A User Study of Visual Linked Data Query and Exploration in Mobile Devices

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Abstract. This paper describes the iterative development and evaluation of high usability mobile user interface elements for query and exploration of geographical Linked Data. It includes an analysis and synthesis of the current state of the art in geographical Linked Data visualization and industry design guidelines for mobile device user interfaces. It addresses the lack of published research on mobile Linked Data application usability or user experience. The usability studies described here compare the usability of custom mobile Linked Data query and exploration interfaces to standard geographical Linked Data interfaces available on fixed platforms. Evidence was collected that suggests that despite the limitations of a mobile interface for complex tasks, such as Linked Data query and exploration, it is possible to attain equivalent usability on mobile devices to fixed platforms. The importance of visual feedback for users was demonstrated when designing for the limited screen area of mobile devices. The user study provides evidence that task-oriented HCI elements or controls are more important for usability than dataset explanation or visualization. The limited screen area of mobile devices often necessitates multi-screen task dialogs. This study provides evidence that minimizing the memory requirements for the user for multi-screen tasks, in terms of visual clues of state in subsequent screens or even animated transitions between screens, produces a better user experience. The prototype mobile application developed as part of this user study delivers highly usable Linked Data geographical dataset exploration and query that compares favourably to state of the art fixed platform geographical tools. The paper also presents a unified analysis of industrial mobile HCI best practice and state of the art Linked Data visualization application requirements that will act as guidelines for future mobile Linked Data application development. The user study provides a case study on how to design mobile Linked Data interfaces for specialized data sets with known use cases.

Keywords: Visualisation, Mobile,

1. Introduction

Linked Data has already demonstrated widespread success as data publication mechanism, especially for specialised interest groups of domain experts supported by knowledge engineers. Nonetheless it must still compete with both traditional and emerging web or enterprise technologies for acceptance as a mainstream data infrastructure. Reaching out to end-users with intuitive, attractive and usable applications based on Linked Data is necessary to convince a new wave of domain expert decision-makers and the wider public of non-technical users that Linked Data is an effective deployment option.

Despite the rich potential of structured semantic data as a basis for applications, and especially information visualisations that provide appropriate context drawn from the web of data and intuitive, yet powerful means to analyse complex data and situations, the Linked Data research community has tended to focus on the back-end infrastructural issues or applications that target the user group that it understands best – knowledge engineers with a technical appreciation of the underlying logic and structure of semantic data. When demonstrated to a non-technical audience these applications are often confusing and of limited appeal. A key element for widespread adoption and consumption of Linked Data is interaction paradigms that allow users to interact with the data in familiar contexts, such as geographical visualisations, with interaction designs that abstract away from the underlying RDF and SPARQL technologies while emphasizing quality of user experience and delivering this on modern mobile platforms, that users have come to expect and rely upon.

This creates many challenges for researchers: understanding best practice for information visualisation of Linked Data, knowledge of the state of the art in interaction design, the resource and interaction constraints of mobile devices, use of specialised mobile platform APIs, identification and recruitment of appropriate user groups, methodologies for user studies and development of appropriate human-computer interface elements that can harness the power of a web of interlinked data while not overloading a non-technical user with underlying details that confuse and obfuscate the application.

In this paper we describe a set of experiments conducted to develop and evaluate high usability mobile user interface elements for query and exploration of geographical Linked Data. Here we define geographical Linked Data as any data-set that contains sufficient properties to be effectively located on a global map in terms of global latitude and longitude. Due to the interlinked nature of Linked Data datasets this may include automated enrichment of an original dataset with appropriate properties from another linked dataset. Our use case is founded on a specific dataset, the US Political Violence dataset [1]that catalogues episodes of fatal political violence in the US from 1780 to 2010. The target audience for the visual dataset browsing and query application (PVGeoVisualisation) was social sciences researchers working with the dataset to enrich the dataset and to answer queries about the topic domain. In addition it is hoped that interested members of the public could use this interface to access and explore the dataset.

The fundamental research question to be investigated in this work was: By what mechanisms and to what extent can mobile applications achieve equivalent usability to existing desktop applications when visualising Linked Data geographical information? Usability is defined here as the attribute of measuring how easy it is to use and learn something based on the definition of Nielsen [32].

To answer this question it was first necessary to survey the state of the art for best practices in visualisation techniques for mobile devices and visualisation of both Linked Data and geographical information. This enabled us to develop a set of generic requirements for mobile Linked Data visualisation applications [Table 2] which were analysed along with the specific requirements of our PVGeoVisualisation application derived from our use case. Then we designed the application architecture, browsing and query interactions for geographical information Linked Data, focusing on the usability and the user experience on mobile devices. A PVGeoVisualisation prototype was developed and evaluated iteratively through a series of user trials. Finally the prototype was compared through a usability study to a desktop counterpart based on the published Map4RDF system [27].

The rest of this paper is structured as follows: Section 2 describes the motivating use case for this work where social sciences researchers with no knowledge of SPARQL wish to use complex queries over a Linked Data dataset from a mobile app. Section 3 identifies requirements by surveying the state of the art in Linked Data visualisation and mobile UI best practice. Section 4 describes the development process and methodology applied to PVGeoVisualisation. Section 5 describes our final evaluation user study comparing the usability of the mobile and desktop visualisation applications. Finally section 6 discusses our conclusions and identifies some directions for future work.

2. Use Case

The US Political Violence (USPV) data-set is a Linked Data data-set describing fatal political violence events such as riots and lynching in the United States between 1780 and 2010. It was originally manually assembled by social science researchers to assist with analysis of the structural dynamics of the US during this period. In 2013 it was converted to a RDFS-based Linked Data representation by the Knowledge and Data Engineering Group at Trinity College Dublin. In addition to vocabulary design and uplift to RDF this involved the creation of interlinks to the DBpedia dataset. It contains RDF descriptions of 1810 historical events in approximately 15,000 triples.

[1] http://dacura.cs.tcd.ie/pv/

Figure 1: Original USPV Event Heat map Visualisation

The USPV was published as Linked Data using Fuseki with a SPARQL endpoint and direct data access. In addition a basic website was created that included HTMLbrowsing of the data via Pubby, a simple form-based query and tabular browsing interface built on SPARQL queries and two simple data visualisations – an event timeline and a configurable heatmap of event counts and locations based on a SVG map of the US (fig. 1). For the current work it was decided to enhance the data visualisation and visual query interface by moving to a mobile device with haptic controls that could facilitate a richer, more engaging experience for non-knowledge engineers interacting with and querying the dataset. This is despite the challenge that quite rich queries are often desired by social science researchers to explore the data. This new application was named PVGeoVisualisation. The use case requirements for PVGeoVisualisation were defined that users of the application should be able to:

- U1. Browse the USPV data set by using an interactive map
- U2. Inspect individual USPV events and be able to access the details of the event without requiring knowledge of RDF
- U3. Find one more events by defining a limit for USPV event properties such as the category or the date
- U4. Filter USPV events without requiring knowledge of SPARQL

Exactly how these requirements could best be achieved in a mobile Linked Data application needed an investigation of existing approaches, technologies and best practice design guidelines. These are discussed in the next section.

3. Related Work

This section introduces information visualisation, along with the main challenges when consuming Linked Data on mobile through different visualisation techniques. The requirements for Linked Data visualisation will be presented and a set of criteria will be established that will be used to evaluate previous mobile Linked Data applications.

3.1. Information Visualisation Design Factors

Information visualisation is the process of understanding data that has been represented graphically in a way that is more meaningful and easier to grasp by humans. This is distinct from information presentation, which is the illustration or representation of information without any application or transformation to ease its understanding to the user [30, 15, 12, 14].

Information visualisation eases data processing by offloading the effort required to create a model of the information onto an external representation, and by taking advantage of the perceptive power of human vision. Thus the presented information can be understood by a person much more efficiently. This reduction in the cognitive load is achieved by reducing the effort in finding information and using visual patterns to detect information among other things [15]

There are two main categories of users for any visualisation scenario: Expert users who are familiar with the information that is being presented and have an in-depth knowledge of its underlying structure. Non-expert users are the users who have no knowledge of the underlying data and have no experience in using the data and with the involved technologies [15].

These two types of users have different requirements for what the visualisation of the information needs to achieve. Expert users require visualisations to better cope with the amount of data that is being handled. Visualisations allow for a good overview of the information and allow easy determination of problematic areas through outliers or unexpected trends. Non expert users require that the visualisation presents them with a view of the data that allows them to easily understand and manipulate it without requiring any prior knowledge of the structure of the data [15, 1, 26, 26].

The main challenge is to find a good visualisation technique for data that is useful for both user groups while fulfilling all the requirements for all users [15]. To present geospatial information, visualisation techniques often place markers, bars, or charts on maps to indicate the geographical properties [30, 26, 9].

The following six areas are identified by Chittaro et al. [14] as the key design factors for information visualisation:

DF1: Mapping: The mapping of information and the relationships between the objects being represented need to be clearly defined and kept consistent throughout the user experience.

DF2: Selection: The relevant set of information should be selected for the visualisation, however sufficient data should be provided for the best experience possible. Unnecessary data will only confuse users.

DF3: Presentation: The information should be presented in such a way that it can be easily seen. Visualisations need to be both attractive and have to display all the required data. If one of these aspects is missing, the visualisation may be ineffective.

DF4: Interactivity: The application should provide some means to interact with the data being presented. Higher usability of the visualisation may be achieved with better and more flexible interactions.

DF5: Human factors: Human cognitive capabilities should be taken into when designing visualisations.

DF6: Evaluation: Visualisation techniques should be tested by users in order to determine whether they are effective and useful.

For the PVGeoVisualisation application these factors will be addressed as follows:

DF1: Political violence events are the fundamental component of our dataset and the most important relationships between them are temporal, geographical and classification-based (event category and motivation).

DF2: The event location is selected as the most relevant information for display, although drill-downs will select more information.

DF3: The information will be presented on an annotated Google map.

DF4: Map-based browsing will be supported along with visual query building to filter and select data.

DF5: The haptic interface of mobile devices will be exploited to increase usability. The design shall account for limitations of a mobile environment (see below). Incremental design and evaluation shall assess the efficiency and usability of the design.

DF6: Multi-stage user trials with different user groups shall assess and guide the development of the interface.

3.2. Visualizing Geographic Information

Geographic information, also referred to as geospatial information, spatial information, or location-based information, is a kind of information that has a reference to a geographical entity. This reference may be to a set of coordinates, but may only be a reference to a geographical location, which in turn has its exact location defined. A majority of the data that is generated today is geographical in nature [9].

Visual exploration of geographical information is essential, as the type of information that is displayed is complex in nature and without graphical representation, creating a mental model of the information is very difficult. Modern geographic visualisations are able to present interactive maps showing different kinds of geographic information. These visualisations are created by incorporating generic cartographic knowledge into the data that is being presented. Maps allow the interaction with geographic information in such a way that the effectiveness of visual thinking is increased [1].

Andrienko and Andrienko [1] present a good overview of the different information visualisation methods of spatial data on interactive maps. They explain that maps should be able to adapt to the requirements of the user and they should be able to change the visualisation of information as they desire. Users often require visualisations that allow direct manipulation of the presented data, allowing for a fast and intuitive user experience. Direct interaction has also been shown to increase user confidence in the results that applications return.

Interactive maps based on dynamic queries allow users to analyse the data that is presented much more efficiently as feedback of the query that is being constructed is presented on the interface, allowing users to explore more of the application and the underlying data [9, 1]. To achieve this, the visual query building interface is directly linked with the graphical representation.

Whenever a user alters a setting in the visual query builder, the application should reflect the changes on the map by displaying the results of the new query. Users should be able to gain more in-depth information of entries by selecting the corresponding markers. The detailed information should be presented in a contextual popup. This behaviour allows for a rapid and intuitive exploration of the underlying data.

It has been shown that on/off visualisations, the situation where only the elements that satisfy the requirements are presented, make it difficult for the users to understand relationships and gain a good insight into the presented information, as users tend to make significantly more errors and interface interactions. It has been suggested in [9], that alternative visualisations for the query results should be presented instead of hiding the elements that do not qualify.

In interactive maps, it is often the case that there are data points that are not presented on the current view of the application, however it is often desired that users are given hints regarding these data points. There are several alternatives for the visualisation of off-screen elements, some of which are Overview&Detail, Focus&Context, Halo, and Wedge [10, 11].

3.3. Mobile Interface Challenges

Mobile devices have several additional restrictions that make interface design and information visualisation more difficult, such as their screen size. This limits the amount of space that may be used for interface elements and the display of information and visualisations, hence desktop visualisations cannot be directly translated to mobile environments purely due to their size, as the data overview would not be entirely visible on the small screen [14].

Users interact with the mobile user interface directly through the use of a touch screen, while in traditional environments users would be interacting with the interface through a mouse or a trackpad. While designing visualisations for this environment, one must consider that part of the available screen is used for input through methods such as virtual keyboards [14, 4].

Traditional solutions for information presentation such as Overview + Detail or Focus + Content [10, 11] do not transfer well to mobile devices due to the limited screen space or the amount of non-essential information presented. However other methods such as off-screen information referencing, such as Wedge and scroll & zoom have showed to be good alternatives for reducing the amount of information presented to the user at any one time but still informing them of the availability of other information [14, 9].

Given that interactive mapping applications often use a visual query interface, the limitations of a small screen, such as on a mobile device, become more apparent. In addition, controls that are used on a desktop may not be applicable or natural on mobile devices [9]. Previous applications have often focused solely on the data being presented, and have ignored the user interface and user experience of the application (Nayebi et al. [31]).

Finally, users of mobile devices tend to find themselves in different scenarios than desktop users, and hence the interaction with the device and the application become a utility, a secondary task, as the main focus of the user is on the environment, hence the amount of attention applications receive from their users is much lower than otherwise [14]. In addition the environment the device may be used in is variable, with different lighting conditions, which affects the perception of the visualisation displayed on the device.

3.4. Industrial Design Guidelines for Mobile

Here we discuss the Apple iOS interface design guidelines [24] as an example of industrial best practice. The design language of Apple's iOS relies strongly on three concepts: deference, clarity, and depth. This section overviews the main ideas and areas of iOS design with respect to these concepts.

3.4.1. Deferring to Content

The design of iOS encourages the presentation of the content over the interface and controls, it is the information that should be the main focus of the application using as much of the screen space as possible. An application should be aesthetically pleasing, combining appearance and functionality in a coherent way. Therefore the design layout should not affect the usability of the controls and the interface, buttons and informative text should be well spaced and easy to interact with.

Different areas of the screen have different level of importance and focus in users' eyes and therefore information should be placed in such a way that it reflects their importance in the interface. More important elements should be placed towards the top left corner of the screen, while less important elements should be placed towards the bottom right corner.

3.4.2. Providing Clarity

An application should allow users to directly manipulate any information that is being presented on the screen, may it be an image, text, or any other resource. A set of multi touch gestures have been designed by Apple that are familiar to users and how these gestures are used should be easily understood by users and fit in the context of both the application and the iOS platform.

Navigating the application should not be an issue to users, and the hierarchy of screens and elements should be well understandable to users. The interface should give visual hints to users regarding their position in the navigation hierarchy. The use of colours and contrast should highlight important information and make it feel better in context.

3.4.3. Use of Depth

Applications should use different visual layers to present information and navigation between these different layers should be achieved through realistic animations that reflect the motions of everyday objects. Animations should be used in the application to provide visual feedback on actions and to enhance the users' feel of manipulating information directly. In addition animations may help users to see the results of their actions easier. However the use of animations should be consistent and not exaggerated, as it may degrade usability.

Information that is not required by users at all times should be shown on a different layer of the interface and shown only when it is required, however the transitions between these layers should be natural and help users in keeping track of the application context and navigation hierarchy.

3.5. Linked Data Visualisation Requirements

Dadzie and Rowe [15] have stated a set of requirements for the consumption and visualisation of Linked Data that are essential to deliver a good user experience for both expert and non-expert users. These findings are summarised below.

Most visualisations share a set of essential features helping users interpret complex data. These visualisations should be able to:

- **A1.** Create and present an overview of the data;
- **A2.** Filter the information to eliminate less important information;
- **A3.** Drill down into, and show more detailed information in the areas of interest.

In addition, visualisation allowing to users to gain more detailed insight into the must be able to:

- **B1.** Visualise relationships;
- **B2.** Use and display of multidimensional data;
- **B3.** Grant the ability to export the visualised data to other applications.

An application satisfying these requirements will be able to visualise the underlying data in a meaningful way helping the user to better understand the data of interest. In addition, these visualisations should be able to ease the use of the data set, increasing users' efficiency [15].

To suit expert users, Linked Data visualisation tools should offer [15, 1]:

- **C1.** Intuitive navigation, allowing undo/redo and back/forward operations;
- **C2.** No restrictions on data exploration;
- **C3.** The ability to access the underlying raw data;
- **C4.** The option to execute custom queries;
- **C5.** Export the underlying data for reuse.

To enable the use of the application by a wider user base, visualisation tools should possess features to:

- **D1.** Help users navigate easily through large data sets;
- **D2.** Allow intuitive exploration of the data to gain understanding of it;
- **D3.** Offer the creation of queries through helper methods, such as visual elements;
- **D4.** Allow analysis of the regions of focus;

3.6. Linked Data Challenges on Mobile

The nature of Linked Data that it is online, however to provide a good user experience; Linked Data applications should be able to offer some functionality even if it is not connected to the Internet. To provide such contextual functionality, some of the Linked Data information would need to be cached.

In addition, Linked Data is heterogeneous in nature, meaning that data may be of different types. Generic Linked Data applications must be able to support the use of different types of information from multiple data end points [15].

The need for information caching is further supported by the fact that most current public Linked Data end points can suffer from poor response times, severely impacting the user experience of applications. Geographic Information and Linked Data

Many datasets can be naturally linked to spatial features such as places, roads, landmarks, etc. This type of information is often visualised on a map since this forms a familiar frame for understanding the data for many users.

3.7. Related Linked Data Applications

This section introduces mobile Linked Data applications that feature different information visualisation techniques with a focus on mobile applications (Table 1) and geographical data visualisation. These applications are analysed and compared at the end of the section with respect to the requirements for Linked Data visualization (section 3.5).

Table 1: Summary of mobile Linked Data applications

Application	Year	Generic or Application-Specific	Target User Type	Geographical Visualization?	Capability Summary
mSpace mobile [44]	2005	Generic	Non-expert	Y	Location-context-based search or browse of any semantic web resource and linked resources. Also supports filtering, information overviews and previews.
DBpedia mobile [4]	2008	Both	Non-expert, Expert	Y	Discovery of real-world objects around the users' location and related information from linked data sources and display on a map-based summary screen. Detailed information view allows users to navigate links from the viewed entity. Uses a semantic web search engine to gather links and build a semantic graph per user, which is extended as the user is navigating and discovering the links between objects on the web.
Stevie [6]	2010	Specific	Non-expert	Y	Collaborative sharing and creation of geographical points of interest.
More! [34]	2010	Specific	Non-expert	N	Allows users to find information about researchers at conferences by scanning a QR code. Information such as current and previous publications, and contact information can be viewed through the application. Based on Research.fm data set.
Ontowiki mobile [20]	2011	Generic	Non-expert	N	Allows users to browse and edit data sets, filter information and present it in views that adapt to the data. List-based data representation.
Who's Who [13]	2011	Specific	Non-expert	N	Users can find information on publications of researchers from a list of researchers. Detailed views of each researcher groups publications by year. A separate view for displaying each publication is available.
wayOu [19]	2011	Specific	Non-expert	N	Provides social and location based information to students and staff of the Open University. Users are able to browse information about other users and edit their own information.
Qpedia [17]	2013	Generic	Non-expert, Expert	Y	Users can search DBpedia by example for entities based on keywords, properties, or geographical location. Results are presented in a list view. Where an entry has a GPS coordinate, the information is shown on a map.

3.7.1. Map4RDF

Map4RDF [27] is a faceted Linked Data browser for desktop computers that enables geographical Linked Data information to be visualised on an OSM or Google Map. It represents a state of the art generic Linked Data visualisation and exploration tool. The information has to be encoded according to the LinkedGeoData ontology or the Basic Geo Vocabulary2 in order for it to be displayed.

The application allows users to filter the geographical objects that are being visualised using a sidebar, where the list of OSM classes (such as airports, cities, routes) is presented. The application allows for the definition of custom queries and the presentation of polygons instead of markers.

In addition to the presentation of the data, the application allows for the filtering of the information based on geographical features, such as "find all nearby features", allows users to inspect the RDF information, as well as see further information from Wikipedia or other linked resources.

3.7.2. Analysis of the applications

Table 2 compares all applications with respect to the presented requirements for Linked Data visualisation tools. Most applications were generic meaning that they presented Linked Data information and allowed its navigation without any application-specific use-case. While applications without any assumptions allow for a much more general exploration of the Linked Data cloud, their usage for a specific purpose may be difficult, as the discovery of the sought for information is much more difficult without a specialised visualisation or interfaces.The applications presented different navigation techniques that may be applicable for PVGeoVisualisation. However DBpedia mobile was the only mobile application which was designed with novice users in mind, fulfilling the visualisation requirements D1, D2, D3, D4, and D5, allowing the use by a wider user base. Users were able to use any Linked Data set, gain more information into the presented data, create custom queries to filter the information to the needs of users, focus the information to a limited area, and allowed to share the information with others.

The technical approaches of the presented Linked Data mobile applications were very similar to each other. All previous approaches have used server side rendering of the interface and visualisation to overcome the performance limitations of the mobile devices, however this affected the latency in the application. Client side rendering of the visualisation would reduce this latency and improve the application's usability.

Only the Ontowiki mobile application has demonstrated the possibility to use it offline. None of the presented applications, except wayOU, have demonstrated approaches which do not rely on a server between the Linked Data end point and the mobile application.

Ontowiki mobile was the most use-case independent application presented, however it is unable to dereference RDF resources, thus only the information that is presented on the interface can be used by users, which makes it more difficult to browse the LOD cloud and follow links. In addition, ontowiki mobile is not a geographical application, as in it is not able to present geographical information on a map.

Table 2: Comparison of mobile Linked Data applications with respect to LD visualisation requirements

Linked Data visualisation requirement	DBpedia mobile	Ontowiki mobile	mSpace mobile	Stevie	Qpedia	More!	Who's Who	way Ou	Map 4 RDF
A1 Overview data	yes	no	yes	Yes	no	no	no	Yes	no
A2 Filter out data	yes	yes	yes	No	yes	no	no	Yes	yes
A3a Detail/Drill down view	yes	yes	yes	No	no	no	no	Yes	yes
A3b Information panel	yes	no	yes	No	no	no	no	Yes	yes
B1 Visualise relationships	partial	yes	no	No	no	no	yes	No	no
B2 Multidimensional data	yes	yes	yes	No	yes	no	no	Yes	yes
B3a Export visualised data	no	no	no	no	no	no	no	no	no
B3b Share current view	no	no	yes	No	no	no	no	Yes	No
C1a Intuitive navigation	yes	yes	yes	Yes	yes	-	yes	Yes	yes
C1b Navigation history	yes	yes	no	No	yes	no	no	No	no
C2a Ability to explore	yes	yes	yes	Partial	partial	no	partial	Yes	yes
C2b Unrestricted Linked Data navigation	yes	no	yes	No	no	no	no	Yes	no
C3 Raw RDF view	no	no	no	No	no	no	no	Yes	no
C4 Custom SPARQL	yes	no	no	No	yes	no	no	No	no
C5 Export data-set	no	no	yes	No	no	no	no	Yes	no
D1 Large data set support	yes	no	yes	No	no	no	no	Yes	yes
D2 Intuitive exploration	yes	no	no	yes	yes	yes	yes	yes	yes
D3 Visual query building	yes	no	yes	No	no	no	no	Yes	yes
D4 Allow analysis of regions of focus	yes	yes	yes	yes	no	no	no	no	yes

3.8. USPV mobile application requirements

As a result of the survey in this section of visualisation design factors, the requirements for mobile Linked Data applications and Linked Data visualisations have been applied to the use-case of the PVGeoVisualisation applications and the basic user needs. The following are the requirements that the design of the applications must satisfy.

- R1. Visualise the USPV event instances on a map: Display markers for each event on the corresponding location on the map
- R2. Access the USPV data through the SPARQL end point
- R3. Use Linked Data technologies such as SPARQL and RDF to access and query the required data set
- R4. Provide the ability to limit the range of visualised events
- R5. Provide an intuitive approach to construct SPARQL queries used by the application
- R6. Provide a method to select an event and display its properties

R7. Be highly usable by novice users, not just data set experts
R8. Hide the underlying technology: users should not need to have knowledge of SPARQL or RDF.
R9. Store and create visualisations locally without the need for a custom server
R10. Be able to work offline once the initial data has been loaded
R11. Provide the most up-to-date version of the data

The next section describes our methodology for satisfying these requirements.

4. Development Process/Methodology

The development process for the PVGeoVisualization application was as follows: (1) define a native SPARQL-client-based mobile application architecture that supported online/offline browsing (requirements: R2, R3, R9, R10 R11) a query-building interface (R5, R8) and a map-based visualisation (R1, R4, R6) through a model-view-controller design pattern; (2) Develop a set of paper-based query and visualisation interfaces for rapid evaluation (R7); (3) Implement a first prototype of the query and visualisation interfaces based on refinement of the paper-based evaluation; (4) Run two focused user trials to evaluate the query and visualisation interface elements and after each trial refine the interfaces in a new prototype (R7); (5) Perform a user trial-based evaluation of the final prototype in comparison to a geographical visualisation desktop application based on the capabilities of Map4RDF.

4.1. Mobile Application Design

The PVGeoVisualization application focuses on visualising Event (pv:Event) instances from the United States political violence data set (see next subsection for details on data structures). The application was designed to be capable of working offline and to not be dependent on a custom server; hence components such as the application and user specific RDF graph and the visualisation engine are included in the mobile application architecture (fig. 2).

The mobile application has a layered architecture, and is based on an RDF graph that has been constructed from data that has been loaded from the USPV end point. The creation of this graph is achieved through an RDF data loader that accessed the selected end point through SPARQL over HTTP. This approach allows the application to work against a local copy of the data-set, while having the ability to load data upfront or in real time. The user interface (Query UI) and the visualisation (Map UI) adapt to the information that is available to them. Altering the user interface is achieved by applying filters to the overall data that queries the underlying RDF graph using SPARQL. These sets of filters are created indirectly by the user through a visual query interface builder, which has its state represented as mappings in the *Query UI State information* module.

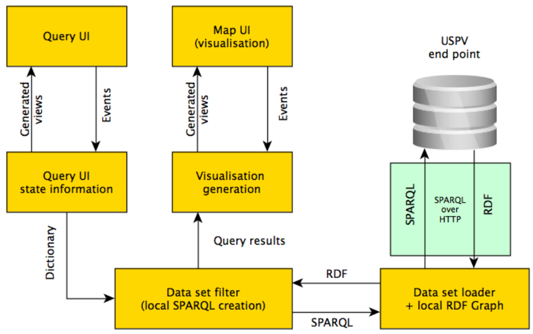

Figure 2: Overview of the general architecture and the application components

The map based visualisation updates whenever there has been a change in the available information. No other information is available to the visualisation but the filtered RDF data. Any visual hints or alterations of the interface are a result of the adaptive nature of the visualisation algorithms [Sections 5.4 and 5.5].

All components in Figure 2 are independent entities, and communication between them uses an event based approach. This improves maintainability and enables the possibility of replacing or altering components separately.

4.1.1. The Data Structure

It was found that if a uspv:Event instance's properties had sub-properties, the time needed for querying the dataset approximately tripled. Since the application was to execute on a processor-constrained mobile device, additional information was added to the uspv:Event data structure to reduce the workload when filtering on a local RDF graph. Direct property links to all relevant information from a uspv:Event node were added (green links in fig. 3).

Originally it was hoped that USPV event data could be discovered from one endpoint and the lat/long properties for the event locations could be looked up from LinkedGeoData endpoints. However it was discovered that the LinkedGeoData end points were very slow for real-time look-up tand hence the geographical information was instead encoded in the source data set directly. This was required in order to enhance the user experience of the application, otherwise each query request would have resulted in a long waiting and processing time which would have been unacceptable for such an application.

4.1.2. Creation of SPARQL queries

Users were able to limit the results based on the Category, Motivation, fatality count, the year, and the location of the events. These are the main properties of a uspv:Event object, which have been set in the application configuration, allowing users to efficiently filter the presented information.

The selected values or range of values were determined based on the state of the visual query interface and reflected in a dictionary that was available to the data filtering module which in turn translated the mappings to SPARQL, to be used on the local RDF graphs.

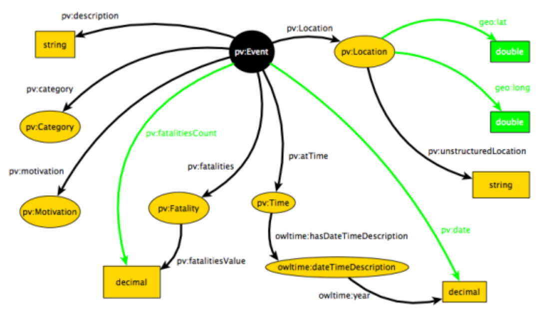

Figure 3: Structure of the visualised information

4.1.3. Interface Design

USPV Events were filtered and displayed on a map. The interface presented the following options:

- The Category and Motivation properties were limited to a set of predefined values as per the USPV vocabulary definition. Users could select values from this displayed list.
- The list of locations corresponded to the list of US states.
- Users were able to define a condition, such as a range or a specific value, for both the fatality count and the event date.

The map based visualisation approach was similar to other geographical Linked Data visualisation tools; however the popup information box was designed in line with the iOS design guideline.

Based on this overview design, the following tasks were mapped to application components as follows:

- Custom query → visual query builder
- Data visualisation → map based visualisation
- Information filtering → custom query building

4.2. Paper Prototypes

This section discusses the paper based prototyping and design of the two main user interface elements: the event information callout box and the query UI. Each had to be carefully designed to account for mobile device screen area and iOS interaction guidelines.

4.2.1. Event Information callout box

The information callout box of events on the reference desktop application (fig. 4) is not optimal for mobile as the text layout and the buttons was designed with a mouse pointer in mind and not touch.

The iOS design guideline recommends the information and controls to be well legible and elements to be spaced out to avoid issues arising from different finger sizes, so a vertical layout approach was taken by placing the elements in a one column table. The initial prototype for the info box as well as the second version correcting the highlighted issues are presented in Figure 12.

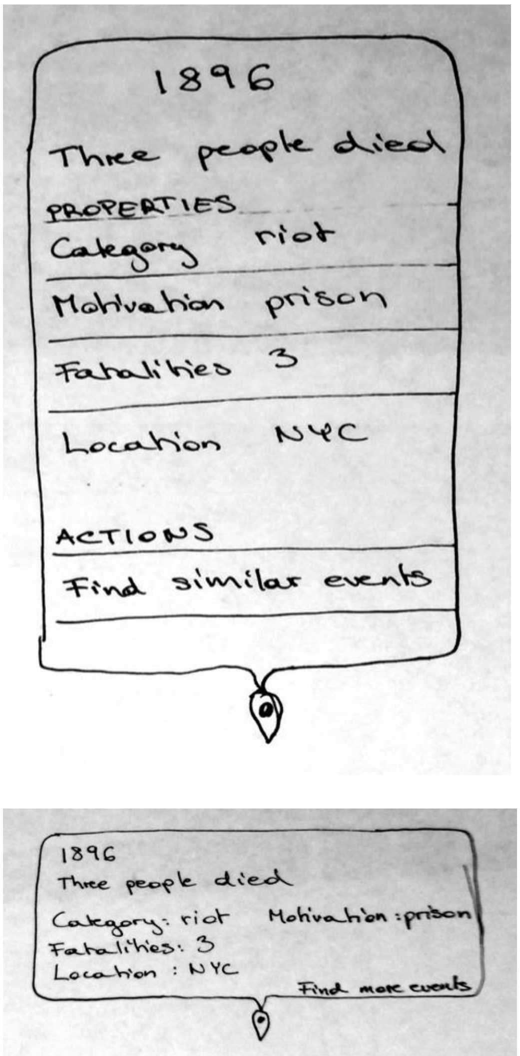

Figure 4: Paper prototypes for the information box

4.2.2. Query UI

Two designs were created for the query UI. The initial approach reflected the design of Map4RDF where the map and the visual query builder were present on one view. Unfortunately it seemed that the resulting query interface would not be able to present all options without the need to scroll significantly to find the desired options. In addition due to the limited space on a mobile display, the entries in the list of options were crowded together, making it more difficult for users to digest the information.

The second approach placed the query UI on different views from the map. By presenting the query interface in a separate context, the elements could be made much bigger and more legible. The default view shows the map on the entire screen and users are able to bring up the query UI with a button press. To reduce the amount of scrolling required, the query UI splits the screen into two columns. On the left the list of event properties is presented, while on the right the list of options was shown for the currently selected property. Two alternatives for the list of options were created, investigating the differences between a table-based and a tag cloud based approach. See the experimental section for details on our user evaluation of the different approaches.

Figure 5: Paper prototypes of the query UI

4.3. Prototype I

The interface design of our initial prototype was based on the paper prototype presented in the previous section. One concern was that the separation of the query interface and the map eliminated the real-time feedback in the visualisation whenever the user altered the query, requiring users to explicitly switch between views to check the effect of any changes they may have done. The impact of this was evaluated in the usability experiments, especially with respect to the desktop application which retained the combined map and query UI interface.

4.3.1. The map

The main interface consisted entirely of a map view. Events were presented on the map using red markers, the default options in the Google Maps iOS library[2]. These markers could be clicked on to create a callout event information box. The design of the event information box was based on the paper prototype (fig. 4) and also allowing user actions such as searching for similar events and viewing a HTML rendering of the underlying RDF for the event. A screenshot of the final event callout design is shown in Figure 6.

4.3.2. Query Building Interface

The design of the query interface followed the two options created in the paper prototyping phase:

- UI1: Query options were presented in a tag cloud. Entries spanned the available screen both horizontally and vertically.
- UI2: Query options presented as list entries which spanned the screen vertically, contained in well-spaced boxes. The text was larger and higher contrast than in UI1.

To present the map and apply the currently query to the data set, the "Search" button on the top of the query UI needed to be pressed. Users had the option to clear the selection for each property individually or reset the entire query to its default state. Later we will show how the user study highlighted the importance of visually signalling the state of the Query UI (in terms of selected fields) to the user given the separation of the Query UI view from the map view in the mobile application.

The two prototype 1 Query UI designs are presented in Figure 15 below.

Note that there were also some additional visual differences between the two interfaces, such as the semi-transparent background in UI2 or the variation in the positioning of the search and reset buttons. Explicit feedback on these differences was sought from users during post-evaluation interviews.

[2]https://developers.google.com/maps/documents/ios/

Figure 6: Screenshots of the map UI and the Event callout

4.4. Desktop application

The desktop application, PVGeoVisualisation, was modelled based on the interface and functionality of map4RDF [27]. The desktop application displayed the pv:Event objects on a map based visualisation which satisfied the criteria for the current selection by the user. These criteria could be specified using the toolbar on the left hand side of the interface.

By clicking on a marker, a popup box appeared with details of the points of interest, using which users could gain more in depth information. Further actions were available using the links available in the popup, allowing users to quickly change their selection to highlight nearby or similar events.

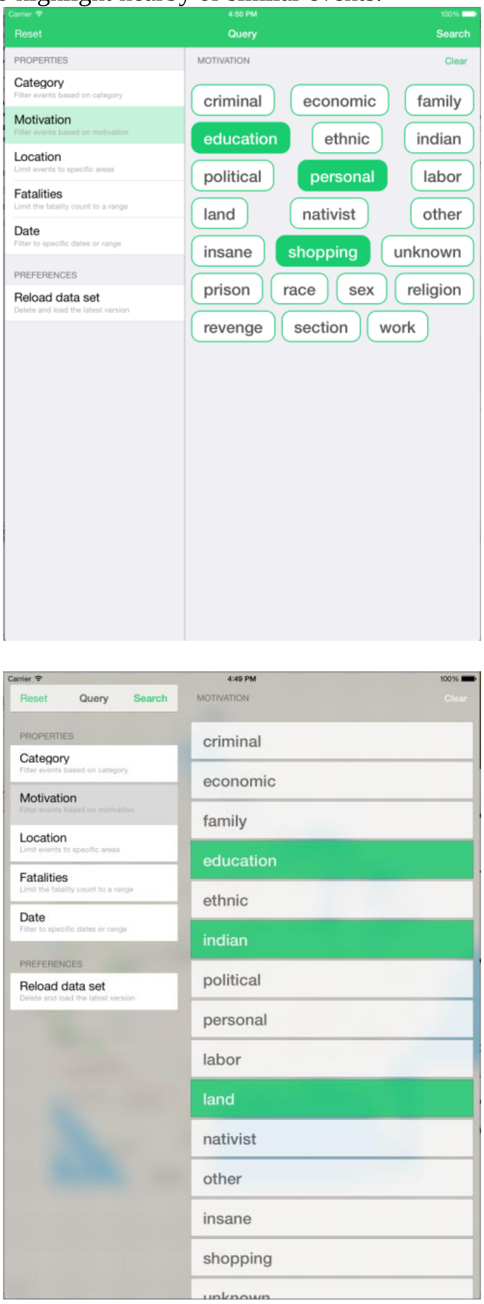

Figure 7: Screenshots of UI1 (above) and UI2 (below)

5. User Study-based Evaluation

The usability and functionality of the mobile application was evaluated through a series of three user studies and an initial a paper prototyping phase. The initial paper prototype was used to rapidly refine the design approach to be taken by the mobile application. This evaluation involved the authors, colleagues and friends; no formalised methods were used in the paper prototype evaluation.

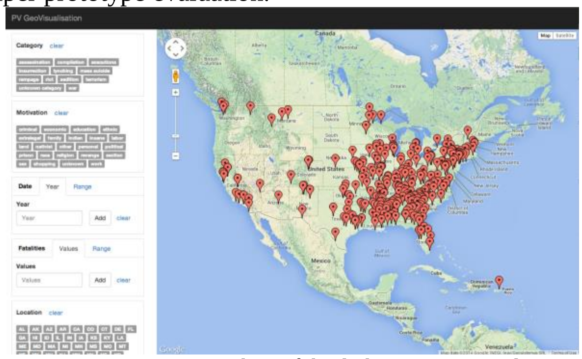

Figure 8: An overview screenshots of the desktop USPV visualisation application

The finalised paper prototype was translated into an iOS application using the architecture outlined in section 4.1. This served as the basis of the first experiment. Based on each set of experimental findings, changes were made to the application to address the usability issues discovered. The effects of these changes were then evaluated in each subsequent experiment. Each experiment collected usability and productivity metrics for the current prototype. In addition each experiment investigated an important aspect of the system: experiment 1 evaluated the relative merits of the two initial designs for the Query UI, experiment 2 evaluated the suitability of the application for both novice and expert users and experiment 3 compared the final mobile prototype to a desktop application in terms of task efficiency and accuracy.

5.1. Evaluation Methodology

The experiments set out to gather information on task-based user productivity and both qualitative and quantitative measures of usability. All experiments followed a similar experimental process with minor changes tailored to the specific experimental hypothesis.

5.2. Experimental scenario and metrics

All participants were asked to execute a series of tasks (section 5.2.1) using the mobile application. In the last experiment, participants were expected to complete a second set of tasks using a desktop application. These tasks asked participants to use the map visualisation and query UI to determine the location of a specific event or to find a relationship that is not directly represented in the data. Participants were encouraged to follow the think aloud protocol. They were allowed take notes and record their answer on a worksheet. The order in which participants used the applications varied; hence to avoid any bias of one application affecting the usability of other due to a user not being familiar with the scenario, each participant was asked to complete a practice task, where the nature of the application and the task requirements were demonstrated.

The investigator observed the subjects during the experiment. A key finding from each experiment was to identify user interaction issues, such as common errors or mistakes with certain features or interface elements. These issues became areas of focus in future experiments where implemented solutions were observed for their ability to rectify the interaction problems. Some examples of such issues were the problem of illegible UI elements, unexpected application behaviour, or the lack of feedback on actions.

Upon completion of the tasks, participants were asked to complete a Usability Evaluation Questionnaire (section 5.2.2). Finally, they were encouraged to comment directly on the usability and the user experience in an unstructured interview. The investigator recorded the comments from the participants, as this information was used to gain further insight into issues with the mobile application. In addition the productivity metrics shown in table 1 were recorded for each participant.

Table 1: Productivity metrics

Metric	Description
M1	Task completion time
M2	Number of errors per task
M3	Number of issues per task encountered

5.2.1. User Tasks

The exact tasks that the subjects were asked to complete changed between experiments to avoid the possibility of someone completing the same task twice. Some examples tasks were:

- In the 20th century, were there more assassinations in the eastern or the western United States?
- The American Civil War was fought between 1861 and 1865. In which states where there fatalities due to the conflicts of this war?
- In the second half of the 19th century, in New Mexico, three people died due to lynching. Who were these people? In which city and in which year did they die?
- Following on from the previous question: Which neighbouring state had the highest fatality rate due to similar events?
- Take Northern Colorado in the 20th century. Where and when did the event with the highest death count occur? What was the cause of these deaths?

The tasks were created based on targeted exploration of the data set using the mobile application. Depending on the focus of the experiment, whether it was the query building experience or the exploration of the dataset, appropriate tasks were created. There was a focus on creating tasks that required users to use multiple features of the application. The answers could not be found by simply looking at the underlying data. The aim of the tasks was to engage users with the geographic visualisation, requiring their perception of patterns and common knowledge to solve the tasks in addition to using the applications.

5.2.2. The Usability Evaluation Questionnaire

The usability questionnaire consisted of three sections.

Section 1: An adaptation of the standard System Usability Scale [3] aiming to determine a quantitative score for the overall usability of the application.

Section 2: A nine point questionnaire, based on Perlmans Practical Usability Evaluation questionnaire [35], aiming to evaluate specific components and features of an application that are essential for good usability. The adapted questionnaire consisted of fewer questions as anything deemed to have been covered by section 1 was omitted. The final score consisted of the sum of the scores for each question.

Section 3: An adaptation of the Lewis After-Scenario Questionnaire [29], which aims to score the application's usability with respect to how well the users feel regarding their completion of the tasks and their opinion regarding the application. The final score consisted of the sum of the scores for each question.

The aggregated data obtained from the questionnaires gave a composite measure of usability and helped highlight problematic areas of the application. By capturing the aggregated usability results at each experiment it was possible to evaluate the impact of design changes on the mobile application through the different versions and to compare the mobile and desktop applications in the final experiment.

5.2.3. Participant Recruitment and Ethical Approval

The participants for the experiments were recruited through social media or internal university mailing lists. Before carrying out the experiments, ethical approval for the studies was obtained from the Trinity College Dublin School of Computer Science and Statistics Ethics committee.

5.3. Experiment 1

The aim of this experiment was to select one of the two alternative designs (UI1, UI2) for information layout in the query interface of the mobile application and to set a baseline set of usability scores for PVGeoVisualisation geographical visualisations and searches. To aid with the analysis of results all subjects were asked during the experiment if they had familiarity with similar applications which required geographical exploration and reasoning using a map visualisation.

5.3.1. Hypothesis

The cloud tag based design for information layout on the visual query interface is more usable than a vertical list based design.

5.3.2. Experimental Design

Participants were divided into 2 groups based on prior experience with map search and half of each group performed the experiment with UI1 and half with UI2. Participants of the experiment were required to interact with the application by performing a set of tasks using either UI1 or UI2. The set of tasks was common for all participants. Tasks were presented on an experiment work sheet, where participants were able to record their answers and record any rough work that they needed. The tasks used were:

T1: In a prison riot in 1959, 2 inmates, 3 guards, and the deputy warden were killed. Where did this event occur?

T2: How many people have been killed due to events with a religious motivation in California after 1990?

T3: Who was assassinated in the second part of the 20th century around the Washington Metropolitan Area? (The Washington Metropolitan Area consists of the District of Columbia and the nearby cities from the neighbouring states.)

Each question was designed to investigate different areas of the application. T1 required users to get familiar with the application and how the visual query interface works. In addition, they are required to interact with the events of the results set by tapping on the markers on the map and inspecting the details of each event in order to find the right answer. T2 investigates how users are able to process information which has multiple results, and how well they are able to create a summary of the results. T3 investigates geographical reasoning using the application.

Participants were encouraged to record their answers on the experiment work sheet. Upon completion of the three tasks, the participants are asked to fill out the usability questionnaire and provide direct feedback to the investigator.

5.3.3. Data and Analysis

This section discusses in detail how the two different designs have performed with respect to usability and users' performance.

Table 2: Mean usability scores from post-experiment questionnaire broken down by section for UI1 vs UI2, and Users familiar with similar application vs not familiar

	Section 1: SUS	Section 2: Practical Usability	Section 3: After Scenario
UI1	70	33.2	14.8
UI2	82	35	17.2
Familiar users	83	35.4	18.2
Unfamiliar users	69	32.8	13.8
Overall	76	31.1	16

The usability results (Table 2) show that UI2 has achieved a higher mean usability rating than UI1; however these results are not significant as shown by the low p-value (the result of the standard t-test) of 0.28 for UI1 vs UI2 and 0.19 for familiar vs non-familiar users.

Table 3: Number of participants with respect to mobile application familiarity and interface version

	UI1	UI2
Familiar	2	3
Not familiar	3	2

It was shown that users who were familiar with similar apps, meaning that they have previously used an application which required geographical exploration and reasoning using a map, felt more confident in using the application. This is reflected by results of the practical usability questionnaire. User satisfaction with respect their performance in completing the tasks also showed that users were 12% more confident in their responses while using UI2. Another source of guidance for further development is the investigation how the application suits people with different skill levels overall. Considering Jeff Sauro's interpretation of SUS scores[3], where he assigns a letter grade to SUS scores based on a survey of more than 600 usability studies, UI2 would have received an A for usability, suggesting that the usability of this design was well above average.

The participants who used UI1 initially had issues finding the category and motivation terms they were looking for. This is reflected in the completion time of Task 1, shown in Table 3, which was significantly shorter for participants using UI2. The alphabetical list based view allowed users to more quickly identify terms by scanning the list also allowing them to anticipate the location of the item in the list. This was not possible in the tag based view, as items were not ordered alphabetically and the spacing between tags was uneven as the ordering was optimised for minimal space usage in the interface. This difference is even more noticeable in users who are not familiar with similar applications.

Table 4: Experiment 1 mean task completion time (seconds)

	Task 1	Task 2	Task 3	Mean
UI1 Overall	241.6	320	254.6	272.1
UI2 Overall	181.6	347.6	378.4	269.2
UI1 Unfamiliar	307.3	423.7	330.8	353.8
UI2 Unfamiliar	198.5	163.5	299.5	220.5
UI1 Familiar	143	164.5	141	149.5
UI2 Familiar	170.3	470.3	264.3	301.6
Overall	211.6	333.8	316.5	270.6

Most errors in the use of the application were caused by participants not selecting multiple options in the query interface, or they set values for the category, which was not required to complete the tasks. Participants in both groups were able to complete the tasks with similar results. Some users had issues trying to find some category or motivation values in UI1's collection view.

5.3.4. User behaviour and usability issues

The ability to select multiple or no values for the Category, Motivation, and Location was not apparent to participants and was a major source of errors. By default, if one did not select any values for a property such as Category, the application would have considered all options. The multiple option behaviour only became apparent to users when they accidentally clicked on a second value while one was already selected. This nature of the list of values was even less apparent in the tag cloud approach of UI1. This issue may be addressed by providing feedback on users' action and possibly by the addition of some tooltips or instructions.

It was not apparent to users, in general, that they had made an error in the creation of a query. They then noticed the errors late, and correcting mistakes was then difficult as the source of the error was not apparent any more. This was aggravated by the inability of the participants to remember their selections in the query UI. Providing real-time feedback on users' actions and their effect on the results set would allow the instant identification of issues, and possibly reduce the amount of time that has been wasted in trying to resolve an error. Additional feedback may be provided in helping users remember their selection in the query interface, avoiding the requirement to double check each query element prior to viewing the results on the map.

It was determined in post-experiment interviews that 80% of the participants were not familiar with US geography, and had significant issues in trying to identify neighbouring states. The use of the map as a helper was not apparent to users mostly due to the separation of map and query views, causing the map to be unreachable from the query interface during query construction. Most users, especially the ones unfamiliar with the geography, would possibly benefit significantly if the geographical aspects of the query construction could be done through the direct use of a map.

5.3.5. Conclusion

The analysis of the data from the experiment shows that the states hypothesis is not true and that users preferred the list-based interface. Overall, UI2 has performed better in all measures The preference for UI2 is larger for novice users.

[3] http://www.measuringusability.com/sus.php

5.4. Experiment 2

The aim of this experiment was to evaluate the improvements made since the first experiment (see 5.4.1 below) and to determine the how well the application suited users with no prior knowledge of the data-sets involved (novices) and those familiar with the data set (domain experts).

5.4.1. Prototype 2 Enhancements

Prototype 2 enhanced prototype 1 in the following ways (see also figure 8):

C1: Both the query interface and the map view now included indicators showing the number of events that satisfy the current query.

C2: More prominent 'Search' button and the relocation of the other query control buttons such as the 'Clear All', renamed from 'Reset', and the addition of an 'Undo' button.

C3: New indicators for each Event property, showing users how many values have been selected. In addition, the individual clear button for each property has been moved next to the indicator for easier access and discovery and the text replaced with an 'X' icon.

C4: Addition of a map to the query UI, presenting all US states with a polygon overlay. Tapping on a polygon will select the respective state in the list and vice versa.

C5: Indication of the selected states on the map by a polygon overlay.

C6: Rework of the numerical value selection tool. Instead of selecting the minimum, maximum, or an individual value, users will be required to define certain conditions on the property, such as whether the date is greater than x. The number picker interface was replaced with a condition editor.

To investigate the difference between the two user types, the experiment separated the participants based on their level of familiarity with the data set. Similarly to the Experiment 1, participants were asked to complete three tasks using the application, However everyone received the same version of the application in this experiment. The two sets of participants were selected to represent data experts and novice users, and reflected the average skill levels of such users.

5.4.2. Hypothesis

Prototype 2 will score higher in usability than the usability baseline for prototype 1 created in Experiment 1, given the addition of visual feedback to the application.

5.4.3. Types of Users

There were two groups of participants, with 9 people overall: novice users (4 participants) and domain expert users (5 participants), all had previous experience with similar apps. All experts were new to the application whereas all novices had participated in experiment 1.

The lack of users with no previous experience of the application (compared to the experiment 1 subjects) may have had a significant effect on the completion time and the number of mistakes users made. However the interface was changed since the previous experiment so the participants may not have gained all the benefits of prior familiarity. However, during analysis, this difference between the two user groups was considered.

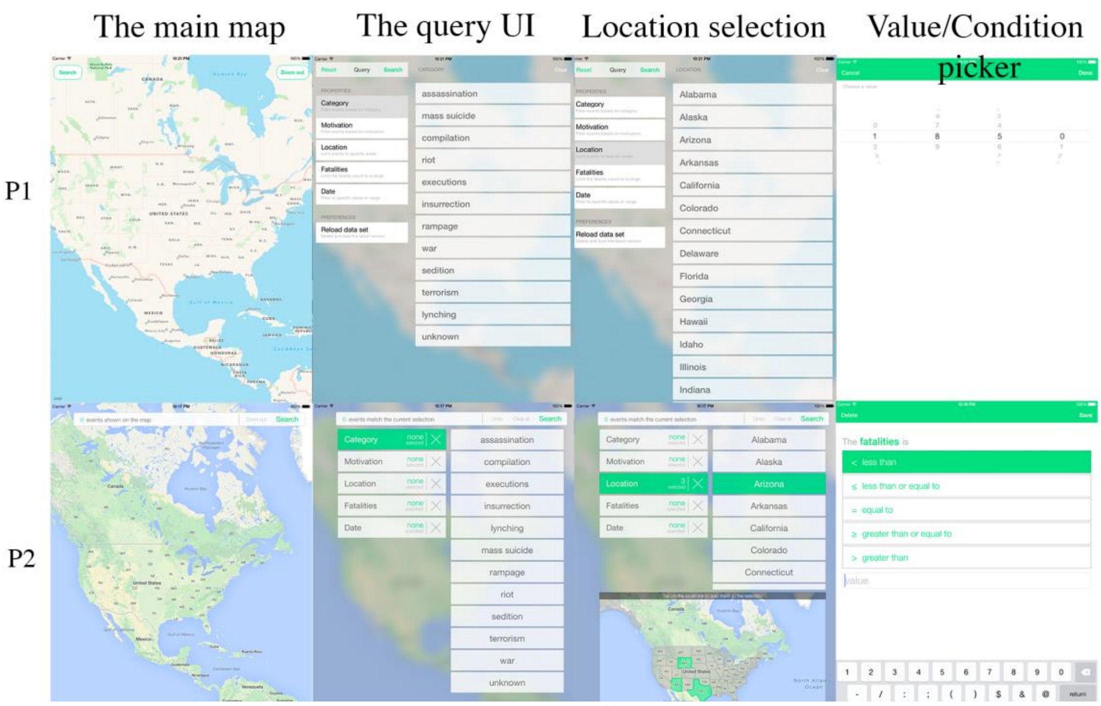

Figure 9: Visual illustration of the changes applied to UI2 and the difference between Prototype 1 (above) and Prototype 2 (below)

5.4.4. Experimental Design

All users were given a common set of tasks designed to exercise the new user interface. These were as follows:

T1: Find all 20th century events that have occurred in a coastal city of California. How many such events were there? And how many of them had a political motivation?

T2: The Kansas City Metropolitan Area includes two events, one from the state of Kansas and the other from a neighbouring state, as well as nearby cities. Which motivation for these events was the most common?

T3: Route 65 is a north-to-south US highway from Gary, Indiana to Mobile, Alabama. Count the number of fatalities along the route which have occurred either in the 19th or the 20th century.

T1 was designed to test the use of geographical reasoning to limit the results set to a coastal area on the map. This query is not possible without spatial reasoning and it is a difficult task for a computer, as the definition of coastal is subjective. In addition, participants are required to interact with the events on the map to find the right answer.

T2 investigates how users determine the area of focus for a task and how they modify the query according to their discovery, and how they discover geographical information.

T3 Investigates how the application can be used for exploration and how suitable it is for collecting summary information without the use of built in functions.

5.4.5. Data and Analysis

The main comparison in this analysis was between the data set experts and the novice users.

Table 5: Prototype 2 mean usability scores per user expertise level and overall

	Section 1: SUS	Section 2: Practical usability	Section 3: After scenario
Novice users	76.63	34.75	14.75
Expert users	85.5	34.2	17.4
Overall	80.56	34.48	16.08

There was a 10% difference in the usability scores between novice and expert users. As it can be seen from Table 4, there was a noticeable difference in the usability rating of the application between novice and expert users. The application was well suited for data set experts as shown by an SUS score of 85.5. The lower scores by novice users may be due to the way the information is presented. The usability rating is often decreased due to too much or too little information being presented. The user interface may suffer from information overload or a lack thereof for novice users. This is also suggested in the After Scenario scores which show a 13% difference in user satisfaction.

The SUS score of the application has dropped with respect to the previous version, showing that the addition of new features have negatively impacted the usability of the application for novice users. However both the practical usability and the user satisfaction ratings have remained at the same level. This shows that users either did not fully appreciate the set of new features or they have not been apparent.

Table 6: Mean task completion time (in seconds) per task per user experience level

	Task1	**Task2**	**Task3**	**Mean**
Novice users	357	455.25	528.75	447
Expert users	183.5	185.5	199	189.33

Data expert users were much more effective at using the application than others. This data reflects observations made during the experiment regarding the levels of confusion of users while interacting with the application and solving the tasks. Expert users when encountering an issue or if they become uncertain, quickly resolved to a trial and error approach, while novices spent time going through each individual section and thinking about what to do prior to taking any corrective action.

Table 7: Mean number of correct answers and errors per question per participant experience level

	Correct answers	**Errors**
Novice users	2.25	2.167
Expert users	2.4	1.6

5.4.6. Feedback

To enable participants not familiar with US geography, a map has been added to the query UI which would ease the selection of US states, however users were unsure how to use the map on the query building interface or how its functionality allowed adding neighbouring states to the query. If users were made aware of this functionality, tasks requiring detailed spatial reasoning may possibly require less effort from users.

While the addition of visual feedback to the query interface has helped some users to understand that the selection of multiple values is allowed, half of the novice users made errors due to only selecting a single value. When asked regarding this issue they commented that they did not realise the possibility of selecting more than one entry. To overcome this issue, the application should provide hints about the multiple selection nature of the interface to reduce errors caused by not selecting all the required options. Comments by users regarding the cumbersome nature of the information inspection, where one would need to individually insect each entry to find the desired information, show that Prototype 2 was not suitable for the investigation of a large result set, instead it was more suitable for exploratory tasks such as Task 3 where users had to follow a route and inspect the events along it.

Many of the participants agreed in that the application is simple to use and the information is clearly presented, however the scores from the questionnaires and their performance show that they do not understand all aspects of the information. In addition, users agreed that they would require some initial help using the application to be more comfortable completing their tasks.

5.4.7. Conclusions

While overall usability of the application remained at similar levels, the SUS scores for novice users has dropped by 6%, this shows that the addition of extra features may not benefit novice users positively.

There is a significant different between the performance of data expert and novices as shown by the completion time, which is less than half for experts than novices.

5.5. Experiment 3

The aim of this experiment, in addition to evaluating the effects of the changes applied in prototype 3, was to determine the difference in both the usability of the desktop and the mobile application and how the two applications affect the efficiency and the performance of users in completing a set of tasks.

5.5.1. Prototype 3 Enhancements

In order to increase the usability of the application for novice users and to resolve some of the issues highlighted in experiment 2, the changes and features that have been added to the application are detailed below (see also figure 9):

C1: Location search: Users are able to search for a location on the mobile application where the results are presented on a map with a blue marker

C2: All application buttons have been made more prominent

C3: Hints and instructions have been added to the query interface

C4: A tutorial feature has been added, which informs users of the major functions of the application and the different UI elements

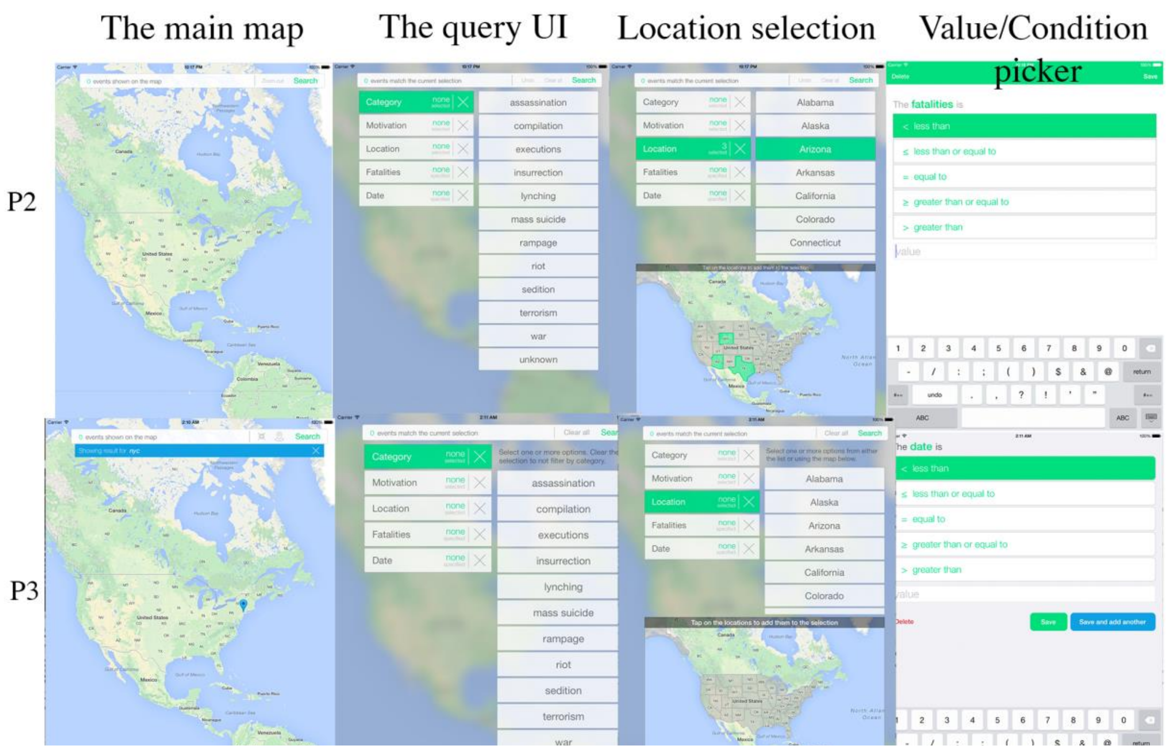

Figure 10: Visual demonstration of the changes applied to P2 to create P3

5.5.2. Experimental Design

Participants were asked to complete two tasks on both the mobile application and a reference desktop application based on the interface of Map4RDF and to complete a usability questionnaire per device. To reduce the impact of bias introduced with respect to the order of devices, participants started with a randomly chosen application out of the two. To avoid a bias due to participants being totally unfamiliar with the data set, a simple practice question was given to them before collecting experimental data.

5.5.3. Hypotheses

H1: Data experts should prefer the desktop application due to its single view nature and the experts' experience with similar desktop tools.

H2: The usability of the mobile application depends on whether the user prefers using mobile devices over desktop applications.

H3: Task completion time should be lower in the desktop application as users have both the query controls and the data visualisation on one view.

5.5.4. Types of users

The participants in this experiment were a mix of expert (4 participants) and novice users (12 participants).

5.5.5. Data and Analysis

So far in the analysis of the experiments, the main focus was the difference between novice and expert users. It may be a possibility that usability scores originating from a person are strongly affected by a user's perception and prejudice of the application and the device being interacted with [H2]. In order to investigate this hypothesis, the participants' results were split up, for analysis, based on their preference of the applications.

Table 8: USPV Application: platform preference of users based on their prior experience with the data set

	Tablet preference	Desktop preference	Total
Novice users	6	6	12
Expert users	3	1	4
Overall	9	7	16

Data experts preferred the tablet application over the desktop one, even though other similar applications that they have had experience with were desktop based. When interviewed regarding their choice, they reasoned that the information in the tablet application was presented in more familiar terms and that it was easier to navigate with the information being presented much more nicely. The result indicate that separating the query UI from the map and having two contexts benefitted usability on the mobile device, as the user was not distracted from what they were doing.

The preference of novice users was not clearly discernible. Exactly half of the novice participants preferred the tablet application. It was expected that novice users would prefer the tablet application because of the simpler interface, given that the desktop application focuses heavily on the data set and the interface presents little help. When asked regarding their choice, some users stated that they are either biased towards desktop computers or simply don't like tablets. Other users found the context switch between the query interface and the map confusing and preferred to have the information and the controls on one view. Hence the preference of users did not depend on their skill levels or their previous experience with other similar applications.

	Section 1: SUS	Section 2: Practical usability	Section 3: After scenario
Mobile			
Novice users	71.25	33.83	14.75
Expert users	88.75	40.5	17.4
Mobile preference	81.94	36.89	17.22
Desktop preference	67.5	33.71	13.86
Overall	75.63	35.5	15.75
Desktop			
Novice users	72.5	34.084	15.5
Expert users	78.75	33	15.5
Mobile preference	66.39	32.11	14.67
Desktop preference	83.93	36	16.57
Overall	74.06	33.81	15.5

One would have expected to have a clear separation of preference based on the skill levels of the users. Based on the literature review, previous research suggested that expert users would prefer the more complex desktop application as it provides faster one-screen controls and immediate full results views. Similarly prior work indicated that the mobile application would be preferred by novice users as it has clearly lain out and explained controls along with a tutorial and has a bigger focus on the exploration aspect.

The practical usability rating (table 8, section 2) reflects the users' perception of the usability of the different system components. When inspecting the responses to individual questions on the scale, it is possible to see that the aspects which scored lower than in experiment 2 are the users' ability to understand the information that is being presented and the functions available. It is surprising to see these scores, as prototype 3 added an online tutorial to address the issue of confusion and uncertainty with respect to the information and interface presented. Given these low scores, it must be concluded that the tutorial does not give the right suggestions to users and either an alternative method of introduction or the addition of less intrusive hints should be created to combat users skipping the tutorial and omitting the help given to them.

The usability scores indicate that the changes have created a mobile application which is very effective and easy to use by data experts. However the usability score obtained by novices is considerably lower, the application requires an easier to use presentation for casual users while still maintaining the current level of usability by experts. When considering simply the users who prefer the tablet application, the results obtained show a SUS usability rating of 81.94, which is above the minimum for an A grade (exceptional) usability, suggesting that these participants have found their experience with the application beneficial and would recommend its use to others[4].

Table 9: Experiment 3 mean task completion time (in seconds) on the mobile and desktop applications

	Task 1	Task 2	Mean
Mobile application:			
Novice users	282.08	283.25	282.67
Expert users	214.5	189.75	202.13
Mobile preference	217.44	236.56	227
Desktop preference	326.57	289.86	308.21
Overall	265.19	259.88	262.53
Desktop application:			
Novice users	223.5	270.09	246.79
Expert users	154	220.75	187.36
Mobile preference	215.67	217.89	217.22
Desktop preference	192.71	309	250.86
Overall	206.13	257.75	231.94

Participants' confidence in using an application depended on how much they liked to use it, which in turn affected the time it took users to complete the tasks and the number of errors they have made during the experiment. Next we examine the productivity metrics obtained and the degree of utilisation of the help functions (table 9).

In experiment 2, it was shown that expert users complete tasks faster and with less errors than novice users. It was expected that this behaviour translated onto the desktop application as well. Especially as expert users were more used to desktop applications. In addition, the single interface should have allowed for a better overview of the information, benefiting completion time, however it was unclear how experts would be affected by the more complex user interface. It was possible that they would be make more mistakes, but it was expected that they would be able to complete the tasks with a similar correct answer rate. Table 10 shows the number of errors and requests for help given per question as well as the mean number of correct answers for the tasks for the tablet and the desktop application respectively.

Table 10: Experiment 3 mean number of correct answers and errors per question on the mobile and desktop applications

	Correct answers	Errors	Help per question
Mobile application:			
Novice users	1.42	1.33	1.08
Expert users	1.25	0.75	0
Mobile preference	1.39	1.11	0.88
Desktop preference	1.36	1.29	0.71
Overall	1.335	1.04	0.54
Desktop application:			
Novice users	1.33	1.13	1.167
Expert users	1.5	0.63	0.25
Mobile preference	1.5	0.94	1.11
Desktop preference	1.21	1.07	0.71
Overall	1.415	0.89	0.709

Following the trend confirmed in the previous experiment, expert users have completed the tasks approximately 25-30% faster than others, have made less errors and required less help. Data set experts completed tasks faster on the desktop and with fewer errors than others. Participants got familiar using the desktop application faster, however task completion times seemed to be equivalent on the two applications. Table 10 shows that on average the task completion times on the desktop application were about half a minute shorter than on the mobile. However when looking at the per task break down, one can see

[4] http://www.measuringusability.com/sus.php

that the time it took to complete task 2 on both devices is identical and that the extra time is accountable only towards the first question. This difference is visible on both the expert/novice and tablet/desktop preference breakdowns. A possible source of this increased time was the presence of the tutorial, which in its current form was slightly intrusive as users were not able to disable it, taking time away from focusing on the task at hand. In order to investigate the effect of the tutorial, a/b testing with the tutorial on and off should be run in future work.

Finally Participants' confidence in using an application depended on how much they liked to use it, which in turn affected the time it took users to complete the tasks and the number of errors they have made during the experiment. In experiment 2, the effect of users' preference on the received SUS grade was discussed, and based on the data presented by Table 9 shows that users' confidence with the application has an effect on their performance and the ability to complete tasks. Participants who preferred the tablet application have completed the tablet tasks faster than the other group. Participants who preferred the desktop application have completed the desktop tasks much faster than the ones who did not. No similar correlation was noticeable for the number of errors, the answer rate, and the number of helps given.

Table 11: Comparison of PVGeoVisualisation mobile to other mobile Linked Data applications with respect to LD visualisation requirements

Linked Data visualisation requirement	PVGeoVisualisation
A1 Overview data	yes
A2 Filter out data	yes
A3a Detail/Drill down view	yes
A3b Information panel	yes
B1 Visualise relationships	no
B2 Multidimensional data	yes
B3a Export visualised data	no
B3b Share current view	no
C1a Intuitive navigation	yes
C1b Navigation history	yes*
C2a Ability to explore	partial
C2b Unrestricted Linked Data navigation	No
C3 Raw RDF view	No
C4 Custom SPARQL	Partial
C5 Export data-set	No
D1 Large data set support	Yes
D2 Intuitive exploration	yes
D3 Visual query building	yes
D4 Allow analysis of regions of focus	yes

Table 12: Comparison of PVGeoVisualisation mobile to other mobile Linked Data applications with respect to features required by the application's use-c

Linked Data visualisation requirement	PVGeoVisualisation
F1 Offline Usage	yes
F2 Server independence	yes
F3 General purpose	no
F4 Local filter	yes
F5 Any data source	no
F6 SPARQL usage	yes
F7 URL dereferencing	yes

5.5.6. Conclusions

Evidence was collected that suggests H2 holds true, as the usability rating for the mobile application was high when the participant liked the application. On the other hand, the users who preferred the desktop application found PVGeoVisualisation to be more usable. Following on the findings, it was shown that there was no noticeable relationship between participants' experience with the data set and which application they preferred; hence the evidence suggests H1 is not true.

Most users preferred the tablet application to explore the data set, including data experts. However comments by users highlight that the unified view of the desktop-based application was preferred over two separate views, but the interface of the mobile application, in general, was more welcoming and simpler. The application possessed some minor issues that made it more difficult for novice users to use, however given the data, it was shown that it possessed the minimal set of features that is required by expert users to use such an application. Overall, the application received very positive feedback from the participants and seemed to be suitable for the exploratory study of the underlying data set.

6. Conclusions

In this study, the usability of the PVGeoVisualisation mobile app was investigated through usability trials. The application addresses the need for a mobile Linked Data application capable of visualizing geographical information and support usage by novice users. A set of 25 requirements were established (table 11, table 12), based on a review of the literature and the analysis of the use-case.

In answer to our main research question, despite the limitations of a mobile platform the PVGeoVisualisation application achieved an equivalent usability to its desktop counterpart, with some limitations. It was found that the usability of the applications depended on users' platform preferences. Participants who liked and preferred to use the mobile platform found it to be much more usable over the desktop application, on the other hand, users who preferred desktop applications found that to be more usable.

The applications were specifically designed for the visualisation of geographical data sets by placing markers on a map.

While this study focuses on the design of an application for a tablet such as the iPad where the platform limitations may be less apparent than on a smartphone, however our findings and approaches may be applied to smaller screened devices. The design-user study-redesign process used for PVGeo-Visualisation mobile ensured that the application achieved a high usability as issues decreasing perceived usability were identified and addressed as part of the development process.

Table 11: Table indicating how the Linked Data visualisation requirements apply to PVGeoVisualisation mobile

	Requirement	Status	Comment
A1	Data Overview	yes	The overview and the off-screen visualisations were combined into one method
A2	Information Filtering	yes	Demonstrated by the continuous use of the query UI
A3	Drill-down into areas of interest	yes	Corresponding to zooming on the map to spread out markers
B1	Visualise relationships	no	The application did not visualise relationships between events. The application has achieved a high usability anyway.
B2	Display multidimensional data	no	The application did not visualise multidimensional data
B3	Export visualised data	yes	This requirement was not in scope of the application's requirement, however the author assumes that users would want to reuse the results in other applications
C1	Clear and intuitive navigation through the web of data	partial	This requirement depends on the use case of the application. Clear and intuitive navigation is essential, however if the use-case of the application does not require it, the ability to navigate the Linked Data cloud is not essential.
C2	Explore the data without restrictions	yes	Users were able to explore the USPV data without restrictions. Upon clearing the query UI, all events were shown on the map and users were able to explore the data-set in its entirety.
C3	Inspect underlying raw data	no	This requirement is use-case specific, however as seen with the mobile application, if the use-case of the application is exploration, there was no need to access the raw data.
C4	Option to run custom SPARQL	partial	Users want to be able to define their filtering options on the data. The users were able to create custom queries visually. Experts did not require the ability to write SPARQL queries.
C5	Extract raw RDF data	yes	Given that the authors assume that exportation would be useful, exporting the raw data would be equivalently useful.
D1	Navigate easily through a large data-set	yes	Users were able to navigate the USPV data set through an intuitive map based interface.
D2	Allow exploration of the data to gain understanding of it	yes	Initially users explored the information on the map prior to accessing the query UI in order to understand what sort of information was being presented.
D3	Offer the creation of queries through helper methods	yes	Without the visual query builder and the hints, novice users would not have been able to filter the presented information.
D4	Allow analysis of regions of focus	?	This area has not been investigated. While the highlight of the selected location helped in the visual analysis of the data, the application did not feature helper methods (e.g. count the number of fatalities) to analyse the presented information.
D5	Present the results of queries and usage to others	?	The mobile application did not feature collaboration techniques, hence this point is unresolved.

It was found in the third experiment that the usability of the applications depended on users' platform preferences. Participants who liked and preferred to use the mobile application found it to be much more usable over the desktop application, on the other hand, users who preferred the desktop application found that to be more usable. Therefore we can say that a single platform solution is unlikely to suit all users.

Participants who were familiar with the data set performed better than novice users both in terms of task completion time and the number of errors committed. On average, users' task productivity on the desktop application was better than on mobile. But it is important to note that once users got familiar with the mobile application, the differences became less significant. While interacting with the desktop application, novice users requested more help on average than while using the mobile app.

Future work will include the development of additional techniques to provide visual feedback to mobile Linked Data users, extended user trials, the application of the approach to new case studies to evaluate the generality of the results and a performance-oriented evaluation of the native Linked Data mobile client architecture.

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8. Annexes

8.1. *Experiment tasks*

8.1.1. *Experiment 1*

T1. In a prison riot in 1959, 2 inmates, 3 guards, and the deputy warden have been killed. Where did this event occur?

T2. How many people have been killed due to events with religious motivation in California after 1990?

T3. Who was assassinated in the second half of the 20th century around the Washington Metropolitan Area?

8.1.2. *Experiment 2*

T1. Find all 20th century events that have occurred in a coastal city of California. How many such events were there? And how many of them had a political motivation?

T2. The Kansas City Metropolitan Area includes the two neighbouring Kansas cities as well as other nearby cities. Which motivation for these events was the most common?

T3. Route 65 is a north to south US highway from Gary, Indiana to Mobile, Alabama. Count the number of fatalities along the route which have occurred wither in the 19th or the 20th century.

8.1.3. *Experiment 3*

Practice task

T1. Find all assassinations with extra-legal motivation. When did they occur?

Mobile application tasks

T1. .Consider the states in the west coast of the US in the 21st century. How many events where there where more than one person has died? What was the most common motivation of these events?

T2. Route 5 is a north to south US highway from the Canadian border in Washington state to San Diego in California. How many riots were there along the route in the first half of the 20th century? How many people have died due to these events?

Desktop application tasks

T1. Consider the states that share a border with Mexico in the 20t century. How many terrorism related events where there where more than 2 people have died? What was the total fatality count?

T2. Route 25 is a north to south US highway from Buffalo, Wyoming to Las Cruces, New Mexico. How many riots were there along the route in the first half of the 20th century? How many people have dies due to these events?

8.2. *Usability Questionnaires*

8.2.1. *Adapted Practical Usability Questionnaire*

1. The application used familiar language and terms.
2. I understood the information the application presented. I did not have to take unnecessary steps or actions.
3. The application allowed me to undo actions or to go back and correct mistakes.
4. I was aware which actions were allowed by the application.
5. The application responded to my actions as I have expected it to.
6. I did not have to remember a lot of my previous actions or decisions.
7. The application gave appropriate feedback on my actions.
8. I have made a lot of errors while using the application
9. The application showed helpful error messages, helping me to find the issues.

8.2.2. *Adapted After Scenario Questionnaire*

1. Overall, I am satisfied with the ease of completing the tasks
2. Overall, I am satisfied with the amount of time it took to complete the tasks
3. Overall, I am satisfied with how well I have completed the tasks
4. Overall, I am satisfied with how well the application helped me in completing the tasks