

Spring 2013

Contemporary Problems of GIS Interoperability: A Review of GIS Integration with Current Technology

Tim Jones

Follow this and additional works at: http://digitalcommons.du.edu/geog_ms_capstone



Part of the [Geographic Information Sciences Commons](#), and the [Spatial Science Commons](#)

Recommended Citation

Jones, Tim, "Contemporary Problems of GIS Interoperability: A Review of GIS Integration with Current Technology" (2013).
Graduate Student Capstones. 41.
http://digitalcommons.du.edu/geog_ms_capstone/41

This Capstone Project is brought to you for free and open access by the Department of Geography & the Environment at Digital Commons @ DU. It has been accepted for inclusion in Graduate Student Capstones by an authorized administrator of Digital Commons @ DU. For more information, please contact jennifer.cox@du.edu.

Contemporary Problems of GIS Interoperability: A Review of GIS Integration with Current Technology

Tim Jones

Capstone Project

GEOG 4993

Spring Quarter 2013

Abstract

This paper examines GIS interoperability with three current technology trends: Open Source, Smart Devices and Web 2.0. It firsts takes a look at both varying definitions of interoperability as well as different types of interoperability. The author samples a variety of GIS formats with examples of each of the said technologies as a way to measure the current state of GIS interoperability with current technological trends. GIS functions such as viewing, editing and analyzing spatial data are used as a scoring matrix to determine the level of interoperability. The methodology of measure focuses on a technical level of interoperability and reveals that among the three technologies studied, open source technology leads the way in interoperability with GIS. Further research confirms this but also shows that smart devices and Web 2.0 are not only also currently interoperating with GIS but actually a driving force in the development and direction of GIS interoperability.

Table of Contents

Abstract	ii
Table of Contents	iii
Introduction	1
Literature review	3
Interoperability defined.....	3
History and Status of GIS Interoperability	4
Levels and Measures of Interoperability	6
Design and analysis.....	9
Results	12
Discussion	17
Areas of further research	20
Bibliography.....	23
Appendix A: Terms and Definitions	26
Appendix B: Code Book	27

Tables and Figures

Figure 1 Levels of Interoperability	7
Figure 2 Test Matrix	11
Table 1 Grouped by Applications	13
Table 2 Grouped by Technology Type	14
Table 3 Grouped by Function.....	14
Table 4 Correlation	16

Introduction

GIS interoperability with related technologies has been an important issue for as long as GIS has been around. Over the past half century, we have seen an evolution of GIS interoperability from Computer Aided Design (CAD) to enterprise spatially-enabled databases to finally smart phone applications. Interoperability is even more imperative today as the growth and expansion of technology accelerates along with the demands for GIS to keep up with the expectations of user-friendly interfaces, intuitive data-mining, and ubiquitous web-based mapping tools. For example, thousands (if not millions) of dollars are still spent by GIS and CAD systems to coexist and work seamlessly in a single environment. GIS users often need to incorporate engineering drawings to add man-made features to their maps such as roads, sidewalks, parks or utility facilities. Conversely, engineers are often interested in GIS layers such as land cover, land use, soil or elevation when designing a project.

Today, there also exists a need for GIS to integrate with a variety of emerging technologies. This research project seeks to determine the degree to which interoperability between GIS current technological trends has been achieved. In this paper, three such technologies are examined: Open Source technology, Web 2.0, and smart device applications. Open Source technology refers to Software in which the source code is freely available to the public to view and contribute to (dictionary.reference.com). Today, open

source software is available for many standard computer programs such as word processors, spreadsheets and slide presentation programs. The advantage with open source programs is that they are not only free, but there is a broad and active community to provide enhancements and support for these products. Many organizations requiring GIS tools that are not able to afford expensive proprietary software have turned to open source alternatives. This paper looks at the degree to which these programs are interoperable with mainstream GIS data. Web 2.0, on the other hand refers to 2nd generation web technology which provides a new set of functionalities pertaining to the ability for the end user to 'interact' with the web. Examples of this include blogs, wikis and social networking (TechTerms.com, 2013). Web 2.0 technologies make it possible for a wider set of a non-GIS audience to not only view, but interact with GIS data. Again, this paper takes a look at the level to which mainstream GIS formats are able to be used by Web 2.0 platforms. Finally, smart devices such as Apple I-PADS, I-Phones and Droid tablets often come with mapping capabilities such as GPS receivers and commercial mapping applications. Organizations needing to bring their GIS data to the field could benefit from these types of technology by finding ways to integrate GIS data with smart devices. Each of these three technologies have opened the way for an unprecedented increase in resources and expansion in knowledge base and are not only being used to

interact with GIS data, but in some cases being used as mediums for streamlining GIS interoperability with other types of data systems.

Literature review

Interoperability defined

GIS interoperability can be defined in a number of different ways. Due to the broad nature of the concept of interoperability, it is difficult to find an all-encompassing definition. One such broad definition is offered by Manso-Callejo and Wachowicz, M. as the "ability of a collection of system components to share specified information and operate on that according to a shared operational semantics in order to achieve a specific purpose in a given context" (Manso-Callejo & Wachowicz, 2009). As we will discuss later in this paper, this definition provides a high level framework for interoperability across seven distinct levels of interoperability. A more focused and specific definition is provided by Safe Software, Inc, the proprietor of an industry leading GIS interoperability software known as FME, as "[...] communication by sharing and distribution of data, and the ability to use that data transparently" (www.safe.com, 2013). According to ESRI's GIS dictionary, GIS is defined as "The capability of components or systems to exchange data with other components or systems, or to perform in multiple environments. In GIS, interoperability is required for a GIS user using software from one vendor to study data compiled with GIS software

from a different provider." (GISDictionary) In this paper, we will look at GIS interoperability from the definition offered by ESRI.

History and Status of GIS Interoperability

The notion of interoperable GIS has evolved over time. Historically, there was not the same expectation of GIS interoperability as there is today. Due to the high costs associated with GIS technology, GIS systems were rare and interoperability was not a high priority (Han, 2001). But as more industries adopted GIS systems, the case for interoperability became more necessary. For example, the ability for GIS to be interoperable with Computer Aided Design (CAD) has been highly sought after for a long time. These are two systems, that both need to be spatially aware but in different contexts (Han, 2001). There is great value in being able to overlay the rich amount of data available in a traditional GIS to engineers who might be interested in topography, land cover, land use and imagery etc. For example, Michael F. Morgan (2009) researched the best methods for integrating CAD and GIS at the University of South Carolina for their facility and space management. He successfully developed a process that took non-georeferenced AutoCAD drawings and brought them into ArcGIS, utilizing automated tools with minimal impact to the current workflow of AutoCAD design. His research and findings serve as an example of both the need for integration as well as a success story for how this can be accomplished.

In addition to GIS interoperability with CAD systems, there has also been a move to integrate GIS with enterprise data systems. A study out of the University of Waterloo discusses the added value that GIS brings to the traditional IT world specifically for Environmental Health and Safety departments of many organizations. It focuses primarily on the natural integration of GIS with relational databases (Environmental Health and Safety Data Integration Using Geographical Information Systems).

The growing need for GIS interoperability has led to organizations such as the Open Geospatial Consortium to provide initiatives for the support and standardization of GIS interoperability. This consortium consists of 480 companies, government agencies and universities working towards open interface standards to support interoperability with a variety of current mainstream technologies. For example, the OGC has worked with the FAA for a solution to automate the dissemination and portrayal of Special Activity Airspace information to the National Airspace System (Open Geospatial Consortium, 2013). This was accomplished using several OGC standards including WFS, FPS and AIXM. The OGC website shows over 50 distinct initiatives like this all dealing with GIS interoperability using open source solutions. The sheer volume of participants in this consortium along with vast array of interoperability initiatives demonstrates the demand for interoperability with current technology in a variety of sectors (Open Geospatial Consortium, 2013).

Today, GIS interoperability has evolved to a point where researchers are now proposing models to move GIS interoperability into a semantic interoperability model. Wang Yandong et al. (Wang, Gong, & Wu, 2007) discuss the lack of a complete semantic interoperability between the vast array of GIS and other supporting data systems. They put forward a model based on Ontology Web Language and tested it on data for western cities in China. The result was successful and showed viability of GIS semantic interoperability which holds a promising potential for the future.

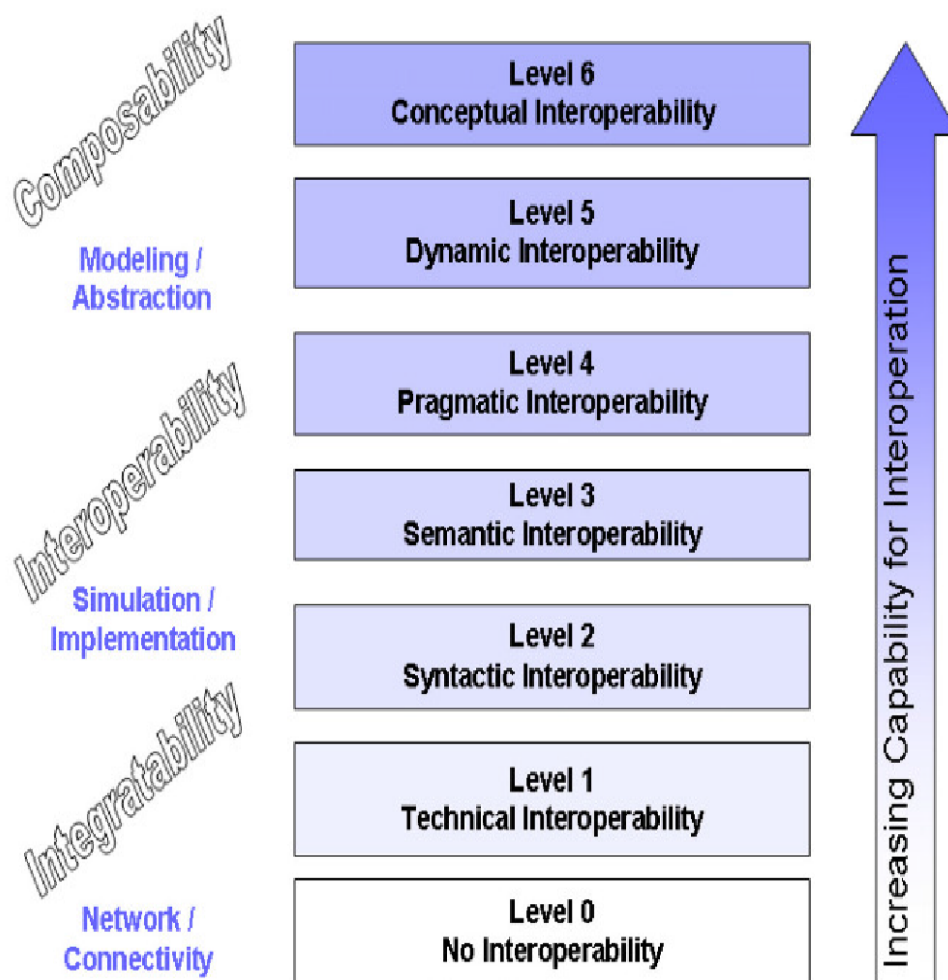
Finally, GIS integration with commercial mapping API's such as Bing Maps and Google has led to a greater public interaction with GIS data (Morris, 2006). Commercial mapping has only a small portion the entirety of GIS data (Morris, 2006). A greater public awareness of GIS data has fueled the efforts of GIS interoperability with mainstream technological trends.

Levels and Measures of Interoperability

With the ever growing demand for GIS to be interoperable with a variety of technologies, it is important for us to understand the many facets of interoperability. Many researchers have offered various methods of measuring the level of GIS interoperability. Manso-Callejo et al. (Manso-Callejo & Wachowicz, 2009) describe seven levels of GIS interoperability ranging from Level 0 which indicates no interoperability to Level 6 which indicates conceptual interoperability. Additional levels also include technical,

syntactic, semantic, pragmatic, dynamic and finally conceptual (see figure 1 below). It is important to note that these levels of interoperability are not necessarily hierarchal in terms of one level being dependent on another level (Manso-Callejo & Wachowicz, 2009).

Figure 1 **Levels of Interoperability**



(Manso-Callejo & Wachowicz, 2009)

When measuring interoperability, it is important to specify what level

of interoperability you are measuring. Technical interoperability focuses on the data formats themselves and the ability for different systems to interact with the data itself. Syntactic interoperability focuses on the need for a common exchange of data models and spatial patterns when integrating data from various data stores. A semantic level of interoperability would focus on more of the meaning of terms across industries and software companies. Pragmatic interoperability deals with interoperability with regards to the intentions of how GIS data is going to be used. Services that provide this type of interoperability must understand and cater to the various uses of that data in order to achieve this level. Dynamic interoperability is achieved when systems are able to account for and take advantage of changes in assumptions and constraints of different systems. Finally, conceptual interoperability takes place when there is a proper alignment of assumptions and constraints between systems. It often appears in the form of something can be documented and understood by a third party. The push for a complete open architecture for integrating various systems is an example of this type of interoperability (Manso-Callejo & Wachowicz, 2009).

While Manso-Callejo et al. (2009) discuss different levels of interoperability; they do not discuss specific methods for testing levels of interoperability between GI Systems. The authors state that further research is needed in order to develop models of testing interoperability.

Furthermore, it is impractical to expect that any test of interoperability would cover all levels mentioned. Instead, they should aim to cover one or two (Manoso-Callejo & Wachowicz, 2009). In this project, I propose one such method.

The method described below provides one approach to measuring GIS interoperability on a technical level only. This method focuses on data types and data formats and their compatibility with current technological trends. This does not serve as a comprehensive measure of GIS compatibility; rather it proposes one matrix for measuring GIS interoperability in a technical sense, especially concerning technological trends.

Design and analysis

The purpose of the research described below is to measure the degree of interoperability of GIS with a sample of technologies representing a wide range of current technological trends. In order to measure this, various technologies are sampled spanning three major trends: Smart Devices, Web 2.0, and Open Source. Five different applications are sampled in these areas including GeoREST, a Web 2.0 technology that provides an easy way to distribute GIS data via the Web in a variety of formats; AutoCAD WS, a smartphone application for AutoCAD drawings; ArcGIS Online, ESRI's cloud-based GIS that is compatible with smart devices; GRASS, one of the leading open source GIS platforms; and finally Mapguide, an open source web-based GIS.

For each of these technologies, a series of tests are run which indicate the degree to which they are interoperable with GIS. In order for a technology to be deemed interoperable with GIS, several variables are considered. They must be able to view, query, edit and analyze GIS data. Also, there has to be a minimal number of steps to translate the data into a usable format. There exists today a vast array of GIS formats. This project looks specifically at six of the most common GIS data formats including a sample of both proprietary and open source data types. These formats are among the most widely used and are mentioned in almost every list of commonly recognized GIS data formats. The formats tested include SHP, DWG, KML, JSON, PostGIS and Geodatabases (GDB). Points, lines and polygons for each format are also included to be sure all feature types of GIS data are tested. For each feature type, a score of '1' or '0' is given for each of the said functionalities above. Also, a negative number is given for each number of steps the data must undergo for data translation. For example, if the technology can directly read SHP files with no translation required, no points are deducted. If, on the other hand, the data first requires a conversion to another format before it can be used then 1 point is deducted. In this way, the degree to which interoperability has been achieved based on these sample technologies and traditional GIS data types is measured. In addition to these functionalities, GIS is also tested with

raster datasets. A score of '1' or '0' is given if either GeoTIFF or JPEG raster datasets are supported.

Figure 2 Test Matrix

Data Format	View (1,0)	Query (1,0)	Edit (1,0)	Analyze (1,0)	# of Data Transformation Required (-1 for each)	Overall Score
DWG (point)						
DWG (line)						
DWG (polygon)						
SHP (point)						
SHP (line)						
SHP (polygon)						
KML (point)						
KML (polygon)						
GeoJSON (point)						

GeoJSON (line)						
GeoJSON (polygon)						
SQL (point)						
SQL (line)						
SQL (polygon)						
PostGIS (point)						
PostGIS (Line)						
PostGIS (Polygon)						
GeoTiff						
JPEG						
Average						

The data for this project was acquired from the US Census Bureau. Fresno County is the sample data set. Landmarks in Fresno County are used as the points, roads as lines and census block groups as polygons. Safe Software's data translation tool FME is used to translate the data into each of the initial data formats needed for the experiment.

Results

For the purposes of data analysis, the independent variable is represented by the tests of interoperability for each data type. In all there are 100 tests using 20 data types for each technology type. This includes 6 unique vector formats for points, lines and polygons including SHP, DWG,

KML, JSON, SQL Spatial and POSTGIS as well as two raster data sets which include GeoTiff and Jpeg.

The dependent variables are represented by each of the scores as determined by the ability to view, edit, query, and analyze the data as well as the number of translations required to use the data types tested for each of the technologies. (Refer to the codebook in Appendix B for the full dataset.)

In order to determine the average scores for each of the specific applications used, the data is aggregated by each application with an average score for each. Scores range from 0 (not compatible) to a maximum possible of 5 (very compatible). The average score by applications sampled is shown in Table 1 below along with their standard deviations.

Table 1 Grouped by Applications

<u>Scores</u>	<u>Applications</u>				
	ACADWS	ArcGIS Online	GeoRest	Grass	Mapguide
Mean Score	0.3	0.06	0.075	2.5	1.75
Standard Deviation	0.73	0.94	0.44	1.43	1.55

Clearly, Grass and Mapguide scored the highest with average scores of 2.5 and 1.75, respectively. Scores for Grass and Mapguide also varied the most with standard deviations of 1.43 and 1.55, respectively. According to this test, Grass and Mapguide have the strongest level of compatibility with other GIS applications.

In addition to aggregating scores by technology type, it is also worth noting the scores based on the technology types. This gives us a comparison on a higher level between the different types of technologies (Web 2.0, Open Source and Smart App). See Table 2 below:

Table 2 Grouped by Technology Type

<u>Scores</u>	<u>Technology Type</u>		
	Open Source	Smart Device App	Web 2.0
Mean Score	2.13	.45	.75
Standard Deviation	1.52	.84	.444

Not surprisingly, smart applications rank the lowest on this list. This was evident in the results from Table 1 which show both ACADWS and ArcGIS online (the only two smart applications studied) as the two lowest scorers.

Finally, it is also interesting to see how different software core functions rank on this scoring criteria. Table 3 below summarizes the data by functionality.

Table 3 Grouped by Function

<u>Scores</u>	Data Portal	Desktop GIS	Web GIS
Mean Score	0.75	2.5	0.88
Standard Deviation	0.44	1.43	1.27

It is not surprising that the only desktop sample used (GRASS) scored the highest. This is probably due to the fact that desktop products inherently are more functional and versatile. However, both a desktop and web-based GIS were sampled as open source technology to provide a more balanced sample set when comparing technology types above. GeoREST was the only WEB 2.0 technology sampled and since it is more of a data portal as opposed to a true GIS, the scores from these samples were among the lowest affecting the Web 2.0 scores in Table 2.0. What this shows is that functionality plays an important part in the level of compatibility. This may be an indication that the test may be measuring technology function as opposed to compatibility. Further analysis below confirms this.

Table 4 below shows the correlations of scores between each of the groups of data. The data shows a moderate correlation between Compatibility Scores in the Application and Technology Type groups with a correlation coefficient of $-.182$. The negative relationship would indicate that as the application compatibility scores increase it is expected that the scores for technology type to decrease. However, the 2 tailed significance tests has a value of $.070$ which is greater than the $.01$ level needed to be significantly significant. This means there is too high of a probability that the correlation is a coincidence and therefore not conclusive. In other words, there could potentially be a relationship between Compatibility Scores in the Application

and Technology Type groups; however the data does not have enough cases to determine this with a high enough confidence level.

The correlation coefficient for the compatibility scores for the applications and functions groups is also a moderate correlation with an r value of $-.165$. Similar to the correlations above, the findings here are not statistically significant either with a significance value of $.1$.

The correlation coefficient for the compatibility scores of the technology type and function groups have a statistically significant positive relationship. The r value of $.365$ indicates a strong relationship which is significant at a $.001$ level. This means that as the compatibility scores for the technology type increase, so do the scores for the function. A possible explanation for this correlation could be due to the fact that the test of compatibility favors certain functions over another. Since some of the technology types have more samples representing specific functions than other technology types, the groups with functions of higher compatibility affect the scores of that technology type. For example, Table 3 shows the functionality of 'Desktop GIS' having a significantly higher mean than any other function. The only samples of 'Desktop GIS' data are all of an 'Open Source' Technology Type which also has the highest mean of scores among all Technology Types (see Table 2).

Table 4 **Correlation**

		Application Compatibility	Technology Type Compatibility	Function Compatibility
Applications Compatibility	Pearson Correlation	1	-0.182	-0.165
	Sig. (2-tailed)		0.070	0.100
	N	100	100	100
Technology Type Compatibility	Pearson Correlation	-0.182	1	0.365**
	Sig. (2-tailed)	0.070		0.000
	N	100	100	100
Function Compatibility	Pearson Correlation	-0.165	.368**	1
	Sig. (2-tailed)	0.100	0.000	
	N	100	100	100

**Correlation is significant at the .01 level (2 tailed).

Discussion

In the three technologies studied to determine interoperability between GIS and current technological trends, open source technology ranks among the most compatible. This is highly due to the fact that desktop GIS's tend to be more functional and lend themselves more easily to open source, and by definition cannot be web 2.0 or smartphone applications. The degree of interoperability scoring difference between open source and the other two categories is quite significant, suggesting from these initial studies that WEB 2.0 and Smart Device applications still need additional development especially in the editing and analyzing capabilities that standard GIS's currently provide. Ultimately, there is definitely interplay between the GIS and the current trends. The fact that at least some categories of technology scored well might also indicate the demand for

interoperability and point the way to potential for growth in interoperability in others as well.

Another question that arises from the results of this data is that of the niche of GIS in these trends. Does interoperability necessarily equal the functional ability of a traditional GIS? For example, Table 1.0 shows that all of the interoperability points for WEB 2.0 data portals such as Geo Rest were in the "view" category. This suggests that the ability for these to translate and view almost any data set may better be categorized more as a facilitator of GIS interoperability and perhaps measured differently in future studies. Similarly, uses for smart device apps may be very different than that of desktop applications. Rather than the traditional data crunching a GIS analyst may be used to, these apps may be better suited for surveyors and data collectors and not require the same functionality. The results suggest a very clear trend that the development of these products are moving in different directions of functionality than that of traditional desktop-based GIS's.

Further research has confirmed that there is a high level of interoperability between GIS and open source technology. However, contrary to my findings above, further research indicates the Web 2.0 and mobile applications have made considerable advances in interoperability with GIS as well.

GIS interoperability with open source technologies appear to be at the most advanced state. Many current articles no longer address the mere basic issues of interoperability, but rather address the needed enhancements for a more perfect interoperability. For example, Jung-Hong Hong et al. discuss the need for visualization of data transformation tools in order to ensure data integrity and proper interpretation of data (Hong & Liao, 2011). There are open source tools available today to merge data from various sources. With these abilities come the important processes of determining if the data is compatible in terms of projections, scale, date collected and other spatial factors. Having the ability to visualize different steps of data merging in order to validate it at each stage is an imperative part of the process of data integration (Hong & Liao, 2011). In addition to the advancement of interoperability tools, there is also a push for integrating traditional GIS with an open GIS architecture. Dunfey et al. (2006) propose a model using SVG for web based vector graphics as a foundational element of a completely open GIS. The authors propose that moving to a more open GIS will allow for a greater level of interoperability between different GIS platforms (Dunfey, Gittings, & Batcheller, 2006). This point could be taken further to say that not only does GIS interplay with open source technology, but open source is in fact a driver of GIS interoperability.

Similar to open source technologies, Web 2.0 also plays a key role in driving GIS interoperability. Web services have become a standard way of

moving data between systems. The OGC has developed standardized open protocols for distributing mapping data including WMS and WFS. These services provide geospatial data in a common way in the both vector and rasterized formats (Zhao, Foerster, & Yue, 2012).

Smart device applications that support GIS data continue to proliferate. A quick search for 'GIS' at the Apple app store lists 23 different applications that are somehow related to GIS. In many cases, web services actually play a key role in providing the infrastructure needed to support mobile applications (Dasgupta & Ghosh, 2011).

Areas of further research

This project merely addresses one aspect of determining the level of interoperability that currently exists between GIS and current technical trends. Further research is needed to explore each of the levels of interoperability, their current status, and relevance to the ever changing state of current technology. In addition, repeatable testing methods need to be developed for each of the layers of interoperability. This paper proposes just one example of such a method. The results showed that though it is possible to measure interoperability in this way, further refinement is necessary in order to ensure a more accurate result. Finally, research on this project has shown that the current technological trends are not only compatible with GIS but in many cases are driving GIS compatibility. Web

2.0 technologies such as web services are used to create service chains that allow migration of data from multiple data formats to another. The OGC has passed initiatives for their open source software pushing for the standardization of interoperability. Commercial mapping applications have led to a greater public awareness of GIS data which creates a demand for GIS integration with mainstream technology. As new and evolving technologies hit the mainstream, it will become increasingly important to research and understand these trends and how they will shape the future of GIS technology.

Works Cited

- (2013). Retrieved May 7, 2013, from Open Geospatial Consortium : <http://www.opengeospatial.org/TechTerms.com> . (2013). Retrieved May 7, 2013, from <http://www.techterms.com/definition/web20>
- www.safe.com . (2013, January). Retrieved April 23, 2013, from www.safe.com
- Dasgupta, A., & Ghosh, S. K. (2011). Service Chaining for Accessing Geospatial Information in Mobile Devices. *Proceedings of the 2nd International Conference on Computing for Geospatial Research & Applications*, (pp. 1-6). Washington, DC.
- dictionary.reference.com . (n.d.). Retrieved May 23, 2013, from [dictionary.com](http://dictionary.reference.com) : <http://dictionary.reference.com/browse/open+source>
- Dunfey, R. I., Gittings, B. M., & Batcheller, J. K. (2006). Towards an Open Architecture for Vector GIS. *Computers & Geosciences*, 1720-1732.
- (n.d.). *Environmental Health and Safety Data Integration Using Geographical Information Systems*. Waterloo, Ont: University of Waterloo.
- GISDictionary*. (n.d.). Retrieved May 21, 2013, from [ESRI.com](http://support.esri.com/en/knowledgebase/GISDictionary/term/interoperability) : <http://support.esri.com/en/knowledgebase/GISDictionary/term/interoperability>
- Han, K. (2001). Development of an Interoperable Geographic Information System Platform for Transportation Applications. *The University of Manitoba Faculty of Graduate Studies*.
- Hong, J.-H., & Liao, H.-P. (2011). Incorporating Visualized Data Completeness Information in an Open and Interoperable GIS Map Interface. *Journal of the Chinese Institute of Engineers*, 37-41.
- Manso-Callejo, & Wachowicz, M. (2009). GIS Design; A Review of Current Issues in Interoperability. *Geography Compass*, 1105-1124.
- Morgan, M. F. (2009). CAD-GIS Interoperability Issues for Facilities Management: Enabling Interdisciplinary Workflows. *University of South Carolina*, 125.
- Morris, S. P. (2006). Geospatial Web Services and Geoarchiving; New Opportunities and Challenges in Geographic Information Services. *Library Trends*, 285.
- Wang, Y., Gong, J., & Wu, X. (2007). Geospatial Semantic Interoperability Based on Ontology. *Geo-spatial Information Science*, 204-207.
- Zhao, P., Foerster, T., & Yue, P. (2012). The Geoprocessing Web. *Computers & Geosciences*, 3-12.

Bibliography

- Advances in Spatial Databases Third International Symposium, Ssd '93, Singapore, June 23-25, 1993 : Proceedings. Berlin ; New York : Springer-Verlag.
- Achard, F., and E. Barillot. "Ubiquitous Distributed Objects with Corba." *Pac Symp Biocomput* (1997): 39-50.
- Babcock, Roger William, and Raymond Walton. "World Environmental and Water Resources Congress 2008 Ahupua`A : May 12-16, 2008, Honolulu, Hawaii." Reston, VA : American Society of Civil Engineers, http://ascelibrary.aip.org/browse/asce/vol_title.jsp?scode=W.
- Barillot, E., U. Leser, P. Lijnzaad, C. Cussat-Blanc, K. Jungfer, F. Guyon, G. Vaysseix, C. Helgesen, and P. Rodriguez-Tome. "A Proposal for a Standard Corba Interface for Genome Maps." *Bioinformatics* 15, no. 2 (Feb 1999): 157-69.
- Bernard, Lars Friis-Christensen E., and Hardy Pundt. *The European Information Society : Taking Geoinformation Science One Step Further* [in English]. Lecture Notes in Geoinformation and Cartography;; Variation: Lecture Notes in Geoinformation and Cartography. Berlin: Springer, 2008. Conference publication (cnp).
- Bhalla, Subhash, and Conf Author: DNIS. "Databases in Networked Information Systems International Workshop Dnis 2000, Aizu, Japan, December 4-6, 2000 : Proceedings." Berlin ; New York : Springer, <http://rave.ohiolink.edu/ebooks/ebc/3540444319>.
- Bishr, Yaser. "Overcoming the Semantic and Other Barriers to Gis Interoperability." *International Journal of Geographical Information Science* 12, no. 4 (1998): 299-314.
- Brendan, W hyte. "Using Excel to Map Boundaries: A New Example." *Globe*, no. 68 (2011): 37-43.
- Charalabidis, Yannis. "Interoperability in Digital Public Services and Administration Bridging E-Government and E-Business." Hershey, Pa. : IGI Global (701 E. Chocolate Avenue, Hershey, Pennsylvania, 17033, USA), <http://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/978-1-61520-887-6>.
- Croner, C. M. "Public Health, Gis, and the Internet." *Annu Rev Public Health* 24 (2003): 57-82.
- Cruz, Isabel F. Conf Author International Semantic Web Conference. *The Semantic Web, Iswc 2006 : 5th International Semantic Web Conference, Iswc 2006, Athens, Ga, USA, November 5-9, 2006 : Proceedings*. New York, 2006. <http://www.springerlink.com/content/978-3-540-49029-6>.
- Devillers, Rodolphe Goodchild H. *Spatial Data Quality from Process to Decisions* [in English]. Boca Raton [Fla.] : CRC Press, 2010.
- Dobesch, Hartwig Dumolard Pierre Dyras Izabela. "Spatial Interpolation for Climate Data the Use of Gis in Climatology and Meteorology." Hoboken : John Wiley & Sons, <http://public.eblib.com/EBLPublic/PublicView.do?ptiID=700766>.
- Donnelly, Francis P. "Evaluating Open Source Gis for Libraries." *Library Hi Tech* 28, no. 1 (2010): 131-51.
- Dredger, S. M., A. Kothari, J. Morrison, M. Sawada, E. J. Crighton, and I. D. Graham. "Using Participatory Design to Develop (Public) Health Decision Support Systems through Gis." *Int J Health Geogr* 6 (2007): 53.
- Egenhofer, Max J., Janice Glasgow, Oliver Gunther, John R. Herring, and Donna J. Peuquet. "Progress in Computational Methods for Representing Geographical Concepts." *International Journal of Geographical Information Science* 13, no. 8 (775).
- El-Rabbany, Ahmed. *Introduction to Gps : The Global Positioning System*. Artech House Mobile Communications Series. Boston, MA: Artech House, 2002.
- Ferraggine, Viviana E., Jorge H. Doorn, and Laura C. Rivero. "Handbook of Research on Innovations in Database Technologies and Applications Current and Future Trends." Hershey, Pa. : Information Science Reference, <http://www.library.uiuc.edu/proxy/go.php?url=http://www.infosci-books.com/content/toc.asp?ID=3290>.
- Fisher, Peter F., and David J. Unwin. *Re-Presenting Gis*. John Wiley & Sons Ltd, 2005. <http://catdir.loc.gov/catdir/toc/ecip0510/2005008556.html>.
- Foley, D. H., R. C. Wilkerson, and L. M. Rueda. "Importance of the "What," "When," and "Where" of Mosquito Collection Events." *J Med Entomol* 46, no. 4 (Jul 2009): 717-22.
- Gao, S., D. Miao, F. Anton, X. Yi, and D. J. Coleman. "Online Gis Services for Mapping and Sharing Disease Information." *Int J Health Geogr* 7 (2008): 8.
- Environmental Health and Safety Data Integration Using Geographical Information Systems. Waterloo, Ont. : University of Waterloo.
- Hilton, Brian N. "Emerging Spatial Information Systems and Applications." Hershey, Pa. : IGI Global (701 E. Chocolate

- Avenue, Hershey, Pennsylvania, 17033, USA), <http://public.eblib.com/EBLPublic/PublicView.do?ptiID=275351>.
- Kabbes, Karen C. "Restoring Our Natural Habitat Proceedings of the World Environmental and Water Resources Congress 2007, May 15-19, 2007, Tampa, Florida, USA." [Reston, Va. : American Society of Civil Engineers, <http://ascelibrary.aip.org/dbt/dbt.jsp?KEY=ASCECP&Volume=243&Issue=40927>].
- Kajan, Ejub, Frank-Dieter Dorloff, and Ivan Bedini. "Handbook of Research on E-Business Standards and Protocols. Documents, Data, and Advanced Web Technologies." Hershey PA : Business Science Reference, <http://proquest.safaribooksonline.com/?fpi=9781466601468>.
- Karim i, Hassan A. Akinci Burcu. "Cad and Gis Integration." Boca Raton : Auerbach Publications, <http://site.ebrary.com/id/10367136>.
- Materials specified: ebrary <http://site.ebrary.com/id/10367136>.
- Encyclopedia of Geographic Information Science. Los Angeles : SAGE Publications.
- Kuhn, Werner, and Michael Tim pf Sabine Conf Author Cosit Worboys. *Spatial Information Theory : Foundations of Geographic Information Science : International Conference, Cosit 2003, Ittingen, Switzerland, September 24-28, 2003 : Proceedings*. New York, 2003. <http://www.springerlink.com/app/home/issue.asp?wasp=p812tjvvrq7u6d62eaak&referrer=parent&backto=journal,69,1374;browsepublicationsresults,301,500>.
- Kwon, Yong-Jin, and Alain Claram unt Christophe Conf Author W. G. I. S. Bouju. "Web and Wireless Geographical Information Systems 4th International Workshop, W 2gis 2004, Goyang, Korea, November 2004 : Revised Selected Papers." Berlin ; New York : Springer, <http://www.mylibrary.com?id=140290>
- Li, Jonathan Zlatanova Siyka Fabbri Andrea G. *Geomatics Solutions for Disaster Management* [in English]. Berlin : Springer, 2007.
- Li, Ki-Joune Corp Author Association for Computing Machinery Conf Author A. C. M. Symposium on Advances in Geographic Information System s. *Proceedings of the Eighth Acm Symposium on Advances in Geographic Information System s, November 10-11, 2000, Washington, D.C., USA* [in English]. New York, N.Y. : ACM Press, 2000.
- Lo, C. P., and Albert K. W. Yeung. *Concepts and Techniques of Geographic Information System s*. 2nd ed. Upper Saddle River, NJ: Pearson Prentice Hall, 2007.
- Logsdon, Tom Logsdon Tom , and system Navstar global positioning. *Understanding the Navstar : Gps, Gis, and Ivhs* [in English]. 2nd ed. New York: Chapman & Hall, 1995.
- Manso-Callejo, M.A., and M. Wachowicz. "Gis Design: A Review of Current Issues in Interoperability." [In en]. *Geography Compass* 3, no. 3 (2009 2009): 1105 - 24.
- Mom oh, James A. "Sm art Grid Fundamentals of Design and Analysis." Hoboken : John Wiley & Sons, <http://public.eblib.com/EBLPublic/PublicView.do?ptiID=818488>.
- Neteler, Markus, M. Ham ish Bowman, Martin Landa, and Markus Metz. "Grass Gis: A Multi-Purpose Open Source Gis." *Environmental Modelling & Software* 31, no. 0 (5// 2012): 124-30.
- Prosperi, David Zlatanova Siyka. *Large-Scale 3d Data Integration* [in English]. Boca Raton : Taylor & Francis, 2006.
- Raper, Jonathan. "Arcpad a Field User's Guide." ESRI Press, <http://www.mylibrary.com?id=290111&ref=to.c>.
- Scholl, Michel O., and Agnès Conf Author S. S. D. Voisard. "Advances in Spatial Databases 5th International Symposium, Ssd '97, Berlin, Germ any, July 15-18, 1997 : Proceedings." Berlin ; New York : Springer, <http://rave.ohiolink.edu/ebooks/ebc/3540632387>.
- Shekhar, Shashi, and Hui Xiong. *Encyclopedia of Gis*. Springer, 2008. <http://catdir.loc.gov/catdir/enhancements/fy0824/2007933825-d.html>.
- Sherman, Gary E. *Desktop Gis : Mapping the Planet with Open Source Tools*. Pragmatic Program mers. Raleigh, N.C. ; Dallas, TX: Pragmatic Bookshelf, 2008.
- Shi, Wenzhong. "Advances in Geo-Spatial Information Science." Boca Raton, FL : CRC Press, <http://public.eblib.com/EBLPublic/PublicView.do?ptiID=952030>.
- Simon C. Lin, Eric Yen. "Managed Grids and Cloud System s in the Asia-Pacific Research Comm unity." Springer Science+ Business Media, LLC, <http://www.mylibrary.com?id=292582&ref=to.c>.
- Suresh, Raja. "Defense Transformation and Net-Centric System s 9-12 April 2007, Orlando, Florida, USA." Bellingham , Wash. : SPIE, <http://link.spie.org/PSISDG/6578/1>.
- Taniar, David Conf Author Iccsa. *Computational Science and Its Applications--Iccsa 2010 International Conference, Fukuoka, Japan, March 23-26, 2010 : Proceedings* [in English]. Berlin : Springer, 2010.
- Theng, Yin-Leng. "Handbook of Research on Digital Libraries Design, Development, and Im pact." Hershey, PA : Information Science Reference, <http://qe2a-proxy.mun.ca/login?url=http://www.infosci->

- books.com/content/toc.asp?ID=3234.
- Thurston, Jeff Moore J. Patrick, and Thomas K. Poiker. *Integrated Geospatial Technologies : A Guide to Gps, Gis, and Data Logging*. John Wiley & Sons, 2003. <http://catdir.loc.gov/catdir/toc/wiley032/2003041166.html>.
- Vckovski, Andrej. *Interoperability in Gis* [in English]. International Journal of Geographical Information Science;; Vol. 12, Nr. 4 (Jun.); Variation: International Journal of Geographical Information Science ;; Vol. 12, Nr. 4 (Jun.). London [etc.]: Taylor & Francis, 1998.
- Vuckovski, Andrej. *Interoperable and Distributed Processing in Gis* [in English]. London ; Bristol, PA : Taylor & Francis, 1998.
- Weng, Qihao. *Remote Sensing and Gis Integration : Theories, Methods, and Applications*. New York: McGraw-Hill, 2010.
- Yeh, Anthony G. O., and Handling Conf Author: International Symposium on Spatial Data. "Advances in Spatial Data Handling and Gis 14th International Symposium on Spatial Data Handling." Berlin ; New York : Springer, <http://dx.doi.org/10.1007/978-3-642-25926-5>.
- Yoon, Jaewan Hoppe Edward J., and monitor. *Development of the Interconnectivity and Enhancement (Ice) Module in the Virginia Department of Transportation's Geotechnical Database Management System Framework*. Virginia Transportation Research Council, 2007. http://www.virginiadot.org/vtrc/main/online_reports/pdf/07-cr15.pdf.
- Zlatanova, Siyka. "Large-Scale 3d Data Integration Challenges and Opportunities." Hoboken : CRC Press, <http://www.yilibary.com?id=65393>.

Appendix A: Terms and Definitions

Open Source – Software for which the source code is freely available for the public to view and contribute to. The software itself is generally free to use.

Web 2.0 – A label introduced in 2004 that refers to the 2nd generation of web technology which provided a new set of functionalities pertaining to the ability for the end user to ‘interact’ with the web. Examples include blogs, wikis and social networking (TechTerms.com, 2013).

Smart device applications – any application that can be used on a smart device such as an iPad, iPhone or Droid tablet.

Data Formats Used

DWG	Autodesk's proprietary drawing format for AutoCAD drawings
GEOTIFF	A specialized TIFF file which stores georeferencing information embedded in the file in order to provide a spatial reference
JPG	A graphic format for hi res images, often used for aerial imagery
GeoJSON	A geospatial data interchange format based on Javascript Object notation (JSON)
KML	(Keyhole Markup Language) An XML based geographic data format used for annotation and visualization initially developed for use with Google Earth.
SHP	A geospatial vector format used in GIS software containing points, lines or polygons and associated attributes
POSTGIS	An open source software program that provides geospatial support for PostgreSQL
SQL Spatial	Microsoft's enterprise database system which supports natively storing spatial data as Geometry or Geography data types.

Appendix B: Code Book

Data Type	Type	V	Q	E	A	T	T	TechType	TechCat	Function	Format
dwgline	l	1	0	1	0	0	2	ACADWS	Smart Device Ap	WEBGIS	Vetor
DWGpoint	p	1	0	1	0	0	2	ACADWS	Smart Device Ap	WEBGIS	Vetor
dwgpolygon	pl	1	0	1	0	0	2	ACADWS	Smart Device Ap	WEBGIS	Vetor
geotiff	r	0	NA	NA	NA	0	0	ACADWS	Smart Device Ap	WEBGIS	Raster
jpg	r	0	NA	NA	NA	0	0	ACADWS	Smart Device Ap	WEBGIS	Raster
jsonline	l	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
jsonpoint	p	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
jsonpolygon	pl	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
kmlline	l	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
kmllpoint	p	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
kmllpolygon	pl	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
line	l	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
point	p	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
polygon	pl	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
shpline	l	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
SHPpoint	p	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
shppolygon	pl	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
sqlline	l	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
sqlpoint	p	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
sqlpolygon	pl	0	0	0	0	0	0	ACADWS	Smart Device Ap	WEBGIS	Vetor
dwgline	l	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor

DWGpoint	p	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
dwgpolygon	pl	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
geotiff	r	0	NA	NA	NA	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Raster
jpg	r	0	NA	NA	NA	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Raster
jsonline	l	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
jsonpoint	p	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
jsonpolygon	pl	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
kmlline	l	1	1	0	0	0	2	2	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
kmllpoint	p	1	1	0	0	0	2	2	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
kmllpolygon	pl	1	1	0	0	0	2	2	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
line	l	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
point	p	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
polygon	pl	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
shpline	l	1	1	0	0	0	2	2	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
SHPPpoint	p	1	1	0	0	0	2	2	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
shppolygon	pl	1	1	0	0	0	2	2	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
sqlline	l	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
sqlpoint	p	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
sqlpolygon	pl	0	0	0	0	0	0	0	Arcgisonline	Smart Device Ap	WEBGIS	Vetor
dwgline	l	0	0	0	0	0	0	0	Georest	Web2.0	data portal	Vetor
DWGpoint	p	0	0	0	0	0	0	0	Georest	Web2.0	data portal	Vetor
dwgpolygon	pl	0	0	0	0	0	0	0	Georest	Web2.0	data portal	Vetor
geotiff	r	0	0	0	0	0	0	0	Georest	Web2.0	data portal	Raster
jpg	r	0	0	0	0	0	0	0	Georest	Web2.0	data	Raster

										portal	
jsonline	l	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
jsonpoint	p	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
jsonpolygon	pl	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
kmllin	l	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
kmllpoint	p	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
kmllpolygon	pl	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
line	l	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
point	p	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
polygon	pl	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
shpline	l	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
SHppoint	p	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
shppolygon	pl	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
sqlline	l	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
sqlpoint	p	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
sqlpolygon	pl	1	0	0	0	0	1	Georest	Web2.0	data portal	Vetor
dwgline	l	1	1	1	1	-1	3	Grass	OpenSource	Desktop GIS	Vetor
DWGpoint	p	1	1	1	1	-1	3	Grass	OpenSource	Desktop GIS	Vetor
dwgpolygon	pl	1	1	1	1	-1	3	Grass	OpenSource	Desktop GIS	Vetor
geotiff	r	1	NA	NA	NA		1	Grass	OpenSource	Desktop GIS	Raster
jpg	r	1	NA	NA	NA		1	Grass	OpenSource	Desktop GIS	Raster
jsonline	l	0	0	0	0		0	Grass	OpenSource	Desktop GIS	Vetor
jsonpoint	p	0	0	0	0		0	Grass	OpenSource	Desktop GIS	Vetor
jsonpolygon	pl	0	0	0	0		0	Grass	OpenSource	Desktop GIS	Vetor

km llin	l	1	1	1	1	0	4	Grass	OpenSource	Desktop GIS	Vetor
km lpoint	p	1	1	1	1	0	4	Grass	OpenSource	Desktop GIS	Vetor
km lpolygon	pl	1	1	1	1	0	4	Grass	OpenSource	Desktop GIS	Vetor
line	l	1	1	1	1	-1	3	Grass	OpenSource	Desktop GIS	Vetor
point	p	1	1	1	1	-1	3	Grass	OpenSource	Desktop GIS	Vetor
polygon	pl	1	1	1	1	-1	3	Grass	OpenSource	Desktop GIS	Vetor
shpline	l	1	1	1	1	0	4	Grass	OpenSource	Desktop GIS	Vetor
SHPpoint	p	1	1	1	1	0	4	Grass	OpenSource	Desktop GIS	Vetor
shppolygon	pl	1	1	1	1	0	4	Grass	OpenSource	Desktop GIS	Vetor
sqlline	l	1	1	1	1	-2	2	Grass	OpenSource	Desktop GIS	Vetor
sqlpoint	p	1	1	1	1	-2	2	Grass	OpenSource	Desktop GIS	Vetor
sqlpolygon	pl	1	1	1	1	-2	2	Grass	OpenSource	Desktop GIS	Vetor
dwgline	l	1	0	0	0	0	1	Mapguide	OpenSource	WEBGIS	Vetor
DWGpoint	p	1	0	0	0	0	1	Mapguide	OpenSource	WEBGIS	Vetor
dwgpolygon	pl	1	0	0	0	0	1	Mapguide	OpenSource	WEBGIS	Vetor
geotiff	r	1	NA	NA	NA	0	1	Mapguide	OpenSource	WEBGIS	Raster
jpg	r	1	NA	NA	NA	0	1	Mapguide	OpenSource	WEBGIS	Raster
jsonline	l	0	0	0	0	0	0	Mapguide	OpenSource	WEBGIS	Vetor
jsonpoint	p	0	0	0	0	0	0	Mapguide	OpenSource	WEBGIS	Vetor
jsonpolygon	pl	0	0	0	0	0	0	Mapguide	OpenSource	WEBGIS	Vetor
km llin	l	0	0	0	0	0	0	Mapguide	OpenSource	WEBGIS	Vetor
km lpoint	p	0	0	0	0	0	0	Mapguide	OpenSource	WEBGIS	Vetor
km lpolygon	pl	0	0	0	0	0	0	Mapguide	OpenSource	WEBGIS	Vetor
line	l	1	1	1	1	0	4	Mapguide	OpenSource	WEBGIS	Vetor
point	p	1	1	1	1	0	4	Mapguide	OpenSource	WEBGIS	Vetor
polygon	pl	1	1	1	1	0	4	Mapguide	OpenSource	WEBGIS	Vetor
shpline	l	1	1	0	1	0	3	Mapguide	OpenSource	WEBGIS	Vetor
SHPpoint	p	1	1	0	1	0	3	Mapguide	OpenSource	WEBGIS	Vetor
shppolygon	pl	1	1	0	1	0	3	Mapguide	OpenSource	WEBGIS	Vetor

n											
sqlline	l	1	1	0	1	0	3	Mapguide	OpenSource	WEBGIS	Vetor
sqlpoint	p	1	1	0	1	0	3	Mapguide	OpenSource	WEBGIS	Vetor
sqlpolygon	pl	1	1	0	1	0	3	Mapguide	OpenSource	WEBGIS	Vetor