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M. Gleicher, T. Landesberger von Antburg, and I. Viola
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# GTMapLens: Interactive Lens for Geo-Text Data Browsing on Map

Chao Ma[1] and Ye Zhao[†1] and Shamal AL-Dohuki[2] and Jing Yang[3] and Xinyue Ye[4] and Farah Kamw[5] and Md Amiruzzaman[1]

[1]Kent State University, [2]University of Duhok, [3]University of North Carolina at Charlotte,
[4]New Jersey Institute of Technology, [5]Concordia University Ann Arbor

**Abstract**

*Data containing geospatial semantics, such as geotagged tweets, travel blogs, and crime reports, associates natural language texts with geographical locations. This paper presents a lens-based visual interaction technique, GTMapLens, to flexibly browse the geo-text data on a map. It allows users to perform dynamic focus+context exploration by using movable lenses to browse geographical regions, find locations of interest, and perform comparative and drill-down studies. Geo-text data is visualized in a way that users can easily perceive the underlying geospatial semantics along with lens moving. Based on a requirement analysis with a cohort of multidisciplinary domain experts, a set of lens interaction techniques are developed including keywords control, path management, context visualization, and snapshot anchors. They allow users to achieve a guided and controllable exploration of geo-text data. A hierarchical data model enables the interactive lens operations by accelerated data retrieval from a geo-text database. Evaluation with real-world datasets is presented to show the usability and effectiveness of GTMapLens.*

**CCS Concepts**

• ***Information Systems*** → ***Information Interfaces and Presentation; Information Systems Applications;***

## 1. Introduction

Geo-text data [Hu18] contains texts and themes linked to geo-locations. Examples include geo-tagged social media, real estate information, community events, crime reports, consumer reviews, and so on. They offer great opportunities for data-driven studies on many social and scientific fields. Many visual analytics systems have been developed for geo-text data (e.g., [AAD*10, SK13, BB17]), which usually combine the following approaches: (1) searching data with keywords and then visualizing corresponding hot spots and locations in the results; (2) selecting critical locations or regions based on domain users' prior knowledge and showing important keywords related to them; and (3) aggregating geo-tagged data items over spatial regions then visualizing the aggregated semantics. Although these approaches are effective for many applications, they do not support the following tasks very well:

- Spatial exploratory analysis where users do not have clear keywords or locations of interest in their mind before an exploration. They want to navigate the geo-space to find important geo-text information. They also look for serendipity discovery to reveal a surprising and useful aspect of data.
- Transition analysis where changes of geo-semantics along paths or between spatial neighborhoods are to be discovered.
- "Cold" spots analysis where sparse and disperse locations having keywords of interest are to be investigated.

For these tasks, users need to scan a wide geographical area on a map to browse the geo-text data, so as to identify and study the associated semantic information. Existing geo-text visual analytics systems do not provide effective interactions for such dynamic information seeking process. Lens technology is a promising approach to address this gap. Virtual interactive lenses provide focus+context exploration in freely selected regions of interest (see a complete survey [TGK*17]). Unfortunately, existing map lens tools are mostly implemented for enlarging local map regions, adjusting map styles, and showing pre-computed POI details. A few works apply to geo-text data where categories or tags are visualized along with a simple browsing lens. However, users cannot easily manage the lens contents with their interests, define and control the moving path, and compare findings at different locations. Effective dynamic visualization and interactions of single and multiple lenses for geo-text data are not well studied and presented. Moreover, the real-time extraction of semantic information with respect to users' interest is not well supported for instant interactions.

In this work, our aim is to investigate what features are needed for focus+context exploration of geo-text data within a lens-based design. For this purpose, we present a GTMapLens (Geo-Text Map Lens) technology that allows users to effectively browse and study geo-text data by interactive virtual lenses on map. The major contributions in comparison with the existing tools include: (1) Identifying interactions desired by domain experts to make lens browsing more effective for their work; (2) Designing, developing, and evaluating a set of efficient geo-text data retrieval and visual representation techniques to meet the requirement of interactive lens browsing; (3) Integrating the new techniques into a visual analytics system that supports lens browsing for map-based text data explo-

† Corresponding author: zhao@cs.kent.edu

ration; and (4) Evaluating the effectiveness of the individual interactions and the system as a whole.

According to our requirement analysis with domain experts, GTMapLens provides the following interactions for lens browsing in map-based text data explorations:

- *Lens Content Control:* Users can move and zoom a focused lens region and enable multiple lenses if needed. The lens content visualizes the extracted and filtered information, such as important keywords, emerging keywords, categories, etc. In addition, a word embedding method from natural language processing (NLP) is applied to learn from a given geo-text dataset, so that keywords closely related to users' interest are presented. The visualization is designed to be easily discerned and understood with the dynamically moving lens.
- *Lens Path Design:* In addition to manually moving a lens, users can define lens paths by free sketching on a map or by picking control points to create a smooth path from B-Spline approximation. This interaction allows users to repeatedly study semantic data along interesting routes.
- *Lens Tracing:* A historical moving trace (trajectory) of the lens, and the important keywords along with it, can be visualized to review the studied information and areas, and then to guide future movement.
- *Lens Anchors:* Users can push a lens at specific locations of interest into a snapshot list as an "anchor". Then, the anchors can be opened on-demand for drill-down and comparative studies.

These new lens interactions are supported by a hierarchical spatial data structure including pre-aggregated geo-text information, which efficiently stores and manipulates massive geo-text data. The techniques were evaluated through expert feedback and user studies which showed its utility and usability.

## 2. Related Work

### 2.1. Geo-Text Data Visualization

A common feature of various geo-text datasets is the association of geo-locations to natural language textual information, either explicitly with GPS locations or implicitly in the text. It thus greatly promotes research and practices that integrate textual data mining with geographical, urban, GIS and social applications. A generalized workflow is presented for geo-text data analysis in a recent review [Hu18], which is formed by data retrieval, parsing, data analysis, evaluation, and visualization. Visualization techniques have been developed to depict spatial, temporal and thematic patterns of geo-text datasets [AAD*10]. The most widely used data is geo-tagged social media, where the application often correlates map-based visualizations with a variety of interactive tools based on mining their text contents [SK13, BB17]. MacEachren et al. [MJR*11] provide a visual monitoring tool for situational awareness of geolocated Twitter data. The data are selected based on spatial grid cells but not using movable lenses. Bertini et al. [BBF*11] analyze the daily occurrence of filtered twitter data by location and time so that users can trace an epidemic's progress at city hospitals. Word clouds are used which are separated from the map view. Nguyen et al. [NTST11] visualize spatially and temporally referenced tags on the map as tag clouds, but they do not allow free selection of regions. Butkiewicz et al. [BDW*08] use coordinated visualizations to depict the local data in user-defined regions in a 3D GIS system. While users can observe and compare data across multiple local regions, the method is not designed for geo text data exploration. Miranda et al. [MDL*17] extract "urban pulse" by analyzing aggregated spatial time series from urban data sets (e.g., Flickr) over seminal public spaces, but movable lenses are not used in interactive exploration. Cho et al. [CWR17] discover events from twitter data and design interactive visualizations to study the identified future events. They further develop VAiRoma which allows users to learn and create new knowledge through visual analytics regarding Roman history by extracting geo information from Wikipedia documents [CDW*16]. Their work however does not focus on interactive exploration of geo text data on maps. Chen et al. [CYG*16] present an interactive visual analytics system of sparsely sampled trajectory data from geo-tagged social media. While users are allowed to explore the semantics of movements but the semantics is not shown with map lenses. Itoh et al. [IYT16] propose a "Word-clouds in the Sky" method that visualizes spatiotemporal events from microblog data as a multi-layered word cloud over map, which however is not freely movable. Li et al. [LDY18] combine metro map with wordle views of POI information in subareas to explore urban spatial characteristics but the subareas are not defined by moving regions. Different from these approaches, we present a context-aware lens for focus+context geo-text exploration and study lens interaction techniques to enhance and control of the exploration process.

### 2.2. Interactive Lenses

The interactive lens is an important visualization technology that depicts on-demand, changing, and less cluttered data details at a local part of the whole dataset along with users' moving focus. Tominski et al. present a comprehensive survey of this technology in visually studying multiple types of data of various applications [TGK*17]. They propose a conceptual model of lenses attached to a standard data visualization pipeline. Bier et al. [BSO*93] use magic lens filters to magnify regions in a see-through interface. ChronoLenses [ZCPB11] enable users to analyze time series data for selected time intervals which are overlaid on original data. The Sampling Lens [ED06] uses a sparsely sampled view over scatter plots and parallel coordinates to reduce point clutters. The EdgeLens [WCG03] and PushLens [SNDC10] use lenses to study a complex node-link graph. Magic Volume Lens [WZMK05] enlarges volume rendering results in a distorted local area over a scientific volume dataset. A planar lens polygon [FG98] shows the volumetric flow field in a spatial area. A lens widget [CC13] is applied on a 3D car model to select a mechanical part and then related text information about this component is extracted and visualized around the lens. Unlike GTMapLens, these approaches do not focus on geo-text data visualization in their lenses.

### 2.3. Lens on Maps

Enlarging map contents is a classic task of lenses. Virtual map lens [Map] is implemented so that users can drag it to investigate details of an inset, where map style and contents can be changed.

JellyLens [PPCP12] uses spatial distortion to connect the magnified region, and adapts its shape to spatial features. Detail Lenses [KCJ*10] allow users to select and visualize multiple critical geographical regions and POIs to represent driving directions. MapMosaic [LAP17] allows users to interactively create and manipulate local composites of multiple vector and raster map layers. These tools do not discover and depict underlying geo-text data behind the map. Our GTMapLens fills this gap by interactively showing the geospatial semantic information on a map.

BirdVis [FLF*11] allows users to explore relative habitat preferences of birds by dragging a rectangle lens over the map, and a tag cloud displays the related bird summary at regions of interest. In contrast to GTMapLens, the tags are not computed in real-time from individual geo-tagged items such as tweets, and it does not have path design and control, as well as anchor function for drill-down and comparative study. TrajectoryLenses [KTW*13] filter massive vehicle trajectories by placing lenses on map and selecting origins and destinations, traversed regions and time periods while geo-text data is not extracted and displayed. In contrast to these work, GTMapLens allows users to browse many geo-tagged data items on a map with interactive spatial text data retrieval and aggregation to study geographical semantics.

With regard to lens interaction on maps, a few techniques contribute to address some of the limitations presented in the introduction. Decal-lenses [RSA*19] manage multivariate visualizations on surfaces, and allow users to control them from the point of view of each lens. RouteLens [AACP14] automatically adjusts a circular lens' position based on the geometry of a path that users steer through. But it does not include path design and control as in GTMapLens. FingerGlass [KAP11] enables users to quickly navigate a lens to different locations and across multiple scales of a scene using a single hand. Its focus is to improve the precision of graphical tasks on multi-touch screens, while it does not include path design and geo-text information extraction. Langner et al. [LKD19] visualize a real-world, multivariate data set of crime activities on interactive wall displays. However, the focus is on exploring spatial-temporal distributions of crimes and the text information is not utilized as we do.

Thom et al. [TBK*12] cluster twitter data to detect spatio-temporal anomalies and overlay semantic layers on a world map for analysts to classify the presented and examined events on a global scale. Lu et al. [LSB*16] link a map view to word clouds and time line graphs for users to discover spatial events based on a time series intervention model. Lenses are used in these two techniques as spatial content filters, but their dynamic paths are not specifically designed and controlled which are studied in GTMapLens.

## 3. Requirement Analysis and Design Rationale

We conducted a requirement analysis with a group of ten professionals from different countries. They are selected to represent domain experts in multiple fields who have worked on geo-tagged text datasets. As shown in Table 1, the experts have been working on different geo-text data (mostly tweets) with a variety of tools and they have 2-30 years of working experience in their fields. The popular interactive tools they used were WordCloud and normal charts in data analysis software (e.g., R). All the experts were keen to use visual tools so that they could browse geo-text data on map directly.

**Table 1:** *Multidisciplinary experts for requirement analysis.*

| Expertise Field | Working Years | Geo-Text Data | Tools Used |
|---|---|---|---|
| Criminal Justice | 12 | Tweets/Microblog | Excel, R |
| GIS | 20 | Tweets/Microblog/Meituan | R, Python, ArcGIS |
| Communication Studies | 30 | Tweets | WordCloud, NLT Toolkit |
| Public Health | 5 | Tweets/Yelp | WordCloud, Google Maps |
| Political Science | 2 | Tweets | WordCloud, Excel |
| History | 5 | Tweets/Yelp | WordCloud, NVivo |
| Human Geography | 10 | Tweets/Microblog | WordCloud, ArcGIS |
| Social Work | 10 | Tweets/Yelp | Excel, WordCloud, NVivo |
| Linguist | 2 | Tweets/Yelp | WordCloud, R |
| Transportation Engineering | 5 | Tweets | R, Python |

In this study, we focus on investigating domain users' requirements of a lens-based visual browsing tool. Therefore, we implemented a simple lens for the experts to freely browse twitter keywords on a map without a time limit. Then they were asked to identify the benefits of lens-based exploration. They agreed on three points including: (1) Users can move their focus freely and easily; (2) Users can uncover dynamic changes of geo-text information over spaces; (3) Users can find cold spots (i.e., sparse and disperse locations having keywords of interest) that deserve attention, and reveal surprising knowledge. Lens tools are promising since they can display semantic information extracted from geo-text data within a geographical context.

While a simple browsing lens is easy to implement, the key motivation in this paper is how to *make the lens browsing tools on map useful for domain work with effective visualization and interaction functions*. The experts were asked to identify the interactions they need, to make the lens browsing more effective for their work. This was implemented as a guided process in which the experts were asked to select important interactions from a given list of candidates. We identified five main visual interaction tasks based on a consensus of their selections as:

- *T1. Lens browsing:* Users can define a lens and freely drag it to visually study preferred contents of geo-text data on a map.
- *T2. Lens semantics discovery:* Users can extract, filter, and then read keywords based on varying interests from spatial semantics along with the moving lens.
- *T3. Lens path control:* Users can design specific paths on a map so that a lens can automatically move following the paths.
- *T4. Location snapshot study:* Users can drill down to investigate details at any location of interest.
- *T5. Spatial comparison:* Users can compare different locations for specified semantic contents.

These tasks (T1-T5) indicate major research topics for designing a geo-text visual exploration tool with interactive lens technology. In addition, the visual interactions should be supported by efficient geo-text data management.

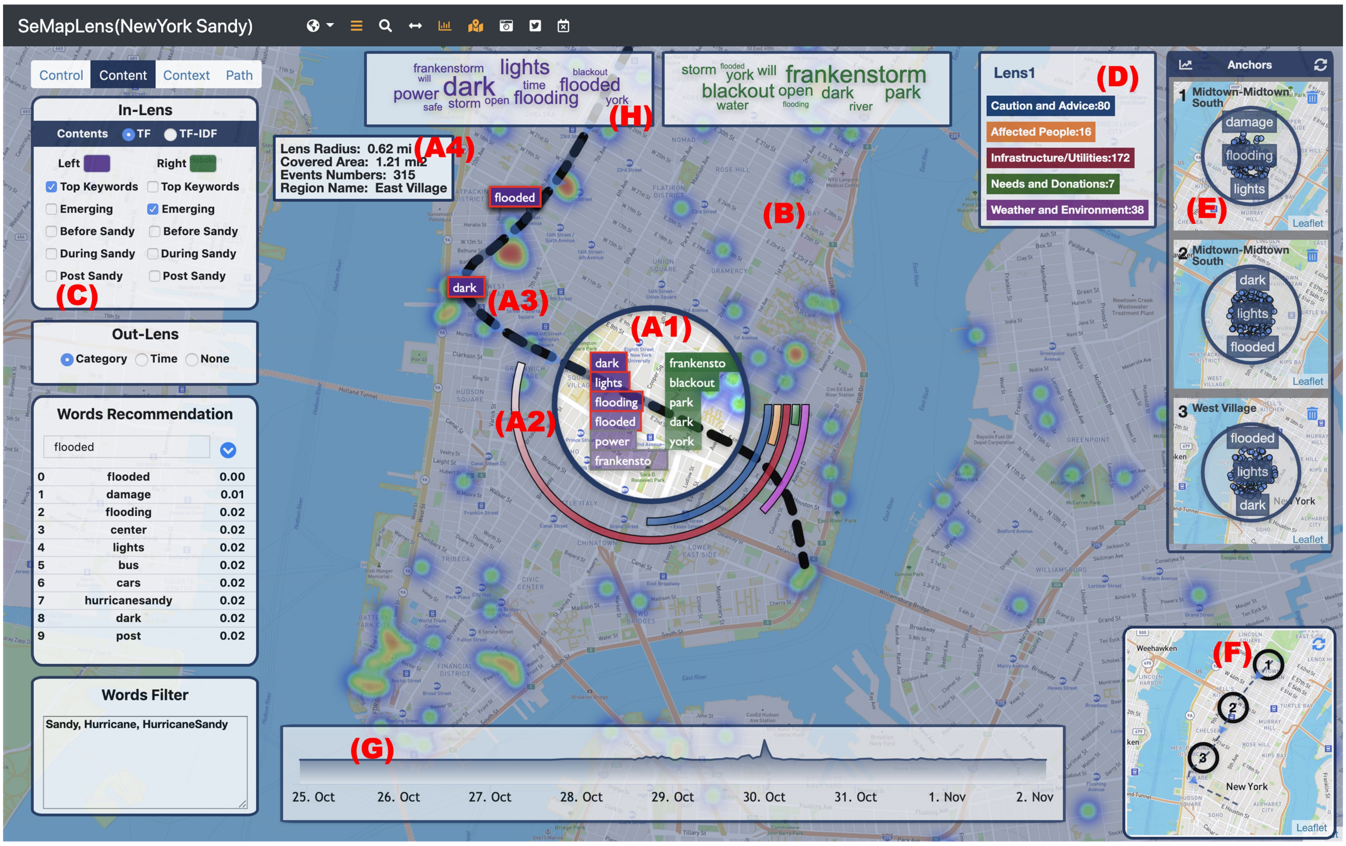


**Figure 1:** *GTMapLens interface. (A1) In-Lens. (A2) Out-Lens. (A3) Moving lens trace. (A4) Lens region information. (B) Map canvas with heatmap context. (C) Control panel of lens attributes, lens contents, lens context, and lens path. (D) Legend view. (E) Anchor List. (F) Historic trace inset. (G) Temporal distribution view. (H) Lens word clouds. All these components can be displayed or hidden by users.*

## 4. GTMapLens Design Overview

GTMapLens is designed for tasks T1-T5. First, it allows users to enable one or multiple lenses anywhere on a map, supported by map functions (e.g., zooming and panning), for free-style browsing to discover locations of interest and examine underlying geo-text data (T1). Second, the geo-text data is extracted and visualized in a dynamic way during browsing (T2). Third, visual exploration with path design and control is well supported by multiple ways such as map sketching. (T3). Fourth, it allows users to record locations of interest as snapshots at any time during lens moving. The extracted snapshots (named as anchors) are pushed to a special anchor list (T4). Finally, users can drill down to investigate and compare multiple anchors and multiple lenses. These actions are enabled by a geo-text database with a specific indexing scheme (T5). Semantic information is extracted from the database in real-time which is then visualized over map canvas for interactive explorations. When implementing GTMapLens, we follow three design principles including:

- *To support effective visualization of dynamic geo-text semantics:* While displaying textual contents of a lens moving on a map, the visualization should support changing contents, interactions, and real-time visualization. Fluid interaction guidelines [EMJ*11] can be taken into account for the design.
- *To guide exploration with focus+context interface:* Lens context information should be provided including the geographical context, the semantic context, and the exploration context.
- *To facilitate comparative studies*: Different locations and different categories of contents should be easily snapshotted and compared during browsing and drill-down studies.

A conceptual model of interactive lenses is presented in the survey by Tominski et al. [TGK*17] with three parts: lens selection, lens function, and lens join. Using this framework, GTMapLens is summarized as:

- **Lens Selection**: When users freely select regions of interest by moving a lens on a map, the underneath geo-text data is extracted in real-time from a spatial database.
- **Lens Function**: It performs data transformation by aggregating selected data items according to important keywords, categories, and temporal dimensions. Visual representations are designed to effectively display the information.
- **Lens Join**: The visual metaphors of the lens are dynamically overlaid on the map following the lens movement. Visual cues are provided to highlight them.

Fig. 1 illustrates the GTMapLens interface, where a lens browses the geo-tagged tweets over a map of New York City. Fig. 1(A1-A4) are components of the lens over a map canvas (Fig. 1(B)). A1 is the inside of lens (In-Lens), A2 is the outside of lens (Out-Lens), A3 is the lens moving trace, and A4 shows the region information. On the left, Fig. 1(C) is the control panel where users can set lens attributes, contents, context, and path in four tabs. The word recommendation and filter tools can also be operated here. Fig. 1(A1) displays two columns of semantic contents (e.g., top keywords and emerging keywords). Fig. 1(H) further shows two word clouds corresponding to the two columns with more keywords. The Out-Lens displays circular bars (Fig. 1(A2)) representing the categorical distributions of tweets in the lens region. Each geo-tagged tweet belongs to one category (labeled by domain experts). A map legend (Fig. 1(D)) shows this distribution and the category names. Fig. 1(G) shows the temporal distribution of these tweets. On the right, Fig. 1(E) is the Anchor List showing three snapshot anchors. Users can click any anchor to open a detail study view. Fig. 1(F) is a historic trace inset to show full trajectories of lenses in the city and locations of anchors. Users can show/hide these views on the map.

## 5. Interactive Geo-Text Data Retrieval

For quickly computing semantic information inside a moving lens region, we utilize a quad-tree based spatial indexing structure to store geo-tagged data points. More importantly, a new method is applied which pre-computes the *cell semantics* of the quadtree cells. Fig. 2 illustrates the quadtree cells that are retrieved by an example moving lens. A quadtree with three layers is used whose cell sizes are 250 meters, 500 meters, and 1 kilometer at different layers. Along with the lens moving, the quadtree is queried to select a set of cells inside the region. If a high-level (large) cell is completely contained in the lens, it is selected. Otherwise, its children are tested until the leaf level. When a leaf cell intersects with the lens border, we do not query all single data points inside it. Instead, we use the pre-computed *cell semantics* for the selected cells. This approach saves query time, while introducing some inaccuracy. We adopt this method because: (1) interactive data retrieval speed is achieved for smooth lens moving; (2) the accuracy is not a big problem as the lens is used to overview geo-text semantics to find locations of interest. In a drill-down study, users can further study accurate detail information; (3) the inaccuracy is limited to the size of the leaf cells which is reasonably small for tweets and yelp data, and can be refined if necessary. In experiments, we found a three layer quadtree is optimal for city-size discovery with tweets data. The resolution can be changed according to spatial scope and density of geo-tagged data points.

The cell semantics is pre-computed for each quadtree cell as top keywords, categories, and topics. For example, one cell stores a vector of keywords of the top $N$ (now $N = 100$) keywords. Each keyword is represented by a weight of term frequency (TF) or term frequency-inverse document frequency (TF-IDF). A vector of topical categorical distribution is also stored. Once a lens region is formed from the quadtree by a set of cells with different sizes, their semantic vectors are accumulated and used in visualization. For example, these cells store the keyword weights (TF or TF-IDF) in several $N$-dimensional vectors. They are added to compute the weights of this region in a whole.

Table 2 presents the real-time performance which is computed

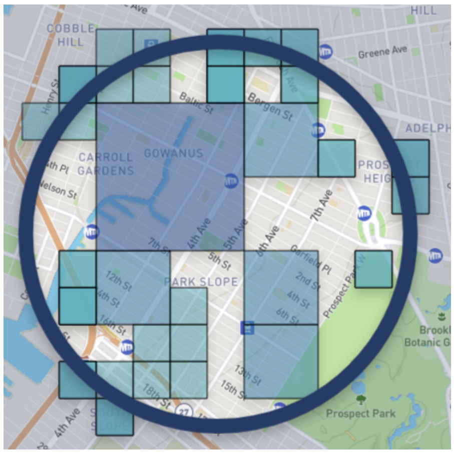


**Figure 2:** *A lens queries the quadtree and finds cells on three different levels. The cell sizes are 250m, 500m, and 1km. The cell semantics of them are aggregated to show semantic contents.*

**Table 2:** *Data retrieval performance in milliseconds (ms) with a dataset of about 20 thousand geo-tagged tweets of New York City.*

| lens radius | number of points | comparison algorithm time | time/speedup (2 layers) | time/speedup (3 layers) | time/speedup (4 layers) |
|---|---|---|---|---|---|
| 750m | 425 | 533ms | 63ms/8.5 | 98ms/5.4 | 165ms/3.2 |
| 1.5km | 969 | 842ms | 85ms/9.9 | 135ms/6.2 | 294ms/2.9 |
| 2.3km | 1795 | 1123ms | 155ms/7.3 | 232ms/4.8 | 432ms/2.6 |

by moving a lens within a dense distribution of geo-tagged tweets on a MacBook laptop (2.3G Core i5, 16G MEM, and 512G SSD). This dataset includes about 20 thousand tweets in New York City. The lens moves about 5 seconds with a speed of about 650 meters/second. The table reports the average number of points during this motion with three lens sizes. We also implemented a *comparison algorithm*, which utilizes a typical R-tree based spatial indexing tool to query the data points and extract the top keywords on the fly. The average computing time (including visualization) of this comparison algorithm is shown, together with our method with 2-, 3-, and 4-layer quadtrees. The 3-layer quadtree (with a size of less than 20 MB) achieves about 232ms refresh time for a large radius lens (2.3km) on an average of 1795 data points (tweets), which cannot observe obvious motion delay. The comparison algorithm cannot support the smooth motion with more than 1 second refresh time (1123ms).

*Scalability:* Our method can handle large numbers of points inside a lens region, since large cells with a fixed size of cell semantics will be retrieved instead of many small ones. On the other hand, when the data is retrieved over the network, the realtime performance may be affected due to the limitation of network transfer.

## 6. GTMapLens Visual Interaction Functions

GTMapLens is designed to support Schneiderman's information visualization mantra: "overview first then zoom and filter, and details on demand". While browsing geo-text data within geographical context, users move, zoom, and select data of interest and they can push those locations as anchors for drill-down study.

### 6.1. Lens Display and Control

A lens browses a focused circular region on a map (referred as LensRegion next) (Fig. 1(A1)). Users can change a set of lens attributes at the control panel (Fig. 1(C)) such as edge width, edge color, and lens radius and zoom-in level. To show semantic contents in the changing LensRegion, the design goal is to prevent text from changing quickly and to enable easy and fast perception. GTMapLens is designed to reduce as much as possible "frequent and sudden changes" of visual layout, position, and retinal properties as summarized in [DAF*17]. For the In-Lens area, we insert two columns of keywords showing a fixed number of keyword labels (Fig. 1(A1)). When the radius of the lens becomes small, these labels are located outside with the appearance of the eccentric labeling [FP07] (Fig. 3). The leading lines of keywords link them to similar locations as in the In-Lens view to make this change of view consistent and easy to understand. When needed, two dynamic word clouds can be opened with expanded information (Fig. 1(H)). This design is improved from an implementation that directly shows tag clouds (used in existing tools such as BirdVis [FLF*11]), which was tried but gave unsatisfactory results. The Out-Lens (Fig. 1(A2)) circular bars are used for visualizing dynamically changing categories that exist in many geo-text datasets. The arcs fit the shape of circular lens and seamlessly integrated with the lens, so that this design is better than a separate bar chart or other visualizations.

### 6.2. Lens Semantics

The semantic In-Lens contents show the top keywords and emerging keywords ranked by TF or TF-IDF weights. The emerging keywords are those keywords that recently appear during navigation. Here we design a delayed updating algorithm: the top keywords and emerging keywords are not computed at each sampling location during moving, since it may lead to disturbing popping keywords. Instead, the keyword frequencies are computed in a time window of a few consecutive sampling locations. This approach is important to maintain consistent, understandable visualization during lens moving. In addition, the left and right columns can also be used to show different sources of geo-text data (e.g., before Hurricane and after Hurricane), or different categories of data, so that the content visualization enables dynamic comparative studies.

### 6.3. Lens Contents Recommendation and Filtering

An important task for visualizing geo-semantics is to allow users to interactively control lens contents. In addition to visualizing top-ranked keywords as mentioned above, GTMapLens provides word recommendation and filtering functions to users. As users give their interesting keyword, the lens contents will automatically trace and show the most relevant keywords in the LensRegion. As shown in Fig. 1(C), users input "flooded" so that in the moving lens (A1) the most relevant ones are highlighted in red. Moreover, the closely-related words are recommended for users as shown below "flooded" for their further study.

Here the "closely-related" words are specifically computed over the given geo-text dataset by the word embedding technique through a pre-executed training process [MYZ13]. After training, for an arbitrary input word, its K-nearest neighbors in the trained word embedding space are utilized for visualizing the relevant words. the cosine similarity between word $w_1$ and $w_2$ is computed as:

$$sim(w_1, w_2) = \frac{\vec{w}_1 \cdot \vec{w}_2}{|\vec{w}_1| \cdot |\vec{w}_2|}, \quad (1)$$

where $\vec{w}$ denotes the vector-representation of $w$ in the word embedding space, and $|\vec{w}|$ denotes its length. In general, GTMapLens could further integrate other NLP (Natural Language Processing) and text mining approaches for better semantic exploration.

GTMapLens also includes a Words Filter. During navigation, users often find some words in the lens are not of importance or interest. They can interactively add such words to the filter, so the visualization does not show these words and gives space to other words.

### 6.4. Lens Contexts

GTMapLens allows users to move lenses around geo-text data for knowledge discovery. Contextual information can guide them to move the lenses and to define preferred paths. First, geo-tagged data points can be shown as markers on a map (e.g., Fig. 4). Second, these points can be aggregated and shown as heatmaps (e.g., Fig. 3). Third, spatial clustering can group these data items into local clusters (DBSCAN [BK07] is used), each of which represents a local region (e.g., Fig. 6), whose top keywords are shown on the region. Lens Contexts can also be dynamically filtered by keywords, categories, regions, and time windows to present hot-spots on the map that provide more detailed guidance for users to operate the lens.

Instead of using a distorted lens (e.g. fish eyes), we adopt a cue-based technique [CKB07] where the map transparency is changed to a darker appearance (controllable by users). It provides highlighting effects for lens contents while does not change the geo-objects for better understanding.

### 6.5. Lens Anchors and Detail Study

For drill-down studies, users can take a snapshot at any time by pushing an anchor to the Anchor List (Fig. 1(E)). Users click on any anchor to start a detail study view. In this view, users finely edit the lens shape as an arbitrary polygon to cover a preferred region (see Fig. 4). In the region, geo-tagged data items can be investigated in detail. Expandable wordcloud and statistic bar charts are provided to users for studying details of interest. Moreover, a topic transition view is designed based on a PCP (parallel coordinates plot) to show the main keyword changes of the anchors (Fig. 5). An alternative approach could be implemented is a composition of multiple circular lenses over surface regions as in [RSA*19].

### 6.6. Lens Tracing

The lens exploration history can be visualized to perceive the areas and paths having been studied, to compare the paths of peer lenses, and to recall locations of saved anchors. In Fig. 1(A3), users can

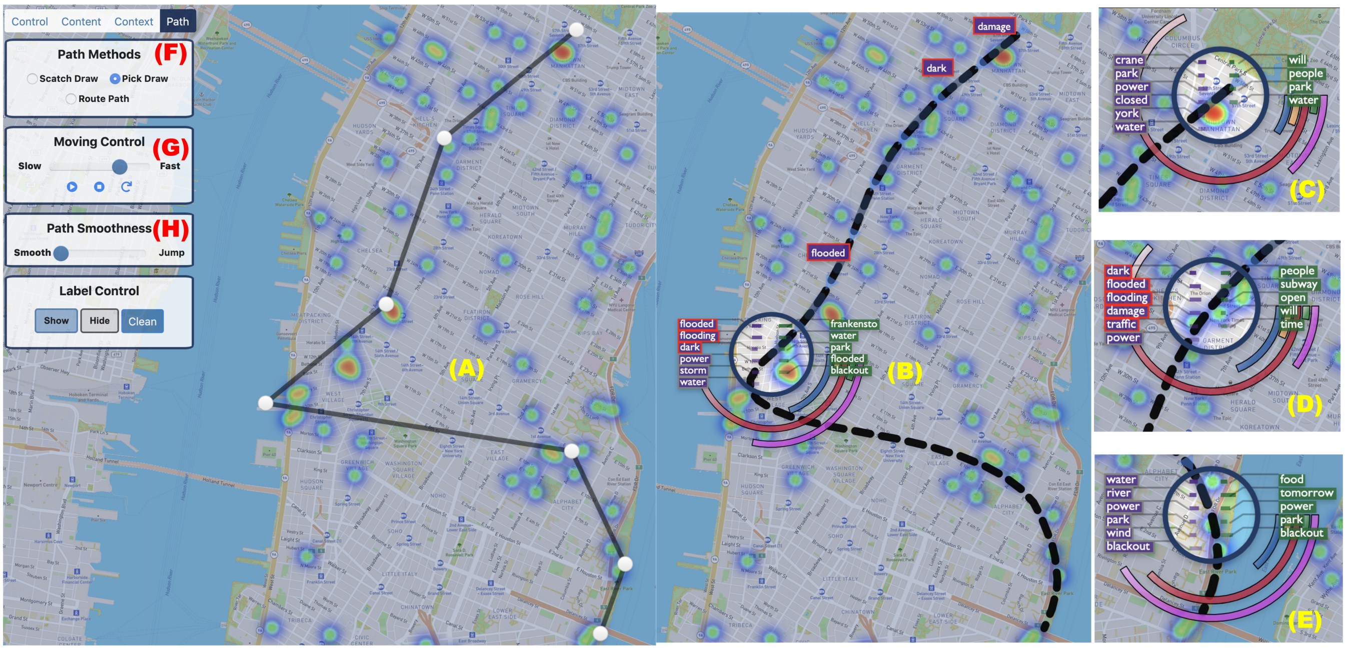


**Figure 3:** *Exploring tweets about Hurricane Sandy on a path over Manhattan. (A) Draw a path along by control points; (B) Generate a smooth path from the input and a lens moving on it; (C)-(E) Three snapshots of lens moving along the path; (F) Generate a path by pick and draw; (G) Control automatic moving speed; (H) Set smoothness factor.*

enable a lens tail to visualize its dynamic trajectory. Users can further activate *trace labeling*, so that the lens movement will automatically pin text labels (e.g. "flooded", "dark") on the map along the path. The labels display the top keywords of the lens history. Moreover, a user can click any text label to add this location as a snapshot anchor for further studies.

In addition, Fig. 1(F) shows a historic trace inlet which visualizes global trajectories of lenses with different colors. Meanwhile, the anchor locations are visualized on a map. This information provides dynamic situation awareness around a moving lens, which can be used to decide whether and where new anchors are needed and guide detail studies.

### 6.7. Lens Path Design

Users can sketch a path (Fig. 3) on the map with a mouse, a touch pen or hand drawing (if supported). A set of sketch points is collected based on the velocity of the sketch operation. Then, a polyline is formed from these points by connecting consecutive input points and extra points are inserted when necessary, so that the path created in a smooth way following users' drawing. Users also can design a path by picking several points on the map (Fig. 3(F)). These points as control points to connect POIs, roads, and other structures to approximate a smooth path as a B-Spline curve (see Fig. 3(A) and (B)). A smoothness parameter (Fig. 3(H)) is controlled by users to generate different B-Spline paths. After defining a path, a lens moves repeatedly and automatically, so that users can focus on the contents. The moving speed is controlled by users on the control panel (Fig. 3(G)) with a slider bar. Users can stop and move a lens at any time. In addition to manually moving lenses, the

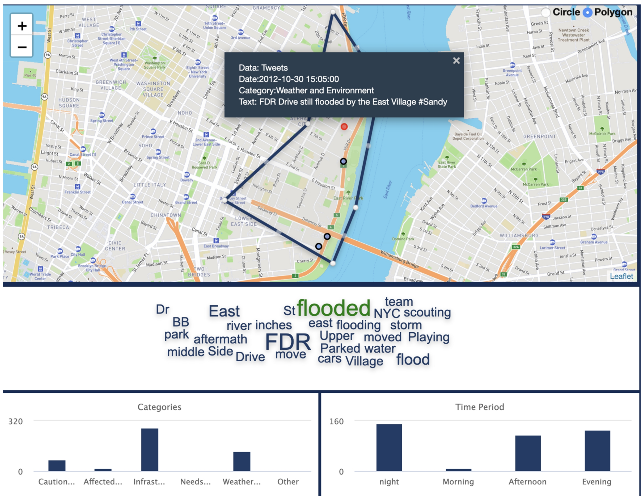


**Figure 4:** *Detail study view of an anchor of Fig. 3(E).*

path design tools provide convenient and controllable interactions which greatly improve the performance of knowledge discovery.

### 6.8. Multiple Lenses Comparison

GTMapLens allows users to perform comparative study in two stages including (1) Browsing: users add multiple lenses on the map, move them to different locations, and identify data differences during navigation; (2) Detail study: in the detail view, users compare multiple anchors for semantic contents, categories, and temporal distributions (e.g., Fig. 6).

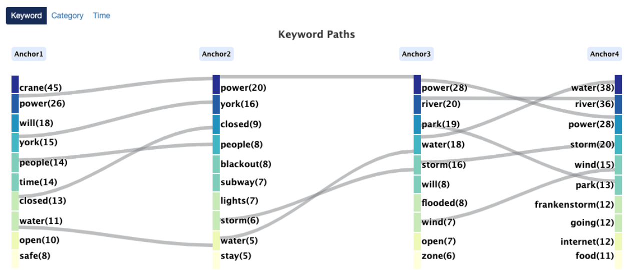


**Figure 5:** *Studying topic transition of the anchors of Fig. 3.*

## 7. Usage Scenarios

### 7.1. Geo-Text Datasets

Two geo-text datasets are utilized in the scenarios. The first dataset is the tweets about Hurricane Sandy (Oct. 22 to Nov. 2, 2012) which caused severe damage in New York. A total of 20,427 geo-tagged tweets in New York City are used here. Each tweet was classified by domain scientists into five categories [WY18]. The second dataset has 18,149 geo-tagged consumer reviews from Yelp about POIs in Las Vegas including hotels, restaurants, and entertainments from 2012 to 2018.

### 7.2. Exploring Hurricane Tweets at Manhattan

An analyst (named as Amy for easy description) studies the tweets about Sandy. She wants to find the change (or transition) of semantics from mid-Manhattan to lower-Manhattan. Amy picks several high-density points based on the heatmap showing the density of the tweets (Fig.3(A)). Then a smooth path is generated as shown in Fig.3(B). She controls the path smoothness in Fig.3(H). Then, Amy sets the automatic moving speed (Fig.3(G)) and starts a lens moving along the path. Four anchors are saved into Anchor List for Amy to compare them in detail. These snapshots of interest are shown in Fig.3(B)-(E). For example, in Fig.3(C), “crane” is an interesting word (a crane knocked down in mid-town due to Sandy), while “dark” is the top word in Fig.3(D) (due to power outage in the region), and “water” and “river” emerge in Fig.3(E) (close to the East River). They indicate different aspects of topics from Mid-Manhattan to Lower-Manhattan. One anchor’s detail view is shown in Fig. 4. In this view, the lens shape is no longer fixed as a circle. A polygon edit tool is applied so that Amy can adjust the study focus region of Fig. 3(E). She reads underlying tweet contents over a word cloud and finds categorical and temporal distributions over multiple charts. Amy also clicks several geo-markers to read the tweets. In Fig. 4, the red location shows a pop-up window in which the tweet indicates flooding status by the East Village. Furthermore, a PCP (parallel coordinates plot) based topic transition view is designed (as illustrated in Fig. 5) for Amy to compare the anchors. Keywords at each anchor are ranked by frequency from top to bottom, and similar keywords are linked. For example, water becomes a hot topic in Anchor 3 and 4, and crane knock down is a local event that does not extend to the other regions.

This usage scenario shows that GTMapLens allows Amy to discover the differences and changes of geo-text foci at different residential areas for the same event.

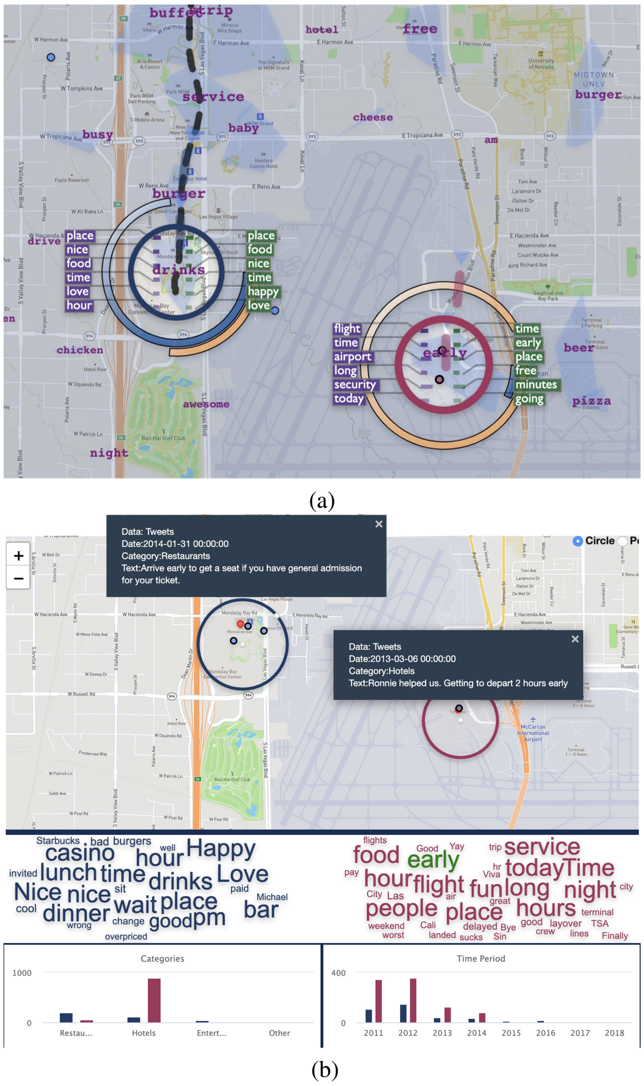


**Figure 6:** *Studying Yelp reviews in Las Vegas. (a) Two lenses with the semantic context showing the spatial clusters of geo-tagged reviews. (b) Detail view comparing the two lenses at the anchor locations (e.g., find reviews with a keyword “early”).*

### 7.3. Studying Yelp Reviews in Las Vegas

As shown in Fig. 6(a), GTMapLens is used in studying Yelp reviews in Las Vegas. In the beginning, Amy selects spatial clustering in different spatial areas from the clustering. Amy finds dense clusters in the middle with “strip”, “service”, etc. Then, she draws a path over these locations by sketching on the map. A blue lens is initiated and automatically moves along this path. When the lens moves to the end of the path, Amy notices a spatial area that shows “early” as a unique keyword. She then starts another red lens to browse this area which is around the airport.

In Fig. 6(b), Amy studies the details of the two lenses. The time and categorical distribution charts show the facts of reviews. The two word clouds show their top keywords of reviews in this region. As she is interested in “early”, she filters the reviews with this word. At the airport area of the second lens, the word is mentioned about early departure. In comparison, the first lens on the Las Vegas Strip, it also has reviews talking about early arrival for show tickets.

In this case, GTMapLens helps Amy form an insight through lens browsing and explore the details at different locations. When multiple lenses may be overlapping, users need to analyze them in the comparison view separately to overcome the cluttering of their contents and labels.

## 8. Evaluation

We evaluated GTMapLens in three steps. First, we asked domain experts (the same group as in the requirement analysis) to evaluate its utility in their work. Second, we compared the new lens functions with an existing tool. Finally, we performed a User Interface Satisfaction (QUIS) survey to evaluate the system interface and functions.

### 8.1. Step 1: System Utility Evaluation

The domain experts in Table 1 were asked to answer the following questions after getting accustomed to GTMapLens with both datasets:

1. "*How are the new lens technology usable for your work with geo-text data? (0-10)*". An average score of 8.2 was achieved which indicates the agreement of the system utility in real-world data analysis.
2. "*How does the tool satisfy your expectation from the requirement analysis?*". Eight experts selected "Match my expectation". Two experts selected "Exceed my expectation" and they provided explanations such as "It exceeds my expectation, since it can not only extract and analyze the texts, but also zoom in to a specific area by using lens. This assists my research a lot." and "It will largely help users know a place and play a great role in research activity".
3. "*To what extent the visual interface design is intuitive and easy to understand? (0-10)*". An average score of 7.9 was achieved which showed the visual design is generally acceptable for our target users not in the computer science and visualization fields.
4. "*Do you think the tool is easy to learn? (0-10)*". They gave an average score of 7.6 which showed that the tool was not very complex to the experts while some learning efforts were expected.

We further asked them about the limitations. The experts pointed out (1) "more NLP algorithms beyond bag of words such as using phrases could improve the software such as finding phrases"; (2)"progress indicator and summary results are needed in the interface"; (3) "provide an export tool to export tables containing the information."; (4) "open GTMapLens up to other open-source outlets"; (5) "should automatically grab Twitter data, and then automatically classify it."; etc. These feedback guides our future work to improve GTMapLens in real-world scenarios.

### 8.2. Step 2: Comparative Study

**Design:** GTMapLens adds interactions to existing lens browsing techniques over geo-text data. We conducted three comparative evaluations (E1-E3) with respect to the functions designed for tasks T1-T5 (Sec. 3). The functions were compared with BirdVis [FLF*11], which is one of the closest works to GTMapLens and the state-of-the-art lens technique for geo-text studies. We implemented the tag clouds inside a free moving lens (named BirdLens from this point on) as shown in BirdVis.

- E1: Participants rated the dynamic lens contents visualization (T1) and keyword display functions (T2) in GTMapLens compared with BirdLens. Both lenses were given the same fixed moving path in the comparison.
- E2: Participants rated the benefits of path planning and control functions (T3) in GTMapLens compared with BirdLens.
- E3: Participants rated the benefits of lens anchor (T4) and comparison functions (T5) in GTMapLens compared with BirdLens.

**Participants**: Fifteen graduate students (5 females, 10 males) participated in the studies. Ten of them were CS major with knowledge of visualization and interface, and the other five were from domain fields in GIS, geography, economy, and urban design who worked with geo-text data. Their ages ranged from 23 to 41. All the participants had used map-based tools before.

**Procedures and tasks**: An instructor presented GTMapLens to the participants and introduced each function for them to practice. Then, they were given 10 minutes to freely use the system. Afterward, the participants conducted the three studies (E1-E3) one by one. In each study, a participant was assigned to one of two groups using a lottery. Group 1 used version (1) before (2), and Group 2 did in the opposite order. The lens settings, such as lens size, map view with heatmap context, were fixed for both GTMapLens and BirdLens.

The participants explored the dataset of Hurricane Sandy for ten minutes with the systems. They were asked to summarize the geo events about the topic related to "flooding" from 7th Avenue Manhattan to Brooklyn Bridge using the systems. After completing each task, the participants were asked to rate both systems with 5-point Likert scale questions [Lik32]. For E1, they rated the dynamic lens content visualization and keywords functions (0-5) for (a) Comprehension: "Are the visualization functions easy to understand and access?"; (b) Recommendability: "Do you think the functions are recommendable for users?"; (c) Adjustment: "Are these visual functions easily adjustable?"; (d) Richness: "Are these functions rich to help the geo-text study?". They also gave a score for these questions for BirdLens.

For E2 and E3, the participants rated the visual interactions (0-5) of both GTMaplens and BirdLens for (a) Intuitiveness: "Is the design intuitive and easy to understand"; (b) Usefulness: "Is the design functional and useful?"; (c) Easy-to-use: "Is the design easy to learn and use?"; (d) Guidance: "Is the design helpful and does it provide certain guidance?"; (e) Sufficiency: "Is the design sufficient for the task?".

**Hypothesis**: We propose the following hypotheses based on existing literature on peer-based learning [XSW*19, DPSS17, DMTK18].

- H1: The lens content visualization and keywords functions of the GTMapLens system are more comprehensive (H1a), recommendable (H1b), adjustable (H1c), and rich (H1d) for geo-

**Table 3:** *Repeated measures ANOVA of three evaluation tasks*

| | | DF | MS | F | P-VALUE |
|---|---|---|---|---|---|
| E1 | Comprehension | 1 | 30.154 | 25.565 | 0.0004 |
| | Recommendable | 1 | 9.846 | 10.741 | 0.0031 |
| | Adjustment | 1 | 34.615 | 70.130 | 0.0001 |
| | Richness | 1 | 30.154 | 72.369 | 0.0001 |
| E2 | Intuitiveness | 1 | 4.654 | 6.981 | 0.0143 |
| | Usefulness | 1 | 7.538 | 17.552 | 0.0003 |
| | Easy-to-use | 1 | 0.154 | 0.316 | 0.5793 |
| | Guidance | 1 | 16.962 | 19.314 | 0.0001 |
| | Sufficiency | 1 | 12.462 | 12.623 | 0.0016 |
| E3 | Intuitiveness | 1 | 13.885 | 22.800 | 0.0007 |
| | Usefulness | 1 | 26.000 | 26.510 | 0.0003 |
| | Easy-to-use | 1 | 7.538 | 12.923 | 0.0014 |
| | Guidance | 1 | 16.962 | 19.036 | 0.0002 |
| | Sufficiency | 1 | 18.615 | 27.923 | 0.0002 |

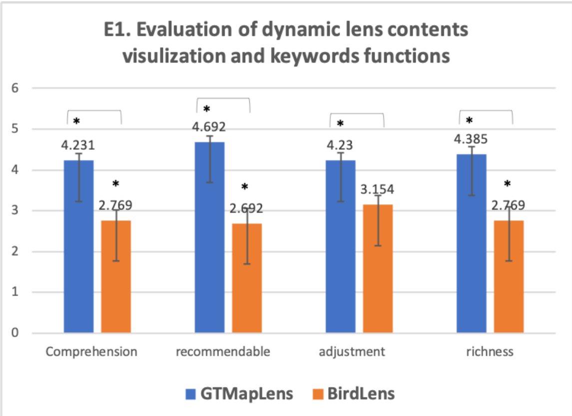


**Figure 7:** *Means and standard errors of E1 results on a 5-point Likert scale (∗: p <.05).*

semantic exploration in comparison with the tag clouds visualization inside the Birdlens system.

- H2: The lens path planning and control functions make the GTMapLens system more intuitive (H2a), useful (H2b), easy to use (H2c), with more guidance (H2d), and sufficient (H2e) for geo-text data exploration than the BirdLens system without these functions.
- H3: The functions of lens anchors and comparison functions make the GTMapLens system more intuitive (H3a), useful (H3b), easy to use (H3c), with more guidance (H3d), and sufficient (H3e) than the BirdLens system without these functions.

**Result and Discussion:** We studied the ratings and feedback, and ran repeated measures ANOVA, followed by the Bonferroni post-hoc test on measures with statistically significant differences. Table 3 shows the statistics results.

Fig. 7 shows the means and standard errors of E1 results. Table 3 reveals a significant difference (p = 0.0007) between the two systems. *Hypotheses H1a to H1d are supported*. This result shows that the visualization of lens contents in GTMapLens performs better than using tag clouds as in BirdLens. Our efforts that simplify the keyword layout and reduce the keyword changes help improve the perception in moving lenses. Moreover, the keyword recommendation and filtering functions are useful for geo-text studies.

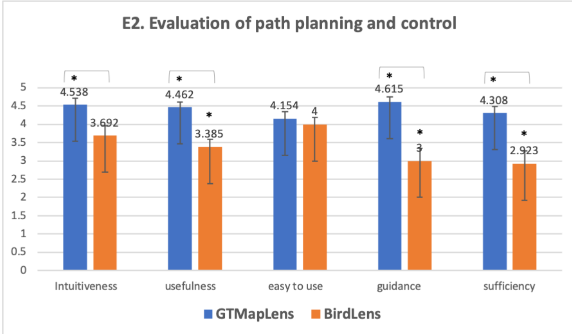


**Figure 8:** *Means and standard errors of E2 results on a 5-point Likert scale(∗: p <.05).*

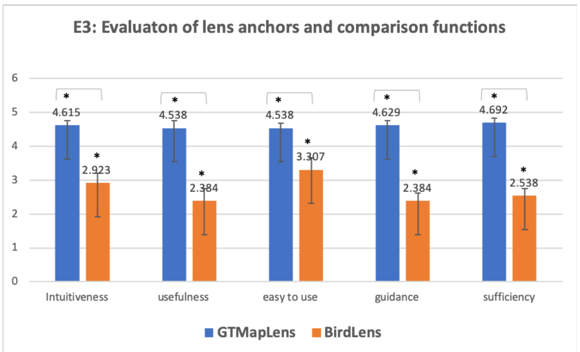


**Figure 9:** *Means and standard errors of E3 results on a 5-point Likert scale (∗: p <.05).*

Fig. 8 displays the means and standard errors of E2 results. *Hypotheses H2a, H2b, H2d, H2e are supported*. Both two systems in easy-to-use evaluation have similar means around 4.0 and have no significant difference in Table 3 (p = 0. 579). *Hypothesis H2c is rejected*. This indicates that the participants experienced some learning efforts for path planning. Fig. 9 displays the means and standard errors of E3 results. In Table 3, it shows a significant difference (p = 0.0002) between the two systems. *Hypotheses H3a to H3e are supported*. The E2 and E3 results are as expected: adding path control functions and anchoring functions significantly augments the usability of a free-moving lens when studying text data associated with a map. These interactions are essential to (1) overcome the cluttering problem when overlaying textual information on a map; and (2) help users explore a spatial space for underlying semantics.

**Feedback:** From the participants' feedback, a set of lens features are expected for further extension such as: (1) beside circular lenses, different shapes may be incorporated; (2) lens shapes may be adapted to urban regions; (3) lens moving positions can be adhered to urban routes if needed; (4) lens moving speed may be automatically adjusted based on lens contents; (5) More importantly, the lens paths may also be computed based on users input or exploration histories. We will design new GTMapLens functions based on these comments.

**Table 4:** *QUIS questions and ratings*

| Questions | Means | SD |
|---|---|---|
| *Part I: Visual Interaction Questions: 0(poor) - 9(excellent)* | | |
| *Lens browsing on map* | | |
| Lens edge weight, edge color, lens radius. | 8.08 | 0.21 |
| Map transparency and zoom level control. | 8.06 | 0.27 |
| Lens keywords and category display. | 7.69 | 0.26 |
| Lens filtering and recommendation. | 8.15 | 0.22 |
| Time period selection. | 7.92 | 0.31 |
| Map context view with semantic marker heatmaps and clusters. | 7.95 | 0.21 |
| *Lens path design and visualization* | | |
| Scratch draw. | 8.62 | 0.18 |
| Pick draw. | 8.39 | 0.14 |
| Map context suggestion with semantic heatmaps and clusters. | 8.46 | 0.18 |
| Path trace and semantic labeling. | 8.54 | 0.14 |
| *Anchors control* | | |
| Save anchor. | 8.62 | 0.18 |
| Compare anchors. | 8.62 | 0.14 |
| *PartII. Visual system rating* | | |
| *Interface* | | |
| Reading labels and icons on screen. 0(very hard) - 9(very easy) | 7.69 | 0.21 |
| Highlighting selected foci in study. 0(not at all) - 9(very much) | 7.77 | 0.30 |
| Organizing information on the interface. 0(confusing) - 9(very clear) | 7.69 | 0.18 |
| Sequential operations on the interface. 0(confusing) - 9(very clear) | 7.15 | 0.30 |
| Interaction on visual tools. 0(very hard) - 9(very easy) | 7.54 | 0.24 |
| *learning* | | |
| Learning to operate the system. 0(difficult) - 9(easy) | 6.62 | 0.45 |
| Performing tasks is straightforward. 0(never) - 9(always) | 7.08 | 0.35 |
| *System* | | |
| System response with good speed. 0(very slow) - 9(fast enough) | 7.85 | 0.22 |
| Designed for all levels of users. 0(never) - 9(always) | 7.39 | 0.35 |
| System reliability. 0(unreliable) - 9(very reliable) | 7.54 | 0.18 |

### 8.3. Step 3: QUIS Evaluation

After the participants completed the comparative study, they answered a QUIS questionnaire for the evaluation of user interface satisfaction. Table 4 shows the questions and ratings about: I. the visual interaction design and functions, and II. the system. The means and standard errors of the user ratings are displayed as well. The GTMapLens functions received good ratings from the participants. In particular, the lens path design and anchor functions received excellent ratings with an average of about 8.5. The system interface was rated very good with an average of about 7.6. The system response, speed, and reliability were rated very good as well with an average of about 7.5. For the system learning, the rating was good with an average of about 6.8, which indicated the participants' opinion that the system may need a training process at the beginning for general users, which was also reflected from their comments.

## 9. Conclusion and Discussion

We present a new visualization tool, GTMapLens, that helps users interactively study geo-text data on a map. It integrates dynamic lens content visualization with keyword recommendation, lens comparison, path planning and control, and anchor-based detail studies. These features were identified by domain experts and shown to be useful for visual studies of geo-text data in our evaluations.

Several limitations were identified through the user study which will be addressed in future work. First, more functions and controls can be added to lens contents, shapes, paths, and context. Second, NLP and text data mining tools may be included such as extracting important phrases and sentences. Third, the tool is good at street or small region level studies. To be used on a large geographical scale, it needs to be specifically revised for performance and visual presentation. The restricted scope of the work is the lens technology, which will be compared with other non-lens tools in a further user study.

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