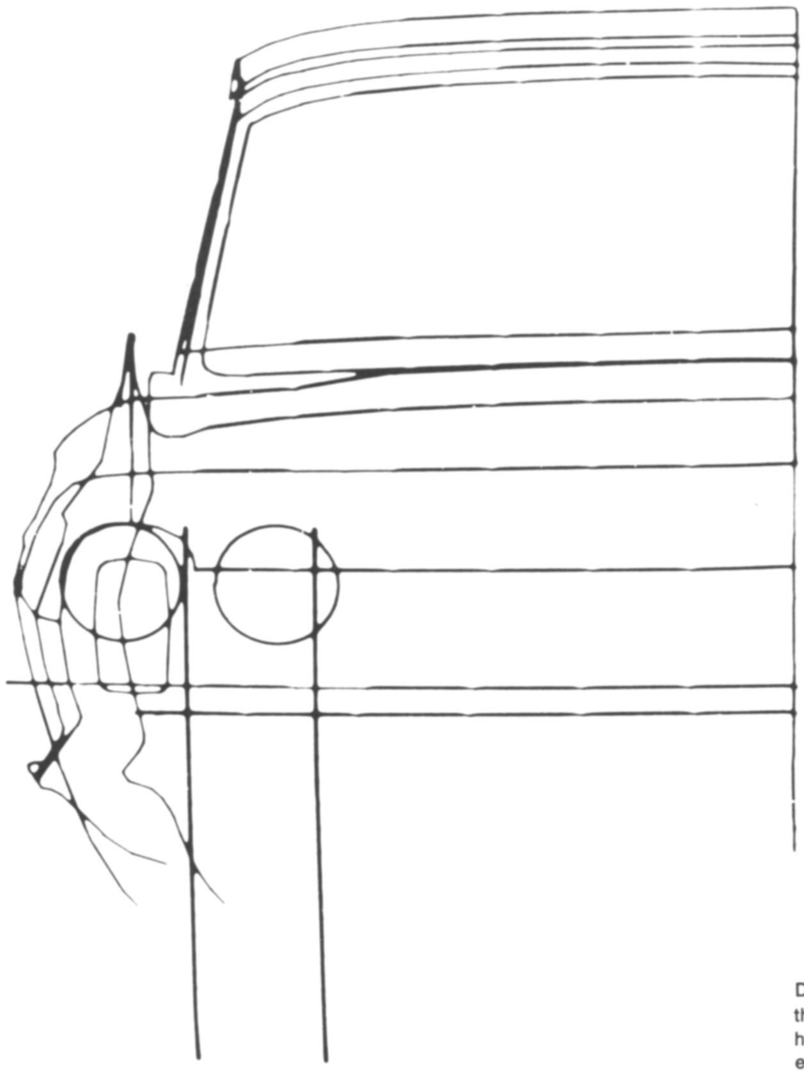
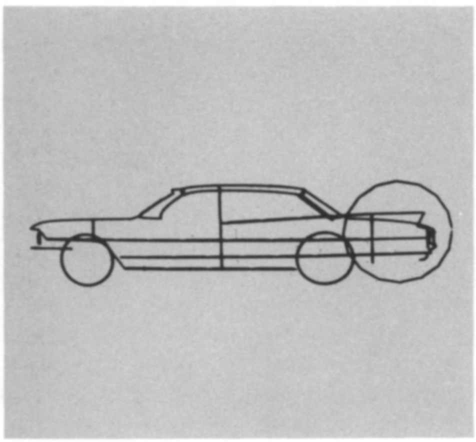
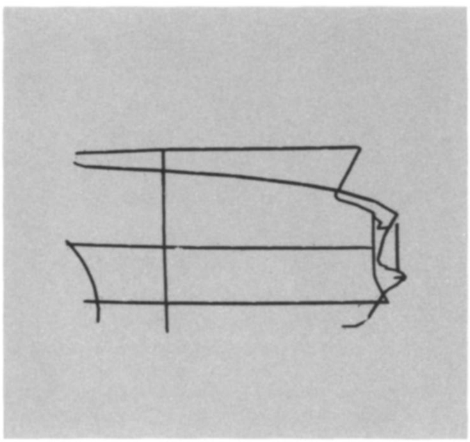
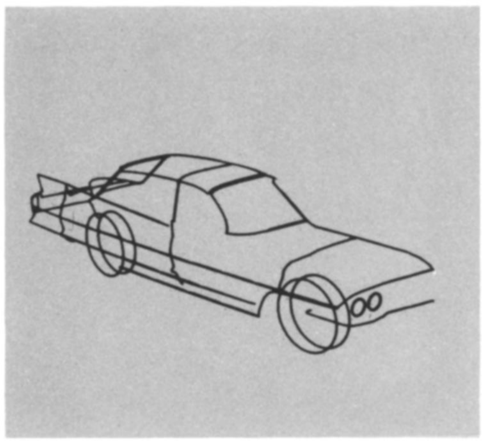


Displays on the screen of the Graphic Console showing how the designer can call up enlargements of the drawing or different perspectives.







DESIGN AUGMENTED BY COMPUTERS

by Edwin L. Jacks

Edwin L. Jacks is Assistant Department Head of the Computer Technology Department at the General Motors Corporation, Warren, Mich.,where a computer system for the study of graphical man-machine communication was established.

Designers in the various automobile manufacturing plants work with blackboard sketches, large drawings, renderings, scale models and sculpture details in many different versions. Proposals are developed by the designer and analyzed by the engineer; adjustments are made and, finally, prototypes produced. Graphical techniques are basic to the design process because they serve as a mechanism for design evolution. Graphical communication between the designer and the engineer, therefore, plays a vital role in automobile design and production.

The computer system at General Motors enables the designer to produce, manipulate and evaluate free-form lines and surfaces without writing complicated program statements. Every element in the picture on the console screen is under the designer's control and can be changed instantaneously. He can revise and select elements on the screen and gradually develop any complex three-dimensional surface for an automobile.

The goal of such experiments is the development of a system where the designer can draw a rough sketch on the computer console screen, make changes and develop his ideas into a final and exact design without translating it into computer language.

Realizing the fundamental nature and importance of graphical communication techniques, the General Motors Research Laboratories has placed into operation an experimental facility for man-to-computer and computer-to-man graphic communication. The system, known as Design Augmented by Computers (DAC-1), provides:

a) a computer complex that permits rapid, high accuracy graphical input and output through a high-speed computer and

b) a flexible programming system to enable the convenient development of man-machine communication experiments.

Through this facility man-machine graphic communication is being explored as a potential technique for placing some of the designer's burden on the computer, thus giving him more time for truly creative work, and making it easier for him to design engineering changes. This could result in improved manufacturing processes, lower costs, and higher quality products.

Engineering has evolved rapidly during the past fifteen years as analysis techniques geared to the computational power of a slide rule and desk calculator have been replaced by techniques that make extensive use of computers. Graphical techniques for converting design ideas into final products, however, have not changed significantly, nor has the role of drawings in engineering design.

Engineering drawing plays a vital role in each phase of the evolution of a product. The original design proposals, the engineering analysis, the design compromises, and the prototype product fabrication all depend on graphical communication among engineers and designers. Whether the product is to be machined, assembled, stamped, wired, welded, or hand modeled, a drawing is made for review by the engineers concerned with the product. Prior to the final product drawing, many ideas are exchanged by means of sketches, drawings, plots, and engineering reports. In many mechanical design situations the two functions of engineering and preliminary product drafting are carried out by the same man. A drawing is his way of exploring design ideas.

Dependence on graphical techniques, therefore, is fundamental to the design process. Graphics serve as a language of communication among design personnel and as a mechanism for design evolution.

In 1952 the General Motors Research Laboratories began using a card-programmed digital computer for engineering and scientific analyses. These early studies showed that the computer could aid the design process. Notably absent from the applications, however, were problems related to graphical design. Subsequently, the G. M. Research Laboratories began a study on the potential role of computers in the graphical phases of design.

Prototype components and programs were developed to investigate the problems of image processing. A cathode ray tube recorder attached to a computer was already being used to plot results of engineering computations and satisfied the requirement for graphical output. An associated display unit provided a graphical display which, along with a simple switchboard, became an elementary man-machine console. A program-controlled film scanner was devised using the cathode ray tube recorder by substituting a photocell detector for the film magazine and connecting its output signal to a computer sense switch. With this setup, lines on film could be digitized under program control. Programs were written for graphic input and output and for the manipulation of images in three dimensions. These early programs and computer components were integrated into an operating system that demonstrated the feasibility of using the computer as an aid in the graphic design process.

On the basis of the early studies, the decision was made to establish a more comprehensive laboratory for graphical man-machine communication experiments. The facilities were to permit the computational power of a large-scale digital computer to be brought to bear on the problems of graphical design in a manner which

The DAC-1 system showing the Image Processor which provides input and output in graphical form (center) and the Graphic Console which contains a cathode ray tube, card reader, keyboard and program function switches and indicator lights (right).

would fully recognize the importance of man in design. This project has become known as DAC-1 (Design Augmented by Computer). (1-4)

The initial goal of the DAC-1 project was to develop a combination of computer hardware and software which would *permit "two way" man-machine graphical communication* and furthermore *provide a maximum programming flexibility* and *ease of use for experimentation.*

The hardware for the system consists of an IBM 7094 computer enlarged with extra disc and drum storage devices, an IBM 7960 special *image processing system* that allows the computer to read and generate drawings, and a *graphic console* equipped with a viewing screen which serves as a direct, two-way communication link between the designer and the computer. The special image-processing system was built by International Business Machines Corporation to specifications provided by the General Motors Research Laboratories. (2)

The supporting software for DAC-1, developed by the Computer Technology Department of the G. M. Research Laboratories, consists of more than ¾ million operating instructions. This makes DAC-1 one of the largest programmed systems in the United States. The software features a multiprogramming system, an algebraic compiler,* a data channel command compiler, a dynamic storage assignment procedure, and extensive facilities for the storage, retrieval, and editing of programs and stored data.

Each major portion of the DAC-1 system — the special image processor, the computer with attached disc memory, the multiprogramming system, the monitoring system, the programming languages used for system development, and the disc filing programs — has contributed to the system's flexibility and ease of use for experimentation.

*Compiler: Systems which translate a problem into special command codes meaningful to the computer without the programmer actually preparing a machine language.

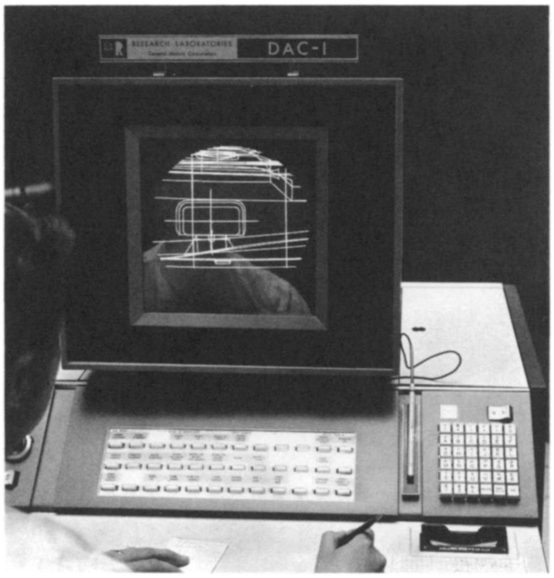
HOW THE DAC-1 IS USED

Before discussing the design objectives of the DAC-1 hardware and software, it would be valuable to describe how the system is utilized by the designer. First, using sketches and drawings as guides, the designer writes out statements of his problem — usually a descriptive geometry problem — in a design language. These statements are key punched on cards and loaded into the computer memory.

Once the group of statements is stored in the computer, the designer commands the computer to perform the functions requested in his program through the man-computer console. As the program is executed, the computer checks each statement for syntax and punctuation. If an error is detected, the computer stops and displays an error comment. Using the console equipment, the designer can inspect the statement, make corrections, and instruct the computer to proceed.

Upon completion of the task, the computer response usually will be visual display of lines forming a simple drawing. The designer studies the display at the graphic console to decide if it is an acceptable solution to the problem. He may enlarge any portion of the display or view it from any angle or perspective. If is is not satisfactory, he can modify it immediately at the console by adding or deleting lines, changing statement parameters, or entering alternate statements. If the display is acceptable, he can direct the computer to produce a permanent copy of the drawing using the image processor. After perhaps many changes, he may have DAC-1 produce control tapes for automatic drafting machines or machine tools.

Since the program itself is general, with details supplied at the console, it can be stored in a library of design programs. As this library grows, designers can select from it programs for those design functions they might require for a specific job.



The Graphic Console is the system's control point. Information displayed on the console screen, for example a detail of a car, can be modified through the position-indicating pencil, control keys or card-input.

IMAGE PROCESSING AND COMMUNICATION

The overall objective of the image processing system[2] was to achieve the equivalent of what is possible with graphical man-to-man communication while using drawings. In establishing systems specifications, four kinds of man-machine communication were sought: static, dynamic, comparison, and non-graphic.

Static Drawing: The objective was to produce a hard copy drawing for engineering use. Conversely, accept a drawing and, under computer control, read the drawing.

Because of the nature of automobile design, it was necessary that the DAC-1 system accept free form curves — curves which are constructed without consideration of particular mathematical representations. Furthermore, to provide compatibility with existing design procedures, precision input and output of such curves were needed. The drawing input-output functions are achieved in the image processor of the IBM 7960 system.

Dynamic Drawing: The objective was to simulate the type of man-to-man communication where one man draws or points at a particular part of a drawing while another man observes or discusses details of the design with the first man.

This capability is provided in the graphic console of the IBM 7960 computer through the combination of a 17-inch display tube and a device called a *position-indicating pencil.*

Comparison Function: The objective was to provide for the overlay of two pictures to permit comparisons of differences and similarities in the information.

This feature is provided by having the image processor designed so that pictures can be recorded on two separate film trains, then projected automatically onto a common view screen. This feature allows, for example, overlay of scanned data with the original film source for verification. By programming techniques, the graphic console also can be used to compare drawing information.

Non-graphic Information: The objective was to provide, via the graphic console, a convenient way to communicate alphabetic and numeric information to the computer, multiple choice decision responses to the computer, and permissible actions by the man.

For alphanumeric information, a 36-position keyboard with upper and lower case and a slow-speed card reader are part of the graphic console. For communication of gross actions such as review or transform, the console has 36 program control keys and 36 message lights. The computer receives a signal when a program control key is depressed by the man, and the man receives a visual signal when the computer turns on a message light.

Studies at the General Motors Research Laboratories were made to estimate the computing facilities required to support adequately the DAC-1 project. Considered in the studies were the number of instructions required to support the experiments, execution time for the required programs, and man-machine response rate. These studies indicated that approximately 200,000 to 500,000 instructions would be programmed for the graphic communication experiments. The computation required for these experiments was estimated in terms of Central Processing Unit (CUP) use per hour and amounted to only six minutes of CUP time for each hour of DAC-1 console use.

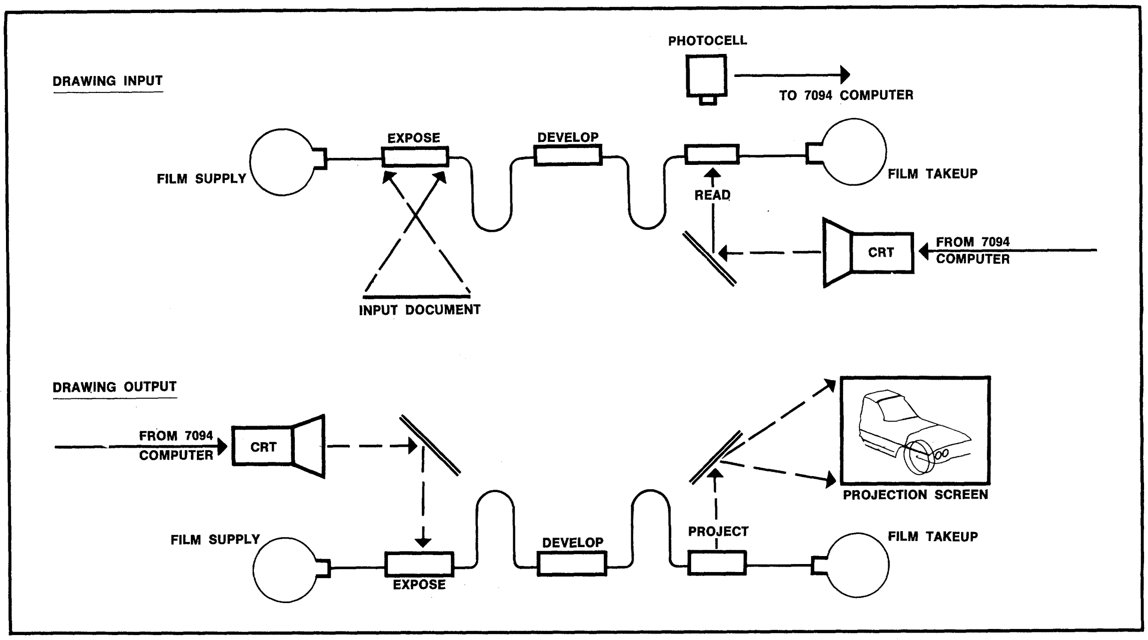
The response rate considerations were stated in terms of system objectives. The designer essentially had to be working on-line with the computer and in *real time.** The measure of real time was that the man and machine could carry on a meaningful conversation about a design at the rate satisfactory to the man. The response consideration then required a real-time approach to receiving and handling data arriving from the man. But the computer programs and the hardware did not need to have a fail-safe time limit approach to sending a response to the man.

Another more independent consideration was the computing requirements of the General Motors Research Laboratories. In the late 1950s, an IBM 704 computer was in use between two and three shifts per day. It was forecasted that an IBM 7090 or an equivalent computer would be required by 1961 to satisfy the continuing needs for an engineering and scientific computing facility.

*Real time — the time the computer needs to respond with a solution.

Schematic diagram of the Image Processor. The Image Processor Unit contains cameras, projectors and cathode ray tubes (CRT) which enable the system to "read" and produce engineering drawings. Drawings are inserted in the unit via a drawer, and photographed onto 35 mm film. The film is then developed and positioned beneath a cathode ray tube and a photocell which are used to "read" lines from the document, convert them into digital language, and store them in the computer memory.

The Image Processor also can produce drawings on 35 mm film. The film is exposed to a cathode ray tube, developed, and projected on a viewing screen. Exposed film may then be mounted in cards for storage. Conventional reproduction copies can be made from the film to produce work drawings.



It was believed that an IBM 7090 computer* would meet the combined requirements of the DAC-1 system and other Research needs. The speed of the IBM 7090 would adequately handle the computational load and the machine would be able to give the response time desired for console comunication and computational purposes. To prevent wasting the estimated 54 minutes per hour of non-Central Processing Unit use by the man, multiprogramming techniques were to be developed and the computer would need to be adapted so that two independent programs could reside in its core memory with a minimum risk of either program modifying the other program. For this purpose, a core memory protection system was designed which prevents instructions from storing into program-specified 4096 word blocks of the memory.

Multiprogramming also implied that a clock should be attached to the computer to provide proper timekeeping for accounting purposes during the switching from program to program. A clock was built by the Delco Radio Division of General Motors with a millisecond as its basic interval of time.

The DAC-1 system requirements for 5 x 10^5 words of program storage could be satisfied by having a disc memory on the computer. The original 7090 configuration had a 1405 disc connected to the computer via a 1401 computer and a direct data connection. The present facility uses a 1301 disc and three drum storage units for the program and data library.

PROGRAMMING SYSTEMS

The combination of the IBM 7090 computer and the IBM 7960 special image-processing system provided an experimental graphical communication facility. To support this system from the software standpoint, programming techniques were developed to minimize the time from the conception of a man-machine communication experiment until the required programs were operating.

The programs had to be able to display situations to the man conveniently. If the man was expected to require more than a millisecond to respond, the programs had to be able to say to a control program, "Control, I am in standby status now and when the man answers my question or takes other action, return control to me."

For programming convenience, the programmer had to be able to do all his programming in a higher level language (higher than an assembly type language, at least) including the programming of the data channel driving the special image-processing system, the loading of programs by name from the disc, and the analysis of all data coming from the image processing or graphic console equipment. In short, he had to be able to program all of his graphical communication experiments in a language similar to FORTRAN* or ALGOL.* An algebraic compiler and a data channel command compiler were developed for this purpose.

The specifications of the programming system revolved around three broad statements of facility operational policy. First, for programming purposes, the 32,768 word computer memory was to be considered as two blocks, with half of it assigned to the DAC-1 console support programs and the other half assigned to the stan-

*In 1963, the originally installed 7090 was upgraded to a 7094.

*Fortran is a composite of FORmula TRANslation, a language that converts programs written in mathematical symbols into machine language.

*ALGOL or ALGorithmic Oriented Language, is an international procedure-oriented language.

dard batch monitor operation. Secondly, all input/output programs in both the DAC-1 and batch monitor operations must use the trapping hardware built onto the Central Processing Unit, and all trap program operations must be compatible with a Trap Control System (TCS) developed by the General Motors Research Laboratories. The Trap Control System program prevents chaos when all five channels simultaneously request priority activity from the Central Processing Unit. The trapping hardware allows each of the five data channels to direct the Central Processing Unit to stop its current activity and handle a priority job for the data channel.

The third policy statement indicated that the batch monitor's use of the computer was limited to the two channels for the tape units while the DAC-1 console program's use was limited to the channels connected to the Central Processing Unit and the disc and drum storage units. This condition was imposed to prevent conflicts in hardware use and means. For example, tapes in use by the batch monitor could not be used by DAC-1 during multiprogramming. One major exception to this rule was that use of the disc was permitted by programs being executed under batch monitor control for purposes of compiling or checking out programs being developed as part of the DAC-1 project.

MAN-MACHINE CONCEPT

The DAC-1 system has been in operation eight hours per day, utilizing extensively the systems hardware and software capabilities discussed here. From the standpoint of a laboratory facility, system performance is excellent. It has proven that man and machine can communicate readily via graphical means.

With the combination of computer-controlled image scanning and man-machine communication,[4] a simple computer program rapidly solves the problem of conversion from graphics to binary data. When any uncertainties arise, the man, as referee, can obtain control. One example of an uncertainty is low contrast input film, which is difficult to scan.

It could be argued that for each uncertainty a program could be written to analyze the situation, then man would not be needed to aid the process. The strong point of man-machine communication via graphic consoles, however, is that for any given problem one may ask which parts are easily solved by the computer and which are best solved by man. This results in programs being written which have decision points in them at which the man at the console can be asked for advice.

Many of the past discussions of man-machine communication have been based on the concept of "let the man get to the computer" so he can ask questions directly of the computer program. Experience at General Motors Research to date has been that that payoff comes not from asking the computer a question, but from assigning the computer a task from which the response is one of the following: "What is my next job? Here is the answer; what next?" or, "I don't understand, but here is my analysis of the situation."

SUMMARY

The hardware for the DAC-1 system includes a large computer augmented with extra disc and drum storage devices, a special image processor that allows the computer to read and produce drawings, and a graphic console that serves as a direct, two-way communications link between the man and the computer.

The software incorporates three major departures from conventional higher level language programming: multiprogramming, source program storage allocation control, and a disc library of programs that is available during program execution.

Multiprogramming permits computer programs to achieve efficient use of the processing unit even though they work at the man's pace. Program storage allocation control allows each program to adjust storage assignment dynamically as a function of data needs. The disc library available at execution allows a control subroutine to view other subroutines as units which require certain inputs to produce outputs. This feature allows continued growth of the design support programs with no change to control programs.

With the new laboratory facilities at the General Motors Research Laboratories, the process of man-machine communication for design is being explored now with both formal (direct comparisons of methods with planned testing) and informal (trying something to see how it works) experiments.

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