



Free and Open Source Software for GIS education

A White Paper by

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1.0 Introduction

This white paper is written with the support from the National Geospatial Technology Center of Excellence (GeoTech Center, <http://www.geotechcenter.org/>). The goal of this paper is to assist GIS educators at various institutes (high schools, community colleges and universities) towards understanding the potential role of open source software (or free and open source software -- FOSS) in GIS education.

The free and open source software "movement" has significantly impacted all aspects of information technology (Tiemann, 2009). We, as GIS educators, are already using many open source software packages daily and may not be aware of them. For example, if you are browsing website contents, 52.26% of web servers on the Internet in 2009 use Apache, currently the most popular web server software (<http://news.netcraft.com/archives/2009/01/>) freely available for download. Firefox browsers, thunderbird email tools and Linux operation systems are examples of popular open source software. However, open source software is not well adopted in GIS education due to the lack of user-friendly guidance and the full integration of GIS learning resources. This paper will provide a basic introduction of some of the available free and open source software with easy-to-follow guidance for both GIS teachers and students. Hopefully, more GIS educators will adopt open source GIS software in their courses to provide a comprehensive range of instructional tools and resources.

1.1 What is open source software?

Open source software is a type of "free" software to be accessed, used or modified by their user groups and developers. There are many similar terms to describe this kind of software, such as "free software", "libre software", "open software", etc. One key feature to distinguish open source software from other types (such as proprietary software and shareware) is their "**free software licenses**", which explicitly define the legal rights to users with freedoms to run, study, change, redistribute, and access the source codes of the licensed software (<http://www.fsf.org/licensing/essays/free-sw.html>, Free Software Foundation). All open source software is required to be "licensed". The procedure of implementing "free software licenses" is necessary to protect their users' legal rights and to ensure the freedoms of the software. There are several organizations that can provide free software license templates, such as General Public License (GPL) and Berkeley Software Distribution (BSD).

Figure 1 (created by Chao-Kuei Hung) illustrates a diagram with different categories of software licenses (you can learn more about different types of software licenses from this website: <http://www.gnu.org/philosophy/categories.html>). This figure illustrates that free downloadable software is not necessarily equivalent to open source software. For example, Google Earth is one of the most popular free Virtual Globe GIS applications that everyone can download and use for free. But Google Earth is not open source software. It is proprietary software.

In Figure 1, one slight change was made to the original illustration. A red box was added to represent the new boundary of public domain software. Because some public domain software may have no copyright restrictions or licenses, the public domain software has been altered to both include and exclude the open source domain. In GIS software, GRASS GIS is a famous example of public domain software. Public domain software can be re-packaged and sold as proprietary software or licensed as open source software (Valdes, 2008). The U.S. Army Construction Engineering Research Laboratories originally developed GRASS GIS in 1985. The

GRASS software development team adopted the GNU GPL in 1999 and GRASS became open source software with its version 5.0 release (GRASS history: <http://grass.osgeo.org/devel/grasshist.html>). Recently, some private companies have also re-packaged the public domain software GRASS, with nice graphic user interfaces and subsequently created commercial, proprietary versions of GRASS, such as OpenOSX GrassPro.

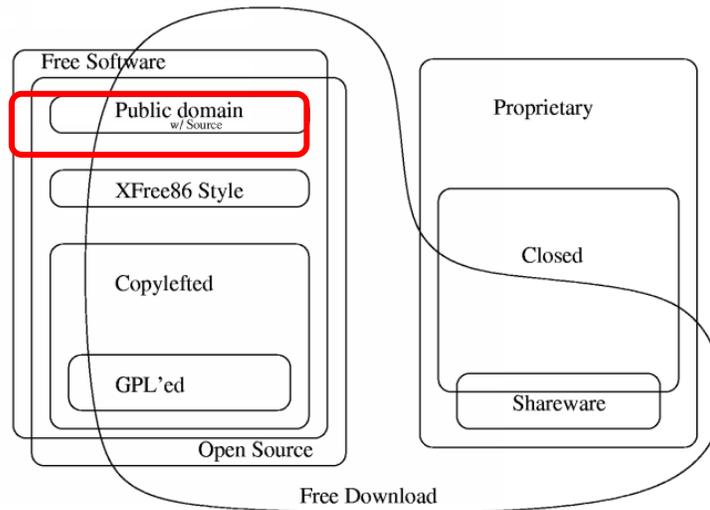


Figure 1. Categories of Free and Non-Free Software. (original image from <http://www.gnu.org/philosophy/categories.html>, by Chao-Kuei Hung).

1.2 When should we use open source software?

Both proprietary GIS software and open source GIS software are equally important for GIS education. Many GIS teachers select proprietary GIS software for GIS education because students can learn the mainstream software skills and have advantages in the job markets. On the other hand, some GIS teachers prefer to use open source software because it is free of cost and allows for the freedom to modify and distribute GIS applications. This paper will not argue which direction is better for GIS education, but rather suggest when GIS teachers should or could use open source software. In the following situations, it may be a good opportunity to consider open source software in your classes:

1. Teachers would like to explore the possibility of teaching GIS in a very short period, but do not have immediate financial support from schools or software vendors to purchase GIS software.
2. Students would like to install and try GIS software on their home computers.
3. School computers are using non-Windows operating systems, such as MacOSX or Linux.
4. Teachers would like to highlight a certain aspect of GIS functions, such as database management, web mapping, remote sensing, or spatial analysis, and they may realize that commercial GIS packages do not provide these individual functions, or the cost of adding these additional functions are too expensive.
5. Teachers would like to demonstrate some unique GIS functions to students tomorrow. (Most commercial GIS software will take more than one week to finalize the licensing with vendors. You can download and use open source software immediately.)

2.0 Popular open source software examples for GIS education

The following section will highlight some useful open source software for GIS education. Some descriptions and experiences are gathered and summarized from the on-line Linden group forum (the group of Open Source Geospatial Foundation) and personal communication with Eric Wolf (USGS) and Lisa Sweeney (MIT libraries). To provide an easy-to-follow guidance for GIS educators, related open source software has been categorized into five domains for GIS education:

1. Basic desktop GIS
2. Remote sensing software
3. 3D visualization tools
4. Others (including Web mapping servers and clients, spatial programming tools and libraries, and spatial databases)

Details of open source software have been illustrated for the first three categories (basic desktop GIS, remote sensing software and 3D visualization tools). Only summarized descriptions for the rest of open source GIS software have been provided due to the white paper page limits.

2.1 Basic desktop GIS

Basic desktop GIS software can provide basic GIS functions, such as data input, map display, spatial query, attribute query and spatial analysis. Most open source desktop GIS software can be installed on multiple operating systems, such as Windows, MacOS, and Linux. However, one common problem in open source desktop GIS software is the lack of advanced cartographic functions and symbolization. Of course, some offer the capability to export the mapping results as a scalable vector graphic (SVG) format to subsequently edit it in OpenOffice Draw (another open source software) or utilize cartographic support with Inkscape (<http://www.inkscape.org/>).

2.1.1. KOSMO (<http://www.opengis.es/>) (download file size: 108MB - including JRE package) (Available OS: Windows and Linux)

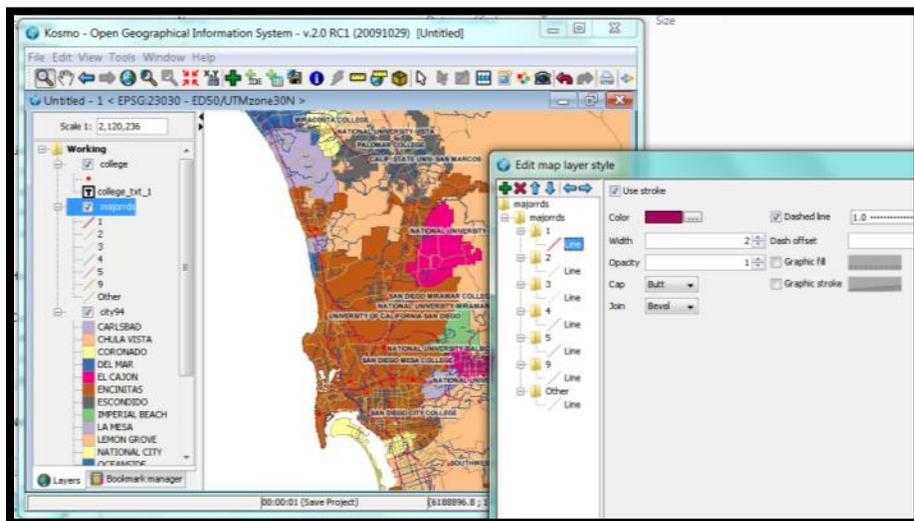


Figure 2. Kosmo and its advanced cartographic design function.

KOSMO is one of the most popular open source desktop GIS (Java-based), providing a nice Graphic User Interface (GUI), GIS data editing tools, and spatial analysis functions (Ramsey, 2007). KOSMO was developed based upon OpenJUMP (<http://jump-pilot.sourceforge.net/>), which is a light (download size: 14MB) and simple version of open source desktop GIS, offering very limited graphic and symbol functions. KOSMO has improved cartographic and spatial analysis functions from OpenJUMP, providing a friendly and comprehensive GIS package for desktop computers. One major advantage of both OpenJUMP and KOSMO is the capability for users to edit/modify vertices (a very detailed level of segment nodes) in vector-based layers.

2.1.2. gvSIG (<http://www.gvsig.com>) (file size: 89MB) (Available OS: Windows, Linux and MacOS X)

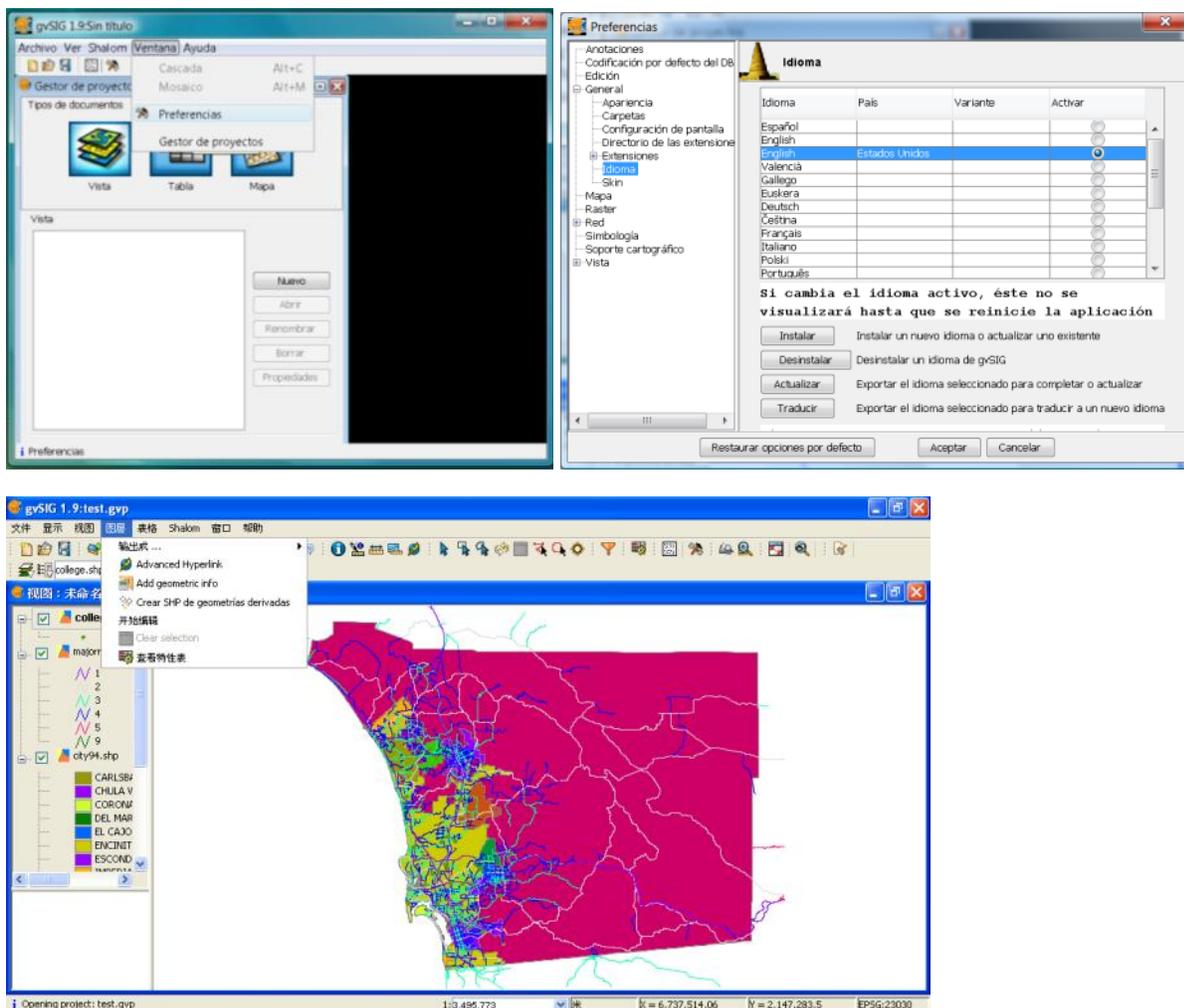


Figure 3. The multiple-language user interface functions in gvSIG (how to switch the language [above] and shown in the Chinese version [below]).

gvSIG was developed by the European GIS community offering multiple language user interfaces. More than ten different languages (including Spanish, French and Chinese) can be selected to display the menus and tools. This feature is extremely useful to teach GIS in a non-

English-spoken community. If you can only read English, it may be challenging to switch the language back to the English version when you launch the software for the first time (the default language is Spanish). You can change the language by selecting [Ventana] → [Preferencias]. Following the Figure 3 selection (In the General option, select [Idioma] → check English → click on [Aceptar]). You must first close the entire program and restart it again to change the language interface. gvSIG is well known for its flexible GIS data input format. You can use various GIS data formats (both vector and raster) and online resources (such as WMS, WCS and WFS).

gvSIG has nice vector data editing functions. Users can easily digitize lines by snapping vertices to existing nodes and generate correct topology. With an easy-to-configure locator map, gvSIG immediately reveals where you are in your dataset. Some GIS professionals believe that gvSIG is becoming close to replacing ESRI ArcMap software.

2.1.3. uDig (<http://udig.refractory.net/>) (file size: 94 MB, Available OS: Windows, Linus, and MacOS).

uDig is also a popular Java-based desktop GIS software. The name, uDig, stands for “User-friendly Desktop Internet GIS”. Therefore, uDig offers strong capabilities to integrate Web mapping technologies, such as WMS, WFS, remote ArcSDE, WCS, GeoRSS and KML. The uDig website includes great tutorials and walkthrough documents for first-time users. uDig is built upon IBM's Eclipse platform with a “clean” user interface. uDig provides several good GIS functions, including the Styled Layer Descriptor (SLD) support, Web Catalog Server support, and thematic mapping with advanced symbology. uDig is also a great choice for Desktop GIS software.

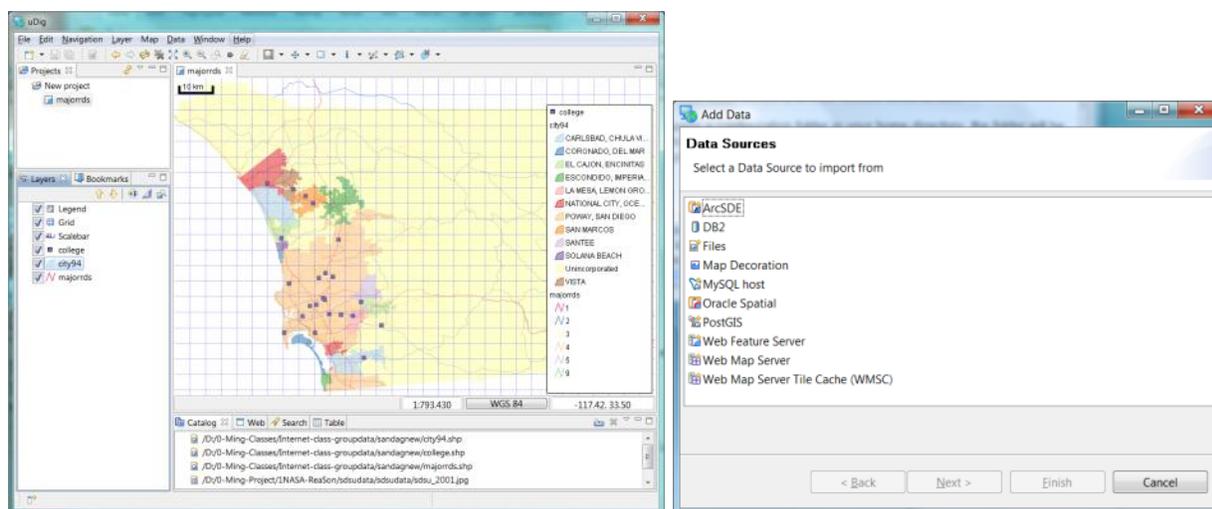


Figure 3. uDig user interface with supported data input format.

2.1.4. Quantum GIS (QGIS) (<http://www.qgis.org/>) (file size: 89MB, 1.0.2 LTS Windows Standalone version, available OS: Windows, UNIX, Linux, and MacOS).

Quantum GIS (QGIS) provides a very nice integration with Python, a scripting language to customize or automate GIS functions. Python is probably the most popular GIS programming language now because ESRI ArcGIS also adopts Python for their programming functions. There are many different versions of QGIS available for download. We recommend the Long Term Support (LTS) version. After the download, it may be necessary to change the installation

directory for QGIS to a root folder (such as C:\QGIS) rather than accepting the default [/programs files] directory if you are using Windows Vista or Windows 7. You may have some problems installing this program initially because of file written permission problems. Changing the default installation directory to a root folder may solve this issue.

QGIS supplies a good manual (<http://www.qgis.org/en/documentation/manuals.html>). The software provides useful GIS tools in spatial analysis, geoprocessing, geometry, and data management tasks. Two unique features of QGIS include the linkage (expendable) to GRASS functionalities and the support of DWG file formats. QGIS supports basic ESRI shapefiles and coverage formats, but not personal geodatabases. It also includes good Web linkages, including WMS and WFS.

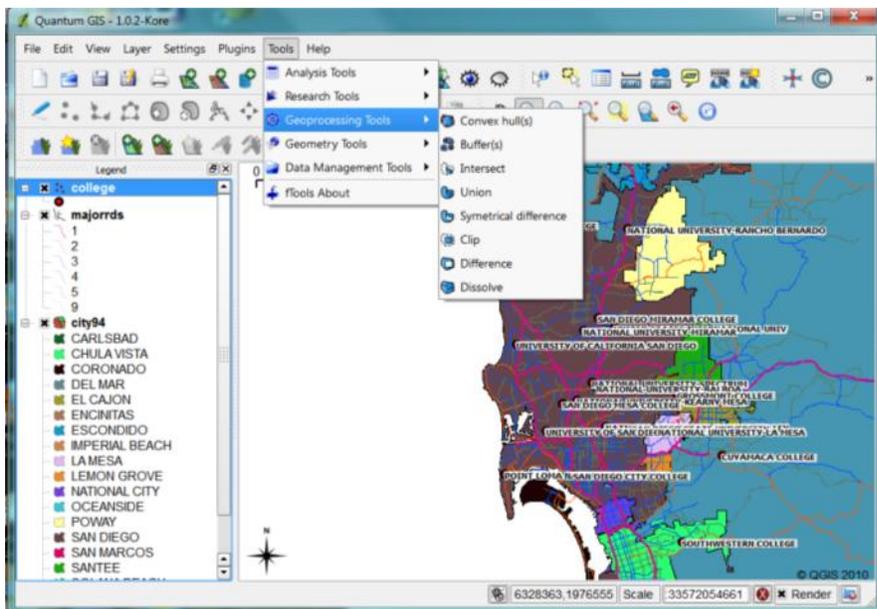


Figure 4. The comprehensive spatial analysis tools in QGIS.

2.1.5. GRASS (<http://grass.osgeo.org/>) (file size: 88MB, available OS: Windows, MacOS, Linux)

GRASS is one of the oldest public domain GIS software in existence and has become open source for quite some time. The full name of GRASS is “Geographic Resource Analysis Support System”. Some development history of GRASS has been mentioned in section 1.1. The U.S. Army Construction Engineering Research Laboratories originally developed GRASS in 1985. It offers comprehensive GIS analysis functions for both vector and raster datasets. The original user interface of GRASS was in command line only. Quantum GIS can embed all GRASS functions via a graphic user interface (GUI) for easier public use. Recently, the new version of GRASS added a new 3D vector engine to support vector-based network analysis (<http://grass.osgeo.org/screenshots/viz.php>). Multiple data input formats are available, including MySQL, .DBF, Post GIS, and SQLite (Reference: http://en.wikipedia.org/wiki/GRASS_GIS). There are many federal government agencies using GRASS for their GIS projects, including NOAA, NASA, and the US Census Bureau. A wide range of applications and extensions of GRASS have been created for different needs of scientific research (Reference: http://en.wikipedia.org/wiki/GRASS_GIS).

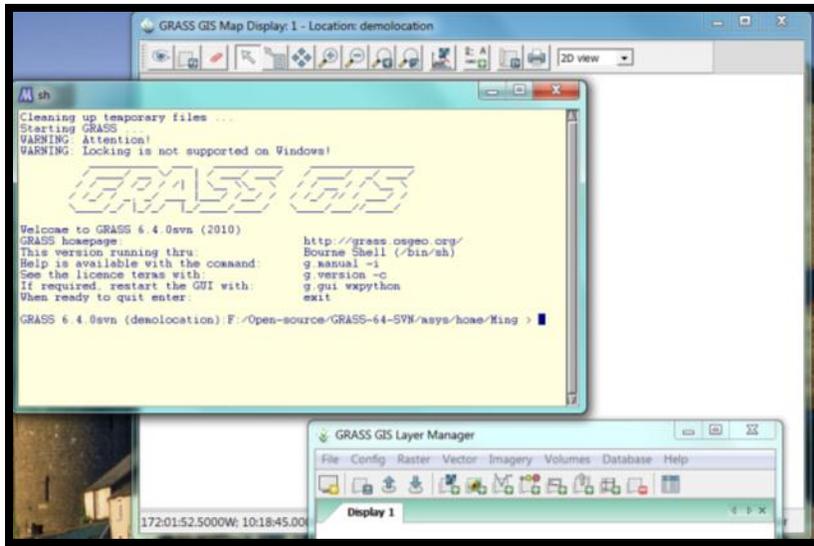


Figure 5. The original command line user interface of GRASS.

In general, there are many excellent open source software packages in the category of basic Desktop GIS. GIS educators can select the appropriate software that suits their classroom needs and/or hardware arrangements. For more detailed information about individual software, Steiniger and Bocher (2009) have a great article published in the IJGIS.

2.2 Remote Sensing Software

Compared to basic Desktop GIS, there are fewer selections of open source remote sensing software packages. While there are fewer, these programs still offer many advanced and comprehensive tools for image processing, enhancement, and analysis. The following remote sensing software are accessible for numerous operating systems (i.e. Windows, Mac, and Linux).

2.2.1. ImageJ (<http://rsbweb.nih.gov/ij/>) (file size: up to 42MB – depending on OS) (Available OS: Windows, Linux and Mac OS X).

ImageJ was developed at the National Institutes of Health as an open source software package. This image processing program can run on any computer with Java 1.4 or later or as an online applet. ImageJ allows users to open, display, edit, process, and analyze 8-bit, 16-bit and 32-bit images in the following formats: TIFF, GIF, JPEG, PNG, DICOM, BMP, PGM and FITS. By downloading or writing additional plug-ins, you can open and process additional image formats and numerous new functions as well (<http://rsb.info.nih.gov/ij/plugins/index.html>). ImageJ includes comprehensive processing capabilities such as geometric transformations, image enhancement (edge detection, sharpening, smoothing, etc.) and color processing (<http://rsbweb.nih.gov/ij/features.html>) (see figure 6). The program can also stack multiple images in one display that are correlated spatially or temporally with the same size and bit depth, allowing the user to scroll through them interactively.

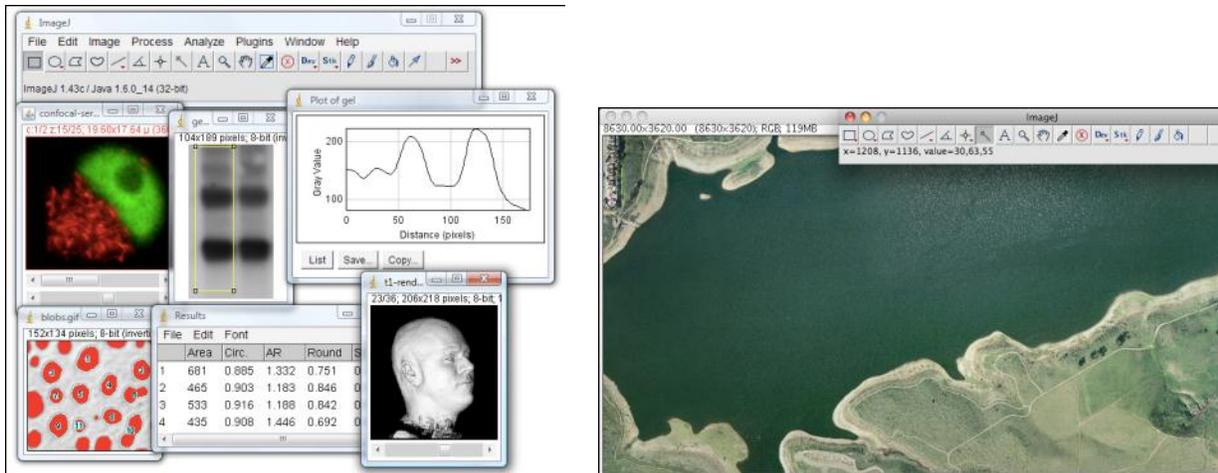


Figure 6. Screenshot of ImageJ examples and interface. (Image from <http://rsbweb.nih.gov/ij/docs/concepts.html>).

2.2.2. OSSIM (www.ossim.org) (minimum size (depending upon OS): 382MB). Both OSSIM and OSSIM Planet are available for Windows, Linux, and Mac.

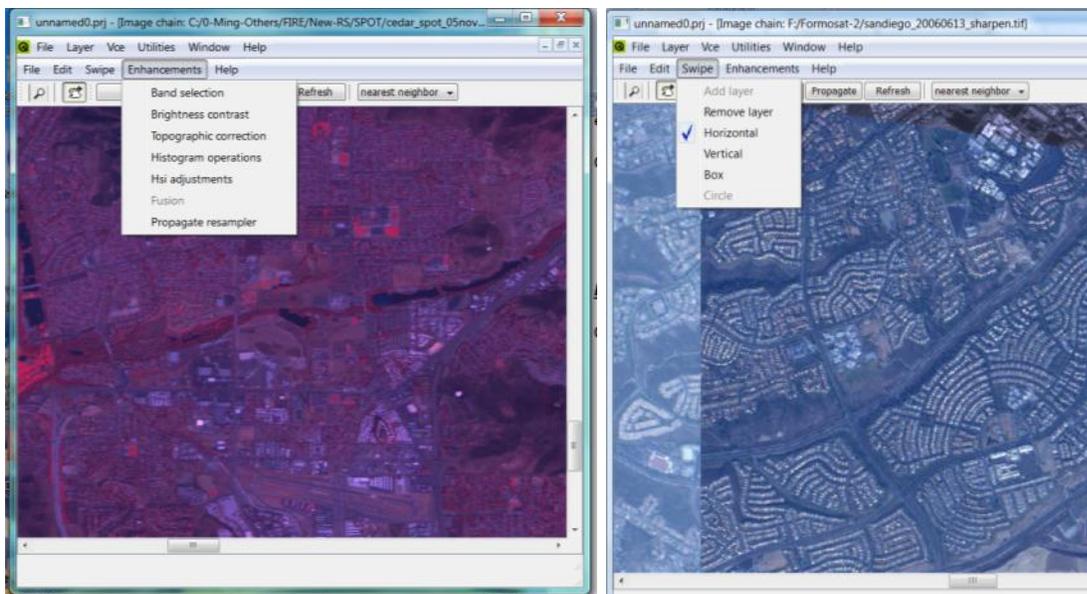


Figure 7. Screenshot of some OSSIM tools (enhancements and swipe) available to users.

OSSIM is a software program that includes numerous advanced image processing tools to support GIS, remote sensing, and photogrammetry. Under constant development, OSSIM aims to improve its processing abilities while funded under a number of US government agencies. The full name of OSSIM is Open Source Software Image Map, which has been nicknamed “awesome” by their first government customer. OSSIM provides useful tutorials in PDF and .mov (<http://download.osgeo.org/ossim/tutorials/>) as well as a user guide (http://download.osgeo.org/ossim/docs/pdfs/ossim_users_guide.pdf). Some functions in the program include: supporting numerous map projections and datums, sensor modeling, native file access, orthorectification, elevation support, vector and shapelib support, histogram matching, and tonal balancing (<http://www.ossim.org/OSSIM/OSSIM.html>) (see figure 7).

ImageLinker is another tool built to work on top of the OSSIM software (File size: 28 MB). Through their Visual Chain Editor (VCE), users can create, connect and change “image chains” (multiple images). Users can also utilize and/or create plugins within ImageLinker to add new functionality to the program.

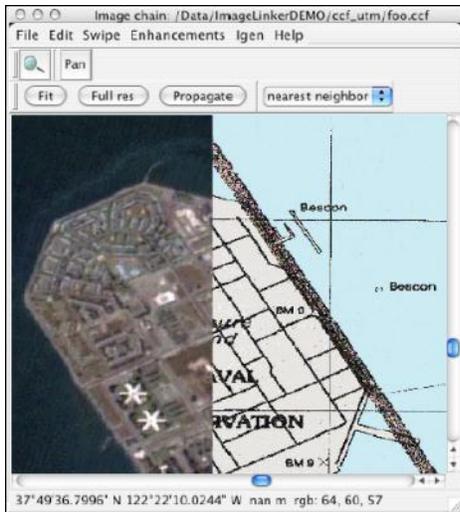


Figure 8. Screenshot of ImageLinker displaying two images spatially linked together. (http://download.osgeo.org/ossim/docs/pdfs/ImageLinker_Tutorial.pdf)

OssimPlanet is another program available for download on the OSSIM web site, which will be discussed in the 3D visualization tools, section 2.3.

2.2.3. OpenEV (<http://openev.sourceforge.net/>) (file size: up to 26.7MB, Available OS: Windows, Linux, Irix, and Solaris)

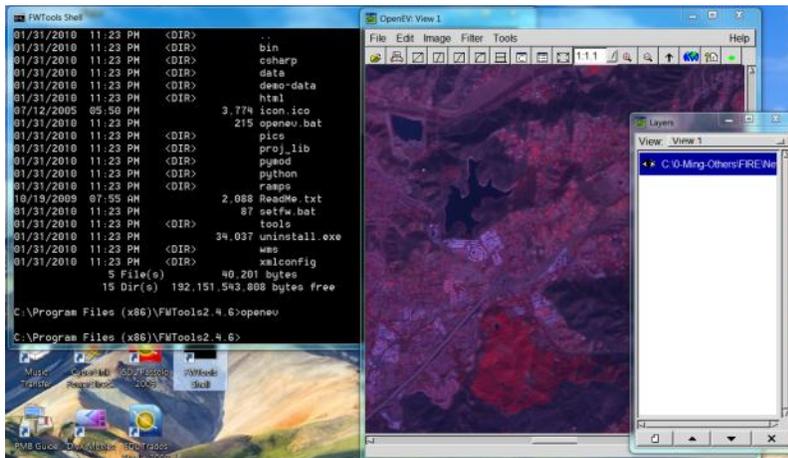


Figure 9. Screenshot of an image display in OpenEV.

OpenEV is a software program that displays and analyzes vector and raster data and offers a library for developers to construct new applications (<http://openev.sourceforge.net/>). First created by Atlantis Scientific (now Vexcel), the program was later obtained by Microsoft and developed into the satellite imagery viewer available now (<http://en.wikipedia.org/wiki/OpenEV>). OpenEV can display large datasets, from georeferenced

all available bands, linking frames, georeferencing, performing filters, automation, and creating your own algorithms (<http://opticks.org/confluence/display/opticks/Feature+Tour+-+Your+Data>). There are also available extensions for additional functionality as well as the ability to develop your own extensions (<http://opticks.org/confluence/display/opticksExt>).

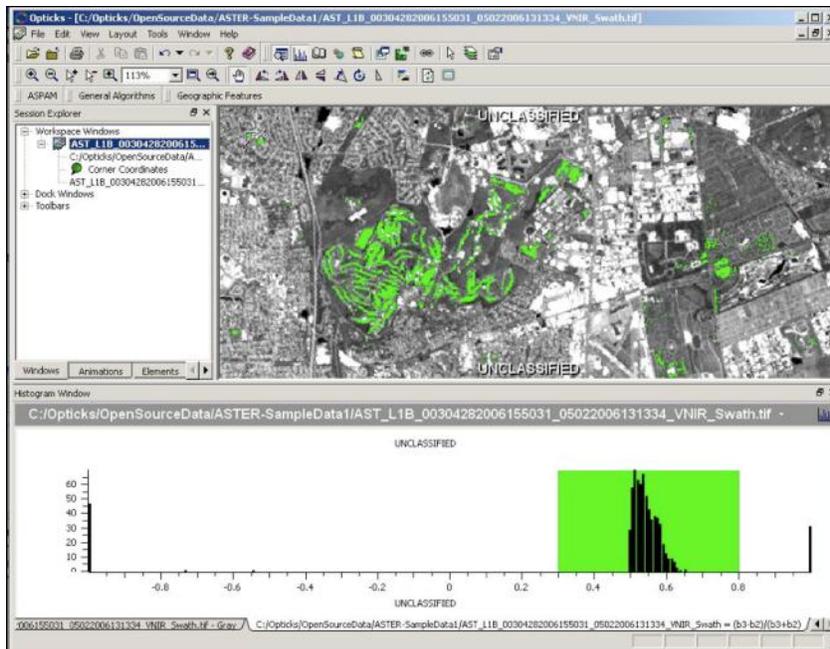


Figure 11. Screenshot of Opticks interface showing a classification and histogram. (image retrieved from <http://opticks.org/confluence/display/opticks/Feature+Tour+-+See+It+In+Action>).

2.3 3D Visualization Tools

In response to the growing popularity of 3D GIS data and Geovisualization, several open source programs are being developed. Through the addition of a new dimension, users can both analyze and visualize more spatial object relationships and spatial patterns than previously available. This additional display space offers room for creativity in visualization. Users are able to not only map elevation of desired objects, but display and represent attribute data with height as well. Some popular open source 3D visualization software packages are introduced below.

2.3.1 ParaView: (<http://www.paraview.org/>) (file size: up to 119MB, available OS: Windows, MacOSX, Linux).

ParaView was first publicly released in 2002 as a joint endeavor between Kitware Inc. and Los Alamos National Laboratory. The program can analyze very large datasets and has the ability to display data in 3D (see figure 12). Some of the different file formats supported include VTK, polygonal files, EnSight, Plot3D, and many more because users can provide their own readers (http://www.paraview.org/Wiki/Extending_ParaView_at_Compile_Time). There are many features offered in ParaView such as filters, extracting and displaying contours, clipping/cutting features, grid computations, statistics and display (<http://www.paraview.org/paraview/project/features.html>). Extensions can add functionality to the software program through download or by scripting your own in the Python language.

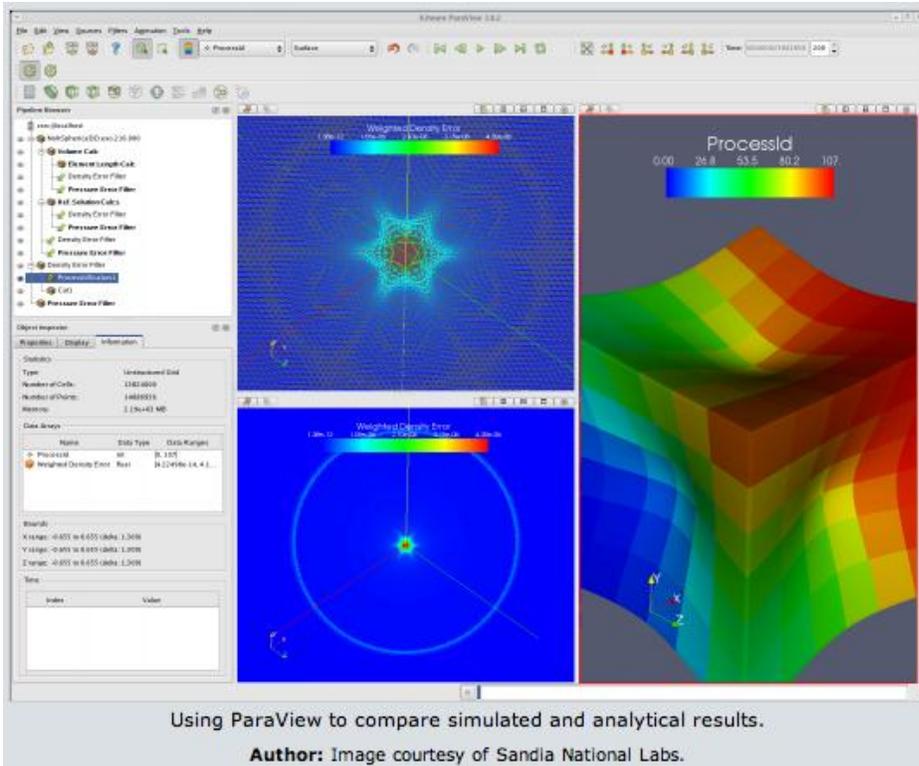


Figure 12. Screenshot of ParaView interface. (Image from <http://www.paraview.org/paraview/project/imagegallery.php>).

2.3.2 NASA World Wind: (<http://worldwind.arc.nasa.gov/download.html>) (file size: 16MB, available OS: Windows, but the new World Wind Java SDK (<http://worldwind.arc.nasa.gov/java/>) will operate for Windows, MacOS, & Fedora Core 6, file size: 24.69MB).

Originally released in 2004, NASA World Wind is a virtual globe that displays satellite images from NASA and USGS, aerial photos, topographic maps and GIS data on a 3D virtual earth (http://en.wikipedia.org/wiki/NASA_World_Wind). Aside from Earth, World Wind has provided other planets (Moon, Mars, Venus and Jupiter) for display and exploration as well. The website includes an easy to follow key chart instructing the user how to navigate the virtual globe with their keyboard and mouse (<http://worldwind.arc.nasa.gov/graphics/keychart1-3.jpg>). Users can import shapefiles, kml/kmz files, and other geospatial data to display on the virtual globe. With an embedded digital elevation model (DEM) and bathymetry, World Wind visualizes objects in 3D, viewable when you zoom into different features that have height and depth, including trenches and ridges. With the high-resolution visualization, it is a great tool for analysis and display because of the great detail it provides. Upon zooming in, political boundaries, place names, and latitude and longitude gridlines can be seen if desired for enhanced visual effects. Like many other programs, World Wind also allows for new plug-ins to add new functionality such as displaying new paths, polygons, and names. USGS has also developed a set of geoprocessing tools that work inside WorldWind.

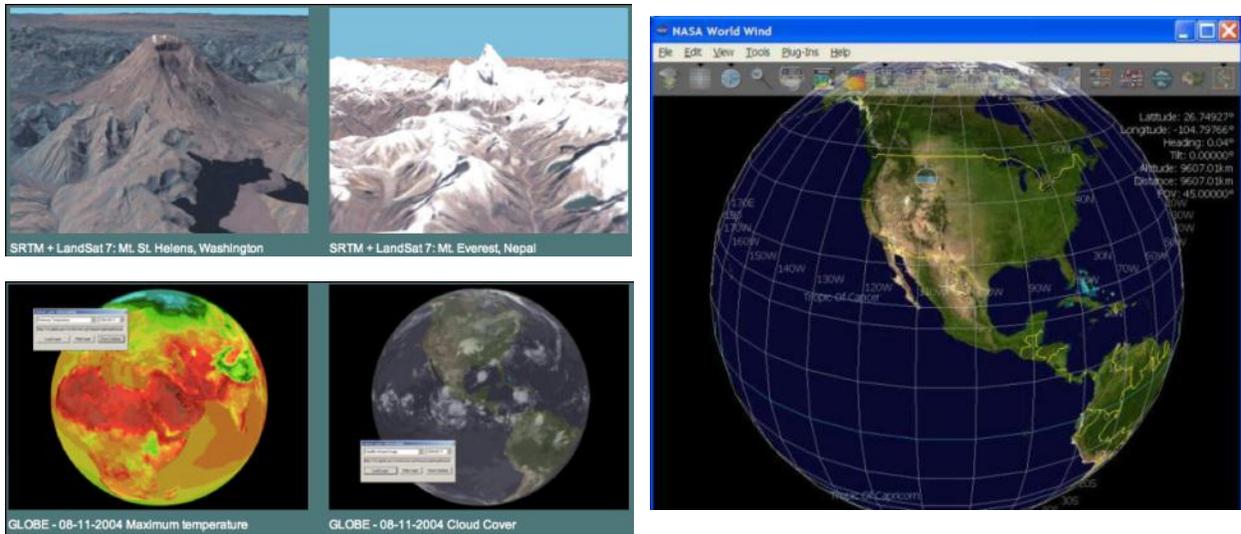


Figure 13. Screenshots of different data visualized in the NASA World Wind Interface (from <http://worldwind.arc.nasa.gov/screenshots-sl.html>).

2.3.3 ossimPlanet: (<http://www.ossim.org/OSSIM/ossimPlanet.html>) (file size depending upon OS: minimum 192MB, available OS: Linux, Mac, Windows).

ossimPlanet is an accurate 3D virtual globe built upon the OSSIM software (described in section 2.2.2) for visualization and remote collaboration. It can handle many commercial and government datasets including OSSIM Geo-Spatial Formats, GDAL Geo-Spatial Formats, kml/kmz files and Predator UAV mpg clips. The virtual globe renders elevation and tree topography on the fly, enriching the visual display for users of ossimPlanet. To help users begin, there is a good instruction manual available for each operating system on the web site (windows manual, <http://download.osgeo.org/ossim/installers/windows/ossimPlanetUsers.pdf>). It is important to note that users must have a three-button mouse in order to navigate the virtual globe.

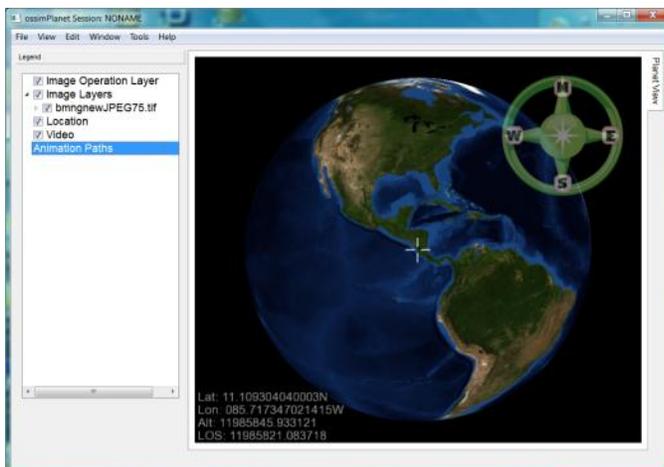


Figure 14. Screenshot of ossimPlanet interface

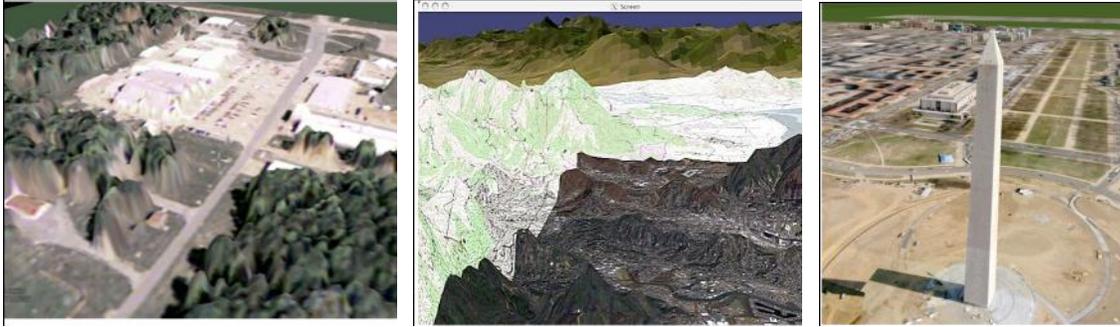


Figure 15. Screenshots of 3D visualization in ossimPlanet (retrived from <http://www.ossim.org/OSSIM/Albums/Pages/ossimPlanet.html>)

2.4 Other Open Source GIS software.

The following open source software packages can provide advanced GIS functions, such as web mapping services, advanced spatial analysis and spatial databases. If GIS teachers need to create specialized GIS courses in their labs or programs, these software may be a good choice. Due to the page limitation, we will only summarize these software for GIS teachers without screenshots nor detailed discussions.

Web mapping servers and clients

The whole GIS industry is moving into the direction of Internet GIS and Web mapping. Thousands of Web GIS applications have been created and used in many websites (Caldeweyher et al, 2007). However, most commercial Internet Map Servers (IMS) are very expensive and not affordable for GIS educators, especially in K-12 schools or community colleges. Open source IMS can provide a good alternative for GIS educators to create and introduce web mapping services to their students. There are two types of web mapping software: server-side IMS and client-side map browser tools.

Server-side IMS:

- MapServer (<http://mapserver.org/>) MapServer is probably the oldest and the most popular open source IMS. The platform was originally developed at the University of Minnesota in 1994 with NASA funding. MapServer is a CGI program (common gateway interface). CGI is an early Internet GIS technology. Therefore, the user interface and mapping functions are limited in comparison to other IMS that use advanced AJAX or FLEX technologies. Despite this, performance of MapServer is still useful for most basic web mapping services.
- GeoServer (<http://geoserver.org/display/GEOS/Welcome>) is also a popular Java-based open source IMS, created by The Open Planning Project in 2001. GeoServer can provide advanced Web mapping protocols such as OGC's WMS and WFS. It can also provide transactional editing. The generic web interface is very interactive and easy to use.
- MapGuide Open Source (<http://mapguide.osgeo.org/>) has a very unique situation in terms of open source software license. AutoDesk created MapGuide originally as proprietary software. In 2005, AutoDesk released MapGuide as open source under LGPL and made the source codes available for open source developers. The installation procedure of MapGuide server is more complicated than other IMS, which may be

challenging for beginners. MapGuide Open Source can provide a very powerful map engine and advanced client-side map browser tools and technologies (such as AJAX viewer and vector-based DWF viewer).

Client-side mapping browser tools:

- OpenLayers (<http://openlayers.org/>) is a client-based JavaScript library that can be customized in a HTML document for displaying map data. Unlike IMS, OpenLayers does not create its own mapping images from GIS databases, but instead displays map layers derived from other (external) IMS engines. Thus, it is a client-side application rather than an IMS. Openlayers is a very powerful client-side mapping tool offering great performance, but requiring a certain level of programming skill in order to use or customize its interface. Additionally, because it is based on JavaScript, it does not work well in Internet Explorer web browsers.
- Mapfish (<http://mapfish.org/>) is also a JavaScript-based client-side mapping tool created by utilizing the Pylon Python web framework. Similar to OpenLayers, Mapfish is compliant with various IMS output protocols, such as WMS, WFS, KML, GML, etc. Many developers combine Mapfish and OpenLayers together to provide better mapping functions.

Spatial Analysis Programming Tools and Library

- STARS (Space-Time Analysis of Regional Systems) (<http://regionalanalysislab.org/index.php/Main/STARS>) is an easy-to-use open source software designed for the analysis for areal data (such as counties or zip-code areas) measured over time. Dr. Serge Rey created the program with the Python programming language.
- PySAL is an open source library of tools for spatial analysis (<http://geodacenter.asu.edu/projects/pysal>) developed by the GeoDa Center at Arizona State University.

Spatial databases

- PostGIS (<http://postgis.refractory.net/>) is the most popular open source GIS database engine built upon the PostgreSQL object-relational database. Many developers consider that PostGIS is a strong challenger to several commercial GIS databases, such as Oracle Spatial and Microsoft SQL Server Spatial.
- GearScape (<http://www.fergonco.es/gearscape/>) is another good open source tool to develop GIS databases. If you are looking for software to learn/teach spatial SQL, GearScape is a good instructional tool because it provides a spatial SQL implementation and the results of the queries are shown directly on the active map.

Most of these open source tools and packages can be accessed from the Open Source Geospatial Foundation (<http://www.osgeo.org/>) and OpenGeo website (<http://opengeo.org>).

Recently, OpenGeo released a powerful web mapping software suite, called “OpenGeo Suite”, which combines five core open source software components (PostGIS, GeoServer, GeoWebCache, OpenLayers, and GeoExt). The OpenGeo Suite is an OGC standards-compliant web mapping platform, supporting various data output formats (including Web Map

Tiling Service and Web Map Service-Caching) and different user needs (enabling rich internet application user interfaces and web widgets). The suite provides two management tools (the GeoExplorer and the Dashboard) for publishing and managing web mapping services. The GeoExplorer tool is designed for web map authoring and publishing tasks. The Dashboard is a web mapping service management tool (similar to the ESRI ArcGIS Server Manager). These new tools created inside the OpenGeo Suite will make the installation and management of web map servers much easier.

Other useful resources for open source GIS are FWTools (<http://fwtools.maptools.org/>), GISVM Desktop (<http://gisvm.com/download.html>) (big file size: 1.2 G) with Virtual Machine Player, and the FOSS4G conference website (<http://2010.foss4g.org/>).

3.0 Conclusion

Although many private GIS vendors and software companies such as ESRI, Microsoft, Google and Intergraph played an important role for GIS development in the past, the Open Source Software Society has become a stronger player recently in the GIS industry. With the introduction of this white paper, we hope that GIS educators can realize the potential of open source GIS software for their courses and instructional tools. For example, NASA World Wind can offer an excellent virtual earth demo by linking to multiple NASA satellite images and the WMS layers directly.

The road to adopt open source GIS may not necessarily be smooth and quick in comparison to commercial solutions, but it is affordable and importantly, offers customization of the software for your students' needs. As Paul Ramsey said in his 2007 white paper (The State of Open Source GIS), "*the change to open source requires a different mindset. Rather than one programme or one suite of programmes delivering everything you need, you go over to different programmes that all communicate with each other and use the same (standard) protocols and data formats.*"

We hope that this paper proves to be useful for GIS educators willing to try open source GIS software. As GIS technology develops and evolves every year, some of the information for open source software mentioned in this paper may be out-of-date or incorrect. Please send us your comments if you find new open source GIS software or any errors in the paper. Please send your comments to mingtsou@gmail.com with the title "*Opensource GIS white paper suggestions*". We will incorporate your suggestions into the next version of this white paper.

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