INTERACTIVE CARTOGRAPHY AT THE ECU: REGIONAL GEOGRAPHY A LA MODE

S.B.M. Bell and D.P. Bickmore
Experimental Cartography Unit
Natural Environment Research Council of Great Britain

INTRODUCTION

This paper describes the Experimental Cartography Unit's system and its use as a practical tool in regional problems of the environment. It also discusses interactive working and the Unit's development of this technique over the last four years.

BACKGROUND

In 1974 the Natural Environment Research Council (NERC) decided that the Experimental Cartography Unit should formally become one of its component bodies, both in order to provide a "service function" to other institutes within the Council, and in order to continue to develop research within the field of automated cartography -- a process initiated by the Council nearly ten years earlier. It is unnecessary for me to dwell on the helpfulness of becoming formally part of the Research Council, and, in consequence, of being able to plan cartographic aspects of environmental research on a reasonably long term basis with many of our institutes.

Perhaps I should explain that the Natural Environment Research Council (NERC) is concerned in a range of disciplines across the board in environmental science. Besides geology and oceanography, there are experts on geochemistry, geomorphology and geophysics: equally so in hydrology, physical oceanography and marine biology: and, at a time when few disclaim interest in ecology, NERC's Institute of Terrestrial Ecology is acknowledged as one of the world's leading organisations concerned with research in this field. These specialists are, by their nature, continually engaged in "surveying" and in collecting data, often on an extensive spatial basis. Much of their "survey" is different in method to that of the topographical surveyor, and some of it assumes a base map. But the demarkation line between topographical survey and these thematic surveys has much less significance today than it had 10 or 20 years ago. Today there are more demands for geographical information about regions on a quantitative as well as qualitative basis, and for mapped information covering a wide range of coherent topics.

To this need, computer systems can bring a number of important facilities; the most important, perhaps, is the ability to correlate different sets of information about the region from data assembled at different scales and with different reliabilities -- "scale variable cartography." The ability to derive additional information from the facts observed is also important (oil field prospecting from geophysical sampling and from bore holes is an obvious example; slope and aspect derived

from contours is another; forcasts based on mathematical modelling is a third).
Another facility is that of offering geographical information in a great variety of
graphical forms, from the ephemeral to the definitive -- from a quick simple CRT
display at a terminal 50 miles away, to complex maps or atlases printed in many
colours: (and the difference in cost between these two forms does not necessarily
favour traditional methods). These are the kinds of thing that geographical infor-
mation systems are about; and today they are no longer figments of imagination.

In the NERC case much of the data that we collect is in digital form, or at
least comes for mapping in that way -- often as a mass of x/y/z triplets. But this
kind of information loses much of its significance unless it is set against a wider
topographical context. To understand patterns of global seismology, the eye needs
some world base map; to comprehend current movements in the Irish Sea, coastlines
and bathymetry are essential. Other kinds of environmental data -- e.g. vegetation
mapping -- may be collected on a sampling basis, and topography seems likely to play
an important part in establishing sampling frameworks, particularly if the right
information is available in digital form before the sampling survey starts. In these
kinds of case the Council's main effort and expense is in collecting, analysing and
displaying the specialised data; it follows that if the specialised data anyhow
requires computer processing, then base map information is also desirable in that
form.

At the same time, we are well aware of the difficulties posed by cost factors
in developing new work based on computers in this whole field. These difficulties
do seem to be particularly great if the automated system is designed to do little
more than can be done by manual methods, and is, at the same time, noticeably more
expensive. And where the automated system has to be constrained to producing exact
copies of "hand-made" maps, experience seems to show that traditional cartography
still remains cheaper: at a time of widespread under-employment there is some
danger that such a form of automation may seem socially unacceptable. Of course
this argument does not, of itself, justify more sophisticated systems, which must
depend on a range of input and output requirements that may be quite unusual in
cartography, sensu stricto.

ECU PROCESSES

Although this paper is particularly concerned with interactive cartography, it
is necessary to say something about the context in which this takes place, and to
describe, briefly, the equipment and the processes that precede interactive work.

PRE-INPUT EDITING

We find that at any one moment we may be handling seven or eight different
projects for quite separate areas, subjects, scales, etc. In addition, over 90% of
the work is for "new" mapping -- as opposed to the translation of existing maps to
digitised form. This is a far cry from "factory cartography" and from a steady
throughput of greatly similar documents. Before any document is digitised, a care-
ful detailed study is made of the compilation, so that it can be marked up with its
appropriate feature codes, and so that the relationships between different areas
that can be derived from the data, once it has been digitised, will be available.

Our system assumes that automated cartography must give back more than a line for a line and a point for a point. Complex areal patterns into which the data falls are part of the essentials that the system should be able to provide. The anticipation of these patterns is, like most forms of pattern recognition, very considerably aided by human editing: we do this generally -- but not exclusively -- before digitising.

We have already emphasised that some of our data comes in the form of point information, e.g. values at each of several thousand points, for a dozen or more different mineral elements derived from samples of stream sediment. Although such data comes to us checked and on a reel of tape, there are still editorial problems in anticipating and organising its cartographic relationships with, e.g. the stream pattern, the geology, etc.

DIGITISING

We are still operating on two "high accuracy" D-Mac digitising tables purchased in 1970. However, both of these now output data on-line to a single PDP-11/05 (plus disk) which checks the arrangement and syntax of the data and protests appropriately if it is unhappy. We also continue to use an overlay sheet of coated paper which is scratched by the digitising point to record what has and what has not been digitised. The digitising is generally by stream mode, for no better reason than that experiment with the kind of shapes and scales involved shows that this is often the quicker and better way for us. But the capability of selecting points and splining through them is there, and is used both in digitising and for adding lines in interactive work on the CRT. The output from the digitising process is a Dectape.

FORMATTING

This stage of our operation translates the PDP-11 Dectape from digitising table co-ordinates to those of the map projection required, e.g. British National Grid, and into the format of our two computers -- PDP-15 and PDP-9 (each with 24k of 18 bit words). At the same time separate sheets or parts of sheets are automatically placed in their correct juxtaposition, and their dimensions can be adjusted by bilinear transform is required. At this stage too, unnecessary co-ordinates that have accumulated during digitising are eliminated so as to produce a tape with just sufficient co-ordinates to produce faithful playback at 1:1.

A very important aspect of this processing is that of representing the digitised data on disk in a properly structured form. Each point or segment of line is allotted a unique number or identifier by the system. This can be found by the operator as and when he requires it, either by pointing at any part of a displayed map, or by naming the identifier on his teletype and seeing it displayed. The development of a cartographic data structure (see Appendix A) has been a prime concern of the ECU over the last four years, and we believe it to be basic to the ability to provide rapid retrieval of information from disk; and that, in its turn, is crucial in our interactive graphics. We particularly acknowledge the work done in this field by our colleague Dr. L. W. Thorpe.

Recently we have grouped programs for formatting digitised data on to disk so that they can be operated in batch mode, i.e. unattended overnight. Note also that the programs involved are 'exportable,' and by the end of this year we hope that these processes can also take place on the Univac 1108 system (see below): alternative routes are always desirable.

CHECK OF POSITIONAL ACCURACY

In our system the next stage is to play back the data set as a plot at digitising scale, so that a critical examination can be made solely of positional accuracy. Again, the process of computer playback takes place unattended and overnight -- over the night after the formatting run in a production schedule. Playback is by our AEG Geagraph flat bed plotter and on to film covering the 1.4 x 1.4 metres of the table. Our light spot projector, in this case, is purposely instructed to use line widths thinner than those on the original compilation. The checking stage that follows, since it is concerned only with comparing positional accuracy and presence as between the film positive and the original, can be a rapid one; and the eye and mind of the checker can concentrate on ensuring that all original lines have been reproduced faithfully. Mistakes (which may be due to errors on the part of the operator during digitising, or -- more rarely -- on the part of the equipment) are corrected either by re-digitising (this of course entails reformatting, etc.) or directly through inter- active graphics -- a much more rapid process, but a difficult one, e.g. for isolated shapes not intersected and located by other line patterns. A program called OVERLAY, which identifies line intersections, is a help in splicing new work to old with a minimum of redigitising within each line segment.

FEATURE CODING AND AREA CHECKING

After establishing positional accuracy, the editor now needs to ensure that feature codes have been correctly allocated to lines, and hence that the different areal patterns held in the information system are correct; and -- if that is what is wanted also -- to ensure the direct production of masks for a coloured map. Again, there are, by design, a number of methods available within the ECU system for this check.

The quickest way to call up each set of coded areas on the CRT and to see that each is correctly self-contained. But this involves the editor or operator in having access to the CRT, and with non-time-sharing computers (such as the PDP-15 or PDP-11 range) this leads to queuing and its tiresome consequences such as shift work. (The answer is to use a time-sharing computer system, and that is one of our main reasons for linking to a Univac 1108; this point is discussed further in Section 3).

An alternative way is to use our plotter, in its overnight mode, to play back maps of each different type of area. Typically, we may have 50 types of area to a specific data set, and to save time and cost we can combine up to 5 or 6 on to one plot by using different boundary symbols. Furthermore, we can reduce scale so as to get, say, 9 or 12 of these mini-plots on to one night's working on the plotter. (Bear in mind that the positional accuracy of the work should already have been dealt with -- this check is to ensure that all coded areas are complete and "water- tight.")

In the past we have found that feature code checking is a meticulous and slow chore that tends to increase exponentially with the complexity of the data set or sets, as when, e.g. topography, soils and administrative boundaries of the same area are overlaid. Any one line segment in the data set can well be the boundary and carry the codes of five different areal patterns to its right and left. To mitigate this, we are now developing an automatic checking program that will work through each feature code, examining the start, end and direction of each line segment. In this way the program will identify any that remain unclosed or odd: from this catalogue of suspects the program will then produce a tape that will display (CRT or overnight plot) a machine-made correction trace; indeed, it seems likely that the system itself

can be taught to correct some, at least, of the errors it finds (but informing the editor when it has done so).

It will be obvious that once the system knows how to access the areal patterns in the data base, it can, from this knowledge, address other matters. For example, it may be desirable to omit all areas of less than 1 hectare of a particular feature -- say, woodland -- when playing back a map at a smaller scale, or to omit them when contiguous with some other feature, or when that category of woodland has some associated statistical measurement. The range and variety of possibilities is formidable. And the fact that many map makers or map users have never contemplated that they could manipulate geographical information in this way does not mean that, given the opportunity, they would not find this a powerful additional cartographic tool. This kind of manipulation on large and complex data sets does, however, demand really efficient and powerful computing linked, e.g. to a Codasyl-based data management system; since that inevitably tends to be expensive, and in short supply, it also points the need for efficient computer communication links -- a field of prime interest in modern computing, and one in which the quantities of data necessary for cartography pose special problems.

AMALGAMATION OF DATA

Another facility of the system is that of amalgamating data -- both in terms of topics for the same area and in terms of area by area relationships. The ability to amalgamate -- and to un-amalgamate -- data is frequently a useful short cut for the cartographic editor, e.g. enabling him to isolate one group of features or one section of the map where there are heavy corrections, and then to reassimilate them with the other elements of his map. In another instance, where ecological information about coastlines, rivers, lakes, etc. had been gathered by grid square, it was possible to map it automatically to the actual segment of coastline or river that fell in the appropriate square. The amalgamation programs are also valuable tools in handling edge match discrepancies; a narrow edge strip of the two adjacent sheets can be unamalgamated from the main files and presented on the CRT, so that the edges can be tidied up heuristically in rather the way in which these things are handled manually; most of our edge-match problems seem simply not susceptible to rule of thumb solutions which could be neatly encoded in an ad hoc program.

DIGITAL DATA IMPORTED FROM "OUTSIDE""

If it was only able to handle data that it had digitised itself, the ECU's main objective would be defeated. There are within NERC -- and outside it -- a growing number of data collecting agencies who satisfy three main conditions: (a) concern with an environmental problem that has significant geographical variations; (b) data that is in digital form (usually x/y/z); and (c) a need to see it expressed graphically as well as statistically. In the early stages of data collection most organisations develop their own idiosyncrasies of digital format: quite often these seem to be imposed by the particular equipment available to them. But sooner or later there comes a need to exchange data, and with it the usual teething troubles and frustrations of translation from format to format. NERC is currently developing its data exchange system, which becomes particularly important where there is a range of different equipments and an interest in seeing the effects of processing data with someone else's more elaborate programs and on equipments that may offer more elegant graphics.

One of the main demands by all environmental scientists is to have their data sets "contoured"; and there abound a multiplicity of programs, each liable to produce significantly different results (although in fact rarely compared). In 1974 the ECU acquired for NERC use the large American program SACM (Surface Approximation and Contour Mapping) from ACI of Houston, and this is now mounted on both an IBM 370/195 and the NERC Univac 1108. This is not the place to discuss automatic contouring programs, none of which is perfect (broadly speaking, the smaller, the worse). They produce different results from hand contouring, both in terms of factual consistency and of graphic cosmetics; with data sets of thousands or tens of thousands of points they score heavily. Like most contouring programs, SACM first derives a grid of values from the data; contouring or the drawing of cross-sections or perspectives, etc. is handled as a second and subsequent stage, and its output is a tape which can be played back on whatever graphics device is convenient -- e.g. a Calcomp drum plotter. We are able, for example, to arrange for SACM tapes to be imported to the ECU, where they can be plotted direct by our flat bed machine, where that is required; alternatively, they can be introduced into our system, structured on disk and edited interactively in relation to other data, e.g. topography, already there.

As we develop the potential of our 9600 baud link line to the Univac 50 miles away, so we expect to see more and more interactions of this kind - and, hopefully, to the point at which it is of no concern to the user which machine is doing what. There are, for example, groups of problems in Engineering Geology that demand just this kind of conversation between an expert geologist and data deriving from relief, land use, drift geology and bore holes. Another field in which this kind of graphical interaction seems to be required emerges from the building of mathematical models of environmental processes. This work has of course the added complication that it may introduce a dimension of dynamics into the cartographic display; we clearly have a lot to learn about how we can best read dynamic maps, let alone how we can interact with them; the computer-generated film can have a useful expository element about it, but as a research tool it has severe shortcomings.

The assumption that contouring is the only valid method of displaying a mass of observations at points that are spatially distributed seems to come all too naturally to those unfamiliar with alternative cartographic forms. But there are cases where it is important to show a number of separate surfaces simultaneously, or to display by symbols the exact quantities as observed at points and to let these speak for themselves. The principal problem of using quantified point symbols arises in areas of congestion where they tend to overlap and obscure each other. (The solution of moving the symbol away from its true location so as to be legible cannot but distort the pattern, and hence seems questionable; equally unsatisfactory is to use larger and larger scales to give more room for a particular style of symbol.) Our rather unoriginal solution is to use wind-rose type symbols where the vector indicates the quality measured and the line length of the arms shows the quantity. This has been extensively adopted in geochemical mapping, where it is, as ever, important to see through the specialised information to the topography, etc. below. In this case we import tapes (in an agreed exchange format) and display them on CRT so as to determine optimal scaling for the symbol arms, or carry out any other editing required before final plotting of positives.

CARTOGRAPHIC "FINISHING"

Given a clean data set, it is gratifying how rapidly finished reproduction material emerges in all its crisp elegance; cleaning the data is still a long slog, so it is just as well that there are some rewards. The quality of work from automatic plotting machines does seem as high as anything produced by hand; but despite

this, very little attempt has been made to explore new graphic possibilities in cartography, and only too often these expensive and elegant machines seem forced to mimic manual specifications laid down fifty years ago.

Apart from drawing attention to this unhealthy symptom from which we all seem to suffer, we mention here two aspects of cartographic finishing that we have found important in ECU practice. (I do not propose to discuss the particular refinements of plotting tables, light spot projectors, or even laser beams, which are adequately dealt with in manufacturers' literature.)

First, it seems noteworthy that high resolution graphics can sometimes contribute to derived geographical information more cheaply and rapidly than by computational means. For example, one particular conservation need was to identify land in the Shetland Islands that lay more than a quarter of a mile from roads. The road network was plotted using a thick symbol whose width represented half a mile at a selected scale. The resulting black "bands" were then masked by the coast and water to produce the areal pattern required. The same technique has also been applied to deriving slope from digitised contours. While these methods lack the finesse and flexibility of a computational approach, they can provide extra routes to a particular solutions.

Secondly, is the ability, which we now have, to organise a tableful of plots for unattended overnight operations; automation is intended to be automatic. This procedure depends on an accurate sectionalising of the large area of our plotting table so that different maps (or the different colour/tone components of a single map) can be assigned to different areas of the table by giving appropriate offsets to different sets of corner points. The master program that controls the process is mounted on one of the Dectapes on our PDP-9, and details of the offsets required, plus the symbols and pecking patterns for the lines and points for each separate plot are punched up on paper tape ad hoc. The program calls up its map data from magnetic tape which has come -- on the completion of editing -- from the disk. The output -- waiting on the table in the morning -- is a film positive, ready for developing, preparation of peel coats (whose peeling is vastly simplified by the omission of any lines that do not form the boundaries of particular colour masks), tint laying, plastic colour proofing and, finally, lithographic machining -- assuming, of course, a traditional cartographic end product whose multiplication is, of itself, a not uncostly business.

INTERACTIVE GRAPHICS IN THE ECU

This section of the paper describes in some detail the development of the ECU's approach in this interactive field. It will be evident that one use of interactive graphics in cartography is as a means of rapid -- and hopefully economic -- correction of errors introduced in collecting or in processing data; another use is in making modifications necessary for smaller scale playback, for new maps, and the like. These uses of interactive graphics assume that the cartographic end product is a printed map. Another use for interactive graphics is comparable with the work of computer aided designers and it assumes that the ephemeral map as displayed and interrogated on a CRT will itself become an end product. In our own immediate experimental work over the last four years we have concentrated on the former, and we believe that this experience leads in to other uses. As time sharing systems become more general, as interactive display terminals become cheaper and more

widespread, so interactive cartography does seem certain to become a practical and useful supplement to the printed map.

PRIMITIVE STAGES OF INTERACTIVE GRAPHICS

It is sometimes assumed that interaction demands very expensive equipment -- large fast disks and refresh displays. This is not the case. Of course there are disadvantages to implementing interaction cheaply and simply; many of these became evident in the first interactive system in the ECU. This was working as a part of our automated process in early 1971.

The map data was, in those days, held on magnetic tape, with a summary of each line and point in a core table. A cheap storage display (c. 2000 Tektronix 611) was used to display the map -- to see that all was well. On a storage display the picture is plotted once and remains visible for up to an hour. A cheap joystick (500), that was merely an 18 position switch, was used to provide interaction. The joystick directed a "refresh" cursor about the display screen, using the 611's small refresh point plotting ability. Our computers were a PDP-9 and a PDP-15, each (then) with only 16k of core (neither with time sharing, of course). With this system it was possible to "window" into any desired part of the map, magnifying it on the screen. The operator could indicate any line or point and delete it or change its significance by altering the feature code. If he required a hard copy he could take a polaroid photograph of what was on the screen. The disadvantages of such a tape-based system could be summarised as follows:

> It is not very interactive. Specifically, it takes a long time to read the data from tape for plotting.

> In addition, the whole data set must be read. It is not easy to skip or search for parts of it.

> Lines cannot be read backwards, as is necessary when joining two lines together.

> No data can be inserted into the middle of the data set.

> The display screen is not large enough to display a whole map in legible detail, nor accurate enough to be used for checking absolute positions of data (though relative positions are displayed).

> In more general terms, it is wasteful to have a dedicated computer for on-line work of this kind, since valuable computer time is wasted while the operator deliberates. On the other hand, effective time sharing demands a major computer.

INTERACTIVE CARTOGRAPHY IN OPERATION AT THE ECU NOW

The main differences between the humble beginnings of interaction and the current ECU system are in speed and the number of types of interaction that can be performed. In consequence, the ways in which the system is used are also changing. The operators still use the system extensively for error correction, but now it is becoming fast and powerful enough to be used by editors for "post-input" design of new maps, if necessary in an interrogatory mode with the specialists who collected the original data in attendance.

The vast increase in speed (about tenfold) and in the number of different inter-
actions is possible through a major change in the way the map data is held. Now it
is on disk backing store (10 million word disk pack) in the form of a direct access
file structure called "Mark I". This structure allows the operator direct access to
any line or point on the map (assuming that its identifier is known). Thus he can
read only a required type of feature, or combination of features, or, as before, the
whole data set. The structure is briefly described in Appendix A; and each inter-
active graphic function in the system is discussed in Appendix B.

The main facilities included in the interactive graphics package, in conjunction
with data organised by the Mark I data-structure, are shown in Figure 1. In general
these facilities can be used either by typing in co-ordinates or identifiers at the
keyboard, or -- more usually -- by indicating points and lines on the displayed map
on the screen using the joystick.

DISPLAY FACILITIES				
WINDOW and magnify data	**GRID** -national grid -mm on the map -grid for display	**SYMBOLS** -display point data with chosen symbol -display with code for the feature	**SELECT FEATURES** display only chosen features, solid, pecked or hatched	**TRANSFORM** rotate, sheer, mirror the map - any bilinear transform

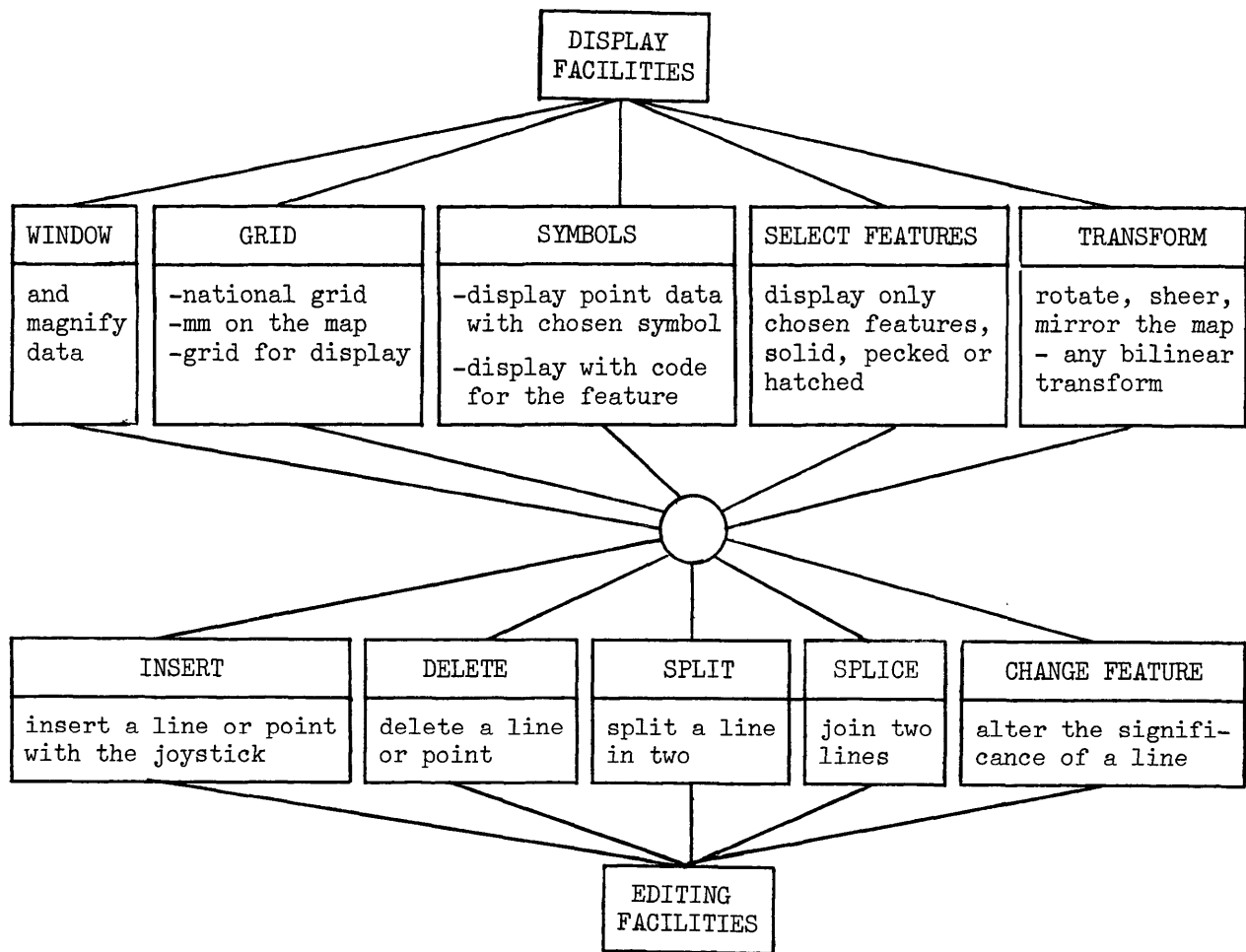| INSERT	DELETE	SPLIT	SPLICE	CHANGE FEATURE
insert a line or point with the joystick	delete a line or point	split a line in two	join two lines	alter the signifi- cance of a line

EDITING FACILITIES

Figure 1

INTERACTIVE GRAPHICS FACILITIES

How far does this present system based on our Mark I structure overcome the disadvantages of our original system with its reliance on magnetic tap backing store?

It is more interactive. Because of the Mark I structure it is possible to access only the relevant parts of the data from disk as and when required. So there are more ways of solving correction problems and each operation is completed much faster. (Observe, however, that another speed limit has now been reached, for the data can now be read from disk rather more quickly than it can be plotted on a storage display.)

Lines can be read backwards, as well as forwards, enabling them to be joined.

New data (e.g. corrections) can be inserted anywhere in the data set.

The hardware (storage tube) is still relatively cheap and simple.

CURRENT ECU DEVELOPMENTS IN INTERACTIVE CARTOGRAPHY

In spite of these improvements, two significant disadvantages remain. The first, and operationally the most serious, is that the system still is not a time sharing one. The very fact that the interactive process is a faster and more practicable cartographic tool now serves to attract more work to it; this tends to lengthen the queue of frustrated people waiting to use it. The second disadvantage lies in the fact that the storage displays are small and have low resolution; hence they require more "blow ups" of complex areas, more separate checking stages, etc., while providing a relatively "unmap-like" display. Current work is concerned to meet these two main problems and some closely related issues.

TIME SHARING

We have placed great faith in the sophisticated potential of Univac 1108 that has recently been acquired by NERC especially in the matter of time sharing and of data management. A link to that machine -- 50 miles away -- by a 9600 baud private telephone line, plus a PDP-11/05 communication concentrator will, we believe, enable us to use this "remote" equipment from within the ECU as though it was our own. (At the time of writing we already have three teletype terminals linked simultaneously and successfully in to the system.) However, if we are to increase the number of graphics terminals in the ECU from which map editing can take place, the display hardware needs to remain as cheap as possible. With this in mind, we are developing our graphics software so that it can be used on similar storage tube displays (Tektronix 4010) to those we have been using over the last four years -- including the ability to use the available refresh capability in these displays to point at or enhance details or the stored picture.

UNIVAC SOFTWARE

Our graphics terminals plus our communication link should now serve as periscopes into the data on the Univac. They should also enable us to transmit data in both directions, to use our own software on the Univac, to use existing Univac software (e.g. statistical packages) to process our data, and to revamp many of our existing programs for more efficient operation in the much greater freedom of a large computing system. We look for benefits, in particular, in the use of Univac's

Data Management System 1100 (now usable by us in Fortran).

LARGE HIGH RESOLUTION DISPLAY

We are currently commissioning the new HRD 1 plotter produced by Laser-Scan Ltd. of Cambridge. This is only the fourth of these equipments to be manufactured, and the first to be used in predominantly cartographic mode. This display (which draws particular lines and symbols and does not operate on a purely scanning basis) will be driven by our PDP-15. We anticipate that it will draw at about the same speed as the storage tube, but over an area of roughly 100 x 70 cms., as opposed to 20 x 15 cms. We shall be using its refresh capability to rather the same effect for interrogation as on the storage tubes. Furthermore, the display itself will be "accurate" and without the pin-cushion distortions of the (very much cheaper) storage displays. Its higher resolution should also enable it to display lettering elegantly and rapidly, and enable us to annotate maps. And since the ECU data structure enables us to generate and store records of areas, we anticipate that Laser-Scan will give us the ability to shade in colour patterns direct for use as reproduction material, though whether this will be economical is another matter. In the first instance we expect to use Laser-Scan primarily as an interactive editing display, with the assumption that the final data will be plotted as now -- unattended overnight. However, hard copy of any display can be provided in microfiche form; eventually we hope also to develop a "long light lever" from the Laser-Scan that will provide cartographic quality film positives at scale.

While Laser-Scan has all the appearance of being a valuable cartographic tool, the hard fact remains that it costs about 20 times more than a storage tube -- and we shall have only one. Our operational plan, therefore, is to carry out as much routine editing as we can on the small storage tube terminals and use Laser-Scan for complex areas or for problems demanding the accurate display of large maps which seem likely to result from the increasing geographical extent of the data bases we are able to hold on the Univac.

CONCLUSIONS


OTHER TYPES OF DISPLAY

In discussing the route which we are taking so far as interactive cartography is concerned, it is worth noting the speed with which technology is still advancing in this field. One alternative to our storage tubes-plus-Laser-Scan configuration would be the use of display that plots entirely in refresh mode, and does so at least ten times more rapidly than on a storage display or a Laser-Scan. In these devices each vector must be replotted about every thirtieth of a second to remain visible, and consequently a buffer or satellite computer is required to hold the current picture for refreshing or for interaction (usually via a light pen). However, these refresh displays (which are of great value in many computer-aided design applications) do not have screens much larger than those of storage displays; they also tend to cost about as much as Laser-Scan (i.e. 20 times more than a storage tube). For the future, too, there is the likelihood of colour displays and a whole rather dazzling range of television-type possibilities, with greater or less possibilities of interaction, and at costs which may eventually become "economic."

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Developing countries, faced with real problems of health and hunger, may well feel that the money and effort spent on trying to set up geographical information systems could be more practically employed. Some may be concerned about loss of jobs; some about lost craftsmanship; others have argued that the working cartographer yearns for new gadgets and the technical challenge of automation is a socially valuable end in itself. Many more will be worried about making large capital investment at a time of such singular technological change. But, surely, these problems are characteristic of any renaissance, and cartography today is certainly in a state of flux.

This, we conclude, is a proper setting for an "experimental cartography" which should play its part in examining new means of understanding the environmental patterns and processes on which we all depend.

APPENDIX A: THE MARK I DATA STRUCTURE

Each sinuous line or individual point in the data is represented as an entity in the data-structure. A point has a single 'IA' (image attribute) record. A line also has one IA record or descriptor, plus one 'SG' (segment graticule) record containing all the internal points for the line in order of digitising. Each IA can be accessed directly by its identifier. IAs can also be read sequentially; either all of them, all with the same feature, or all with the same logical combination of feature codes. SGs can be read sequentially, or a single SG can be accessed from the corresponding IA.

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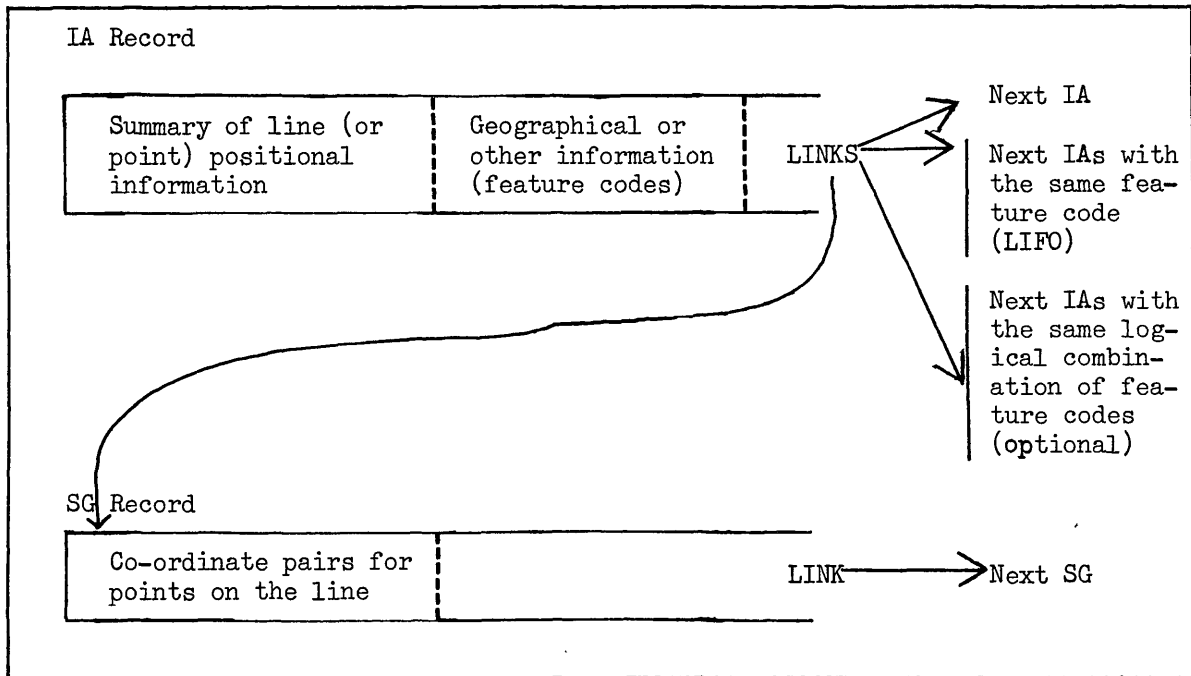
APPENDIX B: A BRIEF DISCUSSION OF HOW EACH INTERACTIVE GRAPHICS FUNCTION IS
CURRENTLY IMPLEMENTED

JOYSTICK TO DATA STRUCTURE: BRIDGING SOFTWARE

     The joystick cursor is displayed by the same software device handler (for the
Tektronix 611) as displays other refresh markers and stored lines and points. When
the operator indicates a direction of N, NE, E, SE, SW or NW with the joystick, the
software updates the position of the cursor by the minimum amount in the direction
indicated. After a timed wait, which may be 'long' or 'short,' depending upon the
value of 'Z-button' that the operator can depress on the joystick, the joystick
direction is sampled again and the cursor position updated in the appropriate direc-
tion. The current cursor position on the screen is returned at the end of the
sequence, signalled by the operator depressing the 'Z button' in neutral. The
screen co-ordinates of the cursor are transformed according to the current window
and other transform, if any, on the displayed map. The transformed co-ordinates are
matched to the start and end points of lines, or single points, held in the IA records.
Only the IA records of the feature(s) last plotted are accessed or read. The search
is conducted first within a tolerance, and second, if that is unsuccessful, for the
nearest start or end of line or single point. The operator is informed which entity
has been chosen with refresh markers, and can choose to continue the search for other
entities in the vicinity without moving the cursor, if he wishes, although in general
this is not necessary.

WINDOWING, MAGNIFYING AND SCISSORING

     The desired window may be specified either by indicating the centre on the
current plot with the joystick and the magnification with a function button, or by
typing the map co-ordinates of its origin and its magnification at the keyboard.
Only two to a positive integer power or one is allowed. This means that the multi-
plication of co-ordinates from the data can be accomplished in assembler, by simple
shifts, if desired, to increase speed for computers with no floating point processor.
Determining which sinuous lines of the data lie within, or partly within, the current
window is performed by using two algorithms. Firstly, the maximum and mimimum points
reached by every line are held in the IA record. If a conceptual rectangle round
these does not overlap the window, then no part of the line can, and the SG record
containing the co-ordinate pairs is never accessed. If there is overlap, each vector
in the line is tested by a software implementation of Ian Sutherland's clipper divider
algorithm, and that part, if any, that lies within the window is plotted.


SPLINING IN LINE INSERTION

     The operator can insert a line by specifying the start point with the joystick
cursor, any number desired of internal points, and the end point. The graphics pack-
age will join the points given either by straight lines or by a smooth curve. For
the latter cubic splines are used, calculated by a modification of Maconologue's
algorithm.

JOINING TWO LINES

     The operator indicates which two lines he wishes to join either with the joy-
stick cursor or by typing in the two identifiers. The program calculates which of

the three possible ways of joining the start and end points of the two lines produces the shortest joining line, deletes the two original lines, and adds to the data structure a new line consisting of both originals plus a straight join.
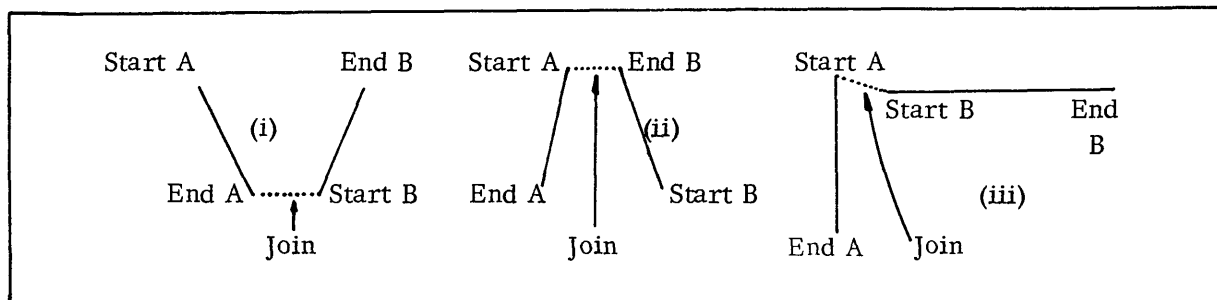
In case (iii) it is necessary to read either A or B backwards and reverse the original order of the co-ordinate pairs on storing.

SPLITTING A LINE

The operator indicates the point at which he wishes to split, using the joystick cursor. The program will split the line either at the base of a perpendicular thrown from the indicated split point on to the line (i), or, if no such perpendicular exists, at an existing internal point on the line (ii), always providing that the distance from the indicated split point to the calculated split point is a minimum for the line.
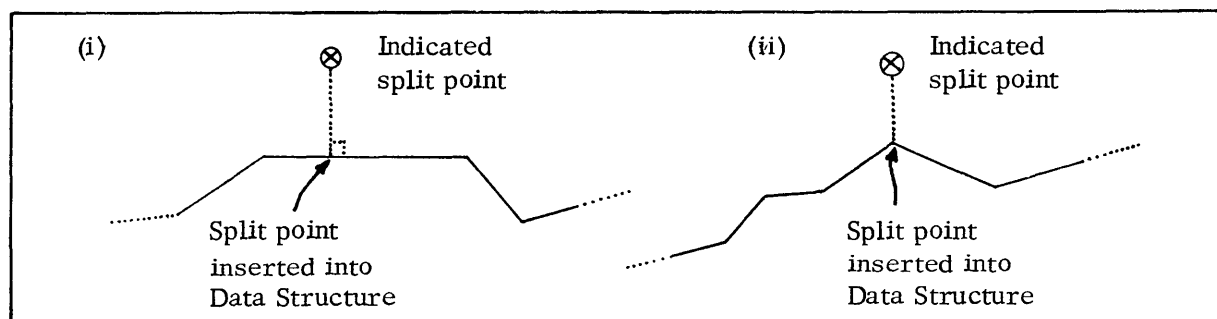
Each straight vector comprising the line is considered in turn. Two algorithms based on spike removal and line tolerancing reject the calculation of a perpendicular base if the indicated split point is too far from the current vector. The calculation for the perpendicular involves floating-point processing and is thus lengthy. For a small percentage of the vectors a perpendicular is calculated. Either the base or an existing internal line point is fed to a fast algorithm for finding the nearest of a series of points to a given point. (This is also used in the bridging software, B.1). The original line is deleted and two new lines inserted into the data structure.

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CO-ORDINATE SYSTEMS AND TRANSFORMS

The systems and the routines used to move between them are indicated below.
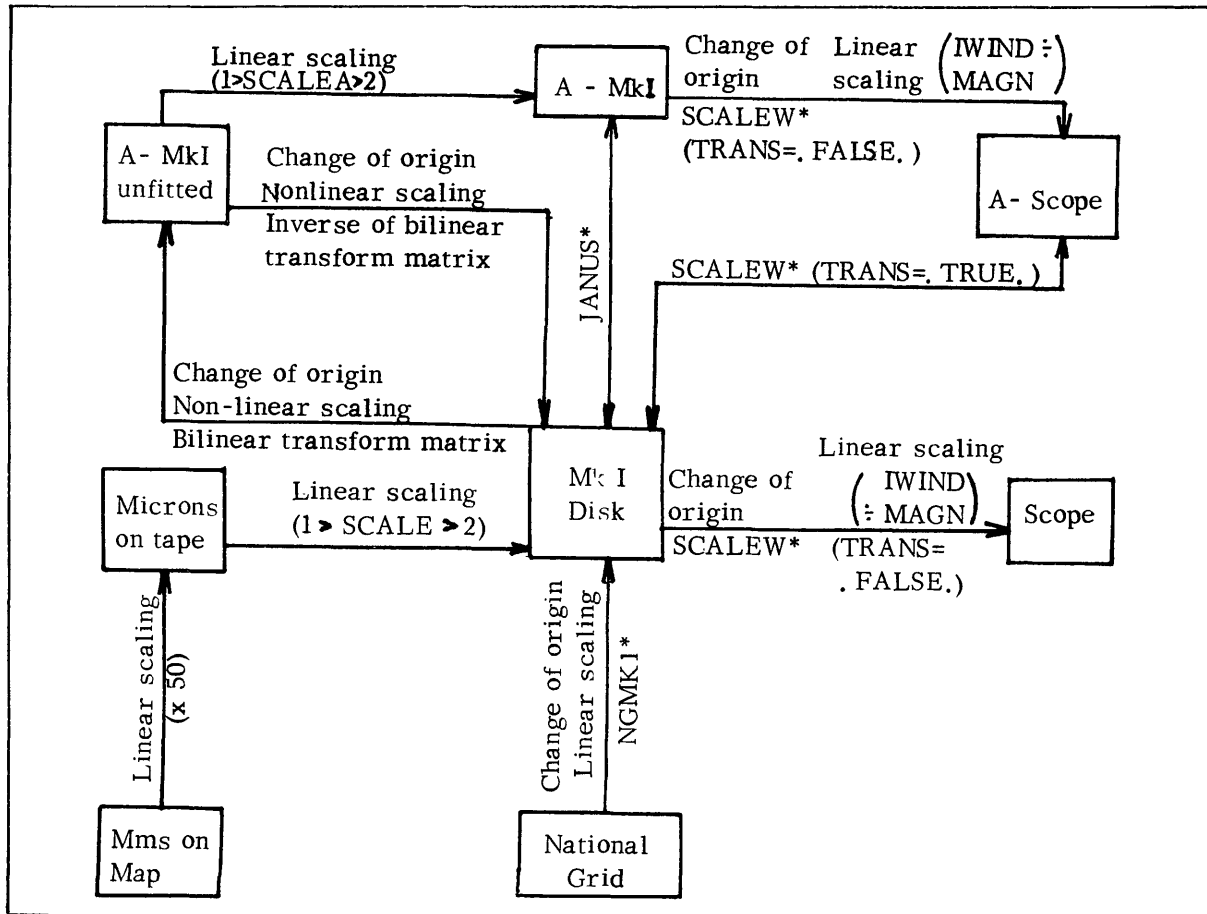
If a generalised transform is desired, the operator types in four new 'corner points' for the transformed map, and a three by three matrix, and its inverse, is set up to produce the required transform.

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1. Bell, S. B. M., Software and hardware for a DEC PDP-15 or PDP-9 Computer to enable the VPA15A CRT to be used with refresh points, and also in an interactive mode, DECUS Proc. 1971 Seventh European Seminar.

2. Bickmore, D. P., New Developments at the ECU: Cartographic Data Banking International Cartographic Association, Ottawa 1972.

3. British Cartographic Society, Automated Cartography, London 1974.

4. Thorpe, L. W., Automatic Contouring Using Oceanographic Data, ICA Technical Symposium, Holland 1975.

5. Reference may also be made to Proc. Commonwealth Survey Officers Conference 1967 and 1971 for earlier developments at ECU.