Frameworks for Sustainability of GIS and Earth Observation Technologies in Developing Countries

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Introduction

Earth observation and GIS technology can undoubtedly be considered as one of the great successes of the use of advanced information technology for the improvement of mankind. The capabilities provided by satellite imagery, digital maps, and associated information have transformed our ability for understanding the forces that shape the geographical space. In developing nations, many of whom lack strong traditions on cartography and mapping, these technologies (referred collectively in this paper as "geoinformation technologies") have proven essential for developing public policies on issues such as deforestation assessment and management, urban planning, agricultural production and environmental assessment.

However, despite a large number of well-documented successful uses of geoinformation technologies in developing nations, their full potential is yet unrealised. Given this scenario, the main aim of this paper is to identify what are the major impediments to the growth of geoinformation technology in developing countries, and to indicate some ways in which these impediments can be reduced.

The initial impetus for the development of geoinformation technology in developing nations was based on international co-operation programs, funded by developed nations, such as the LANDSAT program. However, there is a definitive trend in developed nations to encourage these technologies to be driven by the private sector, and therefore increasingly view the developed world nations as paying customers of geoinformation technology. This trend is already in place in the case of GIS (with some notable exceptions) and this transition is taking place rapidly in Earth Observation. Given the enormous disparities of resources in the developing world, this transition is prone to reduce substantially the potential of usage of geoinformation technologies for the public good in the developing world. At best, it will result in a situation where some niche institutions within these nations will be strong users of geoinformation technology, at the expense of restraining a widespread societal adoption.

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The main response advocated in the paper (which will be elaborated in what follows) is that geoinformation technologies have reached a mature state[2], and that all but its most advanced components can be fully produced by the industrialised nations of the developing world. Therefore, the key to sustainable use of geoinformation technology in the developing world lies within reach of these countries. Should the most technologically advanced developing nations (such as India, Russia, Brazil and China) adopt a public-oriented viewpoint towards the diffusion of geoinformation technologies, as opposed to the private-oriented viewpoint currently taken by the developed world, the benefits for humanity will be significant.

To address the issues of achieving sustainable frameworks for geoinformation technological development in the developing world, we must examine the main factors that make such development possible: (a) the possibility of accessing timely and appropriate spatial data; (b) the access to computerized software tools that enable analysis of spatio-temporal phenomena; (c) the availability of local expertise, especially at the graduate level, capable of developing adequate spatial analysis methodologies. These aspects will be examined separately in what follows.

The Spatial Data Challenge – Part I: Earth Observation

The possibility of accessing timely and appropriate spatial data is a major challenge in developing nations. In the earth observation arena, the US LANDSAT program has been, over the last 25 years, a major source of data about the Earth. The data policy adopted by LANDSAT, which allows copying and distribution of images without additional charges, has proven instrumental for earth observation data to reach a wide audience in the developing world. The LANDSAT program effectively provided the foundation for the establishment of the international Earth Observation research community. Unfortunately, there is a major possibility that the data policies for the LANDSAT program will change substantially in the near future. The plans for the LDCM (Landsat Data Continuity Mission) call for a limited set of data (roughly 1/3 of the total scenes collected daily) to continue to be available at current data policy (called COFUR – cost of fulfilling the user request). Such data set is to be chosen by the US government, and all the rest will be open to exploitation by the commercial US firm responsible for the LDCM satellite. This situation puts those countries that have built large data archives of LANDSAT imagery, and whose intention is to ensure data continuity to allow for longitudinal data comparison, with the prospect of a much-increased data access

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[2] The concept of "mature state of a technology" is defined as a stage where the rate of innovation has been reduced substantially, after an initial phase of rapid development.

fee and restrictions on data distribution. Similar policies are already in place for the SPOT (French) and the RADARSAT (Canadian) satellites.

These data policies have been brought about because the current trend in developed nations is to consider that their countries' taxpayers should not subsidise the use of spatial data by the developing nations. Therefore, such nations are increasingly dealt with as customers of the developed countries' commercial sector. This situation provides a singular opportunity for nations that have developed independent remote sensing programs. Should programs such as IRS (India) and CBERS (China/Brazil) adopt data policies that allow for unrestricted distribution of products without additional licensing costs, such satellite programs would fill the gap that will be created by the changes in data policy on the developed world earth observation programmes. This creates a major opportunity for co-operative programs in Earth Observation within the developing world.

Additionally, we must take a broader view: "*How many EO satellites does the world need?*" This is a utopian, but not superfluous question. In theory, given that the Earth is a finite place, an optimal configuration of EO satellites is possible, covering different ends of spectrum (optical, infra-red, thermal and microwave) and with complementary spatial and temporal resolutions. Given the expected technological advances in the next 10 years, many countries, some with existing space program and some with emerging space activities, could contribute to this global, concerted effort. Countries would not required to abandon their existing international partnerships but rather would adapt their planned EO missions to a global level of complementary configurations. From an EO applications perspective, the first decade of the 21st century is a most promising one. The continuation of the LANDSAT-class satellites (with LANDSAT-8, SPOT-5, CBERS and IRS), the experience with C-band and L-band polarimetric radar images to be brought about by RADARSAT, ENVISAT and ALOS, the high-resolution imagery of IKONOS and QuickBird, the availability of the hyperspectral images of MODIS and of the multispectral thermal infra-red bands of ASTER are bound to give the EO researcher more data than he may ever have imagined. This embarrassment of choices might also prove a breeding ground for the establishment of large-scale cooperation in EO, in which a concerted multilateral effort could provide countries with enormous environmental and urban problems such as most African nations with much needed information, and where humanity as a whole could benefit from the promises of earth observation.

The Data Challenge – Part II: Maps and Spatial Databases

As regards other types of spatial data, there has been substantial progress in recent years in terms of automated map production, especially in the field of digital photogrammetry and use of GPS-based data and LIDAR sensors. These techniques are able to reduce substantially the price for producing up-to-data urban cadastral information, by comparison with traditional map-making techniques. The use of geostatistical techniques has also provided a substantial improvement for proper analysis of field-collected data, in areas such as soils, geology, geophysics and hydrology. Additionally, although there has been substantial scientific research on interoperability frameworks, especially linked to more general interest on scientific ontologies, including the "Semantic Web" initiative.

The main challenge in digital photogrammetry is that the tools and expertise needed to produce accurate spatial data are complex and expensive. Therefore, developing nations need to make a substantial effort to develop and absorb such techniques. In this field, much can be learned by exchanging experiences, and therefore forums for international co-operation in this area (such as the ISPRS and CODATA congresses) can play a major rôle in serving as "information clearinghouses".

A similar challenge on developing expertise also applies to geostatistical analysis techniques, which can make the best usage of sparse field data, which is usually the case in developing nations. These methods require tools and expertise to be used correctly, and here an important challenge is proving them in an open source environment. Additionally, although there has been substantial scientific research on interoperability frameworks, the practical results have been limited, largely because some of the most important efforts (such as OpenGIS) have been industry-driven, and cater only for a limited set of the needs of the spatial data users. The OpenGIS initiative is geared towards simple polygon maps, and has not produced standards for dealing with thematic data, such as topographical and thematic maps. The lack of world-wide interoperability standards also provides an opportunity for developing nations to develop collaborative solutions, which are industry-independent.

The Tools Challenge

Spatial data, either in the form of digital maps or satellite imagery, requires tools for computer analysis. These tools require technical expertise for their use, and have largely been developed by a small number of companies and institutions. By contrast, there is a very limited effort on developed nations to develop an open-source GIS and image processing software. The only notable effort, the GRASS system, has produced significant results, but is in need of a substantial technological update.

Special mention must be made of the IDRISI project, by Clark University. Although IDRISI is not an open-source software, the project has been coupled with a substantial effort for capability-building in developing nations, and IDRISI Resource Centres have been established in many countries. In a similar vein, the Brazilian Institute for Space Research has developed SPRING, a GIS and image processing software freely available on the web, coupled with extensive documentation, training material and books[3].

Since there is already a number of commercial and low-cost spatial analysis tools, one should consider the question: "*Is there a need for an open-source GIS software? What benefits could it bring?*". There are two substantial benefits: (a) the establishment of an world-wide co-operative environment based on the "learning-by-doing" principle; (b) The still unresolved needs of the spatial data community.

An important consequence of pursuing a "learning by doing" approach combined with substantial investment in local human resources is the capacity for developing a critical perspective of GIS. Comparing different commercial solutions can be very difficult. Many GIS managers in developing countries lack in-depth knowledge of the characteristics and capabilities of GIS options relative to their specific application needs. An important benefit resulting from a "learning-by-doing" approach is a very complete understanding of the "core" aspects of GIS technology and a capacity by involved staff to dissect the so-called "black-box" commercial solutions in order to understand their strengths and weaknesses.

A second benefit of the "learning-by-doing" approach is the possibility of establishing a technological strategy that allows for production of continuous innovation. In the case of GIS, the industry is bound to witness substantial change in the upcoming years, induced by technological advances in spatial databases. Current and expected advances in database technology will enable, in the next few years, the complete integration of spatial data types in data base management systems. This integration is bound to change completely the development of GIS technology, enabling a transition from the monolithic systems of today (that contain hundreds of functions) to a generation of *spatial information appliances*, small systems tailored to specific user needs. As an example of such products, a group of R&D institutions in Brazil, led by INPE, is currently developing **TerraLib**, an open-source GIS component library that enables quick development of custom-built applications using object-relational spatial databases[4].

A second important reason for developing open-source spatial analysis tools is the need to resolve the "knowledge gap" in the process of deriving information from images and digital maps[5]. This "knowledge gap" has arisen because our capacity to

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[3] SPRING is available at www.dpi.inpe.br/spring, with more then 25,000 downloads from 60 countries.

[4] The Terralib GIS library, along with documentation, is available at www.terralib.org.

[5] The concept of "knowledge gap" for producing information from spatial data has been proposed and substantiated by John McDonald, founder of MDA.

build sophisticated data collecting instruments (such as remote sensing satellites, digital cameras, and GPS) is not matched by our means of producing information from these data sources. To a significant extent, we are failing to fully exploit the potential of the spatial data we collect. There are currently very few techniques for image data mining, and thus we are failing to exploit our large remote sensing data archives.

Therefore, the geographical information community would have much to benefit from the availability of a general, open source GIS library. This resource would make a positive impact by allowing researchers and solution developers access to a wider range of tools than what is currently offered by the commercial companies. In a similar approach to the Linux and subsequent open source software efforts, we recognise that such development does not happen by spontaneous growth. There must be created a core set of technologies from which further developments may freely extend. This co-operative GIS and image processing software environment would allow researchers to share their results with the EO community, thus reducing the "time to market" from academia to society.

The Expertise Challenge

Traditionally, academic institutions in the developed world have provided a major basis for producing qualified personnel for using geoinformation technology in the developing world. In many cases, graduates of these institutions have initiated their own research groups in their native countries. Such an interchange is most needed and useful and it is hoped that it is maintained and enforced in the years to come. However, it must be recognised that such mechanism can only account for a limited part of the enormous demand for expertise building on the developing world.

The challenges are enormous. The research system in the developed world effectively discourages the production of training material, especially if not linked to a commercial publishing company. There are good books on GIS; unfortunately, these books are in English and are expensive for the average GIS expert in the developing world. Therefore, there is a need for innovative approaches on this area, which would produce good quality open-source textbooks for GIS and remote sensing in many different languages, alongside with extensive training material, including innovative techniques such as distance learning.

In a yet restricted environment, Brazil has attempted to contribute by developing a comprehensive reference work on GIS, producing a three-volume set ("Introduction to GIS", "Spatial Analysis", "Spatial Databases"). Written in Portuguese and available on-line, it is arguably the most complete resource of its kind on the Internet today[6]. The response from GIS users in Brazil has been extremely positive, not only from GIS students and government officials but also from small private start-up companies specialising in GIS and small surveying firms that have wanted to enhance their capabilities.

Conclusion

This paper has investigated three major impediments to the greater use of geoinformation technologies in the developing world: *lack of data, lack of tools,* and *lack of expertise*. In a general sense, it is argued that recent trends for increased commercialisation of geoinformation technologies point to a disturbing picture in the near future, one at which the current disparities between and within developing nations on the use of such technologies could be increased rather than reduced. On the other hand, there has been substantial progress in all aspects of geoinformation technology in the developed world. By combining their expertise, developing nations would be able to respond adequately to this challenge.

By establishing joint projects, and using open source and non-restrictive copyright policies to the greatest extent possible, developing nations are in a position to establish a strong network of co-operative institutions, that would be fully capable of realising the full potential of geoinformation technology for the betterment of mankind.

[6] For access to the on-line book, as well as other training material, please use the webpage www.dpi.inpe.br.