

# Progression of Computer Graphics

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**Abstract:** Computer graphics are all around us. Every screen, every billboard, every display has some sort of graphics that is meant to serve a specific purpose. The purpose varies from person to person, yet we all make use of graphics. But the graphics of today are not a product of overnight change. They have been developed over a course of many years by a multitude of organizations and pioneer inventors who redefined and changed how we perceive the world. In this research paper, we talk about the contributions, changes and radical developments by these people, their devices, techniques and ideas, as well as their applications.

**Keywords:** Graphics, Hardware and software, Optimization Techniques, Applications

## 1 INTRODUCTION

We have come a long way from primitive computers that were huge in size, sensitive to the environment and prone to malfunction, that could, at best, run a few hundred calculations in a second, having displays based on cathode ray tubes, which were bulky and power consuming, to having devices capable of running 5 trillion operations per second in the palm of our hands, running on a battery. While these innovations seem rudimentary now, due to the advent of the technological revolution over the past few decades, they are the product of a series of ground-breaking developments in terms of hardware as well as software. These developments in the various domains have also led to the monumental developments of the arena of computer graphics.

Computer graphics, or CG for short, is a computer's visual output. CG can be anything, ranging from simple primitive shape such as a circle, to a complex render of a protein. In other words, anything that is an output of a computer screen short of sound, is a product of CG.

## 2 PROCEDURE

In the next few sections, we analyse the various changes that have taken place over the course of roughly six decades (1950's to 2010's) in the primary domains of hardware, techniques, applications and the industry, followed by a case study in graphical development.

### 2.1 "The Hardware"

The hardware is the collection of the physical parts of a computer that comprise of all parts like the processor, RAM, graphics card, storage drives, etc. Moore's Law is an observation made by Gordon Moore, Chairman Emeritus of Intel, who noted that the number of transistors in a dense integrated circuit doubles every two years. This gives credit to the notion that hardware develops at an exponential rate. Various milestones in the hardware development are mentioned below.

- i) The oscilloscope (1950)
  - a. Developed by Ben Laposky, it was a device that could project analogue signals on an x-y plane, displayed through manipulation of electronic beams and recording on high speed film.

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- ii) Whirlwind computer (1951)
  - a. It was a vacuum tube computer developed by MIT for US Navy.
  - b. It was among the first digital devices that had a real time display output.
- iii) IBM 2250 (1964)
  - a. The first commercially available graphics computer.
  - b. It was a landmark device that showed a shift in trend where graphics were available to the masses.
- iv) Head Mounted Display (1966)
  - a. Developed by a pioneer in the graphics domain, Ivan Sutherland.
  - b. It allowed two separate wireframe images to be output to each eye, allowing the viewer to see in Stereoscopic 3D
  - c. It was viewed as a precursor to VR technology, more than 30 years earlier than other devices.
- v) Arcade (1970's)
  - a. Widely popular in the 70's and 80's where they raised over \$8 billion by 1981, they were coin operated computers that played single games.
  - b. Shaped like a small cabinet with built in controllers.
  - c. Games like Space Invaders, Street Fighter, Mortal Kombat, etc. were made available for the masses.
- vi) Magnavox Odyssey (1966)
  - a. The first commercially available home video game console.
- vii) Xerox Alto (1973)
  - a. Developed by researchers at Xerox Palo Alto Research Center, it was the first personal computer with modern Graphical User Interface (GUI).
- viii) Apple II (1977)

- a. The first graphics-capable personal computer available commercially.
- ix) Nintendo Entertainment System (1983)
  - a. One of the most successful video game consoles of all time, NES was a revolutionary product for its time, introducing many features like the 'D-Pad' on its controller that would become the standards in the game industry.
- x) Nintendo Gameboy (1989)
  - a. Part of the fourth generation of video game consoles, it was an 8-bit handheld game console that had a dot matrix screen, 5 control buttons and used cartridges to store games. It sold over 115 million units and is the one of the best-selling console of all time.
  - b. It was a landmark achievement for consoles, as it was a portable console that could play home computer quality games.
- xi) Sony PlayStation (1994)
  - a. Part of the fifth generation of video games, it was Sony's first foray into the video game market.
  - b. It was an important development as it led to the classification of discrete GPU- the graphics processing unit of a device. While the CPU handles serial calculations, GPU handles parallel calculations.
- xii) Smartphones (2007)
  - a. Phones such as the Apple iPhone range as well as devices running Google's Android Operating systems come under the umbrella term of smartphones.
  - b. The development and adoption of smartphone technology catapulted the development of smarter devices capable of a plethora of functionality such as Augmented Reality and Virtual Reality integration, as well as highly sophisticated displays in palm fit designs.
- xiii) Virtual Reality Devices (2012)
  - a. With the release of Oculus Rift, another shift in the market was observed. Commercial availability of VR headsets such as the Rift, HTC Vive and others led to development of VR applications and games that opened new avenues in the industry while providing alternatives in fields like digital marketing, education and simulations.

objects must be created to utilize the power of the hardware without hindering software performance.

- i) Bresenham's algorithm (1965)
  - a. It was the "ideal" line drawing algorithm on a raster graphic environment that is still implemented today.
- ii) Bezier curves (1960's)
  - a. It was an algorithm developed by Pierre Bezier, who used for designing curves of cars.
  - b. It is widely used in the domains of animation and user interface.
- iii) Ray casting, ray tracing (1968)
  - a. It is a rendering technique that is now considered to be a quintessential part of any 3D software.
  - b. It was developed by Arthur Appel.
- iv) NURBS (1975)
  - a. Non Uniform Rational B spline curves are very integral to Computer Aided Designs (CAD) and CG in general.
  - b. It is a powerful extension of B Spline curve.
- v) Texture Mapping (1974)
  - a. It is a method to apply an image or colour "texture" to a computer generated graphic or 3D model.
  - b. It was developed by Edwin Catmull in 1974.
- vi) Hidden Surface Determination (1977)
  - a. It is a method to determine which surfaces or object faces are visible from a certain camera or viewpoint.
  - b. It solves the visibility problem, optimizing the display and thus helping hardware resource management.
- vii) Shading (late 1970's)
  - a. Shading is depicting depth perception in 3D models by varying the degree of darkness or light.
  - b. Two different algorithms- Gourard shading by Henri Gourard in 1971, and Phong shading by Bui Tuong Phong in 1975- are extensively used to convert a 3D scene to be displayed on a 2D screen.
- viii) Binary Space Partitioning (1980)
  - a. Binary Space Partitioning, or BSP, is a technique extensively used in video games to only render a particular scene at a time while ignoring the unrequired parts of the scene by selective rendering [1].
  - b. First a binary tree is created. The process uses recursive approach. A single super space is

## 2.2 "The Optimization Techniques"

While development of hardware is integral, well-optimized techniques to implement the basic rudimentary shapes and

divided into 2 subspaces by a hyper plane, and then the 2 subspaces are treated as super spaces and further divided into 2 subspaces. This process is followed until each object is in separate subspace.

c. Nodes from this tree are called as per need.

ix) Physically Based Rendering (PBR)(1980's)

- a. Rendering is the process of converting a 3D digital environment into a 2D image for display on a monitor.
- b. PBR is the process where rendering is done realistically, taking care of all the aforementioned techniques, while adding calculation of flow of light.
- c. The goal is accurate representation of photorealism in CG.

**2.3 "The Applications"**

As stated before, technology changes rapidly. This change or shift can be very noticeable in the applications of said technology. A variety of applications have been developed over the years that showcase the most of the available technologies of their time. These applications show graphical fidelity of their era.

i) Video Games

a. Spacewar! (1961)

Developer	Steve Russell
Platform	PDP-1 Computer
Genre	Space shooter

The first video game that was played and installed at various, primarily academic institutions, as well as being ported to various other computers. The game used an oscilloscope for output.

b. Pong (1972)

Developer	Allan Alcorn
Platform	Arcade
Genre	Sports

One of the earliest arcade games, Pong is a 2D table tennis game featuring simple graphics. It was the first commercially successful video game that help establish the video game market.

c. Super Mario Bros. (1985)

Developer	Nintendo
Platform	Nintendo Entertainment System
Genre	Platformer

Super Mario Bros. was a 2D platformer that used simplistic graphics and controls. Considered one of the greatest games of all time, its introductory level

(World 1-1), the gameplay and music make Mario one of the most recognizable characters from any game.

d. DOOM (1993)

Developer	Id Software
Platform	MS-DOS, ported to almost all platforms after release
Genre	First Person Shooter

DOOM redefined the FPS genre, and had some of the earliest 3D graphics. It pioneered technologies like multiplayer gaming and is considered one of the most significant games of all time.

e. Crysis (2007)

Developer	Crytek
Platform	Microsoft Windows, Xbox 360, PlayStation 3
Genre	First Person Shooter

Crysis runs on CryEngine 2 with graphics by Microsoft's graphics API, Direct3D. At the time of release, the game's requirements were considered very high. The game was commonly used as a benchmarking tool for PC [6].

f. The Witcher 3: Wild Hunt (2015)

Developer	CD Projekt Red
Platform	Microsoft Windows, Xbox One, Playstation 4, Nintendo Switch
Genre	Role-Playing Game

Built using the Red Engine 3, the visual fidelity of the PC version was acclaimed, which could run at resolution of 4k (4096 x 2160p) at 60 frames per second on capable hardware.

g. Beat Saber (2018)

Developer	Beat Games
Platform	PlayStation VR, Microsoft Windows (with VR kit)
Genre	Rhythm game

Beat Saber is a VR based game that is one of the earliest popular VR titles based on its graphical fidelity and simple premise.

ii) Animated Films and Cartoons

a. Luxo Jr. (1986)

- (1) It is a 2 minute short film by Pixar, written and directed by John Lasseter.
- (2) It is one of the first animations done completely through computer.
- (3) Luxo Jr. became a mascot for Pixar after it was shown at SIGGRAPH.

- b. Toy story (1995)
  - (1) Directed by John Lasseter, Toy Story is the first entirely computer-generated feature film, with a run time of 81 minutes.
  - (2) It was a huge critical and commercial success that is considered a milestone in animation and storytelling, and it changed people’s perception towards animation.

iii) Visual Effects

- a. Star Wars (1977)
  - (1) Considered ground-breaking in its practical visual effects and storytelling scope, Star Wars also features some of the earliest forms of Computer Generated Imagery (CGI) [2].
  - (2) The computer effects seen in the movie are vector based- and then filmed externally.
- b. Jurassic park (1993)
  - (1) Directed by Steven Spielberg, this movie is one of the earliest adopters of CGI [3].
  - (2) The dinosaurs were created using CGI provided by Industrial Light & Magic (ILM) as well as life sized animatronics.
  - (3) The visual effects were highly praised and remain respectable even by today’s standards.
- c. Avatar (2009)
  - (1) Written and directed by James Cameron, the entire film was shot in a studio using real actors in motion capture suits [5].
  - (2) The movie was considered ground-breaking for its CGI used in rendering an entire planet, with flora, fauna and alien characters realistically and for its extensive use of motion capture.
- d. Interstellar (2014)
  - (1) Written and directed by Christopher Nolan, this movie has some of the highest resolution of CGI (5600 x 4000p) ever put to film.
  - (2) The film is noted for its scientific accuracy, with one of the best representations of a black hole ever seen. The team had to work with real scientists and engineers to create the scene. Individual frames could take up to a hundred hours to render and totalling at about 800 TB of data.

iv) Image and Video Processing

- a. Photoshop (1989)

Developer	Adobe
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Platform	Microsoft Windows, Apple macOS
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Photoshop is a raster graphics editor that has become synonymous with photo editing. For the past 30 years, it has been the industry standard for digital art.

- b. Cinema 4D (1990)

Developer	MAXON Computer
Platform	Microsoft Windows, macOS, Linux

Cinema 4D is a 3D modelling, animation, motion graphic and rendering software. It is one of the most used software in the domain by professionals and hobbyists alike.

v) CAD/CAM

- a. AutoCAD (1982)

Developer	Autodesk
Platform	Microsoft Windows, macOS, iOS, Android

Developed by Autodesk, it is a commercial Computer Aided Design (CAD) software that is used extensively in the industry by engineers, architects, city planners and other professionals.

vi) Simulation

- a. Flight Simulation

Flight simulator is a device that basically artificially ‘remakes’ the environment inside an actual aircraft. The range of aircraft varies from helicopters to airbus, with each demanding different from the pilot. A flight simulator, hence, is one of the most complex simulators, having controllers and actuators for a plethora of equipment like in a real aircraft.

- b. Protein synthesis

Foldit is an online game about protein folding created by University of Washington. It is a revolutionary approach to protein development through gamification of simulation, which matched or outperformed algorithmically computed solutions that could be identified and studied by biochemistry students [8].

vii) Augmented Reality

- a. Pokemon Go (2016)

Developer	Niantic
Platform	iOS, Android
Genre	puzzle

One of the most popular AR application on the market, it involves seamless integration of our world and the world of pokemon. Players can go out into the world to ‘catch’ pokemon, train them, and battle other players.

b. BBC Civilizations AR (2017)

Developer	BBC
Platform	iOS, Android
Genre	exploration

BBC Civilization AR is an educational app for demonstration of AR in such environment. Users can view historically accurate articles, and locations in fully rendered 3D beauty. It allows showcasing and study of said models like Egyptian Mummies and the pyramids.

viii) Virtual Reality

a. Medicine Simulations

VR is a very powerful tool to utilize in medicine. Doctors and surgeons can inspect, experiment and understand physiology of organisms without the risks or problems of the real environment. It stands as one of the best forms of testing ground before actual practical work.

b. NASA SLS VR

NASA uses VR for developing student and scientist programs called the NASA SLS VR experience. Users can experience viewing and piloting rockets from fully rendered cockpits while sitting in the comfort of their homes [9].

ix) Imaging

a. Ultrasonography

Also called diagnostic sonography, Ultrasonography is a diagnostic tool based on the application of ultrasound and representation using CG. It is used to create images of internal body structures.

b. Deep Space Imaging

While theoretical images of black holes were created using theoretical physics and CG, CG was also employed in creating the first real image of a black hole in 2019. Data from various satellites and telescopes was corroborated with the aid of supercomputers to render the first true image of a black hole [7].

x) Web applications

a. Mosaic Web Browser (1993)

(1) Popularized the World Wide Web for the average user because of its innovative interface that was highly accessible.

b. Adobe Flash Player (1996)

(1) Flash was one of the most significant software for propulsion of graphics to the mainstream media.

(2) It allowed playing video games, videos, images and even coding to some extent directly on the web.

2.4 "The Industry"

The industry has been an active participant in the developments of the CG in various capacities.

i) Silicon Valley (1950's)

- a. Hewlett-Packard began transforming the San Francisco Bay Area into the world's leading computer technology hub- The Silicon Valley.
- b. This region would turn into one of the most influential factors in the CG domain, bolstering both the hardware and the software domains.

ii) ACM SIGGRAPH (1969)

- a. The Association for Computing Machinery society initiated A Special Interest Group on Graphics (SIGGRAPH) [4].
- b. SIGGRAPH is an annual conference on CG that promotes academic presentation and industry trade show.
- c. Cutting-edge developments in CG are showcased here.

iii) Industrial Light & Magic (ILM) (1975)

- a. ILM is a motion picture visual effects company founded by George Lucas.
- b. They have been associated with some of the best visual effects ever put to film, with some of the highest grossing and critically acclaimed movies such as Star Wars, E.T., Jurassic Park, and Harry Potter films being worked on by them.

iv) Adobe Inc. (1982)

- a. Adobe is an American company which is renowned for its suite of creativity and multimedia software that are considered the gold standards of the industry
- b. It is best known for Adobe Flash web software, Photoshop- an image editing software, Acrobat reader- a pdf reader, and AfterEffects- a visual effects software.

v) Pixar (1986)

- a. Pixar is an American computer animation studio, as a part of Walt Disney Studios.
- b. Pixar is considered one of the most significant animation studios of all time, with almost all of their 21 movies being critical and commercial successes.

vi) Rockstar Games (1998)

- a. An American video game publisher, Rockstar has been associated with some of the best

games that push the boundaries of the hardware they are put on.

- b. Their Grand Theft Auto and Read Dead franchises are critically acclaimed and commercial successes, with their graphics being singled out each time.

vii) Oculus VR (2012)

- a. Oculus is an American technology company that specializes in virtual reality based hardware and software products. It is a division of Facebook Technologies.
- b. VR is a new technology for commercial market, with new applications being developed almost every day. Oculus strives to make that technology cheaper and accurate.

### 2.5 “Case Study: Super Mario Bros. franchise”

Graphics tend to be best exemplified by the games they are employed on, showcasing the use of the hardware. Nintendo’s Super Mario Bros. is a franchise created by Shigeru Miyamoto and has undergone a variety of changes since his 1985 debut [11].

i) Super Mario Bros. (1985)

Platform: Nintendo Entertainment System (NES)

Resolution: 256 x 240p



Super Mario Bros. is the first game of the franchise developed for the first Nintendo Console. It features 2D sprites and a basic platforming premise. At the time of its release, it was ground-breaking and helped catapult Nintendo’s position in the video game market.

ii) Super Mario Land (1989)

Platform: Nintendo Gameboy (GB)

Resolution: 160 x 144 p



The first portable Mario game, Super Mario Land was one of the earliest game for the handheld console Gameboy. Owing to the technical limitations of the hardware, the game lacks colour of its predecessors, and as such is monochrome in nature with shades of grey sprites [10].

iii) Super Mario World (1990)

Platform: Super Nintendo Entertainment System (SNES)

Resolution: 256 x 240



Super Mario World was released on the SNES and showcased the increased hardware power with 16-bit sprites. The game had far more elaborate graphics than previous games.

iv) Super Mario 64 (1996)

Platform: Nintendo64

Resolution: 320 x 240p



One of the pioneering games in 3D, Super Mario 64 used the 64-bit console’s power to render simplistic

3D graphics that it used to great effect and was a trendsetter.

- v) Super Mario Galaxy (2007)  
Platform: Nintendo Wii  
Resolution: 640 x 480p



Super Mario Galaxy was released as a launch title on the Wii and it showed the higher hardware power of the Wii along with motion controls which were the first of its kind back then.

- vi) Super Mario 3D World (2013)  
Platform: Nintendo Wii U  
Resolution: 960 x 720p



It is the first truly 'HD' title in the series. It featured a multitude of playable characters and worlds to explore.

- vii) Super Mario Odyssey (2018)  
Platform: Nintendo Switch  
Resolution: 1280 x 720p



The latest game in the franchise, Super Mario Odyssey has the highest level of detail and graphics ever seen in a Mario game [13].

decade. As we have looked at the various changes and developments of the yesteryears and present, we know that the trends point to the widespread acceptance of AR/VR while total photorealism remains the goal to which video games and movies strive to achieve. Gaming and films, hence, tend to be the forerunners in this league of graphical enhancements.

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## 3 CONCLUSION

With all the rapid developments and leaps, one can wonder what direction CG will take over the course of even the next

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