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Geographic Information Systems

Luísa Orvalho
Professor Coordinator at ISTEC Porto - luisa.orvalho@my.istec.pt
Researcher at the Portuguese Catholic University - CEDH- lorvalho@ucp.pt

João Morais
Undergraduate in Computer Engineering at ISTEC Porto
joao.morais.737@my.istec.pt

Carlos Teixeira
Undergraduate in Computer Engineering at ISTEC Porto
carlos.teixeira.739@my.istec.pt

Abstract
With this article we intend to review the state of the art regarding Geographic Information Systems (GIS) and recognize the great technological evolution of the last decades. Identifying the objectives of GIS, describing its components, its main uses, functions and characterizing the available software of this technology are the main objectives of this investigation.

Keyword: *Geographic Information Systems, Uses, Functions, Components, Desktop GIS Applications, Web GIS Applications, Explore Porto Application*

I. Introduction

Although the GIS concept appeared in the 1960s [9], it was not until the 1990s that applications expanded. Many software was developed for control and decision support in different areas: science, health, environment, natural resources management, agriculture, urban construction, transport, population, education, politics. The diffusion of GIS in different areas of development required the evolution of systems that aggregate analytical models with very strong languages that allow integrated queries to provide information for many of the problems. A multitude and diversity of applications, specific systems have been developed. Including systems for

environmental planning, territorial mapping, urban planning and image processing systems associated with the Earth observation satellite program of North American origin, called Landsat [12].
Most information has a geographic context, and this information is overlaid on a map.
GIS is a structure of a system, supported by physical digital equipment to capture, store, integrate, analyse and display data from a geographic perspective [2]. In addition, GIS provides tools to develop models, create scenarios and provide various solutions.
There are many reasons to use GIS, most are based on the need to make decisions, to use our resources efficiently and a pull technology, the interest of using new tools to solve problems. GIS as a technology is grounded in geographic information science, and supported by the disciplines of geography, topography, engineering, space science, computer science, cartography, and statistics.
The GIS as software is the only one capable of manipulating coordinates and attributes with associated data. There are several tools and

software available to help you build a GIS. In an easier term, GIS is the fusion of cartography, statistics, analysis and database technology [2]. GIS, is revolutionizing the creation of new applications. With continuous improvement regarding this technology, the future of GIS looks more promising.

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyse, manage and present all types of spatial data.

GIS is a computer-based toolkit for the study, analysis and visualization of maps/attributes and events through the integration of various data sources based on a common geography [3].

GIS provides the necessary set of tools necessary to gain adequate insight into the places and processes of our environment, society and economy.

GIS combines layers of information about places to give a better understanding of that place. The layers of information are combined irrespective of the purposes, for example, what is the best location in a city for a new shoe store, geometrically analyses the distance from the competition, the probability of the existence of crimes near the new location, detects patterns of demand for that product by the customers.

II. GIS Objectives

The objectives of the GIS are:

1. Provide efficient ways of distributing and manipulating data.
2. Maximize decision-making and planning efficiency.
3. Remove redundancies in databases and minimize duplication.
4. Analyse complex queries involving geographic reference data to generate new information.
5. Provide the ability to integrate information from multiple sources.

III. GIS Components

The Geographic Information System is essentially composed of five main components [4], as illustrated in Figure 1.

Figure 1. Graphical Information System

Source: https://www.openpr.com

a) Hardware:
The central processing unit (CPU) is the main component of the GIS. This is directly connected to a disk storage unit that provides space to store data and programs.

b) Computer Software Module:
The GIS software includes the programs and user interface to control the hardware. Good GIS software requires ease of use, functionality, compatibilities, upgradeability, documentation, and cost-effectiveness.

c) Data
The most important component of a GIS is data. Data may be collected, compiled to custom specifications and requirements, or acquired from a commercial data provider.

d) People:
Without people, GIS technology is of limited value. People can manage and develop plans to apply to real problems. GIS users can be technical experts to design and maintain the system or simple amateur and or sporadic users.

e) Methods:
Methods are the set of procedures and rules for implementing a GIS business' plans and activities.

d) Software – Software is the most well-known element of a GIS. From there, it is possible to manipulate the tools and functions for generating geographic information. There are several GIS software.

IV. Main GIS uses

GIS has multiple applications and, it can be said that if there is a map, there can be a GIS application.
Some main GIS applications explored in this article:

a) Archaeology
Remote Earth Mapping; Land management and public works; Precision agriculture; Navigation;
b) Cartography
Management of natural resources; Photogrammetry; Environmental contamination; aerial video;
c) Geography
Surveying; Environmental contamination; Landscape architecture.

V. GIS Functions

GIS software provides the tools to manage, analyse and display and disseminate spatial data and spatial information. GIS software provides the specific tools to visualize and edit data, manipulate it, generate and extract the information necessary to produce the materials to communicate this developed information [9].
The functions normally provided by GIS software are:
a) Data entry
- Manual collection of coordinates
- Attribute capture
- Capture digital coordinates
b) Edition
- Manual editing of point, line and area features
- Manual editing of attributes
- Automated error detection and editing
c) Data Administration
- Copy, combine data
- Data recording and projection
- Redundancy, data reduction
- Documentation
d) Analysis
- Spatial consultation
- Attribute query
- Interpolation
- Connectivity
- Terrain analysis
- Spatial data overlay
- Algebra map
e) Output
- Map design and layout
- Printing maps on paper
- Digital graphic production
- Metadata output
- Digital map service

VI. Explore Porto: an example of a web application

The Municipality of Porto created a new service, Explore Porto, which challenges citizens and visitors to explore the city differently way, as, for the first time, real-time information about transport and main points is made available on a single platform of interest to the city [5].
This service was created to provide useful and reliable information on mobility and points of interest in the city of Porto, thus guaranteeing the evolution of a planned and static information system based on real-time information.
Explore Porto is an available web application that uses around 1,000 signalling devices spread across the city:
- Blue dots/beacons – to convey information about the place where the dot is located, whether mobility or tourism information. In this way, any citizen or visitor who has a smartphone can instantly access more details about the place, thus being able to explore the surroundings, as well as plan the best way to travel and visit other points in the city. As can be seen in Figure 2, the example of a GIS application.

Figure 2 – A GIS application of Porto

Source: https://explore.porto.pt/

Explore Porto features

As an open project, in continuous evolution, it is possible to highlight the following set of features in this application:
- Itinerary suggestions: plan a route, get real-time information about public transport;
- Exploration of points of interest in the city: with access to description, history, address and opening hours and relevant and updated information;
- Identification of other points of interest near the location where the user is;
- Alerts on temporary changes to the normal operation of public transport routes;
- Favourites selection: save routes or points of interest that you wish to have available;
- Possibility of categorizing points of interest in those who introduce them to the platform.
- Open data and a model that even allows the development of new modules and functionalities that result from challenges of the city's innovation ecosystem.

VII. GIS Desktop Software

1. GRASS GIS

The Geographic Resources Analysis Support System / Geographic Resources Analysis Support System is an open-source Geographic Information System (GRASS GIS), used for geospatial data management and analysis, image processing, graphics and maps, spatial geoprocessing and visualization. Being one of the oldest existing public domain GIS software [6] it is currently used in academic and commercial environments all over the world.

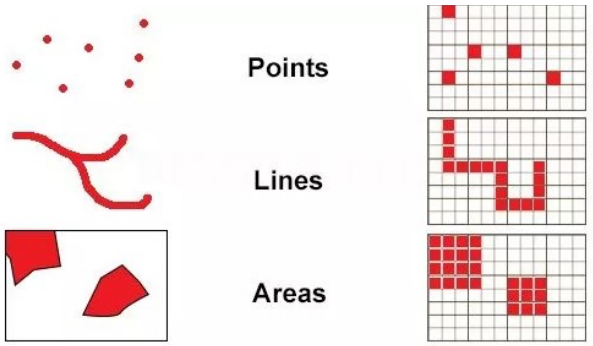
a) Characteristics
GRASS is a raster/vector image processing GIS that uses several open-source geospatial libraries (GDAL, OGR, PROJ4), GRASS supports dozens of raster and vector data formats for import and export. Contains several programs and tools for manipulating maps and images; manipulate raster and vector data, process multispectral image data and create, manage and store spatial data [6]. To facilitate operations, it provides an intuitive Windows interface and command-line syntax. It is written in ANSI-C.

b) Import/Export:
- 2D raster data;
- 3D raster data (voxel);
- Topological vector data (2D and 3D).
c) Platforms:
- Windows, macOS, Linux

2. gvSIG

gvSIG is a free desktop Geographic Information System software designed to capture, store, manipulate, analyse and consolidate any category of geographic information. It provides an intuitive interface, the ability to access the simplest formats, whether vector or raster [7]. It has a wide range of tools for working with geographic information (query tools, layout creation, geoprocessing) which makes gvSIG a powerful and easy-to-use tool.
The difference between vector and raster data:
- Raster or bitmap data are images that contain the description of each pixel, as opposed to vector graphics.

Figure 3 - Vector and Raster



Source: https://www.infoescola.com/

- Vector data is used to represent real-world features in a GIS. A vector feature can have point, line, or polygon geometry. Each vector feature has attribute data which describes it. Geometry feature is described in terms of vertices.

a) Characteristics
- Integrates remote data (files, databases) and remote data through OGC standards in the same view.
- It is designed to be easily extensible, enabling continuous improvement of the application.
- It is an open-source software, under the

GNU/GPL licence, which allows its free use, distribution, improvement and study.
- Available in multiple languages.
- Developed in Java language.
b) Platforms:
- Windows, Macintosh, Linux, UNIX

3. OpenJUMP

OpenJUMP GIS is an open-source GIS. It is written in the Java language through a collaborative effort of volunteers, the application can read shapefiles and files in the GML format [13]. It's free (under the GPL licence).

a) Features:
- It is a Vector GIS that can also read rasters.
- With JUMP / OpenJUMP can edit, save, analyse data.
- Provides a GIS API with a flexible plugin framework.
- Uses OGC standards like SFS, GML, WMS and WFS
- Available in multiple languages.

b) Import/Export:
- Vector Files: GML, DXF (AutoCAD (R) Map), DWG (AutoCAD (R) Map), DGN (Microstation (R), DLG, MAPINFO (R) MIF, ESRI (R) E00, TIGER2000/LINE, SDTS, GeoConcept, KML (Google Earth).
- Raster Files: GIF, PNG, JPG, JPEG, TIF, TIFF, GeoTIF, BMP, EC WErMapper (R), SID Lizardtech (R) MrSID, BIL, ADF ESRI (R) Dem Grid, IMG, JPG2000, SDTS, HF, ERDAS Imagine.

c) Platforms:
- Windows, Macintosh, Linux, UNIX

VIII. GIS / Web Software

1. Map Server

MapServer is an open-source geographic data manipulation engine written in the C language. It was originally developed by the ForNet project at the University of Minnesota (UMN) in cooperation with NASA and the Minnesota Department of Natural Resources (MNDNR). In addition to using GIS data, MapServer allows you to create maps from geographic images, which can direct users and their content [10]. For example, the Minnesota DNR Recreation Compass provides users with over 10000 web pages, reports and maps through a single application. The same application serves as a map search engine and provides spatial context. [10]

a) Characteristics:
- Fully customizable and guided output
TrueType fonts
- Automation of map elements (scale bar, reference map and legend)
- Thematic mapping using classes based on logical or regular expressions.

b) Import/Export:
- Raster and vector data formats TIFF/GeoTIFF, EPPL7.

c) Platforms:
- Windows, Linux, Mac OS X, Solaris.

2. QGIS

Quantum GIS (QGIS) is a free software with open source, cross-platform geographic information system that allows the visualization, editing and analysis of georeferenced data. Similar to other GIS software, QGIS allows the user to analyse and edit spatial information, in addition to creating maps with multiple layers using different projections, which can be created in other formats and for all types of use. [14]. QGIS allows you to compose maps from raster and/or vector layers. Typical of this type of software, data can be stored as points, lines or polygons.

a) Features:
- Fast, compact and easy economic, productive;
- QGIS can connect to data/files (DBase, Access, ODBC) and SQL servers (MySQL), PostgreSQL, Firebird, SQLite, Oracle, SQL server;
- Available in several editions (basic, professional, enterprise, web server);
- Ability to manage large vector and raster datasets.

b) Import/Export:
- Vector data formats:
- ESRI ArcView (.SHP) format files, MapInfo MID/MIF, AutoDesk DXF, MicroStation DGN,

ESRI ArcInfo export files (.E00), MapGuide SDL.
- Raster data format:
- Import JPEG and TIFF/GeoTIFF images.

c) Platforms:
- Windows, Linux, macOS, Android (beta).

IX. GIS Software / Commercial

1. MapInfo professional

MapInfo Professional is a Windows-based geographic mapping and analysis software product for expert location intelligence applications, produced by MapInfo Corporation.
MapInfo Professional can combine and display, on a single map, data from multiple sources and different formats. The software can overlay raster and vector layers on the same map; the former can be semi-transparent, so that they can serve as more than mere backdrops [11]. MapInfo is popular in this GIS medium as it is very easy for the typical user to use to analyse pre-built map data layers.
a) Characteristics:
- Simplicity of Use: Save time and maximize productivity by taking advantage of usability enhancements such as easy access to frequently performed layer operations or quickly selecting the same colour, symbol or line style every time [11].
- New data editing, creation and maintenance tools.
- Maps with better quality, reliability and visualization;

b) Platforms:
- Microsoft Windows

2. Integraph

Intergraph Corporation was an American software development and services company, which since 2010 is part of Hexagon AB, a publicly traded global information technology company specializing in hardware and software digital reality, founded in 1992 and headquartered in Stockholm, Sweden.
Intergraph makes several GIS applications. Most GIS services are designed to be open, and can run in a variety of other GIS software formats. Intergraph has developed products that help GIS interact with information technology (IT) and business process augmentation tools [8]. Offers a GeoMedia family and Modular GIS Environment MGE Suite.
Using an open architecture, the GeoMedia suite of products integrates geospatial information for the customer and provides the tools needed to develop custom and business-to-business applications using industry-standard development tools. GeoMedia offers open access to all geospatial data formats. Currently, at version 4.0, the GeoMedia family consists of GeoMedia, GeoMedia Professional, GeoMedia WebMap, and GeoMedia WebEnterprise.

a) Characteristics
- GeoMedia is universal and serves as a visualization, analysis tool and as an open platform for developing custom GIS solutions.
- GeoMedia Professional is a product specifically designed to collect and manage spatial data.
- GeoMedia WebMap is a web-based map viewing tool.
- Intergraph offers the frameworks for GeoMedia, which offers users a software with great power of visualization, mapping and analysis.

b) Platforms:
- Windows OS

3. ArcGis

ArcGIS is a family of client software, server software, and online geographic information system (GIS) services developed and maintained by Esri, first released in 1999 as ARC/INFO, a GIS system supported by the command line for data manipulation.
It was later incorporated into ArcGIS Desktop, which was eventually replaced by ArcGIS Proem, 2015 [1]. ArcGIS Pro works in 2D and 3D for mapping and visualization and includes Artificial Intelligence (AI).

a) Characteristics:
- ArcGIS is a software engine, a product for programmers to create custom GIS desktop applications.
- ArcGIS provides application programming

interfaces (APIs) for COM, .NET, Java, and C++ for Windows, Linux, and Solaris platforms. The APIs include documentation and a number of high-level visual components to make building ArcGIS applications easier.

b) Import/Export:
- Vector data formats:
- ESRI ArcView (.SHP) format files, MapInfo MID/MIF, Autodesk DXF, ESRI ArcInfo export files.
- Raster data format:
- Import JPEG and TIFF images.

c) Platforms:
- Windows, Linux, macOS, Android.

X. Conclusion

GIS software is unique with the ability to manipulate coordinates and attributes with associated data. To develop a GIS, there are many tools and software available, depending on the user's needs or the query's requirements.
The best GIS software is the one that can be used by everyone and easily, without requiring specific training, but just mastering a few concepts.
We consider that QGIS and ArcGis are among the GIS software studied, with a lot of information on the Web. GRASS is better than desktop GIS software, and ArcGis is better than commercial GIS software.
Applications provide focused user experiences to get your work done and bring your GIS to life. GIS applications work virtually anywhere: on phones, the web, and desktops.
Currently, thousands of organizations use GIS to build interactive maps, which: perform analysis, share information and solve complex problems around the world. This is changing views across the world.

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