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# A CONSENSUS ON THE DEFINITION AND KNOWLEDGE BASE FOR COMPUTER GRAPHICS

A Dissertation

Submitted to the Faculty

of

Purdue University

by

Michael Alden Roller

In Partial Fulfillment of the

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of

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To my family–for their unconditional and steadfast support in all I do.
To my students–may this work guide and inspire you.

"Look to the diffusion of light and education as the resource most to be relied on for ameliorating the condition, promoting the virtue and advancing the happiness of man." - Thomas Jefferson, 1822

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# LIST OF ABBREVIATIONS

AI: Artificial Intelligence

API: Application Program Interface

ASM: Association for Computing Machinery

CA: Computer Art

CE: Computer Engineering

CG: Computer Graphics

CS: Computer Science

CT: Computer Technology

DI: Digital Imaging

HCI: Human Computer Interaction

IT: Information Technology

IS: Information Systems

IxD: Interaction Design

SE: Software Engineering

# NOMENCLATURE

Computer-aided Design (CAD) – software is used by architects, engineers, drafters, artists, and others to create 2D or 3D precision drawings or technical illustrations.

Characteristics – one of the sixteen major headings developed by Alley (2006) that denotes the working knowledge base for Computer Graphics. These headings include Fundamentals, Professional Issues, Physical Science, Mathematics, Perception and Cognition, Human Computer Interaction, Programming and Scripting, Animation, Rendering, Modeling, Graphic Hardware, Digital Imaging, Communications, Art and Design Foundations, Real-Time Graphics, and Visualization.

Graphical User Interface (GUI) – a visual way of interacting with a computer using items such as windows, icons, and menus, used by most modern operating systems.

Intellectual Property – a work or invention that is the result of creativity, such as a manuscript or a design, to which one has rights and for which one may apply for a patent, copyright, trademark, etc.

Light Pen– a handheld, pen-like photosensitive device held to the display screen of a computer terminal for passing information to the computer.

Non-disclosure Agreement – a contract by which one or more parties agree not to disclose confidential information that they have shared with each other as a necessary part of doing business together.

Oscilloscope – a device for viewing oscillations, as of electrical voltage or current, by a display on the screen of a cathode ray tube.

Radiosity – a method of rendering photo-realistic images based on a detailed analysis of light reflections off diffuse surfaces.

Raster Image – In computer graphics, a raster graphics image is a dot matrix data structure representing a generally rectangular grid of pixels, or points of color, viewable via a monitor, paper, or other display medium.

Shader –a computer program that is used in the production of appropriate levels of color within an image, or, in the modern era, also to produce special effects or do video post-processing.

Vector Image – graphics created by using mathematical algorithms, which allow the image to be scaled or modified without loss of image quality or resolution

# ABSTRACT

Roller, Michael Alden. Ph.D, Purdue University, May, 2016. A Consensus on the Definition and Knowledge Base for Computer Graphics. Major Professor: James L. Mohler.

Despite several decades of historical innovation, measurable impacts, and multiple specializations the existing knowledge base for Computer Graphics (CG) lacks consensus, and numerous definitions for it have been published based on distinct contexts. Disagreement among post-secondary academics has divided CG programs into three contextual areas that emphasize different topics. This division has resulted in the decontextualization of CG education, and CG programs now face several challenges in meeting the needs of industry. Employing the Delphi Method, this investigation explored the perceptions among post-secondary educators and industry professionals about the definition of CG and how it is identified in terms of characteristics and context. The outcomes of this investigation identified CG in the technological paradigm, and provided a roadmap towards a true definition and distinct knowledge base necessary for establishing CG as a formal computing discipline.

# CHAPTER 1. INTRODUCTION

This study examined the various characteristics and contexts among two homogeneous groups related to one area of computing, Computer Graphics (CG). The findings clarified the relationship between CG and Computer Science (CS), and provided a definition and a contemporary knowledge base for CG based on a large-scale consensus.

Computing has impacted a broad range of scientific, educational, creative, and communication disciplines in both transparent and opaque ways by creating new and innovative methods for people to achieve tasks, create or use products and services, entertain, and collaborate (Alley, 2006; Charmonman, 2000; Gips, 1990; Jones, 1990; Smith, 1985). The definitions for computing and technology are numerous, resulting in much debate and discussion (Association for Computing Machinery, 2008; Charmonman, 2000; DeVries, 2005; Feenberg, 2006; Mitcham, 1994). Given the speed in which computing develops and the rate at which people adopt it, several theories, models, and pedagogical approaches have been put into practice for the teaching and learning of computing disciplines within post-secondary educational institutions (Alley, 2006; Association for Computing Machinery, 2008; Charmonman, 2000; Gips, 1990; Jones, 1990; Keirl, 2006; Kitson, 1991).

The challenge of balancing artistic principles with the scientific and technical aspects centric to computing continues to raise questions for educators about curricula that meet industrial needs. Many technology programs in higher education remain grounded in the operational aspects of computing for scientific, engineering, and industrial applications (Association for Computing Machinery, 2008; Jones, 1990). However, industrial innovation and the pervasiveness of technology in contemporary society and culture, especially among homogenous groups, have led to the decontextualization of many computing and technology disciplines (Courte & Bishop-Clark, 2009). Decontextualization has led to the inconsistent application and practice of the established computing disciplines and the rise of new areas of computing that contradict definitions and standards.

## 1.1. Statement of the Problem

Despite decades of historical innovation, measurable impacts, and multiple areas of specialization, the definition and knowledge base for CG lacks consensus among experts. Additionally, the perceptions about CG has resulted in a multitude of definitions based on various contexts. Disagreement among post-secondary academics on what CG programs must emphasize in order to meet the needs of industry remains a challenge for higher education (Anderson & Burton, 1988; Aoki, Bac, Case, & McDonald, 2005; Bailey, Laidlaw, Moorhead, & Whitaker, 2004; Hartman, Sarapin, Bertoline, & Sarapin, 2009; Hitchner & Sowizral, 2000; Paquette, 2005). Both of these problems have led to a significant decontextualization of the computing disciplines in post-secondary programs, placing academic communities in a difficult position on how to best prepare students to meet employer expectations and the needs of market sectors.

## 1.2. Statement of Purpose

The purpose of this study was to gain, through qualitative methods, a general consensus about the definition and characteristics of CG among post-secondary academics and industry professionals. Additionally, the goal of this study was to clarify the relationship between CG and CS, and to provide a core curriculum framework for CG for educators in post-secondary programs.

## 1.3. Research Questions

The research undertaken by this study attempted to answer one main question – What are the prevalent characteristics that define CG and its knowledge base among industry professionals and post-secondary academics? Several ancillary questions were addressed in this study, including:

1. What are the shared applications for CG among industry professionals and post-secondary academics?
2. What shared methodologies for CG are evident among industry professionals and post-secondary academics?
3. What distinguishes CG from CS?

## 1.4. Significance

The literature denotes several definitions for CG depending on the context and how it is practiced (Aoki et al., 2005; Bailey et al., 2004; Bliss, 1980; Plazzi, Carlson, Lucas, Schweppe, & Yanilmaz, 1989; Skog, Ljungblad, & Holmquist, 2002; Snelson, Weber, Csuri, & Longson, 1990). The application of CG also depends on the context, and varies significantly within industrial sectors. For example, marketing and design entities use desktop publishing software and image manipulation technologies to create promotional materials, while science and entertainment entities may use the same technologies and applications to create 3D animations and visualizations. Each entity represents a different context, so the role CG has in producing products may influence a person's perspective about it, and in turn may broaden the CG knowledge base. Additionally, these broadening contexts present a challenge for CG educators who are responsible for identifying the topics and core competencies that academic programs must emphasize in order to better prepare students to meet the needs of current and future markets.

### 1.4.1. Main Contributions

The main contributions of this study included the individual perspectives and experiences of industry professionals and post-secondary academics about the characteristics and definitions for CG. The study also described the topics and approaches leading CG programs emphasize in their undergraduate curricula. Additionally, the study identified the differences about CG among industry professionals and post-secondary academics across multiple market sectors.

### 1.4.2. Discoveries

Knowledge about the current state of CG practice and application was a key discovery of this research. Specifically, outcomes suggested that visual problem solving is just as important to CG as technical skills. Additionally, knowledge acquired by this research suggested that the application of CG is unconstrained and beneficial to multiple disciplines. Outcomes also suggested that CG may lead to new applications and directions that will require new policies and standards of practice.

### 1.4.3. Importance

The outcomes of this study provided contemporary knowledge and insights toward developing a definition and knowledge base for CG. These new insights are especially important for post-secondary educators who strive to prepare students to meet the expectations of industrial markets. In turn, this study is also important for industry professionals who want to understand the nature of CG education and practice, and best utilize it to meet industrial needs.

## 1.5. Assumptions

The researcher identified specific assumptions that were generally accepted as being true among his peers and audience. Assumptions evident in the fulfillment of this study included:

1. Participants had no physical disabilities that limited their ability to use standard computer equipment and display devices.
2. Participants were proficient in the use of online communication technologies and web-based communications tools.
3. Participants had no intent to falsify or mislead the study.
4. Participants were able to access all surveys and provide feedback to the researcher.
5. Participants had no knowledge of or contact with one another during the course of the study.

## 1.6. Limitations

Creswell (2002) defined limitations as a way to "identify potential weaknesses of the study" (p.110). Limitations evident in the fulfillment of this study included:

1. Participants' level of cooperation and their availability.
2. Participants' participation throughout the course of the study.
3. Participants' lack of commitment due to professional or personal priorities and obligations.
4. Participants' inability to provide information due to institutional or employer policies on intellectual property.
5. Participants' inability to provide information due to contractual non-disclosure and non-compete agreements.
6. Participants' for this study were selected according to self-reported information and documents accessible in the public domain.

7. Institutional program and curricula data analyzed for this study was limited to ten programs.
8. Institutional program and curriculum data analyzed for this study was limited to documents and information accessible in the public domain.
9. The collective experiences of participants do not reflect all of the genres and areas of practice for which CG is evident.
10. Some participants voluntarily refrained from the member check process to the questions posed in the first round interviews.
11. Consensus for this study was defined by subjective values established in the literature.

## 1.7. Delimitations

Creswell (2002) defined delimitations as a way to “address how the study will be narrowed in scope” (p.110). Delimitations evident in the fulfillment of this study included:

1. The population for the study only included post-secondary educators and senior industry professionals employed at academic institutions and businesses located within the United States of America.
2. Data was accessed and collected between January 1, 2015 and August 30, 2015.

## 1.8. Summary

Chapter one provided an overview of the study; the statement and significance of the problem; the scope and purpose for the research; the questions addressed by the research; and the major limitations, delimitations and assumptions imposed on the investigation. The following chapter provides the justification for the research based on published literature to date.

# CHAPTER 2. REVIEW OF LITERATURE

Literature about CG is extensive in both theoretical and applied contexts. Thus. the researcher limited the literature review to topics relative to the research objectives posed by this study. Although this approach may not encompass all of the seminal research related to CG, the intent was to formulate a review that established a solid justification for this investigation, and to limit the review to pertinent works centric to the research questions.

First, the literature on the philosophical delineation of technology provided the rationale for how technology is defined. Second, a review of literature about the foundations of computing and the establishment of the computing disciplines provided the historical relationship and connections between computing, technology, and CG. Third, a review of literature about ontological and epistemological questions within CS programs provided insight about how computing is perceived. Finally, a review of literature on post-secondary education and pedagogy described the critical issues facing technology educators today. Within these topical areas, the researcher concentrated on interconnecting previous work germane to the research undertaken in this study that directly addressed the research questions.

## 2.1. Philosophical Delineations of Technology

Defining technology is a difficult task and several theories and approaches have been proposed on the subject (DeVries, 2005; Feenberg, 2006; Mitcham, 1994). DeVries (2005) discussed the philosophical connections to technology through the various fields of philosophy, including ontology, epistemology, methodology, metaphysics, and ethics. Feenberg (2006) provided the distinctions between technical, scientific, and modern alternatives for defining technology, specifically how technology “looks to control” while science “seeks to know” (p. 5). Mitcham (1994) conceptualized technology as objects, knowledge, actions, and volitions while dividing the various fields into different approaches for technological education. Although these works may provide a solid framework from which one can define technology, none suggests an absolute definition or a specific approach for doing so. Instead, they only provide informative insights from which one can synthetize a relative definition about technology.

Upon consideration of the aforementioned works, technology seeks to discover knowledge by controlling objects through a series of actions, each dependent upon another, as represented in Figure 2.1.

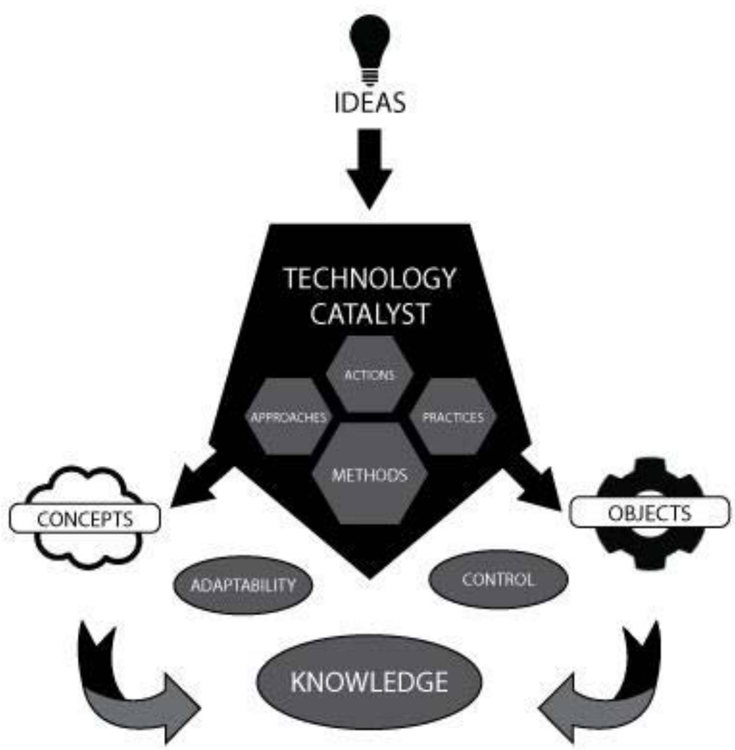


Figure 2.1. The Technology Catalyst.

Additionally, technology is a set of approaches that enhances knowledge through well-defined and constructed practices within specific areas and disciplines. Both sides of this argument can lead to new knowledge. In published literature, Mitcham (1994) and Feenberg (2006) described technology by the actions created to control the essence of an object, suggesting technology is tangible. DeVries (2005) described technology as conceptual, and provided a definition from the origins of technology and historical aspects over time. Thus, the question of whether or not knowledge produced by technology is tangible (which can be applied) or theoretical (that can be conceptualized) remains contested.

What is evident among these positions is that methodology plays a critical role in identifying and defining technology. In the following section, these theories regarding computing technology are examined as it relates to the establishment of the computing disciplines.

## 2.2. The Establishment of the Computing Disciplines

Computing emerged primarily from the field of mathematics, where calculation remained the fundamental priority for thousands of years, evidenced by equations that predicted orbits and fluid dynamics (Corner et al., 1989). These equations were designed to be mechanical and linear, and applicable only for one specific problem. This isolated approach was used until the nineteenth century, when discoveries in the fields of analytical logic and computing machines (based on the work of Babbage and his "analysis engine") facilitated close interaction between mathematics and engineering (Corner et al., 1989). Engineering provided the design component needed to construct the mechanical devices used for executing recursive calculations (Corner et al., 1989).

The cornerstone for the computing disciplines began in the early twentieth century, with the publication of Godel's "incompleteness theorem" and the "Church–Turing" thesis postulated by Alan Turing and Alonzo Church (Copeland, 2000; Corner et al., 1989). These theorems established the ideology that in place of one specific, linear equation for a singular problem, one can solve multiple problems using logic, symbolism, and numerical interpretation via algorithmic procedures. This insight facilitated the development of programming languages, and in conjunction with electronics and information representation, algorithms could now be "encoded in a machine representation and stored in memory for later decoding and execution by a processor" (Corner et al.,1989, p. 11).

In the three decades following 1930, the focus of computing became computationally driven. Computing hardware and maintenance drove the applications and practice of computing, and universities established courses to support this trend (Gupta, 2007). However, beginning in the early 1960's the focus for computing began to shift direction to topics related to programming, heuristics, algorithms, and other practices, mainly due to the insightful leadership and guidance of Louis Fein (Gupta, 2007). In 1968, CS was established as a formal discipline by the ACM, and in turn initiated the rise of the first CS departments at major universities across the United States (Association for Computing Machinery, 2008). The establishment of CS departments marked the separation of computing from the fields of mathematics and engineering within the academy that remains today.

Currently, there are five distinct computing disciplines each addressing specific knowledge areas and application domains: Computer Science (CS), Information Technology (IT), Information Systems (IS), Computer Engineering (CE), and Software Engineering (SE) (Association for Computing Machinery, 2008; Courte & Bishop-Clark, 2009). Figure 2.2 illustrates these disciplines and the foundations upon which they were founded. However, according to a study by Courte and Bishop-Clark (2009), in practice "extensive overlapping between these disciplines occurs" (p. 30). This trend suggests that computing technology and the defined disciplines in which computing is practiced are becoming more interdisciplinary with generalized knowledge areas. In the following section, the researcher will discuss the philosophical paradigms responsible for this trend as it relates to the research questions posed in this study.

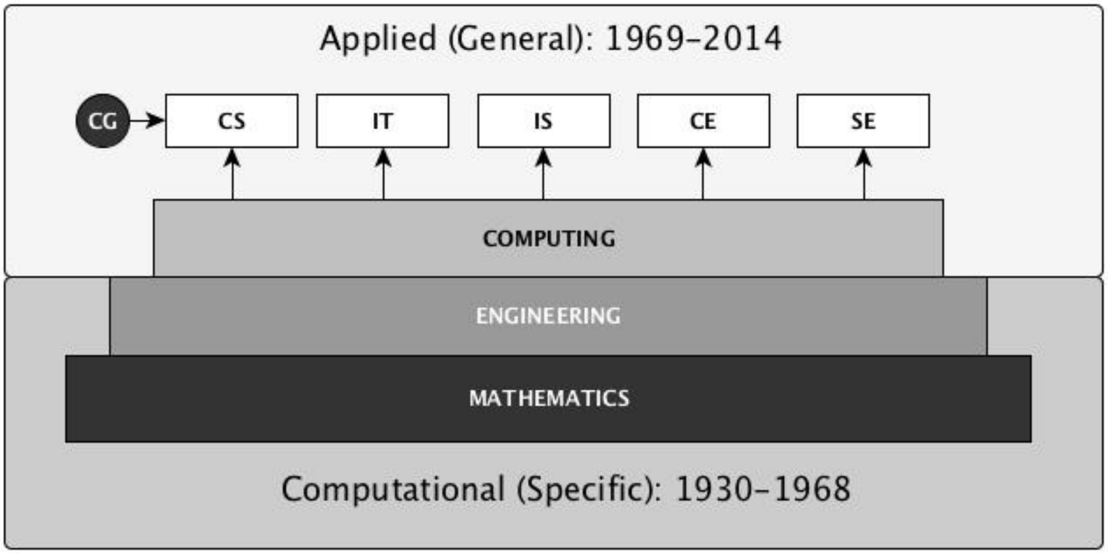


Figure 2.2. The Computing Disciplines.

### 2.2.1. Philosophical Paradigms of Computing Disciplines

Members in most scientific or academic communities subscribe to a set of philosophical beliefs that help shape and define a discipline. These beliefs or paradigms were defined by Kuhn (1968) as "achievements, or normal science" that shared two essential characteristics; "unprecedented to attract an enduring group of adherents away from competing modes of scientific activity, and sufficiently open-ended to leave all sorts of problems for the redefined groups of practitioners to resolve" (p. 10). Biglan (1973) followed up with a more linear definition for paradigms, describing them as a "body of theory that is subscribed to by all members of a field" (p. 210). Kuhn (1968) also identified the importance of scientific education on paradigm acceptance, and how the continual rise in popularity of course textbooks significantly contributes to the formulation and acceptance of paradigms, especially among young scholars. Biglan (1973) agreed, and described how paradigms orientate members of a particular field into a shared directive, which limits deviation from the accepted understanding of what defines a field. These definitions and insights suggest that paradigms create a strong social connection among members, especially in the areas of research, which explains the resistance to any deviation from accepted paradigms by community members.

However, members must challenge existing paradigms in order to advance new ideas. These challenges spark investigations and open pathways leading to new discoveries and fields of practice. These paradigm shifts are highly evident across multiple disciplines, especially within established scientific communities. Kuhn (1968) wrote extensively on paradigm shifts and described them as "scientific revolutions…the extraordinary episodes in which that shift of professional commitments occurs…the tradition-shattering complements to tradition-bound activity of normal science" (p. 6). He went on to provide three core characteristics of paradigm shifts: (1) community rejection of time-honored scientific theory, (2) shift in the problems available for scientific scrutiny and the standards for which a profession determines what should count as an admissible problem or legitimate problem-solving solution, and (3) controversies that almost always accompany shifts in both standards and problem solutions (Kuhn, 1973). In all, paradigm shifts constitute a revolt to known and accepted standards and practices characterized by innovation and change.

Paradigm shifts are not limited to scientific communities. Eden (2007) identified three distinct paradigms germane to CS. First, the "Rationalist" paradigm defined CS as a branch of mathematics centric on deductive reasoning. The "Technocratic" paradigm defined CS as a data-driven, engineering discipline. The "Scientific" paradigm defined CS as a natural (empirical) science grounded on scientific experimentation. Eden (2007) noted that each of these paradigms reflects ontological and epistemological philosophies about computers and programs that are "distinct, inconsistent, and mutually exclusive methodological positions concerning the choice of methods for investigating programs" (p. 137).

Eden's (2007) observations show CS is primarily technocratic, and that most courses in CS programs focus on software, design, and modeling notation in place of traditional computation, theory and logic. Information acquired and reviewed by the ACM supports this trend, as computing now impacts a variety of domains and knowledge areas from Discrete Structures to Graphics and Visual Computing (Association for Computing Machinery, 2008). Additionally, the same report suggested "computing is a broad field that extends well beyond the boundaries of computer science" (p. 4), suggesting a lack of a shared directive and consensus among members of the CS discipline. This would not be the case if CS stayed true to a single paradigm as Biglan (1973) observed, writing "fields that have a single paradigm would be characterized by greater consensus about content and method than fields lacking a paradigm" (p. 202).

Given this evidence from the literature, the definition of a computing discipline is dependent on members of a field following a single paradigm. However, in computing, most members follow a distinct paradigm based on their own philosophical positions on a broad range of issues beyond the discipline itself. Thus, defining a discipline under the existing criteria of established computing disciplines is misleading. Therefore, in addition to methodology, adaptability must be considered as a factor of what and how to identify and define computing technology, and in turn describe a distinct computing discipline.

In the next section, the researcher chronicles the emergence of CG as one area of computing attributed to the technocratic paradigm and its relationship to the fields of mathematics, engineering, computing and CS.

## 2.3. The Emergence of Computer Graphics

The influence and impact of computing on the human condition is highly evident. According to data provided by the ACM, since 1995 around 75% of the economic growth in the United States can be directly attributed to computing and its related systems, hardware, and applications (Association of Computing Machinery, 2008). They also indicated that this growth is attributed to the adaptation of computing technology to various domains, specifically simulation, education, entertainment, and business. This adaptation of computing in ways that were not originally intended has led to new discoveries that have impacted industry and people in a multitude of ways. These discoveries have also led to new directions and application areas for computing, and several computing disciplines now address specific problems and questions that originated from this adaptation (ACM, 2013).

The literature disclosed a reciprocal relationship between computing and graphics. Beginning in the late 1940s, scientists began creating computer-generated images that were displayed on oscilloscopes using analog computers (Jones, 1990). Two decades later, computer engineers, programmers, and technicians developed plotters that produced geometric forms and vector-based graphical objects from digitized computational images (Csuri, 1974; Csuri, 1975; Csuri, Dietrich, Linehan, & Kawano, 1985; Csuri & Shaffer, 1968). Modernization witnessed the growth of computer-based images in the industrial domains of drafting, automation, visualization, and image processing (Csuri, 1985; Jones, 1990; Moltenbrey, 2007), all of which are cornerstones leading up to the contemporary applications of today (Chehimi, Coulton, & Edwards, 2008; Gross, 1998; Igarashi, 2010; Javener, 1994; Kunii et al., 1983; Machover, 1974; Potts, 1974; Skog et al., 2002; Snelson et al., 1990). The following sections highlight the major technological innovations, milestones, and pioneers from 1940 to 2000 that set the groundwork that enabled CG to evolve into its current state.

### 2.3.1. Early Milestones: 1940-1959

One of the cornerstones of CG was established in the field of applied mathematics. During the 1940s, two professors at the Massachusetts Institute of Technology (Committee), Eberle Spencer and Parry Moon, wrote a computer algorithm that generated accurate global lighting models based on the work of H.H. Higbie in 1934 (Masson, 2007). Additionally, in 1950, an artist named Ben Laposky used analog computers and oscilloscopes to generate the first Computer Graphic images (Jones, 1990; Masson, 2007). According to Masson (2007), between 1955 and 1958, MIT pioneer Bert Sutherland designed the first true light pen for use with the SAGE system while his colleagues Steven Coons, Ivan Sutherland, and Timothy Johnson began to manipulate drawn pictures with the TX-2 computer system. In 1957, the US Department of Defense founded the Advanced Research Project Agency (ARPA), which was a major force in the advancement of Graphical Systems (Masson, 2007). Finally, in 1959, Don Hart and Ed Jacks created the first computer-aided drawing system (CAD) called the DAC-1 (Masson, 2007). Each of these milestones represents the beginnings of CG, where the relationship between mathematics, CS, and engineering provided important innovations in image creation, manipulation, and APIs. These innovations would prove an important stepping-stone that would drive rapid advancement for the next two decades.

### 2.3.2. Analog to Digital: 1960-1979

Before 1960, CG was still analog, meaning images required a non-digital system to produce and display an image (Jones, 1990). However, this would rapidly change during the years between 1960 and 1979, where unrestricted ARPA funding was provided to artists, engineers, scientist, and technologists to explore and create without limitation (Masson, 2007).

Between 1962 and 1964, while the first computer game, *Spacewar*, was being created by MIT students Steve and Slug Russell, Shag Graetz, and Alan Kotok, Ivan Sutherland presented his PhD thesis that introduced the first vector drawing system that allowed a user to draw simple primitives on a screen using a light pen (Masson, 2007). In 1963, artist Charles Csuri created computer-assisted drawings based on old masterworks using a custom-built analog computer (Csuri, 1974; Jones, 1990; Masson, 2007). Csuri would also go on to found the first CG program at The Ohio State University in 1965, and create the first vector-animated film, *Hummingbird*, in 1967 (Csuri, 1975; Masson, 2007). In the same year, the first digital film was created by Jack Citron and John Whitney, Sr. at IBM using dot patterns imprinted on 35mm film stock (Masson, 2007). In 1968, University of Massachusetts Department of Art Professor Robert Mallary developed TRAN2, a computer program that created three-dimensional sculptures from mathematical calculations (Jones, 1990; Masson, 2007). In the following year, Alan Kay developed the first Graphical User Interface (GUI) with the Alto Project at Xerox PARC, which would prove in later years to be influential to the design of the Macintosh computer (Masson, 2007).

During the 1970s, many innovations in various areas of CG were made, but none more impactful than in application. In 1972, Nolan Bushnell invented the video game *Pong*, and would eventually found the video gaming console company Atari (Masson, 2007). In the following year, pioneers working at the University of Utah made several advancements in 3D graphic rendering; Edwin Catmull and Frank Crow developed the z-buffer algorithm, texture mapping, and anti-aliasing methods, while their colleague Phong Bui-Toung developed his Phong Shader Method, advancing the applications for 3D graphical objects significantly (Masson, 2007). Additionally, Catmull would also go on to develop TWEEN animation at the New York Institute of Technology in 1975 (Masson, 2007). In that same year, Dr. Benoit Mandelbrot published his paper on fractal geometry, providing the theoretical approach for simulation and recursive rendering (Jones, 1990; Masson, 2007). During 1976 and 1977, two major innovations were made, the first being the development of the Blinn Shader by Jim Blinn, and the second being the application of CG to visualize biological research by Nelson Max, giving birth to scientific visualization (Masson, 2007). Finally, in 1979, Jim Clark developed his “geometry engine” that would lead to the desktop modeling of 3D objects (Masson, 2007). That same year George Lucas hired Edwin Catmull away from NYIT to begin work on three major innovations for his special effects company, LucasFilm; a digital film printer, a digital audio synthesizer, and a digitally controlled video editor (Masson, 2007). The decision to hire Catmull and his colleagues would eventually prove to be a milestone that gave rise to a new industry and revolutionized film-making, as shown in the next section.

### 2.3.3. Rise of Industry: 1980-1999

Prior to 1980, significant work and innovation in CG surged, as well as the technology needed to commercialize it for industrial use. Much of this work took place at major universities or government-supported labs and institutions. However, beginning in 1980, this changed dramatically. Several innovative CG studios were founded, and moved innovation out of the government labs and universities into the private sector. The result of that shift became evident in the film industry during the 1990s, where groundbreaking technology and techniques developed by these new companies would revolutionized the entertainment industry and redefined the meaning of CG.

In 1982, Jim Clark founded Silicon Graphics, Inc. and built IRIS workstations capable of creating high-end computer animations and visualizations. In 1984, the company released its first commercial product, the IRIS 1000 (Masson, 2007). The following year, Wavefront Software Company developed a sophisticated animation package called *PreView* that ran on Silicon's IRIS 1000 (Masson, 2007). Also in 1984, Apple released the Macintosh, allowing artists and designers to visually manipulate two-dimensional graphics using a GUI (Jones, 1990; Masson, 2007; Meggs & Purvis, 2011).

Between 1985 and 1986, two technical innovations were developed relating to 3D scenes. First, Don Greenberg of Cornell University developed Radiosity, and second, Doris Kochanek outlined the I-keyframe interpolating algorithm (Masson, 2007). During this time, Pixar Animation was founded and converted from a hardware development division to a powerhouse for full-length animated films by updating its Marionette and RenderMan proprietary software packages. Later, in 1988, Rhythm and Hues was founded, a notable studio known for artistic mattes and special effects, and Arcca Animation of Toronto, which adapted the first render farm using sun workstations running proprietary software that picked up frames in a sequence as they were completed (Masson, 2007). Later that year, the first use of morphing technology in a feature film occurred when ILM morphed an actor into a goose and back into a human form (Masson, 2007).

Between 1990 and 1999, artists, technologists, and engineers pushed the boundaries of CG technology by constantly improving algorithms and production tools and methods to achieve realism in their final renderings (Masson, 2007). The relationship between engineering, CS, and CG became more intertwined. However, a break from computational mathematics in favor of technocratic methods and tools emerged. This led to a division between theoretical and applied technologies, and the rise of application-centric solutions, detailed in the next section.

### 2.3.4. Expansion: 2000 to 2010

Parallel to the increases in processing power and inexpensive computing hardware, CG applications expanded across multiple disciplines and industries. Significant applications can be seen in the areas of visual science and information processing, multimedia, gaming, information art, scientific visualization, and informatics (Bailey, Laidlaw, Moorhead, & Whitaker, 2004; DiMarco, 2004; Ebert, Buxton, Davies, Fishman, & Glassner, 2002; Próspero dos Santos, 2001; Skog, Ljungblad, & Holmquist, 2002). Literature also suggested the pervading adoption of personal devices and mobile technology will facilitate more CG applications into consumer markets (Igarashi, 2010). Thus, the development of methods and tools to enable personalization, media creation, and shared distribution created a divergence from established definitions found within computing and CS, leading to questions about how CG is to be defined, specifically in relation to the visual arts, technology, or the computing sciences. In the following section, provided excerpts from the literature illustrates this trend.

## 2.4. Computer Graphics Definitions

The popularity of contemporary media has made CG easy to recognize in form, but the history, application and ongoing practice make it difficult to define in established computing criteria. Academic literature provided numerous definitions that reflect the history and applications of CG and its related areas and the various contexts upon how it is perceived (Aoki et al., 2005; Bailey et al., 2004; Bliss, 1980; Plazzi, Carlson, Lucas, Schweppe, & Yanilmaz, 1989; Skog, Ljungblad, & Holmquist, 2002; Snelson, Weber, Csuri, & Longson, 1990). The following are selected quotes from the literature that illustrates this point:

> "Computer Graphics is a powerful medium used to communicate information and knowledge…the pictorial synthesis of real or imagined objects from their computer-based models" (Bertoline & Laxer, 2002, p. 15);

> "The term Computer Graphics describes any use of computers to create or manipulate images" (Shirley, 2005, p. 1);

> "Computer Graphics is concerned with all aspects of producing pictures or images using a computer" (Angel, 2009, p. 1);

> "More simply, Computer Graphics are pictures that are generated by a computer. Computer Graphics also refers to the tools used to make such pictures" (F.S. Hill & Kelly, 2007, p. 1);

> "The term computer graphics includes almost everything on computers that is not text or sound. Today almost every computer can do some graphics, and people have even come to expect to control their computer through icons and pictures rather than just by typing. Here in our lab at the Program of Computer Graphics, we think of computer graphics as drawing

pictures on computers, also called rendering. The pictures can be photographs, drawings, movies, or simulations -- pictures of things that do not yet exist and maybe could never exist. Or they may be pictures from places we cannot see directly, such as medical images from inside your body" (Cornell, 1998, para. 1-2);

"There are two different views of computer graphics, each with its own concerns. A graphics system user is interested in what images are produced, what they mean, and how they can be manipulated. A graphics system programmer is interested in how to write graphics-based applications programs for those users." (McConnell, c2003, pp. Computer Graphics Principles Section, para. 3);

"Computer Graphics is a vast, important, and popular discipline. From its beginning around 1970, CG is now a mature discipline built on a strong mathematical basis and with applications in an ever-increasing number of areas. This is reflected in the undergraduate curricula of various other disciplines, such as physics, engineering, and architecture, which include an optional introductory CG course in some of their curricula" (Paquette, 2005, p. 245);

"Computer Graphics is a commodity…interactive computer graphics would rival word-processing and presentation programs for everyday communications" (Igarashi, 2010, p. 71);

"Computer graphics is the art and science of communicating information using images that are generated and presented through computation. This requires the design and construction of models that represent information in ways that support the creation and viewing of images, the design of devices and techniques through which the person may interact with the model or the view, the creation of techniques for rendering the model, and the design of ways the images may be preserved. The goal of computer graphics is to engage the person's visual centers alongside other cognitive centers in understanding" (Machinery, 2008, p. 74);

"Computer graphics centers about visual output and uses other media/techniques in auxiliary methods" (Jones, 1990, p. 29).

As represented by Figure 2.3, many of these definitions employ the word computer as a central theme, either in a procedural context, a technical concept, or in reference to a physical object or output. Also, a number of them suggest CG is an art, science, medium, or even a discipline. Inclusively, despite representing only a limited selection of published definitions from the literature, these differences in perspective suggest a clear dissent among members of the field on the definition of CG. Thus, a definition of CG based on a consensus of CG experts related to its history, development, tools, methods, technologies, applications, and contexts is needed.

The lack of a common definition for CG can also be attributed to the interdisciplinary nature of its practice. For example, the ACM (2008) defines CG as "The art and science of communicating information using images that are generated and presented through computation" (p. 74). Alternatively, Jones (1990) reports that according to Beyer "CG centers about visual output and uses other media/techniques in auxiliary methods" (p. 29). Furthermore, many other definitions for CG incorporate some contextual aspect related to how it is practiced, whether it's in association with visualization, animation, interaction design, or other known areas of practice (Angel, 2009; Bertoline & Laxer, 2002;

Bliss, 1980; Chehimi et al., 2008; Cunningham, 2007; F.S. Hill & Kelly, 2007; Gross, 1998; Kunii et al., 1983; Machover, 1974; McConnell, c2003; Paquette, 2005; Plazzi et al., 1989; Próspero dos Santos, 2001; Shirley, 2005; Skog et al., 2002; Snelson et al., 1990). Earlier the researcher established that achievements in CG would have never been possible if early pioneers in CS, engineering, and technology did not adapt computers to their work.

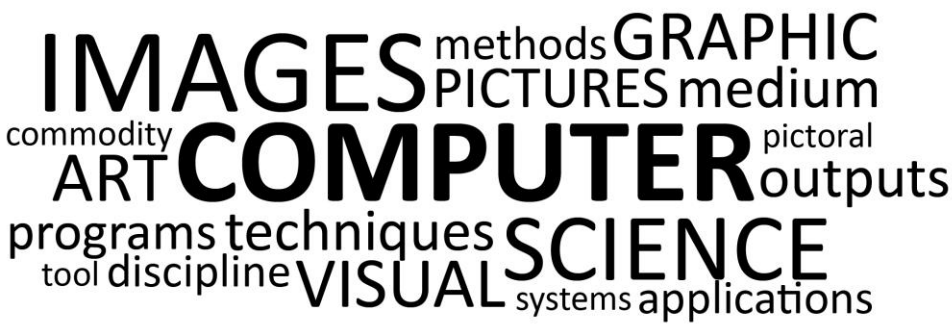


Figure 2.3. Common Word Themes Defining CG.

It is evident that the applied methods and practices of CG and the computing disciplines lack consensus, which contributes to multiple definitions and a shifting knowledge base. The same problem is found in CS, where members of the field subscribe to different paradigms. Evidence from the literature also suggests the same is true for CG, where members follow a distinct paradigm based on their own philosophical positions on a broad range of issues beyond the area itself. Thus, defining CG or CS under the existing criteria of computing or CS without understanding the philosophical perceptions among members of the field, is erroneous.

In the following sections, the researcher turned to the academy, and discusses the types of CG programs found in the area. The analysis included discussions on texts, topics, and curricula and how philosophical paradigms within these areas have led to the decontextualization of CG.

## 2.5. CG Programs, Topics, and Texts

CG provides industry with education opportunities to enhance their products and services for the benefit of users and stakeholders. CG is unique in that it provides a multitude of specializations, topics and applications applicable across many fields. Thus, CG curricula are not only diverse, but varied across applications and program classification, as illustrated by Figure 2.4.

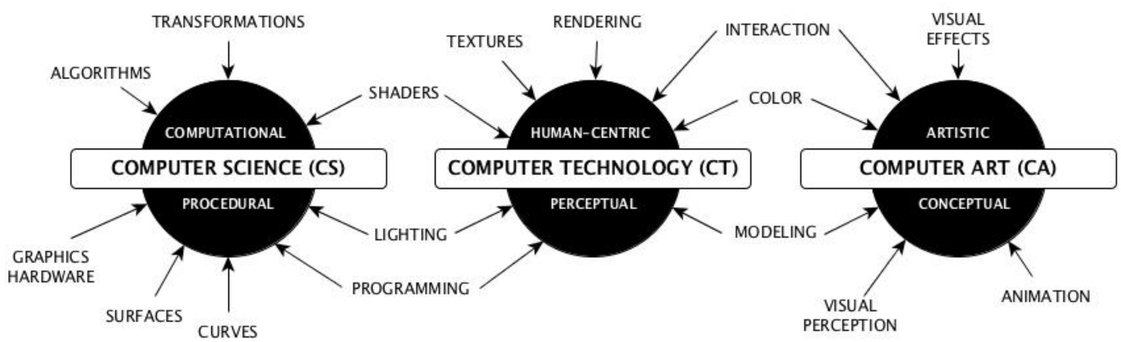


Figure 2.4. CG Program Classifications, Topics and Applications.

In the following section, the researcher describes three classifications for CG post-secondary programs, and provides a summary of the main the characteristics, degree offerings, and curricula for a selection of leading CG programs within each classification.

### 2.5.1. CG Programs and Curricula

The ACM SIGGRAPH Education Committee Index (Committee, n.d.) hosts a database for CG programs. Currently, the database lists around 400 CG post-secondary programs worldwide. Most of these programs can be categorized into three general classifications: Computer Science (CS), Computer Technology (CT), and Computer Arts (CA). CS programs tend to emphasize computational and procedural processes, while CT programs emphasize human factors, perception, and visual literacy. CA emphasizes artistic expression and conceptual development, evidence by programs in visual and graphic design, fine arts, illustration, and visual effects. Although different in perspective and focus, the common bond among these programs is the influence their respected curricula have on the human condition. This influence is evidenced by the diversity of CG degree program types available to students today.

A detailed review of all 400 programs listed in the ACM database was not feasible for this study. Instead, the researcher identified and reviewed the curricula for leading programs within each classification. Programs were first classified by where the program was housed within the host institution and the specific degrees offered by the program. Next, programs were ranked according to (1) the number and significance of externally funded and peer-reviewed research projects and publications, (2) the quality and expertise of its core faculty, and (3) implementation of an accredited curriculum that provided diverse topical areas for students to explore. Once ranked, 10 programs from the ACM database were identified as meeting all three of the ranking criterion. Table 2.1 lists these leading CG programs that are at the forefront of CG education and innovation, and best positioned to define and discover new paradigms for CG. Appendix D provides specific information for each leading program. The following subsections provide a summary of the collective review of the core curricula for each leading program within each classification.

2.5.1.1. Computer Science Programs

The relationship between CS and graphics is evident in contemporary curricula. In parallel to the findings of Li, Huang, & Gu (2009), most of the leading CS programs that offer Bachelor and Master of Science degrees require at least one foundational course in CG or computer-generated imagery that emphasizes the basics of raster and vector techniques, procedural modeling, and hardware programming. Some programs provide options in graphic-centric areas where students can explore data-driven applications, computer vision, Artificial

Intelligence, physics-based modeling and animation, scientific and information visualization, forensics, and sensor technology. Many of these Computer Science programs are housed in independent colleges or schools of applied science, business or engineering and blend the technocratic and scientific paradigms of CS by providing students with an interdisciplinary philosophy on CG.

2.5.1.2. Computer Technology Programs

The pervasiveness of graphical media in the arts, entertainment, medicine, and communications over the past two decades has led to the development of curricula that emphasizes interdisciplinary research in applied technology (Chehimi, Coulton, & Edwards, 2008b; Gross, 1998; Igarashi, 2010; Javener, 1994b; Kunii et al., 1983; Machover, 1974; Potts, 1974; Skog, Ljungblad, & Holmquist, 2002; Snelson, Weber, Csuri, & Longson, 1990). The leading CT programs follow these trends, stressing the human component of technology with specializations in visual perception, human-computer interaction, interactive design and development, and animated media. Degree offerings are diverse and include Bachelor or Master of Science, Bachelor and Master of Arts, Master of Fine Arts, and Doctorates. Although interdisciplinary in nature, many of these programs are independent labs or centers housed within colleges or schools of Technology or Liberal Arts.

The dominant CS philosophical paradigm found within most CT programs is technocratic. Publications and course topics in these programs see technology both as objects and as knowledge, suggesting a viewpoint that CG is as an applied discipline.

Table 2.1. Leading CG Programs

| Institution and Program/Center | Classification | Degrees Offered |
|---|---|---|
| Carnegie Mellon University<br>Graphics Lab | CS | BA in Computer Science<br>BS in Computer Science |
| Cornell University<br>Computer Graphics | CS | BS in Computer Science |
| Massachusetts Institute of Technology<br>Media Lab | CT | MS in Media Arts<br>PhD in Media Arts |
| The Ohio State University<br>Advanced Computing Center for Arts and Sciences (ACCAD) | CT | BA in Technology<br>MA in Technology |
| University of Southern California<br>Cinematic Arts | CT | BA in Technology<br>MA in Technology<br>PhD in Technology |
| Purdue Polytechnic Institute<br>Computer Graphics Technology | CT | BS in Technology<br>MS in Technology<br>PhD in Technology |
| DePaul University<br>Computing and Digital Arts | CA | BA/BS/MA/MS in Animation, Computing, Digital Cinema, Computer Game Development, Computer Science, Information Systems, Information Technology, Interactive and Social Media<br>BFA in Graphic Design |
| Rochester Institute of Technology<br>Imaging Arts and Sciences | CA | BFA in 3D Digital Graphics<br>MFA in Visual Communication Design |
| Bowling Green State University<br>Digital Arts | CA | BFA in Digital Art<br>MFA in Digital Art |
| North Carolina State University<br>Visual Experience Lab | CS | BS in Computer Science<br>MS in Computer Science<br>PhD in Computer Science |

2.5.1.3. Computer Art Programs

CA programs offer courses that adapt technology to traditional contexts relating to graphic design, digital media, illustration, and visual effects. These programs are mostly housed in Fine Art and Visual Communication colleges and schools. This trend reflects the literature, where CA programs are reported to emphasize the principles and elements of design, communication, color theory, composition, creative direction, art direction, and concept development over the technical aspects found in most science and technology programs (Aoki, Bac, Case, & McDonald, 2005; Chehimi, Coulton, & Edwards, 2006; Ebert et al., 2002; Gips, 1990; Igarashi, 2010; McConnell, c2003; Skog et al., 2002; Snelson, Weber, Csuri, & Longson, 1990; Tomaskiewicz, 1997; Wu & Jiang, 2008). Students can earn either a Bachelor of Arts, Bachelor of Fine Arts, Master of Arts, or Master of Fine Arts degrees. Due to the subjective nature of traditional art, the Master of Fine Arts is the terminal degree in the CA area.

Unlike that of CS and CT programs, CA programs are at the end of the spectrum and thus lack a CS paradigm as Biglan (1973) identified. This is mainly due to their close association with the humanities, where individuals independently and subjectively define content and methodology without regard to existing paradigmatic stances found in the computing fields. In the following sections, the researcher provides a discussion about how these programs are structured in regard to textbooks and topics of study.

## 2.5.2. Computer Graphics Textbooks

Leading CG programs in post-secondary education use a wide variety of textbooks as required course texts or as secondary teaching materials. The type of textbooks being used is dependent on the classification of the program and on the objectives of the specific course. Therefore, in order to identify the most popular texts shared among all leading CG programs, the researcher reviewed all required texts for foundational courses in the curricula for all leading CG programs. Textbooks were selected based on the number of leading CG programs that adopted it in at least one course in the core curricula. The six most popular textbooks required in these courses, along with their descriptions, are as follows:

> INTERACTIVE COMPUTER GRAPHICS: A TOP DOWN APPROACH USING OPENGL (5th Edition) by Edward Angel. "This book introduces students to the core concepts of computer graphics with full integration of OpenGL and an emphasis on applications-based programming. Using C and C++, the top-down, programming-oriented approach allows students to quickly begin creating their own 3D graphics. Low-level algorithms, such as those for line drawing and filling polygons, are presented after students learn to create interactive graphics programs." (Angel, 2009, p. back cover).

> COMPUTER GRAPHICS: PROGRAMMING IN OPENGL FOR VISUAL COMMUNICATION by Steve Cunningham. "The growing importance of computer graphics has created the need for a text that covers graphics topics in an accessible and easy to understand manner. The subject is no longer restricted to graphics experts or graduate students because advances in graphics hardware and software have made it possible for users with modest programming skills to create interesting and effective images…This innovative text provides a practical approach to graphics with an emphasis on programming with OpenGL to create useful scenes. By treating graphics topics in a descriptive and process-oriented manner, Cunningham makes the subject approachable at an earlier point in a computer science or similar program. With an excellent graphics API such as OpenGL, students can bypass many details of graphics algorithms and create meaningful interactive or animated 3D images early in the course. This text also includes solid descriptions of graphics algorithms to help

students develop depth in their graphics studies as well as programming skills" (Cunningham, 2007, p. back cover).

COMPUTER GRAPHICS USING OPENGL by F.S Hill and Stephen M. Kelly. "Updated for the latest advances, algorithms, and hardware, this book teaches how to develop and test real OpenGL programs, step-by-step. Students learn through examples that are directly relevant to today's movies, games, Internet and interactive applications. They move from simple line drawings to increasingly complex techniques, including surfaces, shading, and NURBS. Equal weight is given in this edition to both modeling and viewing" (F.S. Hill & Kelly, 2007, p. back cover).

REAL TIME RENDERING by Thomas Moller and Eric Haines. "Thoroughly revised, this third edition focuses on modern techniques used to generate synthetic three-dimensional images in a fraction of a second. With the advent of programmable shaders, a wide variety of new algorithms have arisen and evolved over the past few years. This edition discusses current, practical rendering methods used in games and other applications. It also presents a solid theoretical framework and relevant mathematics for the field of interactive computer graphics, all in an approachable style" (Moller & Haines, 2008, p. back cover).

FUNDAMENTALS OF COMPUTER GRAPHICS by Peter Shirley. "The second edition of this widely adopted text gives students a comprehensive, fundamental introduction to computer graphics. It presents the mathematical foundations of computer graphics with a focus on geometric intuition, allowing the programmer to understand and apply those foundations to the development of efficient code" (Shirley, 2005, p. back cover).

COMPUTER GRAPHICS: PRINCIPLES AND PRACTICE (3rd Edition) by John F. Hughes, Andries van Dam, Morgan McGuire, David F. Sklar, James D. Foley, Steven K. Feiner, and Kurt Akeley. “In this book, we explain the principles, as well as the mathematics, underlying computer graphics knowledge that is essential for successful work both now and in the future. Early chapters show how to create 2D and 3D pictures right away, supporting experimentation. Later chapters, covering a broad range of topics, demonstrate more sophisticated approaches. Sections on current computer graphics practice show how to apply given principles in common situations, such as how to approximate an ideal solution on available hardware, or how to represent a data structure more efficiently. Topics are reinforced by exercises, programming problems, and hands-on projects” (Hughes, VanDam, McGuire, Sklar, Foley, Feiner, & Akeley, 2009, p. back cover).

2.5.2.1. <u>Common Textbook Topics</u>

In order to identify the common topics among the six required texts used by the leading CG programs, an inductive analysis of the collective volumes was completed. First, each text was independently analyzed for topical patterns. Patterns were characterized by subject and the context for which that subject was discussed. For example, color was often discussed in the context of visual perception across multiple chapters in the text; therefore, color perception was identified as a common pattern. Second, the prevalent patterns within each individual text was outlined. Third, the pattern outlines for each text were compared to outlines of other texts in order to identify the collective prevalent patterns across all six textbooks. Finally, the collective identified patterns were coded and categorized, and then ordered as themes according to prevalence. Table 2.2 provides the primary, secondary, and tertiary themes identified from the inductive analysis of the collective texts, ordered by prevalence.

Table 2.2. Prevalent Topics Among Leading CG Program Textbooks

| | |
|---|---|
| Primary Themes | Mathematics, algorithms, color, rendering, lighting, illumination, pipelines, hardware, rasterization, curves, programming |
| Secondary Themes | Shading, texturing, animation, transformations, illumination |
| Tertiary Themes | Visual perception, effects, tools, non-photorealism, interactivity, collisions |

Common topics among the popular textbooks include color, rendering, lighting and illumination. Additionally, these texts shared an emphasis on surfaces and curves, graphics hardware, graphical rendering pipelines, procedural and mathematical modeling, and algorithms. Shading, texturing, animation and rendering were also uniformly emphasized. These topics represented a consensus about the fundamental concepts for CG, and although each text addressed them individually according to the intention of the authors, most of the identified textbooks covered them interchangeably.

However, these texts included specific topics that lack consensus. Examples include visual perception, visual effects, non-photorealistic rendering, and interactive programming. Each topic was treated with various degrees of emphasis and detail. Graphical tools, like APIs, were also irregular among these texts. The emphasis of the textbooks may have been the main cause for these differences, as all but two of them were centric to OpenGL with one being dedicated to real-time rendering exclusively.

The intention of these textbooks was to provide an introduction to the fundamental concepts and methods related to the technical side of CG. Each is written from a technical perspective, emphasizing core methods, processes, technologies, and techniques common to most CS or CT programs. However, within these texts discussions regarding the various applications and communities where CG can be employed, how CG be used to benefit the human condition, and the human factors relating to both the tools and applications of CG were limited.

Additionally, only one textbook included a chapter on the future of CG where readers were asked to consider the possibilities of potential applications and developments for entertainment and games (Moller & Haines, 2008). No other textbook dedicated any significant pages, let alone a complete chapter, that invited readers to think about the future applications and practice of CG. Future editions of these texts need to incorporate topics about how best to advance CG and its related fields.

## 2.6. Paradigmatic Trends, Decentralization, and Decontextualization

Equivocal attitudes about computing and technology remain prevalent within academic disciplines. Some disciplines embrace technology with open arms and adopt it with much fanfare, while others feel it is intrusive, disrupting the very nature of their established practices (Kitson, 1991; Rogers, 2000). Regardless of the attitudes, computing technology is unavoidable and therefore literacy in technology and the computing fields is necessary (Keirl, 2006). Several theories and pedagogical approaches have been dedicated to this subject, and given the speed at which technology develops and the rate in which people can adopt it, it is inevitable that new and existing theories will continue to emerge (Keirl, 2006; Rogers, 2000). In assessing this issue, the researcher attempted to view computing and technology education from a broad perspective. In the following sections, the author summarized significant points from the literature that are germane to contemporary computing education.

### 2.6.1. Paradigmatic Trends in Related Disciplines

The problem investigated by this research is not one limited to computing. Several other related fields and disciplines have struggled to define themselves in the technological paradigm, the most notable of them can be found in engineering. Decades of research in Engineering Design Graphics has disseminated the effects of computing on the curriculum design, pedagogy, and philosophical positions of post-secondary educators, and the challenges these educators face to meet industrial expectations (Clark & Scales, 2009; Hartman, Sarapin, Bertoline, & Sarapin, 2009; Hitchner & Sowizral, 2000; Li, Huang, & Gu, 2009; McGrath, 1999; McGrath, Bertoline, Bowers, Pleck, & Sadowski, 1991; Próspero dos Santos, 2001). Findings by these researchers suggested institutions are producing students who are highly skilled in using software, but have limited problem-solving skills. Additionally, a disconnection between the classroom and the expectation of industrial markets is growing. This has fostered concerns over how to define engineering education, specifically in terms of theory and applied perspectives, and how curriculum needs to be modeled to reverse the trend.

### 2.6.2. The Contemporary Climate

Post-secondary educators within computing technology programs have redefined curricula to address the changing needs of industry and society (Association for Computing Machinery, 2008; Kitson, 1991). Early on, Jones (1990) identified that despite being outside of the mainstream, research has become more interdisciplinary. The decentralization of computing education has given rise to interdisciplinary approaches that focus on technological literacy. For example, Michael (2006) discussed how technological literacy should "inform current educational practice and aspiration" (p. 50), while Keirl (2006) wrote "no longer can technology education be prescribed by populist orthodoxies, which portray technology as things, as neutral, as computers, as applied science or as vocational education" (p. 97). Additionally, McArthur (2010) reflected on the rigid manner in which disciplines remain closed to interdisciplinary ideals and pedagogical approaches that threaten traditional academic programs altogether. This research has suggested a new paradigm in computing education is underway, necessitated by interdisciplinary approaches and shared knowledge spaces, in order to educate learners on being literate in technology.

According to Keirl (2006), literacy in technology requires three dimensions consisting of the "operational, cultural, and the critical" (p. 97) components. Keirl (2006) also identified that technological curricula place an abundance of emphasis on the operational components by undervaluing the cultural and critical ones, echoing Jones (1990) who stated, "as these changes occur we need increasingly to provide citizens with a broad education that includes technology and its relation to human values" (p. 29). This identified a need to understand how technological literacy has given rise to new areas of computing, and how these components have contributed to the decontextualization of the computing disciplines. In the following section, this issue is discussed at length as it relates to the research question for this study.

2.6.3. Decontextualization

The rise of knowledge bases and computing areas that lack definition can be attributed to the breakdown of traditional contexts within established computing disciplines. CG is arguably one of these areas, blending science and art by abstracting conceptual approaches and technical methodologies, as illustrated by Figure 2.5.

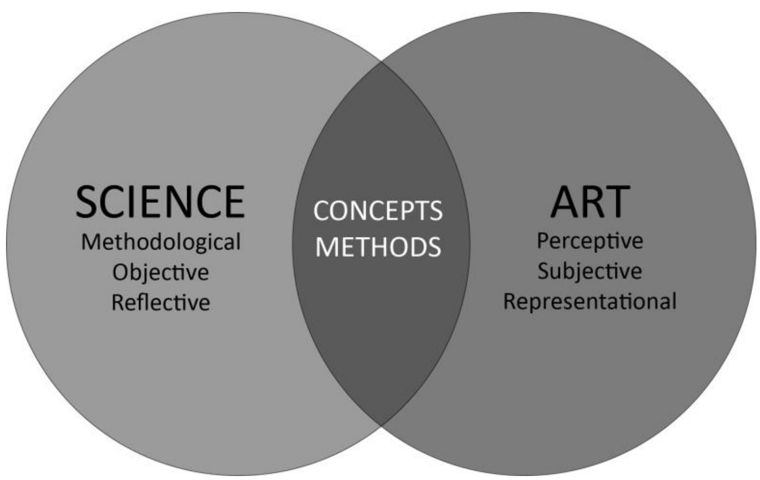


Figure 2.5. Decontextualization of Art and Science.

Jones (1990) clearly identified this practice, writing:

> Consequently, both scientific and artistic sources rely on culturally embedded patterns of reality represented by varying degrees of abstraction in symbolic and material culture. Their shared assumptions about the value of abstract representations of reality have contributed to the practice of decontextualization, to cultural maintenance of that larger embedded pattern. In examining possible and probable trends in computer graphics, cultural maintenance and change must be considered. The gradual shift from decontextualization inherited from our past to our contemporary emphasis on context is reflected in historical and contemporary computer graphics images and purposes" (p. 29).

Despite these insights, institutions struggle to develop curricula that proactively embrace the decontextualization of computing disciplines. This is largely due to factors associated with historical philosophy and perspectives that favor operational curricula (Jones, 1990; Keirl, 2006). In his book, VISUAL THINKING, Arnheim (1997) provided what he feels is a clear statement of how the relationship between art and science is characterized by traditional philosophy:

> The arts are neglected because they are based on perception, and perception is disdained because it is not assumed to involve thought. In fact, educators and administrators cannot justify giving the arts an important position in the curriculum unless they understand that the arts are the most powerful means of strengthening the perceptual component without which productive thinking is impossible in any field of endeavor (p. 3).

The sciences are perceived as reflective of truth because they have been legitimized over time by the acceptance of their methods as leading to truthful reflections of the real world. Alternatively, the arts and humanities are perceived merely as being representative of truth because they are subjective and biased by human intervention. However, technological methods have brought into question the legitimacy of science as truth, as suggested by Jones (1990):

> When scientists take techniques to their logical limits in the technical or scientific realm, they find that they need to borrow the concepts and methods of artistic practice in order to create graphic images that look more real than images based solely on algorithms (p. 28).

Therefore, if science is dependent on concepts and methods evident within the arts to ascertain truth, the traditional arguments supporting scientific legitimacy are open to question. In the case of computing, the blending of multiple knowledge bases and disintegration of the traditional computing disciplines by decontextualization suggest that new areas of computing, like CG, should be defined independently according to their own cultural trends, contexts, and characteristics.

## 2.7. Summary

The literature reviewed in this chapter addressed the historical and contemporary issues for establishing CG as a defined computing discipline. The literature substantiated the importance of understanding how various homogeneous groups within academia and industry employ adaptability and methodology within specific contexts, and validated the need to come to a consensus in a shared knowledge base that consistently identifies and defines CG across these groups. In the fields of computing, literature showed that members follow a distinct paradigm based on their own philosophical positions on a broad range of issues beyond the defined discipline itself. Evidence from the literature also suggested that members within the area of CG follow a distinct paradigm in regard to the philosophical positions based in three distinct contexts, CA, CS, and CT. Inclusively, despite representing only a limited selection of published definitions from the literature, differences in perspective have suggested a clear dissent among members of these contexts on the definition of CG. Thus, defining CG based on a consensus of members according to cultural trends, contexts, and characteristics is warranted.

The methods, practices and computing disciplines in which CG is applied lacks consensus, and in turn has contributed to multiple definitions and a shifting knowledge base. Thus, defining a computing discipline under the existing published criteria for computing technology may be misleading and requires investigation in order to formulate future curriculum and pedagogical approaches for the teaching and learning of CG.

# CHAPTER 3. METHODOLOGY

The methods undertaken for this study was framed upon two theoretical perspectives – the researcher's views about CG and technology, and the study's basis of methodology, specifically on the research approach. In the following sections, both perspectives are addressed in detail.

## 3.1.1. Researcher Viewpoints

The researcher's approach to the study was based on a number of ideas and theories from a broad array of disciplines, including education, engineering, technology, philosophy, and the humanities. Early educational scholars like John Dewey, who championed the equalization of the individual, and Charles Prosser, who wanted education to prepare citizens for serving the society, were vital to the rise of vocational education in America (Dewey, 1916; Prosser, 1949; Scott & Sarkees-Wircenski, 2008). Contemporary technology scholars like Keirl (2006), whose ideas about technology curriculum, ethics, and technological literacy, and the relationship of those ideas to determinism, were also significant. Also of importance was Keirl's (2006) point about how technology education must not only to prepare students for a particular job, but also facilitate the development of personal knowledge through the application of transformative learning. Additionally, the ideas that "where science seeks to know, technology seeks to control" and "technology is instrumentalist in nature" (Feenberg, 2006, p. 5) are particularly important in understanding the contemporary practice of applied technology, especially in the area of CG. Furthermore, the researcher viewed the theories published by Michael (2006) about the relationships between humans and technology, specifically the concurrence of form and function, as an important insight into how technology can be developed for human use. Finally, the work of both Robert Pool and Rudolf Arnheim provided the researcher with insight about how, through social constructivism, science and technology need to be more interdependent (Arnheim, 1969; Pool, 1997).

3.1.1.1. Research Approach

In order to solve the pragmatic problems identified by this study, the approach taken towards the research needed to be contextualized according to ontological, epistemological, and axiological philosophical assumptions. The following paragraphs describes the researcher's approach to the study according to these three assumptions.

From an ontological perspective, reality is a collective of cognitive constructions that are defined by the experiences of individuals within specific cultures. Thus, the nature of technology in one culture may be completely different in another, even when the cultures are homogenous. For example, why do CG technicians in one company employ image editors differently than identical technicians in another company, even if they are in the same industry? Therefore, the researcher viewed technology as a cultural artifact relative to how it is applied and perceived within individual contexts.

From an epistemological perspective, valid knowledge about technology is best obtained through basic research into how people perceive and use it. Data obtained through discussion and dialogue between well-informed researchers and knowledgeable participants is critical for answering the fundamental questions posed in basic qualitative research. Through interactive engagement with participants, and the inductive analysis of data obtained through these engagements, the researcher gained the knowledge necessary to understand the collective consensus between the homogenous groups.

From an axiological perspective, researcher values were viewed as an important factor in qualitative inquiry, as they provide purpose and passion for investigating the phenomena being researched (Berg, 2009; Crestwell, 1998;

Maxwell, 2005). Additionally, the intrinsic values (those that are for their own sake) and extrinsic values (those that may have meanings for other contexts) of the participants and researcher provided the richness to qualitative inquiry necessary to gain consensus across many groups (Guba & Lincoln, 1994). In this study, the values of participants and researchers, expressed by way of interactive discussion, were critical for understanding the constructions about the different realities evident within the homogenous groups.

### 3.1.2. Methodological Basis

The goal of this research was to gain a consensus about the definition and knowledge base for CG among industry professionals and post-secondary academics. Given the nature of CG and its various contexts, the researcher needed to inquire about the perceptions, experiences, and realities of participants in an engaging manner. Additionally, in consideration of literature and his own personal experiences, the researcher believes CG is an area of computing that is subject to constant change and adaptability, and thus must be investigated through interpretive, value-laden discussion and interaction.

## 3.2. Research Design

Upon consideration of the theoretical perspectives and the questions undertaken by this investigation, the Delphi Method was employed. According to literature, the Delphi Method is a qualitative approach that is ideal for investigating complex and multifaceted topics where a consensus is based on the experience of expert participants from different contexts (Grisham, 2009; Gupta & Clarke, 1996; Linstone & Turoff, 1975; Mitchell, 1991; Murry & Hammons, 1995; Okoli & Pawlowski, 2004; Rowe & Wright, 1999). According to Linstone and Turoff (1975), the purpose and intention for the Delphi Method is "to deal with technical topics and seek a consensus among homogeneous groups of experts" (p. 80).

Although many variations of the Delphi Method have been developed to meet the needs of specific investigations, Murry and Hammonds (1995) stated the original method ensures Delphi is a "reliable research method for problem-solving, decision-making, and group consensus" (p. 425). The application of Delphi in social science research is well documented (see Gupta & Clarke, 1996 for a complete review), and contemporary applications of the Delphi Method have extended to the fields of education and technology, specifically in forecasting, mapping future trends, resource management, conflict resolution, and consensus building (Blind, Cuhls, & Grupp, 2001; Dailey, 1988; Gordon & Pease, 2006; Mitchell, 1991; Reiger, 1986).

Additionally, the Delphi method allows expert participants, regardless of proximity from one another, to interact with a researcher on an individual basis independent of and unknown to other participants. The researcher acts as a central point between all participants, compiling information from the collective participants into a summarized analysis (Grisham, 2009; Gupta & Clarke, 1996; Linstone & Turoff, 1975; Mitchell, 1991; Okoli & Pawlowski, 2004; Reiger, 1986; Rowe & Wright, 1999). Independent interaction was maintained for all participants until a summarized analysis was reached. The independent nature of of interaction of this method provided the necessary anonymity between participants to answer the proposed research questions for this study.

### 3.2.1. Procedure

Linstone and Turoff (1975) modeled the traditional three-round Delphi Methodology for use in obtaining group consensus. Figure 3.1 illustrates the various rounds and associated activities undertaken for each round of the model.

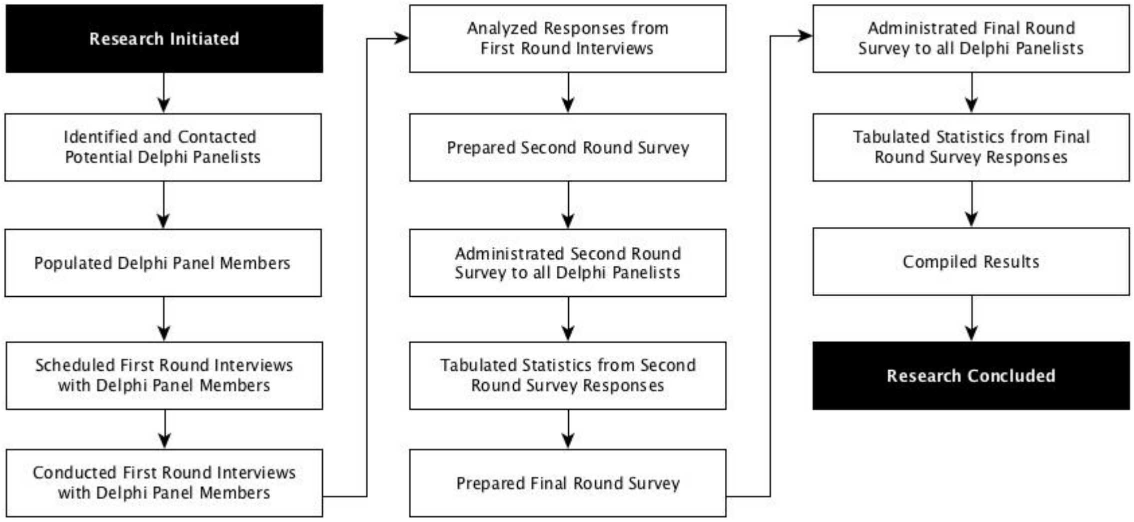


Figure 3.1. Three-Round Delphi Procedure.

First, qualitative data was collected by way of semi-structured interviews with each panelist. All interviews were conducted independently and remotely via the Internet or telephone. Patterns evident within the collective interview responses were identified, labeled and categorized using inductive coding techniques described by Creswell (2002) and Thomas (2006). Finally, core themes evident within the final categories were composed into a survey instrument for panel feedback.

To reach a credible consensus about identified patterns and themes within the collective interview responses, the researcher member-checked the core themes through panel feedback. Core themes were summarized and formatted into a survey instrument that was administered online to all panel members independently. Statistical data was collected from the surveys during the second and final rounds and analyzed for each identified core theme. This process was repeated in two subsequent rounds in order to gain credible consensus among all panel members.

### 3.2.2. Panelists

Delphi requires a panel of experts in order to arrive at a consensus (Grisham, 2009; Linstone & Turoff, 1975; Okoli & Pawlowski, 2004). Murry and Hammonds (1995) defined expertise as “Individual panelists having more knowledge about the subject matter than most people, or that they possess certain work experience, or are members in a relevant professional association” (p. 428). Therefore, the minimum criteria for each panelist was five years or more of either industrial experience in CG or a related field, or teaching or administrative experience at a post-secondary institution in CG or related program with a sustained scholarly record. Additionally, all academic panelists held an earned graduate degree in CS, technology, or the fine arts or a related field. Participants were also selected for the study if they were active members in recognized professional organizations, including the Association for Computing Machinery (ACM) or the Institute of Electrical and Electronics Engineers (IEEE).

### 3.2.3. Sampling Strategy

The number of potential qualified panelists from the population ensured a diverse group of participants. The sampling strategy employed in this study needed to identify common patterns between two homogenous groups. Patton’s (1990) discourse on qualitative sampling methods provided several strategies for choosing participants for the research design. Out of all sampling strategies provided, only maximum variation sampling was appropriate for this study, for it best enabled the researcher to identify both the common patterns and variances between and within each homogenous group (Patton, 1990). Potential participants were sampled according to their industry (marketing, gaming and entertainment, application development) or the contextual classification of their academic program (CA, CS, or CT).

In order to achieve consensus for the research question posed, a large-scale Delphi panel of experts was needed. Literature indicated that a Delphi panel with 12 or more participants is considered to be large-scale (Grisham, 2009; Mitchell, 1991). Once a population of experts was identified based on their homogenous grouping (academic or professional) and contextual classification (CA, CS, or CT), the population was stratified into three groups by type. Panelists selected for the Delphi panel were then assigned to groups: one group consisting of four post-secondary academic researchers and educators or professionals from the CA context, another group consisting of four post-secondary academic researchers and educators or professionals from the CS context, and the final group consisting of four post-secondary academic researchers and educators and professionals from the CT context. These three groups represented the variant contexts for CG, as identified by The ACM SIGGRAPH Education Committee Index (Committee, 2013).

### 3.3. Unit of Analysis

Patton (1990) discussed the importance of identifying the unit of analysis for qualitative research designs. In most cases, the typical unit of analysis are individuals on whom the interpretation of the study will focus. However, Patton (1990) identified that qualitative research may also focus on variations within parts of a program, groups, or sites, writing "Neighborhoods can be units of analysis or communities, cities, states, and even nations in the case of international programs" (p.167).

Panelists for this study were drawn from a national population of CG professionals and academics working in industry or post-secondary institutions within the United States. Each panelist was selected and classified into their respective homogenous group, and then categorized in accordance with their individual experience, background, and occupation within one of three contexts; CA, CS, or CT. Therefore, the unit of analysis for this study was the panelists responses within each context from each of the two homogenous groups.

## 3.4. Data Collection

The literature defined several mechanisms and considerations for collecting data in qualitative research designs (Berg, 2009; Boyatzis, 1998; Crestwell, 1998; Maxwell, 2005; Merriam, 1998; Patton, 1990, 2002). One major consideration for this study was group bias, commonly known as the "bandwagon" effect. Data needed to be collected in a manner that eliminated group bias. One of the hallmarks of the Delphi method is that it limits group bias by allowing the researcher to interact with participants independently, and without limit to location. Since participants only interacted with the researcher and not with one another, the threat of group bias was removed. Thus, it was appropriate to collect data using the Delphi Method (Linstone & Turnoff, 1975; Murry & Hammonds, 1995).

Additionally, the literature on the Delphi Method provided techniques for collecting data based on both qualitative and quantitative principles (Dailey, 1988; Grisham, 2009; Gupta & Clarke, 1996; John W. Murry & Hammons, 1995; Linstone & Turoff, 1975; Mitchell, 1991; Okoli & Pawlowski, 2004). The objective of this study needed to reflect what the characteristics for CG mean to the individual participants within their specific contexts. Therefore, the data collected by this study reflected how CG is perceived by participants within their specific context. These perceptions reflect reality, and in turn provide meaning about the characteristics for CG. Therefore, the qualitative theoretical tradition best suited for this study was symbolic interactionism, structured as a three-staged Delphi Method.

Lastly, the literature provided guidelines and recommendations on how to obtain sufficient data in qualitative research (Bernard, 2000; Bertaux, 1981; Creswell, 1998; Morse, 1994). Most of these sources discussed the relationship between sample size and data saturation, suggesting minimum values for common qualitative theoretical traditions and methodological approaches (see Mason, 2010 for a review). However, due to the numerous factors that may inadvertently determine sample size, none provided a definitive argument for adhering to a suggested value. Furthermore, the suggested sample sizes, combined with the limitations of the study, threatened the feasibility and credibility of data collection. In consideration of these factors, the amount of data necessary in this study to achieve the research objectives was limited to the richness of the participant responses about the characteristics of CG. Richness was defined by the amount of detail and description evident in the raw interview data. In place of suggested sample sizes, the researcher defined data saturation according to the richness of the data collected from the participants, rather than the number of interviews and surveys completed. The following sections detail the purpose, mechanisms and procedures employed for each step of the data collection process.

### 3.4.1. Interview Procedures

According to Creswell (1998), qualitative research is dependent on long-form interviews as the main mechanism for collecting data from participants. In this study, the purpose of the interviews was to obtain a conceptual understanding of participants' perspectives about CG. Specifically, the researcher attempted to ascertain how a participant defines CG, the core topical areas that identify CG, and the contemporary problems and issues that CG professionals collectively address. Additionally, the researcher asked participants to describe the relationship between established academic disciplines and the effect they have on the teaching and practice of CG. Participants were also asked to describe how popular CG specializations were emphasized in their business model or program curriculum. Finally, participants were asked to explain the differences between CG and CS.

Each participant completed one 60-minute semi-structured interview with the researcher. Due to the diverse geographical locations and physical distances between the researcher and the participants, all interviews were conducted via Internet or voice call. Digital recordings for all interviews were transcribed into textual format for analysis.

### 3.4.2. Survey Procedures

Through surveys employed in this study, a general consensus was ascertained among participants about the definition and knowledge base for CG. Each survey attempted to capture the core concepts among participants within each homogenous group relating to how CG is defined, the effects academic disciplines have on CG curriculum, and the way CG is practiced. Lastly, surveys identified the common differences between CG and CS among all panelists interviewed for the study.

Literature provides an abundance of prior work on survey and instrument design for Delphi, most of which suggest that Likert scales provide the most efficient way to collect data on a broad set of topics (Gordon & Pease, 2006; Grisham, 2009; Hayes, 1998; Linstone & Turoff, 1975; Okoli & Pawlowski, 2004; Thangaratinam & Redman, 2005; Williams & Webb, 1994). Survey instruments for this study were constructed based on the findings of all collective interviews from the first round and were framed into surveys that included Likert scales as the assessment model. Survey instruments were administered to all panel members online via secured protocol using the Qualtrics system available to the researcher by Purdue University in West Lafayette, Indiana. Panel members who completed the survey did so at their convenience without the assistance of the researcher.

## 3.5. Data Analysis

Given the scope of the study and the research question to be addressed, multiple methods were used to analyze data collected from participants. Data from first-round interviews needed to be analyzed using an inductive approach, while survey data from the second and final rounds needed to be analyzed using basic statistical measures. The following sections describe the approaches taken to analyze all data collected for each round of the study.

### 3.5.1. Interview Analysis

The literature on qualitative research design and methodology provides numerous approaches for analyzing data obtained from interviews (Boyatzis, 1998; Berg, 2009; Creswell, 2002; Maxwell, 2005; Patton, 1990). However, for this study Patton's (1990) approach on inductive analysis provided the most prudent method for obtaining core themes from the interview data. Central to research objectives, and in alignment with Patton's (1990) approach, was the identification of indigenous concepts from the raw data collected from each interview. These concepts enabled the researcher to identify meanings from the data, rather than placing meanings upon the data. Additionally, Patton's (1990) approach provided the researcher with a degree of flexibility and exploration necessary to allow the core themes to emerge without limitations imposed by other methods.

Transcribed data from the recorded semi-structured interviews was inductively analyzed for indigenous concepts and categories described by Patton (1990). Creswell (2002) and Thomas (2006) outlined a procedural approach for performing an inductive analysis, which required five stages: (1) preparation of the raw data file, including transcription and formatting, (2) close reading of the textual data for familiarity and segment labeling (3) creation of categories and themes (4) overlap reduction, and finally (5) refinement to core themes. Figure 3.1 Interview Data Analysis Procedure illustrates this procedure. This process was applied to the raw data for each unit of analysis independently within each homogenous group, and then combined with the other units to form lower-level themes. The lower-level themes were categorized and reduced to generate the core themes within each homogenous group. Core themes were obtained by analyzing the similarities between each homogenous group.

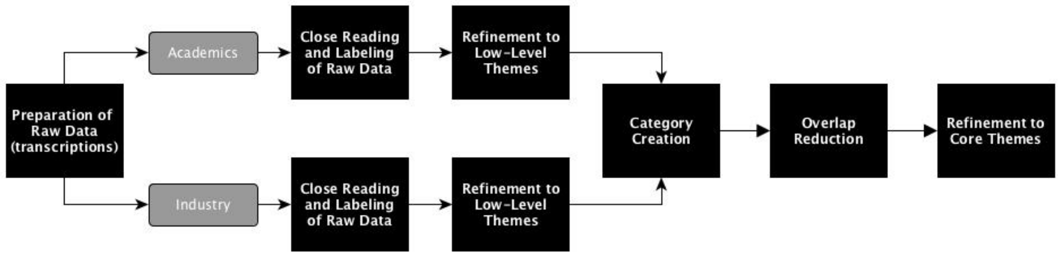


Figure 3.2. Interview Data Analysis Procedure

### 3.5.2. Survey Analysis

Surveys were conducted to gain consensus among panelists about the core themes that emerged from the interview data. Summary statistics for each question on each survey instrument determined which core themes had the highest percentage of agreement among all participants. Both second and final round surveys employed Likert scales to rate participants' opinion about each core theme. The second round instrument employed values according to a 5-point rating scale: 1 = strongly disagree, 2 = disagree, 3 = no opinion, 4 = agree, and 5 = agree strongly. Consensus in the second round was determined by the standard deviation value of 0.9 or lower. The final round instrument used a three-point rating scale: 0 = disagree, 3 = no opinion, or 5 = agreed, with standard deviation values of 0.9 or lower representing consensus for a specific core theme. Questions that panelists failed to answer were not assigned a value and were omitted from the final analysis.

### 3.5.3. Consensus

The literature states that in order for a Delphi Method to conclude, consensus must be reached (Dailey, 1988; Grisham, 2009; John W. Murry & Hammons, 1995; Linstone & Turoff, 1975). However, no one specific measurable value was evident across the literature for what constitutes consensus. Murry and Hammonds (1995) suggested that consensus is reached by stability or convergence, or when “there was no further shifting of panel responses from round to round” (p.432). Additionally, they suggested that when panel responses for an individual criterion differentiates by less than 20 percent, stability is reached (Murry & Hammonds, 1995). Therefore, in this study consensus for all core themes was defined as 80 percent agreement among all panelists. Additionally, core themes that failed to reach consensus in the second round were omitted from the final round survey instrument.

## 3.6. Validity

Validation of qualitative research requires rigorous adherence to the methodology and design (Berg, 2009; Creswell, 1998; Maxwell, 2005; Patton, 1990, 2002). Patton (1990, 2002), Maxwell (2005), Lincoln and Guba (1985) provide an extensive discussion about obtaining validity through qualitative inquiry, which includes two important points – credibility and trustworthiness. The following sections describe how the researcher addressed validity for the study outcomes as it relates to these two points.

### 3.6.1. Credibility

Lincoln and Guba (1985) provide a solid discourse on the nature of credibility as it relates to qualitative research. They specifically discussed the criteria for establishing credibility and the activities for attaining it; “prolonged engagement, peer debriefing, negative case analysis, referential adequacy, and member checking” (p. 301). In this study, credibility needed to be established for both the researcher and the research findings. The following sections detail how credibility was established for each of these points.

3.6.1.1. Credibility of the Researcher

Credibility of the researcher is a major concern in qualitative research. In relation to this study, there were two factors that threatened researcher credibility – competence and predisposed biases (Patton, 1990).

Regarding competence, the researcher who conducted this study has more than a decade of teaching experience in post-secondary education. The topic addressed by this study is one that the researcher has direct experience within a post-secondary academic institution. Additionally, the researcher has designed, developed, and delivered technology courses in CG at both graduate and undergraduate levels, and is well versed in post-secondary curriculum design, assessment, and pedagogical approaches related to CG, technology and computing. Also, the researcher's industrial experience in the fields of design, technology, marketing, business, and education provide him with a unique perspective on the problems undertaken by this research. Combined with his extensive and diverse educational background in both the visual arts and engineering technology, the researcher has the necessary background and experience to conduct this study. The appended vita provides complete details about the researcher's professional qualifications and experiences.

However, the researcher's background and perspectives posed a threat to credibility for this study. Unlike quantitative research, qualitative research lacks the controls that limits the researcher's subjective influence on the outcomes of an experiment. Thus, qualitative researchers must acknowledge that their own experiences and beliefs that may threaten credibility, and then undertake ways to reduce or eliminate outcomes that conform to their existing held beliefs. In order to reduce the threat to credibility posed by the researcher's background, the researcher applied two core practices. First, the researcher's own background informed the realization that CG has multiple realities. This freed the researcher to treat his own experiences as information that enabled an understanding of the data collected. Second, through rigorous and repeated returns to the interview data, the researcher emphasized fairness in place of objectivity during the inductive analysis of all interview data.

3.6.1.2. Credibility of Findings

Findings for this study were the result of qualitative inquiry about participant perceptions about CG relative to two specific homogenous groups, each of whom have different constructions of reality. Ensuring the credibility of the findings was dependent on saturation found in participant interview responses. Generally, saturation is reached when coded data does not add any new insight or understanding about what is being studied. As explained in section 3.4, the researcher defined data saturation according to the quality of the data collected from the participants, rather than the number of interviews and surveys completed. The quality of the data was determined by the detail of responses, and the codes that emerged from the response data. Meanings from the coded data were derived from repeated returns to the interview data in order to gain new insights. When repeated returns provided no new insights, saturation was reached.

Although the Delphi Method requires solicitation of participant feedback through subsequent rounds, that alone did not guarantee credibility of the participant response data. Maxwell (2005) recommended that researchers solicit feedback about the data obtained from participants in order to reduce misinterpretation. Therefore, participant feedback of first round findings needed to be conducted. According to Lincoln and Guba (1985) member checking is "directed at a judgment of overall credibility" (p. 316), which fit the objectives of this research. Thus, at the conclusion of each first round interview, informal member checks were performed where each participant was provided an opportunity to review and revise their responses directly with the researcher. Out of 12 interviews conducted, only two participants readdressed their responses. Both expanded upon their original responses rather than revising them. None changed their original response to the questions posed. These expanded and revised responses provided a degree of credibility for the first round findings.

Credibility of findings for both the second and final rounds were determined by the consensus of the collective group responses. At the beginning of both the second and final round, each participant was informed that the questions in the survey represented the collective opinions of all participants from the previous round. Thus, credibility for the final two rounds was achieved through verification by participants of the collective responses included in each of the two survey instruments.

### 3.6.2. Trustworthiness

The literature provided several criteria for ensuring trustworthiness in accordance with the nature of the inquiry being undertaken (Lincoln and Guba 1985; Patton, 1990). However, Patton (1990) suggested that the nature of trustworthiness in qualitative inquiry is defined not only by the beliefs and preferences of the researcher and how he or she is perceived by participants and users, but also by the techniques and methods for which data is collected. Additionally, attention to validity and reliability of the data collected is also important to ensuring credibility (Patton, 1990). Therefore, rather than adopting a single methodological approach, the researcher employed a mixed-method approach where the collection and analysis of data matched the goals and objectives of the inquiry being undertaken.

Section 3.6.1.1 addressed the credibility of researcher as it relates to the trustworthiness of the findings. However, trustworthiness of the data collected was achieved by maintaining the anonymity of panelists. Panelists remained unknown to one another throughout all three rounds of the research process in order to eliminate group bias and in turn provide the degree of trustworthiness of the data collected. In the first round interviews, trustworthiness of panelist responses was achieved by way of independent correspondence between the panelist and the researcher alone. The second and third rounds of the Delphi process allowed panelists to respond to collective responses of all participants without direct contact or knowledge of other panelists. These three methods provided the necessary degree of trustworthiness to the findings for this study as it relates to data collection.

### 3.7. Summary

This chapter provided the methodology employed in the study. Specifically, the researcher provided the rationale for employing the Delphi Method, along with the identified factors. Population and sampling methods were also detailed, along with data collection and analysis procedures. Finally, threats to credibility, validation, and trustworthiness of findings were addressed. The next chapter will present the data and key findings in accordance to the methods described in this chapter.

# CHAPTER 4. RESEARCH FINDINGS

The preceding chapters introduced the purpose and significance of this study, including a justification from the literature for the research and the methods undertaken. This chapter presents the findings from all data collected in fulfillment of the aforementioned research objectives.

In addition to the findings, this chapter includes descriptions of the panelists, the participants for each round of data collection, and a schedule of when the data was collected for each round. Also, responses from interviews with participants, identified patterns for each homogenous group, and the collective core themes evident in data from the first round are detailed. Statistical outcomes for surveys from the second and final rounds are provided as well. The chapter concludes with a general summary of the significant findings from all three rounds of the data collection process.

## 4.1. Delphi Panelists

Twelve qualified panelists agreed to participate in this study. Each panelist met the required academic or professional qualifications to be considered an expert within CG or a related field. In addition to their professional and academic backgrounds, panelists were also selected by the researcher based upon their specific area of expertise in order to gain a broad representation of the various genres in which CG is evident. The areas represented by the panelists included digital photography and illustration, commercial gaming and animation, cinematic post production and special effects, visualization, computer programming and engineering, website and mobile application design and development, instructional and user-experience design, scientific research, and product development. Although the areas represented by these panelists is extensive, they are by no means exhaustive. The following sections generally describe all panelists by homogenous group.

### 4.1.1. Post-Secondary Academic Panelists

Panelists selected for the post-secondary academic group represented a wide range of backgrounds and experiences. Most had a record of sustained scholarship within CG or related fields. All panelists had at least five years of teaching experience in post-secondary education institutions in a CG or related program, with two having been promoted to administrative or leadership roles. All panelists had significant experience in the industrial sector before entering the academy, providing a broad representation of specializations and expertise among the panelists. The following sections describe each panelist within this group.

#### 4.1.1.1. Panelist 01

Panelist 01 (P01) serves as department chair and program director at a mid-sized public university in the Midwest. P01 professional background spans two decades producing digital animations and multimedia applications for clients across corporate, industrial, and educational sectors. P01 has and earned Master of Fine Arts in CG and animation, and has extensive experience teaching and developing animation and motion graphics courses and CG curriculums.

#### 4.1.1.2. Panelist 02

Panelist 02 (P02) serves as dean and program chair at a large community college in the Midwest. P02 manages and oversees all staffing and teaching responsibilities for a broad array of technology programs, including CG. P02 earned a Master of Arts in communications, and specializes in technology program development and management.

4.1.1.3. Panelist 03

Panelist 03 (P03) is a professor at a large public university in the Midwest. P03 primarily teaches courses in 3D CG programming, high performance computing, and geometric modeling. In addition to an earned Doctorate of Philosophy in CS, P03 has a significant scholarly record in CG and more than 20 years of post-secondary teaching experience in CG.

4.1.1.4. Panelist 04

Panelist 04 (P04) is an assistant professor at a large public university in the Midwest. P04 primarily teaches courses in CG programming, image processing, and scientific visualization. P04 has 20 years of professional experience in the fields of gaming and mechanical engineering, and earned a Doctorate of Philosophy in computer information science and engineering.

4.1.1.5. Panelist 05

Panelist 05 (P05) is an instructional consultant at a large public university in the Southeast where he works with faculty on the use of technology for teaching and learning. P05 has a background that includes engineering design and industrial technology with a focus on instructional design and digital fabrication. P05 has taught courses in interactive design and development, and earned an Educational Doctorate in instructional design and administration.

4.1.1.6. Panelist 06

Panelist 06 (P06) is an assistant professor of computer graphics technology at a large university in the Midwest. P06 specializes in video production and interactive multimedia, and primarily teaches courses in video and motion design. P06 has a professional background that includes media production, industrial design, and educational technology. P06 earned a Doctorate of Philosophy in curriculum and instruction.

4.1.2. Industry Professional Panelists

Panelists for the industry professional group included working designers, developers, scientists, artists, consultants, and executives. All panelists had significant experience within the CG industry or a related field, most within one specific genre. All but one industrial panelist has an earned graduate degree in CG or a related field. The following sections describe each panelist within this group.

4.1.2.1. Panelist 07

Panelist 07 (P07) is currently employed as a software and mobile application developer in a digital products start-up in the Midwest. P07 meets directly with clients and works on project proposals. With five years of experience in corporate web design, P07 also manages and assists other web developers with front-end or server-side programming. P07 is earning a Master of Science in computer graphics technology.

4.1.2.2. Panelist 08

Panelist 08 (P08) is a senior matte painter and set extension artist with a leading animation and film studio on the West coast. In addition to camera matching and tool creation, P08 creates 3D models and develops proprietary products. P08 has more than ten years of experience in the animation industry, and has received the highest accolades for work performed on popular cinematic releases. P08 earned a Master of Fine Arts in computer animation.

4.1.2.3. Panelist 09

Panelist 09 (P09) is a research scientist at a mid-sized university in the Midwest. P09 works specifically in virtual reality, dealing with 3D modeling and interactive programming. P09 has professional responsibilities that include working on sponsored research projects with different companies to develop interactive 3D applications or virtual reality applications. P09 has six years of experience working in virtual reality and simulation, and has earned a Master of Science in CG.

4.1.2.4. Panelist 10

Panelist 10 (P10) is a professional CG consultant working on applying color theory to visualization problems. In a career spanning more than 32 years, P10 has been a consultant for large universities and CG research centers in the United States, including the Center for Visualization and Analytics RENCI at North Carolina State University, the Scientific Computing and Imaging Institute at the University of Utah, the Visualization Group at Stanford University, and the Visualization Center at the University of California, Davis. P10 earned a Master of Science in civil engineering.

4.1.2.5. Panelist 11

Panelist 11 (P11) is a senior-level executive at a global strategic marketing and media corporation based in the Midwest. In addition to management and maintenance of an existing product base, P11 is also responsible for new product development and innovation. P11 has a career that spans over 16 years and include roles for industrial design to system integration across multiple market sectors. P11 earned a Master of Design in human-centered communication design.

4.1.2.6. Panelist 12

Panelist 12 (P12) directs product development at a national educational media company based in the Midwest. P12 has expertise in delivering educational media and content to end-users through the implementation of a variety of different digital media pieces, including interactive simulations, applications, and online courses. Throughout a 24-year career, P12 has worked primarily in the fields of interactive multimedia technology, design, and management. P12 earned a Master of Education in instructional technology.

### 4.1.3. Contextual Classifications

Section 3.3 of the previous chapter detailed how panelists were classified according to three distinct contexts based on the ACM SIGGRAPH Education Committee Index. Table 4.1 shows how each of the selected panelists for this study was classified according to his or her experience, background and current occupation.

Table 4.1. Contextual Classifications of Delphi Panelists

| Homogenous Group | Computer Art | Computer Science | Computer Technology |
|---|---|---|---|
| Post-Secondary Academics | P01<br>P02 | P03<br>P04 | P05<br>P06 |
| Industry Professionals | P07<br>P08 | P09<br>P10 | P11<br>P12 |

## 4.2. Participants

Panelist participation varied between each round of data collection. All 12 panelists were interviewed for the first round. Only seven panelists responded to the survey in the second round. Nine panelists responded to the survey in the final round. However, the ratios of academic to industrial panelists, as well as the contextual representations, were relatively close in both the second and final rounds, as illustrated in Figure 4.1 Participants by Round. The following sections detail the participation of panelists for each round of data collection.

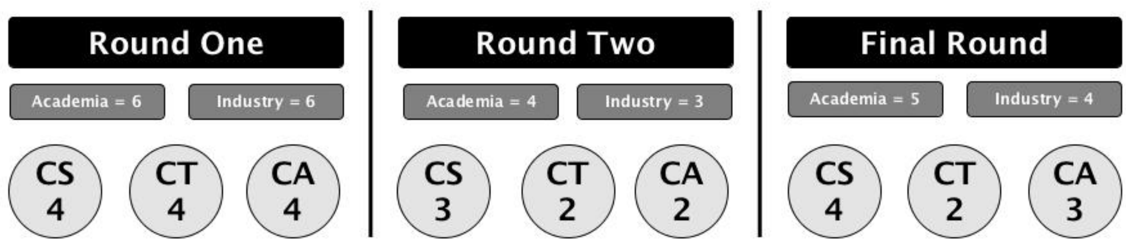


Figure 4.1. Participants by Round

### 4.2.1. First Round Participants

Interviews were conducted with all 12 panelists for the first round of data collection for the study. Panelists were interviewed at random on an individual basis according to schedule and availability. Specific data regarding when the interviews were scheduled and the order in which they were conducted are provided in future sections of this chapter.

### 4.2.2. Second Round Participants

Seven panelists participated in the second round of data collection, generating a total response rate of 58%. Four academic panelists participated (P01, P03, P04, and P05) along with three professional panelists (P08, P10, and P11). P02, P06, P07, P09, and P12 did not participate in the second round. None of the non-participating panelists provided a reason or explanation to the researcher regarding their lack of participation for this round.

Two participants for the second round were from the CA (P01 and P08) and CT (P05 and P11) contexts respectively, with CS (P03, P04, and P10) being the majority context with three participants. Thus, all contextual classifications were represented in the second round results.

### 4.2.3. Final Round Participants

Panelist participation increased in the final round. Nine panelists responded to the final round survey, generating a response rate of 75%. Five panelists from the post-secondary academic group participated (P01, P02, P03, P04, and P05), along with four panelists from the industry professional group (P08, P09, P10, and P11). Only three panelists (P06, P07, and P12) did not participate in the final round.

All contextual classifications were represented in the final round. CA was represented by three panelists (P01, P02, and P08), while CT was represented by two panelists (P05 and P11). CS was again the majority context with four panelists (P03, P04, P09, and P10). No contextual classification was omitted from the final round results.

## 4.3. Schedule of Data Collection

Data was collected over an eight-month period which began in January of 2015 and concluded in August of 2015. Each round of data collection required independent review and approval from the Institutional Review Board (IRB) at Purdue University at West Lafayette. Table 4.2 shows the schedule for each round of data collection, along with IRB exemptions granted for each round. Memoranda of exemptions from the IRB for each round are provided in Appendices A, B and C.

Table 4.2. Schedule of Data Collection by Round

| Round | IRB Approval | Start Date | End Date |
|---|---|---|---|
| One | October 8, 2014 | January 23, 2015 | April 28, 2015 |
| Two | July 15, 2015 | July 15, 2015 | August 1, 2015 |
| Final | August 6, 2015 | August 6, 2015 | August 30, 2015 |

## 4.4. First Round Results

The purpose of the first round was to ascertain the collective perceptions, through semi-structured interviews, about the definition and characteristics of CG within each homogenous group. The interview schedule with the specific questions posed to all participants can be found in Appendix A. All interviews were individually conducted with one participant and averaged 37 minutes in length. Table 4.3 shows the order in which first round participants were interviewed.

Table 4.3. Order of First Round Interviews

| Interview | Participant | Interview | Participant |
|---|---|---|---|
| 1 | P01 | 7 | P03 |
| 2 | P10 | 8 | P07 |
| 3 | P11 | 9 | P12 |
| 4 | P06 | 10 | P04 |
| 5 | P05 | 11 | P09 |
| 6 | P02 | 12 | P08 |

Upon inductive analysis of the interview data, several patterns and core themes became evident. Additionally, coded categories were established based on the interview schedule and patterns identified. The following sections describe these patterns and core themes by homogenous group, and are present according by category.

### 4.4.1. Academic Patterns

Patterns within responses from the interviews of academic panelists suggested that CG is contextually defined, design-centric, problem-based, visually oriented, and applied in practice. The most significant finding was the relationship between visual design and problem solving skills. The following sections detail key findings from interviews supported by direct quotations from participants. The findings are presented according to coded category.

#### 4.4.1.1. Definitions, Topics, and Issues

The majority of panelists interviewed within the academic group defined CG by using a variety of phrases and terms. Responses suggest that all definitions were contextually influenced. For example, panelists within the CA context defined CG by using the term graphic design explicitly, evidenced by P01 stating that CG is “The use of the computer to create graphic design or graphic images.” P02 concurred, stating that CG is “A combination of what would typically be understood as graphic design as well as mechanical drafting.” Panelists within the CS context differed, however, indicating that CG is implicitly defined by application, evidenced by the response from P03 that “CG must be defined implicitly, not explicitly…and is dependent on application.” When asked to define CG, P04 stated that CG involves “Using a computer to generate an image of a scene from some sort of description of that scene.” In significant contrast to CS panelists, participants within the CT context defined CG very broadly, evidenced by P05 stating “The term CG could range from two-dimensional raster, vector graphics and it is use for advertising all the way to three-dimensional computer aided design graphics that are used for manufacturing or animation and film and special effects." P06 had a similar view, stating:

> CG is a very broad term that falls into a couple of different categories. It can look like the application of the computer to different multimedia products, yet be the utilization of the computer towards visual complex systems or algorithms.

Participants from the post-secondary academic group were also asked to identify the fundamental topics most pertinent for CG. A common pattern among both CA and CT contexts was the use of CG for capturing, scanning, editing, and manipulating images, understanding color theory; and knowing the elements and principles of visual design. P02 stated that it was fundamental to understand how "Design is applied to everyday situations, whether commercial or medical illustration or education or marketing." However, participants within the CS context suggested a different approach than visual design, with P04 stating that it is more important to "Know the fundamentals of a programming language to generate pixels on a screen."

Finally, academic participants identified six characteristics that CG professionals exhibit: artistic skills, communication skills, understanding customer needs, adaptability, teamwork, and technical craft. Artistic skills and adaptability were the most evident of these characteristics, especially among CA and CT contexts. For example, P01 stated:

> Competent artistic skills and an understanding of the fact that the computer is just a tool. They have to be adaptive…and learn to adapt to new technologies, and see how we can be involved in producing work whether it's a commercial product or an art product.

P06 was of the same opinion, stating "You have to be versatile in the market place. The people who do well in the market are those that can solve visual problems, communicate well, and have strong design theory to back up their work."

4.4.1.2. Academic Disciplines

Prior work by Alley (2006) outlined key academic disciplines that either inform or affect CG, which include the physical and cognitive sciences, mathematics, visual communication and perception, computer programming, and the fine arts. Participants were asked about the relationship between CG and each of these academic disciplines in an effort to identify how CG is characterized. This section provides the key patterns evident among post-secondary academic participant responses of the relationship of CG to each discipline.

Physics was identified across all contexts as the most informative physical science for CG. Specifically, participant responses described how physics provided the means for the creation of realistic animation and dynamic rendering, which are based on the laws of light and an understanding of optics found in the physics knowledge base. P01 stated, "Physics really informed the discipline of animation. We use real laws of science in the process of making believable animation, and those are things that we use to guide us in the production of animation." Additionally, P01 described the importance physics has to understanding real-world dynamics, stating "We must understand real-world dynamics, and it is an area that we encourage students to investigate through the science of physics here at our university." It was also noted by several participants that the relationship between CG and physics is reciprocal. For example, P05 stated that "some of those disciplines are customers of computer graphics. The computer graphics used in their processes drive visual representation of scientific data." Additionally, P06 amplified this point by describing the role CG can have in CG physical science research, stating "We use 3D visualization and pervasive technology in fields such as the physical sciences. We have this thing called CG and, with the aid of technological innovation, it's allowed us a broader reach into some of those fields."

Participants across all contexts acknowledged the contributions mathematics has made toward the advancement of CG, both past and present. "A lot of the models for visual and graphics processing have come out of mathematical roots," stated P05 while describing how mathematical algorithms enable CG artists and technicians to manipulate 3D objects using sophisticated software packages. Mathematics seemed to have a higher value among panelists representing the CS context. This was evidenced when P04 described how applied math algorithms and techniques are essential to 3D modeling, geometric data manipulation, mesh transformations, and compression, stating "Math is essential for getting those done efficiently." However, in a clear detraction, one CA panelist, P01, suggested that the general emphasis on mathematics has been overstated and is now field-specific, stating:

> Twenty years ago, I think that was a required skill. But now, the programs have adjusted and have become so sophisticated that an artist could jump right into the applications. They can start producing work right there without doing any of the other labor to produce it. However, it is dependent upon the field that you're going for, and then how technical you want to become in that area. Certainly, for visualization, having additional math skills might be helpful.

Regarding visual communication and perception, participant responses in both CA and CT contexts suggested that the use of CG in the development of media technology and digital marketing tools marries design and technology. This marriage is being driven by the need for accurate and effective interpretation and representation of visual information. P01 stated "There's certainly a lot of avenues for designer work...I think people will always look for new ways of getting their products out, and selling those products of those designers." P05 agreed, asserting "CG drives a lot of what we do in teaching…we need digital learning tools now more than ever." P06 described the relationship between visual communication and CG in a similar manner, but in terms of methodology and application, stating "Think about how you would best approach solving a communications problem effectively, efficiently, and in a manner that reaches the end user – visual communications is key."

Among most participants, the relationship between CG and the cognitive sciences, specifically Human Computer Interaction (HCI), centers on the design and development of usable, customized experiences and interfaces. "They're totally intertwined...they're inseparable," stated P02 in response to being asked to describe the relationship between CG and HCI. This was also echoed in a response from P06, who stated "I think that the cognitive sciences enable us to understand people better and solve problems more efficiently and more so in a way that fits with the end user, the customer." Participant responses also suggested that the application of CG to educational learning tools is a driving factor in the cognitive sciences. P03 stated, "Learning is not important for CG, but CG is important to learning." P05 agreed, asserting "There have been numerous studies about computer graphics and vision, visualization, and memory, and communication…I'd call that a strong influencer." P02 echoed these perspectives, stating, "The different kind of learning tools, if nothing else, that you can create with computer graphics programs can have a huge impact on any of the cognitive sciences."

Patterns among participants about computer programming were mixed across contextual groups. Responses suggested that computer programming drives CG by enabling the development of tools based on need, evidenced by P05 who stated:

> CG has a need and then the computer programmer supplies a tool for that need. I would think that CG, and the need to visualize and represent things in a certain way, is a driver of what then is answered to or supplied by programmers.

Participants within CS and CT contexts identified CG as a catalyst for computer programming. To exemplify this point, P06 stated, “Having these different programming languages has made us much more versatile to be able to do things. It's also complicated things too because technology constantly changes, the language is constantly changed and you're needing to learn new things,” and P01, stated:

> I think that we really become at a real cool state in the industry actually right now where the tools are so sophisticated, but yet they’re still open, and we can still adapt them for new and innovate things that we haven’t even thought about.

Lastly, participants described the relationship between CG, visual communications, and the fine arts as a cooperative unification. Responses suggested that the fine arts adapt tools created by CG for artistic purposes. In turn, CG adapts approaches and techniques for color usage and perception from visual communications. P01 described it by using a metaphor, stating:

> It’s like iron sharpens iron. Art pushes the technology, and technology pushes art. They’re the same. I think that’s where the relationship between fine art and technology has certainly been in the last 20 to 30 years…you come up with an idea and then look forth on how to do it in the computer or vice versa.

Other participants described this relationship in more direct ways. “I honestly believe that if you have an artistic background and you understand design theory and you have the ability to communicate your ideas well and you can adapt, you can pick up technology and be able to apply things,” stated P06, while P03 simply stated that “CG is a tool for the fine arts, nothing more.” P02 concurred, explaining:

> A computer has limitations. It's a tool. It's a wonderful tool. I absolutely love them but there are built in limitations to it, whereas our minds do not.

> Especially in the area of creativity or exploring different kinds of design, you can sketch things down and just have ideas and you're not limited to the process of using the tool.

4.4.1.3. Curriculum Emphasis

Academics were asked about how their programs incorporate areas of specialization identified by Alley (2006). These areas included interaction design (IxD), animation, digital imaging (DI), graphical hardware, real-time graphics, and visualization. This section details participant responses regarding these areas and how they are emphasized within each of their programs.

Outside of the CA context where required courses or electives for IxD are core program requirements, IxD is not strongly emphasized within most participant programs. Responses from participants within CS and CT contexts suggest that IxD is mostly taught as an elective or embedded in other core classes, where emphasis is placed on how humans interact with peripheral technology, libraries, and input devices, evidenced by the response from P04 who stated, “We generally use a library that allows student programs to respond to key presses, mouse clicks, mouse dragging, etc.” P06 agreed, stating, “IxD is mostly embedded within core classes to understand how humans interact with different pieces of technology.” P05 identified that IxD was more emphasized 10 years ago when CG systems were less affected by rapid change, stating, “Today the industry is changing so rapidly and there's so many different technologies and tools and standards, the academy can't keep up with it.”

Animation was highly emphasized across all contexts, but in significantly different ways. Participants from CA programs emphasized traditional art-based animation techniques that prepared students for employment in the entertainment industries, evidenced by P01 stating, “Our program develops traditional skill sets first, then leads students toward computers through multiple classes where they start producing actual products.” Responses from participants in the CS context suggested a different approach to animation, where procedural techniques using computers were emphasized, as P05 described:

> We focus on physical simulation and simulating particle systems, rigid bodies, and collisions using libraries, scene graphs and hierarchical animation. This is achieved using an Open Asset Import Library to load a lot of different file formats into a computer system. All animation is defined in those files. We look at how to load these files and then how to write for tech shade or to do the skinning.

P05 also suggested that animation is moving towards automation, stating:

> Animation tools are automated to the point that a person can use them to animate something relatively easily. I don't see it emphasized as much for traditional static imagery because of the amount of effort and energy taken to manipulate and create those types of animations… libraries are already out there and are easy to implement.

DI was highly emphasized across all contextual areas. Responses from participants suggested that DI is the foundational cornerstone for all CG programs, despite variance in application. CA and CT programs emphasized raster and vector DI equally for illustrative and design purposes, while CS emphasized more on procedural and raster-based methods for displaying information. For example, P01 stated "There is no difference between traditional and digital imaging. Like animation, our program develops students from traditional to digital, and is applied across all concentrations." P02 stated, "Our programs have at least two required courses; one for raster and one for vector." P06 indicated that most programs should emphasize raster-based DI in basic courses, "Primarily for photo-manipulation." Regarding CS participants, both P03 and P04 responses agreed that DI needs to emphasize "Procedural imaging for displays" using libraries like OpenGL.

Regarding graphical hardware, only participants within CS contexts emphasized it in their program, and only in one course. Participants in the CA and CT contexts did not emphasize graphical hardware at all, mainly due to a lack of resources. P03 stated, “I teach one course about applying programming APIs for scientific purposes and applications for visualizing large data sets.” P04 described how graphical hardware is emphasized throughout one class, stating, “We do talk about video cards a lot…about the OpenGL abstraction of what happens on the video card as far as the different shaders and cache issues, but that’s mainly it.”

Real-time graphics seems to be a specialized resource for research. Emphasis for real-time graphics was primarily placed on visualizing large data sets using software-based methods. Similar to how graphical hardware is emphasized, P03 summed up the majority of all responses across all contexts, stating “The differences between real-time graphics and raster-based approaches, like ray tracing, local illumination and global illumination, is in working with large data sets, usually medical and scientific data visualization.”

Finally, participant responses regarding visualization suggested limited emphasis at the foundational level, but many acknowledged it is an emerging area, especially for medical and architectural applications. P04 stated, “Emphasis is mainly on volume-based visualization and how that can be used for medical image visualization. Other visualization topics are not really emphasized or discussed.”

#### 4.4.1.4. Differences Between CG and CS

Chapter two provided a brief discourse regarding the history and relationship between CG and CS. Participants were asked to provide their own perceptions about this relationship, and to provide significant differences between the CG and CS. Overall, participant responses across all contexts suggested CG is perceived as being more visual, applied, and user-centric, while CS is more theoretical, mechanical, and engineering-centric. The following paragraphs provide detailed responses for each participant within all three contextual groups.

CA participants described the differences between CG and CS in terms of emphasis and outcomes. P01 stated, “I think CS does emphasize that programming side of things where CG emphasizes the visual side of things”. P02 varied slightly, and focused on outcomes, stating:

> I think of CS more as building computers, understanding how they work, how to work more efficiently. More the hardware and software side of it, in terms of developmental and processing. I look at CG more as a visual end-product that can be created using computers.

Both participants agreed that CG and CS share mutual benefits, evidenced by P02 stating, “I believe that CS people should have a good understanding of the arts and the CG side in order to be better scientists and/or engineers.”

Among CS participants, the differences were not as pronounced. P03 suggested that CG is a part of CS, stating, “CS deals with algorithms, CG deals with algorithms applied to geometric visual results. CG is an integral part of CS.” However, in a mild contrast P04 took a different view, responding:

> When I think of CG it's much more of an applied and engineering discipline than CS, which is much more mathematical and abstract. Certainly one can use the tools of CS to solve problems in CG and you can apply CS to CG, but I don't think the inverse is true, necessarily.

Participants within the CT context identified differences by application. P05 suggested that CG is multidisciplinary, stating “CG is a very applied environment…more user-focused and they're using tools that computer scientists might develop. CG is more of an applied arts focus whereas CS focus might be more scientific, mathematical and theoretical.”

4.4.2. Industry Patterns

Patterns evident within interview responses of industry professionals defined CG mostly by application and methodology. Collectively, response patterns among this group suggested a strong emphasis on knowledge of design and visual media, especially within production environments. Participants also indicated communication of ideas as a defining factor for CG. The following sections provide detailed descriptions and quotations from participant interviews about key findings, and are presented by code category.

4.4.2.1. Definitions, Topics, and Issues

Collectively, industry professional participants defined CG as the use of a computer to generate visuals, images, or designs. Across all contexts, responses indicated that computers were essential to how CG is defined both in terms of application and output. "I would define CG as a domain around technical problem solving that has a visual aspect" said P07, "a big part that makes CG different from other domains, like art design, is the computer part." P10 agreed stating, "CG is the use of computers to generate imagery or to assess computer acquired imaging." Taking a similar view, P11 said "For me CG is really any type of imaging that is computer generated." Regarding applications, P07 said "There's a vested interest in using CG to address technical problems and technical solutions." P12 agreed in stating:

> CG is described by the end result… some sort of visual representation of some thing or process; whether it is a print ad, a website, an interactive piece, any visual part of that element that needs to be designed using a digital environment.

Participant responses among industry professionals suggested that understanding raster and vector imaging, image resolution, and file formats were technically fundamental for CG. P09 stated, "One should know the general differences between raster graphics and vector graphics, file sizes and types, and image specifications based on particular needs." P08 agreed stating, "In addition to resolution, file formats, raster, vector, and texturing, you better know the differences between a trixel and a pixel." Participants identified visual problem-solving skills, typography, visual design, and how to use color as fundamental. P07 emphasized the need for CG professionals to have a solid knowledge of visual design, saying "One can have a specialized skill set, but overall they must have strong visual design and problem skills to be effective." In agreement, P12 said "It is important not only to have the ability to create raster-based images, but also know and understand color theory and how to use space and typography."

Participants responses in both CA and CT contexts suggested that knowledge of visual design, graphics creation, and technical skills are important professional issues. P07 said, "The knowledge of visual design is definitely a through line between all the sub-disciplines." P12 strongly concurred, stating:

> It is extremely challenging to find a good designer. I can find many people on my team and that I look to hire that know software. But the design aspect, the creative aspect is a weak point …it'd be nice to see more people have design skills.

However, this was not echoed in the CS context, where an importance on software skills was highly emphasized. "CG is very interdisciplinary in nature," stated P09, "so there are many different ways to come at calling one self a CG professional. In terms of CS fundamentals, understanding how to handle coding and writing code to create the 3D graphics or 2D graphics is essential."

4.4.2.2. <u>Academic Disciplines</u>

As described in section 4.4.1.2, prior work by Alley (2006) outlined key academic disciplines that either inform or effect CG. In uniform with academics, industry professionals were also asked about the relationship between CG and each of these academic disciplines in an effort to identify how CG is characterized. This section provides the key patterns evident among industry professional panelists responses about the relationship of CG to each discipline.

Regarding the physical sciences, responses among industry professionals across all contexts suggested that knowledge of physics is important for understanding how to create realistic computer-based simulations. “A knowledge of physics would help you test that what you've created is at least physically accurate,” P07 said. P08 agreed, saying “Everything about CG in movies these days is trying to simulate real life as closely as possible.” Additionally, industry professionals see physics as an important foundation for understanding how things interact in real-world situations, especially in developing interactive games. P12 made this point, stating:

> I think knowing the fundamentals of physics in terms of questions you might need to ask or just simple things that you need to understand is important when you're involved with game development. I think it's an important foundation to have.

Responses among all industry professionals, regardless of context, suggested that the role of mathematics was vital to the development of CG. P09 said:

> There's a lot of mathematical elements that go into trying to create a CG presentation. That's why it is only that technical papers that are at a conference like SIGGRAPH have a very large mathematical component associated with. So that's how mathematics plays in.

This was echoed by how participants described the relationship between computer programming and animation. P08 said, “Math is important, folks. Math and art.” P11 agreed, stating “Computers are math machines, they're basically geometric calculators, and once you get into animation you're [programming] physics with trigonometry and calculus." P08 emphasized this point by saying "I often use algebraic expressions to drive procedural shaders, to calculate resolutions, and to build tools."

Both CA an CS shared a similar view about the relationship between visual perception and CG. Responses highlighted the importance of effective realism and understanding the meaning of design. For example, P08 stated, "It is important to study real life to determine what you can get away within faking real life." P09 concurred, stating "Visual perception is a big part of CG because most of the technologies are really trying to trick the brain into perceiving 3D through depth when there is none – especially when you're really looking at a 2D image." Within the CT context, responses suggested that the role of visual perception is important for understanding design meaning, as P11 stated, "[Visual perception] shows the changing landscape of what design means, and how it's basically merged a lot of different roles."

The cognitive sciences were viewed by CS and CT participants for idea communication, specifically for expressing concepts and designing information. P11 expressed this importance, stating "[Psychology] is important for understanding what kind of information we're actually able to process in the brain and what we see in design." Sharing in this view, P10 said "Visual perception, although domain specific, is important for communicating ideas." P12 also identified the importance of the cognitive sciences for understanding how to focus idea construction, stating:

> Knowing how to take an artistic approach and apply it scientifically to get your outcome a little more focused is an important contribution to CG by the cognitive sciences. I think it's very valid.

In a different view, participants from the CA context described the relationship between cognitive science and CG as applied, mainly used in learning tools and technology. P08 said "CG developed without a plan for its use. So then artists came in and figured out how to use this new technology...it's a marriage working together." In agreement, P07 described how cognitive science aids developers in adapting technology, stating "Trying to amass as much knowledge from the cognitive sciences about memory, the brain and thought patterns would be very beneficial for making tools for people to use."

Nearly all participants suggested a positive relationship between HCI and CG. Participants in both CA and CS contexts identified HCI as particularly important for interacting with data and environments, implementing usability, and improving user experiences. P11 described this relationship, stating "American businesses are starting to embrace human-centered design; shifting from the stakeholder to the user. I believe this has greatly been facilitated by CG." P09 agreed, stating, "[HCI] enables how one interacts or finds insights into science and data sets, especially when using virtual reality or various other types of senses." This awareness of how people interact with different environments was echoed by P12, stating, "Having an understanding of how people interact with different environments from a visual and intuitive standpoint can make a graphic designer, or any type of person who produces graphics, that much stronger and that much more successful long-term."

The relationship between CG and computer programming facilitates software development and enables the creation of data visualization tools. Responses among CA an CS participants indicated a mutually dependent relationship between CG and CS, with CG artists being dependent on programmers to develop tools and software, and CG artists facilitating a need for computer programmers. P08 clearly described this relationship, stating:

> Programmers and artists have to work together. Programmers think one way. Artists think another way. To find a common language, to come together and build something together, requires both groups. Without one, you don't have very successful software. Without the other, you don't have any software at all.

Additionally, P10 identified the effects that programmers have on the advancement of CG, stating, “[Programming] keeps on increasing what we can do with CG and the capabilities of what graphics can convey.” Reflecting this view, P12 stated, “Nowadays production is on the digital end. With that comes metadata analytics, interactivity, back-end functionality. So I think today's designers really need to know quite a bit, or at least a foundation, in different types of programming.”

Lastly, responses from industrial professionals about the relationship between CG, fine art and visual communication suggest a close alignment with visual perception. Both CA and CS participants tied visual communication and fine art to CG for the effective communication of ideas, evidence first by P07 response, who stated:

> The visual arts, as well as [visual] communications, are influential in communicating ideas to others in visual form. Since we're in the business of creating ideas that have a strong visual component, the visual medium is one that's really well suited to trying to communicate those sort of ideas, being able to sketch, being able to make wire frames with prototypes, or some other lower cost, lower fidelity version of your idea to communicate it to other people is really helpful.

Additionally, P09 indicated that visual communications are important for understanding how to create good pictures, stating:

> The large part of what I do is to write and teach color theory from areas that were prior to CG, and show how those principles can be applied in digital imagery. Creating a picture or image is something way before computers, and it's fundamental to understanding how to create a good composition.

In agreement, “[We] use graphic and visual communication techniques to successfully convey that small icon or that bigger graphic that's fitting on a web page” P12 said. Along a similar viewpoint, other participants described how the fine arts defined the limit of visual communication. “The lack of being able to share fine art, and the access to it before CG and communication were really standard, were to increase the value of those artifacts” said P11, “However, I think the value is being evaluated, applied and assessed differently now because of access. So I think content is actually becoming more and more important.”

4.4.2.3. Industrial Emphasis

Industry professional panelists were asked about how their companies and organizations emphasized specialization areas related to CG. Once again, these areas included IxD, animation, DI, graphical hardware, real-time graphics, and visualization. This section details participant responses regarding these areas and how they are being emphasized within each of their organizations.

IxD is strongly emphasized by organizations to craft and create compelling interaction and interactive media. Responses from participants within CA and CT contexts suggest that IxD is mostly emphasized when users interact with dynamic elements and interfaces, evidenced by the response from P07, stating:

> Interaction design comes into play when you're talking about anything dynamic. Being able to craft compelling interactions, and what compelling means definitely depends on the users that you're targeting, I would say that crafting compelling interactions is another big way to keep people interested and engaged in the web products and apps that I make.

Within the CS context, emphasis was focused on 3D models and simulations. P10 described this point, stating “A lot of times we're dealing with 3D models that are showing processes that happen over time.” P08 identified that the IxD is emphasized as a bridge between different technologies, stating, “With the increasing demand for virtual reality gaming technology, [IxD] is a real branch between web design, visual effects, and animation in gaming.”

Animation was moderately emphasized by participants across all contexts, mainly for mechanical or physical operations. Participants from CA and CT contexts emphasized animation as a tool for visual indication, evidenced by P11 stating, “Again it goes back to just basic foundational design principles, and I think that has not changed even though the CG capabilities have allowed us to produce stuff.” Responses from participants in the CS context suggested a blended approach to animation, where data-driven animation for simulation is emphasized, as P10 described:

> Animation existed before computer. If you look at Disney and those types of things, you have series of drawings on a table and how do you put those drawing together, cell by cell and bring character to life. That is a very different kinds of skill than data-driven animation found in CS, where we take scientific data sets and display the trends within the data. Those are two very different ways of creating animation.

DI was emphasized across all contextual areas for producing well formatted, compressed, and optimized images. Responses from participants in the CS and CT contexts suggested that DI is emphasized mostly in two ways; scanning and modification of images. P09’s response clarified this point, stating, “In terms of science, emphasis for DI is applications like CAT scans or x-rays. DI can also be capturing images out into the world with a camera and bringing those back in and digitally manipulating them.” P10 agreed, stating, “We use DI to convert images into a format that can be read by different applications.” CA participants emphasized DI equally for optimization purposes, evidenced by P07 stating, “DI role is mainly for optimization, like scaling, removing unnecessary pixels, trying to balance decompression of the image with the quality.”

Responses from participants across all contexts suggested limited or low emphasis on graphical hardware. Participants within the CS and CT contexts described the use of dual video cards and inexpensive peripheral devices mainly for the display of graphical scenes, as described by P11 stating, “We use dual graphics cards in our workstations to boost production, but there's no reason to spend money on a cinema displays when Samsung has the equivalent for, you know, a quarter of the price.” Participants within the CA context described how graphic hardware is unnecessary and taken for granted. The response from P07 exemplified this point, stating:

> In my job, I'm not really doing anything that's computationally intensive enough to warrant a render farm or dedicated graphics card for that sort of performance. The closest thing would be employing specialized graphics cards if a project required it, but that would be on a case-by-case basis.

Real-time graphics were emphasized by participants within the CS context for image output and data representations. Participants from the CA context did not emphasize real-time graphics at all. Participants from the CT emphasized real-time graphics in low-level outputs, evidenced by the response from P03, stating, “Rendering is automated in order to eliminate human error to make sure that the data is represented accurately.” P10 described how graphical hardware is emphasized in forecasting applications, stating, “People are creating a real-time analysis of various weather models from data that they have about weather forecasts. This enables policy makers, like mayors, to make decisions about what to do.”

Finally, participant responses regarding visualization suggested a high emphasis on communicating with pictures, employing sketching, and blueprinting data. P07 stated:

> Definitely a lot of pre-visualization. I'm kind of a visual thinker, so I like to sketch stuff out. I have a white board next to my desk, but I'll use it mostly to diagram and make notes and sketch out rough sketches of interface concepts.

P08 agreed, stating, “Everything is created with a plan, with a style, with art guide. Being able to communicate visually through pictures is important.” Responses from participants within the CS context indicated that visualization was data-based, evidenced by P10 response stating, “We use visualization to make computational data easier to understand.” Echoing this point, P11 stated, “You put frameworks and systems in place, and the data generates what the display is based on framers and rules, much like an iTunes visualizer.”

4.4.2.4. Differences Between CG and CS

Participants were asked to provide their own perceptions about the relationship between CG and CS, and to provide significant differences between them. Overall, participant responses for industry professionals across all contexts suggested that CG is visual and focuses on the seen rather than the unseen. Some participants identified CG as a subset of CS that is primarily scientific, technically and logically driven, centric on computing machines and frameworks, and essential to how computers interact and pass data via networks. Other participants indicated that CG is creative and aesthetically driven, and communicates ideas. The following paragraphs provide detailed responses for each participant within all three contextual groups.

CA participants described the differences between CG and CS in terms of emphasis and outcomes. The response from P07 exemplified this point, stating:

> I would definitely say that the difference between CG and CS is that CG is explicitly focused on the visual parts of technology, rendering, be it the front end of apps or websites. It's inextricably linked with visual communication of some sort. CS, on the other hand, can be more of a scientific discipline; CG focuses on what's seen, CS focuses on the unseen.

P08 agreed with P07, stating:

> CS tends to be more technical, logical, and more hands-on driven, whereas CG is more visual and more aesthetic. However, blending is occurring; a common language of understanding each other, there’s no growth in technology and art together as in unified team. I think that a computer scientist might write the perfect algorithm for a doctor to be able practice surgery on a virtual reality computer, but without somebody

> designing it to make it pretty and make it look right, without that essential feedback, twist of technology, or just because you're doing a simulation of a plane wreck for the government to recreate that, doesn't mean those physics based simulations can't also look attractive in the courtroom.

Among CS participants, the differences were very pronounced. P10 suggested that CS is a framework on which CG is dependent, stating:

> I think the main difference from my point of view is CG is mostly concerned with the communication of the ideas that you're trying to convey. Whereas CS is concerned with enabling the technology to convey those ideas. I think CS is like a framework that CG utilizes. CG is associated with communication, and CS is associated with enabling that communication, the technology by enabling the communication.

However, in a mild contrast, P09 took a different view, responding:

> I very often see CG is a subset of CS, in terms of a faculty member who's hired. A CS department can teach CG. Or, it can be a subset of a design school. Someone can also be hired in a design school to teach CG. So, CG is a subset of both CS and design.

Participants within the CT context identified differences by application. P11 response suggested that CS augments CG, stating:

> CS is tied largely to the hardware and the physics of the computer and the machine, and maybe some of the math and theory behind it, and the ability to do stuff like compression, or do stuff like you know, large data set traversals. I look at CS as something that actually augments or helps evolve CG in the sense that it gives us more capabilities. CG is using the tool as a processor, you're using the tool as a production extension, an extension basically of all the tools that you normally have to use to create a final output. The output is also a lot less abstract than CS.

P12 agreed, stating:

> I think CS would deal more with how computers would interact with a human or themselves, and be able to pass data and collaborate and coordinate with each other computer-wise. I think CG, from my perspective, is now being used as a tool to create and produce something visually to be presented to end-users and engage them in one form or another, whether it be for sales, for education, for personal entertainment, for just having something nice and unique to look at. Again, CS is more about hardware and communication with the computers, more of a programming thing. CG is more about a creative, innovative results; something aesthetic that you can interact with or visually look at.

### 4.4.3. Core Themes

Sections 4.4.1 and 4.4.2 of this chapter detailed the patterns evident among participant responses from first round interviews for both homogenous groups. These patterns were independently reviewed and compared to the raw data from the collective interviews across both homogenous groups.

A total of of 21 core themes from four categories emerged from the first round data. The first category reflected the definition, topics and issues relative to professionals who work in CG-related fields. Core themes in the first category suggested that CG is broadly defined, creative, and technical. Additionally, themes indicated that visual problem solving skills are important characteristics of CG professionals. Core themes in the second category reflected the relationship between CG and established academic disciplines, and how the sciences, humanities, mathematics, and communication effects CG. Core themes in the third category reflected how CG is evident within academic curricula and industrial organizations, and how CG specializations are emphasized in academic programs and industrial contexts. Core themes in the final category reflected how CG differentiates from CS, describing the relationship and purpose of both CS and CG. The following sections list and describe the specific core themes identified between the two homogenous groups, organized and presented by coded category.

4.4.3.1. <u>Definition, Topics and Issues</u>

The following lists the core themes evident among each homogenous groups about the definition, topics, and professional issues for CG:

1. CG was broadly and implicitly defined, and identified by the application or utilization of the computer to create graphics, images, products, designs, and visuals.
2. The fundamental topics of CG included raster and vector imaging, the elements and principles of design, and color theory.
3. CG professionals exhibit visual problem solving skills, technical expertise, strong communication skills, and knowledge of visual design.

4.4.3.2. <u>Academic Disciplines</u>

The following lists the core themes evident among each homogenous groups about the relationship of CG to established academic disciplines:

1. Physics is essential for understanding laws of light and optics, evidenced by real-world simulations and dynamic realism.
2. CG is dependent on mathematics for compression algorithms, evidenced by the utilization of programming languages to enable the creation of modeling and editing tools for geometric data.
3. Visual perception is important to CG for understanding the meaning of design and interpreting visual information as evidenced by products that effectively perceive color, employ image persistence, and facilitate visual literacy.

4. The relationship of CG with the cognitive sciences, specifically psychology, enables communication of ideas, evidenced by the design of educational tools.
5. HCI provides CG with guidelines for the development of usable tools, interfaces, and experiences, evidenced by how we interact with data and digital environments with usable interfaces.
6. CG is based on computer programming, which drives and influences CG, evidenced by versatile software in entertainment and data visualization industries.
7. Visual communication marries design and technology, evidenced by the development of digital marketing tools and the way ideas are communicated.
8. Fine Arts define the development of graphical tools, evidenced by the cohesion between design and technology.

4.4.3.3. Curriculum and Industrial Emphasis

The following lists the core themes evident among each homogenous groups about how CG is emphasized within academic curricula and industrial organizations:

1. Curricula emphasized IxD for the creation of interactive media for learners, while industry emphasized IxD for understanding how humans interacted with mobile devices.
2. Curricula emphasized traditional animation techniques, with limited focus on animation libraries, procedural simulation and dynamics; while industry emphasized data-driven animations for simulation.
3. Curricula emphasized DI as foundational, where raster, vector, OpenGL, and photo-manipulation is highly emphasized; while industry emphasized DI mostly for optimizing, formatting, and compressing images.

4. Graphical hardware was not highly emphasized in CG curricula, mainly in one course that covered OpenGL, APIs, and scientific data visualization; industry emphasized graphical hardware only in specialized contexts involving graphical displays.
5. Curricula emphasized real-time graphics for visualization of large data sets using software based methods; industry employs real-time graphics for accurate data representations for deployment onto multiple platforms.
6. Curricula emphasized visualization for medical and scientific applications; industry emphasized visualization for communication of ideas, sketching, and blueprinting application data.

#### 4.4.3.4. Differences between CG and CS

The following lists the core themes evident among each homogenous groups about how CG differs from CS:

1. CG is visual, applied, creative, aesthetically driven, focuses on the seen rather than the unseen, and communicates ideas.
2. CG is a subset of CS.
3. CS is theoretical, scientific, logical, and engineering-driven.
4. CS enables and augments CG.

### 4.5. Second Round Results

During the first round of this study, the collective interview data obtained from all panelists was analyzed using qualitative techniques, and core themes from the first round data were identified and categorized. These core themes represented the collective perceptions identified by the researcher for all panelists across each homogenous group. During the second round of the study, feedback was solicited from all panelists about the identified core themes from the first round. An online survey was authored and administered to all participants in order to facilitate consensus on the findings from the first round. The second round survey instrument is provided in Appendix B.

As described in section 4.2.2, a total of seven panelists responded to the second round survey. The following sections details the results for this round, presented by coded category.

### 4.5.1. Definitions, Topics, and Issues

In the second round survey, participants were asked a total of 10 questions about the definition for CG. Participants reached consensus on six of the 10 questions, opting for utilization of the computer over application. All four core themes relating to the fundamental topics for CG reached consensus among participants. Regarding professionalism, three of four questions reached consensus, with the exception of technical expertise. Table 4.4 presents the actual results for all questions relating to the definitions, topics, and issues for CG posed to all participants in the second round survey instrument.

### 4.5.2. Academic Disciplines

In the second round survey participants were asked a total of 29 questions relating to the core themes for academic disciplines. Participants reached consensus on 13 of 29 questions. Participants reached consensus on all questions relating to mathematics, cognitive sciences, and visual communication. Regarding physics, participants reached consensus about the physical laws of optics. Participants reached consensus on three of five statements relating to visual perception, excluding of the meaning of design and visual literacy. Participants reached consensus on the development of visual data tools for computer programming. Participants did not reach consensus for any core theme relating to HCI and the fine arts. Table 4.5 presents the actual results for all core themes for academic disciplines posed to all participants in the second round survey instrument.

Table 4.4. Second Round Survey Results for Definitions, Topics, and Issues

| Statements (n=7) | Mean | SD |
|---|---|---|
| Computer Graphics must be defined … | | |
| contextually. | 3.71 | 0.76 |
| implicitly. | 3.43 | 0.98 |
| Computer Graphics is the application of the computer to create… | | |
| images. | 3.86 | 1.35 |
| products. | 3.71 | 1.25 |
| designs. | 3.57 | 1.51 |
| visuals. | 3.86 | 1.35 |
| Computer Graphics is the utilization of the computer to create… | | |
| images. | 4.57 | 0.53 |
| products. | 4.43 | 0.53 |
| designs. | 4.43 | 0.79 |
| visuals. | 4.57 | 0.53 |
| The fundamental topics for Computer Graphics include… | | |
| raster imaging. | 4.71 | 0.49 |
| vector imaging. | 4.71 | 0.49 |
| the element and principles of design. | 4.57 | 0.53 |
| color theory. | 4.43 | 0.53 |
| Computer Graphics professionals exhibit… | | |
| visual problem solving skills. | 4.57 | 0.79 |
| technical expertise. | 4.29 | 1.11 |
| strong communication skills. | 4.14 | 0.90 |
| knowledge of design. | 4.43 | 0.98 |

Table 4.5. Second Round Survey Results for Academic Disciplines

| Statements (n=7) | Mean | SD |
|---|---|---|
| Physics is essential for… | | |
| understanding the physical laws of light. | 3.86 | 1.07 |
| understanding the physical laws of optics. | 3.57 | 0.98 |
| creating real-world graphics-based simulations. | 4.14 | 1.07 |
| achieving dynamic realism in graphics-based simulations. | 3.86 | 1.07 |
| Mathematics is essential for… | | |
| writing algorithms for image compression. | 4.57 | 0.53 |
| utilizing programming languages to create modeling tools for geometric data. | 4.14 | 0.69 |
| utilizing programming languages to create editing tools for geometric data. | 4.29 | 0.49 |
| Visual perception is essential for understanding… | | |
| the meaning of design. | 4.14 | 1.21 |
| how to interpret visual information. | 4.57 | 0.53 |
| color perception. | 4.57 | 0.53 |
| image persistence. | 4.57 | 0.53 |
| visual literacy. | 4.14 | 1.21 |
| The cognitive sciences facilitate… | | |
| the graphical communication of ideas. | 4.14 | 0.38 |
| the design of graphics-based learning tools. | 3.86 | 0.69 |
| Human Computer Interaction is important for… | | |
| the development of graphics-based tools. | 3.86 | 1.07 |
| the development of graphics-based interfaces. | 3.86 | 1.35 |
| the development of graphics-based experiences. | 3.86 | 1.35 |
| interacting with large data sets. | 3.29 | 1.50 |
| interacting within digital environments. | 3.57 | 1.51 |

Table 4.5 (Continued). Second Round Survey Results for Academic Disciplines

| Statements (n=7) | Mean | SD |
|---|---|---|
| Computer programming… | | |
| serves as the basis of Computer Graphics. | 2.86 | 1.21 |
| drives advancement of Computer Graphics tools. | 3.57 | 1.51 |
| enables the development of graphical software applications for entertainment. | 4.00 | 1.00 |
| enables the development of data visualization solutions. | 4.29 | 0.49 |
| Visual communication… | | |
| marries design and technology. | 3.71 | 0.76 |
| drives the development of graphics-based marketing tools. | 3.71 | 0.49 |
| facilitates graphical communication of ideas. | 4.14 | 0.38 |
| The fine arts… | | |
| define the limits of visual communication. | 2.71 | 1.38 |
| determine the value of graphical representations. | 2.86 | 1.57 |
| act as a cohesive agent between technology and design. | 3.14 | 1.57 |

### 4.5.3. Curriculum and Industry Emphasis

In the second round survey participants were asked a total of 23 questions relating to the core themes for curriculum and industry emphasis. Participants reached consensus on 15 of 23 questions. Participants reached consensus on all questions relating to DI, real-time graphics, and graphic hardware. Participants reached consensus on library-based animation and data-driven simulation. Participants reached consensus on all questions for IxD except one, human learning. Medical and scientific visualization were the only two questions which participants reach consensus relating to visualization. Table 4.6 presents the actual results for all statements relating to the core themes for curriculum and industry emphasis posed to all participants in the second round survey instrument.

Table 4.6. Second Round Survey Results for Curriculum and Industry Emphasis

| Statements (n=7) | Mean | SD |
|---|---|---|
| Computer Graphics emphasizes how… | | |
| Interaction Design connects to web design. | 3.43 | 0.98 |
| Interaction Design connects to video games. | 3.71 | 0.76 |
| Interaction Design connects to data visualization. | 3.71 | 0.76 |
| Interaction Design connects to mobile devices. | 3.43 | 0.98 |
| Interaction Design affects human learning. | 3.29 | 1.25 |
| Computer Graphics emphasizes how to create… | | |
| library-based animations. | 3.29 | 0.95 |
| data-driven animations. | 3.29 | 0.95 |
| procedural simulations. | 3.14 | 1.21 |
| real-time dynamics. | 3.43 | 1.13 |
| Computer Graphics emphasizes how digital imaging software is used to… | | |
| create raster graphics. | 4.29 | 0.49 |
| create vector graphics. | 4.29 | 0.49 |
| manipulate photos. | 4.14 | 0.69 |
| optimize graphic-based images. | 4.00 | 0.58 |
| format graphic-based images. | 4.00 | 0.58 |
| compress graphic-based images. | 3.86 | 0.69 |
| Computer Graphics emphasizes graphic hardware… | | |
| with OpenGL to create digital images. | 3.57 | 0.98 |
| with Application Program Interfaces (APIs). | 3.43 | 0.98 |
| to create scientific data visualizations. | 3.86 | 0.90 |

Table 4.6 (Continued). Second Round Survey Results for Curriculum and Industry Emphasis

| Statements (n=7) | Mean | SD |
|---|---|---|
| Computer Graphics emphasizes real-time graphics for… | | |
| visualizing large data sets. | 4.14 | 0.38 |
| creating accurate data representations. | 4.00 | 0.58 |
| deploying graphical assets onto multiple platforms. | 3.871 | 0.95 |
| Computer Graphics emphasizes visualization to… | | |
| enhance medical applications. | 4.29 | 0.49 |
| enhance scientific applications. | 4.29 | 0.49 |
| blueprint application data. | 3.86 | 1.07 |
| communicate ideas effectively. | 4.29 | 1.11 |

### 4.5.4. Differences Between CG and CS

In the second round survey participants were asked a total of eight statements relating to the core themes about how CG differentiates from CS. Participants reached consensus on only one of the eight statements. Table 4.7 presents the actual results for all core themes for how CG differentiates from CS posed to all participants in the second round survey instrument.

Table 4.7. Second Round Survey Results for Differences Between CG and CS

| Statements (n=7) | Mean | SD |
|---|---|---|
| Computer Graphics is… | | |
| a subset of Computer Science. | 2.43 | 1.51 |
| more visual than logical. | 3.29 | 1.25 |
| more applied than theoretical. | 3.14 | 1.07 |
| more creative than scientific. | 3.29 | 1.25 |

Table 4.7 (Continued). Second Round Survey Results for Differences Between CG and CS

| Statements (n=7) | Mean | SD |
|---|---|---|
| more aesthetically driven than Computer Science. | 3.29 | 1.25 |
| Computer Science is… | | |
| augments Computer Graphics. | 3.29 | 1.25 |
| enables Computer Graphics. | 4.57 | 0.53 |
| is more engineering driven than Computer Graphics. | 3.86 | 1.35 |

## 4.6. Final Round Results

In final round for this study, the core themes from the second round survey for which consensus was reached were revised into a reduced survey instrument and administered to all panelists. These core themes represent the common, collective perceptions of all panelists across each homogenous group regarding the questions posed to them in the second round.

During the final round of the process, feedback was solicited from all panelists in order to gain a general consensus about the core themes. An online survey was authored and administered to all participants based on the findings from the second round. The final round survey instrument is provided in Appendix C. As described in section 4.2.2, a total of nine panelists responded to the final round survey. The following sections details the results for this round, ordered by coded category.

### 4.6.1. Definitions, Topics, and Issues

In the final round survey participants were asked to reach a consensus on five questions relating to the definition for CG. Participants reached consensus on all but two. Participants reached consensus on all but one question relating to fundamental topics for CG. Participants reached consensus on all questions relating to professionalism. Table 4.8 presents the actual results for all statements relating to the definitions, topics, and issues for CG posed to all participants in the second round survey instrument.

### 4.6.2. Academic Disciplines

In the final round survey participants were asked to reach a consensus a total of 14 statements relating to the core themes for academic disciplines. Participants reached consensus on all but one statement. Participants reached consensus on all statements relating to mathematics, cognitive sciences, and visual perception and communication. Regarding physics, participants did not reach consensus about the physical laws of optics. Table 4.9 presents the actual results for all core themes for academic disciplines posed to all participants in the final round survey instrument.

Table 4.8. Final Round Survey Results for Definitions, Topics, and Issues

| Statements (n=9) | Mean | SD |
|---|---|---|
| Computer Graphics must be defined… | | |
| contextually | 3.22 | 1.56 |
| Computer Graphics is the utilization of the computer to create… | | |
| images | 4.78 | 0.67 |
| products | 4.33 | 1.00 |
| designs | 4.78 | 0.67 |
| visuals | 4.78 | 0.67 |

Table 4.8 (Continued). Final Round Survey Results for Definitions, Topics, and Issues

| Statements (n=9) | Mean | SD |
|---|---|---|
| The fundamental topics for Computer Graphics include… | | |
| raster imaging | 5.00 | 0.00 |
| vector imaging | 5.00 | 0.00 |
| the elements and principles of design | 4.56 | 1.33 |
| color theory | 5.00 | 0.00 |
| Computer Graphics professionals exhibit… | | |
| visual problem solving skills | 4.78 | 0.67 |
| strong communication skills | 4.56 | 0.88 |
| knowledge of design | 4.56 | 0.88 |

### 4.6.3. Curriculum and Industry Emphasis

In the final round survey participants were asked to reach a consensus on 20 questions relating to the core themes for curriculum and industry emphasis. Participants reached consensus on six of the 20 questions. Participants reached consensus on all questions relating to visualization. Participants reached consensus on all questions for IxD except one, video games. As it relates to DI, participants reached consensus on raster and vector imaging. Participants did not reach consensus on any of the questions relating to animation and real-time graphics. Table 4.10 presents the actual results for all questions relating to the core themes for curriculum and industry emphasis posed to all participants in the final round survey instrument.

Table 4.9. Final Round Survey Results for Academic Disciplines

| Statements (n=9) | Mean | SD |
|---|---|---|
| Physics is essential for… | | |
| understanding the physical laws of optics. | 3.67 | 1.73 |
| Mathematics is essential for… | | |
| writing algorithms for image compression. | 4.78 | 0.67 |
| utilizing programming languages to create modeling tools for geometric data. | 4.33 | 1.00 |
| utilizing programming languages to create editing tools for geometric data. | 4.33 | 1.00 |
| Visual perception is essential for understanding… | | |
| how to interpret visual information. | 5.00 | 0.00 |
| color perception. | 5.00 | 0.00 |
| image persistence. | 4.56 | 0.88 |
| The cognitive sciences facilitate… | | |
| the graphical communication of ideas. | 4.78 | 0.67 |
| the design of graphics-based learning tools. | 4.33 | 1.00 |
| Computer Programming… | | |
| enables the development of graphical software applications for entertainment. | 5.00 | 0.00 |
| enables the development of data visualization solutions. | 4.78 | 0.67 |
| Visual communication… | | |
| marries design and technology | 4.78 | 0.67 |
| drives the development of graphics-based marketing tools. | 4.78 | 0.67 |
| facilitates graphical communication of ideas. | 4.78 | 0.67 |

Table 4.10. Final Round Survey Results for Curriculum and Industry Emphasis

| Statement (n=9) | Mean | SD |
|---|---|---|
| Computer Graphics emphasizes how… | | |
| Interaction Design connects to web design. | 4.25 | 1.49 |
| Interaction Design connects to video games. | 4.75 | 0.71 |
| Interaction Design connects to data visualization. | 4.00 | 1.51 |
| Interaction Design connects to mobile devices. | 3.75 | 1.04 |
| Computer Graphics emphasizes how to create… | | |
| library-based animations. | 3.25 | 1.67 |
| data-driven animations. | 3.75 | 1.04 |
| Computer Graphics emphasizes how digital imaging software is used to… | | |
| create raster graphics. | 4.75 | 0.71 |
| create vector graphics. | 4.75 | 0.71 |
| manipulate photos. | 4.00 | 1.51 |
| optimize graphic-based images. | 4.00 | 1.51 |
| format graphic-based images. | 4.00 | 1.51 |
| compress graphic-based images. | 4.00 | 1.51 |
| Computer Graphics emphasizes graphic hardware… | | |
| with OpenGL to create digital images. | 4.00 | 1.07 |
| with Application Program Interfaces (APIs). | 4.00 | 1.07 |
| to create scientific data visualizations. | 4.50 | 0.93 |
| Computer Graphics emphasizes real-time graphics for... | | |
| visualizing large data sets. | 4.25 | 1.04 |
| creating accurate data representations. | 4.25 | 1.04 |
| deploying graphical assets onto multiple platforms. | 4.00 | 1.07 |

Table 4.10 (Continued). Final Round Survey Results for Curriculum and Industry Emphasis

| Statements (n=9) | Mean | SD |
|---|---|---|
| Computer Graphics emphasizes visualization to… | | |
| enhance medical applications. | 4.75 | 0.71 |
| enhance scientific applications. | 4.75 | 0.71 |

### 4.6.4. Differences Between CG and CS

Finally, in the final round survey, participants were asked to reach a consensus on one statement relating to the core themes about how CG differentiates from CS. Participants filed to reach consensus that CS enables CG. Table 4.11 presents the actual results for all statements relating to the core themes for how CG differentiates from CS posed to all participants in the final round survey instrument.

Table 4.11. Final Round Survey Results for Differences Between CG and CS

| Statement (n=9) | Mean | SD |
|---|---|---|
| CS enables CG. | 4.25 | 1.49 |

## 4.7. Summary

This chapter described each panelist selected for this study, as well as the participants for each round of data collection. It also presented the key findings and statistical results of all data collected in each round. The next chapter will summarize key points of the study, discuss the outcomes as they relate to literature, provide implications as they relate to the research questions posed, and suggest directions for future research.

# CHAPTER 5. SUMMARY, OUTCOMES, AND IMPLICATIONS

This study examined how post-secondary academics and industry professionals perceive, characterize, and contextualize CG. The objective of the research was to gain a general consensus about the definition and knowledge base for CG. The question posed by this study was to identify the prevalent characteristics that define CG and its knowledge base among industry professionals and post-secondary academics. In the following sections, the key outcomes for the study are summarized, and the findings from the data collected and analyzed are discussed. The chapter concludes with implications for the teaching and practice of CG, and potential directions for future research.

## 5.1. Summary of the Study

During an eight-month period, this study examined expert perspectives on how CG is taught and practiced in terms of contexts, characteristics and methodologies. Twelve CG experts from post-secondary academia and industry were engaged in a three-round Delphi Method study that identified and defined the prevalent characteristics of CG and its knowledge base. Additionally, this study investigated the relationship between CG and CS, and provided new insights and directions for post-secondary programs in CG.

## 5.2. Outcomes

Three major outcomes emerged from participant responses and survey results as they related to the research objective and the question posed:

*CG is defined by the utilization of the computer for the creation of raster and vector-based digital images.* Participant responses from the first round interviews provided many perspectives about the definition of CG. Most participants defined CG contextually, connecting graphic design with mechanical drawing, two-dimensional design with three-dimensional visualization, and procedural generated images with representational ones. However, consensus from the second and final round surveys removed the contextual factor from these definitions, and simplified CG to usage and output.

*The definition of CG must acknowledge the importance of visual design, especially for creating meaningful CG-based images.* Participants valued the role that visual design has in CG practice. Outcomes suggest that visual design provides important artistic principles that extend CG beyond the technical aspects of creating images. In simple terms, CG is about more than using a computer to create images, it is also about understanding that a computer is just a tool. CG must emphasize artistic and technical skills equally to produce images that are meaningful to the user and viewer alike.

*The core CG knowledge base must include art and design, animation, digital imaging, physics, visual perception, visual communications, mathematics, cognitive sciences (psychology), and computer programming.* The original knowledge base for CG reflected 17 areas of practice that spanned across all three contextual classifications. However, the outcomes of this study reduced the knowledge base by five, emphasizing areas relating to more artistic and contexts. This outcome suggests a shift toward the technocratic paradigm and away from the scientific paradigm evident throughout the early history of CG.

However, the effects of the limitations on these outcomes must be acknowledged. The availability of the participants reduced the interaction time the researcher had with some participants and in turn limited the amount of data collected. This was especially evident among industry professionals whose schedules prevented them from discussing topics in great detail. Additionally, most participants of the industry professional group were bound by non-disclosure agreements that prevented them from discussing specific methodologies and processes used by their employer. This was especially true for participants in the film and animation industry, where prolific use of proprietary tools necessitates non-disclosure and non-compete agreements as a condition of employment. Finally, although collective experiences of the panelists included many of the genres and areas of practice for CG, gaming expertise was not well represented. In the following sections, the researcher details the outcomes listed above and describes the effects of the limitations upon them.

### 5.2.1. A New Definition for CG

Based on the participant descriptions and the results of the surveys, CG is defined by the use of digital imaging software for the creation of two fundamental types of digital images (raster, which are displayed on a screen using pixels, and vector, which are displayed on a screen using shapes that are mathematically described). These outcomes reflect the definitions published by Jones (1990), Shirley (2005), Angel (2009), and F.S. Hill & Kelly (2007), who defined CG in terms of image production and generation by use of a computer. Participants also acknowledged the importance of visual design in defining CG, especially by how it contributes to the quality of the images being created. Participants understood the meaning of design to be related to the principles and practices of graphic design and visual communications, which emphasize color, typography, composition, and artistic illustration. Consensus among participants also indicated that CG professionals are defined by their visual problem solving and communication skills, as well as their knowledge of design.

The outcomes here suggest that CG can be defined not only by the types of images it creates, but also by the methods and approaches for which raster and vector images are created. Indeed, this outcome aligns with the definition of

CG to the philosophical views of Mitcham (1994) and Feenberg (2006) who described technology as objects, knowledge, and volitions, and by the actions created to control the essence of an object. While this provides a degree of validation for the study, it does not fully explain why this is the case.

These outcomes also suggest that CG must now be defined by how and why an image is produced. But why is this the case? In looking at the contextual classifications of final round participants, a majority of them were outside of the CS context. Also of note, only one-third of the participants in the final round had scientific backgrounds. This may explain why the consensus turned away from the scientific aspects of image production, evidenced by non-consensus of the statements relating to CG products and the elements and principles of design.

### 5.2.2. A Revised Knowledge Base for CG

Alley (2006) first articulated a CG knowledge base which included 17 broad topical areas. The core of the knowledge base included fundamental topics like teamwork and ethics, and expanded to include advanced topics like scientific visualization and dynamic systems. Now a decade later, the outcomes of this study have suggested a small reduction of that knowledge base is now warranted.

In alignment with Alley (2006), outcomes of this study suggested that the core of the CG knowledge base include art and design, animation, Digital Imaging (DI), and physics. Additionally, consensus among participants for this study identified that the knowledge base for CG needed to include mathematics, for it was viewed as essential for writing complex algorithms to drive visualization and simulation systems and for the compression of images. Visual perception was also seen as important for knowing how to interpret visual information, especially as it applies to the use of color. The cognitive sciences, specifically psychology, was viewed as vital for understanding how to better communicate ideas. Outcomes also suggested that knowledge of computer programming was necessary for the development of entertainment and data visualization applications. Lastly, outcomes identified the marriage between art, design, and technology, and how this marriage acts as a driver for the development of graphics-based marketing media. This driver is now understood to be an essential tool for knowing how to communicate ideas graphically. Thus, it was the consensus of the participants that visual communications be included in the revised knowledge base as well.

However, the outcomes did not lend importance to graphics hardware, real-time graphics or rendering. These topics from Alley (2006), along with artificial Intelligence (AI), lost a place in the revised CG knowledge base. The paradigm in CS is now partial to scientific or rationalist approaches, while the paradigm in CG has remained technocratic. The different paradigms for CG and CS may account for why these topics are now distant from CG. Also, this shift may be due to a lack of necessary resources or qualified experts to teach these topics.

Although these outcomes provide important insight about the contemporary CG knowledge base, they need to be interpreted within the appropriate context. Participants in this study were classified within two homogenous groups depending on their self-reported professional and academic backgrounds. Among 12 panelists, nine reported to have backgrounds that can be either technocratic or artistic. Thus, it may explain why the new knowledge base emphasized characteristics that contrast from scientific ones.

## 5.3. Implications

As noted in Chapter One, the broadening contexts for CG presented a challenge for educators responsible for identifying the topics and core competencies that academic programs must emphasize in order to better meet the needs of current and future markets (Anderson & Burton, 1988; Aoki, Bac, Case, & McDonald, 2005; Bailey, Laidlaw, Moorhead, & Whitaker, 2004; Hartman, Sarapin, Bertoline, & Sarapin, 2009; Hitchner & Sowizral, 2000; Paquette, 2005). The outcomes of this study suggested that post-secondary educators develop CG students in two specific areas; Interaction Design (IxD) and scientific visualization. Regarding IxD, consensus among participants suggests programs must connect the approaches and methodologies practiced in IxD to the design and development of video games. Additionally, participants suggested that CG programs provide courses and opportunities for students to learn how to create scientific data visualizations, specifically in the hard sciences and medical fields.

So what do these outcomes mean for post-secondary programs? Based on the researcher's analysis of the leading CG programs identified in Chapter Two, perhaps a change of approach to CG education is warranted. CG curricula must emphasize an interdisciplinary approach, and formulate outcome-based programs that connect scientific, technocratic, and artistic principles together to meet the growing needs of industry. The outcomes of this study have shown that a need exists for CG professionals who can solve problems across the contextual spectrum. Students must not only be able to address and solve technical problems, but also apply the principles found in the visual arts and the soft sciences in the CG products, services, and applications they create. Therefore, CG programs must provide students opportunities to develop and acquire skills from multiple contexts.

### 5.4. Directions for Future Research

When conducting basic research additional topics arise that warrant further investigation. This section acknowledges potential directions for further investigation as it relates to the outcomes of this study.

*Investigate ways to provide CG students with opportunities to develop and acquire skills from multiple contexts.* As discussed in the previous section, industry needs CG experts who are skilled and knowledgeable in both artistic and technical topics who can solve problems regardless of the contextual area. The outcomes of this study have provided the preliminary groundwork on how to approach the development of interdisciplinary CG programs. However, further investigation is needed as to the feasibility and sustainability of instituting interdisciplinary programs as it relates to the current state of higher education.

*Comprehensive investigation of all CG programs.* The number of CG programs within the United States are too numerous for a study of this scope. Time and access to program information limited the researcher's ability to conduct a comprehensive analysis of all CG programs. In order to gain a complete understanding of the state of post-secondary CG instruction, a comprehensive review of all program curricula from internally sourced data not available in the public domain is needed.

*Further investigation on the distinctions between CG and CS*. In alignment with the literature, as well as patterns from the first round interviews, significant differences exist between CG and CS. Consensus about these differences remain unclear among members of the computing fields. Additional exploration about the perceptions regarding CG and CS may uncover important aspects about their relationship that may inform post-secondary computing programs and curricula design.

*Investigate the perspectives, experiences, and practices of gaming experts.* Expertise of game design and development was underrepresented in this study. Participants identified the gaming market as an important growth sector for CG, and suggested that CG educators focus more on game design and technology in their programs. Therefore, qualitative investigation into the perceptions, experience, and practices of game designers and developers may add depth and clarity to the outcomes of this study. However, as noted by the limitations of this study, gaining access to gaming experts who are legally unbound to disclose information about their work will take significant time and effort on behalf of the researcher to overcome.

Indeed, these are just a few directions that warrant further investigation. Upon reflecting on this work, the researcher acknowledges the scope of this research is much larger than anticipated. This study serves as a snapshot of the problems at hand, and more in depth investigation, especially on a larger scale, needs to be conducted.

## 5.5. Summary

This chapter summarized the key aspects of this study, discussed the significant outcomes obtained by the research, provided implications for these outcomes, and suggested directions for future research. Indeed, although this work represents an additional step towards resolving an issue that has long affected CG, more work is needed. In the end, it is the hope of the researcher that this contribution will serve as an example for others to follow, leading to the establishment of CG as an independent computing discipline.

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# REFERENCES


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APPENDICES

# Appendix A: First Round Exemptions, Instruments and Communications

PURDUE
UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

| | |
|---|---|
| **To:** | JAMES MOHLER<br>KNOY 347 |
| **From:** | JEANNIE DICLEMENTI, Chair<br>Social Science IRB |
| **Date:** | 10/08/2014 |
| **Committee Action:** | **Exemption Granted** |
| **IRB Action Date:** | 10/08/2014 |
| **IRB Protocol #:** | 1408015106 |
| **Study Title:** | A Consensus on the Definition and Knowledge ase for Computer Graphics |

The Institutional Review Board (IRB) has reviewed the above-referenced study application and has determined that it meets the criteria for exemption under 45 CFR 46.101(b)(2) .

If you wish to make changes to this study, please refer to our guidance "**Minor Changes Not Requiring Review**" located on our website at http://www.irb.purdue.edu/policies.php. For changes requiring IRB review, please submit an **Amendment to Approved Study** form or **Personnel Amendment to Study** form, whichever is applicable, located on the forms page of our website www.irb.purdue.edu/forms.php. Please contact our office if you have any questions.

Below is a list of best practices that we request you use when conducting your research. The list contains both general items as well as those specific to the different exemption categories.

General

- To recruit from Purdue University classrooms, the instructor and all others associated with conduct of the course (e.g., teaching assistants) must not be present during announcement of the research opportunity or any recruitment activity. This may be accomplished by announcing, in advance, that class will either start later than usual or end earlier than usual so this activity may occur. It should be emphasized that attendance at the announcement and recruitment are voluntary and the student's attendance and enrollment decision will not be shared with those administering the course.
- If students earn extra credit towards their course grade through participation in a research project conducted by someone other than the course instructor(s), such as in the example above, the students participation should only be shared with the course instructor(s) at the end of the semester. Additionally, instructors who allow extra credit to be earned through participation in research must also provide an opportunity for students to earn comparable extra credit through a non-research activity requiring an amount of time and effort comparable to the research option.
- When conducting human subjects research at a non-Purdue college/university, investigators are urged to contact that institution's IRB to determine requirements for conducting research at that institution.
- When human subjects research will be conducted in schools or places of business, investigators must obtain written permission from an appropriate authority within the organization. If the written permission was not submitted with the study application at the time of IRB review (e.g., the school would not issue the letter without

Industrial Professional Recruitment Materials

STRICTLY CONFIDENTIAL

Dear [Participant],

I am writing you today to request your participation in a research study being conducted about the definition and knowledge base of Computer Graphics. The study being conducted is a multi-stage study that requests you to participate in three rounds of data collection consisting of one sixty minute interview and two a twenty minute surveys.

I would like to request a private interview with you to discuss your knowledge and experience about how Computer Graphics is defined and employed within your organizational procedures and processes. The interview will take no more than sixty (60) minutes of your time, and can be done online at your convenience. Any and all personal information you provide will be kept in strict confidence, and will not be made available to anyone other than myself. Please see that attached document entitled "Participant Information Sheet" for the complete details regarding this study.

To schedule an interview, please feel free to contact me directly. I will also be happy to answer any questions you may have regarding this study.

Sincerely,

**Michael Alden Roller**

*Doctorial Candidate, College of Technology*

Purdue University

Voice: 219-989-2354

First Round Interview Schedule

Semi-Structured interview schedule includes suggested probes in parentheses. Other probes or questions on the same topics may be asked.

1. I would like to begin by asking some basic demographic questions.
    a. Can you please state your full name?
    b. Do I have your permission to record this interview?
    c. What is your professional area of expertise?
    d. How long have you been in your current position?
    e. What are your current job roles and responsibilities?
2. How would you define Computer Graphics?
3. What are the fundamental topics that define Computer Graphics?
4. What professional issues pertain most to Computer Graphics?
5. The next series of questions will ask you to describe how specific academic disciplines inform Computer Graphics. Please tell me about the effects [*academic discipline a-h below*] has had toward the development of Computer Graphics Technology?
    a. Physical Sciences (Ex. chemistry, physics)?
    b. Mathematics?
    c. Visual Perception (ex. vision, memory, senses)?
    d. Cognitive Science (ex. reasoning, thinking, learning, understanding)?
    e. Human Computer Interaction (e.g. the methods and techniques for designing, implementing, and evaluating computer interfaces)?
    f. Computer Programming?
    g. Visual Communications?
    h. Fine Art / Graphic Design?
6. The next series of questions will ask you to describe how common areas of specializations among Computer Graphics programs are employed / emphasized in your business / curriculum. Please describe the role [*specialization a-f below*] plays in your business or program?
    a. Interaction Design?
    b. Animation?
    c. Digital imaging?
    d. Graphical hardware?
    e. Real-time graphics?
    f. Visualization?
7. To conclude, what is the difference between Computer Science and Computer Graphics?

# Appendix B: Second Round Exemptions, Communications and Instruments

PURDUE UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

| | |
|---|---|
| To: | MOHLER, JAMES L |
| From: | DICLEMENTI, JEANNIE D, Chair<br>Social Science IRB |
| Date: | 07 / 13 / 2015 |
| Committee Action: | Amended Exemption Granted |
| Action Date: | 07 / 10 / 2015 |
| Protocol Number: | 1408015106 |
| Study Title: | A Consensus on the Definition and Knowledge ase for Computer Graphics |

The Institutional Review Board (IRB) has reviewed the above-referenced amended project and has determined that it remains exempt.

If you wish to make changes to this study, please refer to our guidance"**Minor Changes Not Requiring Review**" located on our website at http://www.irb/purdue.edu/policies.php. For changes requiring IRB review, please submit an **Amendment to Approved Study** form or **Personnel Amendment to Study** form, whichever is applicable, located on the forms pages of our website www.irb.purdue.edu/forms.php. Please contact our office if you have any questions.

Below is a list of best practices that we request you use when conducting your research. The list contains both general items as well as those specific to the different exemption categories.

General

- To recruit from Purdue University classrooms, the instructor and all others associated with conduct of the course (e.g., teaching assistants) must not be present during announcement of the research opportunity or any recruitment activity. This may be accomplished by announcing, in advance, that class will either start later than usual or end earlier than usual so this activity may occur. It should be emphasized that attendance at the announcement and recruitment are voluntary and the student's attendance and enrollment decision will not be shared with those administering the course.
- If students earn extra credit towards their course grade through participation in a research project conducted by someone other than the course instructor(s), such as in the example above, the students participation should only be shared with the course instructor(s) at the end of the semester. Additionally, instructors who allow extra credit to be earned through participation in research must also provide an opportunity for students to earn comparable extra credit through a non-research activity requiring an amount of time and effort comparable to the research option.
- When conducting human subjects research at a non-Purdue college/university, investigators are urged to contact that institution's IRB to determine requirements for conducting research at that institution.
- When human subjects research will be conducted in schools or places of business, investigators must obtain written permission from an appropriate authority within the organization. If the written permission was not submitted with the study application at the time of IRB review (e.g., the school would not issue the letter without proof of IRB approval, etc.), the investigator must submit

Round Two Survey eMail

STRICTLY CONFIDENTIAL

Dear [Participant],

In the previous round of this study, each member of the panel was independently interviewed and responses were transcribed for data analysis. In this second round of three, a survey is being conducted to validate the most significant themes evident across all panel member responses from all transcribed interviews.

The survey is completed online, and should take no more than 20 minutes to complete. I encourage you to complete the survey in a quiet place and time when you are able to concentrate without interruption.

This survey will be available from Tuesday, July 14 2015 until Wednesday, July 22 2015. Please take the time during the next week to complete the survey at your convenience. Simply click on the link below to access the survey tool:

Purdue University requires and ensures your responses be strictly confidential and does NOT allow results that may identify you individually to be published or provided to anyone unless permitted by you directly. Should you have any concerns or questions about this survey or the study in general, please feel free to contact me via email directly at rollerm@purduecal.edu.

I would like to thank you in advance for your continued interest and participation.

- Michael

Michael Alden Roller, Ph.D(c)
Doctoral Candidate
Purdue Polytechnic Institute
Purdue University - West Lafayette
polytechnic.purdue.edu

Second Round Survey Instrument

The following statements represent the significant themes evident within transcribed interviews for all panel members conducted by the researcher in the previous stage. Please rate each statement according to the following scale: Strongly Disagree, Disagree, Neutral, Agree, or Strongly Agree.

---

*The first series of statements relates to the definition, topics, and issues for Computer Graphics. Please rate each statement according to the scale provided above.*

Computer Graphics must be defined…

1. contextually.
2. implicitly.

*Computer Graphics is the application of the computer to create…*

3. images.
4. products.
5. designs.
6. visuals.

*Computer Graphics is the utilization of the computer to create…*

7. images.
8. products.
9. designs.
10. visuals.

*The fundamental topics for Computer Graphics include…*

11. raster imaging.
12. vector imaging.
13. the Elements and Principles of Design.
14. Color Theory.

*Computer Graphics professionals exhibit…*

15. visual problem solving skills.
16. technical expertise in a Computer Graphics specialization.
17. strong communication skills.
18. knowledge of design.

*The next series of statements relates to how specific academic disciplines inform Computer Graphics. Please rate each statement according to the scale provided above.*

*Physics is essential for …*

19. understanding the physical laws of light.

20. understanding the physical laws of optics.
21. creating real-world graphics-based simulations.
22. achieving dynamic realism in graphics-based simulations.

*Mathematics is essential for…*

23. writing algorithms for image compression.
24. utilizing programming languages to create modeling tools for geometric data.
25. utilizing programming languages to create editing tools for geometric data.

*Visual Perception is essential for understanding…*

26. the meaning of design.
27. how to interpret visual information.
28. color perception.
29. image persistence.
30. visual literacy.

*The Cognitive Sciences facilitate…*

31. the graphical communication of ideas.
32. the design of graphics-based learning tools.

*Human Computer Interaction is important for…*

33. the development of graphics-based tools.
34. the development of graphics-based interfaces.
35. the development of graphics-based experiences.
36. interacting with large data sets.
37. interacting within digital environments.

*Computer Programming…*

38. serves as the basis of Computer Graphics.
39. drives advancement of Computer Graphics tools.
40. enables the development of graphical software applications for entertainment.
41. enables the development of data visualization solutions.

*Visual Communication…*

42. marries design and technology.
43. drives the development of graphics-based marketing tools.
44. facilitates graphical communication of ideas.

*The Fine Arts…*

45. define the limits of visual communication.
46. determine the value of graphical-based visual representations.
47. act as a cohesive agent between technology and design.

*The next series of statements relate to Computer Graphics curriculum and practice. Please rate each statement according to the scale provided above.*

*Computer Graphics emphasizes how…*

48. Interaction Design connects to web design.
49. Interaction Design connects to video games.
50. Interaction Design connects to data visualization.
51. humans interact with mobile devices.
52. interactive media affects human learning.

*Computer Graphics emphasizes how to create…*

53. library-based animations.
54. data-driven animations.
55. procedural simulations.
56. real-time dynamics.

*Computer Graphics emphasizes how digital imaging software is used to…*

57. create raster graphics.
58. create vector graphics.
59. manipulate photos.
60. optimize graphic-based images.
61. format graphic-based images.
62. compress graphic-based images.

*Computer Graphics employs graphic hardware…*

63. with OpenGL to create digital images.
64. with Application Program Interfaces (APIs).
65. to create scientific data visualizations.

*Computer Graphics employs Real-Time Graphics for …*

66. visualizing large data sets.
67. creating accurate data representations.
68. deploying graphical assets onto multiple platforms.

*Computer Graphics employs Visualization to…*

69. enhance medical applications.
70. enhance scientific applications.
71. blueprint application data.
72. communicate ideas effectively.

*The final series of questions below relate to the differences between Computer Graphics and Computer Science. Please rate each statement according to the scale provided above.*

73. Computer Graphics is a subset of Computer Science.
74. Computer Science augments Computer Graphics.
75. Computer Science enables Computer Graphics.
76. Computer Graphics is more visual than logical.

77. Computer Graphics is more applied than theoretical.
78. Computer Graphics is more creative than scientific.
79. Computer Graphics is more aesthetically driven than Computer Science.
80. Computer Science is more engineering driven than Computer Graphics.
81. Computer Graphics focuses more on the seen than the unseen than Computer Science.
82. Computer Graphics communicates ideas more effectively than Computer Science.

# Appendix C. Final Round Exemptions, Communications and Instruments

PURDUE UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

| | |
|---|---|
| **To:** | JAMES MOHLER<br>KNOY 347 |
| **From:** | JEANNIE DICLEMENTI, Chair<br>Social Science IRB |
| **Date:** | 08/06/2015 |
| **Committee Action:** | **Amendment to Approved Protocol** |
| **IRB Action Date** | 08/05/2015 |
| **IRB Protocol #** | 1408015106 |
| **Study Title** | A Consensus on the Definition and Knowledge ase for Computer Graphics |
| **Expiration Date** | |

Following review by the Institutional Review Board (IRB), the above-referenced protocol has been approved. This approval permits you to recruit subjects up to the number indicated on the application form and to conduct the research as it is approved. The IRB-stamped and dated consent, assent, and/or information form(s) approved for this protocol are enclosed. Please make copies from these document(s) both for subjects to sign should they choose to enroll in your study and for subjects to keep for their records. Information forms should not be signed. Researchers should keep all consent/assent forms for a period no less than three (3) years following closure of the protocol.

Revisions/Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB using the appropriate form. IRB approval must be obtained before implementing any changes unless the change is to remove an immediate hazard to subjects in which case the IRB should be immediately informed following the change.

Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior to the expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be used for research purposes including reporting or publishing as research data.

Unanticipated Problems/Adverse Events: Researchers must report unanticipated problems and/or adverse events to the IRB. If the problem/adverse event is serious, or is expected but occurs with unexpected severity or frequency, or the problem/even is unanticipated, it must be reported to the IRB within 48 hours of learning of the event and a written report submitted within five (5) business days. All other problems/events should be reported at the time of Continuing Review.

We wish you good luck with your work. Please retain copy of this letter for your records.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

STRICTLY CONFIDENTIAL

Dear [Participant],

In the previous round of this study, you were asked to complete a survey regarding the core themes evident from the first round results. In this final round, we ask that you validate the items that showed a consensus rate of 80% or more among all combined survey responses.

The survey is online, and should take no more than 10 minutes to complete. It is strongly encouraged the survey be completed in a quiet place and time when you are able to concentrate without interruption.

This survey is available through Sunday, August 30 2015. Please take the time to complete the survey before this deadline at your convenience. Simply click on the link below to access the survey tool:

Follow this link to the Survey:
${l://SurveyLink?d=Take the Survey}

Or copy and paste the URL below into your internet browser:
${l://SurveyURL}

Purdue University requires your responses be strictly confidential and does NOT allow results that may identify you individually to be published or provided to anyone unless permitted by you directly. Should you have any concerns or questions about this survey or the study in general, please feel free to contact me via email directly at rollerm@purduecal.edu.

I would like to thank you in advance for your continued interest and participation in this important research.

- Michael

Michael Alden Roller, Ph.D(c)
Doctoral Candidate
Purdue Polytechnic Institute
Purdue University - West Lafayette
polytechnic.purdue.edu

Final Round Survey Instrument

The following statements represent items from the survey administered in the previous round where consensus among panel member responses was highly evident. Please read each statement carefully, and then rate rating each statement according to the following scale: Disagree or Agree.

*The first series of statements relates to the definition, topics, and issues for Computer Graphics. Please rate each statement according to the scale provided above.*

1. Computer Graphics must be defined contextually.

*Computer Graphics is the utilization of the computer to create…*

2. images.
3. products.
4. designs.
5. visuals.

*The fundamental topics for Computer Graphics are…*

6. raster imaging.
7. vector imaging.
8. the Elements and Principles of Design.
9. Color Theory.

*Computer Graphics professionals exhibit…*

10. visual problem solving skills.
11. strong communication skills.
12. knowledge of design.

*The next series of statements relates to how specific academic disciplines inform Computer Graphics. Please rate each statement according to the scale provided above.*

13. Physics is essential for understanding the physical laws of optics.

*Mathematics is essential for…*

14. writing algorithms for image compression.
15. utilizing programming languages to create modeling tools for geometric data.
16. utilizing programming languages to create editing tools for geometric data.

*Visual Perception is essential for understanding…*

17. how to interpret visual information.
18. color perception.
19. image persistence.

*The Cognitive Sciences facilitate…*

20. the graphical communication of ideas.
21. the design of graphics-based learning tools.

*Computer Programming…*

22. enables the development of graphical software applications for entertainment.
23. enables the development of data visualization solutions.

*Visual Communication…*

24. marries design and technology.
25. drives the development of graphics-based marketing tools.
26. facilitates graphical communication of ideas.

*The next series of statements relate to Computer Graphics curriculum and practice. Please rate each statement according to the scale provided above.*

*Computer Graphics emphasizes how…*

27. Interaction Design connects to web design.
28. Interaction Design connects to video games.
29. Interaction Design connects to data visualization.
30. humans interact with mobile devices.

*Computer Graphics emphasizes how to create…*

31. library-based animations.
32. data-driven animations.

*Computer Graphics emphasizes how digital imaging software is used to…*

33. create raster graphics.
34. create vector graphics.
35. manipulate photos.
36. optimize graphic-based images.
37. format graphic-based images.
38. compress graphic-based images.

*Computer Graphics employs graphic hardware…*

39. with OpenGL to create digital images.
40. with Application Program Interfaces (APIs).
41. to create scientific data visualizations.

*Computer Graphics employs Real-Time Graphics for …*

42. visualizing large data sets.
43. creating accurate data representations.
44. deploying graphical assets onto multiple platforms.

*Computer Graphics employs Visualization to…*

45. enhance medical applications.

46. enhance scientific applications.

*The final question below relates to the differences between Computer Graphics and Computer Science. Please rate each statement according to the scale provided above.*

47. Computer Science enables Computer Graphics.

# Appendix D. Leading CG Programs

**Carnegie Mellon University**
Graphics Lab

Website: http://graphics.cs.cmu.edu/

Program Type: Computer Science

Degrees Offered: BA and BS in Computer Science

General Overview:

The BCSA Program was created in 2008 by the College of Fine Arts and the School of Computer Science. It provides an ideal technical and conceptual foundation for students interested in pursuing fields which comprehensively meld technology and the arts such as game design, computer animation, computer music, interactive stagecraft, robotic art, and other emerging media.

Curriculum:

Computer Graphics I

Computational Photography

Computer Game Programming

Human Motion Modeling and Analysis

Animation Art and Technology

Physically Based Character Animation

Learning-based methods in Computer Vision

The Animation of Natural Phenomena

Special Topics in Graphics: Graphics and Imaging Architectures

Pixels to Percepts: Visual Perception for Computer Vision and Graphics

Physics-based methods in Computer Vision

Hands: Design and Control for Dexterous Manipulation

Technical Animation

Vision Sensors

Generating Natural Human Motion

Physical Simulation for Computer Animation

Advanced Computer Graphics

Advanced Perception

Physically Based Modeling and Interactive Simulation

Data-driven Character Animation

Other courses of possible interest:

CFA 51-741: Introduction to Computing in Design

ARC 48-120/48-260/48-760: Computer Modeling

ARC 48-745: Geometric Modeling: Theory, Programming and Practice

ARC 48-760: Digital Narratives

ART 60-110: Electronic Media Studio I: Computer Art

ART 60-210: Electronic Media Studio II: Video

ART 60-410: Advanced ETB: Concepts of Animation

ART 60-415: Advanced ETB: 3-D Animation

ART 60-423: Advanced ETB: Telepresence Art & Applications

ART 60-424: Advanced ETB: Special Topic: Interactive Programming

CFA 51-741: Introduction to Computing in Design

ECE 18-396: Signals and Systems

ECE 18-551: Digital Communications and Signal Processing Systems Design

ECE 18-751: Applied Stochastic Processes

ECE 18-791: Digital Signal Processing I

ECE 18-792: Digital Signal Processing II

ECE 18-796: Multimedia Communications: Coding, Systems, and Networking

ECE 18-798: Image and Video Processing

ETC 53-831: Building Virtual Worlds

ETC 53-871: Dramatic Structures of Interactive Games

MEG 24-201: Engineering Graphics

MEG 24-351: Dynamics

ROB 15-385: Computer Vision

ROB 16-720: Computer Vision

**Cornell University**

Program of Computer Graphics

Website: http://www.graphics.cornell.edu/index.html

Program Type: Computer Science

Degrees Offered: BS in Computer Science

General Overview:

Cornell is a leader in computer graphics, an interdisciplinary area that draws on many specialties including algorithms, physics, computation, psychology, computer vision, and architecture. The Cornell graphics tradition has roots going back to the earliest days of the field, when the Program of Computer Graphics (PCG) was established in 1974 and went on to make breakthrough contributions in areas including light reflection models, physics-based accurate rendering, and visual perception for graphics. Today graphics research at Cornell flows across boundaries to cover a broad area of graphics and related topics, with research in graphics and vision in the Graphics and Vision group in CS, research in graphics and architecture in PCG, and research in human-computer interfaces in the Information Science program, all densely interconnected.

The Program of Computer Graphics at Cornell University ("PCG") is an inter-disciplinary center dedicated to the development of interactive computer graphics techniques and the use of these techniques in a variety of applications.

As a central participant in the new Faculty of Computing and Information Science, the Program of Computer Graphics is actively engaged in interdisciplinary teaching and research across the University. The graduate students based in our lab are pursuing degrees in the fields of Architecture, Computer Science, and Mechanical and Aerospace Engineering, and our

Director holds a joint appointment in Computer Science, Architecture, and the Johnson Graduate School of Management.

At the undergraduate level our portfolio of courses includes Interactive Computer Graphics in the Computer Science Department and an innovative Architectural Design Studio. Our ties to the field of architecture go back to the beginning of the lab, and we still find architectural modeling to be one of the most challenging computer graphics applications.

The PCG faculty teach a number of courses in computer graphics, digital arts, and related areas, ranging from a freshman course in Cornell's Intro to Engineering series to advanced graduate courses addressing current research topics.

Curriculum:
Visual Imaging in the Electronic Age (CS 167, Art 2701, CIS 167, ENRGI 167, ARCH 459)
Disruptive Technologies (NBA 6120)
Introduction to Computer Graphics (CS 465, ARCH 374)
Computer Graphics Practicum (CS 466)
Computer Animation (CS 565, CIS 565, Art 273)
Advanced Computer Animation (CS 566, CIS 566, Art 372)
Physically Based Animation for Computer Graphics (CS 567)
Interactive Computer Graphics (CS 569)
Advanced Interactive Rendering (CS 665)
Physics Based Rendering (CS 667)
Computer Graphics Seminar (CS 718)

**Massachusetts Institute of Technology**
Media Lab

Website: http://www.media.mit.edu/

Program Type: Computer Technology

Degrees Offered: MS and PhD in Media Arts

General Overview:

Unlike other laboratories at MIT, the Media Lab comprises both a degree-granting graduate Program in Media Arts and Sciences (Moller & Haines) and a highly innovative research program focused on inventing a better future through creative applications of innovative digital technologies.

Graduate programs include the Program in Media Arts and Sciences (Moller & Haines), a part of MIT's School of Architecture + Planning. The MAS offers a master of science degree in media arts and sciences and a PhD degree. Students pursuing the PhD degree without a master's in media arts and sciences are usually admitted first as MS students; continuation to the doctoral program is then conditional on performance in the MS program.

The Program in Media Arts and Sciences is only a graduate degree program. However, MIT undergraduates may become involved with Media Lab work through a special Freshman-Year Program that emphasizes project-oriented work. Students in this program attend mainstream lectures for core freshman subjects but take recitations led by Media Lab researchers and faculty. The Undergraduate Research Opportunities Program (UROP) provides close to 150 students each year to work with Lab researchers through this hands-on research program.

Curriculum:

UG: Introduction to Doing Research in Media Arts and Sciences (1-4-1)

UG: Camera Culture (2-0-7)

UG: Integrative Design Across Disciplines, Scales, and Problem Contexts (2-2-8)

GRAD: Camera Culture (2-0-7)

GRAD: Imaging Ventures: Cameras, Displays, and Visual Computing (0-9-0)

GRAD: New Urban Village: Mobility-on-Demand (3-0-9)

GRAD: Social Television: Creating New Connected Media Experiences (3-0-9)

GRAD: Networks, Complexity, and Their Applications (2-0-10)

GRAD: Human 2.0 (0-9-0)

GRAD: Media Lab Entrepreneurship: Digital Innovations (3-0-6)

GRAD: News and Participatory Media (1-2-9)

GRAD: Creative Learning Technologies (3-0-9)

GRAD: The Society of the Mind (2-0-10)

GRAD: Projects in Media and Music (3-3-6)

GRAD: The Physics of Information Technology (3-0-9)

Special Topics in Media Arts and Sciences Foundations

Special Topics: Design and Deployment of Digital Technologies to Support Early Literacy Around the World (2-2-8)

Special Topics: Everywhere Learning: Technologies for Supporting Learning in the Real World (2-0-7)

Special Topics: Fundamentals of Visual Communication (2-1-6)

Special Topics: Integrative Design Across Disciplines, Scales, and Problem Contexts (2-2-8)

**The Ohio State University**

Advanced Computing Center for Arts and Sciences (ACCAD)

Website: http://accad.osu.edu/

Type | Degrees: Computer Science or Technology

Degrees Offered: BA and MA in Technology

General Overview:

The Advanced Computing Center for the Arts and Design (ACCAD) is a collaborative think space, a place to make, create, imagine and above all connect. We conduct research centered on the use and integration of emerging arts technologies. ACCAD has become internationally recognized as one of the original and leading centers of its kind, distinguished by the transdisciplinary approach to research and teaching which is so central to its identity. Located on The Ohio State University's Science & Technology Campus and alongside the Ohio Supercomputer Center, ACCAD is a creative hub for scholars and practitioners of digital arts and sciences.

ACCAD functions as an applied collaborator for time-based digital media production, both in furthering the excellence of its faculty and graduate students in residence and cultivating its own innovative research agenda clustering around animation and interactive media. Our work unfolds in a generous physical space, complemented by specialized and flexible studios for animation, motion capture, interactive design, media production and mediated performance design. ACCAD's collaborative partnerships include a wide interdisciplinary range of campus disciplines and external relationships. Please visit our Project Gallery to see our work.

Curriculum:

ACCAD 3350: History of Animation

ACCAD 5001: Motion Studies Through Hand Drawn Animation

ACCAD 5002: 3D Computer Animation: Form, Light, Motion I

ACCAD 5003: 3D Computer Animation: Form, Light, Motion II

ACCAD 5100: Concept Development for Time-Based Media

ACCAD 5102: Programming Concepts for Artists and Designers

ACCAD 5140: Interactive Arts Media I

ACCAD 5141: Interactive Arts Media II

ACCAD 5142: Interactive Arts Media III

ACCAD 5191: ACCAD Internship

ACCAD 5194.01: Group Studies in Digital Animation and Interactive Media

ACCAD 5500: Group Studies in Digital Animation and Interactive Media

ACCAD 5651: A History of Computer Graphics

ACCAD 6002: Computer Game Art and Design I

ACCAD 6003: Computer Game Art and Design II

ACCAD 6650: History of Animation

ACCAD 6651: Digital and Physical Lighting

ACCAD 7001: Virtual Modeling

ACCAD 7002: Synthetic Cinema

ACCAD 7003: Expressive Animation

ACCAD 7004: Procedural Shading

ACCAD 7005: Experimental Scripting for Animation in Maya

ACCAD 7101: Performance and Installation Technologies

ACCAD 7102: Motion Capture Production and Experimentation.

ACCAD 7103: Designing Immersive Virtual Environments

ACCAD 7104: Procedural Animation

ACCAD 7504: Animation Production

ACCAD 7892: Interdisciplinary Creative Research Seminar

ACCAD 7893: Collaborative Interdisciplinary Research Studio

**University of Southern California**
Cinematic Arts

Website: http://cinema.usc.edu/index.cfm

Program Type: Computer Technology

Degrees Offered: BA, MA, and PhD in Technology

General Overview:

The Bachelor of Arts in Animation and Digital Arts is a unique four-year program granted through the USC Dornsife College of Letters, Arts and Sciences in conjunction with the School of Cinematic Arts. Students study within the framework that combines a broad liberal arts background with specialization in a profession. Areas of concentration might include character animation, experimental animation, visual effects, 3-D computer animation, science visualization and interactive animation.

Undergraduate students take their pre-professional courses in the USC Dornsife College of Letters, Arts and Sciences, including the general education requirements. Major courses are selected from the curriculum of the School of Cinematic Arts. The degree requires 128 units, including a minimum of 16 lower-division units and a minimum of 26 upper-division units in Cinematic Arts

The Master of Fine Arts degree in Animation and Digital Arts is a three-year (six semester) graduate program designed for students who have clearly identified animation and digital art as their primary interest in cinema. The program focuses on animation production and includes a wide range of techniques and aesthetic approaches, from hand-drawn character animation to state-of-the-art interactive digital animation. While embracing traditional forms, the program strongly encourages innovation and experimentation, emphasizes imagination, creativity and critical thinking. Students should graduate with a comprehensive knowledge of animation from conception through realization, an understanding of the history of the medium and its aesthetics, in-depth knowledge of computer animation software and the most important elements of digital and interactive media.

Curriculum:

Undergraduate

| | |
|---|---|
| CNTV 101 | Reality Starts Here |
| CTAN 101 | Introduction to the Art of Animation |
| CTAN 102 | Introduction to the Art of Movement |
| CTAN 201 | Introduction to Animation Techniques |
| CTAN 202 | Advanced Animation Techniques |
| CTAN 301 | Introduction to Digital Animation |
| CTAN 302 | Introduction to 3D Computer and Character Animation |
| CTAN 336 | Ideation and Pre-Production |
| CTAN 436 | Writing for Animation |
| CTAN 401 | Senior Project |
| CTAN 405 | Professionalism of Animation |
| CTAN 432 | The World of Visual Effects |
| CTAN 451 | History of Animation |
| CTAN 496 | Directed Studies |
| CTCS 190 | Introduction to Cinema, or |
| CTCS 201 | History of International Cinema |
| CTPR 495 | Internship in Cinematic Arts |
| FADW 101 | Introduction to Drawing: Studio Projects, Methods, Materials |

Graduate

| | |
|---|---|
| CTAN 451 | History of Animation |
| CTAN 505 | The Business of Animation |

| | |
|---|---|
| CTAN 522 | Animation Department Seminar |
| CTAN 536 | Storytelling for Animation |
| CTAN 544 | Introduction to the Art of Animation |
| CTAN 547 | Animation Production I |
| CTPR 555 | Animation Design and Production |
| CTAN 577 | Fundamentals of Animation |
| CTAN 582 | Basic Animation Production Techniques |
| CTAN 579 | Expanded Animation |
| CTAN 591 | Animation Pre-Thesis Seminar |
| CTAN 594 | Master's Thesis |

**Purdue University**

Purdue Polytechnic Institute

Website: https://polytechnic.purdue.edu/degrees/department

Program Type: Computer Technology

Degrees Offered: BS and MS of Science, PhD in Technology

General Overview:

Computer Graphics Technology prepares visually oriented students for careers in creating and managing the production of computer graphics within a wide range of industries. Students work collaboratively in computer labs to master graphic techniques and concepts, and management skills. Students can choose to generalize in applied computer graphics technology or develop more in-depth knowledge and skills in our entertainment and media design areas, which include web programming and design, user experience, human computer interaction (HCI), interactive media, technical animation, virtual product integration, construction graphics, and gaming.

Curriculum:

Undergraduate

CGT 10100 Introduction to Computer Graphics Technology

CGT 11000 Technical Graphics Communications

CGT 11100 Designing for Visualization and Communication

CGT 11200 Sketching for Visualization And Communication

CGT 11600 Geometric Modeling for Visualization And Communication

CGT 14100 Internet Foundations, Technologies and Development

CGT 16300 Graphical Communication and Spatial Analysis

CGT 16400 Graphics for Civil Engineering and Construction

CGT 21100 Raster Imaging for Computer Graphics

CGT 21500 Computer Graphics Programming I
CGT 21600 Vector Imaging for Computer Graphics
CGT 22600 Introduction to Constraint-Based Modeling
CGT 24100 Introduction to Computer Animation
CGT 25600 Human Computer Interface Theory and Design
CGT 26200 Introduction to Construction Graphics
CGT 30800 Prepress Production and Design
CGT 32300 Virtual Product Integration
CGT 32600 Graphics Standards For Product Definition
CGT 34000 Digital Lighting and Rendering for Computer Animation
CGT 34100 Motion for Computer Animation
CGT 34600 Digital Video and Audio
CGT 35300 Principles of Interactive and Dynamic Media
CGT 35600 Web Programming, Development and Data Integration
CGT 36000 Applications of Construction Documentation I
CGT 41100 Contemporary Problems in Applied Computer Graphics
CGT 42300 Product Data Management
CGT 42600 Industry Applications of Simulation and Visualization
CGT 44200 Production for Computer Animation
CGT 44600 Post-Production and Special Effects for Computer Animation
CGT 45000 Professional Practices
CGT 45100 Multimedia Application Development
CGT 45600 Advanced Web Programming, Development and Data Integration
CGT 46000 Building Information Modeling for Commercial Construction
CGT 46200 Applications of Construction Documentation II

Graduate
CGT 50100 Seminar in Computer Graphics Technology
CGT 51000 Culture and Cognition
CGT 51100 The Development of Graphics In Technology

CGT 51200 Human Factors of Computer Interface Design
CGT 51300 Interactive Multimedia Development And Research
CGT 51400 Product Lifecycle Management
CGT 51500 Introduction to Virtual Environments
CGT 51600 Collaborative Virtual and Augmented Environments
CGT 51700 Product Development Using Virtual Environments
CGT 51800 Augmented Reality
CGT 51900 Projects in Graphics
CGT 52000 Computer Graphics Programming
CGT 52100 Advanced Real-Time Computer Graphics
CGT 54000 Current Topics in 3D Animation
CGT 58100 Workshop in Computer Graphics Technology
CGT 59000 Special Problems in Computer Graphics Technology
CGT 59800 Directed MS Project
CGT 60000 Spatial Ability Research and Assessment
CGT 61000 Visual Intelligence and Perception
CGT 62000 Graphics Processing Unit Computing
CGT 62300 Contemporary Computer Graphics Technology Problems
CGT 68100 Workshop In Computer Graphics Technology
CGT 69000 Research Projects in Computer Graphics Technology

**DePaul University**

College of Computing and Digital Media

Website: http://www.cdm.depaul.edu/Pages/default.aspx

Program Type: Computer Science, Technology, and Arts

Degrees Offered: BA or BS in Animation, Computing, Digital Cinema, Computer Game Development, Computer Science, Information Systems, Info Technology, Interactive and Social Media, Math and Computer Science, Network Technologies; BFA in Graphic Design; MA or MS in Animation, Applied Technology, Business Info Technology, Cinema Production, Computational Finance, Computer Science, Computer, Info, and Network Security, Digital Communication and Media Arts, E-Commerce Technology.

General Overview:

Formerly known as the School of Computer Science, Telecommunications and Information Systems (CTI), we became the College of Computing and Digital Media in 2008 to better convey the scope of our programs to employers and industry professionals.

CDM is now organized into two schools: the School of Computing and the School of Cinema and Interactive Media (CIM). No matter which major you declare, you may choose minors and electives from either school to gain the skills you seek. More importantly you'll get the right blend of theory and experience to prepare you to ride the wave of changing technologies throughout your career.

Our degree programs offer innovative foundations and practical applications of today's most sought after skills and credentials. Our academic facilities are kept continually up-to-date with industry-current equipment and technology.

CDM's Undergraduate Programs reflect DePaul's focus on a broad liberal education with specialized and rigorous study in computing and digital media.

Our degree programs offer academic options in technology, computing, and media that stay closely connected to emerging trends.

Our Graduate Programs are designed for working professionals to advance their careers. Classes are offered in the evenings in the Loop and online. Ten of CDM's graduate programs are also offered completely online.

Our Professional Development certificates offer short-term and specialized learning options for IT and Computer Science professionals to stay on top of the latest technology developments and trends.

Curriculum:

Computer Graphics and Motion Technology

GPH 205 - Historical Foundations of Visual Technology

GPH 211 - Perceptual Principles for Digital Environments I

GPH 212 - Perceptual Principles for Digital Environments II

GPH 213 - Perceptual Principles for Digital Environments III

GPH 250 - Digital Modeling I

GPH 255 - Hand Prototyping for Graphic Visualization

GPH 259 - Design Geometry

GPH 269 - Graphic Geometries

GPH 279 - Science and Design of Sundials

GPH 321 - Computer Graphics Development I

GPH 325 - Survey of Computer Graphics

GPH 329 - Computer Graphics Development II

GPH 336 - Smooth Surface Modeling for Graphics and Animation

GPH 338 - Survey of 3-D Animation

GPH 339 - Advanced Rendering Techniques

GPH 340 - Procedural Shading

GPH 341 - Advanced Lighting Techniques

GPH 345 - Digital Surface Modeling
GPH 346 - Smooth Surface Modeling for Graphics and Animation
GPH 348 - Rigging for Animation
GPH 350 - Digital Modeling II
GPH 355 - 3D Scripting for Animators
GPH 358 - Computer Graphics Automation
GPH 360 - Modeling Spaces
GPH 372 - Principles of Computer Animation
GPH 374 - Computer Games
GPH 375 - Advanced Graphics Development
GPH 376 - Artificial Intelligence in Computer Games
GPH 380 - Visualization
GPH 387 - Forensic Animation
GPH 388 - Production Pipeline Techniques
GPH 389 - Real-Time Graphics Techniques
GPH 390 - Topics in Graphics
GPH 395 - Computer Graphics Senior Project
GPH 399 - Independent Study
GPH 425 - Survey of Computer Graphics
GPH 436 - Fundamentals of Computer Graphics
GPH 438 - Computer Animation Survey
GPH 448 - Computer Graphics Scripting
GPH 450 - Digital Modeling I
GPH 465 - Survey of Visualization Applications
GPH 469 - Computer Graphics Development
GPH 487 - Forensic Animation
GPH 4RVW - Department Review for Course Placement
GPH 536 - Smooth Surface Modeling for Graphics and Animation
GPH 538 - Rigging for Animation
GPH 539 - Advanced Rendering Techniques

GPH 540 - Procedural Shading

GPH 541 - Advanced Lighting Techniques

GPH 560 - Modeling Spaces

GPH 565 - Designing for Visualization

GPH 570 - Visualization

GPH 572 - Principles of Computer Animation

GPH 574 - Computer Games

GPH 575 - Advanced Graphics Development

GPH 576 - Artificial Intelligence in Computer Games

GPH 580 - Hardware Shading Techniques

GPH 595 - Topics in Graphics

Animation

ANI 101 - Animation for Non-Majors

ANI 105 - Intro to Visual Design

ANI 150 - After Effects Workshop

ANI 151 - Flash Animation Workshop

ANI 201 - Animation I

ANI 206 - History of Animation

ANI 207 - Anime History

ANI 220 - Storyboarding and Narrative Development

ANI 222 - Illustration Foundations

ANI 225 - Graphic Narrative

ANI 230 - 3D Design and Modeling

ANI 231 - 3D Animation

ANI 240 - Animation Production I

ANI 260 - Motion Graphics

ANI 300 - 3D Character Animation

ANI 301 - Advanced 3D Character Animation

ANI 310 - Motion Capture

ANI 315 - Audio for Animation

ANI 320 - Hand-Drawn Animation

ANI 321 - Animation Mechanics

ANI 322 - Animation Styles and Techniques

ANI 324 - Story Development

ANI 325 - Visual Storytelling

ANI 326 - Visual Concept Development

ANI 330 - 3D Character Modeling

ANI 332 - 3D Rigging

ANI 336 - 3D Modeling Studio

ANI 337 - Environment Modeling

ANI 339 - 3D Texturing and Lighting

ANI 340 - Animation Production II

ANI 341 - Animation Production III

ANI 344 - Visual Design for Games

ANI 345 - Character Design

ANI 350 - Animation Production Studio

ANI 351 - Advanced Motion Capture Studio

ANI 352 - 3D Scripting

ANI 355 - Stop Motion Animation

ANI 356 - Experimental Animation

ANI 360 - Advanced Motion Graphics

ANI 364 - Animation Research Seminar

ANI 365 - Cinema, Animation, and Art

ANI 366 - 3D Movie Production

ANI 370 - Acting for Animators

ANI 375 - Demo Reel and Portfolio Workshop

ANI 376 - Post-Production Workshop

ANI 378 - 3D Dynamics

ANI 379 - 3D Compositing

ANI 390 - Topics in Animation

ANI 393 - Topics in 3D Animation

ANI 394 - Animation Project I

ANI 395 - Animation Project II

ANI 399 - Independent Study

ANI 405 - 3D Animation Survey

ANI 415 - Audio for Animation

ANI 420 - Hand-Drawn Animation

ANI 421 - Animation Mechanics

ANI 422 - Animation Styles and Techniques

ANI 425 - Visual Storytelling

ANI 430 - 3D Character Animation

ANI 431 - Advanced 3D Character Animation

ANI 432 - 3D Rigging

ANI 433 - Advanced 3D Rigging

ANI 435 - 3D Character Modeling

ANI 436 - 3D Modeling Studio

ANI 437 - Environment Modeling

ANI 438 - 3D Organic Modeling

ANI 439 - 3D Texturing and Lighting

ANI 440 - Collaborative Short Animated Film

ANI 444 - Visual Design for Games

ANI 445 - Character Design

ANI 446 - Game Art Pipeline

ANI 450 - Motion Capture

ANI 451 - Advanced Motion Capture Studio

ANI 452 - 3D Scripting

ANI 453 - Advanced 3D Scripting

ANI 455 - Stop Motion Animation

ANI 456 - Experimental Animation

ANI 460 - Animation Graduate Seminar

ANI 466 - Cinema, Animation and Art

ANI 470 - Acting for Animators

ANI 478 - 3D Dynamics

ANI 479 - 3D Compositing

ANI 480 - Animation Production

ANI 490 - Topics in Animation

ANI 493 - Topics in 3D Animation

ANI 4RVW - Department Review for Course Placement

ANI 540 - Animated Short Film Part I

ANI 541 - Animated Short Film Part II

ANI 560 - Graduate Teaching Seminar

ANI 599 - Independent Study

ANI 639 - MFA Pre-Thesis

ANI 640 - MFA Thesis Animation

**Rochester Institute of Technology**

College of Imaging Arts & Sciences

Websites: http://cias.rit.edu/schools/design and http://computergraphics.rit.edu/
Program Type: Computer Technology
Degrees Offered: BFA in 3D Digital Graphics; MFA in Visual Communication Design

General Overview:
The BFA in 3D Digital Graphics (3DDG) prepares [students] to use three-dimensional computer modeling for applications such as motion and broadcast graphics, game art and design, medical and scientific simulations, data visualizations, architectural and engineering modeling, instructional multimedia, accident reconstruction, and more. The curriculum integrates traditional art and design skills, the utilization of commercial 3D software, and design principles related to time, motion, and lighting. [Students] will also study research methods and a range of problem-solving principles, and develop critical thinking and creative capacities. Most important, as a graduate of the 3DDG program, [students] will have the ability to adapt to the constantly-changing needs of the industry in order to create 3D models and simulations for a wide variety of industries.

The MFA Visual Communication Design program at RIT embraces the changing landscape of people's everyday interactions that has blurred the lines between respected design fields…giving designers new responsibilities to shape experiences. Designers must increase their knowledge in all areas of design, including print media, human-computer interaction design, motion graphics, and 3D digital graphics. This new ideology is addressed through its curriculum that addresses these merging skill sets. It provides a learning environment for advancement in innovative research, user-centered design, and professional practice focusing on the creative potentials of visual communication through a full spectrum of media.

The program is professionally focused to inspire and empower graduates to become practicing designers, entrepreneurs and contributors who impact interactions among people, products, and environments. This program takes a rigorous, full spectrum approach to design implementation and integration into multiple forms of media that includes: web and mobile, print media, motion graphics, 3D modeling and motion, information design, user interface and experience design, and branding and identity system design. The skill sets required of graphic, interactive, and digital design have now crossed over and are interrelated. It doesn't matter what medium; the common element is design.

Curriculum:
Visual Communication Design
3D Modeling and Motion
3D Particles and Dynamics
3D Visual Design
Branding & Identity Design
Design History Seminar
Design Systems
Design Theory & Methods Seminar
Digital Design in Motion
Digital Video and Audio
Environmental Graphic Design
Information Design
Interaction Design
Motion Graphics
Professional Practices
Programming for Designers

Project Design & Implementation

Typography

Web and UI Design

**Bowling Green State University**
School of Art; Division of Digital Arts

Website: http://digitalarts.bgsu.edu/
Program Type: Computer Art
Degrees Offered: BFA and MFA in Digital Arts

General Overview:
The Digital Arts program focuses on creative expression using digital technology. Students are encouraged to investigate aesthetic and perceptual possibilities as they engage in alternative art discourses. Digital Arts courses investigate theoretical, aesthetic, and technical information while providing hands-on-experience with state-of-the-art equipment. The courses merge the technical and aesthetic aspects of Digital Arts. The Digital Arts program, with over 175 majors, at BGSU has become one of the leading programs in the nation for studying Digital Arts and animation. Digital Arts is an exciting area with dynamic, ambitious, self-motivated students who push themselves and their artwork to the edge.

The School of Art offers a BFA degree in Digital Arts with three areas of focus.

Computer Animation & Video - both 2D and 3D animation with a strong emphasis on 3D including non-linear digital video editing and compositing. Students work with narrative, and non-narrative experimental animation and video art as well as character animation.

Imaging - a focus on still images using digital photography, digital painting, collage and hybrid media. Works may be created using various printing techniques including large format, and experimental as well as 3D ceramic rapid prototyping.

Interactive Multimedia - emphasis on creative art development using HTML, CSS, Javascript, and Processing for online and mobile devices as well as installation and interactive physical artworks.

Curriculum:

Undergraduate
ARTC 2210 Digital Imaging
ARTC 3000 Contemporary Practices in Digital Arts I
ARTC 3100 Animation Principles &
ARTC 3110 3-D Modeling
ARTC 3120 3-D Digital Animation
ARTC 3310 Interactive Art
ARTC 3440 Digital Video Art
ARTC 4000 Contemporary Practices in Digital Arts II
ARTC 4090 Professional Practices and Presentation in Digital Arts
ARTC 4130 Digital Character Animation I
ARTC 4140 Digital Character Animation II
ARTC 4180 Senior Studio in Digital Arts
ARTC 4230 Advanced Digital Imaging Art Studio
ARTC 4240 Alternative Digital Print.
ARTC 4250 Photography for Digital Artists
ARTC 4330 Advanced Interactive Art Studio
ARTC 4410 Collaborative Multimedia Development
ARTC 4420 Art and Virtual Environments
ARTC 4430 Artistic Animation Effects
ARTC 4440 Advanced Digital Video Art
ARTC 4700 Independent Study in Digital Arts
ARTC 4700 Independent Study in Digital Arts

ARTC 4890 Computer Art Practicum

ARTC 4950 Workshop in Digital Arts

Graduate

ARTC 5030 Digital Art Development

ARTC 5130 Digital Animation Studio

ARTC 5230 Digital Imaging Studio

ARTC 5240 Alternative Digital Print

ARTC 5250 Photography for Digital Arts

ARTC 5330 Interactive Art Studio

ARTC 5410 Collaborative Multimedia

ARTC 5430 Artistic Animation Effects

ARTC 5440 Digital Video Art

ARTC 5820 Special Topics in Digital Arts

ARTC 5860 Workshop in Digital Art

ARTC 6130 Advanced Study in Digital Animation

ARTC 6230 Advanced Study in Digital Imaging Art

ARTC 6330 Advanced Study in Interactive Art

ARTC 6860 Independent Study in Digital Arts

North Carolina State University
Department of Computer Science and the Visual Experience Lab

Website: http://www.csc.ncsu.edu/about_us.php and http://vxlab.csc.ncsu.edu/
Type | Degrees: Computer Science
Degrees Offered: BS and MS in Computer Science - Game Development Concentration, PhD in Computer Science.

General Overview:
The NC State Computer Science Undergraduate Program provides first-rate preparation for employment or graduate research, engages students in research, and enjoys national recognition as a top tier program. For example, in 2003 we were third nationwide among departments affiliated with an engineering school or college in bachelor degrees awarded in Computer Science. The department offers a modern curriculum focusing on fundamental scientific and engineering principles and methods, exposure to cutting-edge technology, and the opportunity to work on exciting problems with real-world impact.

Graduate programs in Computer Science provide a variety of excellent educational and research opportunities to students from across the U.S. and all over the world. Our Master's Degree Program offers several options: the Master of Science (thesis), the Master of Computer Science (non-thesis, available via either distance learning or on-campus enrollment,) and a Master of Computer Networking (thesis or non-thesis, on campus or via distance learning). The flagship degree is the Ph.D. in Computer Science, which prepares students for leadership positions in academia, industry research labs, and government.

The Visual Experience Lab, the CG arm of the CSC department, is interested in visual technologies that move us: how digitally created imagery affects human emotion, thinking and behavior. Their work spans computer graphics, human-computer interfaces, visualization, psychology and design."

Curriculum:
Students take all courses required for the CSC major. Concentration course selection for Restricted and Other Electives is constrained to focus on specific courses directly related to game design and development. Specifically, all students pursuing the concentration must take both CSC 461, Computer Graphics, and CSC 481, Game Design and Development. Further, students must take either CSC 462, Advanced Graphics Projects or CSC 482, Advanced Game Development Projects. Students must select two additional CSC courses from the following list:

CSC 411 Artificial Intelligence
CSC 454 Human-Computer Interaction
CSC 462 Introduction to Graphics
CSC 482 Game Design and Development
CSC 484 Building Game AI
CSC 582 Computer Models of Interactive Narrative

Students pursuing the Game Development Concentration must select their Other Electives from the following list (note that, with the exception of MUS 306, these classes are approved as Other Electives ONLY for the Game Development Concentration)

COM 327 - Critical Analysis of Communication Media
COM 427 - Game Studies
ENG 282 - Introduction to Film
ENG 288 - Fiction Writing
ENG 376 - Science Fiction

ENG 377 - Fantasy

ENG 492 - Special Topics in Film

MUS 306 - Music Composition with Computer

VITA

VITA

**Michael Alden Roller**

APPOINTMENTS

*Associate Professor of Computer Graphics Technology*
Purdue University Northwest; April 2016 – Present

*Associate Professor of Computer Graphics Technology*
Purdue University Calumet; August 2011 – March, 2016

*Assistant Professor of Computer Graphics Technology*
Purdue University Calumet; August 2005 – July 2011

*Creative Director*
Marketing Impact, Inc.; July 2004 – July 2005

*User Interface (UI) | User Experience (UX) Designer and Developer*
New Source Solutions, Inc.; June 2003 – June 2004

*Adjunct Instructor*
East Tennessee State University; January 2001 – May 2003

*Technical Designer*
King Pharmaceuticals: January 2001 – August 2003

*Proprietor, Designer & Developer*
Module11, LLC; January 2001 – August 2003

*Graphic Designer*
Creative Energy, Inc.; December 1997 – December 2000

PEER REVIEWED PRESENTATIONS AND PUBLICATIONS

Abramowitz, H., Johnsen, E., Roller, M., Zhao, W., Liu, X., Zhang, L., Zhang, X. (2014). *Visualization of ternary phase diagrams in 3D*. Materials Education Symposium, University of IL, Champaign/Urbana.

Abramowitz, H., Johnsen, E., Roller, M., Zhao, W., Liu, X., Zhang, L., Zhang, X. (2014). *Visualization of ternary phase diagram tutorial update*. Proceedings from the Association for Iron and Steel Technology Conference, Indianapolis, IN.

Abramowitz, H., Johnsen, E., Roller, M., Zhao, W., Liu, X., Zhang, L., Zhang, X. (2013). *Demonstration of tutorial for 3D visualization of ternary phased diagrams.* Proceedings from Materials Science & Technology 2013; Advanced Steel Metallurgy: Design, Processing, and Technological Exploitation. Montreal, Quebec: Material Science & Technology.

Roller, M. (2010). *An Implementation Model for Experiential Learning Standards of Practice in Online Technology Courses*. Proceedings from the Association for the Advancement of Computers in Education 2010 E-Learn Conference. Orlando, FL: Association for the Advancement of Computing in Education.

Trekles, A., Kristin, S., Roller, M., Jin, G. (2010). *Second Life as an Experiential Learning Opportunity*. Proceedings from the 2010 Computer & Writing Virtual Worlds Conference: West Lafayette, IN.

Roller, M. (2010). *Universal adaptation of avatar technology and the metaverse for online learning: A New Approach*. Proceedings from the Association for the Advancement of Computers in Education 2010 Global Learn Asia Pacific Conference. Penang, Malaysia: Association for the Advancement of Computing in Education.

Abramowitz, H., Ye, J., Xu, D., Johnsen, E., Hagen, T., Zhao, W., Roller, M. (2009). Construction of a Web Based Tutorial for 3D Visualization Ternary Phase Diagrams. Iron & Steel Technology, 6 (10), 75-85.

Roller, M. (2009). *Utilization of Avatar Technology within Virtualized Learning Environments*. Proceedings from 2009 Distance Education Conference: Youngstown, OH.

Abramowitz, H., Ye, J., Xu, D., Johnsen, E., Hagen, T., Zhao, W., Roller, M. (2009). *Construction of Web Based Tutorial for 3D Visualization Ternary Phase Diagrams*. Proceedings from the 2009 Iron & Steel Technology Conference and Exposition. St. Louis, MO: Association for Iron and Steel Technology.

Roller, M., Higley, J. (2008). *Innovation versus Analysis: A Case Study in Improving Technology Courses*. Proceedings from the 2008 IEEE National Conference. Pittsburgh, PA: Institute of Electrical and Electronics Engineers.

Roller, M. (2007). *Employing Interactive Three Dimensional Computer Graphics for the Visualization of Ternary Diagrams* Proceedings from the 2007 American Society for Engineering Education Rocky Mountain Conference on Leadership and Innovation in a Global Environment. Provo, UT: American Society for Engineering Education.

Roller, M. (2006). *Visualization of Ternary Phase Diagrams*. Proceedings from the Harvard University School of Engineering and Applied Science Initiative in Innovative Computing – Image and Meaning 2.2 Workshop and Conference. Chicago, IL.

CONFERENCE PROCEEDINGS AND INVITED TALKS

Roller, M. (2014). Making your Bones. Insight Design Conference; Hammond, IN.

Roller, M**.** (2010). Using online discussions for facilitating reflection. Distance Learning Certification Workshop; Purdue University Calumet, Hammond, IN.

Roller, M. (2010) Developing 100-200 level Experiential Learning courses. Experiential Learning Faculty Focus Workshop; Purdue University Calumet, Hammond, IN.

Roller, M. (2006). Animation Technology: Applications and Workflow. Jiangsu Provincial Office; Changzhou City, China.

GRANTS AND CONTRACTS

Purdue University Calumet (2014): Mobile Device Field Testing Units for Student Developers (funded); $6,810.00, Principal Investigator.

National Science Foundation (2011-2013): Development of Virtual Safety Laboratory Exercises to Transform Undergraduate Manufacturing Education (proposed); $199,975.00, Co-Principal Investigator.

National Science Foundation (2012-2013): An Undergraduate RFID Course incorporating Laboratory Experiments with State-of-the-art Equipment and Virtual Reality Technology Duration of Funding (proposed); $200,000.00, Co-Principal Investigator.

National Science Foundation (2010-2012): Development of Virtual Safety Exercises in Manufacturing (proposed); $149,564.00, Co-Principal Investigator

National Science Foundation (2010-2011): An Undergraduate RFID Course Incorporating Laboratory Experiments with State-of-the-art Equipment and Virtual Reality Technology (proposed); $147,551.00, Co-Principal Investigator.

Hewlett-Packard Co.(2009-2011): An Interdisciplinary Initiative for Developing Teaching and Learning Virtual Models (proposed); $250,000.00, Principal Investigator.

Purdue University West Lafayette (2009): Summer Research Grant (funded); $3000.00, Principal Investigator.

EXHIBITIONS

Roller, Michael A (1996). Untitled. ETSU Summer Arts Festival; Digital Art Exhibition. Design and print works in computer imaging.

Roller, Michael A (1996). Untitled. The Mockingbird Art and Literary Magazine. Published photography submission.

Roller, Michael A (1992). Various Works. National Endowment for the Arts Scholastic Competition and Exhibition; one of 50 selected works for expo from 14,000 nationally submitted portfolios in photography and the visual arts, Washington, D.C.

EDUCATION

Doctor of Philosophy
Purdue Polytechnic Institute
Purdue University, 2016

Master of Science
College of Business and Technology; Department of Engineering Technology, Surveying, and Digital Media
East Tennessee State University, 2003

Bachelor of Fine Arts
College of Arts and Sciences; Department of Art and Design
Graphic Design & Narrative Photography
East Tennessee State University, 1997

ORGANIZATIONS AND OUTREACH
American Society for Engineering Education
Voting member, 2010-2012

Association for Advancement of Computers in Education
Voting member, 2010-2012

Association for Technology, Management, & Applied Engineering
Voting member, 2012-2014

East Tennessee State University
Digital Media Program Advisory Board, member 2008-2010

Institute of Electrical and Electronics Engineers
Organizational member, 2008-2009

Ivy Tech Community College Northwest
Design Technology Program Advisory Board, member 2013-Present

Sigma XI: The Scientific Research Society
Organizational member, 2006-2007

ACCOLADES
American Advertising Federation
District 7 Gold Addy: Interactive Media (2003)

Tri-Cities Metro Advertising Federation
Addy: Interactive Media-Online Macro or Mini Sites (2005)
Addy: Mixed Media Campaigns-National Cross Platform (2005)

Addy: Interactive Media-CD (2003)
Addy: Interactive Media-Web (2000)
Addy: Product Catalog Design (2000)
Addy: Series Packaging (2000)
Addy: Trade Ad (2000)

Addy: Direct Marketing – B2B Campaign (1999)
Addy: Single Poster Design – Campaign (1998)
Citation of Excellence: Outdoor Advertising (1999)
Citation of Excellence: Brochure Design (1998)
Citation of Excellence: Publication Design (1996)