

APPLICATION OF INTERACTIVE COMPUTER GRAPHICS
TO THE ANALYSIS OF PHYSICAL PROBLEMS

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ABSTRACT

This paper describes two applications which illustrate the advantage of interactive computer graphics to the analysis of physical problems of the class where deterministic methods are impractical. The approach outlined will be most useful for poorly defined problems or for problems which are at a stage of development that still requires considerable expert involvement. A brief description of the two applications and the facilities provided to each of the two scientists to help them study their problems is included. Discussion from a user's point of view centers on system response and constraints and the use of control devices to communicate with the computer.

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ABRÉGÉ

Dans cet article l'auteur démontre, au moyen de deux applications, quels sont les avantages des graphiques donnés par un dialogue avec l'ordinateur lors de l'analyse de problèmes physiques qui ne peuvent pas être pratiquement étudiés par les méthodes déterministes. L'auteur donne comme exemple les problèmes mal définis dont la solution ne peut pas être précisée ou ceux dont le degré d'avancement est tel qu'il faut encore s'assurer la participation d'un expert. Les deux applications sont décrites brièvement ainsi que les installations au service des deux ingénieurs de recherche dont les points de vue sur le temps de réponse, les contraintes du système et l'utilisation des commandes sont discutés.

In this paper it is suggested that interactive computer graphics is a useful tool for the initial attack on poorly defined or poorly understood problems. The goal is to permit the person to get as close as possible to the solution process, to permit him to use his accumulated experience with the problem, even in instances when he is unable to precisely describe his ideas for use in the computer or even describe them to another person. The ideal would permit all the nebulous attributes of human reasoning, even intuition, to be combined with computer processing. Two problems in experimental physics are being studied using a stand alone computer graphics system. In both instances attempts at solution using deterministic methods have failed.

The first example problem is concerned with the analysis of thermal desorption spectra, and may be characterized as an exercise in simulation. The physicist, seated at the graphics console, tries to simulate the theoretical process which would generate the set of measured results he has obtained as the result of an experiment. The second application concerns the preliminary analysis of telemetry data from rocket borne plasma probes. The physicist is concerned with editing his data and making a few key measurements that permit further processing in a conventional manner. These two applications on first examination are conceptually quite different. They have in common, however, the characteristic that both are concerned with phenomena which are poorly understood; thus their attraction to the experimental physicists. Both problems are unpredictable in the sense that decisions leading to a solution must be made based on criteria which are very difficult to describe in advance. Although mechanisms influencing the experimental data are not well understood, it is still true that the experimenter has sufficient appreciation of the phenomena to make decisions concerning the validity of various hypotheses. Also much of the experimenters' previous evaluation has been done on experimental results which are in graphic form similar to the computer generated display. The investigation of both these problems using the approach to be outlined require expert involvement - the interactive display is a tool useful generally to a single person.

The first application, analysis of thermal desorption spectra, is a problem in simulation in which the model is separated into two parts: the first part, may be described exactly as a mathematical representation generated by the computer; the second part, that which is less well defined, is the responsibility of the user. The actual simulation process is an iterative procedure in which a theoretical curve

generated at the console is visually compared on the CRT display to a curve produced as the result of an experiment. This theoretical curve is sum of component curves (dotted curves in figure 1 at x-axis extremities) precisely described by the mathematical model within the computer, but their location is specified by the user in accordance with constraints which he must set. In generating the theoretical curve and comparing it to the experimental curve, the user makes use of experience, constraints, and trends derived from earlier trials as well as the immediate data displayed. It is extremely difficult to program a computer to use this information, but such information is potentially powerful when the user may scrutinize the validity of his hypothesis immediately and, if necessary, modify the hypothesis and try again. For the analysis of rocket borne plasma probe data, editing is required since the data are far from predictable and are complicated by various transient phenomena. Some of the events which cause trouble are telemetry drop outs, interference pulses, range switching, roll modulation and signal limiting. In addition to the processing difficulties associated with such signal perturbations, real effects of unexpected nature may occur. This information which is a measurement of new geophysical or physical phenomena is of great interest. A typical flight may generate as many as 10^6 data points for each telemetry channel, hence computer processing is very attractive. The use of interactive computer graphics permits the scientist to use computer processing without the risk of ignoring new and unexpected results. The appendix describes in more detail the facilities provided to the scientists working at the graphics console.

Timing considerations have two aspects. Firstly since this work is done on a refresh type display the amount of data being displayed must be carefully considered. The principal avenue of communication is the CRT display and noticeable flicker will result in rapid fatigue. The second aspect of this is the system response to user commands. In a global sense this should be fast enough to encourage the user to experiment with different hypotheses for the basis of his decisions. However, in a highly interactive environment, particularly that of the first application, for desorption spectra analysis, the delay associated with commands in the simulation process must not exceed the user's attention span or he will lose his train of thought. This hazard cannot be overemphasized in my opinion. Related in our experience and not separable from response delay is the CRT presentation during the delay. In the desorption spectra analysis application the

maximum delay is about 1 1/2 seconds, the time to generate a peak at the high end of the temperature scale. This time decreases to approximately 1/2 second at the low end. Over the temperature range most used by the experimenter the delays varied from 1/2 to 1 second. The user was unaware of this variation, leading one to postulate that delays up to one second can be tolerated. However, during this delay the display image at the time the command was issued remains until a new image appears. Although we have no actual experience with longer delays, in our opinion a delay of 3 seconds certainly would be distracting.

All options available to the user are selected from lists presented on the display screen. Control is exercised through two devices, a 6 button keyboard and a pair of orthogonally mounted shaft position encoders. Their orientation relative to the user and the CRT display are shown in Plate 1. The user's left hand operates the keyboard and the right hand operates the encoders. The teletype keyboard is not used during interactive procedures. The number of devices was purposely limited to two, one for each hand, and consequently are shared among many functions. This philosophy forces careful design of the command organization but has the advantage of being simpler to use. The user is free to concentrate on the progress of his solution as communicated to him via the display.

In this discussion constraints are the characteristic of the system which forces a certain discipline on the user. They result in user awareness of the computer. For a well designed system, these should result in no more than a minor annoyance. For instance the amount of data that may be displayed is limited by the speed of the display system. This limitation forces the use of windowing techniques as described in the appendix. Constraints of this type should be minimized. Other constraints may be problem oriented. As one learns more about the problem under study, a number of constructive constraints may be desired in the system. The user will be able to specify only a few constraints initially since they imply precise knowledge of the problem. As his understanding increases the system must allow him to add more problem specific constraints. Eventually the solution procedure may become sufficiently well defined to be transferred from the highly interactive environment used here to more conventional facilities.

In conclusion, interactive computer graphics can provide an attractive tool for approaching new problems during their definition and initial attempts at solution. To be useful in this application one requires a highly interactive, on-line computer graphics system which is able to provide more than simply a response to the variation of parameters to a fixed problem.

ACKNOWLEDGEMENTS

To attempt to demonstrate the usefulness of the approach outlined without real problems would have been futile. In addition to providing these problems I would like to acknowledge the constructive criticism offered by the two scientists involved, E.V. Kornelsen and A.G. McNamara.

APPENDIX

Analysis of Thermal Desorption Spectra

The experimental data take the form of two analog curves on chart paper. The first is a plot of desorption rate as function of time; the second is the corresponding calibration of crystal temperature vs time. These curves are digitized and the data pre-processed on the NRC IBM System 360/67 to provide a single curve of desorption rate vs temperature suitably formatted for the graphics system. The experimental curve is displayed as a series of solid vectors and the theoretical curve is a series of broken vectors. The curves are displayed on the CRT screen on a 10 inch x 10 inch area with resolution of 1:1000 for the amplitude of the desorption rate and 1:500 for temperature (x-axis).

A brief description of the commands available to the user follows. MODSCALE adjusts the amplitude of the display of the desorption rate curve. OFFSET and ZERO OFF permit the user to displace the experimental curve from the x-axis and reposition it precisely. X-SHIFT and RESOLUTN are necessary, as the number of curve coordinates being displayed must be limited to avoid flicker. X-SHIFT moves a "window" of approximately one half the temperature range across the experimental curve. RESOLUTN moves a similar "window" on the theoretical curve or allows choice of full range display at one half resolution. The actual matching procedure in which the theoretical curve is generated and modified to match the experimental curve uses the next three commands, CONSTRCT, DELETE and MOVE PEAK. A pointer positioned on the screen with the thumbwheel encoders determines where a peak of a component desorption rate curve will be located. Keyboard release begins the curve construction. The DELETE command removes the component curve whose ordinate is closest to the pointer. The MOVE PEAK command is the combination of the other two. Only the composite theoretical curve which has been generated is displayed but the locations of the peaks of the component curves are shown with triangular markers. The four digit numeric display indicates the temperature at the pointer location. The CALC ERR command computes

$$\left(\frac{\sum \text{Diff}^2}{N} \right)$$

the RMS difference between the two curves over a temperature range selected by the user and displays a third curve which is a plot of these differences again over the selected range. The command DISPLAY generates a display of the two curves only. This is useful when peak markers begin to obscure the display of the curves.

The display presented to the user is as shown in Fig. 1. Theoretical component peaks unrelated to the experimental data have been added above and below the main desorption peaks to indicate the form of the solution. The largest experimental peak has been matched by three component peaks, with maxima at the lower apices of the base-up triangles. The pointer being moved by the thumbwheels is the point-up triangle. The function being executed (MOVE PEAK) is printed in the upper left hand corner. A spectrum identification number (08 164) and the pointer ordinate (temperature) (1428) appear in the upper right corner.

A further series of commands permits the user to keep the results of his modelling attempt. Parameters of the theoretical curve just generated may be stored on disc for future regeneration of the curve. Plotter output provides a paper record of the curves and peak markers. The parameters which describe the theoretical curve may be typed out by the console typewriter for a permanent record or the same data can be displayed on the CRT for quick assessment.

Analysis of Rocket Borne Plasma Probes

The interactive graphics facility provides for editing and preliminary analysis of the telemetered volt-ampere characteristics of plasma probes. The scientist is able to examine his data, smooth through degraded regions, and make enough measurements on his data for a preliminary assessment of their value. Furthermore he may resolve any ambiguities which are likely to cause problems during detailed analysis later on NRC IBM 360/67 computer. The digitized data are entered via magnetic tape into the graphics system where they are stored on disc. Data from a rocket flight are recorded as "cycles" each approximately 2,000 samples (1 to 2 seconds). Each cycle becomes the unit length for data transfers from disc to core. Refresh rate considerations limits data display to about 500 samples. Continuous windowing over the cycle is provided.

A brief overview of the commands available to the scientist follows. NEWCYCLE transfers a cycle from disc to core. Viewing of this data is through a window approximately 1/4 cycle wide. The cycle to be entered is selected

by the keyboard and is either +1, -1, +10 or -10 cycles from the current one. SUMMARY presents in tabular form on the CRT key measurements from processed cycles for comparison with similar measurements for the current cycle. Information is entered from disc by keyboard control as for NEWCYCLE. Three gain ranges 1X, 10X and 100X exist in the measured data. Abrupt changes in recorded data occur at the transitions after the 1X and 10X ranges but not after the 100X range. The scientist is forced to specify the end of this range with the END 100X command. The GAIN CHG command initiates a search by the computer for ends of 1X and 10X ranges and displays its selection on the CRT. The scientist may change incorrect choices by moving a pointer to where he thinks the transition occurred. Drift in the DC zero level in each of the three gain regions may be corrected for by using the ZERO command. The SMOOTH command allows the scientist to specify smoothing of data between sets of selected data points. The COMPOSIT command unfolds the curve into a single scale display, compensating for zero offsets. The LOG command generates a curve from the natural logarithm of above curve data. Measurements are of two types. One group records a pre-determined set of measurements on the recorded data, whereas the command PAIRS permits the scientist to specify from the CRT console up to 50 coordinate pairs to be recorded for later processing. During all measurements the scale of the displayed curve may be continuously changed.

Another group of essentially housekeeping commands provide for; a plot of the cycle, hard copy of the summary data at the teletype, generation of a magnetic tape with the cycle data and its measured constants for system 360/67 processing, and saving and restoring the scientist's data library on disc. Exact gain for the three regions is entered from the teletype as well as scale factors for numeric readouts. Each parameter which is measured by the system exists as duplicate constants, one scaled for display and one at the scale of the users data and which is recorded. Each time a new cycle is entered those constants at the "user" scale are destroyed in preparation for a new set of measurements but most of those at the display scale are not changed. This technique provides the equivalent of memory to the system and so facilitates rapid analysis over areas of the rocket flight where data is changing slowly.

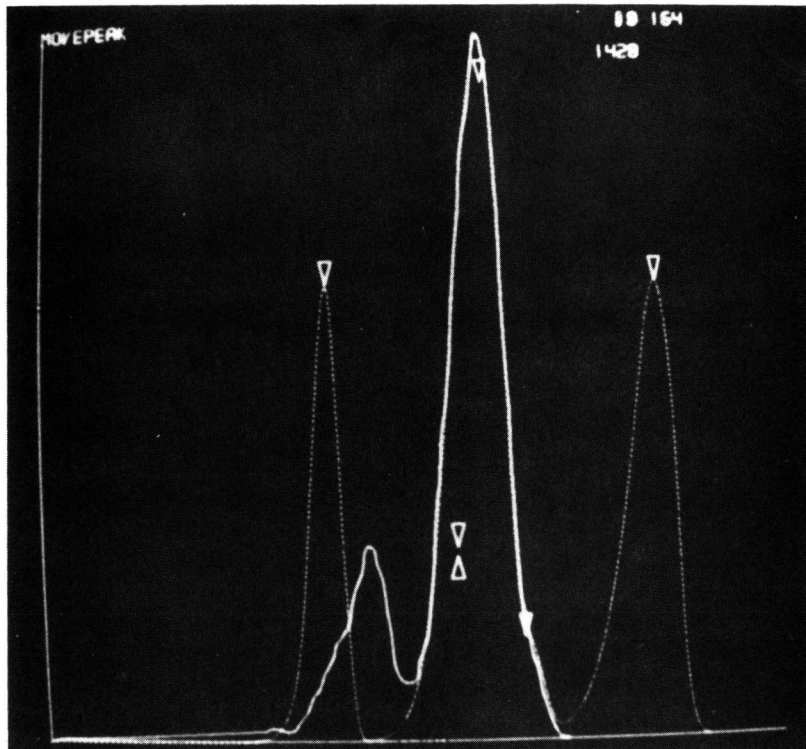


Fig. 1 - CRT display for the analysis of thermal desorption spectra

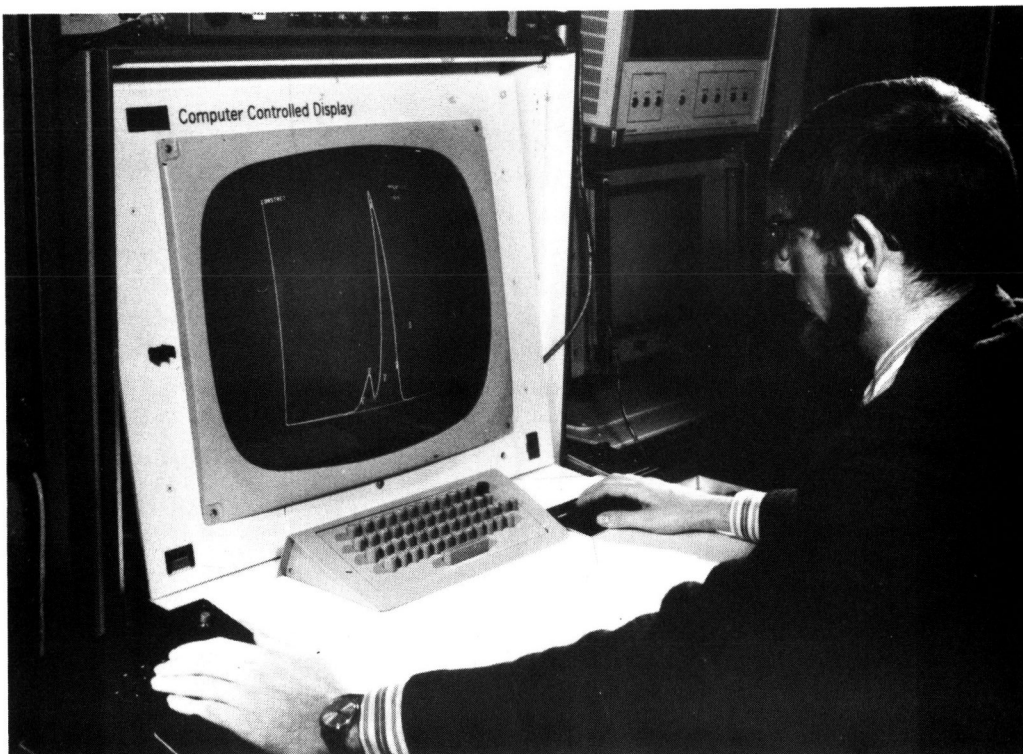


Plate 1 - User orientation relative to CRT and the control devices, keyboard at left hand and shaft position encoders at right hand.