

The Role of an Automated GIS in the Development and Management of Renewable Natural Resources of Northeastern Brazil.

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ABSTRACT

Northeastern Brazil is primarily semi-arid and contains areas that are undeveloped or underdeveloped. Effective development requires a detailed understanding of the natural resources including soils, geology, hydrology, vegetation, land use and land cover, climate, topography, etc. The geographical information system (GIS) is a major spatial data handling tool for solving complex natural resource planning problems. In the initial phase, we are studying selected areas of four states: Paraiba, Pernambuco, Rio Grande do Norte, and Piaui. Later the studies will cover all nine states of the Northeast. Major objectives of the study are to: (1) determine aspects and characteristics of a GIS, (2) design an appropriate GIS, (3) prepare procedures for acquiring data, (4) prepare procedures for data input, and (5) develop plans for training Brazilian personnel and for technology transfer.

Data for the GIS come from two sources: universities, federal and state agencies, and from interpretation of Landsat Thematic Mapper and SPOT imagery. Two up-to-date software systems are being utilized: The Earth Resources Data Analysis System (ERDAS) which is raster oriented, and pcARC/INFO which handles data in vector format. Both are used to prepare resource planning scenarios and to maintain spatial data planes. Thus, the GIS will be used to store, retrieve and analyze the myriad data required to develop effective long-range plans.

INTRODUCTION

Geographical Information Systems (GIS) generally are used to store large volumes of spatial data derived from a variety of sources, including remote sensors, and to efficiently retrieve, manipulate, analyze and display these data according to user-defined specifications for entire regions or parts of a region. A GIS can facilitate decision-making based upon analysis of complex spatial interrelationships in a rapid, cost-effective manner.

This paper describes a remote sensing and spatial data analysis procedure for the development and management of earth resources data about northeastern Brazil, especially for land use planning in the semi-arid regions.

STUDY AREA

The area known as northeastern Brazil comprises nine states: Alagoas, Bahia, Ceara, Maranhao, Paraiba, Pernambuco, Piaui, Rio Grande do Norte, and Sergipe. It is quite large, covering approximately 20% of the total area of Brazil. In the first stage of this project, selected areas are being studied in the states of Paraiba, Rio Grande do Norte, Pernambuco and Piaui. After completing this research, similar methodologies will be used to study all nine states of northeastern Brazil. The entire area and areas selected for study in the first stages of this research are shown in Figure 1.

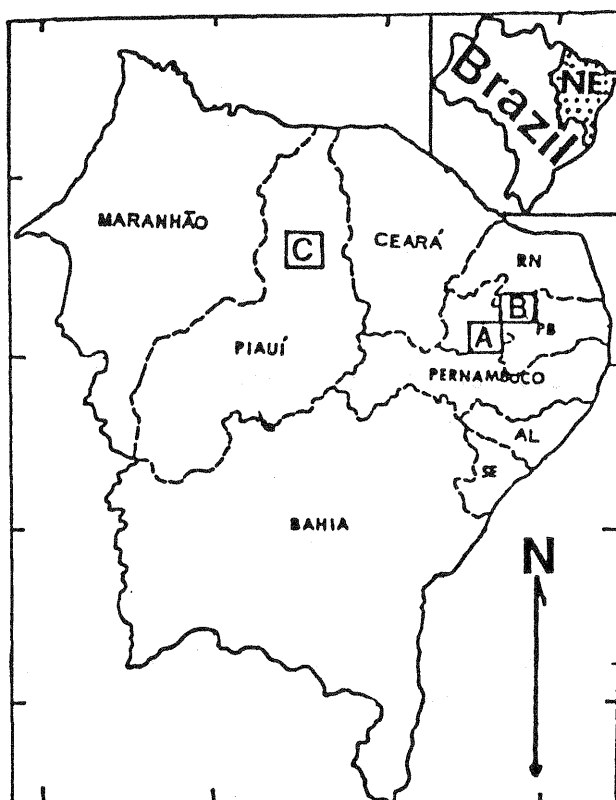


Figure 1. Selected test sites in northeastern Brazil: A. Pernambuco/Paraiba, B. Paraíba/Rio Grande do Norte and, C. Piauí. The location of northeastern area is shown on the inset map of Brazil.

The study area is mainly semi-arid and has various types of dry lands with elevations ranging from 200 to 900 meters. Various types of physiographical relief features and geomorphological forms such as alluvial plains, cultivated fields, hills, inselbergs, rock ridges and grassy plains are encountered. Crop production in the area is dependent principally on natural rains as very little of the area is irrigated with water that has collected in ponds and lakes during the rainy season. It is also covered by natural pastures, wastelands and xerophytic vegetation. Hydrologically, the area is covered by a network of rivers, many of which are intermittent. Soils derived from recent stream sediments in the area are rich, whereas others are poor to moderate in their natural fertility. The soils vary from shallow to very deep. The major soil orders encountered in the study area are: Entisols, Alfisols, Inceptisols, Ultisols, Lithic subgroups of various orders and rock outcrops.

Crop production and animal husbandry are the major agricultural and economic activities of the region. The principal crops of the region are maize, beans, cotton, sugarcane and sisal; animals raised are goats, sheeps and cows. The area also has extensive areas of various drought-resistant trees and shrubs. This semi-arid region, because of its uneven topography, climatic limitations, agricultural problems, unavailability of sufficient funding for research and development, inadequate planning and lack of trained personnel, has lagged in its development compared to many other parts of Brazil.

Nowadays, remote sensing and geographical information systems (GIS) are important and advanced tools for the inventory and analysis of renewable natural resources for regional and area-wide planning at both small and large scales in undeveloped and developing parts of the world. The demands for more effective management and utilization of Brazil's natural resources will not be met without the ready and effective sharing of data in our nation's interest.

GEOGRAPHIC AND EARTH RESOURCES INFORMATION AVAILABLE

Data about the various components required for the research are being gathered from sources as follows:

<u>Information</u>	<u>Source</u>
1. Land use	Aerial photographs, field measurements, satellite data
2. Soils	Aerial photographs, soils maps of various scales, soil survey technical reports and field surveys.
3. Slope and elevation	SUDENE
4. Droughts and floods	IBGE
5. Climatic date (temperature, rainfall, humidity)	EMBRAPA, University Centers
6. Geological, hydrological and geomorphological (erosion) data	State departments and units Secretariates of state governments
7. Slope classes	USDA, Soil Conservation Service, EMBRAPA
8. Vegetation and forest data	EBDF
9. Economic data	IBGE, Banco do Brazil

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| 10. Irrigation and drainage data | DNOCS, Water resources Secretariats |
| 11. Municipality and state boundaries | Administrative units of each state and city, SUDENE |
| 12. Aerial photographs | FUNDAP, INCRA, Secretaries of Mines and Energy of various states |
| 13. Landsat Thematic Mapper images and data | INPE (Brazil), EOSAT (USA) |
| 14. SPOT images and data | SPOT Image Corp. (France and USA) |

All of this information will be evaluated for completeness and accuracy. As well, additional computer compatible tapes of both Landsat TM and SPOT data will be acquired so as to provide temporal as well as spatial coverage of the study sites.

SOFTWARE AND PROCESSING OF DATA

The principal remote sensing image processing system being used is ERDAS—the Earth Resources Data Analysis System. ERDAS is a micro and minicomputer-based multipurpose, raster-oriented image analysis and GIS software system. At the University of Connecticut, ERDAS is installed on both a DEC micro VAX-II, with a Gould IP8500 image display system, and on an Intel 80386-based super-microcomputer with a Number Nine Revolution image display system. Both installations enable 512 by 512 by 32-bit full color image display with an 8-bit graphics overlay (a total of more than 16 million colors).

Data also are converted into the vector format for input to the pcARC/INFO geographic information system installed on another 80386-based micro-computer. Vector data are captured using a 36 by 48 inch Calcomp 9100 digitizer. Both of these systems are being used to implement natural resources planning scenarios as well as to maintain the digital spatial data planes from remote sensing data, existing map information and field observations. Figure 2 shows the software and image processing system being used in this investigation.

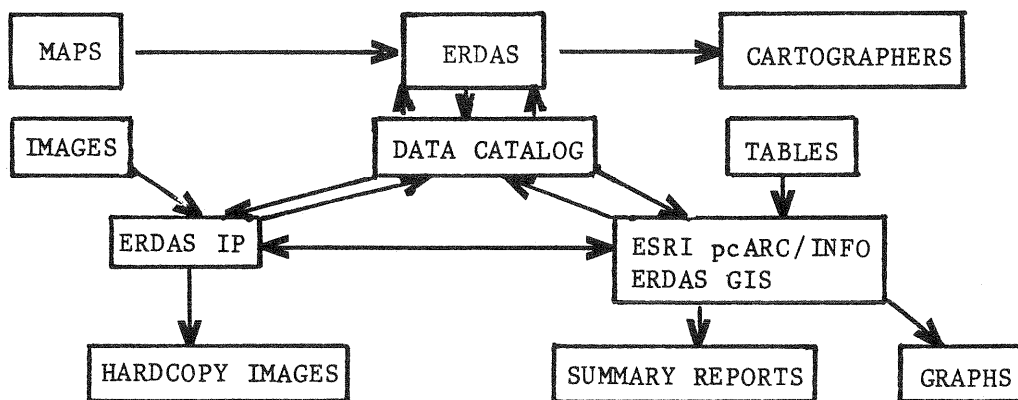


Figure 2. Software and image processing system for remote sensed data in the Laboratory for Remote Sensing at the University of Connecticut.

A hybridized unsupervised-supervised classification approach is being used for the analysis of land use, land cover, and other earth resources information from both Landsat Thematic Mapper and SPOT multispectral digital remote sensing data. The classification scheme is being modeled after the United States Geological Survey System for use with remote sensing data (Anderson *et al.*, 1976), modified to account for local conditions within the study areas in Brazil. To ensure that multispectral data from several dates are directly comparable, scene preprocessing will be applied to normalize all images to a reference image to account for atmospheric and solar illumination variations (Volchok and Schutt, 1986). Other preprocessing procedures are being examined for their utility in improving land use and land cover classification, especially band ratioing, principal components analysis, canonical analysis and other types of linear and non-linear image transformations.

Available reference data in the form of aerial photographs (1:20,000 and 1:30,000 scales) and topographic maps (1:25,000 and 1:100,000 scales) are used to assist in supervised training area selection for land and land cover features of interest. These reference data, supplemented by field visits, will also serve as the basis for accuracy assessment of the computer-assisted, satellite-derived earth resources maps which are being produced.

Once satisfactory land use and land cover classification accuracies have been achieved, the digital thematic maps will be corrected geometrically and projected into a UTM coordinate system. These data files will then be transferred into the ERDAS geographic information system in their raster format, as well as 'vectorized' for input into pcARC/INFO.

Beyond the preparation of baseline earth resources thematic maps from satellite data, procedures will be developed for the operational, routine, periodic update of such information from Landsat and SPOT data as they become available. This methodology involves a coordination of both the image processing activity itself as well as maintenance of the derived information within the geographic information data base management subsystem. A tentative geo-data processing system to be used in storing information on land use, land cover, soils, slope, climate, hydrology, vegetation, drought, relief, geology, erosion, municipal and state boundaries, etc. is shown in Figure 3.

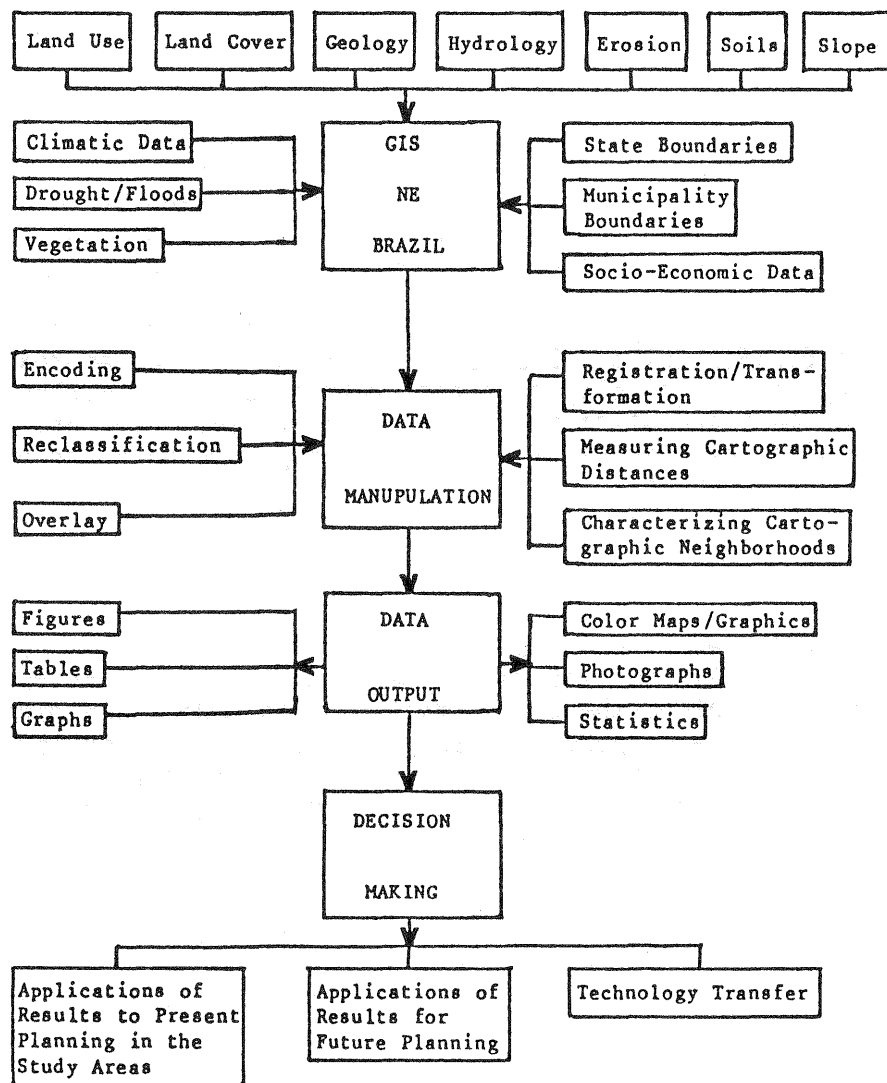


Figure 3. A tentative geographic information system for northeastern Brazil.

DATA MANIPULATION

Data manipulation of the system focusses on data retrieval and overlay analyses. Data retrieval manipulations include browsing, windowing, and multiple sheet spatial query. An automated overlay analysis will be applied to intervariable relationships created by overlaying or stacking two or more data planes. In such procedures, location is held constant while several variables are evaluated simultaneously. Because raster formatting spatially organizes and arranges data, vector-formatted information frequently is converted to a grid cell structure for overlay analyses. Such processing improves data handling efficiency. Overlay analysis encompasses overlay for map composite, map dissolve, overlay for area calculations and modeling through the weighting of various attributes.

OUTPUT AND PRESENTATION

A GIS can retrieve and display data in graphic or tabular form or in a combination of the two. Output from the system includes color displays on a monitor from which photographs can be taken for slides or prints. Scaled, color paper maps are produced on a Tektronix color ink jet printer. The map output on the monitor is generally in the raster format with 512x512 cells. Each cell covers an area of approximately 30x30m. Maps can be displayed of data retrieved or by overlay analysis. Line printer maps and statistics also are produced. Line printer maps in black-and-white are convenient for preliminary work on planning and for making area calculations.

MAIN MODEL DESIGNS

Under this study, eight main earth resource models are being prepared to integrate the results for the development and management of renewable natural resources of northeastern Brazil. Main models are derived from a set of eight or nine components, each of which is directed towards a specific land management and land use planning objective. The main models under preparation are: (1) erosion, (2) fertility, (3) soil suitability, (4) land irrigability, (5) soil salinity, (6) water management, (7) soil survey and (8) land use/cover. As an example, the erosion model is derived from several components: geology, topography, soils, hydrology, vegetation, climate, etc. (Figure 4). Geologic analysis considers the texture and structure and consistency of the different parent materials and their resistance to erosion. The topographic landscape submodel permits analysis of the environmental characteristics of a site in relation to elevation, slope and their direct and indirect relationships to erosion. Soils at the level of subgroups are placed in the correct classification based on their morphological characteristics and their degree of erosion tolerance. The natural vegetation submodel can be used to determine the optimal vegetation species for each area in a site and their capacity to check erosion. The hydrology submodel will be used to explain drainage patterns, surface water presence, and the possibility of

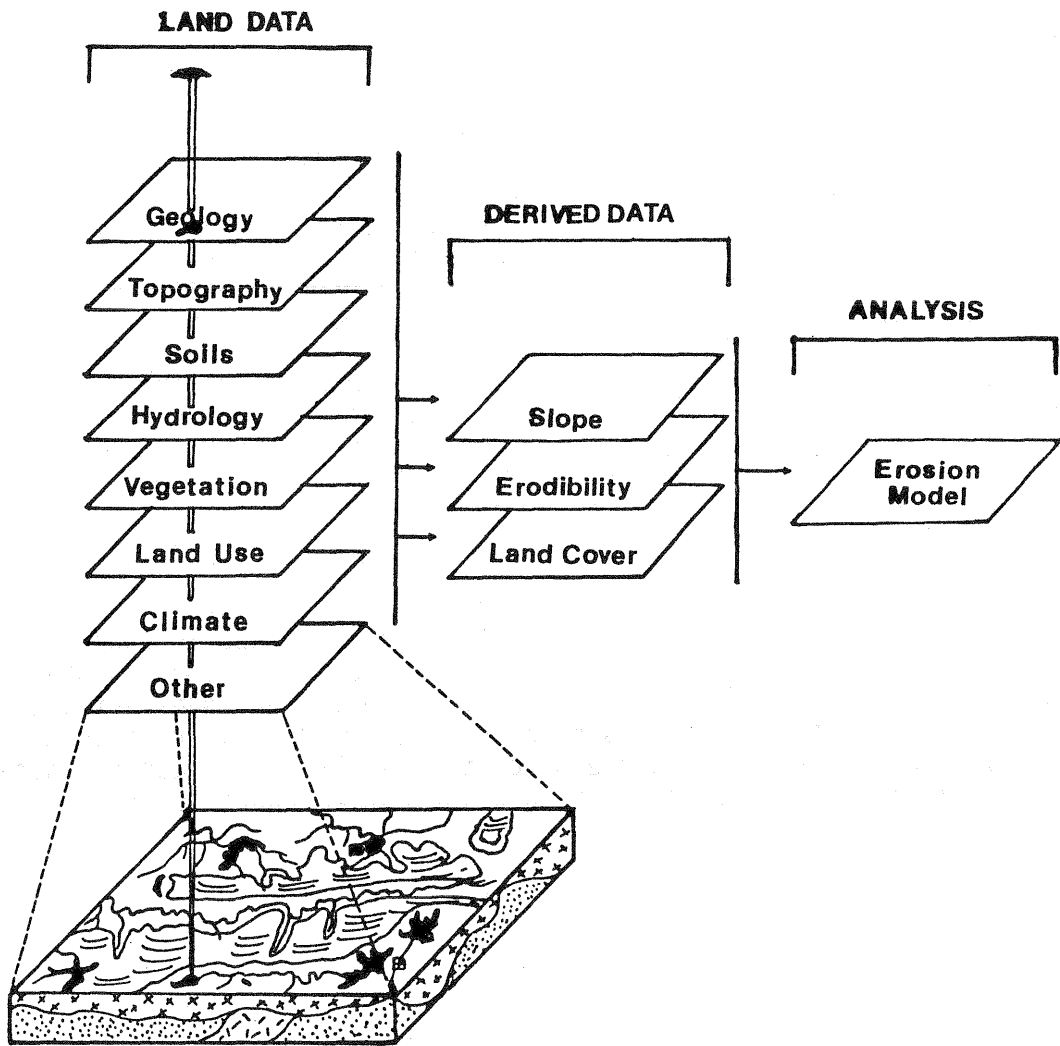


Figure 4. An example of the use of an erosion model for an area in northeastern Brazil (Santa Luzia Municipality, Paraiba).

subsurface water. Also, it will be used to determine the quantity of water which affects the type and extent of erosion. The land use and land cover submodel will identify different levels of the land use and land cover classification systems (Anderson et al. 1976) considering the climate and site of the study area and their roles in erosion. The climate submodel will describe the annual mean, maximum and minimum temperatures, annual precipitation and diurnal humidities. The final submodel will utilize socio-economic survey data to determine practices that agriculturists can use to obtain higher crop and animal production. The principal purpose of each model will be to provide sufficient up-to-date information to land use planners at both the regional and state levels. They also will aid planners, scientists, managers and administrators in selecting the topics for more detailed investigations. In the future, the models may be used for suggesting soil conservation practices such as soil and water management, reclamation procedures, etc. Models are designed to be altered according to the site, time, requirements and policies of a particular region.

One procedure to be used is the Universal Soil Loss Equation (USLE) which is designed to predict the long-term average soil losses in runoff from specific field areas under particular cropping and management systems. (Wischmeier and Smith, 1978). Widespread field use has substantiated its usefulness and validity for this purpose. The equation is used to compute soil loss for a given site as the product of seven major factors whose most likely values at a particular location can be expressed numerically.

The soil loss equation is: $A = R K L S C P$

Where,

A = computed soil loss per unit area

R = rainfall and runoff factor

K = soil erodibility factor

L = slope-length factor

S = slope-steepness factor

C = cover and management factor

P = support practice factor

To construct this erosion model as part of our program, three basic steps are employed: a) creation of a database, b) implementation and c) evaluation and utilization.

The erosion model is used to prepare land suitability maps. It is also used as a component in determining the minimum mapable unit size for an integrated output map for management and planning. After completing the first analysis using this erosion model, various scenarios will be prepared by changing the values allocated to each factor in the equation. New output maps will be prepared and evaluated. The final product will be maps that best meet planning and management objectives.

CRITERIA FOR LAND USE PLANNING

Land use planning processes that apply to the problems of developing countries are somewhat different from those used in developed nations. Economic development, agricultural production and the provision of basic housing and service facilities are problems of high priority in a developing country such as Brazil, especially in its northeastern section. However, although planning problems and priorities are substantially different between developed and developing nations, the structure of the planning process and the information requirements are essentially similar. Classification schemes are needed therefore which represent these facets clearly and unambiguously. The expandable land use/land cover system devised by the United States Geological Survey (Anderson *et al.*, 1976) is generally accepted world-wide and is being used in a number of operational mapping programs of both developed and developing nations. With two levels of detail (Levels I and II), it can be used with remotely sensed data at various resolutions and scales. It serves also as a framework for more detailed regional and local classification systems because it is sufficiently inclusive. For our study of the semi-arid regions of northeastern Brazil, this classification system is being modified in accordance with the local climate, local needs and existing conditions. This system of classification can be extended to the more detailed Levels III and IV through the use of large-scale aerial photographs and field observations. The work on land use/land cover for land use planning in Paraiba by Teotia and Ulbricht (1985) will be considered. Also, the classification system prepared for the state of Connecticut (USA), as described in the "Interpretation of Aerial Photographs" (Avery and Berlin, 1985) will be used to some extent to classify the remotely sensed data to Level III of the USGS system. The functions that land fulfills usually are associated with certain types of cover; thus, the image interpreter and researcher must identify the land cover patterns and shapes as a means of deriving information about land use.

During the conduct of this project, we will use the following important criteria suggested by the USGS:

1. Interpretation accuracies in the identification of land use and land cover categories from remote sensor data should be 85% or greater.
2. The classification system should be applicable over extensive areas.

3. The categorization should permit vegetation and other types of land cover to be used as indicators of activity.
4. Multiple uses of land should be recognized where possible.
5. The classification system should be suitable for use with remote sensor data obtained at different times of the year and in different years.

In addition, the following criteria suggested by Colomb, Kennard and Civco (1985) and by Civco and Kennard (1983) will be considered:

1. Individual land use and cover classifications should be customized to facilitate interpretations of digital images with different resolutions.
2. To reduce processing costs and increase accuracy, digital images should be classified and then corrected geometrically.

CONCLUSIONS

The experience gained to date during the preparation of a GIS for land use planning and management of the semi-arid regions of northeast Brazil suggests that design of the GIS and creation of data base and models require considerable effort, time and funding.

These studies have demonstrated that it is technically feasible to identify land ownership parcels, land use classes, different soil types and their principal characteristics, to prepare land suitability maps with updated information and to identify soil and water problems which are necessary for planning the management and development of renewable natural resources of the region. Finally, combining the two technologies, Geographical Information Systems (GIS) and Remote Sensing, has the potential for studying the complex problems which must be solved before development of this important area can take place.

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