Scientific Visualization: An Experimental Introductory Graphics Course for Science and Engineering Students

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A new course, 'Scientific Visualization', has been offered by the Graphic Communications Program at North Carolina State University. The purpose of the course was to expose undergraduates to the use of computer based graphics as both a problem-solving and communicative tool in engineering, the sciences and other technical areas. Rather than focus on the more traditional areas of engineering graphics, this course explored a much broader role of graphics in science and technology. A single section of the course is offered to 14 students in a lab equipped with 7 Macintosh II computers and a broad range of graphics software packages. The course consisted of lecture, demonstrations, field trips and both in-class and out-of-class lab work on the computers. In addition, there were readings in current applications of graphics in various scientific and technical fields. Recommendations are given to the future direction of this course and its role in the engineering design graphics curriculum.

Wiebe, E. N. (1992). Scientific Visualization: A New Course Concept for Engineering Graphics. Engineering Design Graphics Journal, 56, (1), pp39-44.

INTRODUCTION

Motivation for the class

Beginning in the Spring 1990 semester, the Graphic Communications Program at NC State University chose to engage in an exploration of the future direction of technical graphics in higher education. Rather than simply focusing on the instructional nuances of teaching Computer Aided Design and Drafting (CAD/D), current thought on the role of graphics in science and technology was explored. The experimental class, 'Scientific Visualization', was a vehicle for exploring a new paradigm for an introductory course in technical graphics. The goal was to develop a course in which students in varied technical and scientific disciplines would be exposed to a broad range of graphics-based tools and to develop visualization skills — both important to their future success in their professions (Bertoline, 1989; Cunningham, 1990).

The engineering professions have followed the Information Age in a movement away from the tangible and towards the conceptual and theoretical. In this way, these professions have moved closer to the hard sciences in their approach to research and professional practice. Arriving as part of the Information Age in the late 20th century was the advent of affordable computer technology capable of producing extremely sophisticated graphics. This technology allows those in the sciences, engineering and related technical fields to produce images that lend a new way of evaluating theoretical problems. The same technology also creates virtual objects on the computer that conceptualizes what might some day be tangible (Grady, 1989). The popular title that has been given to this trend is the same as the one used for this course: 'Scientific Visualization'.

The research community has actively embraced the tenets of the current movement in scientific visualization. It is not that the techniques lumped under the umbrella of scientific visualization all of a sudden appeared out of nowhere but, rather, the new generation of computing technology - from supercomputers to microcomputers - forced us to completely rethink the possible role that graphics can play in the scientific and technical communities. The revolution is prominent enough for the National Science Foundation to sponsor a major study titled "Visualization and Scientific Computing" (McCormick et al, 1987). Though rethinking of the role of technical graphics is happening at the research level, it must also happen at other levels of education as well. The course, 'Scientific Visualization', looks at how this new brand of visualization can be integrated into a survey course for undergraduate engineering and science majors.

Visualization as a Central Focus

No amount of sophisticated computer graphics tools can make up for a lack of visualization experience and ability. To some degree, the operator needs the ablility to mentally predetermine what the graphics are going to look like before giving the computer its instructions. These "look ahead" abilities greatly enhance the efficiency of manipulations on the computer and are analogous to viewing in the mind's eye an object before it is drawn (Wiley, 1989).

Visualization also plays a role in the ability to analyze and synthesize displayed graphics for problem solving. One of the prime motivating factors for integrating graphics into scientific and technical fields is the ever-growing volume and complexity of information needing analysis. Computers are a prime cause of the information glut but also offers a solution through graphic imaging. When a researcher generates large quantities of data, they cannot afford to narrowly and deeply analyze every bit of it. An alternative is analyzing the information at a grosser, more holistic level; looking for overall trends rather than localized events. This alternate view of the information is often referred to as right brain thinking and graphics are the primary vehicle for processing information in this mode (Sadowski, 1989). Once a promising tack of inquiry is identified using holistic mehods, other more focused tools — some graphical, some not — are used to further explore the problem. What is important is applying both the narrow, focused techniques and broad, holistic techniques to successfully work through the problem (Tovey, 1986). Whereas graphics may very well be useful for the focused work, they are critical for right-brained techniques.

Visualization becomes a subset of the larger concept of right-brain thinking and this style of thinking needs reinforcement in science and engineering students. These students have plenty of practice in working through math and chemistry problems using linear, left-brain thinking with numbers and words as tools. Very few, though, use graphic tools and right brain thinking to work through the very same problems. Enhancing this holistic-synthetic style of thinking with graphics-based tools was the central focus of the 'Scientific Visualization' course.

Current computer technology allows numerous methods for viewing graphic information. These methods are categorized into two sets of complementary methods: static-dynamic and sequential-presentational (Nishmura, 1985). Computers can recreate the information viewing styles of print/paper mediums (static/sequential and static/presentational) and those offered to us by film and video (dynamic/sequential). Even more exciting is the way the computer can extend information display into the fourth possible combination: dynamic/presentational. With this last method, the user interactively views graphic information in a non-linear fashion at real or near real time. Combined or individually, these viewing techniques offer the user a high degree of flexibility in visualizing and solving the problem at hand. Exposing the students to these different viewing techniques also has the reciprocal benefit of offering students an environment shown to enhance their developing visualization skills (Wiley, 1990).

Course Strategy

Certainly one of the challenges in developing the course was to find ways to engage the students with relevant course content. Real world examples from a broad cross section of science and engineering disciplines were reduced in scope and packaged into classroom assignments. These assignments then were reinforced with videotapes, trade journal articles, field trips, etc.; re-expanding them back to their true proportions. It is not enough just to have a technologically up-to-date "vehicle" for the curriculum, the course content itself must also reflect the changes in approach to problems occurring in industry and research.

Engineering design graphics demands the use of many tools to generate graphics. Changes in technology have not altered this fact. In a traditional survey course in engineering graphics, students employ a number of mechanical drafting tools to solve problems. The 'Scientific Visualization' course also centers around the use of tools to solve problems; the difference being the tools used and the problems solved. It was impressed upon the students that most software packages are not a single tool but, rather, a collection of tools. Each one of these individual tools inside of the software package is evaluated on its own merits. To solve a problem, a whole group of tools are used and these tools may or may not all reside in the same software package.

There are, of course, practical limits to this tools-based approach and these limits often center around the exchange of graphic information between software packages. This is an area where the Macintosh computer possesses advantage over most other platforms. Apple, Inc. has not only demanded a high degree of consistency in the user interface between software packages, but also in the graphic data format used. The consistent user interface makes learning new software packages and accessing new tools easy and the data format consistency makes exchange of graphic information between packages easy too. As the semester progresses and new software packages are learned, the students are encouraged to go back and use tools contained in earlier software packages whenever appropriate. Though the focus of the class moves from one piece of software to another, just as in the more traditional drafting courses, the students are expected to draw upon the full repertoire of tools they have learned.

COURSE ORGANIZATION

Classroom Setup

The classroom where 'Scientific Visualization' was taught consisted of 7 Apple Macintosh II computers equipped with 2 Mb of RAM, 40Mb hard disk drives and Apple 13" high resolution color monitors. One of the computers was stationed at the front of the class with a LCD overhead projection screen attached for use by the instructor. The instructor's station was also equipped with a Apple CD-ROM player and was networked to the other 6 student stations via an AppleTalk network and TOPS networking software. The class met twice a week for 1 hour, 50 minutes. Approximately 50 minutes of each class was lecture with the rest of class time devoted to answering assignment problems and hands-on computer demonstrations. In addition to the classroom time, the students were required to sign up for at least one two-hour lab session per week.

Course Content

The course was divided into roughly eight segments with concepts from many of the segments overlapping one another. Following is a sampling of some of the segments covered in the course.

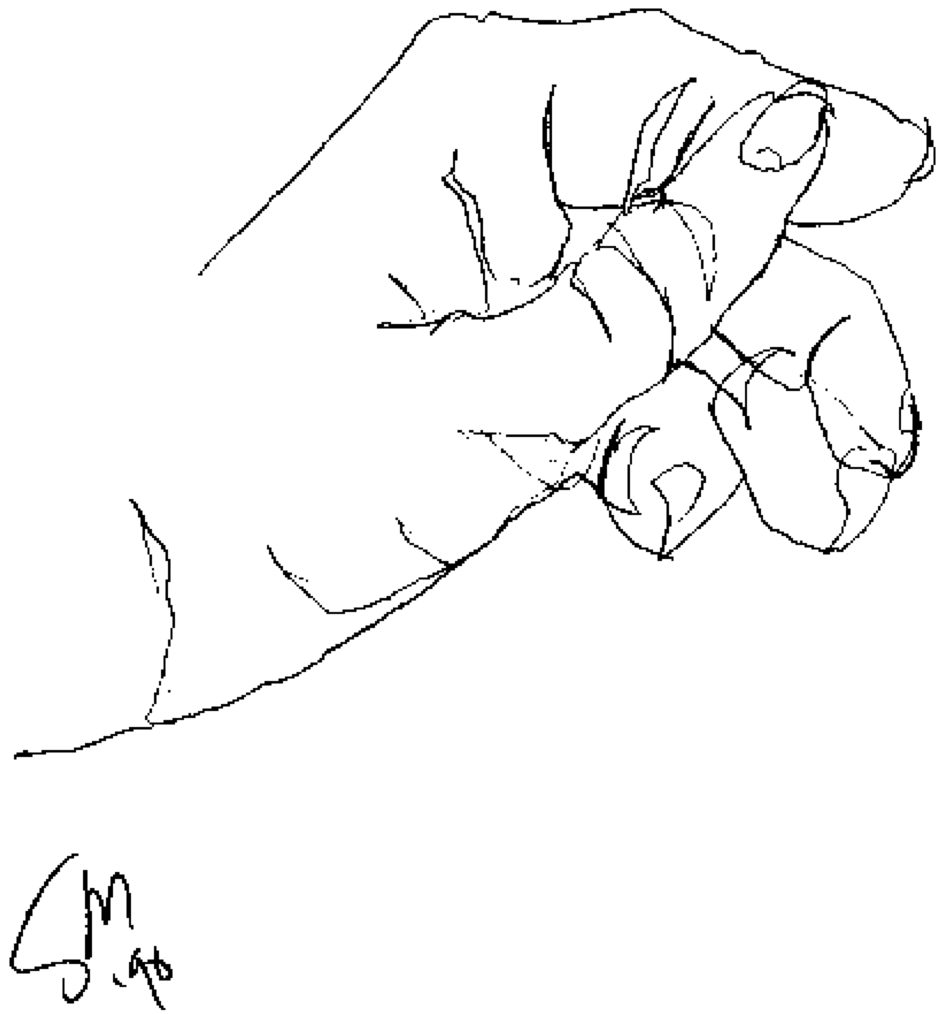

Figure 1.

Right Brain Exercises / Macintosh Introduction

The course started out with a series of exercises adapted from Drawing on the Right Side of the Brain (Edwards, 1989) and designed to make students aware of right brain modes of thought. In first week, students worked strictly on hand sketching exercises for homework (Fig. 1) with their lab time spent orienting themselves to basic Macintosh operation. The MacPaint software package was introduced during the second week of class to complement the hand sketching exercises. As an archetypal Macintosh graphics package, it introduced students to the design and layout of other graphics packages used in the course. By adapting some of Edward's visualization exercises to be done in MacPaint, students continued their work with visualization while learning about computer graphics tools. After MacPaint, MacDraw II was introduced to the class with the third week's assignment being to design a personal weekly class schedule with the package. It was during this week differences were drawn between two basic kinds of graphic data structures:

bit-map (as represented by MacPaint) and object-oriented (as represented by MacDraw).

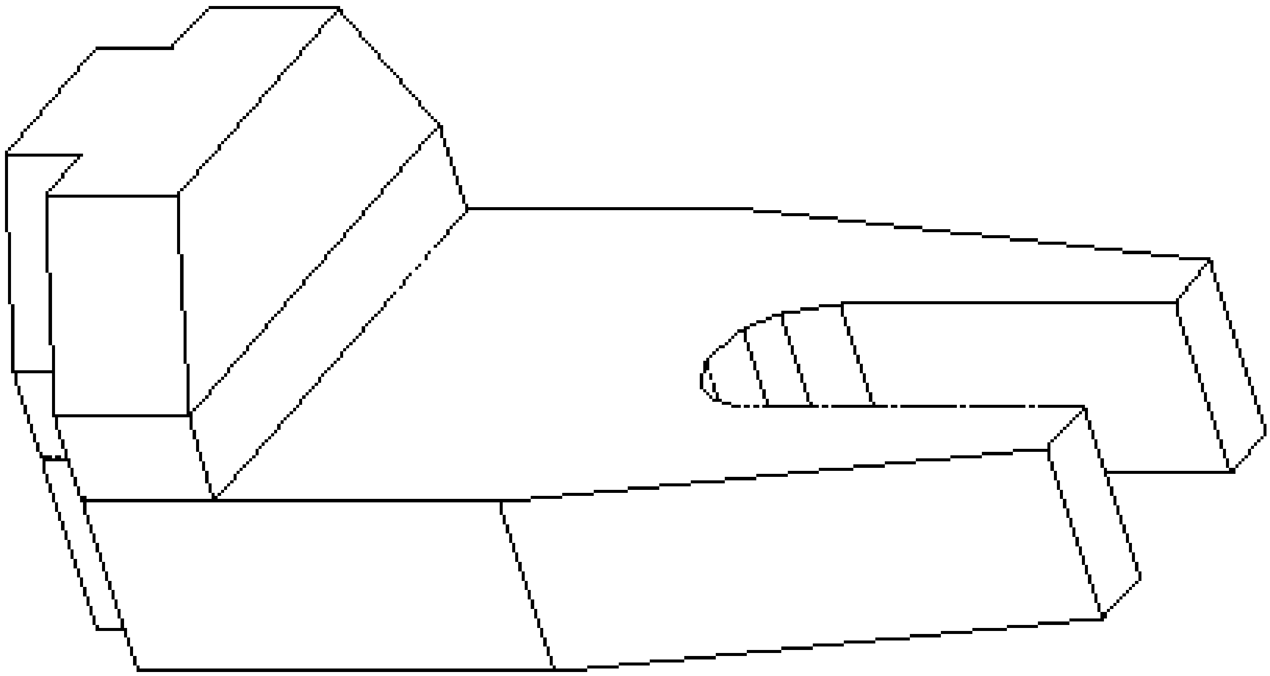

Figure 2.

3D Visualization

After the initial exercises in visualization, the class moved into visualizing and manipulating virtual 3D objects. This was done using a 3D "sketching" software package, Swivel 3D. Rather than begin with generating 3D forms, the first week using this software package was spent viewing and manipulating an existing 3D form (Fig. 2). During the second week of this segment, the students began to make their own virtual objects in Swivel 3D. The students were introduced to the basic concepts of generating forms and then asked to design an object synthesized from at least 6 3D forms.

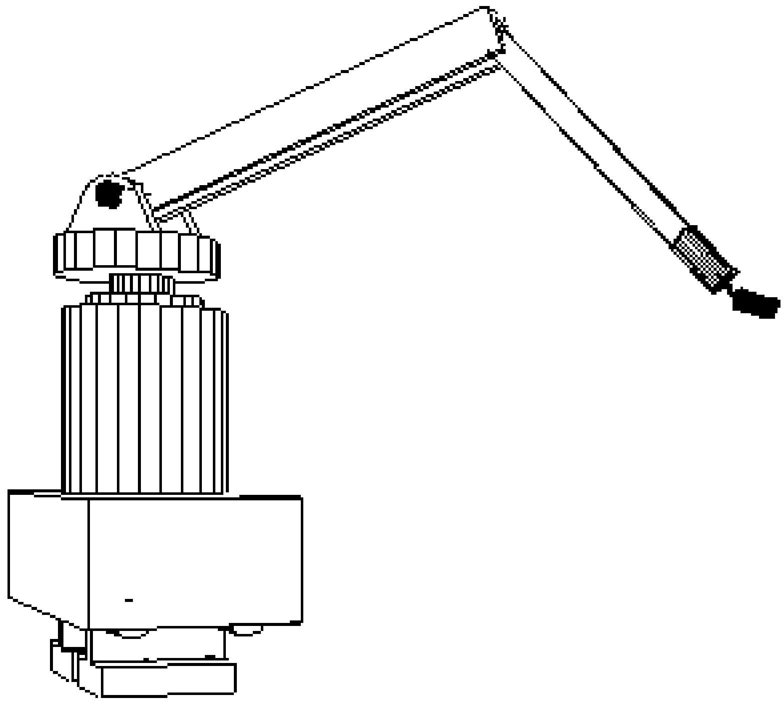

Figure 3.

Robot Arm Project

The organization of object primitives into a hierarchical tree in Swivel 3D allowed for additional instructions as to how segments of the tree were "joined"; tree segments could be locked so there was no relative movement at all or allow constrained linear or rotational movement. The skills of viewing and generating objects were brought together with these articulation techniques in a two week project designing a robot arm (Fig. 3). After an initial brainstorming session where the basic specifications for the robot arm were developed, the arm was broken down into six logical components and a 2 or 3-student team assigned to each component.

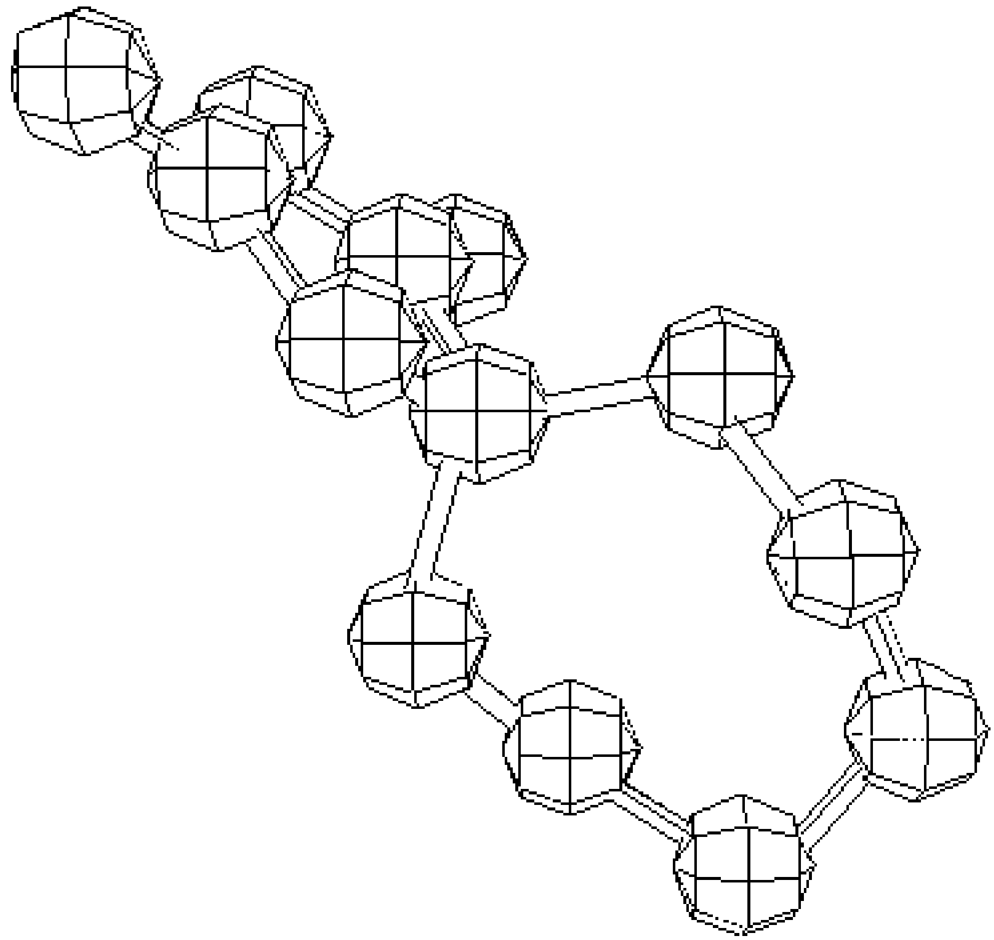

Figure 4.

Molecular Modeling

Though still concerned with 3D modeling, this segment on molecular modeling took the class from human scale objects to micro scale ones. There was also a shift from working with a relative coordinate system to an absolute one. Given an edited copy of X-ray crystalography data of a molecule, the assignment was to construct a "ball and stick" model of the molecule using the given Cartesian coordinate and connectivity information (Fig. 4). The students not only had to locate each atom at its precise location, but also label it with an appropriate name for later identification. Because the students had no initial picture of what the molecule looked like, they had to rely soley on their transformation of numerical data and topological information into a graphic model. The second week of this segment extended this concept by again taking edited crystalographic data and constructing a unit crystal cell from the previously constructed molecule.

Medical Imaging

This segment of the course marked the move away from 3D to 2D graphics and from object-oriented data formats to pixel-based ones. The software used for this portion of the class was a free software package distributed by the National Institutes of Health (NIH) called Image. Image was designed to edit and process color and grey scale images, extract measured data and display the resulting images. The first assignment of this segment was to generate and notate density line plots of images of electrophorises gels (used commonly in the biological sciences). The purpose was to explore the translation of pixel-based images into graphs and finally into numeric information. The next assignment worked with a electron microscope image of rat lung. Students were to measure and visually highlight red blood cells and capillaries by identifying and manipulating the grey-scale density values of these elements in the image.

Other In-Class Curriculum Materials and Field Trips

In addition to completing the weekly lab assignments, the students were periodically required to read trade journal articles and a textbook (Friedhoff, 1989) on closed reserve in the library. This gave them an in-depth exposure to some industrial and research applications of graphic techniques discussed in class. Because the articles were coming from trade journals rather than research journals, the writing style and content was relatively accessible to the students. Field trips were another way that the students were able to get exposure to actual graphical applications. These field trips were taken to both research labs on campus and to private companies.

CONCLUSIONS

Being a course that not only used computer software, but many different ones, very much influenced the development of the course (Table 1). As was mentioned above, the sheer number of software packages being introduced to students over a 15 week period demanded a highly consistent user interface that lent itself to a soft learning curve. The Macintosh platform was the only computer platform available that could provide this and, even still, software had to be chosen carefully in order to make sure that it adhered to Apple's interface guidelines. This consistency between software packages had many advantages. For instance, with each succeeding software package introduced, the class as a whole was able to quickly assess the types and quality of the graphic tools available and integrate them into a repertoire of existing tools.

Software	Application
MacPaint	2D pixel-based drawing
MacDraw II	2D object-oriented drawing
Swivel 3D	3D sketch modeler
NIH Image	2D pixel-based image processing
Theorist	Symbolic math
The Game of Fractals	Fractal image generation
MacroMind Director	Animation

Table 1.

The development of graphical user interface standards such as Motif on UNIX workstations and Windows on PC's raises hopes that added pressure will be brought to bear on software developers to work on more intuitive, consistent front ends to their software packages. There is the added benefit that these new user interface standards also include some level of support for inter-application communications; encouraging a more "tool"-based approach to software usage.

One of the primary goals of this course was to improve visualization abilities; to be able to mentally perceive and manipulate 2D and 3D forms and patterns. It is hoped that improvement of these abilities would in turn lead to the tendency of using more holistic, right-brained techniques in problem solving. In the subjective judgement of the author, there was considerable improvement in the visualization ability of the students over the course of the semester.

What portion of 'Scientific Visualization' belongs in a survey course really depends on how the educational mission of engineering design graphics is defined. If the survey course should only include graphics that impact on the mainstream engineering profession and even more narrowly on mechanical and civil engineering, then there are certainly many portions of the 'Scientific Visualization' course that are not relevant. Even with this more narrow focus though, the first 7 weeks of the course has the potential of being integrated into the more traditional survey course or developed into a course of its own. This new class would focus on right brain thinking and 3D visualization. This focus would also reduce the number of software packages to 2 to 3 from 7 covered during the 15 weeks.

For all of the material covered, there is still other material worth examining. As an example, by the fourth week of the course, the students were applying color to their work, yet there was virtually no discussion in class on the use of color. Another element of the course that deserves further exploration is that of the role of animation in visualization. The subject of animation appeared regularly in the lecture component of the class. The students began to explore it in labs beginning with the robot arm project and then again in their final projects. Animation in the context of this course cannot easily be relegated to an isolated segment of the course. As with the issue of color, the value of animation as both a vehicle for improving visualization skills and a problem-solving technique needs to be evaluated against the time constraints in the course.

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