The Electronic Push

Who could see, when the computer was born, how it would reshape the modern world?
When looking at the subject of computers and engineering design, one can easily go back to the earliest days of the computer age, since the initial rationale behind developing these machines was to assist in making technical calculations. In the early 1940s, there was little awareness that within 60 years there would be literally hundreds of millions of computers in use, doing everything from financial accounting to playing games. Nor was their intense use in mechanical design and analysis foreseen. The use of computers for mechanical design is often referred to as mechanical design automation,
The following is a list of the top 10 engineering achievements of the 20th century as selected by our readers. In ascending order, *Mechanical Engineering* will run articles commemorating each achievement every month this year.

1. **Automobile**
2. **Apollo**
3. **Power Generation**
4. **Agricultural Mechanization**
5. **Airplane**
6. **Integrated Circuit Mass Production**
7. **Air Conditioning & Refrigeration**
8. **CAD/CAM & CAE Technology**
9. **Bioengineering**
10. **Codes & Standards**

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Of MIT graduate school and was the lead programmer on that project. The third project, called DAC-1, was a joint effort between GM and IBM. Out of that project came the IBM 2250 display terminal as well as many advances in computer timesharing, the use of a single processor by two or more terminals.

**Minis in the ’60s**

During most of the 1960s there were few attempts to commercialize mechanical design automation technology. Most graphics hardware was sold into research environments. Although some work was done on systems that would support design and drafting, it was far from the majority of then-current research activity.

This period was characterized by large computers, vector refresh display terminals, in which a beam draws figures directly on a screen, and software development done in assembly language, very low-level programming with primitive support tools. Toward the middle of the 1960s, two hardware developments helped to accelerate development of interactive design technology. The first was the rise of the minicomputer and the second was the introduction of the storage tube display, in which the image is permanent until the screen is erased and totally redrawn. This latter development from Tektronix brought down the cost of computer graphics dramatically.

Vector refresh displays were still widely used in larger systems. In 1964, IBM introduced the 2250 display which, along with subsequent versions, was used extensively in the aerospace and automotive industries for many years.

The only significant attempt to create a commercially viable system was Control Data Corp.’s Digigraphics organization. This was a successor to the ITEK project. At nearly $500,000 for a system that...
would support only a couple of users, the technology was not price competitive with traditional design methods and only a few systems were sold.

8k and 2-D

Serious commercialization of computer graphics for design and drafting began in 1969 with the founding of Computervision and Applicon. The two companies took somewhat different approaches to the market. Computervision was a pragmatic organization. It felt that the traditional designer/draftsman would be reluctant to accept drawings created on a CRT screen unless there was some form of immediate feedback. The result was a user workstation that was a combination of a large table digitizer, or mechanical scanner, and a plotter, a wide-format printer.

Applicon, on the other hand, was more research-oriented. The most distinguishing feature of its system was the use of pattern recognition for command entry. The operator would sketch a symbol on a tablet, such as a square, and the system would interpret this to mean that it should zoom into the selected area on the CRT screen.

Several other companies began to offer automated design and drafting systems in the early 1970s, some of which made very little impact and faded rapidly from the scene. Others were quite successful, at least for a while. Calma was a manufacturer of digitizers that saw design and drafting systems as a logical extension of its product line. Auto-trol Technology was also a digitizer manufacturer that moved into graphic systems to expand its business. A few years later, these firms were joined by M&S Computing, which eventually became Intergraph, and by Gerber Systems. Gerber, in particular, went after the mechanical design market, with emphasis on manufacturing applications.

During the early 1970s, the typical system consisted of a 16-bit minicomputer with 8 kilobytes to 16 kB of main memory (a kilobyte represents \(2^{10}\) bytes of information), a disk system that held 2.5 megabytes to 10 MB of data (a megabyte represents \(2^{20}\) bytes), and a custom designed interface using an 11-inch storage tube display. The software was limited to fairly simple two-dimensional drafting tasks.

The operating systems provided by the computer manufacturers at that time were primitive by today's standards. Nearly every system vendor either wrote its own operating system or significantly modified the computer manufacturer's. Typical systems had one to four user stations and sold for $100,000 to $600,000.

In addition to turnkey system vendors, there was a significant amount of internal development at major automotive and aerospace firms. GM, Ford, and Chrysler all had design/drafting projects under way,
while Lockheed was hard at work on Cadam. These systems were more focused on three-dimensional surface design than were the early commercial systems. Some of this software is still in use today. While the commercial systems were minicomputer and storage tube display oriented, these in-house projects tended to use mainframe computers and vector refresh displays.

The commercial market picked up significantly in 1975, when new 19-inch storage tube display terminals became readily available from Tektronix. These units could be used with minicomputers without custom interfaces, and they could display substantially larger drawings than the older, 11-inch units. Display speed was not particularly fast, however. Since early storage tubes had to be totally erased in order to change anything on the screen, on-screen menus were available only on vector refresh displays. The storage tube-based systems used hard copy menus on tablets and digitizers for user interaction. The late 1970s saw rapid development in graphics technology. Computervision introduced the first CAD terminal using raster display, current line-scan technology, in late 1978. Most mechanical analysis was done on mainframe computers. The process involved filling out coding forms, entering the data on punch cards, submitting the data to a computer center, and receiving the results back in the form of printed listings. The entire process could easily take several weeks. Toward the end of the decade, software became available for defining finite element models using interactive graphics tools. This reduced the analysis process from weeks to several days.

By the end of the decade, the typical turnkey MDA system was still a 16-bit minicomputer but now with 128 kB to 512 kB of main memory, 20 to 300 MB of disk storage and two to eight terminals. System prices continued to run about $125,000 per seat. Software was predominantly written in assembly language, although most of the vendors were making the transition to compiler languages such as Fortran. Computer manufacturers' operating systems were used more extensively. Vendor modifications were still common, however.

**More for Less**

The 1980s saw tremendous growth and change in mechanical design automation. While the predominant computer continued to be the 16-bit Digital PDP-11, there was growing interest in Digital's 32-bit VAX 11/780. Display products were starting their transition from Tektronix's storage tube units to raster displays, with color raster just around the corner. There was also interest in making user terminals more intelligent. If display support functions could be moved from the host minicomputer to the terminal, then the computer could support more terminals.

Some significant changes also started taking place at the software side of these systems. Three-dimensional graphics became prevalent as did the ability to define complex surface models. Solids modeling, however, was still more of a research project. For the first time, there was serious interest in being able to transfer data from one system to another. This was the start of standards such as IGES (initial
A new generation of lower-cost systems was introduced in the mid-1980s. The major vendors introduced systems with entry-level prices in the $60,000 to $100,000 range. A new class of vendors began offering systems priced from $35,000 to $60,000. These were primarily drafting-oriented solutions with little design or manufacturing capability.

As the 1980s progressed, several significant developments were beginning to unfold. In 1981, IBM introduced its first PC. It was based upon a 4.7-MHz Intel 8088 microprocessor, had limited memory, used a 5¼-inch single-sided single-density floppy disk and cost about $6,000. But it started a tidal wave of technology that eventually changed the entire MDA industry.

Several organizations began to develop drafting software that would run on low-cost PCs. By the time the software had gone through an iteration or two, the hardware was beginning to evolve to where it could handle serious engineering drawings. Autodesk's AutoCAD was the primary PC drafting package. The development of a CAD dealer distribution channel also helped the market grow.

For a long time, most turnkey system vendors tended to ignore the impact of the PC market and the inroads AutoCAD was making in it. At the same time, however, the system vendors were starting to go through a transition. They had been equipment manufacturers that sold software to help move hardware. Now they were becoming software developers that also sold industry standard computers that users could use to run the software.

Significant changes were taking place on the technology side at this time. The key one was the move from minicomputer-based systems to a new generation of engineering workstations. Apollo and Sun were early leaders, with Hewlett-Packard, IBM, Digital, and Silicon Graphics joining in later. The key concept was to use industry standards, have an open architecture, use networking techniques to link the workstations and servers, and use on-screen menus as the primary user interface. Ethernet networking, Unix operating systems, the X-Windows System graphics application programming interface, and other industry standards took on greater importance.

From the start, most of the turnkey vendors had licensed their software only to customers who also purchased hardware from them. Typically, the software would run only on hardware that was built or modified by the system vendor. As they began using standard platforms, the system vendors were pressured by their customers to license software unbundled from the hardware.

Some of the more significant software developments during the late 1980s were the integration of solid modeling into
the design software, the linkage of engineering drawings with the solid models, the extensive use of on-screen menus, NC software that could handle complex surfaces with little user intervention, software that would run on PCs and could be sold by dealers, and the use of industry standards such as IGES and STEP to exchange information between different proprietary CAD systems. Analysis software also became more interactive with both modeling and analysis software running on the same workstations.

By the mid-1980s, the mechanical design functions offered by most vendors had reached a plateau where it stayed for several years. Nearly all high-end systems had fairly comprehensive 3-D wireframe capabilities and reasonable surface geometry. Solid modeling was typically sold as an option and was used infrequently for production design. The predominant use of MDA technology was to produce 2-D engineering drawings.

In late 1988, Parametric Technology Corp. changed the status quo when the company introduced Pro/Engineer, which incorporated solid modeling and parametric constraints at its core. A single geometric model now supported a multitude of different applications, including analysis and manufacturing as well as design and drafting. By 1990, users could work effectively with feature-based, parametrically driven solid models. Drawings became a by-product of the design process. With these tools, the impact of a single design change could be propagated throughout the design model, even between different parts.

**Choice Selections**

The 1990s was a decade of constant movement for the MDA industry. One major change was the demise of the turnkey system vendor and the emergence of task-specific or point solution software and hardware vendors. For the most part, users today are quite comfortable with purchasing hardware from one source and software from another source or even multiple sources.

Today, there are numerous software companies that offer everything from simple symbol libraries for AutoCAD users to complex mechanical and electronic analysis programs. A significant development was that users came to expect that key software products would run on most of the available workstations as well as on PCs. For the most part, the mechanical design software vendors are out of the hardware business.

A major change has been the introduction of component software. No longer is it necessary to create MDA packages from scratch. Geometric modeling is readily available from companies such as Spatial Technology and Unigraphics Solutions, while constraint management, advanced
surfacing, display management, and many other capabilities can be licensed inexpensively from other developers.

The 1980s ended with the introduction of a new design paradigm by PTC. During the first half of the 1990s, the other major vendors responded to PTC's competitive threat by developing their own feature-based parametrically driven design software. By mid-decade, these new packages had matured, and now they are in wide use.

During the 1990s, tremendous progress was made in areas as diverse as assembly modeling, interference detection, design optimization, and interactive analysis. It is now practical to share geometric data between different systems, although it is still difficult to share design intelligence between systems.

During the past five years, a new group of vendors has entered the fray, selling significantly lower-priced mechanical design solutions based upon component software. The leading member of the group is SolidWorks, which was acquired by Dassault Systèmes in 1997; Autodesk, and Solid Edge. Solid Edge, initially a division of Intergraph, was sold to UGS. One interesting development is that SolidWorks uses Parasolid, which is developed and marketed by UGS.

**WHAT HAVE WE ACCOMPLISHED?**

As we start a new century, more than one million mechanical engineers and designers worldwide use advanced 3-D solid-based modeling technology and probably another two million use 2-D mechanical drafting. In 20 years, we have gone from systems capable of no more than simple drafting tasks and costing $125,000 per seat to $12,000 PC-based systems with 3-D solid modeling capabilities that are able to interactively handle designs consisting of thousands of individual parts.

Today, entire automobiles, airplanes, and jet engines are being designed in an integrated manner. The Internet is being used to exchange design data among teams scattered around the world. Now you can work with people on the other side of the world as easily as if they were just down the hall. MDA technology deserves a significant portion of the credit for the tremendous productivity improvements we have seen in the economy in recent years. Products that previously took several years to bring to market can be developed in just months. They are more reliable, meet customer expectations better, and are less costly to manufacture.