Graphics and digitizing automatic transduction of drawings into data bases

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INTRODUCTION

Figure 1 is a computer graphic rendition of a sketch of Einstein by Hans Erni. The original hard-copy source document was digitized in less than 1 minute by a Visicon AD-1 system. Approximately 20 seconds of IBM 370/165 digital computer time were then required to organize the resultant data into list structures and generate plot commands. The plot itself required roughly 7 minutes of Calcomp 718 digital plotter time. The entire process was simple, fast, accurate, and inexpensive. It is a sample of the power of an automatic digitizing system operating in a computer graphics environment.

The automatic digitizing system used contains a drum type raster scanner which yields the digital coordinates of the black points on hard copy drawings. These coordinates are then processed by a graphic collation software package to produce a list structure representation of the black areas on the drawing. These list structures can then be processed to yield such plots as shown in Figure 1.

DIGITIZATION PROBLEMS

Historically the development of computer graphics has been severely constrained by an inability to transduce hard copy drawings into computer data bases in an economical and rapid manner. Although excellent methods have been developed for displaying and recovering permanent copies of drawings from such data bases, the input mechanisms have been largely constrained to tedious and error prone line tracing methods inadequate for complex work. In essence, computer graphics has operated as a television industry with no television cameras. The development of the automatic digitizer has now provided the camera, the graphic collation software, the signal converter between the camera and the television set.

The magnitude of the task of transducing even a simple drawing into a computer data base may be glimpsed by examining statistics taken from Figure 1. This drawing of Einstein required 531 distinct pen strokes which were constructed from 13,475 straight line segments. The digital representation of such data more than amply justifies the adage that a picture is worth a thousand (computer) words.

The visual information in this drawing is contained in the nuances of the shape and thickness of the individual lines that compose it as well as the spatial inter-relationships of those lines to each other. Each line carries its own important message, and the impact of the drawing is reproduced only by faithfully copying all of its features by a camera-like process.

Line tracing methods involving such equipment as manual digitizers, automatic line followers, or graphic data tablets are inadequate as they cannot capture the drawing in its original form. Aside from the fact that they do not standardly record variations in line thickness, such devices suffer from positional accuracy problems generated by the requirement that they track individual lines separately. On the one hand there is a high correlation in the positional accuracy of the points which determine an individual line so that the detection and removal of errors by smoothing methods are ineffective. On the other hand, as there is no correlation in the positional accuracy of the points on separate lines, the inaccuracy of separate lines relative to each other can be twice that of the individual points themselves. As a result, traced lines can fail to intersect or intersect when they should not, and there is no contextual information provided which can identify and resolve the problem automatically. The resulting distortions can create large deviations in both shape and topology of the drawing which are exceedingly difficult and expensive to detect and remove.

These problems, however, are minor when compared to those a human can interject into the system when manual tracing methods are used. Errors of commission and omission become rampant when a human is required to concentrate both visual and motor skills in the laborious and tedious act of line tracing. His muscular coordination and mental attention will deteriorate rapidly if tracing is required over an extensive period of time. Although the equipment he uses is often highly accurate itself, the human is not, and worse yet his errors are not sufficiently repeatable for a verification process to be meaningful.
AUTOMATIC DIGITIZATION

Much of the power of an automatic digitizer is embodied in its ability to capture all the visual aspects of a drawing to an accuracy exactly specifiable by the mechanical and optical properties of the device itself. Its performance must be predictably repeatable within these known limits. Figure 1 for example was digitized at 200 samples per inch, and each digitized point was repeatable to an accuracy of 0.005 inches.

The power of the graphic collation process, on the other hand, is derived from its ability to transduce this data into graphic data structures in a rapid and efficient manner with no attendant loss of information. The graphic collator software performs this function in times essentially proportional to the length of lines on the drawing and independent of their complexity. The derived data structures are organized by curves in such a manner that distinct lines on the drawing are represented by distinct list structures.

As these data structures include both line width and line intersection information, they constitute both a pictorial and a topological representation of the source data to an accuracy identical to that of the digitizing process. Moreover, their manipulation and analysis can be performed by standard list processing techniques.

Figure 1 for example was obtained by plotting lines around the peripheries of the dark areas of the drawing. The points defining these lines were smoothed by least squares techniques to remove the 0.005 inch digitizer quantizing noise. Alternatively line thinning techniques could have been employed, or the data could have been fed directly to electrostatic (raster) plotting devices. As line connectivity information is also included, network analyses of the drawing can be obtained directly.

PROBLEMS OF AUTOMATIC DIGITIZATION

Unfortunately, automatic digitization does not yet imply that all desirable input functions will automatically be performed. First, the labeling, or identification, of graphic elements must still be done by hand. On-line methods can use standard interactive techniques employing such tools as data tablets, light pens, and joy sticks. Off-line techniques can profitably employ manual digitizers for locating and identifying important points on the source document. The computer correlation of these points with those derived through automatic digitization can be efficiently accomplished during graphic collation provided reference lines are included for orienting the document. The accuracy of the manual digitizer can now play a decisive role in resolving the identity of tightly spaced lines. Moreover, the human error factor has been greatly reduced as the muscular coordination required in line tracing is not involved.

The second problem involves the identification and removal of unwanted information which is included in the data because the entire drawing has been transduced. Such information is readily and economically identifiable provided it has unique localized characteristics. Noise, for example, is easily handled when it occurs in the form of isolated dots or short, thin line segments. Lettering can also constitute unwanted information if there is a requirement to replace it by coded text. Such lettering can be isolated if it can be uniquely described by its localized high spatial frequency characteristics. The recognition of individual letters is not necessary if the coded text is inserted and correlated by other means.

Automatic editing will in some instances not be totally successful, and human auditing of the results may be required. The effectiveness of such interaction on-line will be considerably enhanced if the data structures describing deleted material are available. The power of the system will still be in evidence even if considerable on-line manipulation is necessary. The suppositions are that the bulk of the task has been accomplished correctly, and that the interactive erasure of unwanted information on a line-by-line basis is a far easier and more accurate task than the creation of new information by sketching.

SUMMARY

This process is a realization of an economical, accurate, and easy method for capturing drawings for use in com-
puter graphics systems. The implication is a far more productive utilization of computer graphics console time with emphasis on image manipulation, editing, and analysis rather than on image creation.

The value of automatic digitization lies in its ability to rapidly and accurately transduce drawings into computer data bases. Such ability implies that drawings may directly act as the original source of information for the various purposes for which they were conceived. That is, the data base will be in one-to-one correspondence with its own drawing and may therefore hopefully provide the same information to the computer that the drawing does to the human.

The dream of computer graphics is of man and machine working intimately toward the solution of complex problems by combining the visual power of the human with the computational power of the computer. This dream is indeed realizable provided that the data upon which it must feed is readily accessible, for the strength and viability of any computer system is measured by the data which it processes.

REFERENCES

1. Erni, H., Study of Albert Einstein, Meggen, Lucerne, Switzerland.