

Visualizing the Results of Interactive Queries for Geographic Data on Mobile Devices

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ABSTRACT

The capabilities of current mobile computing devices such as PDAs and mobile phones are making it possible to design and develop mobile GIS applications that provide users with geographic data management and cartographic presentations in the field. However, research on how to properly support users who interact with geographic data on mobile devices is still lacking. In this paper, we present an approach to geographic data analysis that allows users to exploit interactive dynamic queries as a technique for filtering geographic information. Moreover, the proposed approach displays the results of queries through visualizations that are aimed at facing the screen estate problem typical of mobile devices. We will show how this approach can be applied to different domains by illustrating two examples of its application: (i) a decision support tool that allows tourists to search for points of interest (e.g., hotels, restaurants,...) that best satisfy their preferences and (ii) a tool allowing users to retrieve information about soil properties in a geographic area to meet a number of user's constraints.

Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces—*graphical user interfaces, interaction styles, screen design*

General Terms

Human Factors, Design

Keywords

Dynamic queries, visualization, mobile devices, GIS

1. INTRODUCTION

The continuous evolution of mobile computing devices offers new possibilities and opportunities in those domains

where geographic data plays an important role, such as cartography, tourism, soil science, natural resources management, emergencies management, etc. Indeed, mobile devices such as PDAs and high-end mobile phones can assist mobile users by providing access to up-to-date spatial (and non-spatial) information, anytime, anywhere, in an individual, dynamic and flexible way. Since published estimates suggest that up to 85% of all information has a spatial component [21], the opportunities to gain useful knowledge from geographic data through mobile devices in the field are significant. However, effective visualizations are needed to ensure that users easily access and understand the relevant information for their tasks. How to effectively visualize spatial and corresponding non-spatial information on mobile devices is thus a key research topic. A related and equally important topic concerns interactive techniques for exploratory geographic data analysis. Indeed, besides providing effective visualizations, users must be given proper tools for interacting with geographic data to easily generate valuable knowledge and support their decisions. Typical interactions supported by current applications for managing geographic data are represented by panning and zooming operations on maps, information retrieval about points on maps (e.g., address,...), search of points of interest (POIs) (typically by name, address, etc.), path planning, distance measurements, annotations. However, providing users with advanced tools that allow them to interact with geographic data and analyze it on mobile devices is still an open research topic.

When dealing with geographic data on mobile devices, device limitations pose constraints on the design and development of proper visualization and interaction solutions. Indeed, techniques and practices that are effective in the desktop scenario cannot be simply adapted to the mobile scenario but must be refactored to achieve usability and performance goals on such equipment. Moreover, novel solutions are often needed to obtain better results.

Geovisualisation on mobile devices is heavily affected by size constraints of small displays. For example, viewing a large area in its entirety on a small display may provide only an overview of the area without sufficient detail, while a zoomed-in view provides more detail, but only of a limited subset of the area. Panning and zooming can thus quickly become cognitively complex, disorienting and tedious. While screen size represents their main limitation, mobile devices are also hindered by limited CPU power, limited storage capabilities, reduced battery life, limited bandwidth of the available wireless networks.

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Moreover, application programming interfaces (APIs) for mobile devices are poorer than their desktop counterparts and limit the possible design solutions.

In this paper, we present an approach to geographic data analysis on mobile devices that allows users to exploit interactive dynamic queries as a technique for filtering information. The approach is based on providing users with an effective interface for specifying queries and on visualization techniques that are aimed at facing the screen estate problem typical of mobile devices. We will show how this approach can be applied to different domains by illustrating two examples of its application: (i) a decision support tool that allows tourists to search for POIs (e.g., hotels, restaurants,...) that best satisfy their preferences and (ii) a tool allowing users to retrieve information about soil chemical properties in a geographic area to meet a number of user's constraints.

The paper is organized as follows. Section 2 surveys related work on the visualization of geographic data on mobile devices. Section 3 presents our approach to geographic data analysis on mobile devices (in particular, PDAs), describing requirements and challenges and how we dealt with them. In Section 4, we describe the application of the approach to two different domains (tourism and soil science). Section 5 presents conclusions and future work.

2. RELATED WORK

In the latest years, research on employing geographic data on mobile devices has received a substantial boost, due to the growing availability and increasing power of PDAs and cellular phones. First attempts at adapting some GIS functionalities to the mobile context are being carried out by major GIS companies, such as ESRI and Trimble, and open standards such as Geography Markup Language (GML) [2] and Scalable Vector Graphics (SVG) [3] are considering representation, transmission and visualization of geographic data on mobile devices.

A considerable part of research to date has focused on the development of tourist-oriented context-dependent systems (e.g., [27, 33]), that exploit information such as user position, current time and place, task at hand, to provide tourists with the most useful data and services for a given situation. Examples of such systems, commonly known as *mobile tourist guides*, are Cyberguide [4], GUIDE [14], CRUMPET [23], and Lol@ [18]. An analysis of the main features of mobile guides is provided by Baus et al. [10]. The visualization of geographic information in mobile guides is usually limited to raster maps with superimposed information, such as paths or POIs, while the possibility of interaction is usually limited to panning, zooming, search and selection operations. In the Lol@ project [18], the map has been optimised for the display size of a Smartphone and has a slight skew that, together with the stylized representation of important POIs, gives a perspective spatial effect. In the GiMoDig project [22], alternative map designs are examined and guidelines elaborated.

Other researchers have specifically focused on the visualization of maps on mobile devices. Chalmers et al. [13] have studied the adaptation of the content of maps to different bandwidths. Reichenbacher [26] focuses on the adaptive and dynamic generation of SVG-based maps for mobile users, describing the personalization of the presentation according to the current user, context

and device. Zipf [32] offers a first overview of the design steps involved in adaptive map generation and gives some examples of map adaptation: culture-specific map colouring, map generalization, user oriented-maps, and focus maps. Focus maps [34] are of special interest on small displays. The basic idea is to move the most relevant spatial information in focus, showing it in full detail, while displaying the other contextual information with less detail. Fisheye views of city maps have been studied in the MoVi project [25]. The city map has a regular scale in the focus area (generally in the middle of the map) and is distorted in the other parts of the map, represented at smaller scales. The generation of variable-scale maps has also been demonstrated by Harrie et al. [20]. A discussion on the design and use of map representations on mobile devices is presented by Dillemath [15].

Some research results on map generalization can be used to deal with the problem of visualization on small displays. Shape simplification in map representations is typically employed for two reasons: abstracting irrelevant details to reduce the cognitive effort of the user, and simplifying the process of creating a lower scale map from a detailed one. Agrawala and Stolte [5] developed some techniques for the generalization of cartographic data that allow one to improve the usability of maps for road navigation on mobile devices. Strategies for real-time generalization in mobile applications are also presented by Sester and Brenner [28] and Hampe et al. [19].

In spite of these recent achievements, there is still little research on advanced tools and visualizations that allow users to analyze geographic data in the field for decision support purposes. A possible approach to exploratory analysis of geographic data on mobile devices could be inspired by *dynamic queries* [9][29]. Dynamic queries are typically used in desktop scenarios to explore large datasets, providing users with a fast and easy-to-use method to specify queries and visually analyze their results. The basic idea of dynamic queries is to combine input widgets (called "query devices" [8]), such as rangesliders, alphasliders [6], check buttons and radio buttons, with graphical representations of the results, such as maps, scatterplots [7] or other visual displays. By directly manipulating query devices, users can specify the desired values for the attributes of elements in the dataset and can easily explore different subsets of the data. Visual results must be rapidly updated to enable users to quickly learn interesting properties of the dataset. Dynamic queries have been successfully employed in domains such as real estate [31] and tourism [16] and, as shown by user studies [9][31], are a more usable and powerful technique than lists, form filling, or natural language systems, to perform queries.

3. THE PROPOSED APPROACH

Geographic data are extraordinarily rich with respect to the number and types of attributes that can be associated with geographic locations, particularly when diverse datasets concerning the same location are integrated. Providing users with effective tools for exploring such an information space is challenging. Moreover, the development of mobile GIS applications must face both technical and usability issues with respect to desktop applications due to mobile devices limitations.

To face these issues, we propose an approach that

combines dynamic queries with specific visualizations of query results, in a flexible and informative interface that aims at facing the screen estate problem typical of mobile devices. By using dynamic queries, this approach allows users to specify queries incrementally (through query devices) by interactively imposing constraints on the attributes of the elements in the considered dataset and immediately see the effects of their actions on a map of the considered geographic area. Users are thus in full control of the system and can flexibly explore and analyze the solution space because they can iteratively re-sequence previous steps based on the knowledge sought and the nature of the information learned in the process. However, implementing this approach on a mobile device is difficult because:

1. The standard behavior of dynamic query systems is to filter out those solutions that do not satisfy all specified constraints. However, to perform an exploratory analysis of a geographic dataset we need a visualization technique that is able to display partially satisfied results so that users can easily make comparisons among all elements.
2. Results must be visualized as the user manipulates query devices so that effects can be seen in real-time. Since screen size is limited and users must be able to easily set various constraints on different attributes, a specific solution is needed.
3. Users must be able to quickly detect interesting attribute values associated with the elements under examination while performing queries. Limited screen size forces to come up with proper solutions.

The following sections discuss how we dealt with these issues. Section 3.1 will present our solution for the visualization of query results, while section 3.2 will deal with the other issues by describing in detail how the proposed interface allows users to specify queries.

3.1 Visualizing Query Results

The most common approach in visualizing the results of dynamic queries is to display all and only the elements that satisfy the query. However, this approach is not always adequate for exploratory analysis of geographic data because, as pointed out by Spence [30], only those objects whose attribute values satisfy all users' constraints are displayed. It is thus impossible to have a global view that shows also partially satisfied results, and to see how changing a query affects them. In particular, elements whose attributes fail to satisfy only a few constraints (e.g., only one) would be especially worthy of more detailed consideration. Moreover, when an empty result is obtained, the user has to backtrack without knowing how to find elements that are closest to the originally derived ones.

We thus employ a visualization technique that helps users maintain contextual information on the whole dataset they are exploring. In our approach, an element in the explored dataset is represented by an icon that is superimposed on a map of the geographic area, and is augmented by a vertical bar representing how much the element satisfies users' queries¹ (see Fig. 1).

¹It must be noted that vertical bars can be also associated to whole geographic areas (such as regions, districts, parcels, etc.) without employing icons.

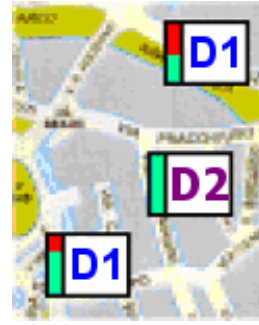


Figure 1: An element in the dataset is displayed as an icon. The icon identifies the dataset and is augmented by a vertical bar showing how much the element satisfies users' queries.

This technique is an evolution of an idea presented by Fishkin and Stone [17] who introduced the concept of “real-valued queries” by assigning a real-valued score in the $[0,1]$ range to each element in a dataset, based on the value of a specific attribute and on the particular scoring function that is being used. The score is visually presented by showing each element as a partially filled-in bar: the higher the score, the more the bar is filled. Instead of visually displaying a score dependent on the value of an attribute, we display a score dependent on the number of constraints satisfied by an element. We then fill the bar associated with each element with a green² area whose size is proportional to the number of satisfied constraints, while the remaining area gets filled in red. This way, users can visually compare how much different elements satisfy the specified set of constraints, obtaining a deeper understanding of the visualized dataset. Combining this visualization technique with dynamic queries, users can visually perceive the result of their queries by observing changes in the color-filled areas of the bars.

3.2 Specifying Queries through the Interface

In the interface we propose, most of the screen is devoted to show a map of the geographic area under examination (see Fig. 2). The map can be easily panned by dragging the pen on the screen in the desired direction and zoomed using the specific icons in the toolbar at the bottom of the screen.

To specify a query, users have first to load the dataset they want to explore. Different datasets can be loaded at the same time by checking the proper options in the form that appears by tapping on the item “Data” in the menu bar. Each dataset represents a different layer of information that can be displayed on the map and is identified by an icon that will be used in the map to display related elements. Once the form is closed, the icons identifying the selected datasets appear in the toolbar in the lower part of the screen and the map is populated with all the elements in those datasets. In this way, users can choose which dataset to activate, and all activated datasets are merged in the displayed map. When more than one dataset is loaded, users can separately specify queries on each dataset. This allows users to visually analyze and correlate different datasets.

²In the greyscale printed version of this paper, wherever colours are mentioned in the text, light grey in the figures corresponds to green, dark grey to red, black to blue.

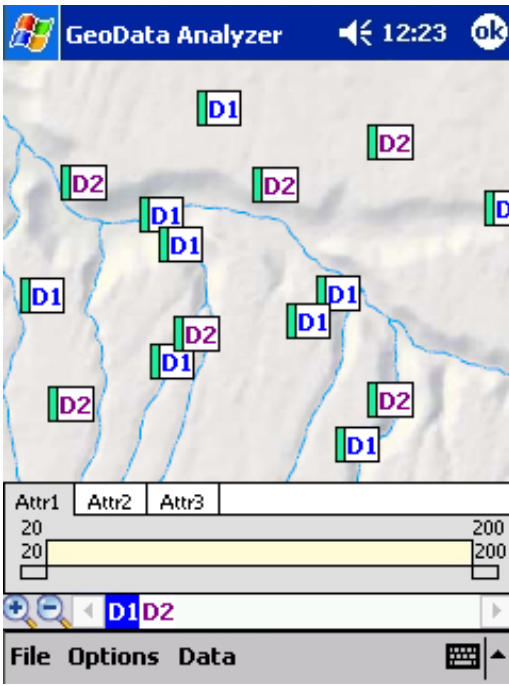


Figure 2: The map displays all elements of the datasets that have been selected by the user. A tabbed panel contains all query devices related to the currently selected dataset, which is identified by the highlighted icon in the toolbar at the bottom of the screen.

By tapping on a dataset icon in the toolbar, the user can specify constraints on the attributes of the dataset elements using the set of query devices that appears. Query devices are organized in a tabbed interface placed above the toolbar, where each tab allows users to specify values for a single attribute of the considered elements. Figure 2 shows an example where the user has selected the dataset “D1” (see the highlighted icon in the toolbar) and can specify preferences for the attributes “Attr1”, “Attr2” and “Attr3” by accessing the corresponding tabs. This layout gives users the flexibility to specify their constraints in any order while visualizing results at the same time, thus simplifying the exploratory analysis of the datasets.

Various query devices are commonly used in dynamic query systems to specify queries. In our approach, we implemented three types of query devices that can be used to deal with different classes of attributes. The first device is the classic rangeslider, usually associated with continuous attributes (e.g., price, time, ...): the user acts on two independent handles to change the range of values of the related attribute. Figure 3 shows an example of this query device where the user has specified a range between 40 and 80 for the “Attr1” attribute. The selected range is highlighted by using color and by showing the numeric value of the bounds.

The second query device (Fig. 4) is a modification of the rangeslider that can be used to deal with ordinal values (e.g., the number of stars of a hotel). Users operate this query device as the classic rangeslider but its behavior is slightly different: when the user stops dragging on one of the

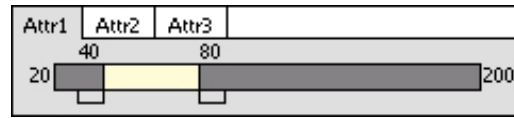


Figure 3: Query device for continuous attributes.

two handles, the handle is automatically positioned at the nearest lower limit (for the lower handle) or at the nearest upper limit (for the upper handle).

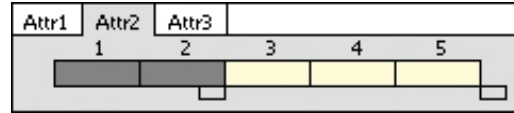


Figure 4: Query device for ordinal attributes.

The third query device is based on checkboxes and can be used for boolean vector attributes (e.g., types of services offered by a hotel). An example can be seen in Fig. 5: an element satisfies the “Attr3” constraint if all the checked values (e.g., “Value2” and “Value6”) are true for it.

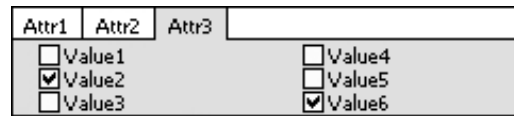


Figure 5: The query device related to boolean vector attributes.

To allow users to quickly look at detailed attribute values while performing queries, the system provides a details-on-demand functionality: at any time, the user can tap on any element on the map to obtain further information about it. As shown in Fig. 6, the tapped icon on the map is highlighted and details are shown in the tabbed interface. In particular, a color coded line in the upper area of each tab tells if the element satisfies (green line) or not (red line) the related constraint. In this way, a user can learn at-a-glance which constraints are satisfied (and which ones are not), without having to examine the details. Moreover, attribute values for the selected element are visualized in the query devices by using a blue (the same color as the highlighted element) horizontal bar inside sliders and by displaying blue boxes beside checkboxes. For example, in Fig. 6, the horizontal bar inside the query device shows the range of values for the “Attr1” attribute of the selected element, while, in Fig. 7, blue boxes highlight that “Value1”, “Value2”, “Value3” and “Value4” are true values for the “Attr3” attribute of the selected element. This details-on-demand functionality aims at making the system easier to use by providing rapid access to information which is usually more difficult to obtain in traditional systems and that can be used as a guide for modifying a query. The tab named “Info” can be used to display additional information (e.g., name, coordinates, ...) about the selected element.

4. APPLYING THE APPROACH

The approach we propose can be easily applied in different domains. Indeed, since query devices are automatically

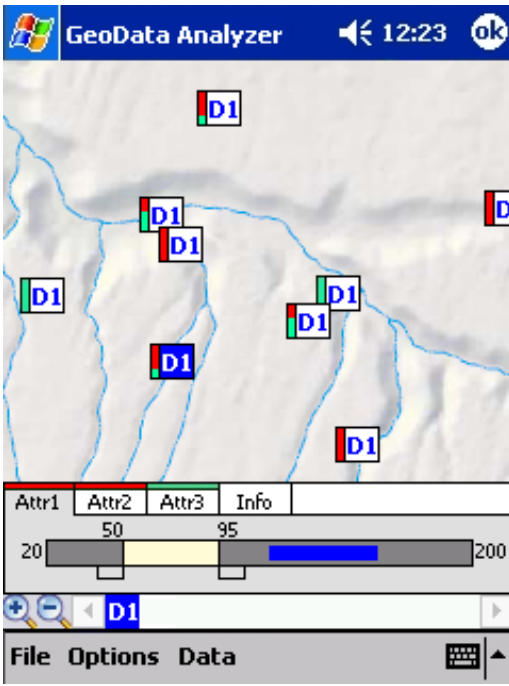


Figure 6: The screen after the selection of an element on the map. As shown by the color-coded lines on each tab, the constraints on “Attr1” and “Attr2” are not satisfied. A blue horizontal bar inside the “Attr1” query device shows the range of values for this attribute for the selected element.

Attr1	Attr2	Attr3	Info
<input type="checkbox"/> Value1	<input type="checkbox"/> Value2	<input checked="" type="checkbox"/> Value3	<input checked="" type="checkbox"/> Value4
<input checked="" type="checkbox"/> Value1	<input checked="" type="checkbox"/> Value2	<input checked="" type="checkbox"/> Value3	<input type="checkbox"/> Value4
<input checked="" type="checkbox"/> Value1	<input checked="" type="checkbox"/> Value2	<input checked="" type="checkbox"/> Value3	<input type="checkbox"/> Value4
<input checked="" type="checkbox"/> Value1	<input checked="" type="checkbox"/> Value2	<input checked="" type="checkbox"/> Value3	<input type="checkbox"/> Value4

Figure 7: Blue boxes highlight true values for the “Attr3” attribute of the selected element in the map.

generated by the system according to the attributes (in particular, their type and range of values) of the elements in a dataset, it is sufficient to load specific datasets and their corresponding geographic maps and identifying icons to obtain different applications. To demonstrate this flexibility, we show in the following how we have applied the approach in two different domains that involve geographic data: tourism and soil science.

4.1 Preference-based Search for Tourists

In the tourist domain, we used our approach to develop a Preference-Based Search Tool (PBST), which is a decision support system that helps users in finding the outcomes (e.g., multi-attribute products or services) that best satisfy their needs and preferences. Examples of this class of tourist applications for mobile devices are the Michelin Guide for PDAs [1] and CityGuide [16]. The Michelin Guide for PDAs is a commercial application that allows users to search for hotels or restaurants in a specific city by entering their preferences through drop-down lists and checkboxes. Results are then visualized as a ranked list ordered by

quality (number of stars). CityGuide is an application that allows users to browse an extensive restaurant guide of the city of Glasgow by specifying preferred price and quality. The result of a query is immediately displayed on the map as a set of icons displaying the position of restaurants that satisfy users’ preferences.

Our PBST is specifically aimed at filtering the amount of information about different categories of POIs (e.g., hotels, restaurants, pubs, museums, parks, etc.) in a geographic area, supporting users in the search of the most suitable solution to their needs (e.g., a POI or combination of POIs satisfying a set of preferences). In this case, each layer corresponds to a POI category and users are thus able to specify separate queries for each category. It is also easy to associate the attributes of elements to each type of query device. For example, we can associate the “Price”, “Quality” and “Services” attributes of the “Hotel” category respectively to the continuous range slider, discrete range slider and checkboxes query device.

By applying our approach to this domain we are able to satisfy requirements for decision search tools and their interfaces [24]. In particular, it is possible for users to specify their preferences incrementally (that is, without being forced to specify all preferences initially and then examining the results); users are able to specify their preferences in any order; the decision tool displays partially satisfied results and helps users in decision tradeoff analysis; domain knowledge is revealed whenever possible.

We carried out a preliminary usability evaluation of the application to point out problems with the interface and obtain information to plan possible improvements. Results show that most system features received high ratings and positive comments from users. Details on the evaluation have been reported in [12].

Figure 8 illustrates a session with the system, where the user is visiting a city for a two-day conference and needs to find a hotel to stay overnight. After selecting hotels as the category of POIs to be displayed, she sets her preferred price range (40-80 Euro) using a continuous range slider (Fig. 8a). She then sets the Quality constraint (asking for at least a three-stars hotel) using a discrete range slider (Fig. 8b) and the Services constraint (she wants air conditioning and prefers to pay with her credit card) using checkboxes (Fig. 8c). Then, she looks at the visualization, singles out a hotel satisfying all the specified constraints and taps it on the map to check its attributes (see Fig. 8d) and then obtain contact information through the Info tab. She also checks the hotel that is nearest to the conference venue to know why it does not satisfy all her constraints and she immediately notices (by looking at the colored lines on the tabs) that it does not satisfy the Price and the Services constraints (Fig. 8e). In particular, the price range is too high for her. Then, she wants to find a restaurant near the chosen hotel. She thus selects the restaurant category and defines the constraints (she wants a restaurant that is open on Tuesday and does not cost too much, see Fig. 8f - 8h). Looking at the only two restaurants satisfying all the constraints she sees that they are far from her hotel (Fig. 8i). She then looks at partially satisfied results near her hotel and finds one that satisfies all constraints but “Type” (Fig. 8j). This seems to be a good tradeoff for her needs and she proceeds getting contact information through the “Info” tab.

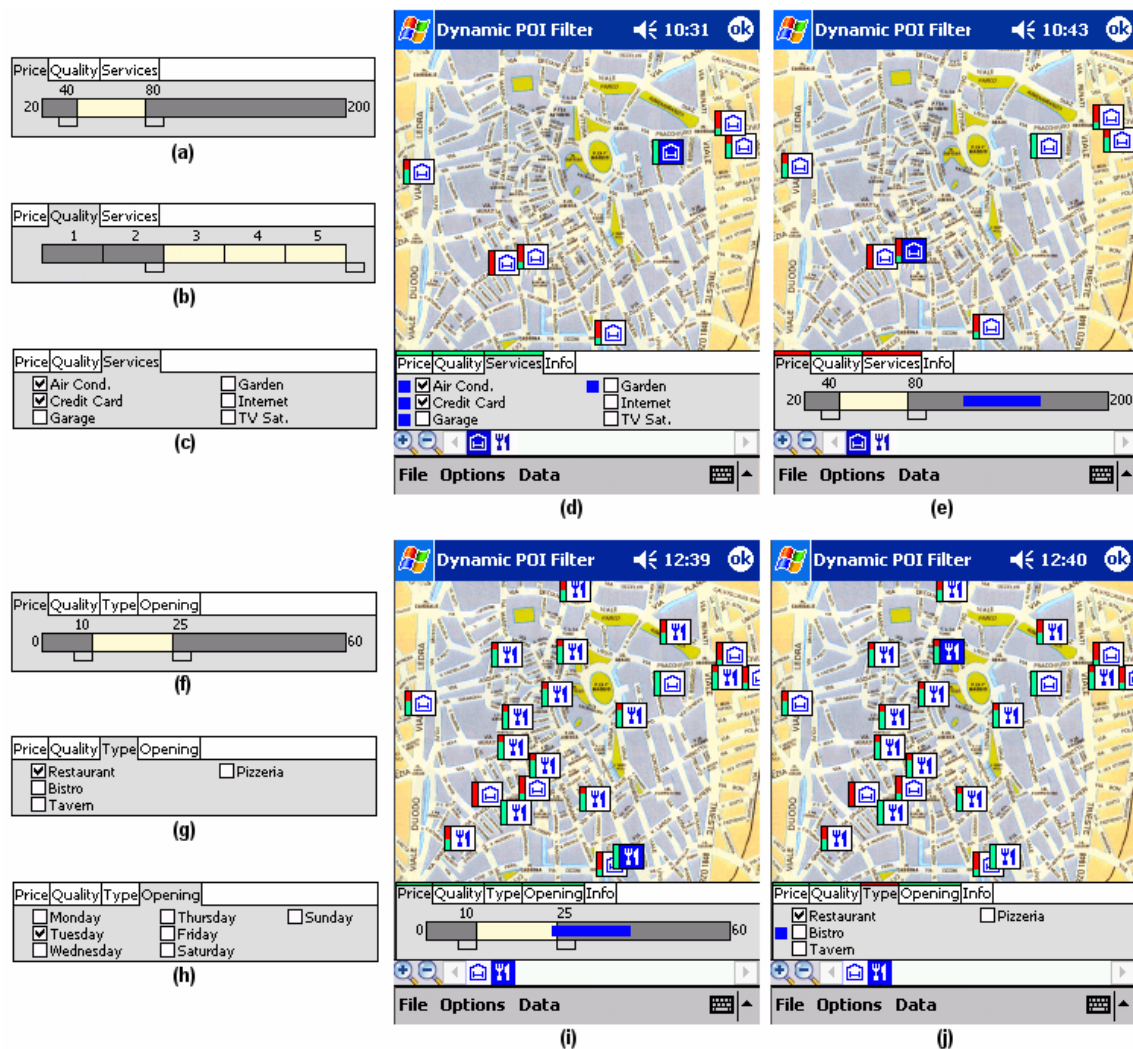


Figure 8: Example: (a-b-c-d-e) finding a hotel, (f-g-h-i-j) finding the most suitable restaurant near the chosen hotel.

4.2 Exploratory Analysis of Soil Chemical Properties

In this section, we examine the application of our approach to a very different domain, i.e. soil science. In particular, we show how it can be used to analyze a dataset concerning soil chemical properties in a geographic area.

Each element in the considered dataset is a geo-referenced probe of the soil, performed to obtain data about soil pH, salinity and cation-exchange capacity (CEC)³. Soil pH is the single most important aspect of soil chemistry and is a measure of alkalinity and acidity [11]. The pH scale runs from 0 to 14. Seven is neutral, 0 is the most highly acidic value and 14 is the most alkaline, or basic, value. Salinity is a measure of the electrical conductivity of a soil, which is dependent on the levels of salt [11]. CEC is the ability of a soil to retain cation nutrients and prevent nutrient leaching [11].

³For simplicity, we limit this example to these three fundamental properties.

Each of the three properties is associated to a continuous range slider, since they are continuous attributes. By manipulating the sliders and looking at the results on the map of the considered geographic area, users are able to dynamically explore the dataset and identify patterns, outliers and clusters in the data. For example, by knowing the correlation between soil chemical properties and vegetation it is possible to identify what probed areas are the most suitable for different plant species. Indeed, most plants grow best in the pH range of 6.5 to 7.0, but the so-called acid-loving plants prefer lower pH, in the range of 4.0 to 6.0. Under 4.0, few plants are able to survive. Figure 9 shows a possible scenario. In this example, a 50-300 interval has been specified for the CEC property (these are typical CEC values for an organic soil type), a 5.5-7.5 interval for the pH property (optimal pH values for plant growth) and a 0-4 interval for the Salinity property (values above 4 may restrict growth of many plants). As shown by the visualization, areas on the left are more suitable for vegetation compared with areas on the right.

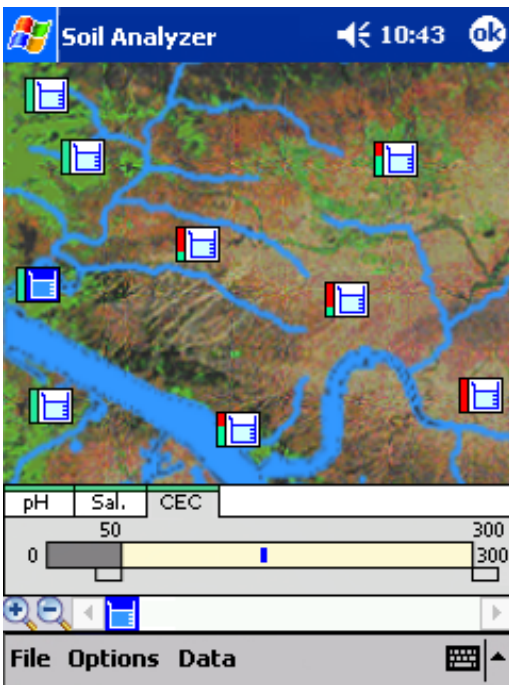


Figure 9: Analyzing correlations between soil chemical properties and vegetation.

5. CONCLUSIONS AND FUTURE WORK

In recent years, research on visualization and interaction techniques for mobile GIS applications has been very limited, with the exception of a few attempts to design suitable map representations aimed at solving the screen real estate problem typical of mobile devices. In particular, flexible applications that allow users to perform analysis of geographic data are still lacking. This paper described an approach to geographic data analysis that allows users to exploit dynamic queries as a technique for interactively exploring geographic information. Query results are displayed by means of a visualization that aims at providing users with a more comprehensive view of the explored dataset. Limitations of the mobile device, in particular the reduced display area, are faced by adopting solutions such as tabbed organization, tailored versions of standard query devices, details-on-demand functionality.

To demonstrate the flexibility of the approach we have shown two different applications (tourism and soil science), aimed at supporting very different activities in the field.

We plan to apply the approach in additional domains to gather feedback for refining the solution. We will also explore alternative visualization techniques so that users can choose the ones that best suit their needs. Another research direction concerns the “out-of-view data” problem: due to the limited screen space of mobile devices, some query results may end up off-screen and unnoticed. A proper solution is thus needed to highlight the presence and position of out-of-screen elements.

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