APPLIED COMPUTER GRAPHICS IN A GEOGRAPHIC INFORMATION SYSTEM - PROBLEMS & SUCCESSES

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ABSTRACT

A Geographic Information System (GIS) in the general sense refers to systems which collect, store, manipulate, report and **display** data which are referenced to geographic locations. As opposed to automated cartography, where graphic output is paramount, geographic information systems often have developed graphic output as an after-thought or secondary product. The Canada Geographic Information System, (CGIS) the world's first GIS, was designed (in 1965) with no graphic output capability, but now some 20 years later, provides its broad user community with an extensive variety of interactive and hard-copy graphics on a day-to-day basis. These graphics are applied to problems in land evaluation, land use monitoring, natural resource planning, wildlife habitat conservation, and so on.

Three categories of graphic outputs in map form are required, interactive displays, working diagrams and publication quality diagrams. These have been successfully achieved using remote interactive colour and monochrome terminals, ink-jet plotters, vector-based plotting on a high quality drum plotter and the direct production of publication quality colour separates on a large format optical scanner with laser plotter capabilities.

INTRODUCTION

A Geographic Information System (GIS) is a system designed to capture, store, manipulate, retrieve and **display** data which are referenced to geographic locations. Such systems are distinct from **automated cartography** where the primary goal is the production of printed graphic output. In a GIS graphic output represents only one mode of data retrieval and only a subset of the system functions, which may include a wide range of spatial as well as non-geometric data manipulation. Graphic output capabilities have often been developed as an after-thought to a GIS which was primarily designed for tabular statistical reporting. In practice, however, the output of graphic images in the form of some sort of "map", almost always forms part of the retrieval repertoire of a modern GIS.

The Canada Geographic Information System (CGIS), the world's first GIS was initially implemented (in the early 1960's) with no graphic output capability. Now, over 20 years later, it is incorporated into the comprehensive Canada Land Data System (CLDS) and provides an extensive variety of interactive and hardcopy graphics on a daily production basis. These are applied to problems in ecological land evaluation, land use monitoring, natural resource planning, wildlife habitat conservation, and so on (1). The implementation of computer graphics techniques into a high volume multi-user production environment has been a long and gradual process presenting a series of challenges to system designers.

Graphic Output Requirements of a GIS

There are two principal types of graphic output required in a GIS - **Statistical Graphics** which include conventional displays such as bar-graphs, pie charts, scatter diagrams, linear plots etc, and **Cartographic Graphics** which include a range of map-like products. Statistical graphics are addressed easily by the many packages available and are hardly unique to the GIS.

The cartographic output requirements are more challenging and range from simple diagramatic maps where no spatial accuracy is expected to large size monochrome or colour maps with accuracy approaching that expected of high quality production printed cartography.

Any cartographic product presents challenges for computer production because of the need to combine together vector elements such as: line-work, space filling elements such as polygonal areas, textual annotation in several fonts and sizes and other special features such as scale-bars, north-arrows, borders, legend boxes, etc. (2). These requirements are far more complex than any other form of graphics with the possible exception of the simulation of three-dimensional objects. In addition there is an inevitable element of esthetics to be balanced with technical accuracy.

These graphic outputs fall into three categories according to their intended use, as follows:

1) **Interactive Analysis Graphics**
These graphic outputs are required for interactive analysis of geographic data bases mainly by users seeking to explore relationships between data elements, and to a lesser extent to make directly land resource decisions. The essential query is "show me where" qualified by various attribute and/or spatial criteria. The user wishes to select, display the mapped result, reselect, and redisplay repeatedly, often interspersed with non-graphic queries and reports. Another common need is the direct retrieval qualified only by region - the "show me what exists in this region" query (3).

The desired graphics are ephemeral; no permanent record is kept. To be useful the images must be created and displayed quickly, usually in less than one minute. This in itself is a problem as the data bases to be queried are large and complex, often too difficult to analyse without the use of the computer.

2) **Working Diagrams**
This second group of graphic outputs are hard-copy maps and cartographic diagrams, often page-sized, for use as working documents - for desk reference, internal reports, group discussions, strategy and research decisions, administrative decisions, and as preliminary "proofs" for the design and selection of ultimate high quality publication graphics. Neither these nor the interactive outputs are accurate cartographic products, but rather, diagramatic representations in map form. It is not expected, for instance, that measurements of distance and area will be made from these diagrams. Fast output, preferably at or near the work location, is essential. Reproduction is desired usually in limited quantity if at all.

3) **Publication Quality Maps**
Publication quality graphics require the production of cartographically accurate maps, often heavily detailed and multi-coloured, with full textual annotation and legends. These are usually reproduced by conventional printing techniques in relatively large quantities (eg. several thousand).

Graphics in the Production Environment

It is always a long and perilous step from successful research and pilot demonstration to production implementation. In a GIS, solutions found in a pilot project with controlled test data sets often do not stand up well to general implementation. It is conventional wisdom that an operational system must have versatile, friendly, yet bullet-proof software. It must operate on reliable, continuously available hardware.

Data files in a GIS are often extremely large and have complex structures, involving data compaction techniques and multi-threaded chains. (Some files in CLDS have over 1,000,000 polygons comprised of about 6,000,000 line segments each of which may have hundreds or thousands of x-y pairs, and of course large volumes of attribute data) (4). Queries are complicated, difficult to predict and the output graphic requirements for maps vary widely from project to project, in map scale, projection texture and density of information, nature and quality of annotation etc. No one output device or medium can meet all the categories of graphic output for all or any data set.

An added dimension in CLDS is that many users operate remotely from various centers across Canada. As far as we know, this is the only GIS which provides long-distance remote interactive cartographic output.

Notwithstanding the long and successful history of the CLDS, success in meeting the user's requirements for effective, reliable graphics at a reasonable cost has been a slow and gradual process, and has often had to await technological advances at each step.

Some Successes

Although the original designs of the early CGIS around 1963 included the concept of maps being displayed on a graphics screen, based on queries, the actual production implementation of such a capability had to await the routine availability of the "low-cost" storage tube graphics terminals, such as the early Tektronix 4000 series. The earliest implementation of the system provided no graphic output whatsoever, only tabular reporting, and the addition shortly thereafter of a flat-bed pen plotter went only a short way towards meeting the needs for working diagrams, even less for publication quality maps and did nothing for interactive analysis graphics.

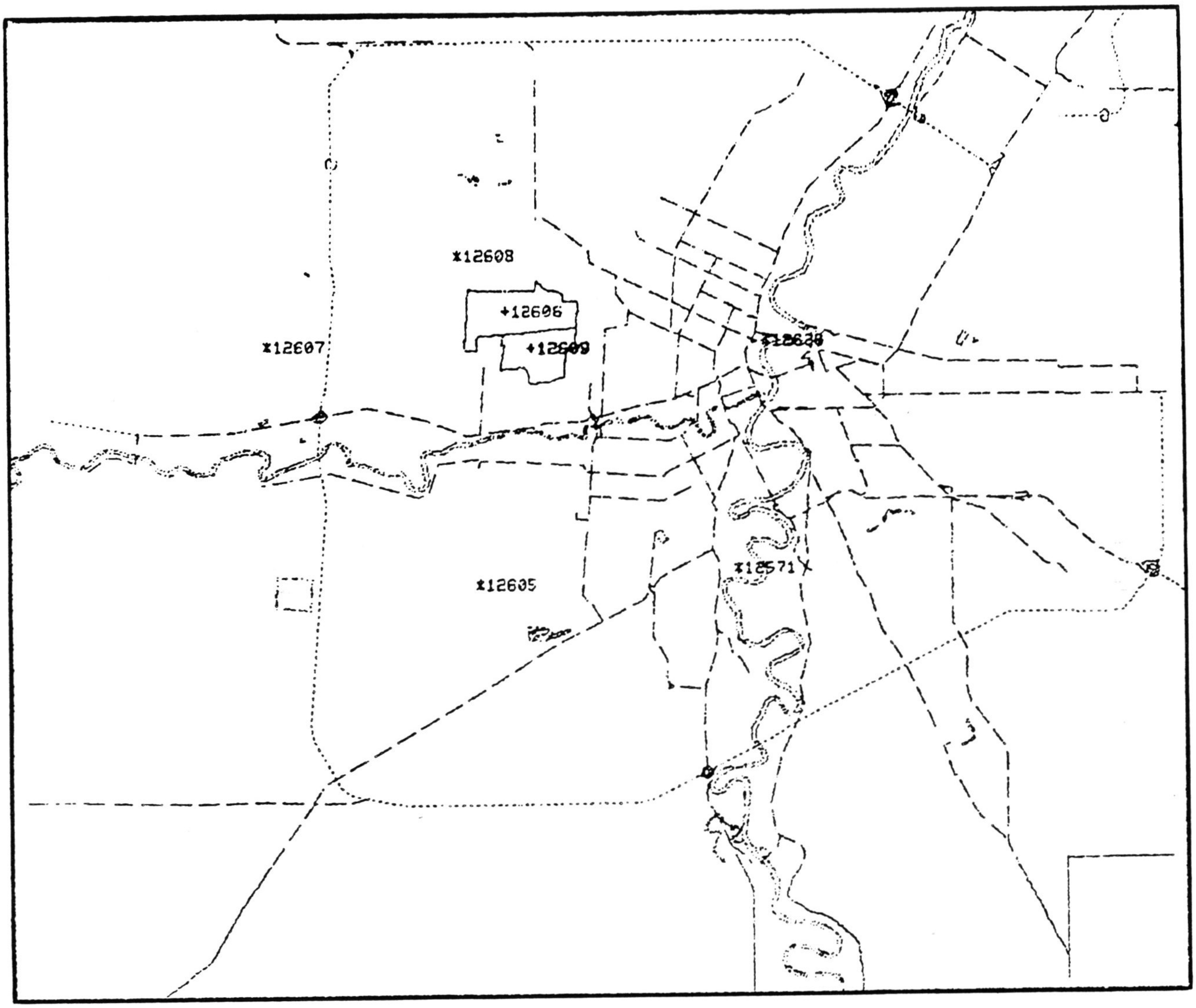

FIGURE 1 - INTERACTIVE GRAPHICS SAMPLE MAP

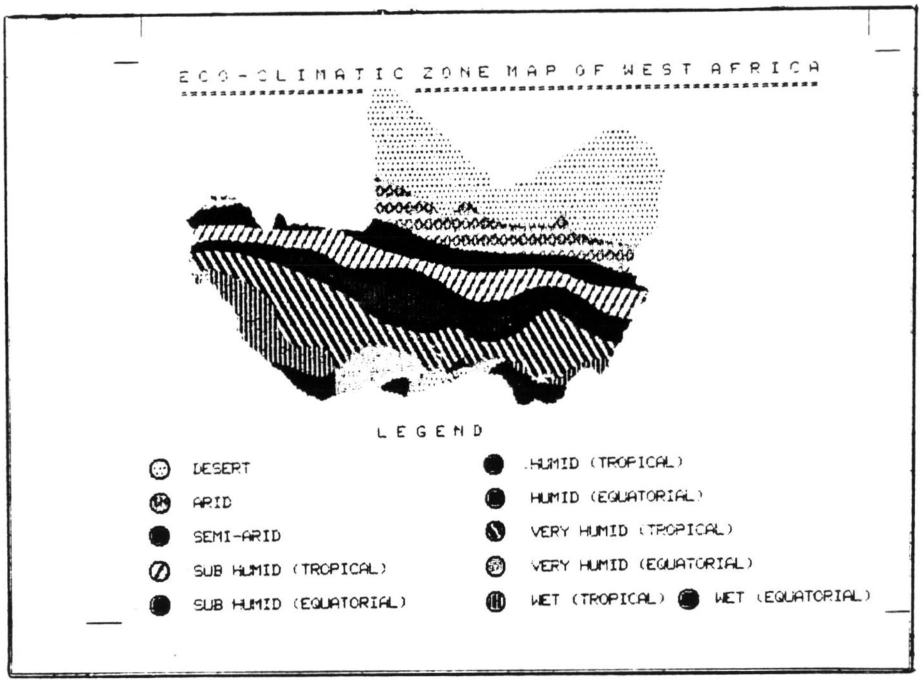

FIGURE 2 - COPY OF A COLOR INK-JET PLOT

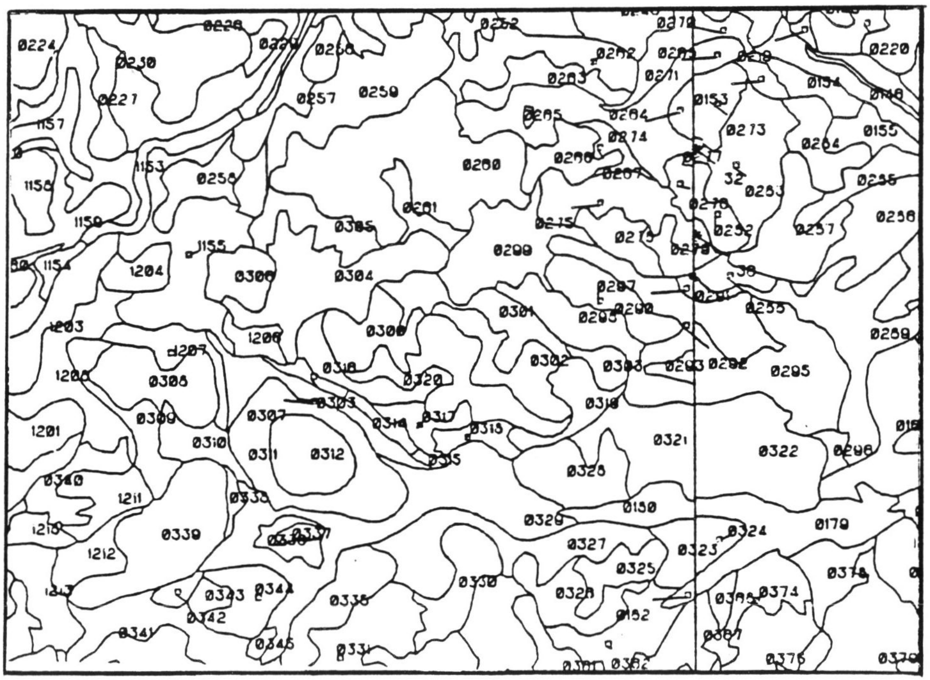

FIGURE 3 - PORTION OF A MAP WITH LABELS

The introduction of the storage-tube screens in the early 70's provided for the first time simple rapid, on-the-spot graphics. Coupled with poor quality (but adequate) hard-copy attachments, these terminals also provided simple working diagrams for desk reference. This type of output, used mainly to display outlines of regions which met selection criteria, proved to be a workhorse for geographic data analysis for over a decade. Increases in software sophistication have greatly increased the query capabilities and interactivity, but this basic graphic product, such as in Fig. 1 is still in production use.

The limitations of monochrome graphics are obvious, even for interactive analysis and working diagrams. The information content of this essentially binary medium is highly constrained to depict "selected" or "not selected", "in" or "out", etc. The use of shading patterns to depict multiple themes is of limited additional benefit, especially when small areas are to be identified. The solution is the colour graphics screen, and again, production implementation had to await the relatively recent commercial availability of these devices. Colour working diagrams have only been feasible in the last two years with the availability of ink-jet plotters for colour screen copying, and these devices still have questionable reliability for routine production use.

The colour screen enables the depiction of multiple themes on a map and improved discrimination of relatively small areas. Resolution restrictions of common low-cost terminals restrict the annotation capabilities and maps must by necessity be relatively simple and small in area. In spite of these restrictions the majority of the requirements for interactive analysis and working diagrams are achieved. Fig. 2 shows an example of such a map, reproduced here in black and white from a colour ink-jet plot from the graphics screen.

Very high resolution interactive colour graphics for data analysis purposes on a production basis remains unachievable (at reasonable cost) at the present time.

The requirements for working documents extend beyond hard-copy reproduction of graphics screens. There is a need as well for large format maps of some reasonable accuracy as desk reference, for interim display or use in the field during further studies. This requirement is best met through the use of a high quality flat-bed or drum plotters on various media. The plots are designed and commanded through the interactive user terminal, but produced off-line at a central facility, since this type of plotter is too expensive to warrant user-site replication (CLDS uses a Gerber model 4200 drum plotter).

The two most commonly requested products are labelled polygon plots in black-and-white, and color shaded maps. The former consists of an outline map with attribute labels placed centrally in each polygon. Automatic placement of these labels can be algorithmically complex, especially where polygon sizes are relatively small and the required attribute labels contain many characters (eg. ten characters). Consideration must be given to placing labels so that they do not overlap with others and yet remain clearly referenced to the correct area, and minimum size of the label is constrained by readability (5).

The approach, as used in several other systems is to tie the label to the polygon with a pointer if it will not correctly fit in the region, and to compress the large labels in extremely crowded areas to a one or two-digit code number, which is expanded in an accompanying automatically generated legend. Fig. 3 shows a portion of such a map.

For colour maps, colour fill is generated by horizontal shading on the plotter, with ball point type pens. A much more limited number of themes can be identified this way compared to the labelled map, however the colour shaded map is commonly desired as a "proof" for designing a publication quality map.

Meeting the need for publication quality maps has been a difficult task for most operational GIS. Most approaches, including those used until recently at CLDS, continue to be clumsy, slow, only partially automated, and relatively expensive. One such approach uses the flat-bed or drum plotter to generate thematic separates where each polygon of a theme is completely filled with black ink. Such a map is produced for <u>each</u> theme - ie. each colour shade on the final map. These thematic separates are then photographed and colour dot screens added to eventually produce three-colour printing negatives. All annotation is drafted manually or by partially automated means and integrated as a fourth black overlay. Registration of a large number of themes is a major problem, small areas are often poorly defined, colour choice by the user is awkward and so on. The various manual steps and photography add to the costs and delays.

The practical solution to this problem recently adopted by CLDS comes close to completely automating the process and keeping costs and turn-around to a minimum. The output device used for the coloured polygon fill is an

Optronics X4040 scanner/plotter. Although this device is primarily designed for input, ie. to scan black and white documents for data capture, it also can output binary images in raster form with adjustable pixel resolution from 25 to 200 microns. The adopted process first uses software to rasterize the colour-fill areas of the output map directly from the GIS. This raster grid is then assigned the ultimate printing colour by the user as chosen from a master colour chart (of 4096 colours). These colour assignments are then used to reformat the raster grids by applying various dot patterns to three separate files representing the three primary colours (cyan, magneta, and yellow). Registered full size negatives are then exposed directly on film using the optronics scanner (6). An intermediate step is usually used to produce an approximate colour-proof map on a large format ink-jet plotter for final approval or colour reselection by the user.

Annotation and any necessary black line-work on the map is produced through a commercial interactive map drawing package called GIMMS, which provides for a wide range of fonts, borders, north-arrows, scale bars, etc. (2). This output is pre-viewed interactively, test plotted in ink on the drum plotter and finally plotted directly on film using a photo-head attachment on the plotter. The four negatives then can be applied directly to make the three colour and one black printing plate. Fig. 4 shows the result (without the black plate) of such a process.

The Remaining Problems

The ultimate goal for graphic output in a GIS is for the user to be able to select and view any part of his data set interactively and to be able to design and pre-view planned hard copy outputs, including publication quality large format maps. These goals are not achievable with today's technology. Reasonable cost data communication and colour display terminals allow only a simplified approximation to be achieved in a production system. Additional break-throughs in these areas are needed to make these further steps, and current research activities indicate that there is reason to be optimistic of rapid progress.

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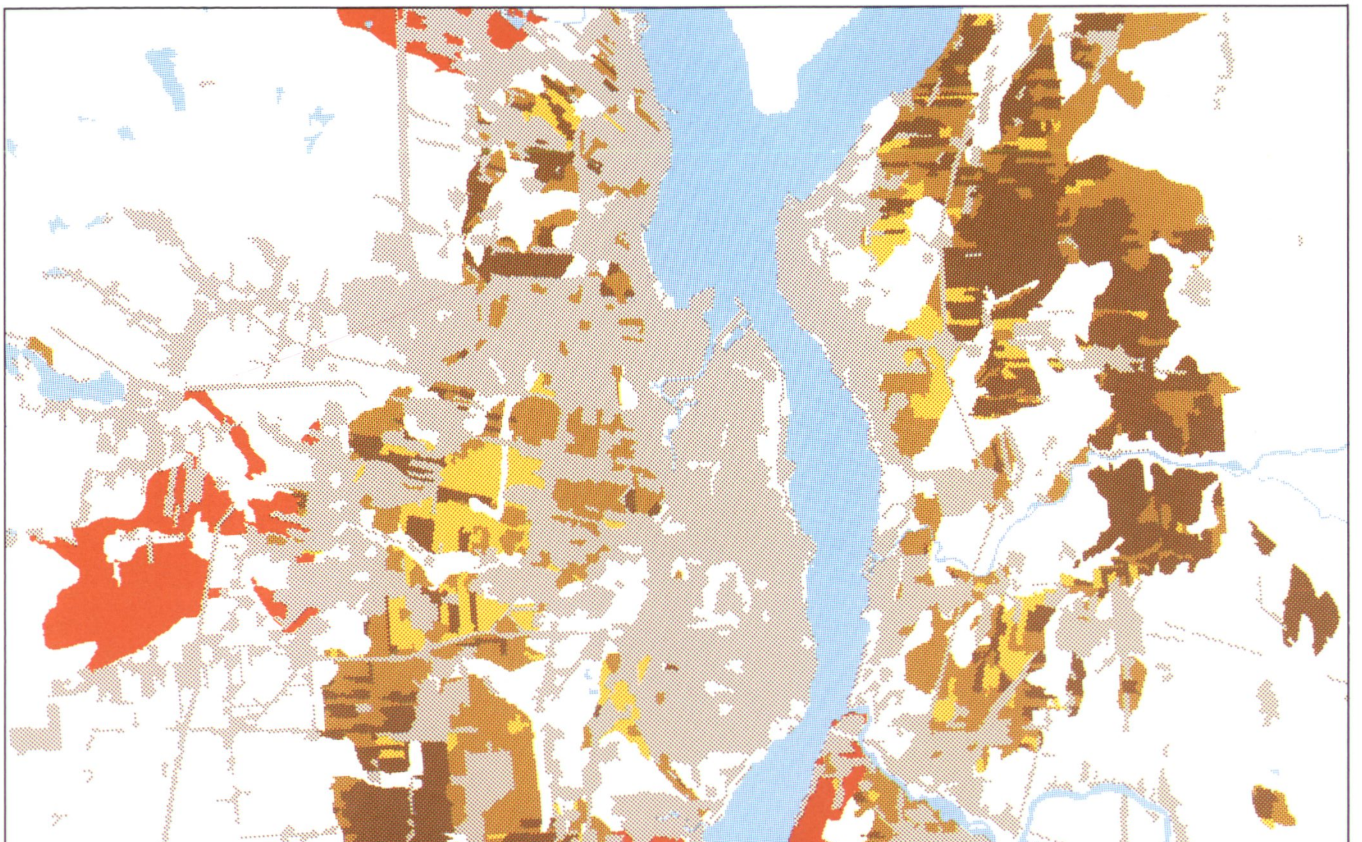

FIGURE 4: LASER PLOTTER MAP