

SPRING: OBJECT-ORIENTED GEOPROCESSING

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ABSTRACT

This work describes SPRING, an object-oriented GIS for UNIX workstations. Developed using the C++ language and the X Window System and integrated on a data base environment, SPRING is based on a general data model which breaks the raster-vector dichotomy. SPRING is being developed by INPE, with important support from EMBRAPA and the IBM Rio Scientific Centre.

1. INTRODUCTION

This paper describes the design and initial implementation of SPRING, a geographic information system designed using the object-oriented approach. SPRING works on UNIX workstations, under the X window system, and uses the extended relational DBMS PostGRES (Stonebraker and Kemnitz, 1991). The development language is C++.

The SPRING project is aimed at constructing a geographic information system (GIS) for the nineties. As such, it not only uses state-of-the-art technology, but also aims at solving the problem of dealing with the complexity of environmental data. The system combines image processing, geographic analysis, digital terrain modelling functions and a spatial data base in a single environment.

SPRING is being developed by the Image Processing Division of INPE (the Brazilian National Space Institute) in cooperation with EMBRAPA (the main agricultural research organization in Brazil) and the IBM Rio Scientific Centre.

2. THE OBJECTIVES OF SPRING

Currently, most available "off-the-shelf" solutions consist on various packages, each aimed at one specific type of geographical data (vector, DTMs, image processing). The current trends (Ehlers et al., 1989) point to a much tighter link between these functionalities, by providing the user with a unified view of data.

The need for conceptual advances has also been stated on the NCGIA research plan (NCGIA, 1989):

"Current GIS are either raster-based or vector-based and have limited abilities to combine the two. (...) While current systems are built using one model or the other, an ideal GIS would offer both and allow full interaction between them".

SPRING was aimed at meeting these challenges, by integrating various data types in a single system, together with a data base management system. Its system objectives are :

- A highly interactive environment for visualization, manipulation and edition of images, thematic data, networks and digital elevation models.
- Integration with a data base environment for archival and retrieval of spatial data and its attributes.
- Data is organized physically on a relational DBMS and logically in an object-oriented data model;
- The generation of a class library, for flexible and general-purpose development of GIS applications.

SPRING development is based on the existing products SITIM and SGI, respectively an image-processing and a GIS environment for microcomputers, developed by INPE. SITIM and SGI constitute the leading GIS environment in Brazil, and a significant amount of organizations in this country use it for environmental projects.

3. MAJOR DESIGN ISSUES

The design choices for SPRING illustrate clearly the scenario for GIS developers. To meet the system objectives, two major design decision had to be taken: the programming language and the database management system. These choices are described in detail below.

Why an object-oriented language ?

To solve the problem of diversity of formats and structures, the use of object-oriented methods for the design and construction of GIS is a natural solution (Duecker et al., 1987; Egenhofer and Frank, 1989). Unlike conventional programming methods, the objective of OOP is to allow a natural mapping between the problem space (the real world or a model of it) and the solution space (the computer programs and systems). This mapping enables treating each type of geographical information as an abstract entity, regardless of its format.

Why the PostGRES DBMS ?

The current trends in the design of GIS software point to a scenario where proprietary solutions for the archival of non-spatial attributes are being replaced by the use of commercial data base management systems (DBMS). An important research topic has been to use the new generation of DBMS, which are aimed at applications such as GIS (Cattell, 1991). We choose PostGRES as the underlying DBMS for SPRING for the following reasons:

- PostGRES is available free of charge. This is a substantial benefit, since we intend to make SPRING available free of charge for universities and research institutions.
- PostGRES is an extensible DBMS, and provides facilities for the construction of query processing methods suitable for geographical data. We intend to use these facilities in later versions of the system.
- PostGRES still maintains backward compatibility with the classic relational model, which may be advantageous to users which would like to use commercial RDBMS. In fact, a version of SPRING which uses INGRES has been developed by the IBM Rio Scientific Centre.

We also plan to implement a version of SPRING using the object-oriented DBMS O2 (O. Deux et al., 1991).

4. THE CONCEPTUAL DATA MODEL

SPRING provides a single environment that integrates the different formats and types of geographical data. This requirement has led to a conceptual model which:

- archives and retrieves geographical entities, using the idea of *geo-objects*.
- represents how the user sees the data, with the concepts of *category* and *geoclass*.
- provides expressive data types for the different data formats.
- enables logical organization of the geographical data, by the notions of *geocoded data base*, *project* and *information layer*.

A companion paper, also presented at ISPRS (Camara et al., 1992) describes the data model in a more formal fashion.

Geo-objects

SPRING data is a collection of geographical objects, or *geo-objects*.

A geo-object is an abstraction of reality, and corresponds to an individualizable entity of the geographic realm. Each geo-object corresponds to an element of the a relational data base, to be controlled individually by SPRING.

There is no restriction to the graphical representation of the geo-object, which may be an image, a city (thematic region), a digital terrain model, an oil well (point) or a sewage pipe (network).

For additional flexibility, the model accepts the definition of geographical objects without an associated graphical representation. Called "real world objects", the idea is to enable the user to associate generic information to an entity, which will have different graphical representations. This idea is very useful for building features of a sheetless system into SPRING.

Categories and geo-classes

The ideas of category are used to build the taxonomy of the geographical data. Each category represents environmental data of a different nature, viz.: Temperature, Elevation, Satellite images.

Data in one category may be partitioned further in geo-classes of common features. For example, a climate map (of the Climate category) will have its data partitioned according to the Koppen methodology.

The notions of category and geo-class guarantee a coherent working methodology for the SPRING user. Each geo-object belongs to one category and one geo-class. The user will define non-spatial attributes for each category and geo-class, which will be instantiated for each geo-object.

Built-in data types

In order to deal with the different types of geographical data, SPRING supports five built-in data types, corresponding to the five general geometries of geographical data: thematic maps (polygons), digital terrain models, networks, images and points (observations).

Geocoded data base, project and information layer

SPRING provides facilities for data organization and data archival. At the highest level, the user defines a *Geocoded Data Base* (GDB), repository for the data of a given study. A GDB is a collection of geocoded information and its nonspatial attributes. Its data need not be on the same projection, nor have spatial continuity. The only restriction for a GDB is that the methodology for its construction be coherent (that is, categories and classes have been pre-defined by the user).

A GDB is partitioned into *projects*, where each project corresponds to data for a specific geographical area, scale and projection.

A project contains a set of *information layers* (known as "infolayers"), where each infolayer aggregates geo-objects with similar features: same category, projection and spatial resolution (in the case of images). Examples of infolayers are: a LANDSAT TM scene, with 7 spectral bands; a digital terrain model or a political division map for a state, where each county will correspond to a different geo-object.

5. DESCRIPTION OF SPRING

The SPRING software consists of three components:

- the user interface, with facilities for selection, edition, visualisation, image processing, analysis and plotting control.
- the class library, containing methods (functions) for dealing with different types of geographical data;
- the data base interface, which provides links to the various DBMS to be used by SPRING.

The user interface

The SPRING user interface consists of a set of menus, using the X window system. Images and graphics are drawn on up to four drawing areas, and the interface allows for control of each particular drawing area, and for copying of data between them.

A user on typical working section on SPRING could perform the following tasks:

- Create a new Geocoded Data Base (GDB), by defining the working methodology (categories and geo-classes) or selection of an existing GDB.
- Create a project, which the basic unit of work and corresponds to a geographical area of interest. Each geo-object in the GDB belongs to one project.
- Import to the project data from other systems or from other projects. New data from digitizers and digital sources can also be included in a project.
- Select an existing project. After the selection, the spatial data base management system retrieves the corresponding data.
- Analyse, edit, process and visualise geo-objects.
- Query the GDB for attributes of geo-objects of a given project.
- Produce cartographic documents.
- Save the project in the current GDB.

Overview of the SPRING class library

The SPRING class library is a general tool for building GIS systems. It contains methods for dealing with the various types of geographical data, organized according to the built-in data types (see section 4).

The classes in the SPRING library can be grouped in the following fashion (some examples are given):

- data organization (object, Geo-object);
- geometries (Image, grid, thematic);
- user interface (window, menu, panels);
- graphics functions (SDrawable, ToolLine);
- database interface (Postgres, Ingres);
- primitive spatial objects (Point, Line, Polygon);
- cartographic projections;
- data structures (Doubly Linked List, K-d-trees);
- image processing applications (Filter, Colorcompress);
- spatial analysis.

The properties of the C++ language have been heavily used on design of the class library. *Operator overloading*, the possibility to redefine an operator giving another meaning to it, is used, among other cases, on primitive spatial objects. The "Point" operation set includes, for example, adding, assignment and comparison.

An example of *function name overloading* is the definition of the drawing area. The drawing area may be defined by its geographical centre, scale and projection, by its four corners in latitude/longitude, or by scale, and projection. In all cases, the method "SDrawable::Init" is called to handle the necessary actions.

Polymorphism, sending a message to an object whose execution depends on the object type, is used throughout the class library. Methods for initialization and visualization are typical examples of polymorphism. For example, a method called "show" is used for the generation of graphical output on all classes. By polymorphism, the same operation ("show") is able to display raster, vector or gridded data, generating intermediate results, if necessary.

The DBMS interface

SPRING has been designed to achieve independence from any particular DBMS. There is a clear interface, achieved by a class called "DBase", which has derived subclasses for each specific relational DBMS to be linked to SPRING.

Due to the properties of inheritance available in C++, a general set of methods used by the DBase class have specific implementations for different DBMS systems. The methods of this class use, whenever possible, the standard SQL programming interface, making the porting to different DBMS straightforward.

6. THE FUNCTIONALITY OF SPRING

SPRING is intended to be a software product and not only a research tool. The initial version of SPRING has the following functionality:

* Image input

- LANDSAT, SPOT and NOAA data

* Thematic maps input

- digitalization (table or mouse)
- line and arc edition
- labelling and polygon generation

* Digital Terrain Models input

- digitalization of sparse points or isolines
- regular grid generation

* Geographical Analysis

- Reclassification
- Cross Tabulation
- Polygon overlay
- Area and Perimeter calculation
- Slope and Aspect calculations
- Volume and profile calculation on DTMs

* Image Processing

- histogram manipulation
- filtering
- image enhancement
- image segmentation
- IHS - RGB Transformation
- principal component analysis
- NOAA vegetation index
- maximum-likelihood classifier
- clustering

* Visualisation

- overlay of charts and images
- multispectral image display
- zoom
- countour lines generation
- 3D DTM rendering
- 3D combination of images and DTMs

* *Selection (Data Base interface)*

- selection of geographical objects (by attributes)
- definition of relations in the data base

* *Output*

- import DXF format symbols
- management of a symbol library
- cartographic document generation
- HPGL and Postscript output

* *Format and Projection Conversion*

- vector-raster transformation
- raster-vector transformation
- import/export of DLG/DEM data formats
- import/export of SGI/SITIM data
- support for 12 projections
- image-chart registration (by control points)

* *Documentation*

- User Manual (Portuguese/English)
- Reference Manual (English)
- Installation Manual (Portuguese and English)

This initial version has more than 130.000 lines of C++ code and an effort of 25 man/years has been involved in it.

SPRING has versions for SUN SPARCs, IBM RISC 6000 and Silicon Graphics IRIS families of workstations. SPRING is available at no charge for research and non-commercial uses. For further information, please contact the second author by e-mail (gilberto@dpi.inpe.br).

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