Frank, A. U. "Computer Education for Surveying Engineers." *The Canadian Surveyor* 39, no. 4 (1985): 323-31.

Computer Education for Surveying Engineers

ANDREW U. FRANK
Surveying Program
Dept. of Civil Engineering
University of Maine at Orono
Orono, Maine

This paper starts with a discussion of the likely technical changes in computers during the next twenty years, and how these are expected to influence the surveying profession. It then goes on to define the surveyor's role in the future and what education and skills will be needed.

Detailed goals for computer education in understanding of hardware, programming and software engineering, numerical problems, computer graphics and office automation must follow from the expected need by the profession. The surveying curriculum at University of Maine includes two introductory courses which treat the above topics, but depends on the integration of computer usage in other courses (plane surveying, geodesy, etc.) to give students the necessary experience.

Using modern equipment (Apple Macintosh, Digital Equipment MicroVAX), we can reduce the amount of machine-specific detail a student has to master and concentrate on the principles, which remain valid and will be applicable to other hardware as well.

L'article débute par une discussion portant sur l'évolution technologique des ordinateurs au cours des deux prochaines décennies et de l'effet de cette transformation sur la profession de l'arpentage. Par la suite, le rôle de l'arpenteur est définie par rapport à cette progression et on tente d'établir quels seront les changements à apporter à l'éducation de façon à développer les aptitudes nécessaires pour répondre adéquatement à cette évolution technologique.

Des objectifs clairs et précis devront être formulés afin de permettre une meilleure compréhension du matériel, de la programmation et du logiciel d'ingéniérie, de l'analyse numérique, des graphiques tracés par ordinateur et de la bureautique pour répondre aux attentes et aux besoins de la profession. Parmis les nombreux cours offerts en vue de l'obtention d'un brevet en arpentage à l'université du Maine, deux de ceux-ci offrent aux étudiants une introduction à l'informatique, mais l'expérience nécessaire dans le domaine sera acquise lorsque les étudiants entreprendront tous les différents cours, tels arpentage planimétrique, géodésie, etc.

En utilisant de l'équipement spécialisé tel Apple Macintosh, Digital Equipment Micro-VAX, nous pouvons réduire la quantité d'information technique que l'étudiant doit assimiler et concentrer ses efforts sur les principes fondamentaux de l'informatique lesquels seront toujours valides et applicables lors de l'utilisation de d'autres systèmes.

Introduction

Asking what we should teach our students is, in fact, asking what we expect our students to do during their professional lives. Students in surveying engineering who graduate this year will work for approximately thirty to forty years in their professional fields. It would be shortsighted to orient our curriculum to the present professional practice, and not take into account likely changes in technology which will induce corresponding changes in the profession. Forty years is a very long time span to predict what the technical environment will be and what skills surveying will require. Consider for a moment a surveying engineer working in the 1940s and his tools: tables and mechanical calculators for computations, chains or rods for distance measuring. Changes in the last forty years have occurred within the profession to a large extent through the availability of electronic computers, which have not only facilitated the surveyor's computing, but have influenced his work in a more comprehensive way. Many of the devices he operates today include some small computers, which make the instruments easier and simpler to use. Both the electronic distance measurement instruments and the systems to determine global positions are made possible by electronics. All this new equipment made many of the difficult problems encountered by surveyors in the past relatively easy to solve.

In observing computer science and the computer industry we see no indication that the fast pace with which new developments appeared recently will slow down in the near future. The physical boundaries that will ultimately limit the growth of computers are still several orders of magnitude away and we must expect that new computers with far improved performance will continue to be introduced to the market. Users should be aware that new computers will not only be much more powerful for the same price, but that improved machines will make it possible to tackle more complex problems. The development we must expect is not a 'more of the same kind' future, but the increased power will qualitatively change the services computers are rendering. Not only does this cause financial and managerial problems for the users buying new machines, but will in the long run substantially influence the practice of surveyors.

To determine what we should teach surveying engineers today, we need some expectations of what techniques will be used by surveyors in the future and what professional services surveyors will deliver. This should help us to discover what skills surveying engineers will need and enable us to appropriately educate students today. Obviously, such a perspective view can only show us the general trends and is not expected to provide details. The immediate future is influenced by available hardware, software or experience and by marketing decisions difficult to forecast.

This paper discusses specific knowledge and skills surveying students should acquire and explains how we used those considerations to design the computer education component of the surveying engineering curriculum at the University of Maine at Orono. The paper concludes with some information about practical solutions.

Technical Changes Most Likely to Occur in the Next Twenty to Forty Years

It is fair to assume that computers will become more powerful and relatively cheaper than today — as a general rule, users should expect to pay about the same amount they do today, but receive highly improved services. Computers will be used not only for computations but increasingly for storage and organization of data as necessary in the surveyor's job, and to help produce graphic output (maps and drawings) automatically. In many cases results of the surveyor's work will be transferred directly to the client's computer without human intervention. Most instruments used for measuring will contain some smaller computers with their own programs and storage and reduce the complexity of measuring considerably—I expect that the use of traditional surveying instruments (theodolites, transits, distance measuring instruments and levels) will become so simple that most laymen will be able to operate them and produce acceptable results for most standard tasks (e.g., traverses).

Satellite based global positioning systems will be available which produce positions for a point in a comparably short time span without any complications.

Photogrammetric equipment will be available that will facilitate the work of the operators considerably. Correlation between the two plates will be mostly automatic and instruments will be able to follow distinct features in a photograph at least in a half-automatic mode.

What Will the Surveyor's Role Be in the Future?

Considering the probable changes in the technology surveyors use today, it becomes apparent that many of the tasks we consider typical for surveyors today will be simplified to an extent that nearly anyone will be able to carry them out. Thus we have to ask ourselves in a more profound manner what is typical for a surveyor, and what do surveyors excel in? In a personal view I see two topics:

- Measuring: Surveyors can determine position and extension of objects in space with arbitrary precision (provided the client has enough money). As stated above, surveyors will lose the market for simple, direct measurement; however, only surveyors can design measuring methods using complex arrangements to take into account inherent errors and yield results of higher precision and reliability than conventionally possible. I believe that there will always be a market for higher precision measuring that will be easy to achieve with future technology; the market may move more towards industry, shipyards, etc.
- Data collection and presentation for land management decisions: Surveyors are traditionally concerned with information regarding land and its management. They are trained to determine the legal boundaries of land property and their services are often retained to determine and collect data about other properties of land (e.g. wet land boundaries, flood plains, wood stands). Even as techniques to collect the data become more accessible to non-surveyors, surveyors will remain in business if they offer an overall service providing the client with the information he needs for his decision in the form most appropriate for him. This requires that the surveyor understands the client's needs, has access to efficient data processing facilities, and understands how to present data in a form that makes it easy for the client to extract the information necessary for his decision.

Surveyors and cartographers have traditionally been involved with data collection, storage and rendering without being really conscious that this constitutes one of the central parts of their profession. I assume they can become land information specialists who integrate their surveying services with services from other professions into a comprehensive package of information useful in the decision process of the client.

What Computer Knowledge and Skills are Necessary?

Surveyors in the future will undoubtedly interact more often with computers — this general statement is true for nearly any profession today. They need the skills to use computers effectively to achieve their professional goals and produce the results the clients desire. Moreover, we assume that surveying engineers educated through a four-year program will be professional leaders and thus more involved with planning operations, instructing others how to use the tools for execution of these plans and overseeing activities of others rather than measuring themselves. Surveyors must be in a position to knowledgeably select the hardware and software they need for their office, and discover how they can use it to best advantage. They must be capable of advising their clients on the most appropriate and most economical manner to fulfill their information needs. Both these requirements demand that surveyors have a principal understanding of how computers work and process data. The stress must be on 'principles' because only those will remain similar over an extended period of time — the details of one specific computer hardware system or programming language is changing too fast to be of any help over periods longer than a few years (consider the changes in FORTRAN or in Hewlett-Packard desk-top computers often seen in surveyors' offices). Some of the surveyors should have an extended knowledge in order to help build the programs and systems other surveyors will use. Computers will be used to do tasks too complex for each surveyor to program himself. Programming modern comprehensive systems is a complex task, reserved for specialists who master the necessary tools. However, experience in the last years has shown that writing good application programs should be done by professionals of the application area (e.g., surveyors) who have extended programming knowledge. Programs written by computer scientists often lack the fine touch and the handy abbreviations that make the difference to a program useful in practical applications. The profession therefore needs a small number of educated surveyors with substantial experience in computer programming who will build the application programs for the surveying area.

Computer Education for Surveying Engineering Students

Obviously, we want the students to learn the principles of computer operations in order to understand how they later can use them in their profession. Unfortunately we cannot teach these principles independently of and without the help of practical examples, using today's hardware and software. The critical point is to have students recognize the practical vehicle we use to show them the principle, and have them concentrate on the principles. The following list indicates single topics that should be treated together, with indications as to why they are of interest to surveyors.

Electronics

With the exception of very few surveyors working for the instrument building industry, surveyors do not need elaborate knowledge of the electronics used in computers. The introduction of transistors in the physics course seems sufficient.

Computer Hardware

Surveyors should have a knowledge of the different hardware parts that form a computer system. They should understand the physical principles involved, the performance characteristics of the devices and how they relate to other devices. It seems necessary today to introduce students to at least the hardware of a personal computer and a smaller mainframe system. Students must have access to sales literature and the more consumer-oriented computer magazines.

Programming

It should not automatically be assumed that our students have to learn programming. After all, we assume that most of them will not program their own computers in their professional careers. Nevertheless, we advocate teaching more than the basics of a programming language.

- It seems impossible to teach the abstract principles without asking the students to work on practical assignments; however, a programming language (and the corrresponding software) is necessary for most practical work with computers.
- Only by learning how to master a programming language, can the student gain a feeling for the power and the limitations of computers. It is necessary to experience the required detail of specification of a successfully executed algorithm to see how much computers lack the common sense of the professional and an understanding of the circumstances typical for human beings.
- Using a structured programming language and having the compiler strictly enforce formal detail might help students to improve their skills in writing technical reports. We generally see, both in programs as well as in reports, a lack of structure (no subtitles, little logical connection between paragraphs, etc.) and often there is insufficient attention to detail. A programming course might help the student to learn to concentrate on those issues.
- Students need programming skills for working on problems in other courses. To achieve this we have found it very important to assure that the curriculum includes at least one course per semester that contains some heavy computer use to keep skills current. A one-semester introductory course in sophomore year does not help in the least for a course in senior year that uses the computer. If students are not forced to use the computer in the meantime, they will have forgotten most of what they have learned and the regular changes in the operating system will be sufficient to cause major confusion.

The language to be taught should be selected for clarity and ease of teaching. It should contain all constructions currently found in programming languages. The main reason for selecting a particular language is not its predominant use in the practical world, but its teaching value. First it is difficult to reliably predict what language or languages (and also which dialects) students will use in practice. Second, having learned a well structured language it has proven fairly easy to acquire a second or third language. Languages well suited as the first teaching language are Pascal or Modula-2. Pascal has been intentionally designed as a tool for teaching and is a very small, orthogonal collection of basic constructions. Neither BASIC nor FORTRAN are suitable, as they do not help the student to avoid errors; do not commonly lead to structured programming and lack some of the more advanced constructions (e.g., pointers and dynamic data structures). Moreover, they lead to the use of unsafe programming techniques, exemplified by the use of 'goto' and 'common blocks'. To prepare students for the 'practical world', a few weeks should be spent explaining the differences between Pascal and FORTRAN and the students should program a few example programs. We observe that students easily transfer the skills they have learned with Pascal to FORTRAN and become fairly proficient in an extremely short time.

Programming in the Large

The simple skills to write short and easy programs should not be confused with the building of complex software packages as they are used by engineers (e.g. adjustment packages, finite element packages or computer assisted drafting programs). Designing large systems is an engineering discipline — commonly labeled 'software engineering' — and should not be attempted by the uninformed. Organizing systems with hundreds of thousands of lines of code requires methods and tools, otherwise a disaster results: programs that do not reliably work because of programming bugs, programs that are difficult to use because of inconsistencies in their interfaces, etc. (in short ... the present state of affairs).

For many surveying engineering students it will only be necessary to understand the basic problems of organizing large systems and design their specifications from the outside in — not very different from organizing large hardware engineering systems. They need sufficient knowledge about 'human interfaces' to be able to judge a prospective program for ease of use and to know what to expect from the user documentation delivered with a program. However, a number of students should receive sufficient training to become software designers for surveying software.

Numerical Problems

Computations on today's computers are mostly done using fast operations with limited precision (floating point operations). This creates a number of problems that are mathematically very difficult to solve and reasonably easy to treat in an approximative manner (e.g. integration or solving non-linear equations). On the other hand, limitations in the methods need some attention for special cases — there are no methods known that are optimal in all situations. Engineers in general must be aware of the limitations so they may detect problems in the results of programs they use.

Computer Graphics and Computer Aided Design

Surveying students should learn about computer graphics and how programs can be used to generate graphical output. They should probably understand the basic methods used in Computer Aided Design (CAD) programs. It would be desirable that they have some practical experience with CAD systems to appreciate their impact on the profession.

Computers for General Office Automation

Surveying engineering students can use computers for the more mundane tasks of report writing, cost estimating and project planning, using the same software other professionals use. Word processing software, especially if formulas and graphics can easily be inserted in the text are a must for preparing technical reports, and there is great promise in the use of 'spreadsheet like' software for many engineering calculations. Surveyors who intend to work in private practice should be familiar with such software packages.

Computer Education and the Curriculum

The above description of many very desirable, if not indispensable skills and parcels of knowledge for a surveying engineer seems to ask for a large number of computer oriented courses. How can this be accommodated in our already overloaded curriculum?

We do not believe that many more computer courses are necessary, or desirable. Surveying engineers should not become computer science students, but acquire a very special knowledge, that enables them to do their work. At the University of Maine at Orono we have included most of the topics listed above into the curriculum in the following sequence:

Introductory Course

During sophomore year, students take a two-semester course, "Computer Usage for Civil Engineers" (and surveyors) [*Frank* 1985]. This course covers the introduction to computer hardware and programming using Pascal in its first part. Students are asked to write a large number of small programs which are somewhat connected to engineering. From the very beginning, good programming style is stressed and the breakdown of larger tasks into smaller procedures and functions is required. As much as possible, programs written for one assignment are reused in a following assignment. Students build a library of routines for matrix operations as a practical example of the 'tool-box' concept in programming.

The course also introduces principles of computer graphics and the students write some programs that produce graphical output on a screen.

This first course also includes an overview and some practical experience with text and graphics editors, spreadsheet software etc. as they are typically found on a personal computer and very useful for students to prepare reports etc. in many courses.

In the second semester the course then concentrates on numerical methods. It extensively covers approximation methods in general. Students use many different methods to find the approximations to the roots of a non-linear equation. We then show methods for solving systems of linear equations with and without computing the inverse. Finally, methods to compute numerical solutions to differential equations, especially of second order, are discussed.

The last weeks of the course are used to introduce FORTRAN and students are required to write several programs to familiarize themselves with that programming language.

In the first semester the Apple Macintosh personal computer is used and in the second semester the University mainframe (IBM 370 under VM/CMS) is also used, to cover both small and large computers. We recommend that sophomores buy their own Macintosh, but we provide sufficient machines for students who do not have their own to complete all assignments.

The overall goal of this course is an engineering oriented basic computer education. It is taught by the engineering faculty, rather than by the computer science faculty in order to be able to select examples from the engineering realm and to motivate students. The course must not only provide the surveyors with the necessary understanding, but they must also acquire sufficient programming skills to be used in the following courses.

Computing in Surveying Courses

Surveying students then go on and take adjustment, photogrammetry and geodesy courses where they need their programming skills to write small programs and use prepared libraries of routines to solve typical numerical geodetic and adjustment problems [*Leick* 1984]. Students are free to use whatever computer and programming language they deem adequate for the problem. Often they select the FORTRAN language as the existing libraries are prepared in this language. However, new Pascal libraries are being created to solve common problems written by students. The most advanced group uses a fifth generation language — Prolog [*Clocksin and Mellish* 1981] as an interactive environment to combine common numerical methods with computer graphics.

Land Information Systems Courses

Surveying students also take two undergraduate courses in land information systems where information structuring and database management are extensively discussed.

The first course discusses information and data. It introduces a theoretical framework for information systems and then concentrates on database management systems. Assignments in these courses include the design of a database schema for part of a parcel database. Students also program the necessary procedures to store and retrieve data, for example, parcel database. These programs use a complex, large database program, of which the design is explained to the students in detail. The students' programs must fit into this system and they learn practically how to design very large software systems.

The second course concentrates on the programs necessary to retrieve data stored in an information system and present them in graphical form as maps. Students learn about different graphics devices on the market and discover their capabilities (with regard to computer mapping); and see how graphics programs have to be separated into device-dependent and device-independent parts. They are shown the architecture of a computer graphics system specially designed for cartography and write some programs to extend this system.

Graduate Courses in Computer Cartography

Every semester we offer a graduate course in computer cartography which is attended by graduate (and some advanced undergraduate) students who wish to improve their understanding of computerized land information systems. The course follows a seminar format and each semester we choose a different topic for concentration, alternating between data storage and modeling on one hand and data presentation and graphics on the other. In these seminars students are expected to design and implement significant new programs, but the emphasis lies more on the theoretical background (mainly logic and mathematics) and the implementation does not pose any significant problems to those students.

Experience

Computer education in the surveying program at University of Maine is not a still picture as the above description might make one believe. We have progressed from a situation where solution of numerical methods using FORTRAN was predominant, are passing the present Pascal and database oriented phase, and moving towards increased application of artificial intelligence methods. These changes reflect the fast change in the field of computer science today, and most of our present students are familiar with more than one of these methods.

We have tried to reduce the amount of detail students have to learn in order to have more time for principles. Students are first learning with the extremely simple Apple Macintosh personal computer and later learn to use one mainframe operating system (presently VM/CMS from IBM, soon to be replaced by VMS from Digital Equipment Corp.), and we provide them with command procedures for all non-trivial tasks.

We believe that our students eventually master the usage of computers to a level where they can use them productively to solve other problems; the computer itself is not the problem anymore. Using computer programs in many other courses contributes to this goal, but using the computer contributes equally to the educational goals of those courses. Programming an adjustment or a photogrammetric problem helps the student 'understand' the problem to a higher degree than just discussing the relevant formulas in class.

There are, of course, a number of problems due to limited resources, e.g., the number of terminals, and the number of faculty and teaching assistants. We work towards improving this situation.

Conclusions

Designing computer education for surveying engineering students requires us to discuss what the essentials of the surveying engineering profession are. No accurate prevision of the future is possible and we cannot know exactly what knowledge and skills our students will need during their active professional lives. It is more important to teach them the principles that are not likely to change rapidly, and therewith enable them to learn and adapt, as they experience the changes in technology. In fact the rapid change in computer science is reflected in our own curriculum: teaching Pascal as a first language does not exclude the use of the traditional FORTRAN programming language and file oriented data processing in some courses and most advanced artificial intelligence methods in another.

Our emphasis is on integrating computer usage in all courses where it is applicable and minimizing the 'pure' computer science courses taught — computers are tools that help us to work better, faster and cheaper. The engineer's responsibility is to make good use of this tool to further the commonwealth.

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