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Designing Search Engines for Interactive Web-based Geovisualizations

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Abstract. With the proliferation of interactive (geo) visualizations, their findability has become increasingly challenging and new tools are needed to facilitate their search. This work is a preliminary exploration of features for (geo) visualization classification and users' wishes regarding search tools for interactive (geo) visualizations. The features were derived through manual inspection of various websites and the users' wishes were compiled from laddering interviews with eight participants. The results obtained are relevant to the design of software crawling and classifying online geovisualizations, and presenting the results in a user-friendly way.

Keywords. geographic information retrieval, visualization search, FAIR interactive visualizations, user-centered information retrieval

1 Introduction and Related Work

The interplay of research on information search and visualizations takes many forms: using *visualizations to formulate inputs* for search (e.g. Russell and Smart (2008); Russell-Rose et al. (2019); Scheider et al. (2017)), using *visualizations to depict outputs* of search activities (e.g. Hienert et al. (2012); Sebrechts et al. (1999); Vegas et al. (2003)), and investigating the impact of *search as a design feature* of online visualizations (e.g. Feng et al. (2018)). This work focuses on another area involving both research on information search and visualizations, namely that of the *search of online visualizations*. As pointed out in (Degbelo, 2022), despite the large volume of search queries today, the findability of online geovisualizations using existing search engines is currently limited.

Interactive systems enable the user to make incremental and reversible changes, allowing for direct manipulation of illustrated objects without a complex syntax to generate immediate results (Brodbeck et al., 2009). When these systems refer to visual displays that explore and derive insights from geodata (Kraak, 2003), the topic at hand is *interactive geovisualizations*. Interactive geovisualizations are produced for a variety of purposes, such as storytelling in data journalism and the presentation of research data (Kraak, 2003). They are available as web documents and tools are increasingly needed to make them FAIR (findable, accessible, interoperable, reusable). Although current search engines partly address the findability of *static* or *animated* geovisualizations (e.g. they have dedicated sections for the search of images/pictures of geographic data), research on the search of *interactive* geovisualizations needs more attention so that effective search engines for these information products can emerge. In this work, the prefix 'geo' is used to refer to the visualization of geographic data - in the form of interactive maps or geodashboards (Degbelo et al., 2022; Figgemeier et al., 2021).

The long-term goal of this work is to build a search engine for indexing and querying interactive geovisualisations on the Web. Since interactive geovisualizations often come in the form of HTML documents, the issue of geovisualization search may be modelled as a code search problem. Nonetheless, and contrary to code search that aims at helping developers find code snippets they can reuse and thereby increase their productivity (Liu et al., 2022), the search for online interactive geovisualizations may be done by an analyst interested in gaining inspiration from diverse ways of visualizing one or many datasets.

Previous work to improve the findability of visualizations has so far addressed the harvesting of static maps and semantic annotation. As for the harvesting of map images, Tan et al. (2009) proposed an approach to extract figures from digital academic documents and classify them as maps and non-maps. Goel et al. (2011) proposed an approach to retrieve pictures from web-based image search engines and PDF documents, and categorised them as maps and non-maps. Work on semantic annotation proposed computational ontologies to annotate different aspects of geovisualizations for improved search, for example: map content (Mai et al., 2022; Scheider et al., 2014b), metadata about maps (Scheider et al., 2014b), map legend (Gao et al., 2016), what users learned during their interaction with maps (Degbelo, 2021), and the process of creating maps (Mai et al., 2022; Huang and Harrie, 2020). Lai and Degbelo (2021) compared the use of typing and speech as modalities for the semantic annotation of maps and reported that combining both could be beneficial to GI-metadata creation user interfaces. Prototypical tools to enable the search of static historical maps were presented in (Scheider et al., 2017, 2014a), and examples of websites to browse static historical maps include the Alexandria Digital Library (Goodchild, 2004; UC Santa Barbara Library, 2022) and the David Rumsey Map Collection (Cartography Associates, 2022). Next to these works, approaches to enable the search of interactive maps were proposed in (Hu et al., 2015a, b; Mai et al., 2020), but their scope was limited to the ArcGIS online platform.

While these works provided valuable contributions, what makes web documents as *interactive* (geo)visualizations unique, and what users wish regarding design elements of search engines for these geovisualizations, are still unclear. Answering the first question is useful for developing effective crawling strategies while answering the second question will be relevant to designing user-friendly search interfaces for interactive online geovisualizations. These two gaps are the focus of this work in progress, which looks at the following two research questions:

- Which conditions (necessary and sufficient) are useful for distinguishing interactive visualizations and interactive geovisualizations on the Web?
- What are users' wishes regarding user interfaces for search engines for interactive geovisualizations?

2 Features for Visualization Classification

To learn about the features that could be relevant when crawling geovisualizations from the Web, we collected 75 websites from a broad range of domains (e.g. health, earthquakes, demographics, finance, music, news, photography, mapping, translation, encyclopedia articles, open data portals, to mention a few). The sample had 25 instances of three categories: websites with at least one interactive visualization (IV), websites with at least one interactive geovisualization (IGV) and websites without an interactive (geo)visualization (noIV). 51 websites (i.e. 17 per category) were inspected manually to get an idea of the distinguishing features of each type and build a rule-based decision tree, while the remaining 24 (i.e. 8 per type) were used to test the performance of the preliminary decision tree. In that sense, this work is exploratory and aims at informing classification strategies for all types of interactive geovisualizations on the Web, not only SVG-based (Scalable Vector Graphics) visualizations that were the focus of (Battle et al., 2018). The work rested at this point on the following premises:

C1 The website having an element that contains an IV is **necessary** for the website being an IV, but **not sufficient** for the website being an IGV.

C2 The website having an element that contains an IGV is **necessary** for the website being an IGV.

C3 The website not having an IV or IGV is **necessary** and **sufficient** for the website being a noIV.

Since interactive visualizations are often implemented using JavaScript frameworks/libraries, the three conditions above can be more concretely phrased as:

C1.1 The website having IVs or IGVs as an external framework is **sufficient** for the website being an IV, but not sufficient for the website being an IGV.

C2.1 The website having IGVs as an external framework is **sufficient** for the website being an IGV.

C3.1 The website having no IV or IGV as an external framework is **necessary** for the website being a noIV.

The underlying assumption of C1.1, C2.1 and C3.1 is that developers of interactive (geo)visualizations on the Web follow the *law of parsimony*. That is, they do not include any library/framework in their code without a purposeful use, as advocated by software design principles such as YAGNI (You aren't gonna need it) (Jeffries, 2000). Additional non-sufficient and non-necessary conditions for being an IV include **C4**: the website having a title or description (in the header) that contains *phrases* that indicate it might be an IV; **C5**: the website having an HTML element with an *id* that indicates it might be an IV; **C6**: the website having an HTML element with a *class* that contains a phrase that indicates it is an IV. **C7**, **C8**, and **C9** use the same principle (sentence in the title/description, id and class as possible indicators) as non-sufficient and non-necessary conditions for being an IGV.

Table 1 shows phrases, id and classes identified during the manual inspection. Since this study is exploratory, the features only mirror the information available in the sample used and are by no means exhaustive. These identified features were used to implement a rule-based algorithm to classify the websites. The algorithm implements the decision tree in Figure 1 with reference to the conditions in Table 1. Since conditions C4 - C9 are neither sufficient nor necessary for the website to be an IV/IGV, we decided to declare a website as IV/IGV, if at least two of the three corresponding conditions are true.

From the algorithmic perspective, we formulated the problem as an information search within a web document, which is eventually accepted or not in one of the three categories, based on the pre-defined constraints it satisfies (Hills et al., 2015). A qualitative user study was then conducted with a two-fold objective: (i) collect classification data from the participants and use them to evaluate the decision tree; and (ii) learn about the features that could

Table 1. Examples of frameworks, phrases, ids and class names identified during the manual inspection of the 51 websites.

Cond.	*Type*	*Examples identified*
C1.1	framework; IV	highcharts, recharts, tableau, d3, apexcharts, chartkick, amcharts, dataviz
C2.1	framework; IGV	leaflet, cartodb, earth-js, earth.js, esri, mapboxgl, cartovista, strava, mangomap, amcharts, maptiler
C3.1	-	-
C4	phrases; IV	interactive, interactive visualisierung, Datenvisualisierung
C5	id; IV	apexcharts, highchart, viz, viz-client-container
C6	class; IV	apexcharts, tableau, highchart, recharts, VictoryContainer, rv-xy-plot, v-charts, map
C7	phrases; IGV	map, interactive, geovisualisierung, geovisualization
C8	id; IGV	map, globe, county-map, cartoVistaDiv, mapholder
C9	class; IGV	esri, esri-map, mapboxgl, cartoVista, leaflet

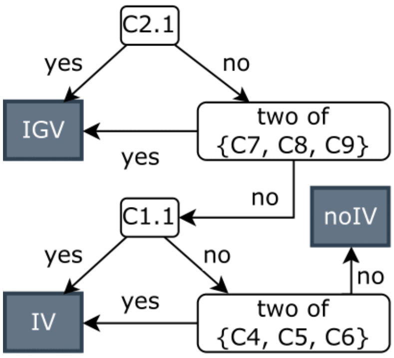

Figure 1. Decision tree of the rule-based algorithm used in the current prototype.

be relevant to an improved user experience. The qualitative study with eight participants (see details in Section 3) was designed so that each of the remaining 24 websites received two independent classification annotations. In a few instances, there was disagreement between the two annotators. To cope with this, a ninth participant was recruited to annotate the websites with conflicting annotations. The examples of IV, IGV and noIV used for the evaluation as well as the corresponding annotations are available in the supplementary material.

Table 2 presents the confusion matrices comparing three types of data: ground truth (classification made by the researchers), decision tree (classification made by the prototype), and participants (classification made by the users). There are a few observations. First, the participants' annotations were mostly accurate (96%), except for one instance, where they seem to have mistaken an animated visualization for an interactive visualization. This suggests that a crowd-sourcing approach to collect classification annotations for the research area of interactive (geo)visualization search would be useful. Still, care should be taken to train users to distinguish animation and interaction before starting the study. Second, using the annotations of users as a reference, the overall average classification accuracy of the rule-based approach was 63% (the sensitivity values per class were: IGV: 50%, IV: 56%, noIV: 86%). This indicates that the features extracted in Table 1 show promise, given the small number of instances examined (e.g. the classification accuracy for SVG-based visualizations over a sample of 40,000 instances was 86% in Battle et al. (2018)). Thus, these features can be used while training machine learning models for the classification task in subsequent work, in line with the idea of 'machines that learn from hints' (Abu-Mostafa, 1995). The accuracy and sensitivity values were computed using the R package caret (Kuhn, 2008).

Figure 2 shows a screenshot of the user interface used during the user study. The front end was implemented using Vue.js and Vuetify. The screenshots showing the previews of the geovisualizations were generated through the Python package html2image. For a couple of geovisualizations (around 3-5), the screenshots produced using html2image were not of good quality. Since the main purpose at this point was to evaluate the user interface, these were re-taken manually and incorporated into the prototype as an image. The descriptions of the geovisualizations were extracted programmatically from the metadata in the header of the HTML document. The prototype implemented a simple string matching to return relevant geovisualizations to a user query. The backend was implemented in Python and used several packages: lxml, requests, json, pandas, scrapy, slugify, and html2image.

3 Users' Wishes

As mentioned above, the second objective of the qualitative user study was to learn about the features that could contribute to an improved user experience during the design of search interfaces for online geovisualizations. To give some time to users to experience the interface, each participant was asked to run about three queries and classify the results. The results of the classification were already discussed above. The experimenter also gave them three questions to answer while interacting with the tool: 1) Write down max. two features of the prototype that you liked; 2) Write down max. two features of the prototype that you disliked; 3) Write down max. two features of the prototype that you missed. The participants' ages ranges from 23 to 55 (five men and three women). They were recruited via personal contacts. Six of them were students (three studying Geoinformatics) and the remaining two were employed at the time of the experiment.

Table 2. Confusion matrices for the classifications of the 24 websites used for evaluation. Left: participants vs automated decision tree; middle: ground truth from the researchers vs decision tree; right: ground truth vs classifications from the participants.

	Decision Tree		
Participants	noIV	IV	IGV
noIV	6	1	0
IV	3	5	1
IGV	4	0	4

	Decision Tree		
Ground Truth	noIV	IV	IGV
noIV	6	2	0
IV	3	4	1
IGV	4	0	4

	Participants		
Ground Truth	noIV	IV	IGV
noIV	7	1	0
IV	0	8	0
IGV	0	0	8

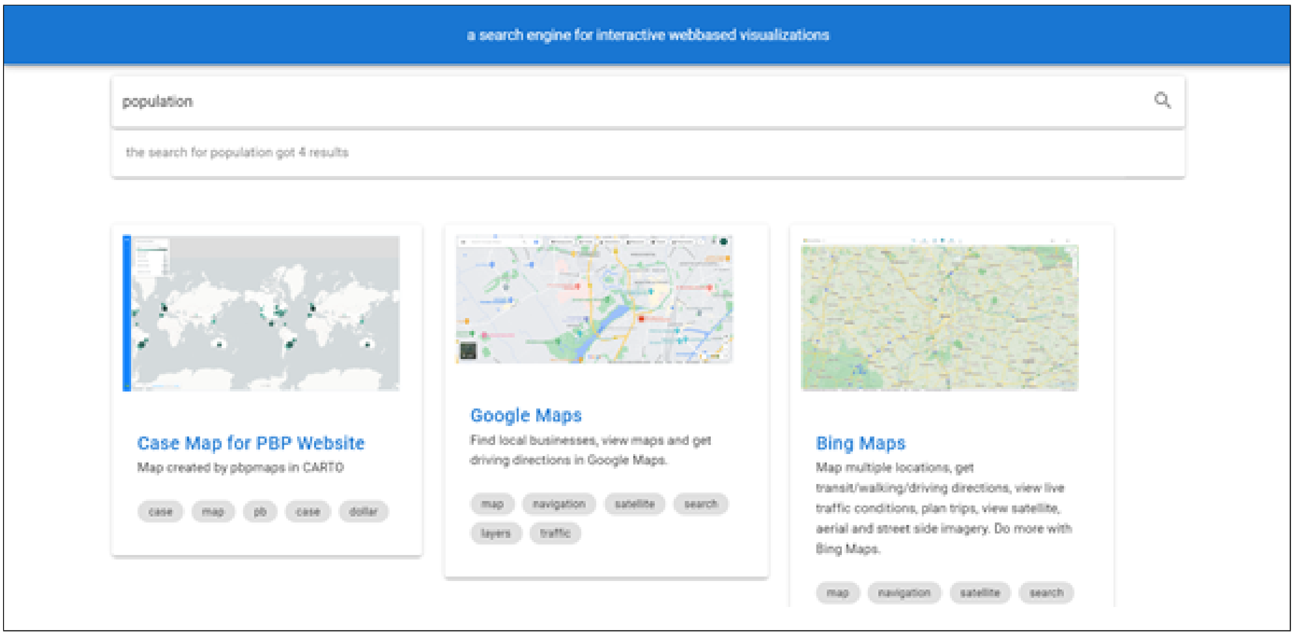

Figure 2. User interface of the prototypical search engine for interactive (geo) visualizations used in the user study.

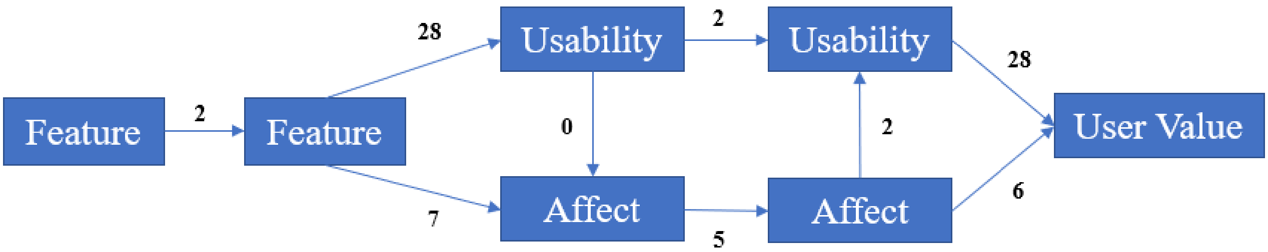

Figure 3. The Attribute-Consequence-Value model from (Reynolds and Gutman, 1988) adapted to the context of user interface analysis. A number next to an arrow indicates the frequency of the relationship in the qualitative feedback from the participants.

After the participants completed the search tasks and answered these questions, the experimenter conducted a short semi-structured interview according to the laddering method (Reynolds and Gutman, 1988), to find out the reasons for their answers. The laddering method is an interview technique that helps to discover the underlying reasons for people's views about a product or service, see Tomitsch et al. (2018), page 82. As mentioned in (Tomitsch et al., 2018), the peculiarity of the laddered interview is to apply predefined levels of abstraction when asking questions and coding the resulting data. The levels of abstraction are (i) features/attributes of the product or service, (ii) consequences of these features/attributes, and (iii) personal user values. The three questions asked during the interview were: a) What did you like about the features you named in 1), b) What didn't you like about the features you named in 2), and c) Why did you miss the features you named in 3). Hence, the laddered interviews were useful here to uncover both the wishes of the participants and reasons for these wishes. The experiment was approved by the institutional ethics board and pilot-tested with two participants.

The interviews (in German) of eight participants were fully transcribed and the coding was done according to the three levels of abstraction above. Since the laddering interview method originated from marketing research, a few adjustments were needed for our purposes. In particular, the model from Park et al. (2013) seemed particu-

Table 3. Features wished for by the participants, their potential consequences and the user values they point at. The diagrams showing the linkages between attributes, consequences and values for each participant are shown in the supplementary material.

Type	Users' wishes
Attributes	same size for preview grids; real-time preview of websites; same information shown for all websites; information about the kind of visualizations; keywords; information about the tools used to build the visualization; user-friendly design; tile-based results; summary of results; description of the possibilities of the search engine; example of successful query; no ads; background color; search suggestion; many results; trustworthy websites; limiting number of results; faceted navigation; user's native language; clear and concise; classification of visualizations; access to history of searches; suggestion of correct query if typing errors; easy usage; quick loading of preview images; side-by-side mode
Consequences	informativeness; accessibility; consistency; delicacy; user control; adaptability; helpfulness; error prevention; efficiency; simplicity; attractiveness; legibility/readability; effectiveness;
Values (Taxonomy 1)	customer need; customizability; self-satisfaction; pleasure; usefulness/utility; trustworthiness; expectation;
Values (Taxonomy 2)	convenience; curiosity; money; competence; intelligence; self-actualization; trust;

larly fitting. They proposed to view UX as composed of three components: usability, affect and user value. We hypothesised that given the focus of the investigation on the user interface, consequences of the presence/absence of features can be translated into usability and affect implications. These then could be linked to user value implications as shown in Figure 3. User value, in turn, is a subset of life values (see Park and Han (2013)) and has several sub-elements as discussed for example in (Boztepe, 2007; Park et al., 2013). The interview inputs were analysed using structural coding (i.e. apply conceptual phrases answering a research question to a segment of data, see Saldaña (2009)). The conceptual phrases to tag the interview segments were taken from Park et al's taxonomies of usability sub-elements (Park et al., 2013), affect sub-elements (Park et al., 2013), and user/life values (Park and Han, 2013; Park et al., 2013). As for the features, they came from the written input from the participants.

Table 3 presents the results. 28 features were mentioned in the qualitative feedback, which are related to 13 distinct usability and affect dimensions. While some comments touched on characteristics that apply to search engines more broadly (e.g. no ads, access to the history of searches), a few comments did touch on features that could be peculiar to search engines for online geovisualizations, in particular, those that touch upon how the results are visualized. Most notably, the participants gave some positive feedback about a tile-based design with some images that preview the returned visualization, but they wished for a) those tiles to be of the same size, b) the previews to be real-time; and c) some information about the type of visualizations returned as well as their provenance (Table 3). As for the values, two taxonomies were used to enable a comparative assessment: the taxonomy of user values from (Park et al., 2013) and the taxonomy of life values from (Park and Han, 2013). We learned from their use that the taxonomy by Park and Han (2013) is more adequate. For instance, the value 'customer need' of (Park et al., 2013) still needs a subdivision of categories in order to cope with the variety of user values relevant to the current context.

4 Conclusion and Future Work

Through a manual inspection of various websites and qualitative feedback from users, this work has learned about features for the classification of interactive (geo) visualizations, and features wished for by users regarding user interfaces for geovisualization search. We have outlined necessary and sufficient conditions for distinguishing interactive visualizations, interactive geovisualizations and websites, and compiled a list of features (i.e. frameworks, ids, and class names) relevant to the classification of existing websites into interactive visualizations and interactive geovisualizations. The evaluation of the rule-based algorithm implementing these features has shown that they hold promise. Besides, we have also collected some data about user interface (UI) features wished for by participants and their rationale. These UI features inform the requirements for the design of user-friendly interfaces for the search of interactive online geovisualizations.

Directions for future work include the harvesting, indexing and classification of web-based interactive geovisualizations at Web scale, as well as improving the current user interface for a large-scale user study. In particular, the next version of the prototype will use the classification features identified in the current work as input for a classification model for interactive geovisualizations on the Web. Here, the rule-based approach will be used as a baseline to compare the performance of more sophisticated machine learning models. From the user's point of view, the design of relevance-ranking strategies for interactive geovisualizations also presents interesting opportunities for future work. Ultimately, the search engine for interactive geovisualizations will break through the walls of specific galleries and portals (e.g. ESRI Map Gallery, the Observable platform, Tableau Public) to offer GIScience researchers a single point of access to interactive geovisualizations in their field, in a similar spirit to past/ongoing initiatives aiming at providing one-stop shops for research products in GIScience (Keßler et al., 2012) and in the Earth System Sciences (NFDI4Earth, Bernard et al. (2021)).

Data and Software Availability

The source code of the prototype can be found on GitHub (https://github.com/phuef/ba). The results of the qualitative analysis are available as supplementary material (https://doi.org/10.6084/m9.figshare.21362994).

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