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Evaluation of Web GIS Functionality in Academic Libraries

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EVALUATION OF WEB GIS FUNCTIONALITIES IN ACADEMIC LIBRARIES

Abstract

The rise of web-based GIS resources has expanded the scale and scope of spatial information seeking in most, if not all, academic libraries. Even without formal GIS training, users can search for spatial information, create customized maps, as well as perform simple spatial analysis. However, few systematic evaluations have been conducted to summarize common web GIS functionalities as GIS moving from traditional desktop applications to the web. In this study, we evaluated and assessed the major functionalities of web GIS applications and their potential value for information discovery and access, using six most popular applications in the academic libraries. In addition, since web GIS targets non-GIS professionals, we also conducted an empirical usability evaluation of the six GIS applications in academic libraries. As the result, we identified eight major GIS functionalities that web GIS offers for information seeking purposes. The usability evaluation suggested that a user-friendly web GIS application should provide users a clear starting point, predictable map interaction, flexible customization capabilities, and familiar web experiences. Our study is one of the first studies to examine web-based GIS functionalities and their associated usability in a systematic way. The results will serve as an important reference for web GIS developers.

Key words: web GIS, GIS functionality, usability, information seeking

1. INTRODUCTION

With an increasing number of web map standards (OGC, 2013) and web mapping Application Programming Interfaces (API), web GIS applications have reached new levels of sophistication and prominence unheard of in earlier decades (Batty, Hudson-Smith, Milton, & Crooks, 2010; Crampton, 2009; Haklay, Singleton, & Parker, 2008). As a result, the use of web GIS to deliver information is facing a dramatic expansion (Chow, 2008). This brings new opportunities for information-seeking and visualization in academic libraries (Weessies & Dotson, 2013), as spatial information is often embedded in various library databases. Taking business data as an example, it is estimated that more than three-quarters of data in the libraries contains a geographic component (Brody, 1999).

Meanwhile, GIS functionality has also evolved (Kim & Kim, 2002; Kraak, 2004; Lu, 2005). Unlike traditional GIS software supports, it is unnecessary for each web GIS application to include all geospatial operation components. On the other hand, new expectations emerge, such as a user friendly interface design, as the number of users without formal GIS training increases (Newman et al., 2010; Nivala, Brewster, & Sarjakoski, 2008). Web GIS developers need to rethink and redesign traditional GIS tools and features to enhance their usability, especially in terms of learnability, flexibility and robustness.

In this paper, we conducted functional reviews and usability tests of six commonly used web GIS applications in academic libraries to explore the major functionality and usability factors that enhance the performance of web GIS as an information discovery application. We highlight the prevailing web GIS functions and their usability concerns, which will serve as a reference for web GIS researchers and developers.

2. BACKGROUND

GIS functionality has been classified and discussed from the very beginning of GIS technology (Goodchild, 1987; D. Maguire & Dangermond, 1991; D. J. Maguire, Goodchild, & Rhinds, 1991). Traditional desktop based GIS functionalities, including mapping, database, and spatial analysis, has been challenged when desktop GIS moves onto the web (Kraak, 2004). For mapping, web users pay more attention to map interactivity, manipulation capability, as well as usability, in addition to the traditional static map products (You, Chen, Liu, & Lin, 2007). For databases, data models are hidden in the back-end from web users, and database query function becomes more important than before. Spatial analysis is still an important component in web GIS, although it is not necessary for web GIS to include as many spatial analysis functions as traditional GIS. Web GIS applications should deliberately pick a reasonable number of goal-oriented spatial functions to provide users the query or analytic capability while not overwhelming them (Musser, 1997).

In the academic library research literature, there have been several review studies introducing web GIS for information users. Cobb and Olivero (1997) reviewed several online GIS services and listed some possible "pitfalls" GIS websites might have, including non-intuitive design, too intensive mapping functionality, lack of cartographic design, etc. A more recent review has considered the map import/export capabilities as the major GIS functions for information seekers (Kidd, 2010). From the research and education support perspective of academic libraries, Weessies and Dotson (2013) used three case studies to demonstrate the importance of historical data and data download functionality of web GIS. Although some important GIS functions and web GIS design flaws have been identified by information scientists, these web GIS functionality and usability issues have not been systematically studied to address the needs of web GIS users and assist developers in improving web GIS applications. In this paper, we extend previous research and identify major web GIS functions together with related usability concerns from an information seeking perspective.

3. RESEARCH METHOD

The six web GIS applications selected for this study were Reference USA (RU), SimplyMap (SM), PolicyMap (PM), Social Explorer (SE), Proquest Statistical Datasets (PQ), and ESRI Business Analyst Online (BAO). RU offers Google Map based database information on U.S. and Canadian businesses, employers, and residents. SM, PM and SE enable non-technical users to create custom maps and reports with focuses on business and marketing (SM), political science (PM), and current and historical census information (SE). PQ offers a collection of 17 subjects statistical data in both map and table formats. And ESRI BAO is a web map-based solution for business site evaluation and market analysis.

These applications were selected based on their prominence among academic libraries as could be ascertained by reviewing library resource pages. An email was sent to the business librarian listervs BUSLIB-L (2000 subscribers) and BRASS-L (900 subscribers) in May 2013 to request feedback on the working list of web GIS databases. These requests resulted in 18 responses, mostly affirming the list already gathered. The functionality and usability evaluation discussed here was based on the latest version of the six applications as of December 2013. For functionality evaluation, we collected product information from vendors and we documented and ran test cases of all listed functions for each web GIS platform. We then synthesized and classified the functions available in each application into different categories for comparison.

Based on the identified GIS functions, we designed four tasks for usability evaluation, which are commonly used in web GIS platforms and represent a typical workflow of using a web-based mapping application for users without GIS background. These four tasks include: (1) create a customized map about a business-related variable for Indianapolis, IN; (2) change the color and corresponding data range of mapping units on the map; (3) search for another location (Provo, UT) on the map; and (4) export the map and save it to a local computer. Seventeen university students were recruited through an advertisement posted on the Purdue University Libraries website for usability tests. The participants reported extensive experience with Google Maps or similar products but very little experience with other GIS software or web GIS applications. Response measures of each task include: (1) score of the participant's successfulness in completing the task (0 – completed with ease, 1 – completed with difficulty, and 2 – failed to complete); (2) time to complete; and (3) number of times an error occurred. In addition, we encouraged participants to "think aloud" and recorded their computer screen activity and voice using TechSmith Morae software during each test period. A researcher sat next to participants, answered questions and provided prompts when participants explicitly requested, and made observation notes about participant behavior. Participants completed the System Usability Scale (SUS; Brooke, 1996) questionnaire and answered open questions about their overall experience of each application. At the end of the evaluation, participants ranked their preferences of the applications they used. Each evaluation session lasted approximately one hour.

4. RESULTS

Based on the traditional GIS functionality framework, we have identified eight core web GIS functions by summarizing the detailed function list of the six applications we studied and the notes from our GIS functionality tests (Table 1). In this section, we discuss the details of each function and associated usability test results.

TABLE 1
FUNCTIONS OF WEB GIS APPLICATIONS IN LIBRARIES

GIS functionality	Details for web GIS
Mapping	1. Basemap availability
	2. Legend customization
	3. Map elements
	4. Map products
Database	5. Information query
	6. Location search
	7. Reporting
Analysis	8. Selected sets of spatial analysis

4.1 BASEMAP AVAILABILITY

The basemap varied in different web GIS applications from very simple state and county boundaries in PQ, to multiple choices of street map, imagery, and topography in BAO. Common basemap information in these applications included state and county boundaries, major cities, transportation networks, rivers and water bodies, parks, and landmarks. All of the applications except for RU used Choropleth maps, i.e. areas are shaded in proportion to the variable values, as the information delivery method. The basic mapping units in these Choropleth maps included state, county, census tract, and block groups. Three applications (BAO, SE, and SM) allowed users to turn on and off layers and labels.

To evaluate the basemap usability, we asked participants about their initial impression of the application and then gave them the task of creating a customized map using a business-related variable in the Indianapolis, IN area. For their initial impression, users preferred applications with an easy and clean interface, big upfront map area, and clear starting point. They liked basemaps with distinguishable colors, or ones familiar from their previous web map experience, such as the Google Map style. Usability test scores (TABLE 2) indicated that applications with an easy entry-point had higher task successfulness (e.g., SM), while applications with overwhelming functions (e.g., BAO) or confusing tool bars (e.g., PM) had relatively lower task successfulness. Although getting started with maps and utilizing multiple map options are not a hurdle for GIS professionals, it becomes a design issue for general users.

TABLE 2
DESCRIPTIVE STATISTICS FOR CREATING MAP TASK

Application	Task Score*	Task Time (second)	Number of errors

	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
RU	0.2	0.45	0	1	73.3	48.2	22.2	133.7	1.2	0.8	0	2
SM	0.14	0.38	0	1	60.7	27.6	34.5	113.0	1.4	1.3	0	4
PM	0.57	0.53	0	1	80.2	52.5	22.5	165.9	2.1	1.4	0	4
SE	0.29	0.49	0	1	117.9	97.0	25	297.1	3.9	2.9	0	8
PQ	0.13	0.35	0	1	41.6	39.4	9.7	127.0	1.3	1.2	0	3
BAO	0.63	0.74	0	2	126.6	90.7	36.6	305.8	1.8	1.4	0	4

* 0 – completed with ease, 1 – completed with difficulty, and 2 – failed to complete

4.2 LEGEND CUSTOMIZATION

All web GIS applications in this study offered the flexibility to edit polygon features in the legend except for RU, which only offered point information. With legend customization, users can change map legends by color, number of categories and different classification methods. In addition, some applications, such as BAO, also gave users the flexibility to change the transparency and outline thickness.

We designed two tasks to evaluate the usability of legend customization: (1) change the colors of the map legend, and (2) perform a user-defined classification (TABLE 3). For the first task, users didn't have much difficulty locating and using this function even though they had no past experience in editing map legends. Results of the second task reflected a conflict in interface design between functionality and usability. Web GIS applications with advanced data range-editing feature (e.g., BAO and SE) took participants longer to learn and use the function. FIGURE 1 compares the advanced data range-editing feature in BAO and simple version of data range-editing in SM. BAO's interface used drag-and-drop mechanisms to edit the data range; while SM required users to type in the data range directly.

TABLE 3
DESCRIPTIVE STATISTICS FOR MAP LEGEND CUSTOMIZATION

Application	**Task Score ***				**Task Time (second)**				**Number of errors**			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
	Task 1											
SM	0.67	1.03	0	2	19.7	13.7	6.9	35.6	0.8	1.0	0	2
PM	0.33	0.82	0	2	17.2	21.8	3.5	61.1	0.5	0.8	0	2
SE	0	0	0	0	10.5	7.7	4.3	22.1	0.4	0.8	0	2
PQ	0.33	0.82	0	2	32.4	16.9	3.7	51.6	1.5	1.2	0	3
BAO	0	0	0	0	7.3	2.7	5.3	12.6	0.3	0.8	0	2
	Task 2											
SM	0	0	0	0	27.0	17.3	13.6	50.3	1.0	0.8	0	2
PM	0.2	0.45	0	1	37.3	30.6	13.8	85.1	0.8	1.3	0	3
SE	0.17	0.41	0	1	47.2	64.2	12.4	176.5	0.7	1.2	0	3
PQ	NA				NA				NA			
BAO	0.5	0.55	0	1	63.7	37.0	23.7	125.5	1.3	0.8	0	2

* 0 – completed with ease, 1 – completed with difficulty, and 2 – failed to complete

FIGURE 1
DATA RANGE-EDITING INTERFACES IN BAO (LEFT) AND SM (RIGHT).

4.3 MAP ELEMENTS

Map elements, such as scale, title, overview map, and north arrow, which are important in cartographic design, are often neglected in web GIS applications. On the other hand, new interactive features equivalent to these traditional map elements such as interactive map zoom and pan are more frequently used owing to the dynamic nature of web maps. All applications except for PQ had a typical set of interactive zoom modes including zoom lever or zoom in and out buttons, and mouse wheel zoom. PQ did not use this style because it was developed using a previous Java-based web GIS technology. Only three applications (SM, SE, BAO) showed a scale bar, and only SM showed an overview map. None of the applications had a measuring tool, even though it has been mentioned as a preferred component for web based mapping (Musser, 1997). During evaluation, we observed that users quickly learned zooming by mouse wheel and panning by drag and drop. They tended to neglect zoom buttons for rectangle based zoom and zoom to previous and next view, which are more familiar to GIS professionals.

4.4 MAP PRODUCTS

The map products in the academic libraries context include three types: save a map, share a map online, and download a map in graphic format. The save-a-map option is limited to the same user login. The map URL or option to embed the map into a web page allows users to share the resulting map online with others even if they do not have access to the application. The download option allows users to insert the map into their documents, or share with others. TABLE 4 lists the available map products in each application.

TABLE 4
DELIVERABLE MAP PRODUCTS IN THE SIX SELECTED APPLICATIONS

Application	Save map	Share map link	Downloaded map format
RU	N/A	N/A	JPG, PNG, GIF
SM	Yes	N/A	PNG, JPG, GIF, SVG, PDF, Shapefile
PM	Yes	Share by link or embed into webpage	PDF, PNG, JPG
SE	Yes	Share by link or embed into webpage	PNG, PPT
PQ	N/A	Generate link with Digital Object Identifier	PDF, Shapefile
BAO	N/A	N/A	PDF, JPG

In the usability evaluation, we asked participants to export the map from each application and save the result to a local computer. The task results (TABLE 5) revealed some design issues in this function. Participants took much longer to download the map in PM, because the export function is under the button labeled "Print" and most participants expected this button to physically print the map. Some applications (e.g., BAO and PM) took a considerable amount of time to generate the PDF file and showed a notification when the file was ready. Participants tended to ignore the notifications because they were too subtle in the interface. FIGURE 2 shows the downloadable link notification from BAO. Almost all the participants ignored the link and clicked the OK button to close the dialog.

TABLE 5
DESCRIPTIVE STATISTICS FOR MAP EXPORT

Application	Task Score *				Task Time (second)				Number of errors			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Reference	0.33	0.71	0	2	45.7	17.8	20.5	71.5	1.3	1.1	0	3
SimplyMap	0.43	0.79	0	2	61.9	35.5	28	128.1	1.4	1.1	0	3
PolicyMap	1	0.82	0	2	96.8	69.7	31.1	186.2	3.4	2.8	0	8
Social	0.14	0.38	0	1	39	18.6	21.4	68.2	0.7	1.5	0	4
Proquest	0	0	0	0	29.9	7.2	17.4	38.8	1.1	1.1	0	2
ESRI BAO	0.57	0.79	0	2	70.2	51.9	22.9	177.8	1.7	1.4	0	4

* 0 – completed with ease, 1 – completed with difficulty, and 2 – failed to complete

We observed that the exporting map task poses a design challenge between customizability and efficiency. Applications with longer map exporting times usually provided more options to customize the map layout, text, etc., while applications with shorter task times only generated screenshots of the map. Although current GIS technology may not be able to significantly reduce the map generation time, a better interface design is needed to notify users about the generated file and possible additional actions required, such as downloading.

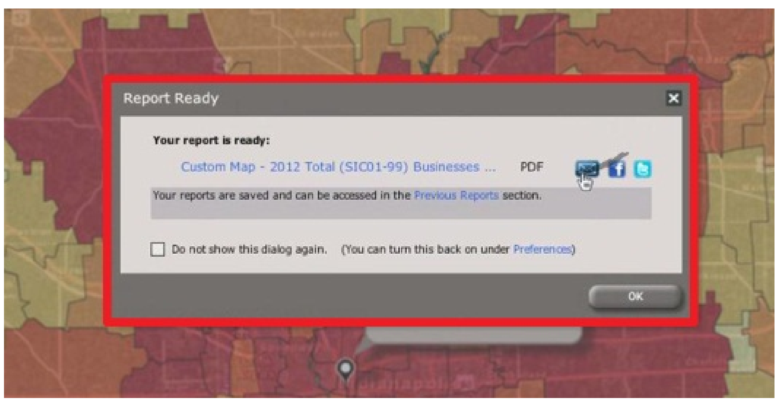

FIGURE 2
DOWNLOADABLE LINK NOTIFICATION IN BAO

4.5 INFORMATION QUERY

All applications in this study had location-based identification function with details listed in TABLE 6. Traditionally, GIS applications had legacy identification buttons to orient the user to the location. As more web GIS applications are being developed for general users, users expect to read map information in a more direct way such as mouse hover or direct click. Another difference of web GIS applications compared to traditional GIS software is that web

GIS applications may not provide interactive tables (e.g., RU, SM, PM, SE). In our usability evaluation, we asked the participants to take some time to read the map information such as the value of an interesting map unit. Based on our observation, the map information upon hovering was extremely helpful for participants in order for them to become familiar with the map and understand the map information.

In addition to the simple information identification, some web GIS applications also allow users to generate filtered maps. PQ and BAO provided map filtering for the currently displayed variable, and SM allowed users to generate filtered map based on multiple criteria.

TABLE 6
LOCATION BASED IDENTIFICATION FUNCTION IN SELECTED APPLICATIONS

Application	Action	Information	Interactive table/chart
RU	Click	Business point information	NA
SM	Click	Location name	NA
PM	Click	Variable value and larger scale average	NA
SE	Hover	Variable value and percentage	NA
PQ	Hover	Variable value	Yes
BAO	Hover	Variable value and percentage	Yes

4.6 LOCATION SEARCH

Location search is essential for users to find areas unfamiliar to them. We observed two types of location search mechanisms from the applications: list selection and free text search (TABLE 7). For list selection, the system predefined location names and associated coordinates in the database. Users could only select from available locations in the lists. Usually, list selection allows users to search for a location by state, county, city, congressional district, zip code, census tract, and census block group. The free text search allows users to input free text and zoom to the location with the best match. The search box usually accepts address, city, town, place, state names, zip code, or latitude and longitude information. In our evaluation, participants preferred free text search for its efficiency and simplicity. In reality, the accuracy of free text search depends on both user input and the geolocator of the application.

TABLE 7
LOCATION SEARCH TYPES IN SIX SELECTED APPLICATIONS

Application	List selection	Free text search
RU		√
SM	√	
PM	√	√
SE		√
PQ	√	
BAO	√	√

To test the effectiveness of these two location search methods, we gave participants the task to find Provo, Utah on the map using available location search tools in each application (TABLE 8). For applications with free text search, participants spent much less time to find the target location. Users of ESRI BAO spent a relatively longer time on the task. We observed the map was zoomed in too much by the application and participants had to zoom out to see the city area. Although PQ only provided list selection, its dataset was relatively simple and the location list was upfront on the interface, which was easy to use. The location list for SM was hidden under the menu and offered several options for location search (e.g., find location by city, county, congressional district, census block), which took participants much longer to understand and use.

TABLE 8
DESCRIPTIVE STATISTICS FOR LOCATION SEARCH

Application	Task Score *				Task Time (second)				Number of errors			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
RU	0	0	0	0	17.4	3	14.1	20.7	0.5	1	0	2
SM	0.5	0.55	0	1	72.5	34.2	31.9	115	2.2	1.3	1	4
PM	0	0	0	0	18	12.4	7.7	38.7	1	1.1	0	3
SE	0	0	0	0	14.9	3	9.9	17.7	0.2	0.5	0	1
PQ	0	0	0	0	12.8	5.5	9.2	19.2	1	1	0	2
BAO	0.17	0.41	0	1	28.7	26	8.5	78.3	1.2	1.2	0	3

* 0 – completed with ease, 1 – completed with difficulty, and 2 – failed to complete

4.7 REPORTING

All six applications had reporting functions that allowed users to select variables and locations to generate sorted reports. BAO only provided users with reports in PDF format, while other applications allowed users to download data in CSV, Excel or SAS format for further analysis in other statistical software. Some applications offered pre-built standard variable sets for particular topics (e.g., PM), while other applications allowed multiple variable selection or multiple location comparison (e.g., SM). Since user requirements of the reporting function depend on the context of use, we did not include report functions in the usability test.

4.8 SPATIAL ANALYSIS

Depending on the intended user groups, some web GIS applications provide spatial analysis capability. In academic libraries, potential spatial analysis functions include buffer analysis, map algebra, and heatmaps. A buffer in GIS is a zone around a map feature measured in units of distance or time, which is usually used for proximity analysis (Sommer & Wade, 2006). In this study, SM, PM and BAO offered Euclidian distance-based buffer analysis reports. An advanced buffer analysis generated the buffers based on driving distance (BAO). PQ is the only application in this study that offered map algebra, which allows users to generate new variables based on the combination or statistics of existing variables. This is a convenient feature for GIS laypersons to explore the relationships between different spatial variables without using traditional GIS software. The heatmap function provides an immediate visual summary of information and allows the viewer to understand complex data sets. In academic libraries, heatmap visualization is a useful way to summarize the spatial distribution of point based datasets, if the point information is rich at a large scale. For example, RU generated heatmaps for business locations if there were more than 300 records shown in the current zoom level.

Spatial analysis provided by web GIS applications is not limited to the functions we observed in this study. GIS laypersons may lack understanding of spatial analysis methods. Depending on potential users' needs and the nature of the dataset, more spatial analysis functions could be implemented in web GIS applications. For example, in the academic library environment, cluster analysis could help users to analyze patterns within the dataset. Web GIS applications need to be well designed to balance the spatial analysis functions and usability so that GIS laypersons are not misled or confused when using those functions.

5. DISCUSSION AND CONCLUSION

Of the six selected web GIS applications, we characterized eight common functionalities and evaluated four of them via usability tests. For the mapping capability, our results show that a user-friendly web GIS application should offer a clear starting point, a familiar basemap, and enough flexibility for map customization. In this study, SM has a clear starting point and easy-to-follow interface, which enabled a higher success rate in the map creation task during the usability study. Other mapping features such as editing the legend and exporting a map show a trade-off between functionality and user-friendliness. For database interaction, the usability test results indicate that an easy-to-use web GIS application should have predictable map and information interaction. Although spatial analysis is an important part of web GIS application, we were not able to test the usability of various spatial analysis functions due to its high variability among different applications. Web GIS developers should take into consideration the experience level and expectations of general users in the application design phase. It is important to note that some applications were updated with new functions and interface designs between the times of usability test and when this paper was completed. For example, PM modified its interface with larger map area and simpler search bar.

The usability evaluation is only based on commonly available GIS functions in the six selected applications. There are some important aspects of web GIS functions that we could not fully test due to this limitation. For example, although map measuring tools and overview maps are mentioned many times in the literature (Cobb & Olivero, 1997; Kidd, 2010), most of the selected applications did not have those features; further, we cannot test the users' expectations. Also, some other functions, such as reporting and spatial analysis, vary across different user cases, and we could not design common tasks to test their usability across applications.

As the(Chapman & Brothers, 2006) adoption of web GIS increases, users' experiences and skills may improve accordingly. A consistent design of features and functions across applications will provide a better user experience in terms of familiarity and learnability. The functional review and usability concerns we have identified in this study contribute to the ongoing efforts of addressing the challenge of providing spatial information discovery for general users of academic libraries and improving the overall user experience of web GIS applications. As the next steps in our research, we will design user interfaces of web GIS application based on the major GIS functions and usability concerns identified in this study, which will serve as spatial information access points for academic library users across disciplines.

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