CARTOGRAPHY IN A GIS ENVIRONMENT

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ABSTRACT:

Rock and stone drawings that ancient man made, were the beginning of the discipline of cartography. At first cartography developed gradually over the centuries. Influenced by scientific and technological developments, it grew rapidly from the eras of explorations and scientific inventions to reach a high level of perfection in the 20th century. Practice and research have continued to improve the products (maps) from the discipline. It became an autonomous mapping discipline by its own right. In the same way a written language is governed by certain rules, so too cartography is guided by cartographic rules (grammar), which are intended to achieve effective graphic communication. So whoever wanted maps he/she consulted experts, namely cartographers, who were versed with such rules and principles, much in the same way a sick person consults a physician. The development of Geographical Information Systems (GIS) technology has relegated the autonomy that cartography had enjoyed for a number of centuries hitherto. Cartography has now become a tool of GIS in which map production is but one of the functions. Since many people now use GIS, it means that more people are now involved in map design and production than has been the case before. StatMap Web has floated the following message in the Internet: 'Maps are a great way of displaying and analysing statistical information but they need to be properly designed. This can be a tricky business until you know what you are doing and desktop mapping and GIS systems rarely provide much help. Most software packages will allow us to produce really bad and misleading maps'. Moreover, Kraak and Ormeling (1997, p. 2) observe that cartographic rules that are so necessary for effective communication of spatial information are not a part of GIS software. The majority of the GIS implementers may be proficient at designing and using GIS without having had adequate education or training in graphics design, or theories of cartographic communication. This poses an issue of concern to cartography. The author explores this aspect and suggests options.

1. INTRODUCTION

Cartography is understood to have developed from making very simple and crude drawings to the present-day sophisticated and refined map documents. Early maps and map-like drawings were produced on mud slab, soft clay, rock, skin, cloth etc. The making of the drawings constituted the beginnings of map making. In historical times, such drawings were probably an expression of the thinking of mankind about his immediate environment in which he lived. They were a record of his visual description of the places surrounding him.

The oldest map discovered is reported to have been drawn on a clay tablet in Mesopotamia (the land between rivers Euphrates and Tigris, what is now part of eastern Iraq) at about 3800 BC. This map depicted mountains, water bodies and other geographic features. The map showed a round, though presumably flat earth with Babylon in the centre (Thrower, 1972). Recorded history also shows that the ancient Egyptians carried out cadastral surveys along the Nile flood plains and made cadastral or property maps at around 3,000 BC (Thrower, 1972; McEntyre, 1978). Possibly the early maps were also a means of information communication. Robinson et al. (1984, p. 20) observe that map making is probably as old as communication by written language. The rationale in this may be based on the reasoning still held today that a diagram (or a map) says much more than a thousand words. Indeed, graphics are to date the most efficient means of communicating information as well as effecting data analysis and display in GIS environments. So the early maps and map like drawings could have complemented the written/verbal language in the same way they do today.

As mankind fought wars against himself, (man fighting man), he had to travel from one location to another. In the process he learnt how to describe routes and locations, which were far from his immediate neighbourhood. He had to describe locations where to find things as water, salt, game, treasure, enemy dwellings, and so on. Most maps were then made for travellers, soldiers and mariners (Brown, 1960). Seemingly, the major purpose of maps was then for navigation and route finding.

Unfortunately most of the maps that early man made cannot be traced today partly because some of them were drawn or carved on precious material such as gold, bronze and copper which had to be smelted to make more useful things. Even rocks and stone on which such drawings were carved were precious building materials. Moreover, maps were destroyed by fire or by the very people who made them, fearing that the maps could be captured by enemies and thus reveal the secret information they contained. Others became old and got torn perhaps because the materials they were made of were too delicate to last for long times. These were some of the reasons, which made the drawings (maps) not to be available to us today.

The world today owes a lot from ancient Greek thinkers, among them being Eratosthenes (276-196 B.C.) and Ptolemy (90-168 A.D.). Eratosthenes was a geographer and a librarian at Alexandria. Through scientific measurements and calculation of the circumference of the earth, he laid the foundation of scientific cartography. Ptolemy was also a librarian at Alexandria. He made maps and wrote the *Geographica*, which was a guide to making maps. Arab scholars such as Ibn Battuta (858 – 929 A.D.) used and improved on Ptolemy's maps (Thrower, 1972; Bernhardsen, 1992). Several inventions and developments made significant contributions to the development of cartography among them: The magnetic compass (13thCentury), the making of the sailing charts (*portolan)* bearing compass roses (1300 A.D.), printing (15th Century) and map projections (17th – 18th Centuries). The era of global explorations and national mapping programmes in Europe (17th – 19th centuries) had great impacts on conscious development of cartography. The invention of aerial photography, the development of photogrammetry and the two world wars, accelerated the progress of mapmaking (Bernhardsen, 1992, p. 26). Maps were thence made not based on visual description alone, but mainly from actual measurements obtained by surveying and photogrammetry. Accurate maps emerged. Maps were made for various purposes of which sea and land travels, military operations, tax collections and planning were just a few of them. In this way, maps were made to meet specific demands. Good, effective communicative maps appeared, and experts in map making emerged.

2. CARTOGRAPHY, MAPS AND GIS

Cartography is considered as the theory and practice of mapmaking and map use, notably in the context of graphic communication. The distinction between conventional analogue cartography and modern digital cartography is contextual. A generalized definition of a map may refer to it (map) as a 2-D graphic representation of the attributes of spatial relationships of geographical features to scale. GIS, on the other hand, may be regarded as a computer-based system for data input, management (storage and retrieval), manipulation and analysis, and displaying of spatial data (Aronoff, 1989, p. 39; Bernhardsen, 1992, p. 3) from the real world. Bernhardsen (1992, pp. 220-222) in a discussion about the potentials and limitations of GIS in cartographic communication draws useful comparisons between maps and GIS.

The key issue between cartography and GIS is that cartography is concerned with *representation* while GIS is concerned with *analysis* of spatial relationships. GIS is a product of the development of computer-assisted cartography, which generated geo-referenced spatial digital databases. The databases became the platform for the creation of data structures that could be linked, processed, analysed and results displayed in the form of maps, tables and reports. The systems for these functions became known as Geographical Information Systems (GIS). Because of this developmental interconnectivity, Aronoff (1989, p. 103), observes that GIS is often confused with cartographic systems that store maps in automated form. Aronoff (ibid) further notes that:

While the main functions of the cartographic system is to generate computer stored maps, the function of a GIS is to create information by integrating data layers to show the original data in different ways from different perspectives.

3. MODERN CARTOGRAPHY

Theories of cartographic communication models have been developed (for example see Wood (1972), Robinson and Petchenik (1975), Keates (1982), Tyner (1992) and Dent (1993)) to analyse each stage of map making and map use processes, and to find out how they operated and the factors affecting them. Such inquiries led to various researches in cartography, which made it to be seen as a branch of knowledge and a discipline by its own right, as opposed to earlier thinking which saw it as an aggregation of isolated techniques. It has been modelled as a vehicle for graphic communication. Until fairly recently, whoever needed a map consulted the specialist in cartography who would design, produce and cause the printing of the required map(s). In this way cartography has been growing, and cartographers have been making a living out of it.

Come the Computer Age, also comes a revolution that has posed opportunities and challenges to the land surveyor as well as the cartographer. All along, the surveyor had specialised in the science of measurement, computing (data processing), analysis and displaying the coordinate values, which have always been the cartographer's raw data for mapping. The computer revolution has brought with it the Global Positioning System (GPS), which gives the coordinates (that the surveyors used to labour so much to get) in real-time. What goes on in the black box is no longer the surveyor's business. The cartographer has also not been spared by this scientific and technological revolution.

The development of computer software and Geographical Information Systems (GIS) has made it possible for anybody who can operate a computer to get a map output from the GPS coordinates. So any person, (not necessarily a surveyor or a cartographer) who wants a map, takes out a GPS, goes into the field, gets coordinates, downloads them into a GIS system and gets a map. Are the surveyors and the cartographers being made redundant by technological advancements? Has GIS relegated the field of cartography? Ironically any GIS user becomes a mapmaker overnight! Is this feasible? Perhaps to get answers to these questions and others, we need to ask ourselves another question, the answer of which will guide us to the probable solution. What's the look of the map products we get from GIS systems with non-cartography persons seated before a monitor like? Dent (1993, p. 19) summarises the situation thus:

The possibilities today for maps without ethics are compounded by the proliferation of off-shelf computer programs allowing non – cartography trained persons to produce maps that may look good, but are not consistent with any established professional standards or conventions.

Bernhardsen (1992, p. 215) observes that GIS enables less skilled persons to produce maps, … but it also has the drawback of permitting the production of artless maps that are at best *unattractive* and at worst *misleading* (emphasis is of the author).

StatMap Web complements these observations as follows:

*Maps are a great way of displaying and analysing statistical information but they need to be properly designed. This can be a tricky business until you know what you are doing and desktop mapping and GIS systems rarely provide much help. Most software packages will allow us to produce really bad and misleading map**s*** (emphasis is mine).

Can we conclude that non-cartography trained people are likely to produce ineffective and therefore unacceptable maps because the GIS systems they are using are not providing much help? The meanings of these statements have far reaching implications. Kraak and Ormeling (1997, p. 2) drive the message home by noting that GIS allows users to produce their own maps even when they are unaware of cartographic (*language and*) grammar. They conclude that there is no guarantee that the maps will be effective. To this we may add that such maps may also not transmit the intended meaning(s) to map users at all. They can only be misleading.

There is no doubt that the science (of map making) that has been consciously developed for over five hundred centuries is now witnessing a flouting of all the rules and norms for mapmaking principles. Sadly the proliferation of badly designed maps will soon be a common feature among us and upcoming generations may accept and adopt them as good maps of their day!

4. GIS IN THE CONTEXT OF THE MAPPING SCIENCES

Prior to the emergence of GIS, cartography occupied a pre-eminent position in relation to the other mapping sciences, namely Remote Sensing, Photogrammetry, Geodesy and Surveying. Each of these fields, used to submit a file for information display/mapping directly to cartography. Come GIS, that eminent position has been reduced significantly. Cartography no longer communicates directly with the other sciences. GIS has assumed the position of coordinator with Remote Sensing, Photogrammetry, Geodesy and Surveying each being regarded as a module for data input into it, which in turn communicates with cartography. Cartography has therefore continued to display/present graphic information but with an added role of data input into a GIS system as well. Kraak and Ormeling (1997, p. 17) regard cartography as an essential support for nearly all aspects of handling geographical information. They argue (ibid. p. 18) that although it is possible to do without maps in GIS, the information transfer without maps (e.g. through tables) would be cumbersome.

In its apparent coordinating role, GIS may be viewed essentially as a management and visual decision support tool. Figure 1 illustrates the relationship between GIS and the mapping sciences.

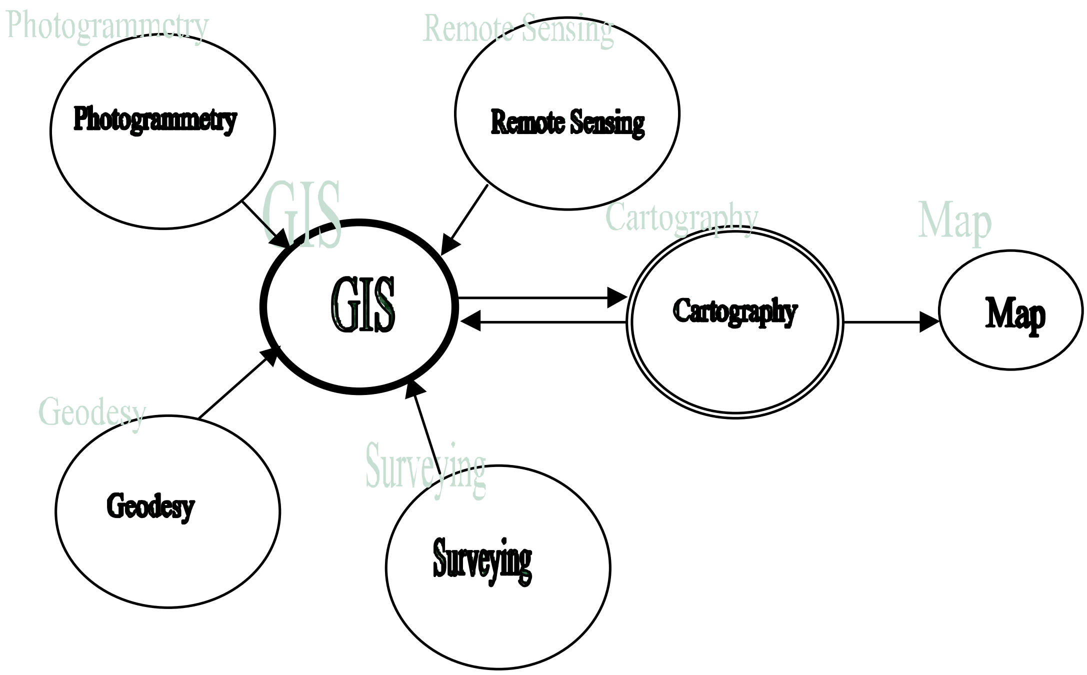

Figure 1. The coordinating position of GIS among the mapping sciences with cartography featuring as a data input and map output module of a GIS system

5. SOME NOTED CARTOGRAPHIC SHORTFALLS IN GIS ENVIRONMENTS

Map projections, contents, symbolisation, generalisation, scale, layout and overall design of maps, constitute some of the major components/processes of effective cartographic communication. The implementation of these is today going through a rapid degradation of the basic principles necessary for map making and understanding.

A GIS operator, not conversant with cartographic principles and theories of (carto-)graphic communication, may select for his/her map output, an incorrect projection from a GIS library. Instead of specifying an equivalent, conic projection for showing spatial distribution of a given phenomenon of a country in the mid-latitudes, he/she will easily (and there are several examples) specify say a Mercator projection, which may be suitable for the Equatorial areas, is conformal and therefore unfit for effective display of distributions in the mid-latitudes. What is being said here is that a suitable map projection should consider map purpose and choice made of a projection that minimises distortion of the geographic properties of the region being mapped. Indeed some times no regard is made to the projection of a map document, which is to be digitised as an input into a GIS system.

The same situation goes for the selection of legend symbols particularly for linear features. Often, the author has seen several examples of zigzag lines on legends (selected from the 'automatic legend' on Arc View GIS), which do not have a matching on the face of the map (Appendix A) and Bernhardsen (1992, p. 221). Colour selection by many GIS operators poses another significant departure from standard cartographic practices. Users enchanted with strong colours, often select strong colours to represent area features forgetting that area colours have a dominating effect and always form an obstructive background for the display of linear and point features as well as text occurring in the same areas. This way the communicative aspects of such maps are not enhanced. The use of colour has many dimensions that may affect the look of maps. Only a few of them are highlighted in this discussion. Many thematic (notably statistical) maps employ colour to identify areas and their values. For practical reasons (for example see Balsinhas (2001, pp. 28-31)), a map visualised on a monitor, its colours look different from those of the same (digital) file printed on paper. Bernhardsen (1992, p. 222) notes that:

GIS supports an enormous range of colour hue, tone and intensity, but in practice the ranges available may be more restricted in producing hardcopy maps.

Persons working in GIS environments need to be aware about these facts because at the end of the GIS processes, a digital map needs to be available on paper.

Mapping of statistical data requires data classification (generalisation) to determine class boundaries and therefore the number of classes into which the data will be put. This activity needs to be done carefully to ensure that a suitable routine is used so that the profile of the classified data matches, as closely as possible, that of the original data. The relevant questions here include: Does the available GIS software support this type of analysis? Are the persons using the GIS aware about such a limitation?

Compared to black and white map production where the use of 3 –4 greys are possible without using patterns, colour use stretches this range quite considerably to as many as 20 different levels. But, mapmakers should avoid using all these (if they can) and stick to 5 – 6 colour levels for clarity (StatMap Web, 2002). The reason for this limitation is clear. The map user should be enabled to read colours from the map and identify matching colours in the legend without any ambiguity. Some thematic mapmakers have tried to set too many classes for their statistical data with the result that the contrast between adjacent colour levels on the legend is not adequate[1].

At times enough distinctions are not made as to whether the map being produced is qualitative or quantitative. Many coloured maps have failed in this domain: A map intended to be qualitative is inadvertently made quantitative by the selection of colour screens, which imply differences in quantity.

Many maps made from GIS systems tend to be overloaded with information that do not have any bearing with the titles (purpose) of the maps. A look at Appendix A, which is on 'Distribution of Cattle and Tsetse Flies in Tanzania', reveals a number of inconsistencies. Apart from the fact that the map is hanging, a number of anomalies are evident. Some of them are: the scale of 1: 9315789 is rather weird; the shadings used for cattle distribution is too coarse; the hierarchy of the levels of the information mapped has not been established; the water areas have dominated over the themes mapped; the text is not easily readable; and some of the map contents (e.g. the road and the railway networks) do not enhance understanding of the theme and instead contribute noise to the graphic communication. It should be realised without much explanation that, in cartographic context, the map purpose, the intended audience/user, conditions in which the map will be used, the scale of the map, its contents and amount, design, colour used and the entire graphic presentation are quite important for effective graphic communication and contextual understanding of the meaning of the map information. It is important to stress that every map has a specific communication objective. All who make maps should always be aware about these basic facts.

While a GIS system may be packed up with all the information possible on earth (!), a graphic output should be purposeful and therefore selective. Some GIS professionals overlook the fact that while with a digital map they can perform selective display, magnification (windowing) and highlighting of different visual layers on a screen, the same flexibility is extremely limited for hardcopy map outputs from the same system. On a thematic map (hardcopy), for instance, only two layers namely, the theme and the reference base information can be highlighted successfully. Trying to print out all the GIS contents on one sheet will only give a map that is overloaded and therefore difficult to communicate efficiently. Determination of the level of detail required on a map should additionally be a function of the map scale. Moreover, on a digital map, the user can easily control the data density without the need to resort to generalisation. This is not possible for hardcopy map outputs. On hard copy outputs, different scales imply different levels of generalisation of the map contents. These anomalies by non-cartography GIS operators have been clearly expressed by Fisher and Lindenberg (1989, p. 1433) as follows:

… While GIS professionals are not primarily concerned with the quality of the graphics that may be derived from the information, they should be cognizant of the implications of data manipulations upon the message presented in a resultant map.

6. SOME ASPECTS OF MAP DESIGN IN GIS ENVIRONMENT

All maps have one basic objective, namely to serve as a means of communicating information about spatial patterns, relationships and attributes. The communication aspect is accomplished through the use of suitably designed graphical marks called symbols. The appearance of a map affects how it is perceived and consequently how readily the user interprets the information it contains. So a suitable design of the symbols, their hierarchy, similarities and differences relating to the real world features they represent, as well as their arrangement on the map and the entire map layout are a prerequisite for an efficient and effective communication of information to map users.

[1] For example see AMBIO, The Journal of the Human Environment, Vol. 30, No. 7, November 2001, p. 389. On this colour map, annual rainfall is shown in 14 classes. Clearly, some adjacent colour levels are not contrasting sufficiently. Similarly, the map of 'Ocala National Forest' Lake George Range District, in Aronoff (1989, Plate 1), gives a legend with 28 differently coloured forest cover types.

Poorly designed maps restrict the communication of information, and may convey false ideas about the facts contained in the data as displayed. This is particularly dangerous if cartographic output is presented to persons (e.g. executives) who are only remotely involved in a particular project but are involved nonetheless in making final decisions (Weibel and Buttenfield, 1988, p. 350). It need not be over-emphasized that maps constitute one of the most single important outputs from a GIS analysis. Without them suitable decisions may never be forthcoming. So we should spend some time to ensure we get suitably designed maps that present something worth the work, effort and often, high investments already made on data acquisition, processing and analysis. Any complacency in the display process of the results will definitely waste all the investment, or worse, be a cause of inappropriate decisions that will result into more waste of costly resources.

In order to avoid production of poorly designed computer maps, a suitable GIS software should be one with extensive documentation about map design principles. Its successful use elsewhere and continued support by the authority that developed it should be added advantages. Inclusion of a qualified cartographer on the staff implementing a GIS is an important prerequisite for successful map outputs. Furthermore, it is important that all GIS operators and users are exposed to at least the basic concepts of map design and cartographic communication. This can be done through a scheme of short courses and formal academic education.

Land surveying students have to embrace both GIS and cartography, not by choice, but by the necessity arising from the nature of their profession as outlined in Figure 1. For this reason, while at UCLAS, they are given an adequate dose of cartographic education to enable them to acquire the basic know-how and to make rational decisions in GIS environments. We explore this aspect in the rest of this paper.

7. THE EDUCATION IN CARTOGRAPHY AT UCLAS

UCLAS has been a constituent College of the University of Dar es Salaam since July 1, 1996 when the former *Ardhi* Institute was affiliated to the University. The College offers degree courses in six academic departments, which are allocated to two faculties. The department of Land Surveying is in the Faculty of Lands and Environmental Engineering (FLEE).

Cartography is taught as a part of the BSc degree in Land Surveying. The degree programme lasts for four years. An academic year consists of two semesters. The cartography taught is sufficient to equip students with enough knowledge to enable them to work and make reasonable decisions in a GIS environment. Cartography is taught in the first and fourth years of study. The course in cartography is basically structured to cover basic knowledge in cartography and graphics (semester 1), metrics (semester 2) and thematic and computer assisted mapping (semester 7). The teaching integrates theory and practice in the form of exercises and take-home assignments.

In the first semester cartography is taught for 60 hours. The topics covered include: developments in cartography, maps and aerial photographs, cartographic symbols including colour use, graphic variables, cartographic communication, image generation, typography, map design principles and layout (LS, 2001, p. 30). In the second semester 30 hours are taken to cover: The concepts, principles, distortion, and choice of map projections (LS, 2001, p. 37). Cartography in the fourth year (semester 7) is taught for 60 hours. The topics covered include: Computer assisted cartography, thematic map design and production (LS, 2001, p. 69).

8. CONCLUDING REMARKS

Although no one knows exactly when cartography was first used, recorded history suggests that cartography was used in the early ages of history of mankind, probably as a means of graphic communication. Out of the simple and crude drawings, there developed a distinct mapping discipline, namely cartography, which together with the other mapping sciences complements the functions of GIS today.

Cartography developed gradually over centuries and reached a high level of perfection in the 20^{th} century. In the same century, the computer technology ushered in a revolution that brought with it opportunities and challenges in the science and art of map making – computer cartography emerged. Vast amounts of data (spatial and non-spatial) could be handled, processed quickly and maps at different designs, projections, scales, layouts etc. produced within minutes.

The development of the computer based GIS, has facilitated the making of maps by virtually anybody. Map making has ceased to be a monopoly of cartographers. Cartographers and (many) non-cartography trained people working in GIS environments can now make maps. As a result the world is witnessing a degradation of the product that has taken many centuries towards perfection. While it may be argued that the user has the right of choice, we may also say that such choice should at least conform to established conventions, standards and ethics. Moreover, it is rare that the mapmaker is also its exclusive user. Just as essays are written to bridge a knowledge gap, so are maps made to express or communicate information, which is either unknown or little known, to others. In this regard, it is vital that maps made in GIS environments are both easy to understand and are effective.

To tackle the emerging problems, a number of aspects need to be addressed: GIS system designers and developers ought to give more design consideration to the cartographic modules of the GIS software. Hence, there should be some form of standardised but flexible as well as interactive guidance in map (notably, symbol) design procedures. All GIS users will do good service to GIS and cartography by learning the alphabet, language, grammar and the vocabulary of cartographic communication so that whoever is involved in map making uses the same (cartographic) vocabulary to make maps that communicate efficiently and effectively. Trained cartographers, on their part, have a crusade to preserve and improve on the cartographic qualities already attained. Any form of degradation in this should be resisted vigorously.

Every profession has acceptable justifications for being protective and insular. But all together, they have a mission for sustainable human development, which can be realized only through collective efforts.

Given its role within the mapping sciences, GIS could reconstitute itself into an amalgamating platform for the effective management of change. To do this, it will have the task of bringing together discussion groups from all professionals who are related to or are affected by it. In other words, GIS conferences, seminars, workshops, etc. should cease to be an exclusive possession of GIS experts. The synergy of such a conglomeration will result into discussion of integrated global GIS issues in which the values of each profession will be appreciated and improved upon. Thinking in this direction is the only way to guard against waste of resources invested in GIS and all the geosciences.

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APPENDIX A. A GIS MAP PRODUCT WITH A NUMBER OF SHORTFALLS