Computer Graphics and Animation at The Ohio State University

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The research and production of computer graphics imagery and animation at The Ohio State University started with the artistic work of Prof. Charles Csuri. He developed the Computer Graphics Research Group in response to the award of a National Science Foundation Grant in 1974, and the group transferred its technology to a commercial production effort, Cranston/Csuri Productions, Inc., in 1981. CGRG evolved into the Advanced Computing Center for the Arts and Design in 1987. This article provides an historical review of the significant activities of these groups.

At the end of the 1950s and into the early 1960s, advances in computing technology spawned the beginning of the discipline of computer graphics. With efforts at industrial and academic institutions, researchers saw the advantages of developing the human–computer interface for a number of creative reasons.

Research activities at the Massachusetts Institute of Technology helped shape early computer and computer graphics developments, most notably related to computing and graphics display hardware. In particular, the TX-2 computer at MIT's Lincoln Laboratory was key in the evolution of interactive computer graphics. It was on this computer that an MIT student named Ivan Sutherland looked at the simple cathode ray tube and light pen on the TX-2's console and thought one should be able to draw on the computer. Thus was born *Sketchpad*, and with it, the birth of the discipline.

In the heartland of the United States, while Sutherland was doing his groundbreaking work, a Professor of art at Ohio State, Charles Csuri, was also experimenting with the use of the computer, but with the specific goal of realizing his artistic vision—using emerging computing technology to advance his art. These innovative activities that he started have continued for over 50 years.[a]

Beginning in 1963, Csuri assembled a small group of faculty members from various departments at the university to assist in connecting this vision with the evolving technology. His artistic/technology interests ultimately resulted in a prominent computer graphics research laboratory that was established with funding from the National Science Foundation and other government and private agencies.

These early federal grants and investments played a major role in pushing the evolution of the field in academic institutions across the country. In particular, Advanced Research Projects Agency (ARPA) funding at the University of Utah and National Science Foundation (NSF) funding at Ohio State, along with focused industry funding, changed the direction of research in this important technology innovation.

Over the next several decades, the resulting work at OSU revolved around computer art, computer animation languages, complex 2-D and 3-D modeling environments,

[a]Csuri was an All-American football tackle in 1942 at Ohio State, playing for Coach Paul Brown. His college days were interrupted when he joined the service and fought at the Battle of the Bulge in WWII. He joined the faculty in Art at OSU after graduation. His career was featured in a 1995 cover article written by Paul Trachtman of the Smithsonian magazine, titled *Charles Csuri is an 'Old Master' in a New Medium*.

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FIGURE 1. *Sine Curve Man.*

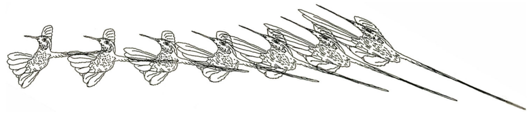

FIGURE 2. Still images from *Hummingbird* film.

user-centric interfaces, human and creature motion descriptions, and other areas of interest to the discipline.

In this article, we document the development and growth of efforts at The Ohio State University that have contributed to both educational and industry institutions that engage with computer art, computer animation, and computer visualization writ large. These pioneering efforts span the broad spectrum of computer graphics in general.

EARLY WORK AT OHIO STATE

Working as a painter, Csuri became increasingly fascinated with the computer and its potential as an artistic tool. His early "computer" work involved the creation of an analog device to process images, much like a pantograph traces an image. By changing the length of one or more components of a drawing, the image could be redrawn in a transformed state. His early work utilized the University's IBM 7094 mainframe, a CalComp 563 plotter, and a CalComp 835 microfilm plotter.

In 1965, Chuck Csuri met James Shaffer and Leslie Miller, two faculty members in the Department of Mathematics. Csuri was interested in making art with computers and they were interested in helping him. By 1967, they were using OSU's IBM 360 mainframe computer to write programs for Csuri that could distort, warp, and otherwise transform his drawings into something quite unique.[1] They also wrote programs that could interpolate, duplicate, randomly position, and randomly orient objects, and even move them along a path. Lacking an output medium for recording his idea of a primitive animated sequence, they plotted the individual animation frames on paper using an IBM plotter to create some of Csuri's most famous and haunting images, including his famous *Sine Curve Man* (see Figure 1).

That same year, he continued with this experimentation on other sequential drawings, including one of a hummingbird in flight. Csuri produced over 14,000 frames, which exploded the bird, scattered it about, and reconstructed it. These frames were output to 16-mm film, and the resulting film *Hummingbird* (see Figure 2) was purchased by the Museum of Modern Art in 1968 for its permanent collection as representative of one of the first computer animated artworks.

Csuri continued to work with graduate students and fellow faculty members from the arts and sciences for the next several years, experimenting with different approaches to instruct the computer to display and animate the various artifacts that he conceived. In 1969, he received a prestigious grant from the National Science Foundation to study the role of the computer and software in the arts discipline. It was very unusual for an artist to receive an NSF grant and showed the level of significance of the work at OSU at the time. According to Csuri, program managers at NSF wanted him to keep publicity of the $100,000 grant to a minimum. They were afraid of pushback from the scientific community, many of whom felt strongly that an artist could not do quality scientific research and therefore did not deserve one of these hard-to-get NSF grants.

COMPUTER GRAPHICS RESEARCH GROUP

In 1970, Csuri published one of the first papers related to the complex issue of animating objects in real time.[2] The work described in the paper resulted in the award of a second NSF grant in 1971. The University provided matching equipment support, and the fledgling research consortium began transforming itself into one of the most important academic computer graphics facilities in the world.

In 1971, Csuri built on this external interest and proposed a formal organization at Ohio State, called the Computer Graphics Research Group (CGRG), in order to realize the potential of the application of computer animation to the studies by students in the Art Department and to have a formal cohort that could attract additional external research support. Grant proposals were submitted to agencies and programs, both in and out of the University, and funding was provided for studies that would extend the capabilities of the evolving discipline.

The new funding allowed CGRG to replace the old IBM 1130 system that had been used with a powerful

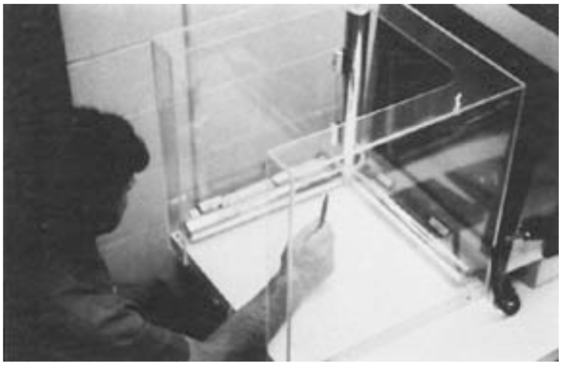

FIGURE 3. Charles Csuri using the CGRG sonic pen device to draw 3-D paths (photo courtesy of CGRG).

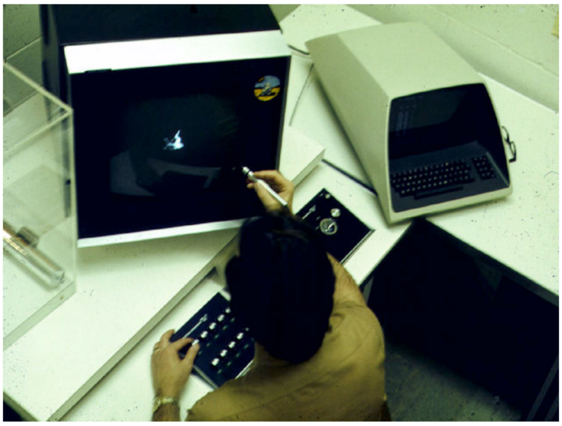

FIGURE 4. Csuri interacting with a light pen at the VG3D display, showing buttons, dials, and joystick. To the left is the sonic pen device, and to the right is the VT100 (photo courtesy of CGRG).

DEC PDP-11/45 minicomputer that was much faster and could support four times more memory. The 11/45 came with a VT05 terminal and new storage peripherals, including paper tape, DECtape, and a fast RK05 removable disk drive that held a whopping 2.5 megabytes!

The 11/45 was connected to a large 4K high-resolution Vector General graphics display with 3-D hardware transformation capabilities (VG3D), replacing the old IBM 2250 that had previously been used for interactivity. The VG3D came with 16 function buttons, 10 dials, a 3-D joystick, a 2-D light pen, and a custom built sonic pen digitizer (see Figure 3 and Figure 4).

With the new NSF grant, Csuri found he could hire an actual resident staff. The first hires were Manfred Knemeyer as the new full-time Associate Director and systems manager, and Gerald Moersdorf as a part-time technician. The grant also provided support for three new graduate students—Tom DeFanti and Mark Gillenson, both from the Computer Science Department, and Wayne Bennett from the Fine Arts Department.

The GRASS Era at CGRG

With programming help from Moersdorf and Gillenson, DeFanti began developing the Graphics Symbiosis System (GRASS) as his Ph.D. dissertation research. GRASS was a simple but powerful graphics system for producing real-time computer animation. It was loosely based on the structure of Fortran, but it was not a full-featured programing language. Instead, it focused solely on transforming objects in three dimensions in real time. It still required programming knowledge, but the real-time feedback made it much easier to learn. GRASS quickly replaced all previous standalone Fortran programs used for image making in the lab.

While GRASS could create 3-D objects from scratch, its main purpose was to assign the control of an object to the interactive control devices for quick and easy real-time manipulation of position, rotation, or scale. It could also be scripted to control and animate the transform parameters of one or more objects over time. Then, using a special "filming" mode, it could record the scripted animation to a computer-controlled Arriflex 16SR 16-mm camera one frame at a time.

After DeFanti received his Ph.D. in 1973, he set up a duplicate GRASS system at the University of Illinois – Chicago Circle. That replica system was later used by famous computer artist Larry Cuba to create 3-D computer animation for the "Attacking the Death Star" briefing scene in the movie *Star Wars*, directed by George Lucas in 1977.

Gillenson added a number of special extensions to GRASS to create an interactive system on top of it called WhatsIsFace that used techniques of key frame animation to blend images to create facial drawings. This system created a significant amount of interest in the police and investigative communities and was one of the first formal contributions to the technology that is now called "morphing."

Graduate student Robert Reynolds joined CGRG around 1973. Instead of using GRASS for his research, he wrote standalone programs for the PDP 11/45 and used the VG3D to create stunning animations of interacting and colliding galaxies. Film segments from Reynold's animation were later used by Carl Sagan in Episode 10 of his 1980 hit TV show *Cosmos*.

In 1973, Allan Myers was hired as a full-time system manager replacement for Moersdorf. Myers, Sam Cardman, and Knemeyer started a new project called ANIMA. This was to be a serious full-featured programming language compiler with graphic hooks to produce real-time animation from a number of object formats and output to a variety of display and recording devices. By 1974, Myers began working on a new visible surface algorithm that could provide real-time output displayed on the VG3D.

Also in 1974, Richard Parent and Ron Hackathorn joined CGRG. Hackathorn was the second Art student to join the group, while Parent came from the Computer Science Department to develop geometric modeling tools for animation. He created a groundbreaking new data generation system he called "Computer Clay" (renamed DG). His program allowed any user to easily and intuitively push, pull, poke, tug, distort, combine, intersect, and generally sculpt one or more virtual objects, as if they were made of real clay.[3] These interactions were displayed in real time on the VG3D using his fast hidden-line algorithm.

Later in 1975, Myers successfully completed his real-time visible surface program. It used the VG3D to display a raster scan of one or more polygonal objects with hidden surfaces removed. These scanned objects were primarily controlled in real time using dials, but could be parametrically controlled for simple rotations or translations. The raster-scanned images could also be recorded one frame at a time off the VG3D using the Arriflex camera. That same year, Hackathorn created two of the earliest, if not the first, fully computer animated 3-D TV commercials broadcast over public airwaves. They advertised the Buckeye Tennis Tournament and an Ohio-based Savings and Loan.

John Staudhammer, a Professor at North Carolina State University, was introduced to CGRG by David Kasik and Ed Edwards, who worked at Battelle in Columbus and were visiting Staudhammer's lab. Staudhammer contacted Csuri with an exciting offer. His new company, Digitech, had developed a special run-length encoding storage and display device, and he was interested in CGRG being the first lab to try it out. The device converted raster-scanned run-length segments into a full color NTSC video stream that could be recorded on any standard video recorder.

By 1976, the first commercial Staudhammer system was installed at CGRG. The Myers visible surface program was used to raster-scan a polygonal object and convert the raster output into run-lengths and store them on our new DEC 88 MB RJP04 removable hard drive system. A separate playback program would then read and channel the run-lengths into the Staudhammer output device, where it was converted to a standard NTSC color signal. The real-time NTSC video stream was recorded on a Sony 3/4" U-matic video deck. Further video editing was done at WOSU, our local PBS affiliate, using Ampex 2-inch "Quad" videotape machines.

But this new color video system presented new challenges. GRASS was designed solely for the vector-based random access display and could not be easily adapted to the Staudhammer box. Plus, using it required programming and math skills that art students and many university researchers did not have. And, unfortunately, after over 2 years of work, the ANIMA system could not be adapted to the new color video system and also failed to meet any of its initial goals. The result was cancellation of the entire project.

The ANIMA II Era at CGRG

As often happened during the early days of the evolution of the discipline, the ACM-SIGGRAPH Conference provided the kind of rich environment for creative discussions and planning. At the 1976 conference in Philadelphia, Parent and Hackathorn discussed the situation at CGRG. Immediately after the conference, Hackathorn developed a new animation system that pulled together Parent's DG system, the Myers' visible surface algorithm, and the Staudhammer video storage and display system. Tying it all together was a unique graphics command language, developed on the PDP 11/45. This was perhaps the first animation system to use high-level graphics scripts.

This animation language system completely replaced GRASS and launched an important new chapter at CGRG. Hackathorn called this new command language ANTS (for Animated Things in Space), though Csuri later changed the name to ANIMA II.[4]

ANIMA II was targeted at nonprogrammers by using a simple syntax. The commands were executed in parallel so multiple objects could be animated simultaneously and scheduled to start and stop at different times.

In 1977, Tim Van Hook joined CGRG and quickly started making interesting artistic animations using ANIMA II, including his highly regarded "Pong Man" video. Later that year, Wayne Carlson (Computer Science) and Rodger Wilson (Fine Art) joined the group. Wilson and Parent were investigators on a grant to make artistic animated films for the Ohio Arts Council, and the entire team collaborated on several innovative films that were entered into the SIGGRAPH Film and Video Review sessions at Conferences in 1979, 1980, and 1981.[b]

The ANTS Era at CGRG

In 1978, the PDP-11/45 used as CGRG's main research computer for six years was replaced by one of the earliest DEC VAX 11/780 models on the market. Karl Olson

[b]In addition, CGRG and ACCAD had videos in the SIGGRAPH film and video shows every year from 1981 to 1992.

from the Electrical Engineering Department worked with Parent and Hackathorn to build CGRG's first 512 × 512 frame buffer (to interface with the VAX) with direct video output.

Hackathorn replaced the ANIMA II system with a new version of the animation system, which he again called ANTS. ANTS ran natively on the 11/780 and included many new features such as animating objects, light sources, and cameras along 3-D paths. The previous visible surface algorithm was replaced with a new and faster raster algorithm that used the frame buffer for determining visible surfaces.

Animation sequences were recorded on a new Ampex VR-5000 1-inch reel-to-reel video recorder, which was modified to record single consecutive frames under computer control. This overcame the limitations of using a frame buffer for video output rather than the real-time run-length playback of the previous color video system.

The object pipeline was also completely reworked to remove limits on the amount of complexity that ANTS could simultaneously process. ANIMA II stored all the objects to be animated in memory, which severely limited the amount of detail that could be processed. In ANTS, objects were now defined as a collection of elements (e.g., points, lines, triangles, patches) that were read by the system one element at a time from disk storage. They were then transformed by the ANTS language and Z-sorted into the frame buffer. This increased the total complexity of an animated frame from a few thousand elements to hundreds of thousands of elements.[5]

In 1979, Frank Crow, a Ph.D. student of Ivan Sutherland at the University of Utah, was recruited from the University of Texas. At CGRG, he investigated multiprocessing approaches to image synthesis and other algorithmic solutions for complex images. During Crow's tenure at OSU, the CGRG staff shifted from writing all its code in assembly language to employing the C language running in the Unix/VAX environment.

Carlson worked with Rodger Wilson and Bob Marshall to expand the procedural animation capabilities[6] introduced by Martin Newell of the University of Utah. As part of his Ph.D. research, Carlson developed an expanded surface-modeling environment that used higher order curves and surfaces, such as Bezier and b-splines. He also investigated points as a display primitive that could be used to efficiently compute and display "fuzzy" objects, i.e., those with no "solid" 3-D structure (e.g., smoke, fire, and water). He applied this research to generate an image of smoke and recalculated the interacting galaxy sequences first produced by Reynolds, increasing the geometry from several hundred geometric primitives (stars) to over 30,000 in each galaxy and displaying it in raster format. His DG2 system expanded the modeling work of Rick Parent and was a system for modeling geometry that included points as a geometric primitive (what would later become known as particle systems), Boolean operators on surface patches, and a unified approach to sweep operators.[7]

Mark Howard moved to OSU from Staudhammer's North Carolina State University graphics program and designed and built a controllable 512 × 512 frame buffer that allowed real-time playback of animation tests. This frame buffer, built with IKONAS Graphics Systems memory boards, and later versions were the mainstays of the image creation and representation capabilities at CGRG and at the animation production company Cranston/Csuri Productions, Inc.

Hackathorn developed a third version of the ANTS system for a PDP-11/23 microcomputer with 128 kB, dual floppies, and an attached 256 × 256 frame buffer, running the RT-11 operating system. This was an experimental system that was being investigated as an affordable microsystem for developing animation scripts that could then be executed on the VAX.

Graduate student David Zeltzer developed goal-directed motion description capabilities for skeletal and creature animation (the Skeletal Animation System, or SAS). His system and the underlying theories are some of the most significant contributions to the area of autonomous legged motion description in the discipline.[8] His SAS system provided procedural control of the motion of an articulated figure over flat terrain, and his SAS2 system extended the control to uneven terrain.

Don Stredney pushed the limits of the modeling systems of Carlson and Parent to develop complex anatomical models, including the human skeleton called "George" used by Zeltzer in his research. George became a graphics "cult" figure, and the geometric model was distributed widely and used by other artists and researchers throughout the field.

Julian Gomez developed TWIXT, a track-based keyframe animation system. This system allowed for the specification of key-framed motion for independent objects that moved over the same time interval. It had real-time playback with shape morphing and was device independent.[9]

Michael Girard and Anthony Maciejewski investigated modeling techniques for animating legged figures utilizing pseudoinverse control in order to solve problems associated with manipulating kinematically redundant limbs. They developed a system, called PODA. They modeled kinematic, legged locomotion in a way that let animators control the complex relationships between the motion of the body of a figure and the coordination of its legs.[10]

Lessons Learned

In the early days, the devices that were needed to realize our goals of creating artistic animated sequences were not available. We had to innovate and build our own digital and analog hardware or modify existing devices with varying success. For example, we built a spinning color wheel (with primary color gels) that was placed between a camera and the monochrome display in order to film colored vectors. We built a mechanical 3-D viewer with shutters for each eye in order to view a 3-D image that was displayed in 2-D. The sonic pen was unstable, often being influenced by noises in the lab that corrupted the data.

One of the most significant early problems we had to overcome was the limited computer memory available, both for system CPU throughput as well as for the storage of animation sequences. We were forced to create our own memory configuration for frame buffers used in our early scan line approaches to images. At one point, we even (unsuccessfully) attempted to convert a refrigerator-sized cabinet of core memory to make a primitive frame buffer.

Speed was always an issue, since the computation of multiframe animated images required significant processing. (We added a ping-pong table to the lab, and one game took about as long as it took to calculate a short animation sequence.) With the PDP 11/45, limited main memory and a 16-bit address space meant we had to do everything in assembly language in order to get the most speed out of the system. That also meant that coding practices were thrown to the wind. Rick Parent used some innovative programming practices, e.g., if he needed a constant and could find it encoded in some instruction, he would use that instead of defining and allocating space for it. We were, therefore, ecstatic when we installed our VAX 11/780 that promised 1 MIPS throughput. We also changed from VMS to Berkeley UNIX, making programming in C more productive.

Early in the life of the lab, we realized that software that was to be used by noncomputer types needed intuitive interfaces. We therefore spent a lot of time developing integrated systems with menu driven interaction. Some of our most important research contributions during this period were complex 3-D modeling systems, fast rendering algorithms, run-length encoding as a display approach, procedural modeling for complex scenes, alternative data representations such as particle systems, shape interpolation, integrated animation systems, character animation (articulated motion control), procedural textures, procedural data modeling, and animation as an art form.

CRANSTON/CSURI PRODUCTIONS, INC.

In 1981, Charles Csuri approached Robert Kanuth of The Cranston Companies, a financial securities firm in Columbus, to fund the transfer of the computer animation technology created in the CGRG lab at Ohio State to the commercial world. Kanuth was a serial entrepreneur and investor and expressed significant interest in the proposed venture, eventually funding the operation with investment partners.

The core activities of the CGRG research lab were duplicated at Csuri and Kanuth's new company, which was called Cranston/Csuri Productions, Inc. CCP, as it became known, joined an elite group as one of the premier companies of the time that were producing computer-generated imagery for the small and big screens. These companies included Information International Inc. (III), Digital Effects, MAGI, Robert Abel and Associates, and three other emerging companies (Pacific Data Images and Digital Productions on the west coast and Omnibus Computer Graphics in Canada).

Kanuth appointed one of his officers at The Cranston Companies, Jim Kristoff, as President of CCP, and he recruited six of the CGRG researchers to join the company as a core group. These six CCP staff (Michael Collery, Wayne Carlson, Bob Marshall, Don Stredney, Ed Tripp, and Marc Howard) rewrote the software that was developed and used in the university research lab so that it was faster, more user-friendly, and less research oriented. They added specialized utilities for character animation, procedural effects, rendering, geometric modeling, and postproduction. The CCP technologists also expanded the capabilities of the hardware, including proprietary frame buffers developed by Marc Howard, to provide tools for the growing animation staff.

During the technology transfer first year, Carlson reworked the modeling program DG2 and the renderer, Julian Gomez rewrote the animation language in TWIXT, and Stredney and Collery produced a sequence of animations that were edited together into preliminary demonstration reels that could be shown to potential clients (see Figure 5). One of the first major clients was ABC News (CCP was subsequently contracted to produce promotional graphics and openings for all eleven of the ABC network news

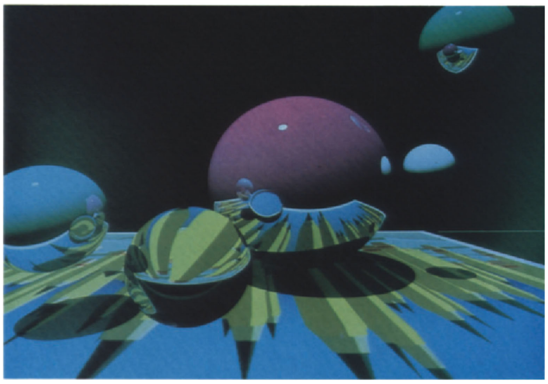

FIGURE 5. Image "Pencil City" by Michael Collery is used as background in ray-traced image by Hsuen Ho for CCP promotional poster (courtesy of CCP).

programs, which proved to be a significant contract that also attracted other clients).

The strengths of CCP were high-quality image making hardware and software that was focused on the limited markets they chose to serve: television broadcast and promotion, advertising, and medical documentaries. The production environment included a market-appropriate direct-to-video solution that made the production pipeline very efficient.

Special purpose hardware used at CCP included the Marc III and Marc IV custom frame buffers, which were designed and built exclusively for the company by Howard. These frame buffers provided the ability to do extended low-resolution previsualization motion tests that were stored in frame buffer memory and played back in real time. The computing environment included VAX 11/750s, 11/780s, Pyramid 90x and 95x computers, Sun-3 workstations, Megatek, IMI and E&S Picture Systems vector displays, and a modified Ampex Electronic Still Store (ESS), which was originally designed to be used for slow motion replay by the television network sports industry. Images were calculated and stored on one of several magnetic disks on the ESS, and the machine was programmable to facilitate 30 frames per second playback with direct NTSC video output.

CCP also had a Celco 4000 film recorder, which could be used for 16-mm, 35-mm, and 70-mm motion picture film, or 35-mm slide or 4 × 5 transparency still output.

In the several months before the company closed, it experimented with the Transcept TAAC-1 graphics boards for the Sun workstations (developed by Nick England, Mary Whitton, and former CGRG member Tim Van Hook in North Carolina).

During the seven-year period that they were in business, CCP produced almost 800 animation projects for over 400 clients worldwide. A long-standing relationship with the ABC television network resulted in continuous contracts for the production of graphics for ABC News and ABC Sports. Work was also done for other major national and international networks and local TV affiliates, including opening graphics for three Super Bowls, special effects for music videos, animations for training, and Clio-nominated and award-winning advertisements for well-known companies and products.

During this period, CCP staff continued to extend the research boundaries and publish new and innovative results. At its peak operation, CCP employed over 70 animators, software developers, researchers, and designers.

In 1985, CCP licensed their production software to Japan Computer Graphics Laboratory (JCGL) for use in the Japanese market. JCGL's president was Japanese businessman Mitsuro (Mits) Kaneko, who later became a friend and business partner with Jim Kristoff.

The relationship between Kristoff and the board of CCP cooled in late 1986 and early 1987, primarily because of Kristoff's position that an office needed to be opened in Los Angeles to allow CCP to expand into other markets, particularly the motion picture and games markets. In fact, a number of former Robert Abel and Associates employees, including Tim McGovern, Con Pederson, Neil Eskuri, and "Doc" Baily, were hired and relocated from L.A. to Columbus for training, ostensibly to prepare to staff an office in California.

Kaneko and Kristoff proposed an investment strategy that would increase their control, but the funding was not available. Kristoff resigned, and later opened Metrolight Studios in L.A. Wayne Carlson was named CCP's President, as Chuck Csuri had left the company in 1985 to return to his OSU duties at CGRG and to develop the new ACCAD educational facility.

Plans to reorganize were discussed with CCP's board, but ultimately it was decided that the effort would not be in the best interest of the company and its investors. Commercial CG technology had advanced rapidly, with powerful and affordable computer workstations from Sun and Silicon Graphics on the market, and animation software was now available from companies such as Wavefront Technologies. These advancements allowed competition from other niche startup companies, while CCP remained saddled with its own large investments in computer mainframes and locally developed software. The combination made for stiff competition in the markets. Carlson therefore saw the company through Chapter 11 liquidation and Cranston/Csuri formally closed in October 1987.

Lessons Learned

The process of converting from a research-focused environment to a commercial animation production environment was very enlightening. We purchased and installed newer display equipment and workstations that required a significant reworking of the software. Animators shared frame buffers for reviewing their motion tests and defining colors, and that required the development of a flexible scheduled production approach that was somewhat foreign to the staff.

The major difference was defined by the production delivery schedule. Deadline for production delivery was new to us. As I often said to the animators, they can't delay the Super Bowl because we are not yet done with the graphic open animation. The other major differences were due to the profit margin requirement, and the fact that we were working with agency or network art directors that sometimes were oblivious to the difficulties of implementing new image-making approaches that matched their expectations.

THE ADVANCED COMPUTING CENTER FOR THE ARTS AND DESIGN

Just prior to the closing of CCP, Tom Linehan and Chuck Csuri oversaw the conversion of the Computer Graphics Research Group into the Advanced Computing Center for the Arts and Design (ACCAD), with funding from the University, a long-term Ohio Board of Regents Academic Challenge grant, and another National Science Foundation grant. ACCAD was established to provide computer animation resources in teaching, research, and production for all departments in the College of the Arts at Ohio State.

During this early period of ACCAD's existence, significant research and production was done in the area of animation by the affiliated faculty, staff, and students. For example, David Haumann's Ph.D. research contributed to the area of the use of physical dynamics to animate flexible objects. Haumann developed system architecture for the construction of a software test-bed in which experimental behavioral simulations could be developed and tested. James Hahn investigated the same kinds of interactions for rigid objects. His system modeled complex interactions between objects (including continuous contacts) by using collision detection and impact dynamics.

Csuri remained very active at ACCAD, continuing to make art in this rich collaborative environment that joined artistically creative students and technology

FIGURE 6. "Horse Play" by Charles Csuri (artist print from the collection of Wayne Carlson).

students working together. There are numerous examples of the dialog between experts from different interdisciplinary fields in Csuri's research groups over the years. An excellent representational example can be found in the interaction of Csuri with Steve May, who was then a doctoral student in computer science. This collaboration is mentioned frequently, because many of Csuri's later artworks draw on tools developed through their dialog.

Csuri approached May with inquiries into the notion of procedural drawing in 3-D space. Csuri had studied the works of the great Japanese painter, calligrapher, and wood-block printer, Kitagawa Utamaro (1753–1806) and became interested in Utamaro's use of bold, flowing, yet elegantly controlled calligraphic lines to render form. Csuri wanted to use "lines" that had depth and width, and also wanted these "lines" to reflect light and cast shadows.

May chose the language of *Scheme* and embarked on the development of scripts that would create such a pseudoline in 3-D space. Csuri now refers to the code as the "ribbon tool." With this tool, he can adjust the width, length, and movement of the line by varying the parameters in the code. Csuri used this tool to create some of his most engaging later art works, such as "Entanglement," "Horse Play" (see Figure 6), and "texturePerhaps."[c]

[c]Csuri was featured in a series of retrospective exhibitions of his work. The SIGGRAPH professional graphics organization hosted an exhibition of his work titled *Beyond Boundaries, 1963-present* in 2006 in Boston. The catalog for the SIGGRAPH exhibition can be downloaded at http://alturl.com/gbks7

ACCAD continues to be a viable research and production center at Ohio State (Rick Parent also established the CG Lab in the Computer Science Department). Wayne Carlson returned to the University after CCP closed and served as the ACCAD director from 1991 to 2001. During this period, grants were obtained from federal and state agencies and various industries. Research was done in the areas of animation, visualization, interactive museum installations, and virtual training systems, and of course artistic computer imaging and animation.

Several influential graduate students came through the Computer Science CG Lab, some working specifically in the lab, and others also working through or together with ACCAD. For example, Doug Roble won an Academy Award for his work at Digital Domain on motion tracking software; Michael Girard started his own company in 1993, Unreal Pictures, that created the animation software *Character Studio*, later purchased by Discreet (Girard worked with OSU graduate Robert Lurye to produce the famous Dancing Baby (BabyChaCha) Internet meme in 1996); Dave Haumann went to Pixar and was the Lead Technical Director on the 1997 Academy Award winning *Geri's Game*; Ferdi Scheepers has worked on *Cars* and a number of full length and short features at Pixar, one of which was awarded an Academy Award in 2017; and Steve May was a technology lead on *Monsters Inc.*, *Finding Nemo, Up!* and other films and later became the Chief Technology Officer for Pixar.

CONCLUSION

This article describes the evolution of research activities in the areas of computer graphics and computer animation at The Ohio State University. These activities were built on the model that interdisciplinary cooperation between those in the arts and those in the sciences, engineering, and technology fields could yield results that exceeded the capabilities of each discipline on its own. The focus has always been on animation as an artistic expression. This model was used in the establishment of the Computer Graphics Research Group, the Advanced Computing Center for the Arts and Design, and several other entities at OSU (e.g., the Ohio Supercomputer Graphics Project and Chris Yessios' lab in Architecture).

Many of the CGRG and ACCAD research developments were noted as "firsts" in the discipline. One of the earliest research agenda items was the development of integrated and robust animation systems. DeFanti's GRASS, ANIMA, Hackathorn's ANIMA II and ANTS systems, TWIXT, and the extensions of these systems used in the commercial venture were prime examples of successful developments. Steve May created another animation language, AL, as part of his Ph.D. work.

Another research area was related to interactive data modeling systems, as was demonstrated with Parent's DG system; Carlson's DG2; the addition of alternative data representations, such as particle systems (used in Reynold's innovative galaxy simulations and Carlson's smoke clouds) and surface patches; David Ebert's gaseous models; and approaches to procedural modeling that were used to create trees and forests and complex city scenes.

Character animation has been a major focus throughout the history of the OSU research centers. Early character motion by Tim Van Hook (*Pong Man*) followed the interpolated surface and flexible dynamics of Rick Parent's whale demonstrated in ANIMA II. Girard and Maciejewski investigated kinematic approaches to articulated figures, and Zeltzer developed techniques for controlling skeletal motion over different terrains.

John Chadwick looked at skin and muscle layering over skeletons for more realistic looking characters. Ferdi Scheepers took it a step further with complex muscle representations for limbs. Girard used his character motion system in concert with a flocking system developed by Susan Amkraut for their groundbreaking film *Eurhythmy*. Haumann and Hahn developed systems for the interactions of flexible and rigid characters, respectively. Rob Rosenblum published his work on the movement of human hair, and several research results for facial animation were obtained in the labs.

These research activities have involved many students and faculty who, through their research contributions, have impacted industry and academic institutions all over the world. Graduates of the OSU CG program are leaders in the film industry, the advertising world, in automotive and aerospace companies, independent research labs, and many technology areas. A large number of these graduates are now leading educators in similar programs at universities and art schools around the world.

Ohio State also showed how the research activities inside a university laboratory could be transferred to impact the development of a renowned commercial production facility in the form of Cranston/Csuri Productions, Inc.

Prof. Charles Csuri saw the potential of using the computer to extend the creative art-making activities of a fine artist. The results of his pioneering vision have had a significant impact on all aspects of image making using computing technology. While other evolving research labs were focused on computer-aided design and other industrial focused applications, his efforts focused on artistic uses of the computing resources, an emphasis that continues to this day in the research labs at OSU that grew from his original, pioneering vision.

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