Evolution of Computer Graphics and its Impact on Engineering Product Development

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Abstract

Computer graphics matured over many years and played an important role in the development of engineering products like automotive and aircraft components. The current CAx (CAD/ CAM/ CAE) tools use computer graphics extensively, while helping in conceiving better designs with improved quality. Nowadays, engineering product development is being done concurrently and collaboratively, due to the advances in computer graphics. This paper presents a brief overview on evolution of computer graphics over the years. It also attempts to present, how advances in computer graphics, have revolutionized the current engineering product development and what future technologies will offer.

1.0 Introduction

In the early years of human evolution, cavemen used pictures as a way of communicating their ideas with one another and with other tribes. Humans have used maps, charts and paintings for ease of communication throughout the ages, and in all civilizations. 'Graphics' are visual representation of objects or ideas. The Computer graphics (CG) is a domain that deals with use of graphics on computer. Behind the sparkling graphics screens that we see today, lies decades of research, innovation and evolution in both hardware and software fronts. CG is widely used in engineering product development, across multiple industries like automotive, aerospace, ship building, architectural, civil, mechanical, heavy engineering, oil and gas. CG helped in Visualizing large scale data in real time, concurrently and collaboratively there by reducing the product development cycle time drastically, Improving the quality of the end product, and Post deployment of the product – operations and maintenance. CAx applications provide rich interactivity, ease and flexibility while designing, which is difficult to achieve through manual approach. The interactivity is facilitated by graphics in the form of Graphical User Interfaces (GUIs), 2D/3D mouse, joy stick etc. GUIs with a good backing of algorithms from geometry, mathematics and graphics (Fig 1.), serve as powerful tools, enabling planners, analysts, designers, manufacturers and sales people to handle problems hitherto unsolved and unheard of[1],[2]. As depicted in Fig.1, graphics plays a key role in most of the CAx applications.

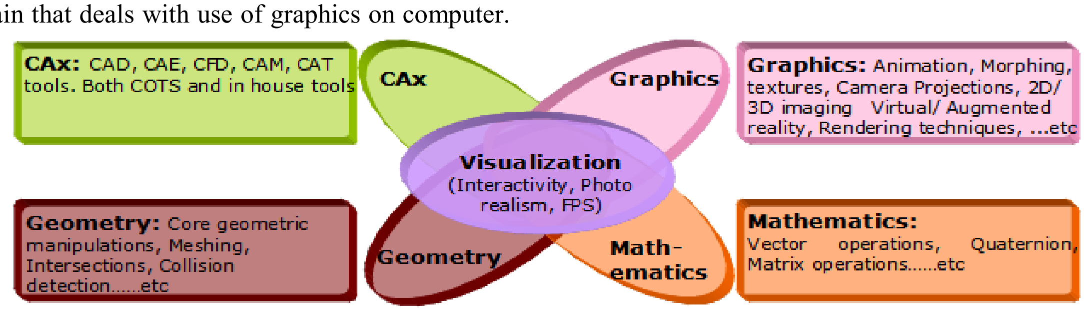

Fig1. Graphics, Visualization and CAx

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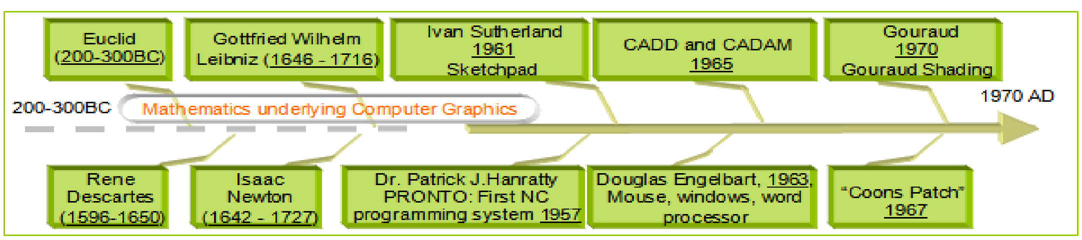
Various computer graphics techniques such as bump mapping, texturing, animation, morphing, fractals and ray tracing help a great deal in achieving realism in models generated. Further, rendering techniques like point based rendering, image based rendering and volume rendering have helped in pushing the frontiers of applications of graphics in visualization. Today, Computer Graphics applications form a trillion dollar industry spread worldwide. No wonder, bitter competition and so called 'wars' (kernel wars, GUI wars, browser wars etc..) engulf the product life cycle management (PLM) market in the past, present and perhaps in future.

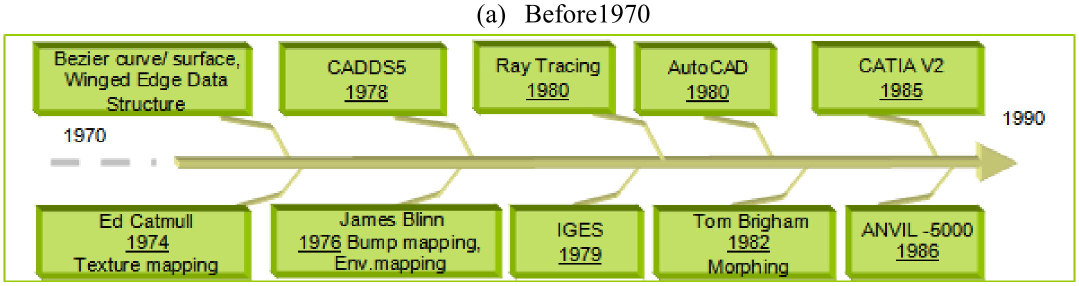
The evolution and application of computer graphics, in engineering product development space, is presented in the following sections.

2.0 Initial application phase

Initial groundwork of graphical algorithms can be traced back to Mathematicians and scientists like Euclid (200-300BC), Rene Descartes (1596-1650), Gottfried Wilhelm Leibniz (1646 - 1716) and Issac Newton (1642 - 1727) [3]. However the tremendous scope of graphical applications got revealed only after the computers reached common man's desk. Patrick J.Hanratty (known as "Father of CAD") used graphics extensively in his CAD systems [4]. His first contribution began in 1957 with PRONTO, the first commercial numerical control programming system. In 1960, William Fetters of Boeing coined the word "Computer Graphics" [4]. In 1961, a computer drawing program called Sketchpad was created by Ivan Sutherland. Sketchpad allowed users to draw simple shapes on the computer screen using a light pen, save them and recall them later. Because of his pioneering work in this field, Ivan Sutherland is considered as "Father of Computer Graphics". Ivan Sutherland's Sketchpad System can be identified as the first application of computer graphics in engineering design space. In 1963 Douglas Engelbart, developed the first computer mouse, windows, e-mail, and the word processor. He is widely known as "father of GUI". The late 1960s saw an outburst of activity in Computer Aided Design (CAD) in both hardware and software. The first commercial solid modeler is "Syntha Vision Solids Software" by MAGI. Steve Coons published a surface patch called "Coons Patch" in 1967, which is widely used in the CAD community. Pierre Bezier while working at Renault developed Bezier parametric curve/surface representation that has revolutionized interactive free surface creation for various automotive & aerospace applications. Constructive solid geometry (CSG) and Boundary representation (B-Rep) concepts have been developed to model large solid and surface models. Bruce Baumgart introduced "Winged Edge Data Structure" for efficient representation of 3D objects using B-Rep concepts. Brief sketches of the developments are depicted in Fig2 (a) and (b).



(a) Before1970



(b) After 1970

Fig2. Initial Development and Application

In early 1970's the Hidden Surface algorithm was invented by the team led by Evans at university of Utah. The widely used Gouraud shading was found in early 1970's. Gouraud shading provides good rendering quality compared to flat shading without taking more computations. In the hardware front, early 1970's saw the introduction of microprocessor. Color frame buffer and animation techniques for motion pictures were used during this period. The arrival of NURBS geometric entities in late 1970's revolutionized the computational geometry. Most of the geometric entities like free form curves and surfaces can be easily represented in generic NURBS framework. Thus NURBS have become industry standard representation for complex geometries [5]. In 1974 Ed Catmull covered Texture Mapping, Z-Buffer and rendering curved surfaces in his Ph.D. thesis [6]. Texture mapping provided a new level of realism in computer graphics. Texture mapping is used in generating models particularly in Architecture, Engineering, Construction and entertainment industries [7]. In 1974 Phong Bui-Toung developed a new shading method known as Phong shading, that gives accurate shading compared to the traditional Gouraud shading [8]. Models without shading called 'wire frame models' are used mostly only for previewing the model. In 1975 Benoit Mandelbrot found the Fractal Geometry which can be used to create realistic simulations of natural phenomena such as mountains, coastlines, wood grain, etc [8]. In 1975 Avionics Marcel Dassault (AMD), now Dassault Systemes, purchased CADAM (Computer-Augmented Drafting and Manufacturing) tool from Lockheed becoming one of its first customers. James Blinn developed a new technique called "Bump Mapping" and "environment mapping" in 1976. Without these techniques, 3D objects would look flat and un-interesting. By 1977, AMD assigned its engineering team the goal of creating a three dimensional interactive program CATIA (Computer Aided Three dimensional interactive application). Computervision introduced the first CAD terminal using raster display technology in 1978. Its CAD tool CADDS5 has considerable presence in aircraft and ship building industry. In 1979 Boeing, General Electric and NIST developed a neutral file format called IGES (Interactive Graphics Exchange Standard). By 1980, the entire value of all the computer graphics systems, hardware, and services reached about a billion dollars [8]. Turner Whitted published a paper in 1980 introducing "Ray tracing". Though ray tracing is not so popular in CAx, there are packages like BRL-CAD solid modeling system by Mike Muuss. There are recent publications about application of ray tracing like visualizing large data of Boeing 777 [9]. Another major milestone in the 1980's for computer graphics was the founding of Silicon Graphics Inc. (SGI) by Jim Clark in 1982. In 1982, John Walker and Dan Drake along with eleven other programmers established Autodesk Inc. In 1982 Tom Brigham found the "Morphing" technique. This technique is being used many CAD/CAM models development [10]. Autodesk introduced AutoCAD in early 1980's which is a computer assisted design software package for 2D and 3D design and drafting. Structural Dynamics Research Corporation (SDRC) brought IDEAS CAD tool in 1982 for mechanical computer aided engineering. Prior to this software SDRC released tools like Super FEA, Modal Plus and Super TAB tool for modal testing analysis and modeling. By 1985 CATIA Version 2 contained fully integrated drafting, solid and robotics functions making it leader in aircraft industry. Late 1980's saw the development of multimedia. At the 1989 SIGGRAPH, Autodesk unveiled a new PC based animation package called Autodesk Animator. Animation is a great way to showcase the behavior and workflow of the CAD models.

3.0 Matured application phase

During 1990's most of the aerospace and automotive industries embraced CAD/ CAM/ CAE tools in their product development programs. This has lead to concurrent product development there by improving the productivity and quality. CATIA, CADDS5 and Unigraphics have dominated most of the aircraft industry. However, CATIA with its version 5 software dominated the majority of the industry. Parametric Technology Corporation (PTC) introduced Pro-E software to cater the automotive, equipment and heavy engineering industry brought new concept like parametric modeling in product development. Solidworks Corporation introduced the first powerful 3D CAD software available on windows platform based on Parasolid kernel. Many finite element pre and post processors like PATRAN, Hypermesh, LS-Post, and ABAQUS used graphics extensively for preparation of input data for finite element analysis and also analyzing the output. Numerous mesh generation algorithms were developed for both 2D and 3D models.

Advances in Computational fluid dynamics (CFD) have also fueled the growth of computer graphics. In this period, aerospace and automotive industries could fully utilize computer graphics in almost all the stages of product development cycle. The role of computer graphics in various stages of product development is given in Table 1. About a decade back, product development was a laborious manual process involving huge amount of product data and its tracking. Any changes in specifications or design modifications resulted in long time delays before release of new drawings to shop floor. As the complexity of the products increased, it became humanly impossible to keep track of the data. People started using computers for problem solving and data storage. However the data at various stages of product development was stored discretely and there were no tools to link all the data. Introduction of visualization based PDM and PLM tools enabled uniform way of storing, tracking and visualization of the data. Visualization in this domain is typically through windows, GUIs, display of graphic models and drawings. Links can be established between data at various product development stages. Any changes in data at one stage of the process can be easily upgraded in other stages. Moreover the changes can be tracked and reverted back if necessary. Effect of the changes can be visualized which is easy to share with the stakeholders. Complex problems necessitating decades of experience to solve, can be handled even by people of less experience. Digital mock-ups and virtual prototyping is extensively used by all the aircraft OEMs, which was made possible due to advances in visualization techniques. Many high end packages like CATIA, NX have included knowledge based engineering and features for integration with legacy PLM tools.

4.0 Current trends in computer graphics application

Recent changes in CAx landscape have been more due to developments in both Information Technology and hardware fronts, rather than changes in the actual core algorithms or the techniques (Fig. 3). In May of 1990, Microsoft shipped Windows 3.0. It followed a GUI structure similar to the Apple Macintosh, and laid the foundation for a future growth in multimedia [11]. In 1990, Autodesk shipped 3D Studio: their first 3D Computer animation product. Graphical Kernel system is the ISO standard for 2D and 3D Computer Graphics but in early 1990s' SGI came up with OpenGL and Open Inventor. OpenGL, with all the basic 3D graphics libraries soon became the De facto standard. Open Inventor provided many advanced features like scene graph, which facilitated fast application development and interaction with complex 3D scenes. Many applications particularly games started appearing in the IT market. Soon Microsoft came up with its proprietary DirectX and Direct3D libraries with more features like DirectSound and DirectInput which OpenGL was lacking. Even now most of the CAx applications and games use either OpenGL or DirectX. Virtual reality Modeling Language (VRML) based on Open Inventor, enabled programming and visualization at a high end, which was not possible earlier. The Graphical World Wide Web (WWW) is started with the release of NCSA Mosaic in 1993. With this began the new 'collaborative' design approach in CAD. Later on Netscape and Internet Explorer quickly captured the browser market. Late 1990s saw the development platform independent Java3D API, web applications and browsers. The latest Windows Presentation Foundation (WPF) by Microsoft supports declarative programming through XAML. Another area of intense work and competition is in providing hardware acceleration for the graphical rendering pipeline. Many Companies particularly NVIDIA and ATI are making better and faster Graphics Processing Units (GPUs) using which many of the calculations can be done at the hardware level. Khronos group has come up with OpenVG and Scalable Vector Graphics (SVG) for the vector graphics world. With easy availability of GPUs, Vector graphics is making fast inroads to desktop graphics. Particularly the new Windows release (Vista) by Microsoft relies heavily on GPUs and Vector Graphics. Rendering based on ray tracing and vector graphics is becoming popular in many visualization tools. Many research papers suggest that Ray Tracing becomes feasible when the scene has more than a million polygons [12]. Other developments in Computer Science like data sharing standards (for example XML), language and platform independent programming, parallel processing and Rich internet Applications(RIA's) have enabled development of independent modules and integration at a later stage [13]. The usage of various graphics techniques in CAx is presented in Table2.

Stage	Role of Graphics	Commercial Tools
Concept/Preliminary / Detailed Design/ Prototyping	Creation of initial geometric entities, free form curves and surfaces; Tolerance analysis, detailing and drafting; Geometric and Solid modeling;	CAD tools like CATIA, UG, PRO-E, IDEAS,
Analysis and Optimization	Pre and processing of large analysis data	Hypermesh, PATRAN, LS-POST
Manufacturing simulation & Data generation	Visualization of tool paths, Assembly sequence visualization; Virtual prototyping	DELMIA, NC modules of CAD tools
Testing	1D/ 2D/ 3D visualization of physical test data	Internal and commercial tools
Maintenance	Visualization of damage and repair data	Internal and commercial tools

Table 1: Role of Graphics in Various Stages of Product Development

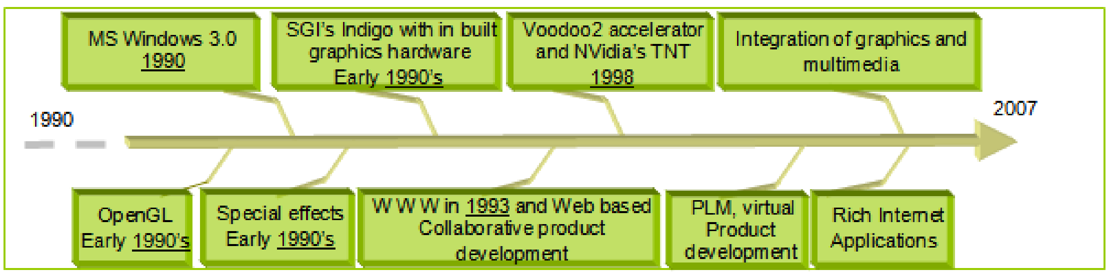


Fig3. Computer Graphics Current trends

Activity	Technique Used
Drawing generation	2D GUIs and 2D Graphics
3D model generation	2D/3D GUIs, 3D Graphics, texturing, bump mapping, environment mapping, Morphing
Digital mockup, Assembly, Disassembly, Collision Checks	3D Graphics, Animation, texturing, bump mapping, environment mapping, Morphing, Virtual reality concepts, Augmented reality concepts
Data Visualization	2D/3D GUIs, 2D/3D Graphics, Contour generation, multitexturing, mipmapping, texture cube, special effects, stencil and depth buffering, point based rendering, volume rendering, image based rendering
Large Data Modeling (LDM)	Tile based rendering, GPU based rendering
Analysis & Optimization	3D Graphics, Mesh generation concepts, Animation, Deformable body physics, Contour generations
CFD	Scalar and Vector Volume Visualization
Manufacturing simulation & Data generation	Collision detection, Path generation algorithms
Testing	2D/3D GUIs, Image processing, Volume visualization
Maintenance, Structural health monitoring	Volume visualization, Image Processing, pattern recognition
Training	Animation, multimedia, virtual reality, augmented reality

Table 2: Usage of Computer graphics Techniques in CAD

5.0 Future role of computer graphics

In 2007 among CAD users, 63% are still working in 2D, and 37% work in 3D [13]. Revenues for 3D CAD programs are higher. In all revenues for 3D CAD accounted for 53% of the market and 2D CAD accounted for 47% of the market. Development of modern day cellular networks, wherein data acquisition and data interpretation can be done using Mobile devices, has made life easy in fields like Geographical Information Systems (GIS), Location based services (LBS). The virtual and augmented reality concepts [14] are going to help engineers, technicians and shop floor personnel in effective and improved communication from design concept to final finished product. Another area that holds promise for the future is integration of Vision, Audition, Olfactory, Vestibular and Haptics [15]. The future of product development systems will be integrated knowledge based systems. Computer graphics plays a major role in knowledge elicitation, storage and dissemination. Computer graphics will also play major role in analyzing the large volume data in real time and help in realizing optimal designs with improved productivity and quality. Voxel based volume visualization concepts have lot of potential in health monitoring and maintenance of mechanical systems. Visualization and representation of Nano-materials at nano scale will pose many challenges for computer graphics. Ubiquitous Computing (or Pervasive Computing) is a future technology that would be always available, often monitoring or anticipating the user's needs, even when the user was not explicitly aware of the technology [16]. The main issue for computer graphics seems to be the potential lack of need for sophisticated 3D graphics to accompany small portable pieces of computers [17]. With all the promise of exciting developments like Ubiquitous Computing, Software as a service(SAS), 3d printing, mobiles and cellular networks, it can be confidently stated that 'Imagination is the only limit for Computer Graphics development'(Fig4).

6.0 Conclusions

Computer graphics played a vital role in the engineering product development from conceptual design to manufacturing and post production stages. CG helped in creating improved products with reduced cycle time. Digital prototyping and manufacturing is being carried out on regular basis in all the new and current product development programs. A brief point of view on how computer graphics have helped in engineering product development is presented along with some thoughts on future applications of computer graphics.

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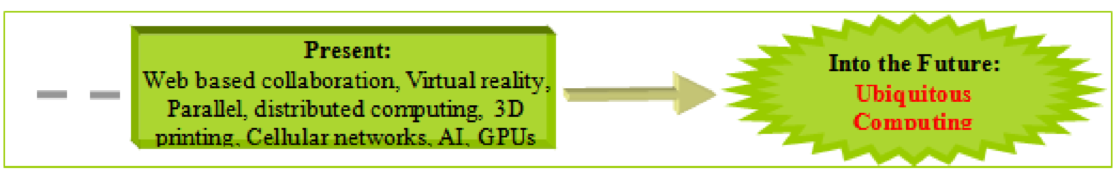

Fig4. Future of CAx

References

1. Frank Nielsen," Visual Computing: Geometry, Graphics and Vision",2005
2. Rogers, D.F., and R.A.Earnshaw: Techniques for Computer Graphics,1987.
3. www.cs.fit.edu/~wds/classes/graphics/History/history/history.html
4. http://accad.osu.edu/~waynec/history/timeline.html
5. Piegl, L. and Tiller, W., The NURBS Book, 2nd Edition, Springer Verlag Berlin, 1997
6. www.cs.cmu.edu/~ph/nyit/morrison/1970s.txt
7. Foley,J.D., and A.Van Dam: Fundamentals of Interactive Computer Graphics,1982
8. http://hem.passagen.se/des/hocg/hocg_1960.htm
9. "Exploring a Boeing 777: Ray Tracing Large-Scale CAD Data", doi.ieeecomputersociety.org /10.1109/MCG.2007.147.www.cadanda.com/CAD_4_6__04.PDF
10. www.cs.cmu.edu/~ph/nyit/morrison/1990s.txt
11. http://www.intel.com/technology/itj/2005/volume09issue02/art01_ray_tracing/p10_authors.htm.
12. http://en.wikipedia.org/wiki/Rich_Internetapplication
13. http://www.jonpeddie.com/special/CAD_report.shtml
14. www.avl.iu.edu/~ewernert/I590_VR/lecture3.1.pdf
15. http://ubiqcomputing.org/Overview.pdf
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