

# The History of Unigraphics, 1974–2001

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*Unigraphics was a first-generation commercial computer-aided design and manufacturing (CAD/CAM) system, initially released by United Computing Corporation in 1974. This article provides a firsthand account of the evolution of Unigraphics from 1974 through 2001, during which authors Paul Sicking, George Allen, and Wil Valenzuela were members of the development group. The authors describe the motivations behind each major step in the evolution of Unigraphics as well as the underlying technical strategies. The article also highlights some of the distinctive aspects of the organization’s culture and the continuity of leadership that helped navigate challenging product transitions despite changes in corporate ownership. Although this article only covers the period until 2001, Unigraphics continued to evolve thereafter with a different brand identity (NX), which is still a leading CAD/CAM product, now developed by Siemens Digital Industries Software.*

The history of Unigraphics presented here is organized into three time periods that correspond to changes in corporate ownership:

**United Computing Corporation:** Unigraphics was initially released in 1974 based on the ADAM code licensed from MCS. Over the next several years, the company debugged and enhanced the software and restructured it to prepare for its long-term development. In 1976, McDonnell Douglas Automation Company (McAuto) purchased United Computing and began operating it as a wholly owned subsidiary.

**McAuto:** In 1979, United Computing merged into McAuto. Shortly thereafter, the company’s technical leaders produced a strategic product plan that served as a vital roadmap for development throughout the decade. In 1987, General Motors selected Unigraphics as its computer-aided design and manufacturing (CAD/CAM) standard, beginning a partnership with Electronic Data

Systems (EDS). In 1988, McAuto acquired Shape Data Limited (SDL) for its Parasolid solid-modeling kernel and CAD expertise.

**EDS:** In 1991, EDS acquired Unigraphics from McAuto. Competitive threats led to significant development investment in Unigraphics, most notably in its architecture, user interface, platform support and parametric modeling capabilities. In 1998, the Unigraphics division became a publicly traded company operating under the name Unigraphics Solutions, Inc.

For each period, we discuss the major architectural and functional improvements to Unigraphics, particularly in geometric modeling, as well as the rationale and strategy for developing them. We also highlight changes in the organization and the contributions of key people.

This article is based primarily on our personal recollections as well as those of former colleagues with whom we have recently consulted. Another primary resource is a document on the early history of Unigraphics prepared in 1991 by George Allen and Wil Valenzuela. Most subsequent accounts of the Unigraphics early history [8], [10] are based, at least in part, on that document. Some online sources cite dates that differ from the ones in this article, but we are convinced that ours are correct because they are based on firsthand knowledge.

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## UNITED COMPUTING, 1963–1979

The prehistory of Unigraphics begins around 1963 with the founding of the United Computing Corporation by John Wright, an engineer who worked at Northrop. The company's original offices were two rooms above a hair salon in Torrance, California.

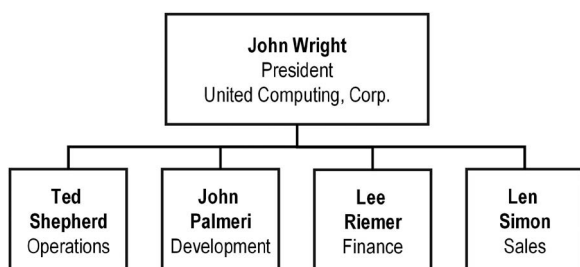
Later, United Computing relocated a few miles away to offices in Carson, California, in a building that had previously been a post office. Occasionally, someone would wander in, hoping to mail a parcel or buy some stamps.

The executive management structure of United Computing is shown in [Figure 1](#).

John Wright was an experienced user of Automatically Programmed Tool (APT), a high-level part programming language that was used to define numerical control (NC) machining instructions for cutting parts. United Computing initially developed custom postprocessors, which are programs that translate the NC instructions generated in APT into a form understood by an NC machine. The postprocessed instructions were encoded onto punched paper tape for input to an NC machine to manufacture the part.

APT programs ran on large mainframe computers like the IBM S/360. United Computing developed the first implementation of the APT language on a minicomputer and, in 1969, released it with the name Uniapt. Uniapt was written in United Computing's United's Programming Language (UPL), a proprietary language that was also used to write postprocessors. UPL provided an isolation layer that enabled United Computing to port Uniapt to different minicomputers, such as the General Automation SPC-16, Burroughs 1700, Data General 230, and DEC PDP 8 and 11.

In the 1970s, United Computing's marketing brochures touted the company's many years of leadership in NC programming, with more than 150 Uniapt installations and the world's largest library of more than 800 American National Standards Institute standard NC postprocessors.



**FIGURE 1.** United Computing executive management.

## UNI-GRAPHICS

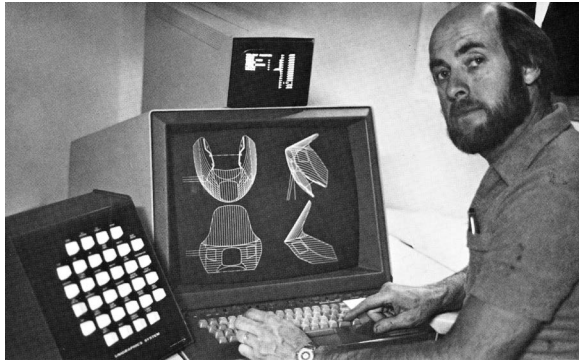
The history of Unigraphics, United Computing's CAD/CAM product, begins in 1973, when John Wright envisioned that customers could interactively create and visualize geometry instead of defining it textually, as in Uniapt. He received positive feedback from some key Uniapt customers and decided that the quickest solution would be to buy the CAD/CAM Automated Drafting and Machining (ADAM) program. In July 1973, United Computing licensed the rights to ADAM for a little more than \$100,000 from Patrick Hanratty's company, MCS, which also sold ADAM licenses to other companies, like Computervision and Gerber. The software consisted of about 600 Fortran subroutines that came in the form of card decks.

United Computing was fond of using the "uni-" prefix for everything, including its internal newsletter UniNews, so it rebranded the ADAM software as UNI-GRAPHICS when it was initially released in August 1974. CAD/CAM was largely unknown technology at the time, as evidenced by this description in United Computing's 1974 annual report:

UNI-GRAPHICS might be described as an elaborate typewriter for constructing engineering drawings and programming numerically controlled machine tools. Integrated with this typewriter is a TV screen which communicates back and forth with the operator in order to discuss how the part being programmed is to be drawn and machined. The part drawing and, if desired, the cutting path of the machine tool used to make the part are displayed on the face of the TV screen for visual monitoring.

Although CAD/CAM was in its infancy, forward-looking companies understood its potential and started buying Unigraphics. Early adopters included the Los Alamos National Laboratory, Alcoa Aluminum, Corpus Christi Army Depot, and 3M.

The Unigraphics design station consisted of a Tektronix 4014 graphics device, a program function keyboard (PFK), and a small alphanumeric message monitor (see [Figure 2](#)). The PFK had 32 labeled buttons for accessing Unigraphics functions and responding to prompts displayed on the message monitor. The geometry, drawing, and tool path were displayed as wireframe curves on the Tektronix display screen, which used storage-tube technology that required a redisplay of the entire image whenever anything was modified. The user selected geometry using the thumbwheels on the keyboard to position a crosshair on the item of interest.



**FIGURE 2.** Early Unigraphics design station (c. 1974).

United Computing, a small company with limited resources, underestimated the effort needed to maintain and enhance a commercial CAD/CAM product. Of the 90 employees in the company at the end of 1974, many were developing NC postprocessors and porting Uniapt to various operating systems (OSs). During that year, the Unigraphics staff grew from two to seven programmers, including three talented people who would provide crucial technical leadership throughout the early years of Unigraphics development: Gary Block, Gary Newell, and Paul Topping. Wil Valenzuela was hired by Unigraphics as a programmer in 1974.

Unigraphics was advertised as an interactive graphics system for 2-D drafting, design, and machining, but it had inherited significant deficiencies from the purchased ADAM software. The company promptly addressed these deficiencies:

- › NC machining tool-path generation was unreliable. Because NC capabilities were the key to the company's reputation, it began to develop new algorithms, starting with two-axis operations.
- › Some drafting symbols, like form and position tolerances, were unavailable.
- › There were no user-defined views.
- › Unsuitable parameterizations of conic curves caused a jagged display and numerical issues.
- › The numerical methods used to compute curve intersections, fillets, and closest points were unreliable.
- › The file structure needed to be changed to improve performance and facilitate conversion between hardware platforms.

Initially, Unigraphics was strictly a single-user system, but it needed to be multiuser to be cost-effective. Gary Block and Gary Newell led the development of United Computing's proprietary OS called Time Slicing System (TSS), which allowed up to four concurrent users. TSS

was initially delivered on the General Automation SPC-16 minicomputer and, later, the Data General Eclipse.

In 1976, United Computing released the Unigraphics Graphics Interactive Programming (GRIP) language, thanks largely to Paul Topping. Growing out of a demand for parameterized standard parts, GRIP became the answer to many users' requests for functionality not available in Unigraphics. This was the beginning of a long history of "openness" for the company's CAD/CAM products. Unigraphics customers wrote specialized applications in GRIP and contributed them to a library for sharing with other customers. Even Company President John Wright wrote GRIP programs.

### McAuto Subsidiary

In April 1976, McAuto, the data-processing service division of McDonnell Douglas Corporation (MDC), purchased the assets of United Computing Corporation for \$1.5 million and set it up as a wholly owned subsidiary. McAuto's main business was selling consulting services and computing time on its mainframe computers, but it also provided specialized engineering programs and was eager to expand into the CAD/CAM market. Prior to the acquisition, MDC had developed its own CAD/CAM system called CADD that was widely used throughout the corporation, particularly in the aircraft division (McAir). However, MDC considered CADD to be a competitive internal design advantage, so it placed restrictions on how McAuto could sell CADD. This was a major factor in McAuto's decision to purchase United Computing.

Shortly thereafter, engineering departments throughout McDonnell Douglas began adopting Unigraphics, especially in the astronautics division (MDAC), where Unigraphics was considered superior to CADD in drafting and in programmability with GRIP.

### Restructuring

By 1976, United Computing realized that the Unigraphics architecture was impairing its ability to enhance, maintain, and port the software to different hardware platforms. Consequently, the company decided to restructure the code and improve its processes to be more productive while deferring development of new major functionality. Although tedious and time-consuming, restructuring was necessary for long-term survival.

Gary Block and Gary Newell led the restructuring initiative with support from Paul Topping and Wil Valenzuela. As a new subsidiary of McAuto, the company was able to hire a few more people to proceed with the restructuring. By mid-1977, there were a dozen programmers working on the project. The developers

rewrote ADAM functions that didn't work, modularized the code, and established review processes and standards. They also wrote a Fortran preprocessor that enforced those standards and isolated the code from OS dependencies, which made porting much easier in later years.

The restructured Unigraphics product (R1) was first released in April 1978. The following three releases (R2 to R4) over the next 12 months included bug fixes, new functionality (like editing dimensions and drafting symbols), and improved usability for commonly used operations (like selection by chaining and the generic point subfunction).

## Double Precision

During restructuring, the company also realized that some numerical algorithms for geometric design and NC machining would require the use of double-precision floating-point operations for stability and robustness. Because this would impact data compatibility for existing users, it was decided to introduce double precision into the next generation of Unigraphics, the first release of which (known as D1) occurred in December 1979.

The solid architecture provided by restructuring and double precision enabled the delivery of new functionality in the series of D1 through D4 releases:

- › modeling enhancements (cubic splines, sculptured surfaces, conic sections, surface intersection, offset surfaces, and analytic surfaces),
- › new machining modules (multiaxis and lathe),
- › view-independent work coordinate systems,
- › drafting (flexible editing and user-definable fonts),
- › schematics and finite-element modeling applications, and
- › an improved Unigraphics file management system called UGFM.

## The Organization

In 1978, Tom Rafferty was hired to manage Unigraphics CAD/CAM development. The Unigraphics development team consisted of 26 people, divided into two CAD groups and a CAM group.

Wil Valenzuela was the new leader of the core CAD group, which needed to be rebuilt to replace programmers who had left during the restructuring. In 1978, Wil hired several young and inexperienced but enthusiastic college graduates, who had not even heard of CAD/CAM before their job interviews but would rapidly gain expertise and thorough knowledge of Unigraphics. Along with Gary Newell, George Allen (who had joined in 1977), and Paul Sicking (who had transferred from

McAuto), these new members of the group would form a strong and stable foundation for the Unigraphics development organization. They would remain with the organization for the next four decades, as would dozens of others who joined the organization over the next few years. This level of employee retention is highly unusual for a high-tech company. To maintain the casual and friendly company culture, when hiring new software engineers, we evaluated the candidate's potential to both excel at technical work and fit in well with our culture.

The company's congenial atmosphere extended across the organization. For example, unlike at our competitors, there was not a strict separation between the sales and development groups, and sales would often involve development in the early stages of an engagement.

## MCAUTO, 1979–1991

Although United Computing had been acquired by McAuto in 1976, it was operated as a wholly owned subsidiary for the next several years. Besides the McDonnell Douglas logo on our company letterhead, not much had changed since the acquisition. However, the status quo began to change when, on 20 March 1979, it was announced that United Computing would be fully merged into McAuto. In the announcement, McAuto President William Orthwein stated, "The full consolidation of United Computing's personnel and systems into MCAUTO will enhance MCAUTO's leadership position in the growing CAD/CAM market." At the time of the merger, United Computing had 150 employees, who joined the newly created McAuto CAD/CAM directorate, which also included CADD and Fastdraw (a finite-element modeler). The merger announcement stated that McAuto planned to aggressively develop both Unigraphics and CADD.

Our new McAuto executives were appalled by our office situation in Carson, so, in 1980, we relocated to the Cypress, California, office. Our new home was a cluster of four humble one-story buildings in the corner of a large strawberry field. The new Cypress office was more professional, but the informal culture persisted for many years.

As a result of the merger, John Wright and other United Computing executives left the company, and much of the United Computing organization was placed under the direction of George Meister, a veteran leader within McDonnell Douglas. George reported to John Clancy, who was also responsible for CADD. Except for a few applications developed in St. Louis, Missouri, Unigraphics development (about 40 people) was consolidated under Wil Valenzuela in Cypress (see [Figure 3](#)).

UGII

In January 1982, George Meister traveled to St. Louis for John Clancy’s staff meeting. One of the main topics at this meeting was the future direction of Unigraphics, a topic that George was ill prepared to discuss because our development plans did not extend beyond the D3 release scheduled for midyear. John would not accept the excuse that we were too busy with D3 to do any long-range planning, so he told George that he had to remain in St. Louis until he could produce a proper product plan. Motivated to minimize his time in wintry St. Louis, George immediately delegated the planning task to Tom Rafferty, who delegated it to Wil.

Wil quickly organized a weeklong meeting on the *Queen Mary* ship, which was moored permanently in Long Beach, California. He selected the following people for his planning team: George Allen, Chuck Grindstaff, Vic Hambridge, Chris Mehling, Gary Newell, and Paul Sicking (see Figure 4), all of whom had thorough knowledge of the internals of Unigraphics and experience with users. In addition, several had expertise in critical areas: Gary in systems and computer architecture, George in geometric modeling, and Chuck in NC machining. This team would be referred to as “The Seven Dwarfs” for many years thereafter.

On the morning of Monday, January 25, the seven of us checked into the *Queen Mary*, blanketed by a thick marine layer covering Long Beach harbor. We found a cramped 1930s-era meeting room with a whiteboard and proceeded to work. The meetings were lively and sometimes contentious, but, by Friday afternoon, we had a solid strategic plan with a concrete multiyear release proposal, which allowed George Meister to return home.

On a strategic level, the product plan clarified the areas where Unigraphics would compete (mechanical design, documentation, and manufacturing planning) and where it would not (electrical design, enterprise applications, and real-time manufacturing). It also identified key enabling technologies: 32-bit computers, 3-D visualization, solid modeling, and data management. Recognizing that these emerging technologies would be disruptive for the current user base, the plan outlined a scheme for enhancing and maintaining three overlapping generations of Unigraphics; the current product would be called UGI, and the next two generations would be UGII and UGIII.

On a tactical level, the product plan detailed the contents of the first UGII release. It would contain major functional enhancements, such as flexible 3-D geometry construction, associative dimensioning, file management, and raster-based visualization. These enhancements and others envisioned for subsequent releases would require the power of 32-bit computers as well as fundamental changes to the Unigraphics architecture, including a new data manager that could handle variable amounts of data and orchestrate change propagation. Modifying geometry would trigger automatic changes to drawings, NC tool paths, and assemblies, a forerunner of the parametric capabilities that would become popular a decade later. We also developed a migration utility to convert UGI data into the UGII format. This emphasis on upward data compatibility had been in place since the early days of Unigraphics and would continue throughout the future of the product, proving to be an important differentiator relative to the competition.

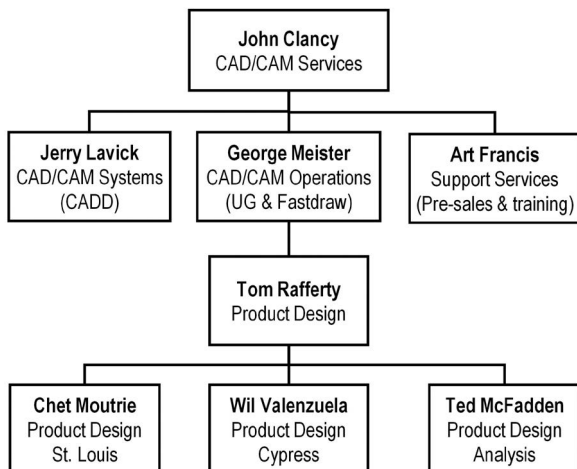


FIGURE 3. Management structure (October 1981).



FIGURE 4. The Seven Dwarfs (George Allen, Chuck Grindstaff, Vic Hambridge, Chris Mehling, Gary Newell, Paul Sicking, and Wil Valenzuela) and a few friends.

The plan was fundamentally risky because virtually all of our existing customers had 16-bit computers, which would not support UGII. One of the first public disclosures of UGII was at the Unigraphics regional user meeting hosted by Los Alamos Labs in the summer of 1982. The users complained vehemently that UGII would not run on their existing 16-bit systems and doubted that we would continue to enhance UGI. However, these objections diminished considerably over the ensuing years, as 32-bit computers quickly dominated the industry. Fortunately, we had anticipated that trend early enough to capitalize on it.

The first release of UGII was our most aggressive development effort to date due to its technical complexity and project interdependencies. The release was largely coordinated by the Design Review Board (DRB), which was composed of the Seven Dwarfs. Every project required detailed functional and design specifications that we thoroughly reviewed in DRB meetings. These meetings were time-consuming and often emotionally charged, but they helped to ensure consistency and coherence among the projects. Chuck Grindstaff was particularly influential in the DRB meetings because he was quick-witted and articulate, traits that would enable him to later rise to the highest level in the company.

UGII required more developers, so we took advantage of the McAuto hiring organization to recruit nationwide. It was relatively easy to entice college graduates to relocate to southern California from schools in the Midwest and on the East Coast, given our climate and interesting work. Within two years, the Unigraphics development staff in Cypress had doubled to 84 people.

Wil continued to manage the group, which was divided into two sections, led by Chuck Grindstaff and Paul Sicking, respectively. The two sections did not have clearly defined lines of responsibility, which confounded our McAuto executives, who were used to more rigid organizational structures. However, the fluid lines promoted teamwork, flexibility, and cross training among staff.

In August 1984, we released UGII V1 on VAX VMS and Data General MV8000 computers. This initial release was a major step forward for Unigraphics in terms of functionality and provided a firm foundation for many subsequent releases that achieved the product goals envisioned on the *Queen Mary*.

### Hardware Independence

When developing Uniapt, United Computing understood the importance of building software that was

largely independent of the computer and OS on which it ran. Similarly, hardware independence was a goal for the Unigraphics restructuring initiative in the late 1970s. We accomplished this in several ways. First, we developed a Fortran preprocessor so that programmers could avoid writing code with machine-specific syntax, such as for character-string data. Second, we created well-defined modules to isolate code that was inherently dependent on the computing environment or graphics device. Finally, we instituted programming standards to minimize other types of dependencies. In subsequent years, we employed code checkers as we moved to programming languages like C and C++. Hardware independence would prove to be a key to our future success.

Our goal was to run on a variety of standard, commercially available computers and graphics devices, which was highly valued by the IT departments of prospective customers. From its earliest days, Unigraphics ran on standard minicomputers and used standard graphics terminals. This contrasted with some competitors, like Computervision, which built its own computers, and other companies whose CAD software required using custom hardware devices.

Most of the architectural work supporting platform independence was in place by the mid-1980s. By then, many engineering departments wanted to move their computing hardware out of special-purpose, air-conditioned labs and into the office environment. We took advantage of this trend by quickly adopting commercial workstations from vendors like Sun, Apollo, HP, and Silicon Graphics as they became popular. These workstations were powerful 32-bit computers, with networking and, often, sophisticated graphics capabilities. They employed various versions of the Unix OS. They required us to port, but that was straightforward thanks to Unigraphics's platform-independent architecture.

We also developed hardware-agnostic products for file management (UGFM) and networking (UGNet) that enabled Unigraphics data to be managed and transferred seamlessly across a network of dissimilar computers.

### General Motors

From 1984 to 1987, EDS ran a \$2.5 billion program called C4, aimed at standardizing General Motors's engineering and manufacturing IT systems. The program was headed by Tony Affuso, who was then vice president of technology and strategy at EDS. In 1987, GM was using 26 different CAD/CAM systems, which were costly to

support and hampered data exchange. Their goal was to reduce this number to one.

GM and EDS evaluated all of the leading CAD systems at the time. Because Unigraphics was not well known then, it was not originally included on the candidate list, but Affuso insisted that it should be. The Unigraphics benchmark was conducted in St. Louis over four days in April 1987. UGS, GM, and EDS personnel executed approximately 50 different tasks, covering a broad range of system functionality. UGS assigned a team of around 50 people to participate. (UGS is the generic name used in this article to refer to the organization developing, selling, and supporting Unigraphics, although it has had many different names over the years.)

Unigraphics fared well, largely due to its breadth of functionality, superior CAM capabilities, and hardware independence. (GM and EDS people were amazed when we transferred Unigraphics files seamlessly between DEC, Data General, and IBM computers). As a result, Unigraphics was selected, as was CADAM (developed by Lockheed), primarily for its drafting functionality. GM decided to continue using their internally developed CGS system for body design. The 26 systems were reduced to three.

Over the next few years, GM and its suppliers adopted Unigraphics worldwide, especially in the powertrain and component groups. A few years later, GM abandoned CADAM and, in 1996, discontinued CGS, so the C4 program finally achieved its goal of establishing a single strategic CAD system throughout GM. By 2005, GM was using around 10,000 seats of Unigraphics.

### Free-Form Surfacing

One of the fundamental advantages of a 3-D CAD system is its ability to represent complex free-form shapes that are difficult to describe via traditional engineering drawings.

The original ADAM software was weak in this area; there was just a Wilson–Fowler spline [4] and no free-form surface functionality at all. In 1977, we implemented an exponential spline-under-tension [3]. This turned out to be a mistake, and, in 1980, we adopted a more conventional cubic spline curve, which served us well until the introduction of nonuniform rational B-spline (NURBS) curves [5] in 1988.

Free-form surfacing technology is closely associated with the automotive and aerospace industries, but, at UGS, our work in this area was prompted in 1980 by Sandvik, a customer that wanted to model the surfaces of milling cutter inserts.

We shipped our “sculptured surface” function in the D2 release in September 1980. It was unique in the industry, and, together with our strong NC machining capabilities, it spurred strong growth in the tool and die industry. Our capabilities were highlighted by a demo at the International Manufacturing Technology Show (IMTS) in 1981, where a visitor could design a toy race car and have it milled from foam, all driven by Unigraphics (see Figure 5).

In the mid-1980s, European customers began urging us to use Bézier and B-spline surfacing techniques. Furthermore, after its introduction into the Initial Graphics Exchange Specification (IGES) in 1981, many CAD companies were implementing NURBS geometry [5]. We felt that NURBS geometry was too general, but the technology had great momentum, and many systems were adopting it. Therefore, mostly for reasons of intersystem compatibility and data exchange, we did the same. Various NURBS surfacing capabilities were developed from 1987 onward. Parasolid uses NURBS as well, so, when we embedded it into Unigraphics in 1989, our old sculptured surfaces functions were finally retired. (See the next section, “Solid Modeling,” for more details.) Today, even the original advocates of NURBS technology believe that its generality is problematic [6], but a less-than-ideal standard is certainly far better than no standard at all.

By the end of the 1980s, Unigraphics had solid-modeling capabilities that included strong free-form geometry functions. This made it especially well suited to the design of turbine blades, which led to some big wins at Pratt & Whitney in 1989 and General Electric Aircraft Engines in 1991. Eventually, Unigraphics became the dominant system in jet engine development.

### Solid Modeling

Our interest in solid modeling began when Tom Rafferty introduced us to Herb Voelcker at the University



FIGURE 5. A toy racecar from IMTS 1981.

of Rochester in 1981. We were immediately attracted to the idea that a solid model is a complete and unambiguous representation of a part and can serve as a source of information for all downstream activities, so solid modeling became a key element of the *Queen Mary* plan.

In the early days, there was a widespread misunderstanding: Many people thought that solid modeling was just a way to produce “solid” shaded images and questioned its value. Therefore, we began to educate people [1], including our own executives, our customers, and the press. Applicon had released a solid-modeling add-on in 1981, and competitor actions were always a strong motivator at UGS, so momentum grew.

Voelcker’s group had produced a system called PADL-1 [9]. Although its capabilities were limited, it was enough to show the potential of the technology, so we used it to build a prototype that we shipped to a few customers in 1982. One of its capabilities was the automatic production of cross-section views (see Figure 6), something that John Wright had been trying to do in his GRIP programs since 1977.

Encouraged by the customer feedback, we sponsored the PADL-2 project [2] and built a system called Unisolids from the resulting code, which we shipped in October 1982 (see Figure 7).

Development of Unisolids continued for several years, but we grew increasingly nervous about the limitations of its core technology. It was a constructive solid geometry system, which made it difficult to handle free-form geometry and to tightly integrate with Unigraphics. Thus, we turned our attention to boundary representation (b-rep) solid modeling. A b-rep is essentially a collection of trimmed surfaces glued together with topology information (see Figure 8).

The necessary trimmed surface technology had been supported in Unigraphics since 1986, so we were only lacking the topology caulk and some solids-based construction functions.

We created various plans and prototypes during the mid-1980s, but we were unhappy with the results. By 1987, we were facing strong competition from the Pro/Engineer system from Parametric Technology Corporation (PTC), and we felt we could wait no longer, so we decided to go shopping. We considered buying Aries Technology and even PTC. We also evaluated the Romulus kernel, then owned by the company Evans & Sutherland. Romulus had been created by SDL, a small company in Cambridge, United Kingdom, the birthplace of b-rep solid modeling. In 1988, we discovered that SDL was working on a new kernel called Parasolid, which included support for NURBS geometry. We sent a team to Cambridge to evaluate Parasolid. They were

impressed and recommended that we integrate Parasolid into the core of Unigraphics.

Although the technology path seemed clear, we were concerned about licensing costs and the risk of relying on a third-party company for a crucial element of our product. To make matters worse, we discovered that the Shape Data company was for sale. Not wanting to lose control of Parasolid and potentially have it fall into the hands of a competitor, we entered negotiations with Evans & Sutherland and Caterpillar (who owned the intellectual property rights) to purchase the

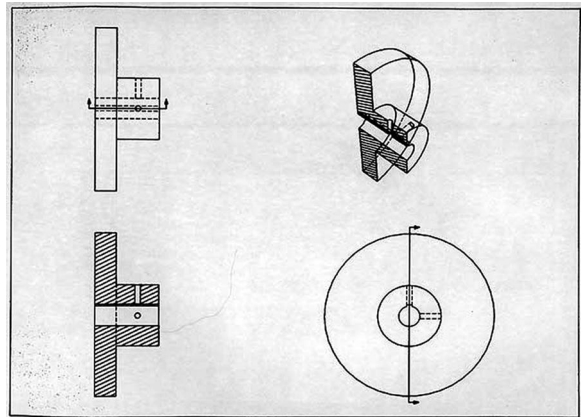


FIGURE 6. Drawing from the Unigraphics PADL-1 prototype (1982).

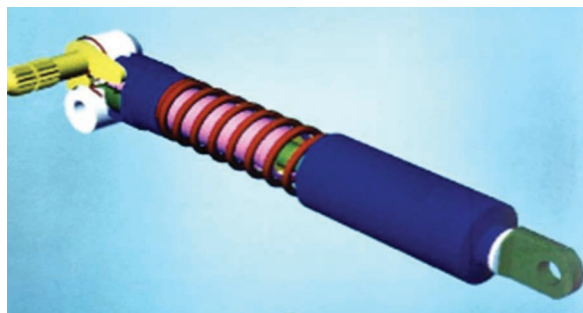


FIGURE 7. Model produced using Unisolids.

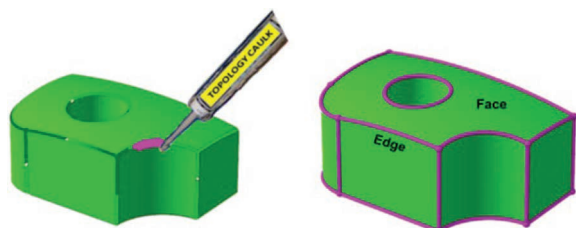


FIGURE 8. The b-rep concepts.

Shape Data company. These negotiations proceeded quickly, and, in October 1988, McAuto acquired SDL.

Integrating Parasolid into Unigraphics went smoothly, resulting in the UG-Solids module that we shipped with UGII V7 in December 1989. Unlike our earlier Unisolids product, UG-Solids was embedded within Unigraphics, allowing applications, such as drafting and NC machining, to access the solid model directly and to respond to changes in the model.

Parasolid has been continuously enhanced over the past three decades and now serves as the foundation of dozens of CAD systems.

## The Organization

In the early 1980s, George Meister was the head of the Unigraphics business, reporting to John Clancy, who was responsible for all McAuto CAD/CAM products. They concentrated on expanding the distribution of Unigraphics by establishing dedicated sales branches, removing them from interference and neglect by McAuto's enterprise sales management. By 1987, Clancy and Meister had retired, after which John Mazzola took over as head of UGS. Mazzola revamped sales compensation to be based on margin rather than revenue and, like his predecessors, was supportive of the development organization, entrusting them with the direction of the product. These changes immediately increased the company's profitability.

Throughout the 1980s, the Unigraphics development organization had grown considerably, but it remained relatively stable, with Wil Valenzuela leading both the Cypress and St. Louis development groups. In 1988, Chuck Grindstaff resigned from McAuto to start a company to develop a PC-based product for digital sound editing in the entertainment industry. Wil also resigned later that year to join Chuck's new company, so Paul Sicking took over leadership of Unigraphics development in Cypress and St. Louis. Paul reported to Bob Loss, who reported to John Mazzola. Ron Belcher, who also reported to Bob Loss, led the newly acquired Shape Data staff in Cambridge (Figure 9.)

The Cambridge team was composed of two groups: one developing Parasolid and the other Romulus-D, an end-user CAD product that was in the process of being retired. Senior members of the Romulus-D staff proposed that they define and develop a next-generation CAD software platform using object-oriented technologies and other modern software engineering practices. The project was called n-Able and would be staffed mainly with developers transitioning off Romulus-D.

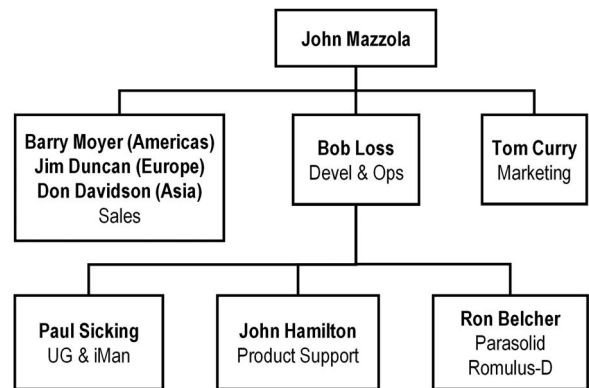


FIGURE 9. Management structure (September 1990).

## EDS, 1991–2001

In November 1991, EDS acquired McDonnell Douglas Systems Integration Company (formerly McAuto), which included Unigraphics and other commercial software, such as the architectural GDS product. However, it was Unigraphics that EDS really wanted because of its strategic importance as the standard CAD/CAM tool for GM's component and powertrain divisions. The acquisition was spearheaded by Tony Affuso, who had led the C4 program that selected Unigraphics in 1987. Tony was then a division president within EDS, but he joined the Unigraphics group shortly after the acquisition to ensure its success. Tony reported to John Mazzola, who remained the head of UGS, providing stability and leadership through the transition. John and Tony (with his strong ties to EDS corporate management) were instrumental in securing the necessary staffing to fund the aggressive development plans that emerged in the early 1990s.

## Unigraphics V10

In the summer of 1991, shortly before the EDS acquisition, John Mazzola convened an emergency multi-day meeting in Innsbrook, Missouri, with leaders from sales, marketing, and development to discuss the serious competitive threats that the company was facing. The competitive pressure was coming primarily from PTC, which was successfully promoting parametric modeling that would allow parts and assemblies to be updated efficiently by altering dimensions and geometric relationships. Although the UG-Solids module partially addressed this threat, we realized that our parametric and assembly modeling capabilities were deficient. Mazzola felt that the future of the company was at stake and insisted that we accelerate our development plans to address the new wave of competition

while ensuring that we continue to satisfy the requirements of our large customers.

Over the ensuing months, a team of senior members from development, sales, and marketing formulated a plan for the next generation of Unigraphics that would run strictly on workstations and provide major new functionality:

- › 2-D parametric sketching,
- › parametric feature-based solid modeling,
- › advanced assemblies for parametric positioning and scalability to large products,
- › hybrid surfacing and solid modeling, and
- › a graphical user interface (GUI).

In many ways, this product fulfilled the UGIII concept proposed in the *Queen Mary* product plan a decade earlier. Furthermore, like the UGI-to-UGII transition, we realized that this could be disruptive to some of our customers because it would make certain hardware obsolete, require user retraining, and necessitate significant data conversion. However, we learned from our UGII experience that the conversion should be transparent and not require a separate migration utility. Similarly, we refrained from calling this UGIII because we wanted to signal that, although the technology was revolutionary in key areas, the product was evolutionary in others and leveraged the many strengths of UGII, especially its applications. Consequently, the first release of this next generation of Unigraphics was simply called V10, no longer with the UGII prefix.

In July 1991, Paul Sicking invited Bernie Solomon (chief architect of n-Able and future chief architect of Unigraphics) to a private lunch at the Clarendon Arms pub in Cambridge to propose a new direction for the n-Able team. Instead of developing a new software platform, the team would work on the core of Unigraphics, integrating key n-Able components (especially the Object Manager) and adopting its advanced development tools. The Cambridge team would also develop a next-generation assembly modeler in Unigraphics leveraging their expertise from Romulus-D.

Bernie agreed with the proposal, especially since it would give the Cambridge team a more integral role in the organization. The proposal was subsequently approved by Ted McFadden, head of Unigraphics development, and Ron Belcher, head of Cambridge development. The plan was risky from an organizational perspective because it required remote development across eight time zones (at a time before widespread Internet access). However, we were able to manage the risks and, in fact, cultivated remote development

processes that were beneficial in the coming years as new development sites emerged across the globe through later acquisitions.

V10 debuted publicly at the Detroit Autofact trade show in November 1992 and was released the following June. Reaction was positive, such as in the CAD/CAM Watch newsletter published in August 1993, that stated, “We were impressed with the enormous step taken in V10 to regain UG’s competitive position.”

A monumental undertaking, V10 was worth the effort because we were now competitive in parametric feature-based design, assemblies, and user interface. The new architecture was robust and performant, providing the foundation for the V10 enhancements and many other innovations in following releases.

## Parametric Modeling

One of the fundamental concepts introduced by PTC’s Pro/Engineer in 1986 was parametric modeling. The key idea is that each object remembers the inputs and the operation used to create it. Then, the model can be edited by “replaying” it with new inputs.

The 2-D sketch curves remembered the dimensions and constraints that were used to define them, and the curves were computed by solving the sketch. This idea originated in Ivan Sutherland’s Sketchpad [7] in 1963 and was commercialized by a few little-known companies, but PTC introduced it into mainstream CAD.

Assembly modeling also benefited from parametric techniques. A component part remembered its relative position via “mating” relationships that connected it to other adjacent parts, so it could be repositioned automatically when those adjacent parts were modified.

In a sense, all of this was just an extension of the “associativity” idea Unigraphics and other systems had used for a while, but it was pervasive in Pro/Engineer, and it provided enormously powerful editing capabilities.

Strong competition from PTC in the late 1980s made it clear to us that good, solid modeling alone was not enough, and we needed parametric feature-based design and constraint-based sketching. A small group was formed to do some development work, including a constraint-based sketcher. The result was a product named UG-Concept, released alongside Unigraphics version 8 in March 1991. Initially, UG-Concept was a separate system, although it could exchange data with Unigraphics. The UG-Concept ideas were greatly expanded and merged into mainstream Unigraphics at version 10, which we shipped in 1993, finally giving us parity with PTC in parametric design. In 1997,

we improved our capabilities further by replacing our homegrown sketch solver with one licensed from D-Cubed, a Shape Data spin-off company led by John Owen that we later acquired in 2004.

### Free-Form Surfacing in Aerospace and Automotive

In the early 1990s, much of our free-form surfacing work was driven by the aerospace industry. McDonnell Douglas had chosen Unigraphics as its corporate CAD system in 1990, and Northrop was also a significant customer. We developed many new NURBS-based functions, but some aerospace design folks were unhappy with them and wanted to continue using their own internally developed surfacing technology, which we regarded as bizarre and unnecessary. We reached a compromise, deciding to allow “exotic” aircraft surfaces as “foreign geometry” in Parasolid and NX. We never thought this was a good technical approach, but sometimes it’s easier (and more lucrative) to give customers what they want, rather than what they need.

There had never been much motivation for developing surfacing capabilities for the automotive industry. GM was our only automotive customer, and EDS was serving their surfacing needs with the internally developed system CGS. This all changed in 1996, when GM decided to abandon CGS and choose a commercial system for body design. Our main competition at GM was CATIA (a Dassault Systèmes product), and our inattention over the previous decade had allowed it to gain a significant lead in this area. Also, the GM selection committee was chaired by an executive from the Saturn Division, where they used CATIA, so we felt vulnerable. GM made its big decision with astonishing speed. We went to Detroit to do our final sales pitch, and, when we got off the plane back home, there was a message waiting for Tony Afuso telling us we had won. What followed was two years of hard work enhancing Unigraphics and teaching GM how to use it to do body design. This led to a further surge in surfacing development and further successes in the automotive industry, including Isuzu in 2000 and Fiat in 2001.

### Assembly Modeling

Any nontrivial mechanical product is assembled from many individual component parts and subsystems. Modeling these product assemblies had always been an important functionality in Unigraphics, but the V10 architecture enabled significant improvements. Instead of the UGII approach of copying geometry from a component into the assembly in which it belongs,

V10 assemblies referenced the component geometry in an efficient manner, requiring less memory and less storage and resulting in faster processing. Also, the user could choose a lightweight (faceted) representation of components and subsystems, which allowed Unigraphics to handle large assemblies, such as entire automobiles.

This idea of referencing, rather than copying, geometry had far-reaching consequences that we did not anticipate initially: our customers invented the “master model” mode of working. The idea was that part geometry resided in one file (the master model), while derived data, such as drawings and NC tool paths, resided in separate files. Different people could work in parallel on the part geometry, the drawings, and the NC tool paths. Changes to the part geometry would propagate automatically to drawings and tool paths, increasing parallelism and compressing engineering schedules.

This architecture also enabled users to efficiently examine variations of the assembly, such as configuring a car assembly for automatic transmission and then easily switching to the manual transmission variation of that same assembly. This worked well when the Unigraphics files were managed by the OS and worked even better when the files were managed by our product data management system called iMan, which had formal rules for configuring the options and variants of a product.

### Windows

By the mid-1990s, Microsoft Windows-based computers had become sufficiently powerful to host sophisticated CAD applications, as witnessed by the emergence of products like SolidWorks and Solid Edge for the mid-range mechanical CAD market.

In January 1998, UGS acquired Solid Edge from Intergraph, attempting to position it and Unigraphics in separate market segments: Solid Edge was to compete with the likes of SolidWorks on Windows and Unigraphics with the likes of CATIA and Pro/Engineer on Unix. However, it quickly became apparent that the markets were not so distinct. More and more Unigraphics customers wanted their engineers to have a single desktop, often Windows based, for engineering and office applications.

Consequently, we started building a version of Unigraphics on Windows. Thanks to our hardware-independent architecture, it was relatively easy to modify Unigraphics to run in the Windows OS. However, the bigger issue was the user interface, which used the proprietary Motif toolkit that was standard

on most Unix workstations. As a first step, we acquired a Motif emulator that ran on Windows for use in the first release of Unigraphics on Windows (V15 in November 1998). The emulator was functional, but it gave Unigraphics a different look and feel from other Windows apps. Consequently, we developed a user interface abstraction layer, which allowed Unigraphics to run natively on both Motif and Windows while minimizing the impact on our code. This was released with V16 in January 2000. Unigraphics was now a Windows application and quickly became a popular platform for customers of all sizes.

Unigraphics on Windows opened many new opportunities for sales because the 1990s saw a shift in how hardware was purchased for CAD/CAM users. In the past, engineering and manufacturing departments had decided themselves what workstations to buy, but now those decisions were often being made by chief information officers who valued standard Windows hardware across the entire company.

## The Organization

After the EDS acquisition in 1991, John Mazzola was appointed president of the new EDS Unigraphics division. Shortly thereafter, Tony Affuso joined Unigraphics as a senior vice president, reporting to John, to help execute the vision that he foresaw for UGS when he orchestrated the acquisition. Tony was highly regarded by EDS executives and provided a strong link between them and UGS. Tony initially headed the marketing organization, which was later combined with development and called product marketing and development (PMD). John Mazzola established the PMD organization because he insisted that the responsibility for product strategy be as close to development as possible, in contrast to other companies where product decisions were made by a disconnected group in sales or central marketing. A strong leader, Tony helped to navigate the merger of the informal UGS culture with the more structured EDS one. He did not enforce the standard EDS dress code of suits and wing tip shoes but did request that developers at least wear a tie whenever an EDS executive visited.

UGS continued to be a technology and product-driven organization, but Tony added a persistent focus on customer satisfaction that was reinforced with his oft-repeated motto: "Never Let a Customer Fail."

During our first few years in EDS, Ted McFadden headed the Unigraphics development group, after which it was decentralized into a set of product business units (PBUs), all reporting to Tony. Each PBU was responsible for the product marketing and development of a functional area of Unigraphics (such as design,

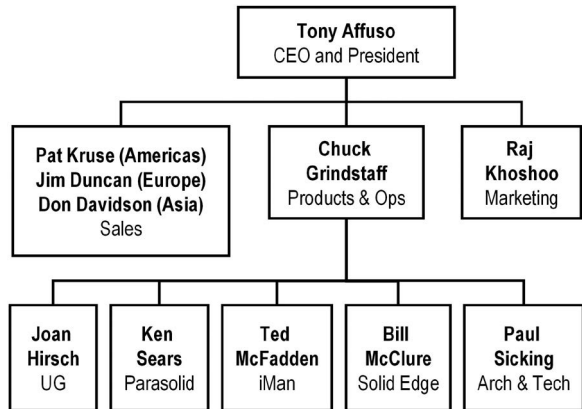


FIGURE 10. Management structure (August 2000).

computer-aided engineering [CAE], and NC machining). Tony formed the Office of Architecture and Technology (OAT) to oversee technical issues across the PBUs. The OAT was led by George Allen, Paul Sicking, and Wil Valenzuela, who had returned to the company in 1991.

In 1995, Chuck Grindstaff also returned to UGS and quickly assumed ever-increasing leadership roles. By 2000, Chuck was executive vice president of operations, including all R&D.

In 1998, EDS spun out the Unigraphics division into a publicly traded company operating under the name Unigraphics Solutions, Inc. with John Mazzola as CEO and Tony Affuso as COO. Two years later, John retired, and Tony became CEO and president (see Figure 10).

Although Unigraphics Solutions was a publicly traded company, EDS controlled 86% of the shares. In September 2001, EDS bought back Unigraphics Solutions at \$32.50/share, a sizable appreciation from the \$14/share at the time of the IPO in 1998.

## CONCLUSION

By 2001, UGS had a proven track record of commercial success, with a solid technology base, experienced organization, and strong corporate support. At the Daratech Summit in February of that year, UGS President and CEO Tony Affuso presented the state of the company, which included the following highlights:

- Sales of UGS products continued to outpace the market, with a 24% compound annual growth rate over the previous 25 years.
- The customer base had grown to more than 17,500 companies, including General Electric, Pratt & Whitney, Kodak, Boeing, and General Motors, not to mention many companies with much smaller engineering staffs.

- › There were more than 1 million software licenses of UGS products.
- › In the previous year, UGS had signed more than 80 large contracts with a combined value exceeding \$300 million.

Although UGS had expanded its product portfolio to include data management (iMan) and visualization (EAI), Unigraphics continued to be the flagship. One distinguishing characteristic of Unigraphics is continuity, in terms of technical leadership and technical evolution. This continuity has undoubtedly contributed to our remarkable resilience and longevity; of the top five CAD systems of the early 1980s, only Unigraphics has survived.

Many of the key people from the 1970s and 1980s spent virtually their entire careers with UGS. In the development organization, the Seven Dwarfs were all back together by 2000, serving in various technical and managerial roles. As in the past, development managers had strong technical skills, and senior technical people had strong leadership skills. This heritage of seasoned leadership was also true in sales, support, and other UGS organizations. Leadership talent from acquired companies (such as EAI and Intergraph) provided complementary expertise and market insight.

On the product side, the current Siemens NX CAD/CAM product has a direct lineage to the Unigraphics product of the 1970s, which contrasts with many other CAD systems of that era (such as those from Computervision and Calma) that were eventually retired. At key points in our history, we debated whether to abandon the current product and start afresh or to transform it in sometimes radical ways. The latter approach repeatedly won the day. We evolved Unigraphics to minimize disruptions for our customer base as they upgraded from one generation of the product to the next.

The evolution of Unigraphics involved not only increasingly sophisticated functionality but also adaptation to changes in the computing environment, programming paradigms, modeling techniques, graphics technology, data management, and software architecture, among others. By 2001, Unigraphics was a fully parametric, solids-based product with a range of functionality for design, analysis, and manufacturing; it had a modern GUI with state-of-the-art 3-D visualization; it ran on the most popular engineering computing platforms (Unix and Windows); and its object-oriented architecture enabled the ongoing development of efficient applications in varied domains.

Product strategies could be developed quickly and efficiently because McAuto and EDS were not primarily in the commercial software industry. Because we were profitable, they exerted limited influence. Notwithstanding, Unigraphics was strategically important to our parent corporations and received the necessary financial backing to fund development, especially through challenging product transitions.

Despite its success, UGS had a size disadvantage relative to some competitors, especially Dassault Systèmes. A Toyota executive made this abundantly clear to us in 2000: sitting in a restaurant, he placed the saltshaker on top of the pepper shaker to indicate that a combination of UGS and Structural Dynamics Research Corporation (SDRC) was needed to compete with Dassault and succeed at Toyota. Consequently, EDS acquired SDRC in October 2001 and combined it with UGS to form a new entity called EDS PLM Solutions, with a combined annual revenue of more than \$1 billion.

The second CAD special issue of *Annals* will describe the subsequent history of Unigraphics. That article will explain the strategies for unifying technologies from UGS and SDRC, especially in the areas of CAD/CAM/CAE and data management. It will also cover changes in ownership from EDS to private equity and finally to Siemens.

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