Computer Graphics Applications in the Education Process

Biju Bajracharya

Ball State University

bajracharya@bsu.edu

Jeyaprakash Chelladurai

Lock Haven University of Pennsylvania

jxc136@lockhaven.edu

Abstract
Computer graphics have played an important role in information and computer technology studies. It touches many facets of everyday activities: online or offline digital content. Traditionally, computer graphics were studied and researched by computer scientists or programmers to design and develop tools to create graphics and media content. Computer graphics tools and techniques are used by artists for creation of digital artifacts with media rich digital content. With proliferation of various graphic tools, rapid production of new computer hardware capabilities, and cost affordability, educational systems and business enterprises are adopting computer graphics for data visualization, graphical data processing, interactive learning, immersive learning, virtual and augmented reality, presentations, etc. This paper introduces the topic of computer graphics, its history and potential applications of computer graphics, in educational systems that can open new perspective for educators.

Introduction

Traditional forms of art, before the advent of the printing press and mass communication, are paintings, sculpture, and architecture. Development of traditional art form over thousands of years, graphic design, emerged as one of the most advanced forms of visual communication and expression (Kim & Geissbuhler, 2018). According to Hembree (2006), graphic design serves as a method for improving society through effective communication that makes complicated things easier to understand and use. Design helps people, as in how to navigate or assemble something such as assembling drawing, assembly instruction of basic computer, etc. It identifies and informs the public about a wide range of topics, from a company and its products or services. A designer conveys complex ideas in a simple and effective manner (Hembree, 2006).

Advent of computer technologies transformed visual communication media including blueprints, charts, diagrams, schematics, tables, drawings, posters, maps, cartoons, comic books, etc. into a digital form. Visual communication tools are replaced with computer software. Digital graphics created by computer software are called computer graphics. Computer graphics has got much attention in interactive learning software, multimedia software, online courses and many other applications. It is one of most important component of computer-assisted learning system, which is an educational application area with tremendous potential.

Many students are visual learners; therefore, computer graphics models have the potential to help these students to understand problems that they would not thoroughly understand simply through reading about them or solving word problem. Traditionally, teachers have been using non-computer-based simulations in their classrooms, in the form of science labs and demonstrations. As a result, teachers recreated and modeled these situations using hands-on materials and props. This approach has many disadvantages as it requires extensive labor work, necessary participation of a larger number of people to show the demonstration and it could take several days. With the advancements in technology and computer graphics methods and tools, educators can create virtual objects that obey the laws of nature. These tools allow users to save time and effort by conducting virtual experimentation.

A Brief History of Computer Graphics

The term "Computer Graphics" was coined in 1960 by William Fetter, a graphics designer for Boeing. This term has been recognized as common language following the publication of Ivan Sutherland's PhD thesis on the Sketchpad program at MIT (Sutherland, 1964). Computer Graphics can be defined as use of computers to create and manipulate digital images. Sutherland's Sketchpad was the first fully functional interactive Graphical User Interface (GUI) for drawing primitives such as lines, circles, and polygons and perform operations such as clipping and zooming on those primitives with the use of a light pen. Through the invention of Sketchpad, Ivan Sutherland became known as the "Father of Computer Graphics." Although Sketchpad ran on outdated technology in the form of a 64KB Lincoln TX-2 computer and a monochrome Cathode Ray Tube (CRT) monitor, it grabbed the attention of many researchers for exploring the possibilities of GUI. While the first iteration of Sketchpad was strictly 2D, a few years later Timothy Johnson released Sketchpad 3.0 which expanded its capabilities into three dimensional formats (Johnson, 1963). The CRT display was divided into four familiar views which are widely known today as orthographic front, top, side and perspective. Following the invention of Sketchpad, Sutherland developed the first head mounted display, Sutherland, 1968), which replaced the initial camera device with computer generated images that allowed for remote viewing. This device is now widely known as a virtual reality device. Later, Sutherland's work on hidden-surface removal algorithms gained significant recognition because it solved critical problems in rendering and display technology (Sutherland & Hodgman, 1974). Subsequent advancements in raster algorithms made it possible for the implementation of parametric surfaces, hidden surface removal algorithms, and the use of homogeneous coordinates for differentiating points from vectors. These advancements played a foundational role in the development of projective geometry in 3D graphics (Weiler & Atherton, 1977; Catmull, 1986). Over the past decade, the progression in computer hardware, software, and modeling methodologies has expanded the use of computer graphics to a variety of industries.

Computer Graphics in Education System

The term Computer Graphics covers a broad range of content. For example, the computer graphics-related topics can be found in courses related to computer science, architectural design, mechanical engineering design, arts and design, data visualizations, graphical problem solving, computer simulations etc. Thus, the content of computer graphics education depend on the goals and skills of the area of application, as well as the nature of the student's degree program. Computer graphics courses can be categorized into following groups:

a) **Computer Graphics related to Graphics Development**
Computer graphics courses in computer science, engineering and mathematics primarily cover API based programming languages like OpenGL, WebGL, Python for graphics, OpenCV, etc. These courses typically center on the algorithms, methods, techniques, and models that help companies to identify user insights of how specific principles might work.

b) Computer Graphics in Model Designing and Development
Computer graphics courses in engineering that relate to computer-aided drafting include teaching graphics software like AutoCAD, FreeCAD, Autodesk Inventor, SolidWorks, AutoCAD Architecture, etc. These courses teach how to design components in electrical, mechanical, electromechanical, and electronic devices those necessary for building automobile bodies, civil structures, airplane, ships, optical systems.

c) Computer Graphics for Arts, Games, and Graphics Design
Computer graphics for arts, movies, games, and graphics design courses includes teaching software like Photoshop, InkScape, GIMP, Autodesk Maya, Blender, Cinema 4D etc. These courses primarily teach how to use graphical tools to create and manipulate artistic or computer-generated images. Such images are generated for movies and games, and used in the advertisement of products and services.

d) Computer Graphics for Data Scientist (Simulations and Visualization)
Computer graphics for data analytics courses includes teaching programming languages like Python and, R, and software tools like MatLab, Tableau, Infogram, ChartBlocks, and Datawrapper. These courses employ statistical methods and tools to find interesting patterns among data.

Computer graphics learners studying in the above in the above categories develop customized tools and packages for a wide variety of applications. Several applications are discussed in the following section.

Application Areas of Computer Graphics
With the advent of computer technology, computer graphics has been widely adopted. Traditionally, computer graphics were used to visually represent realistic images in a computer system. Computer graphics are now used as a communication medium to express ideas that either can't be communicated using words or are easier to understand when presented using visual imagery. These days, computer graphics are used in many facets of everyday activities to improve the quality and speed of the user's work. This increased efficiency has been aided by the rapidly increasing power and flexibility of consumer graphics hardware. hardware. Today's standard PC has the capability to render very complex 3D scenes. Through the effort of researchers and developers who design efficient algorithms, users are now able to carry out a wide range of visualization tasks (Ganovelli, Corsini, Pattanaik, & Benedetto, 2015). Additional application areas are discussed below.

Computer Graphics as Communication and Presentation Medium
Computer graphics are used in web design which is the skill of designing presentations of content usually with hypertext or hypermedia. This content is delivered to end-user through the

World Wide Web (WWW), with the aid of a Web browser. The process of designing web pages, web sites, web applications or multimedia for WWW may involve multiple disciplines, such as animation, authoring, communication design, corporate identity, graphic design, human-computer interaction, information architecture, interaction design, marketing, photography, search engine optimization, and typography.

Computer Graphics in Entertainment, Games, and Creative Art

Computer-generated images are used for movie making, video games, and the design of catalogs and other commercial arts. Most Hollywood movies are shot inside a studio room in front of blue or green screens known as background plates. These colored plates are replaced with computer generated imagery or overlapped with other real images (often, with many layers) during the post-production stage. This work is made possible using software like Adober After Effects, Nuke, Cinema 4D, etc. This technique, known as Visual Effects (VFx), significantly cuts the cost of movie making because the background plates can be replaced with virtual environments or stock footages available from the internet. Accessing this technology is significantly less expensive than filming on live locations or on mock studio sets. Computer generated images used in games, however, these images are generated and rendered in real-time based on how a player moves during the game. A more current technology, known as Virtual Reality (VR) allows users to interact with a computer-simulated environment with a head-mounted. The simulated environment can be made to feel like the real world when designed for virtual tourism or simulations for pilot or combat training. Virtual Reality has been used to describe a wide variety of applications, commonly associated with its immersive, highly visual, 3D environments. Video games are played in highly immersive 3D environments with commercially available VR headsets like the Samsung Gear VR, HTC Vive, and Microsoft HoloLens (augmented reality). Computer graphics is also widely used in image processing. For example, computer graphics can be used to color grade movie shots to ensure uniformity of lighting between scenes. It is also used for generating 3D models from a set of 2D images, which is the reverse process of getting 2D images from a 3D scene (Moons, 2008). Computer graphics are to create art on a computer in digital form. The impact of digital technology has transformed traditional activities such as painting, drawing and sculpture with drawing and painting on a tablet, or creating and sculpting a model with 3D graphics software like Maya and Blender.

Computer Graphics as Designing Tool

The area of design and drawing was one of the earliest and most useful application areas of computer graphics. In all areas of engineering, civil, mechanical, electronic, etc., drawings are said to be the language of engineers. The ability of computers to store complex drawings and display them on demand triggered the development of Computer Aided Design (CAD) software. Using CAD software, results from engineering calculations can be drawn on the screen. If the design needs to be changed, the values of parameters in formulas are modified and the results are immediately seen on the screen. In architectural and landscape visualization, walk through animations are performed in the virtual models before actual construction. The Vegreville egg, a Ukrainian-style Easter egg and a major tourist attraction in Alberta, Canada was the first physical structure designed entirely with CAD (Lesiv, 2010). CAD software such asSolidwork, allows Computer Aided Manufacturing (CAM). While teaming, integrated CAD technology with Computer Numerical Control (CNC) machines, virtual models can now be printed using a 3D

printer (Berman, 2013). CAD is also used to produce computer animated special effects for movies, advertising, and technical manuals.

Computer Graphics as Analysis Tool

Due to the proliferation of data (known as big data) in recent times, resulting from the increased use of online websites and social media, computer graphics are being used more frequently in information visualization and data analytics. Information visualization is the study of the visual representation of large-scale collections of non-numerical information, such as files and lines of code in software systems and the use of graphical techniques to help people understand and analyze data. The field of information visualization focuses on ways to convey abstract information. Using the improved processing power of computers, users are able to use information visualization to identify and communicate relationships among data. Data analytics is now an indispensable part of all applied research and problem solving in industry. The most fundamental data analysis approaches are visualization (histograms, scatter plots, surface plots, tree maps, parallel coordinate plots, etc..), statistics (hypothesis test, regression, principal component analysis, etc.), data mining, and machine learning methods (clustering, classification, decision trees, etc.) Information visualization, or visual data analysis, is dependent on the cognitive skills of human analysts but it allows for the discovery of interesting patterns among data. Analysts do not have to learn any sophisticated methods to be able to interpret the visualizations of the data (El-Assady, Sevastjanova, Keim, & Collins, 2018). Visualization of large text data has applications in domains like stock exchange, ecosystem modeling, and space research.

Computer Graphics in Biology and Medicine

Along with the increased accessibility of hardware technology and interactive devices, the use of computational simulation graphical models began to rise in the field of biology and medicine. A computer simulation model also known as a computational model is a computer program, or network of computers, that attempts to simulate an abstract model of a system under study. These computational models offer the speed necessary to simulate and visualize models at interactive or close-to-interactive rates.

The use of computational techniques increasingly pervades developmental biology, from the acquisition, processing and analysis of experimental data, to the construction of models of virtual organisms and their development with unprecedented visual fidelity. General-purpose mathematical software (e.g. Mathematica and Matlab), modeling programs (e.g. GFtbox), and more specialized packages for modeling plants (e.g. Virtual Laboratory, L-studio, OpenAlea, and Virtual-Leaf) facilitate model construction (Kennaway, Coen, Green & Bangham, 2011; Prusinkiewicz, 2004; Pradal, Dufour-Kowalski, Boudon, Fournier, & Godin, 2008; & Merks, Guravage, Inze, & Beemster, 2010).

Software tools, such as Virtual Touch software being developed by Sonny Chan at the University of Calgary use advanced interactive computing technologies such as haptic devices to improve medical education and healthcare delivery (Mostafa, Ryu, Takashima, Chan, Sousa, & Sharlin, 2017; Ryu, Dharampal, Mostafa, Sharlin, Kopp, Jacobs, et al., 2017; Won, Hwang, Lim, Cho, Paek, Lossorelli, Salisbury, & Blevins, 2017). Chan's research group primarily investigates computational methods in image analysis, computer graphics, medical visualization, haptic

rendering in 3D environments, and immersive simulation that help medical professionals utilize medical image data.

Benefits of Computer Graphics in Education

Some of the major benefits of computer graphics education are:

- It allows virtual experiments to be conducted on virtual models that obeys the laws of nature. An example is the L-Studio/V-Lab for modeling and visualizing plants, developed by Prusinkiewicz (2004) and his research group, which makes it possible to simulate plant development with unprecedented biological and visual fidelity. Such tools can be used to teach difficult concepts and working principles with ease.
- It allows users to create simulation models of natural systems in computational physics, chemistry and biology; human systems in economics, psychology, nursing, and social science; and new technologies to study systems and observe behaviors. (Eylon, Ronen, & Ganiel, 1996; Jimoyiannis & Komis, 2001; & Konieczny, 2016).
- In the plan update from U.S. Department of Education (2017), it discusses benefits of using new technology in education. According to this report, using digital technology including media rich contents enhance interaction and collaboration among educators and learners. It improves learner's performance and increases learner's accountability. It extends learning beyond classrooms through self-paced education. Students are effective learners when they can learn at their own pace and when they can access digital contents at their convenience. It also helps working professionals to learn and update their knowledge during their free time.

Future of Computer Graphics Applications

Classroom instruction has experienced a shift due to the growth and increased accessibility of digital technologies. Computer graphics technology is evolving and adapting to the latest advancements in hardware and software technologies. The graphics capabilities of computers, connectivity to web-delivered content, and ready access to video mediums, including animated content to augment instruction and interactive educational video games. They have provided considerable potential for application in multiple teaching environments and in unlimited course contexts. The recent emergence of online and offline courseware, including massive open online courses (MOOC), has provided for an immersive computer-based environment with opportunities for self-paced learning. Several online courses are integrated with university curricula and allow users to access useful features like any features like reminders, flash cards, practice quizzes, progress reports etc.

Challenges of Computer Graphics Education

Currently, computer graphics is one of the key components of digital information. Computer graphics have the potential to transform the education system into a modern computer-assisted learning system. Some of the challenges that system reformers face are outlined below:

- The reluctance of educators to adopt new technology (Mumtaz, 2000).
- The cost associated with updating software and hardware (Ali, 2011).
- Rapid technological development makes it difficult for educators to keep abreast of changing tools and methodologies (Ali, 2011).
- A need for course content to reflect current information.

- Most educators with non-computer science background lack education or training to use technology effectively in their teaching (Mumtaz, 2000).

Conclusion

This paper outlined the development of computer graphics technologies and various applications in the educational environment. Computer graphics has grown over the past decade tremendously due to the advancements in algorithms, hardware, and software technologies. After working to address any local challenges, educational systems can employ computer graphics to enhance meaningful and flexible learning opportunities for students.

References

Ali, A. (2011). Software Upgrade Cost Justification – Making a Case. *Proceedings of the 2011 InSITE Conference*. doi:10.28945/1441

Berman, B. (2013). 3D printing: The new industrial revolution. *IEEE Engineering Management Review,41*(4), 72-80. doi:10.1109/emr.2013.6693869

Catmull, E. E. (1986). A subdivision algorithm for computer display of curved surfaces. *Ann Arbor, MI: University Microfilms International* (300 N. Zeeb Road, Ann Arbor, Michigan 48106).

El-Assady, M., Sevastjanova, R., Keim, D., & Collins, C. (2018). Thread Reconstructor: Modeling Reply-Chains to Untangle Conversational Text through Visual Analytics. *Computer Graphics Forum,37*(3), 351-365. doi:10.1111/cgf.13425

Eylon, B., Ronen, M., & Ganiel, U. (1996). Computer simulations as tools for teaching and learning: Using a simulation environment in optics. *Journal of Science Education and Technology,5*(2), 93-110. doi:10.1007/bf01575150

Ganovelli, F., Corsini, M., Pattanaik, S., & Benedetto, M. D. (2015). *Introduction to computer graphics: A practical learning approach*. Boca Raton: CRC Press.

Hembree, R. (2006). *The Complete Graphic Designer: A Guide to Understanding Graphics and Visual Communication.* Rockport Publishers.

Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning: A case study on students understanding of trajectory motion. *Computers & Education,36*(2), 183-204. doi:10.1016/s0360-1315(00)00059-2

Johnson, T. E. (1963). Sketchpad III: *Proceedings of the May 21-23 1963, Spring Joint Computer Conference on - AFIPS 63 (spring).* doi:10.1145/1461551.1461592

Kennaway, R., Coen, E., Green, A., & Bangham, A. (2011). Generation of Diverse Biological Forms through Combinatorial Interactions between Tissue Polarity and Growth. *PLoS Computational Biology,7*(6). doi:10.1371/journal.pcbi.1002071

Kim, H. H., & Geissbuhler, S. (2018). *Graphic design discourse: Evolving theories, ideologies, and processes of visual communication.* New York: Princeton Architectural Press.

Konieczny, L. (2016). Using High-Fidelity Simulation to Increase Nursing Student Knowledge in Medication Administration. *Teaching and Learning in Nursing,11*(4), 199-203. doi:10.1016/j.teln.2016.08.003

Lesiv, M. (2010). From Ritual Object To Art Form: The Ukrainian Easter Egg Pysanka In Its Canadian Context. *Folklorica,12*(0). doi:10.17161/folklorica.v12i0.3782

Merks, R. M., Guravage, M., Inze, D., & Beemster, G. T. (2010). VirtualLeaf: An Open-Source Framework for Cell-Based Modeling of Plant Tissue Growth and Development. *Plant Physiology,155*(2), 656-666. doi:10.1104/pp.110.167619

Moons, T. (2008). 3D Reconstruction from Multiple Images Part 1: Principles. *Foundations and Trends® in Computer Graphics and Vision,4*(4), 287-404. doi:10.1561/0600000007

Mostafa, A. E., Ryu, W. H., Takashima, K., Chan, S., Sousa, M. C., & Sharlin, E. (2017). ReflectiveSpineVR. *Proceedings of the 5th Symposium on Spatial User Interaction - SUI 17*. doi:10.1145/3131277.3132174

Mumtaz, S. (2000). Factors affecting teachers use of information and communications technology: *A review of the literature. Journal of Information Technology for Teacher Education, 9*(3), 319-342. doi:10.1080/14759390000200096

U.S. Department of Education (2017). Reimagining the Role of Technology in Education: 2017 National Education Technology Plan Update.

Pradal, C., Dufour-Kowalski, S., Boudon, F., Fournier, C., & Godin, C. (2008). OpenAlea: A visual programming and component-based software platform for plant modelling. *Functional Plant Biology,35*(10), 751. doi:10.1071/fp08084

Prusinkiewicz, P. (2004). Art And Science Of Life: Designing And Growing Virtual Plants With L-Systems. *Acta Horticulturae*,(630), 15-28. doi:10.17660/actahortic.2004.630.1

Ryu, W. H., Dharampal, N., Mostafa, A. E., Sharlin, E., Kopp, G., Jacobs, W. B., . . . Sutherland, G. R. (2017). Systematic Review of Patient-Specific Surgical Simulation: Toward Advancing Medical Education. *Journal of Surgical Education,74*(6), 1028-1038. doi:10.1016/j.jsurg.2017.05.018

Sutherland, I. E. (1964). Sketch pad a man-machine graphical communication system. *Proceedings of the SHARE Design Automation Workshop on - DAC 64.* doi:10.1145/800265.810742.

Sutherland, I. E. (1968). A head-mounted three-dimensional display. *Proceedings of the December 9-11, 1968, Fall Joint Computer Conference, Part I on - AFIPS 68 (Fall, Part I)*. doi:10.1145/1476589.1476686

Sutherland, I. E., & Hodgman, G. W. (1974). Reentrant polygon clipping. *Communications of the ACM,17*(1), 32-42. doi:10.1145/360767.360802

Weiler, K., & Atherton, P. (1977). Hidden surface removal using polygon area sorting. *Proceedings of the 4th Annual Conference on Computer Graphics and Interactive Techniques - SIGGRAPH 77*. doi:10.1145/563858.563896

Won, T., Hwang, P., Lim, J. H., Cho, S., Paek, S. H., Losorelli, S., Salisbury, K., Blevins, N. H. (2017). Early experience with a patient-specific virtual surgical simulation for rehearsal of endoscopic skull-base surgery. *International Forum of Allergy & Rhinology,8*(1), 54-63. doi:10.1002/alr.22037