Teaching Three-Dimensional Computer Modeling: Past History and Future Plans

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Abstract

For more than ten years, three-dimensional modeling has been a part of the Graphic Communications Program curriculum at North Carolina State University. Originally taught using a wireframe modeling package on a proprietary microcomputer, 3-D modeling is currently part of both our introductory and advanced CAD courses and includes both wireframe and solids modeling on Unix workstations. Initially 3-D modeling occupied a peripheral role in the curriculum at NC State, but has since evolved into a primary focus. As industry has moved toward the use of integrated 3-D product databases in a concurrent design and manufacturing environment, NC State has responded by teaching their students how 3-D product models are developed, documented, and integrated into design and manufacturing, Also discussed is how the instructional approach to 3-D CAD differs from either drafting or 2-D CAD.

Historical Overview

In 1979, the engineering graphics department was transferred out of the School of Engineering to the School of Education and Psychology and its name was changed to Graphic Communications. This new department had but one course, GC-101, a freshman level mechanical drawing course for engineering students. Shortly thereafter, in 1983, a need was felt to begin preparing students for the future of engineering graphics. It was then that Graphic Communications took its first steps into teaching the rudiments of three dimensional computer graphics. The department purchased a computer workstation from Micro Tech Unlimited. The MTU was an Intel 8088 based computer with two 8" floppy disks and monochrome monitors. In 1984 this was augmented by the additional purchase of three more upgraded Intel 80286 MTU workstations and a plotter. At this point there was almost a $45,000 commitment to computer aided design in place. The MTU system was capable of constructing two dimensional, as well as three dimensional wireframe drawings. This system was used in the department's brand new GC-200 course developed by Mr. William Ross; at the time, the only computer based course in the curriculum.

By 1987, GC-200 had been switched from the MTU's to a Macintosh™ based graphics package. This was done not only to gain more seats, but also due to the instability of the MTU platform. The software that was then chosen was PEGASYS™ and later PEGASYS II™, the latter adding a 3D wireframe component. The class was then held in a special computer teaching facility with 20 Macintosh computers and an overhead video projection system.

At the same time, the department was able to fulfill a long term goal of bringing truly state-of-the-art CAD software into its courses. Graphic Communications purchased two Hewlett Packard™ 320 workstations, storage devices, and a plotter as well as licenses for the ME-10™ and ME-30™ CAD software. Again, a significant investment of almost $55,000 was made in order to keep the department on the leading edge of computer technology. The ME-10 package was an extremely sophisticated 2-1/2 Dimensional package while the ME-30 software allowed students, for the first time, to perform true Boolean - based three dimensional solids modeling in house. A new course was immediately set up to utilize this new equipment. It was initially housed under our GC-496 (Special Topics) heading and taught by Mr. William Ross. This became the second CAD course offered by Graphic Communications.

By 1990, GC had acquired 6 more HP workstations. The ME-10 software had been moved to the GC-200 course replacing PEGASYS and a new course, GC-300, had been created to teach ME-30 and three dimensional solids modeling. The GC-496 course still remained the highest level CAD course, but with a new generation of hardware and software, it was used to teach those who wanted to go even further than GC-300 the techniques of rendering and shading as well as other advanced concepts.

In 1992, Graphic Communications experienced a major shift its programs. Since 1983 the department had been teaching two different mechanical drawing classes. GC-101 to fulfill a two hour requirement for engineering students and GC-120, a three hour mechanical drawing and sketching course for non-engineers. The Department began to explore methods for implementing CAD into an introductory course curricula. The software of choice was Generic CADD™ which was taught in our college computer facility. The initial offerings of this course were extremely popular. In 1993 the decision was made to begin offering sections of this course to engineering students. Additionally, a decision was made to switch to CADKEY™ as our CAD software for this course. This was because of CADKEY's three dimensional capabilities and its availability to the students over the newly established student computing environment of networked UNIX based workstations. During the remainder of the year and throughout 1994, the number of GC-120 sections continued to increase as non-engineers took the course to gain a competitive advantage in today's job market and engineering students took the course in place of their GC-101 requirement. During this time the College of Engineering began to express an interest in a series of specialized courses with both mechanical and computer based content. The content of this course includes sketching, basic mechanical drawing, 2D CAD, and 3D Wireframe modeling. Several of the departments have now changed their requirements, going with the updated courses.

Currently, in 1995, with enrollments in the GC-101 course shrinking and enrollments in the GC-120 course still on the rise, another switch was made from CADKEY to the AutoCAD™ suite of products. Next year GC will continue the integration of new materials and techniques into several of our courses. In the GC-300 course such topics as B-Rep Modeling and 3D Parametrics will be added, in addition to advanced CSG Modeling. There will also be a change in software, most likely to ProEngineer™. Many of the introductory solids modeling techniques will be shifted down into our GC-200 course which will begin to use a combination of AutoCAD AME & Designer software. The GC-120 course will most likely stay at a 3D wireframe or simple solids level with the possible inclusion of AutoCAD AME or Designer and some discussion of 2D parametrics.

Looking into the crystal ball and viewing the distant future (3-5 years) there will remain a strong emphasis on 3D solids modeling, even at an introductory level. This would permit students to become proficient in many of the analysis techniques that the computer revolution has spawned. Entire courses devoted to how a CAD database may be distributed and used in many other parts of a modern business can also be envisioned. Instruction in the use and manipulation of CAD databases in addition to the mere creation of the geometric data will become increasingly important in the future.

Evolution of Teaching Technical Graphics

It is quite natural that the evolution of teaching technical and engineering graphics at North Carolina State should parallel the development of the field as a whole. In the course of this evolution there has been a tremendous number of articles written on both the teaching of traditional drafting, 2-D CAD, and, more recently, 3-D CAD. What there has not been, however, is a much work comparing historical and contemporary engineering/technical graphics and evaluating how the evolution of technology has changed the way the subject matter is taught.

Historically, technical graphics was means by which physical objects, either existing or planned, could be accurately described via projection methods in 2-D paper documents (Bertoline, Wiebe, Miller & Nasman, 1995). Using descriptive, plane, solid, and analytic geometry as its base, object representations could be mechanically produced as a series of projections with enough accuracy and robustness to serve as the basis of communication for the design and manufacture of complex, highly engineered objects and structures. Using a combination of the projective principles, descriptive geometry, and a sophisticated symbology, standards such as ANSI Y14 provided a uniform method of communication between engineers and technicians both within and between organizations.

As sophisticated as the theories were, the reality was its practice was limited by the means in which these documents were produced; that is, a drawing instrument depositing markings on a flat, 2-D media. For that reason, the teaching of technical graphics was as much an 'art' as it was a 'science'. The teaching was as much about the technique of drawing as it was about imparting concepts of projection theory. As was regularly driven home to students, the clarity of your communication was based as much on the quality of your lines as it was about the appropriate choice and placement of symbols.

The physical reality of having to manually create the document also meant that the choice of projection methods would be dictated not only by the clarity in which that view might describe an object, but also the ease in which that projection could be created. For example, the lack of popularity of dimetric and trimetric pictorial projections has more to do with the difficulty in producing them than it does with their general appropriateness in application. Even with relatively easy to produce projections, the limitations of the tools has meant a limitation in the accuracy in which complex geometries could be represented. Though analytic geometry affords us the mathematics to very accurately represent conics or higher order curves, the physical representation of these curves on paper is typically reduced to estimations created with the help of French curves. Though Ferguson (1993) rightfully argues that the physical limitations of the drawing help remind the engineer of the physical limitations in accuracy of the object/structure being designed, ideally the engineering limitations should be what drives the content of the drawing, not vice versa.

Historical precedence, convention, and the limitations of the medium have put forth the multiview drawing as the standard document of communication within the manufacturing setting. Though civil engineering, architecture, and allied fields tend to limit a drawing to a single view, their views — like the traditional working drawing — tend to be an orthographic projection capturing two of three possible dimensions. Though easier to draw, it now is left up to the trained observer to piece these views together to create a mental representation of the 3-D object. The time-intensive nature of creating and modifying a drawing tended to limit the scope of application of these documents. Where the highest degrees of accuracy were required, such as in describing a part for manufacture, formally drafted drawings were used. On the other hand, earlier in the design phase where rapid iteration of a rapidly changing concept was the norm, sketching and ideation techniques (using the same medium) were applied. The challenge for the drafter, often, was to capture the design intent embedded in rough sketches, notes, and calculations in a final document accurately representing both the geometry and the method of manufacture.

The Transitional Period

The emergence of 2-D CAD tools could, in many ways, best be described as a transitional period for technical graphics. As Rooney & Steadman (1989) note, 2-D CAD is often (and accurately) described as computer-aided *drafting*. In many respects, the introduction of 2-D CAD has done little to change the profession other than to replace the physical paper with a virtual sheet of paper. 2-D CAD has had a number of factors both supporting and detracting its acceptance into the workplace and into the classroom. At least initially, one of the biggest drawbacks to the use of 2-D CAD was the expense, anemic performance, and difficulty in technical support for early CAD workstations. As discussed earlier in the paper, in the mid-1980's, outlays of considerable sums of money did not buy you many seats or much horsepower. What was working for 2-D CAD is that in so many respects it left untouched the end product. There is still being produced a 2-D drawing based on the same conventions as one produced by hand. This stability in product means that much of what the educator presents in class is unchanged and to the engineering manager, how technical graphics fits into the design process has also been left untouched.

The reasoning process most engineering managers use in making the decision to adopt 2-D CAD is based around money: can the increased productivity of the drafter/designers make up for the capital outlay for the computer systems? In large part, 2-D CAD was sold on its ability to automate time-consuming processes such as the creation of tangent arcs, hatching, and dimensioning. Additionally, the ease in which drawings can be modified and reused is an important factor in purchasing 2-D CAD system. For example, the use of symbol libraries to represent common geometries is substantially more flexible and powerful than templates used in mechanical drawing. Another element that sets 2-D CAD apart from mechanical drafting is the increased precision in which the geometry can be created. A conic curve that might be drafted using a French curve can now be created using the mathematical precision of a Bezier or rational B-spline curve. Even for straight or circular elements, the ability to specify coordinates to eight or more units of precision means the removal of most cumulative error in a drawing.

The increase in accuracy coupled with the automation of time-consuming tasks has had a different impact on the educator than it has on industry. The area it has had the most impact has been in the teaching of the 'art' of technical graphics. As mentioned earlier, the conceptual base of technical graphics is left virtually untouched by 2-D CAD. What has changed, however, is those elements in a course which focus on technique born out of the use of mechanical drafting equipment. For many technical drawing courses, the time needed to teach the mechanics of a CAD program replaces the time spent learning the mechanics of lettering or geometric construction. At the same time, the use of 2-D CAD often introduces a certain fallacy of accuracy of construction that does not exist. While working within a CAD package the numerical accuracy of the package does limit cumulative error, but as long as the final document for communication still consists of a printed or plotted page, many of the limitations of the medium return. Whether produced by hand or by 2-D CAD, direct numeric notation through dimensioning is needed on the document since the level of accuracy of the manufactured part usually surpasses the level of accuracy of representation on the physical page.

Towards the Future

Unlike the move from 2-D drafting to 2-D CAD, the move to 3-D modeling has the potential of radical changes in the way technical graphics is taught in schools and used in industry (Leach & Matthews, 1992). Articles on 3-D modeling have focused on topics such as the integration of 3-D modeling into the design process (c.f. Barr & Juricic, 1992), the relationship of geometry and computational load (c.f. Ault, Barsoum & Qureshi, 1993) and the impact modeling has on the development of 3-D visualization abilities (c.f. Devon, Engel, Foster, Sathianathan & Turner, 1994; Sexton, 1992). Of more interest here is the translation of issues such as design process, model geometry, and visualization into specific techniques for teaching the concepts and capabilities of a 3-D CAD modeling system. By directly comparing how 2-D and 3-D methods are taught, what elements of instruction change and which stay constant can be identified. In this light, issues such as visualization can be brought into a practical, if not theoretical, context for change.

With 3-D modeling one of the most fundamental changes is the movement from a 2-D document to a 3-D geometric database. Instead of one or more views which represent specific projections of a 3-D object, the 3-D object is represented directly as virtual model of the proposed or existing object. The use of a virtual 3-D model alters the methods for both generating the geometry and representing it. To begin with, with a 2-D document, the mode of representation was decided on first (e.g. an orthographic multiview, a perspective pictorial, etc.) and the geometry was then generated to match that representation. With a 3-D model the geometry creation is the initial driving force and representation is then decided on at the tail end. With a 3-D model the process of projection is automated; there is no longer motivation to use an isometric pictorial over any other axonometric projection simply because it is *easier* to draw. With a 3-D modeling system any axonometric projection (or perspective projection) is equally easy to draw, the skill now comes in being able to choose the appropriate projection which clearly communicates the information of interest. This choice of projections can be driven by the geometric features of the object rather than convention or ease of production.

Geometry creation strategies also change when moving from 2-D documentation to 3-D modeling. Whereas 2-D projections are largely created tied to a local coordinate frame on the projection plane, 3-D models are created in a singular global coordinate frame. For 3-D models, local reference frames tied either to image planes or geometric features on the model can be used to assist in model creation. In 2-D documentation, the fact that the geometry being created is of a projection of the object rather than the object itself, puts a tremendous burden on the user to provide error checking for the geometric validity of the drawing. Certainly a major emphasis in a traditional 2-D based course is to correctly interpret a 3-D object as a multiview drawing; you can create an 'impossible' object in a 2-D CAD package and the software will not blink an eye. On the other hand, most 3-D solids modeling software packages have considerable restriction on geometry creation. Not only will solids systems not allow you to make 'impossible' geometry (or crash if you do), but in guaranteeing the integrity of its database, it restricts you from making many geometries which could exist in the real world.

The move of error checking for geometric integrity from the user to the software parallels an instructional shift away from an emphasis on descriptive geometry towards analytic geometry. The user of a 3-D modeling system must be well versed in the types of geometries which can be created directly in the system, what types of geometries can be created indirectly, and what types cannot be created at all. For example, in most constructive solid geometry (CSG) modeling systems, solid primitives can only be constructed from planar and circular curved surfaces (Zeid, 1991). For that reason, if you wanted to create an inclined elliptical face on the end of a cylinder, the system will not let you define an elliptical profile and extrude it through space at an angle. On the other hand, you can create the elliptical face by first drawing a circular profile, creating a cylinder from it, then coming back and using a Boolean operation to slice the cylinder with a planar profile to create the planar, elliptical face. The limit on circularly curved surfaces will mean, however, you would not be able to create an elliptically curved surface.

The use of a 3-D modeling system to create a virtual model means a change in the role of documentation and the use of symbols to notate a design. 3-D modeling systems can be used to develop virtual model databases shared throughout an organization (Garcia, Gocke & Johnson Jr., 1994). Since the 3-D model contains such a robust description of the model — one not tied to a particular projection — the role of documentation changes dramatically. Rather than capturing a particular projection of a model on a 2-D document, a person involved in the design process can query the 3-D model directly; choosing the viewpoint which is most advantageous for depicting the features he is interested in.

In addition, the need to dimension the object, a process traditionally linked to a specific projection, is minimized since the user can query the model directly for dimensional information and/or translate it directly into manufacturing instructions. When information such as tolerancing or material requirements need to be attached to the model, it can be done by associating the information to a specific feature in the database; it will then be up to the individual viewer of the model whether this information is displayed. By removing the need to go to paper documentation, the inherent loss of accuracy on such media is removed; where the lack of accuracy of the paper document necessitates the need to show dimensions, the 3-D electronic model can be queried directly for highly accurate dimensional information.

Finally, the use of virtual models in manufacturing and construction has meant shifts in the role of technical graphics in the design process (Bertoline et al., 1995; NRC, 1991; McMahon & Brown, 1993). Instead of being largely restricted to documenting a finished design for manufacture, 3-D models can be created early in the conceptual phases of the design process. The current generation of solids modeling tools such as ProEngineer™, Unigraphics™, and IDEAS™ not only have parametric tools which ease the ability to alter the geometric characteristics of the design as it evolves, but they also have links to powerful database tools to coordinate the design and manufacturing activities which make use of this virtual model. Parametrics are a natural addition to a technical/engineering graphics course (c.f. Howell, 1994) and there is likely to be considerable interest among graphics educators as to how these tools fit into a modeling course. There is a need, however, to look at the larger organizational impact of modeling in industry and rethink the context we place graphics in as we teach our students.

Conclusion

As the evolution of CAD continues, with packages becoming more sophisticated along with more powerful hardware to run them on, the transition from descriptive towards analytic geometry will only increase. As we progress along this path, it will surely be argued the "art" of graphics is slowing being lost. Ultimately, this may indeed be the case. There is, however, also something to be gained from this transition. Just as with many other professions, there will be a shift from "art" to "science". Regardless of what happens and how fast, the practical applications for graphics will continue to increase. The ultimate outcome of this evolution will depend, to a large extent, on how we, as a profession embrace this change. If we can successfully adapt and integrate these changes into our curricula our future and our profession will be the better for it.

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