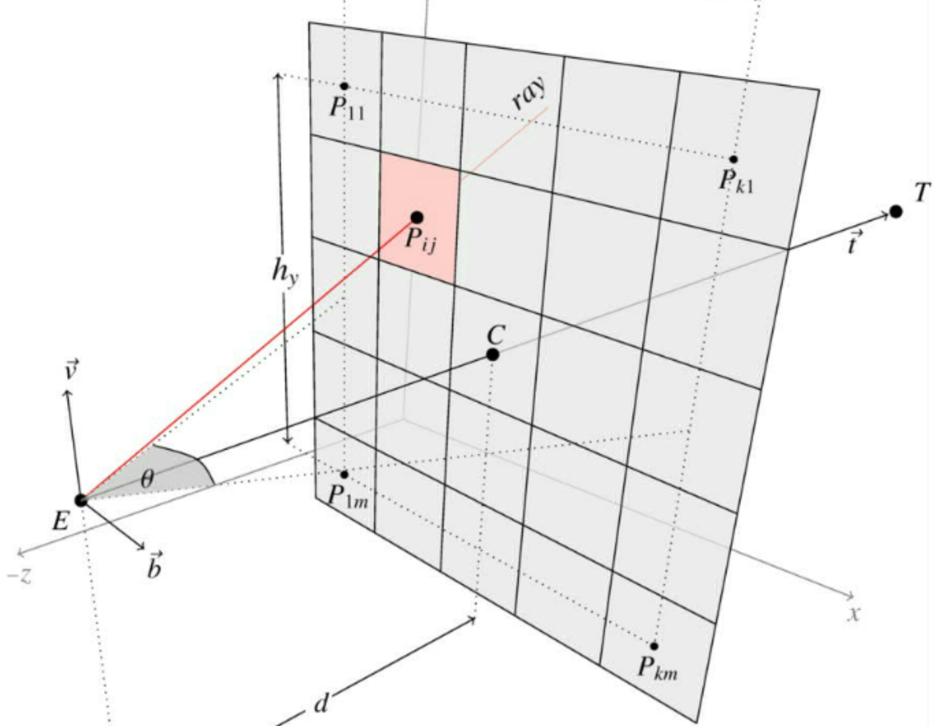
Ray Tracing - 03

- With Whitted's technique, when a ray encounters an object in the scene, the color and lighting information at the point of impact on the object's surface contributes to the pixel color and illumination level.
- If the ray bounces off or travels through the surfaces of different objects before reaching the light source, the color and lighting information from all those objects can contribute to the final pixel color.
- Another pair of papers in the 1980s laid the rest of the intellectual foundation for the computer graphics revolution that upended the way movies are made.

Ray Tracing - 04

- Combine this research with modern GPUs, and the results are computer-generated images that capture shadows, reflections and refractions in ways that can be indistinguishable from photographs or video of the real world.
- That realism is why ray tracing has gone on to conquer modern movie making.


GENESIS
PINK FLOYD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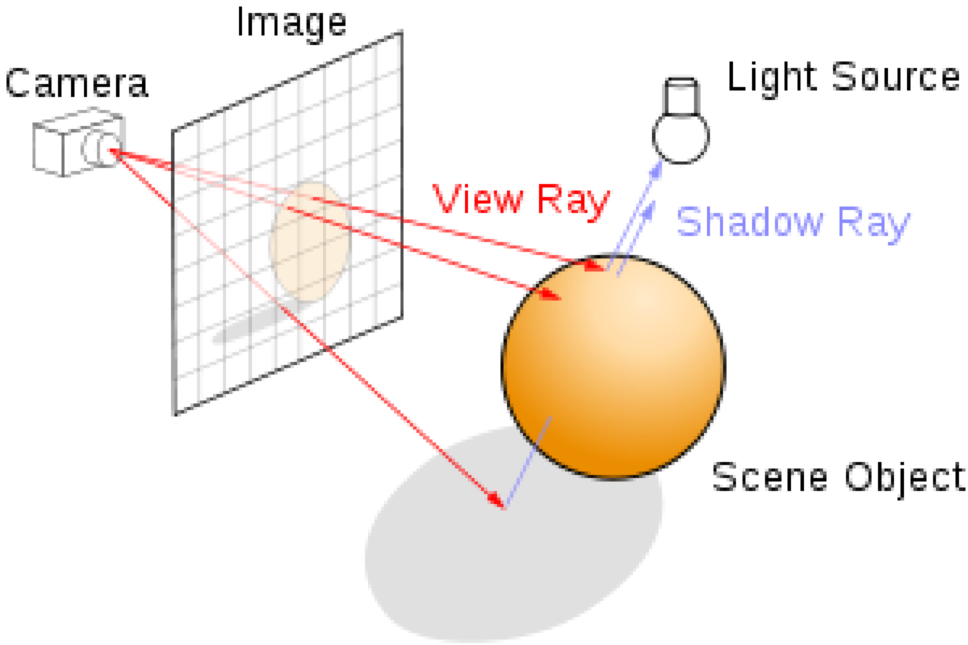
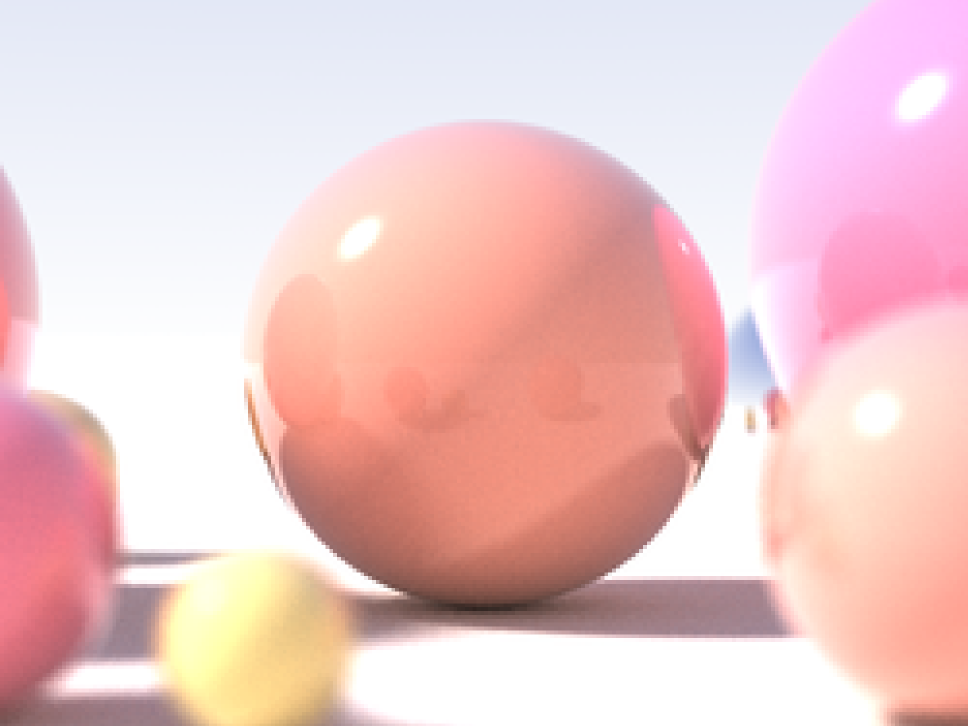
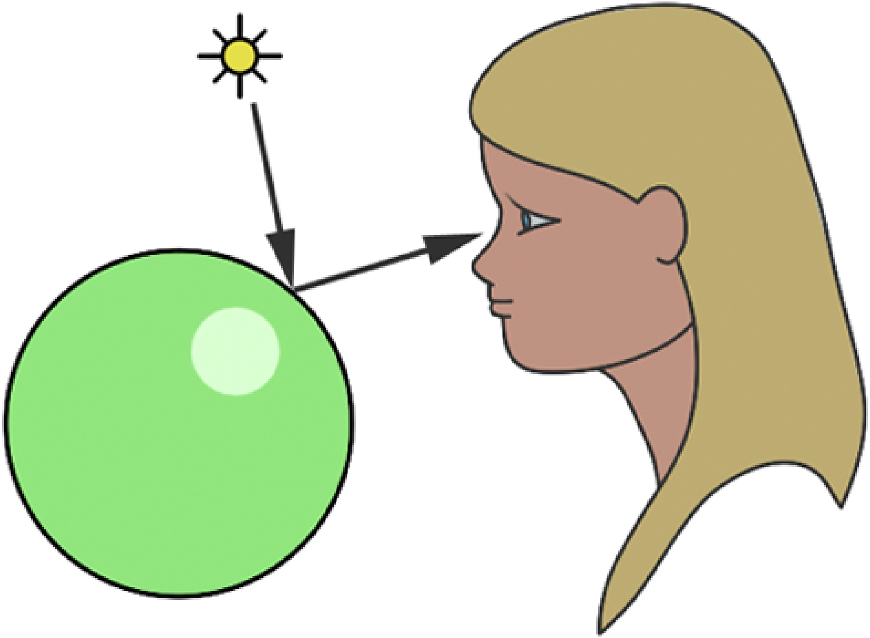


Image
Camera
Light Source
View Ray
Shadow Ray
Scene Object

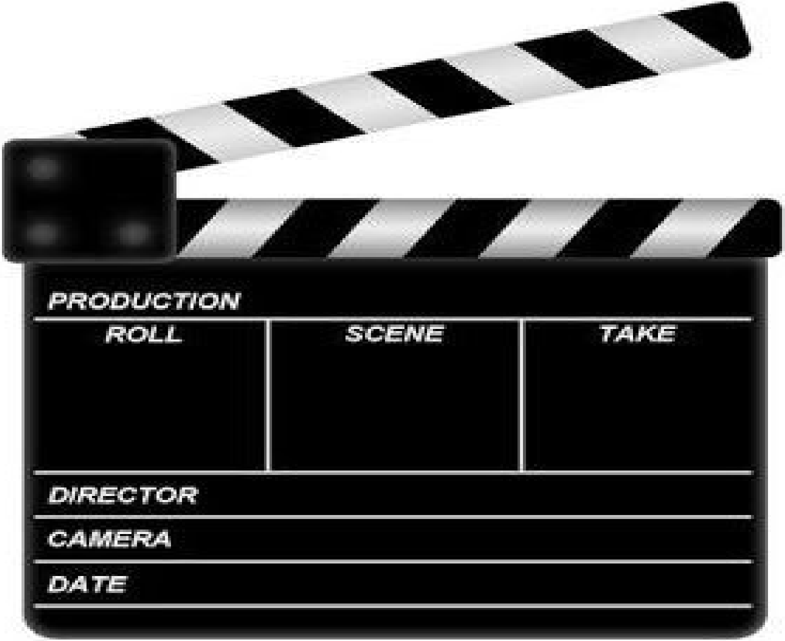


Ray Tracing - Note

- Like the concept of perspective projection, it took a while for humans to understand light.
- The Greeks developed a theory of vision in which objects are seen by rays of light emanating from the eyes. An Arab scientist, Ibn al-Haytham (c. 965-1039), was the first to explain that we see objects because the sun's rays of light; streams of tiny particles traveling in straight lines were reflected from objects into our eyes, forming images.



MOVIE
MOVIE


PRODUCTION
ROLL
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DATE