# Mobrex: Visualizing Users' Mobile Browsing Behaviors

Stefano Burigat, Luca Chittaro and Lucio Ieronutti

**ABSTRACT**
**In this paper, we propose interactive visual analysis to study specific visualizations of users' mobile browsing behaviors and gain insights beyond those obtainable from performance-based studies alone.**

**KEYWORDS**
**Information visualization, map browsing, small-screen devices, mobile interaction, user studies**

## Introduction

People are increasingly using mobile devices to browse information spaces - including documents, pictures, Web pages, and maps - that were traditionally available only to desktop and laptop users. However, the mobility context and technical limitations (such as small screen size, different input peripherals, and limited computational capabilities) make it impossible for application designers to simply port successful browsing techniques from desktop computers to mobile devices. [4].

When browsing an information space on a small screen, users must select a portion of that space to visualize, leaving the remaining space off-screen. They do this by using the screen as a window, or *viewport*, that they can move over the information space. Depending on their device controls, they might:

- scroll, using horizontal and vertical viewport controls;
- pan, by dragging the viewport in any direction; or
- zoom, to obtain multiple perspectives by changing the information space's scale.

User browsing strategies thus depend on the specific interaction technique they use to scroll, pan, or zoom. Researchers have proposed various browsing techniques' but few have studied their effects on performance and user satisfaction. Further, the existing studies typically obtain results using statistical analysis of user performance data, such as the time needed to complete a browsing task or the number of user actions. While such analysis is important for comparing browsing techniques' effectiveness, interactive visualizations of user browsing behavior could help improve our understanding of user performance and clarify the causes of browsing problems.

We've designed the Mobile Browsing Explorer (Mobrex) to give analysts a set of visualizations that highlight various aspects of how users browse an information space. Here, we describe the tool and demonstrate its support of a user study of three browsing techniques for mobile maps. Although we mainly focus here on PDAs and mobile map browsing, Mobrex can easily support analysts studying user interaction with other information spaces and other devices, including mobile phones and desktop computers.

## Related work: visualizing user browsing behavior

Researchers have proposed various techniques to simplify scroll, pan, and zoom operations for mobile devices (e.g., [8][9]). Comparing these techniques could offer a comprehensive view of such user actions and offer developers important insights. Unfortunately, literature that deals with visualizing this data is limited.

Most research focuses on studying user behavior while browsing Web sites, using visualizations of Web navigation and interaction logs (e.g., [3][0]). A few projects have focused on visualizing eye gaze or mouse trails. MouseTrack, for example, is a usability analysis system for Web pages that visualizes mouse trails, using color-coded segmented lines augmented with arrows that indicate movement direction [1]. The size of a shaded area around the trail allows researchers to see the time users spent over a particular point; shade intensity encodes mouse hesitation over continuous zones. Similarly, the ReVise toolkit lets researchers capture and reuse usage sessions with geovisualization tools [10]. In particular, it automatically records users' interactions - such as key-presses, mouse movements, and annotations - and lets researchers subsequently display them in an overlay to examine how people used tools and data.

Other projects focus instead on visualizing users' navigation and interaction behaviors in 3D virtual environments. Such visualizations are typically based on superimposing icons and glyphs or color-coded overlays on a 2D map of the VE. For example, Borner and colleagues record and visualize spatially and temporally referenced user interactions such as navigation or object manipulation [2]. In contrast, Hoobler and colleagues focus on the visual analysis of team strategies and competitive behavior in team-based combat games [7]. Their system acquires interaction data - such as player movements, fire actions, and status (such as current health) - and visualizes them over a bird's-eye orthographic view of the VE as a match progresses. These two approaches focus on visual analysis of group behavior in multi-user YEs. However, our recently
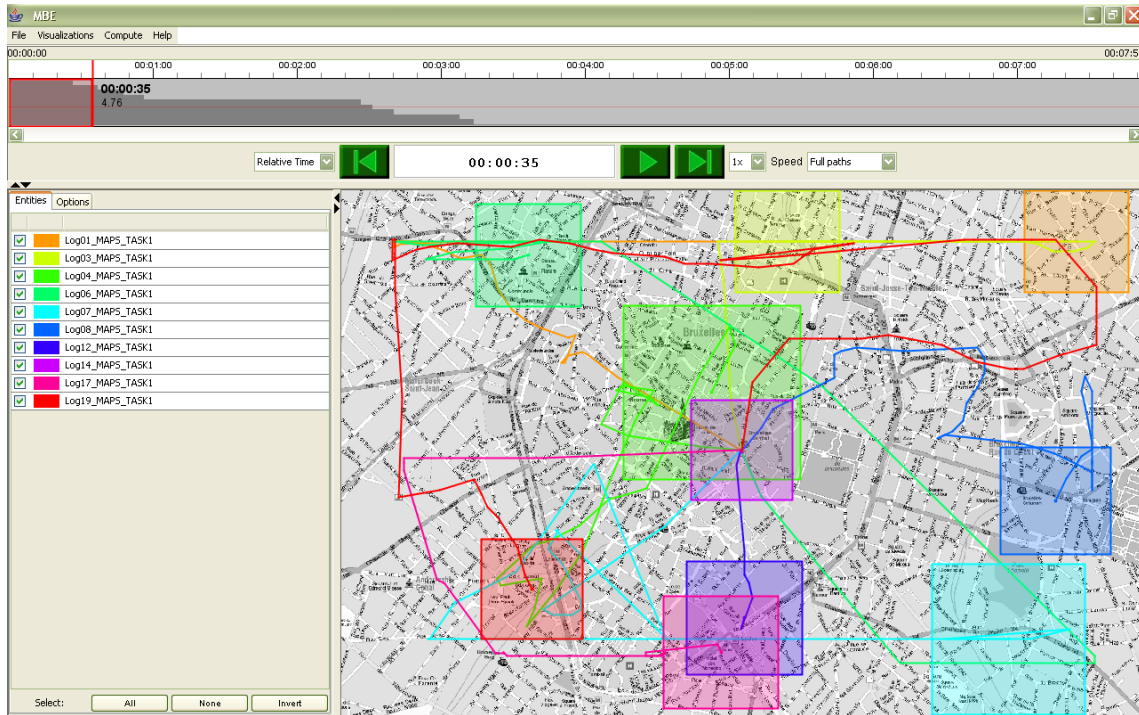
**Fig. 1.** Individual sessions visualization: the browsing trails for the sessions selected on the left are visualized over the map on the right; the system displays the portion of trails up to the instant selected in the timeline in the upper part of the interface. The colored rectangles highlight the area of the map users are looking at in the considered instant.

developed Visualization of User's Flow tool allows researchers to analyze the navigation patterns of moving entities, such as users, vehicles, or virtual characters, in multi-user and single-user VEs [5]. With VU-Flow, researchers can compare navigation data recorded in different sessions by postprocessing position logs and visualizing user behavior over the VE's 2D map.

## Mobrex overview

Our work is partially inspired by projects that focus on visualizing users' navigation behaviors in VEs (see previous section). Rather than track and visualize user movements in VEs, however, we track and visualize user operations while browsing information spaces on mobile devices.

### Logged data

Mobrex processes log files (hereinafter, *browsing logs*) of user browsing sessions. Each line of these logs describes a specific event recorded during a specific browsing session, and is structured as follows:

- type of event (e.g., panning action, zooming action),
- current zoom level,
- currently displayed area of the considered information space (identified by the coordinates of its upper left corner and its height and width,
- timestamp.

Additional information (e.g., size of information space, user identifier) is recorded once inside each log file.

### Visualizations

The visualizations provided by Mobrex can be grouped into two categories:

- *Detailed visualizations.* These visualizations are aimed at highlighting the spatio-temporal evolution of specific browsing parameters (e.g., the zoom level or panning speed) for each individual browsing session. They are based on simultaneously displaying the spatial evolution over the considered information space and the temporal evolution on a timeline. They are aimed at highlighting different aspects of the browsing behavior of individual users, allowing one to compare browsing patterns of different users, but can be also used to identify group behavior and temporal patterns (e.g., the distribution and length of panning and zooming actions).

- *Aggregated visualizations.* These visualizations are aimed at highlighting browsing patterns of groups of users, e.g., by identifying the areas of the information space where users spent more time. In these visualizations, data belonging to different browsing sessions are first aggregated, and then visualized over the space.

### Detailed visualizations

The spatial part of detailed visualizations is based on plotting the browsing behavior of users as a trail that connects the sequence of center points of the viewport as it changes over time while users browse the information space. The size of the viewport at the currently
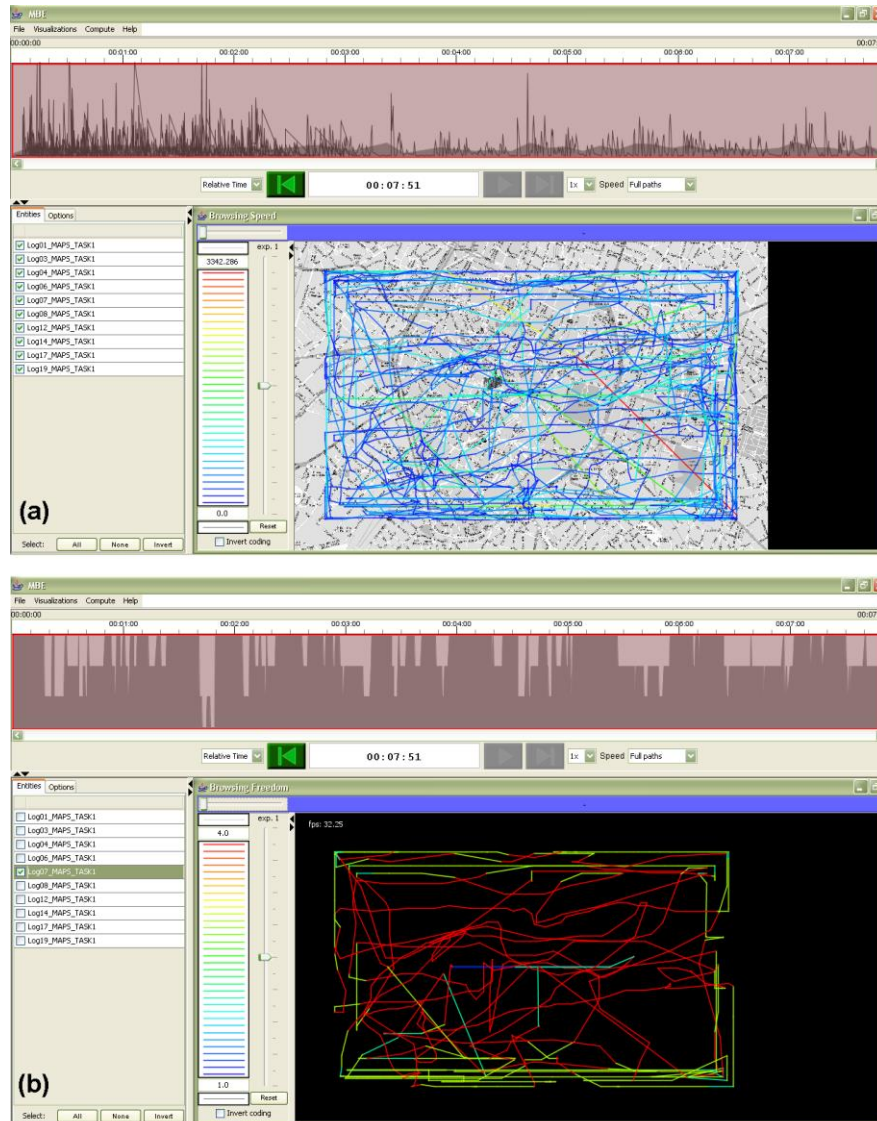
**Fig. 2.** (a) Browsing speed visualization: the color of each trail displayed on the map is used to encode the speed at which each user browsed along her browsing path. The timeline on the top shows instead the evolution of browsing speed over time as a separate segmented line for each session and the mean browsing speed as a shaded area. (b) Freedom of movement visualization: color of trails is used to encode how much freedom of movement (in terms of the four cardinal directions) users had while browsing the map; the timeline shows the number of available directions (on a 4 levels scale). In this example, the background map has been turned off to improve trail visibility.

considered instant is accurately displayed by means of a rectangle (as in Fig. 1). The color of each trail is used to encode the specific browsing parameter under examination. For example, in the *individual sessions* visualization of Fig. 1, the color of lines is automatically chosen so that each browsing session is associated to a different color. This allows one to examine the spatial evolution of the trails of multiple users (or multiple sessions of the same user). The timeline is displayed in the upper part of the interface and shows the time length of all the considered browsing sessions.

A different example is illustrated in Fig. 2(a), where the color of each trail is used to highlight *browsing speed*. Following the rainbow color scale displayed to the left of

the map, red lines are associated to the maximum browsing speed within all selected browsing sessions, while blue lines indicate the minimum browsing speed. Intermediate speed levels are associated to intermediate colors. The timeline in Fig. 2(a) shows instead the evolution of browsing speed for all selected browsing sessions as a function of time. Each session is displayed as a separate segmented line, and the mean speed at each time instant is also shown as a shaded area.

Detailed visualizations are useful to identify global trends or spatio-temporal patterns involving the considered browsing parameter. For example, in Fig. 2(a), one can notice that browsing speed is higher at the beginning of

the sessions and is generally similar among the selected browsing sessions, with some isolated peaks.

Beside browsing speed, we provide additional visualizations to study the following aspects of user's browsing behavior:

- *Trail evolution over time*. This visualization employs the color of trails to codify the time at which each user was in a specific position on the information space. It is used to obtain an overview of how trails evolve over time, without requiring the analyst to replay each browsing session.
- *Zoom level*. Color of trails encodes the zoom levels selected by users.
- *Browsing actions*. This visualization allows one to discriminate when users are panning, scrolling, zooming, or idle. Each type of action is mapped into a different color in the spatial part of the visualization, and into a different value in the timeline.
- *Browsing direction*. This visualization allows one to discriminate among horizontal, vertical and diagonal movements (blue lines are associated to horizontal direction, red lines to vertical direction and intermediate colors to other directions).
- *Freedom of movement*. This visualization highlights the number of cardinal directions in which users could move while browsing. For example, when users browse along the borders of a map they are limited in the directions they can follow compared to when they are moving in the middle of the map. This is illustrated by the example in Fig. 2(b), which shows the trail of one user. Blue lines correspond to movement constrained to one direction only, cyan to two directions (this is common at the corners of the map), yellow to three directions (along the borders of the map) and red to four directions (maximum freedom). The timeline on the top shows the number of available directions (4 discrete levels are displayed) at different time instants.

Mobrex allows one to analyze multiple sessions related to the same user as well as sessions related to multiple users. To support comparison among sessions, the visualizations are typically produced in a relative-time mode, where all considered sessions are visualized as if they started at the same instant in time. Alternatively, it is possible to use absolute time, showing the possible time gaps that occurred among starting instants of sessions.

The interface of Mobrex provides the analyst with a high level of flexibility in interacting with the visualizations. Indeed, one can:

- Replay movements using VCR-like controls located below the timeline, including the possibility to fine tune the replay speed.
- Select a specific time interval, by dragging the mouse from the starting to the ending instant of the desired interval on the timeline in the top part of the interface. As illustrated by Fig. 1, the desired interval is highlighted by a red rectangle and only the portion of the trails belonging to that time interval is displayed in the spatial visualization. This feature allows the analyst to focus on specific parts of browsing sessions (e.g., the first 10 seconds).
- Select which browsing session to analyze by using the checkboxes in the right part of the interface (see Fig. 1 and 2). This feature allows the analyst to focus on specific browsing sessions.
- Specify a sliding time window to determine what portion of the trails to draw (e.g., last 10 seconds, last minute). This feature allows the analyst to focus on a sliding part (e.g., the last 10 seconds replayed) of the browsing sessions.
- Decide whether to display the rectangles that highlight the map area viewed by each user.
- Zoom and pan the visualization to analyze its details. Zooming the timeline allows one to analyze the user behavior at a different timescale.
- Choose the color scale used to encode data. Besides the rainbow color scale used in Fig. 2(a) and Fig. 2(b), it is possible to use a scale based on two-colors exponential interpolation [11]. The transition between colors can be fine-tuned by using the slider displayed beside the color scale in Fig. 2(a) and Fig. 2(b) to set the parameter used for exponential interpolation between colors. This solution allows one to more clearly highlight subtle differences between values and is particularly effective when values are not uniformly distributed. Alternatively, it is possible to replace the color scale with a scale that maps values into the thickness of trails.
- Convert the background map to greyscale or hide it to improve trail visibility.

**Aggregated visualizations**

Aggregated visualizations are aimed at discovering patterns that cannot be easily revealed by detailed visualizations only, due to the cluttering issues that occur when multiple or very long browsing sessions are displayed. In these cases, browsing data should be presented at a level of abstraction that makes it easy to visually detect peculiar behaviors or patterns.

Aggregated visualizations are obtained by subdividing the information space into a discrete number of cells (the number can be interactively changed by the analyst) and filling cells with color or colored hedgehog arrows. The analyst can customize the color scale employed by each visualization as with the detailed visualizations, vary the transparency of cells (to improve the visibility of the underlying information space) as well as zoom and pan to analyze specific parts of the visualization in more detail. Moreover, if the analyst chooses a specific interval in the timeline, aggregated visualizations are computed for that time interval only (i.e., they are based on the data in that interval).

The *browsed areas* visualization uses color to show how many times different areas of the information space were browsed. For example, in Fig. 3(a), this allows us to identify a diagonal area through which, on average, users moved more often than anywhere else. This visualization is *time-independent*, i.e., it does not take into account time spent in the area. As a result, it is not affected by the browsing speed of users.

The *speed* visualization uses color to show how fast users browsed different areas of the information space. For example, in Fig. 3(b), user average speed was quite homogeneous across all areas, with the exception of a slightly higher speed in a limited area on the left and at the bottom.

The *time spent* visualization uses color to indicate how much time was spent by users in different areas of the information space. It is *time-dependent* and thus takes into account browsing speed, because the slower users move, the greater is the time to go through an area. For example, Fig. 3(c) highlights how users spent most of their time browsing a diagonal area and focused in particular on the extreme and middle points of this area.

The *flow* visualization informs the analyst about the predominant direction and intensity of browsing, using colored hedgehog arrows. More specifically, the direction of each arrow indicates the predominant direction of browsing in the area, while the color of the arrow is associated to the intensity of browsing. Intuitively, the intensity of browsing highlights how much uniform was the direction of browsing in an area. Flow visualization is time-independent, and thus does not take into account the speed of users. For example, in Fig. 3(d), we can determine that users browsed diagonally from the center of the map to the lower left corner, vertically from the bottom to the top of the map near the vertical borders, horizontally from left to right at the top of the map and from the center of the map to the right border. In all other areas of the map there is no clearly predominant direction, as highlighted by the dark blue color of arrows.

It is important to highlight that the color scale employed for aggregated visualizations is built by associating the lowest value of the considered data to one endpoint, the highest value to the other endpoint, and intermediate values to intermediate colors according to the chosen interpolation. For example, the visualization in Fig. 3(b) highlights that browsing speed was quite homogeneous across all areas but does not inform the analyst about absolute values (i.e., the blue color is associated to low speed relatively to other data values in the same visualization only). The value associated to each cell is displayed inside tooltips when users move the mouse pointer over cells. Moreover, the analyst can modify the
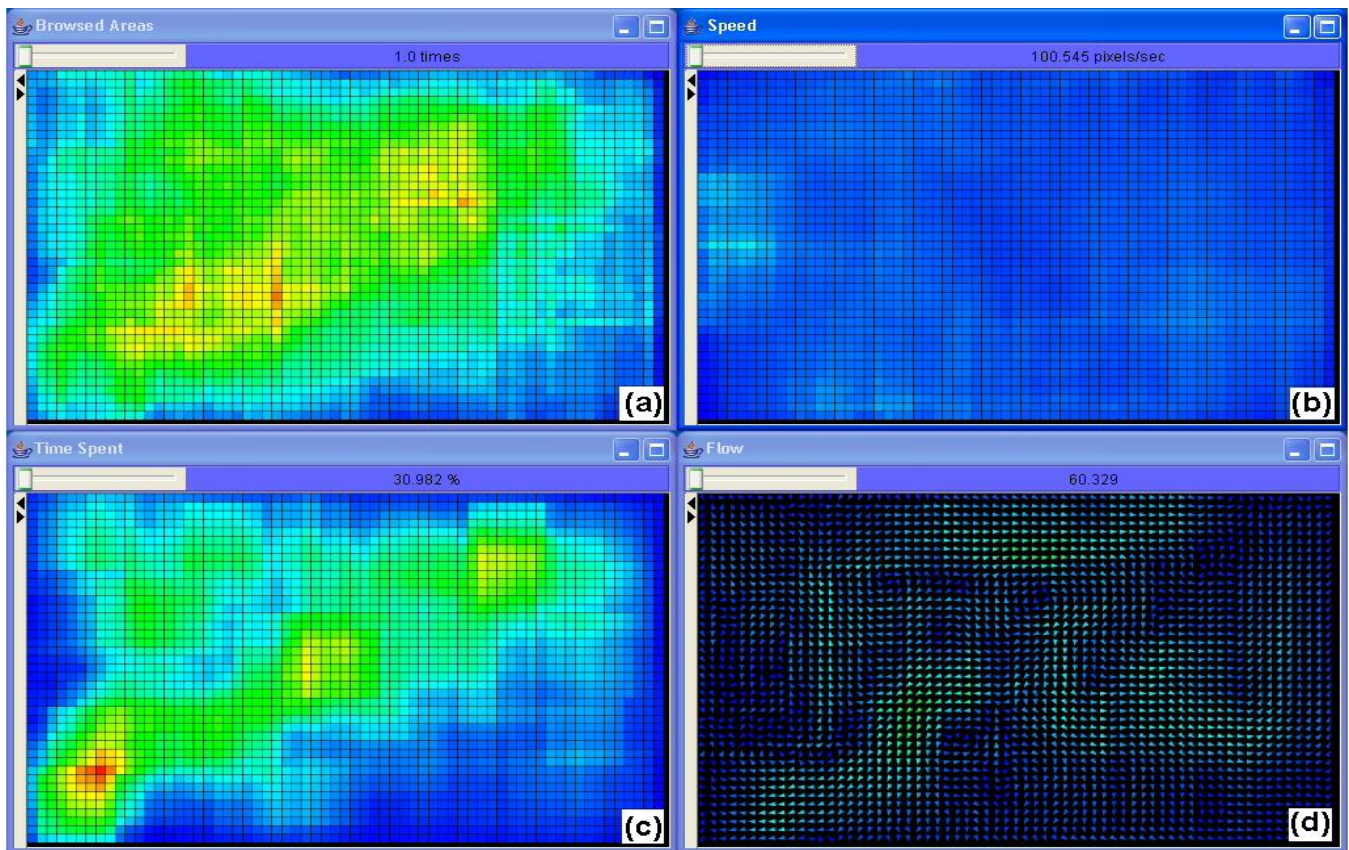


**Fig. 3.** Aggregated visualizations: browsed areas visualization (a), speed visualization (b), time spent visualization (c), flow visualization (d)

mapping of colors by associating custom values to the scale endpoints. In this way, it is possible to define an absolute scale, e.g., by associating the value 0 to one endpoint.

## Case study

This section shows and discusses the output of Mobrex on a real user study. We collected the logs during an experimental evaluation that compared three different techniques to support browsing on mobile devices.

### The considered techniques

Two of the evaluated techniques are frequently employed in desktop as well as mobile user interfaces. The first technique (hereinafter, *DoubleScrollbar*) allows users to perform scrolling operations by using separate vertical and horizontal scrollbars (Fig. 4), and zooming operations by choosing a specific zoom level among a predefined set. The current level is indicated by a percentage and users can change it either through a menu (Fig. 4) or by tapping two specific icons depicting a magnifying glass with a plus or minus sign. The plus (minus) icon is also grayed out when the maximum (minimum) zoom level is reached. As users perform panning or zooming operations, the position and length of both scrollbars thumbs (i.e., the draggable sections of scrollbars) change dynamically to highlight which
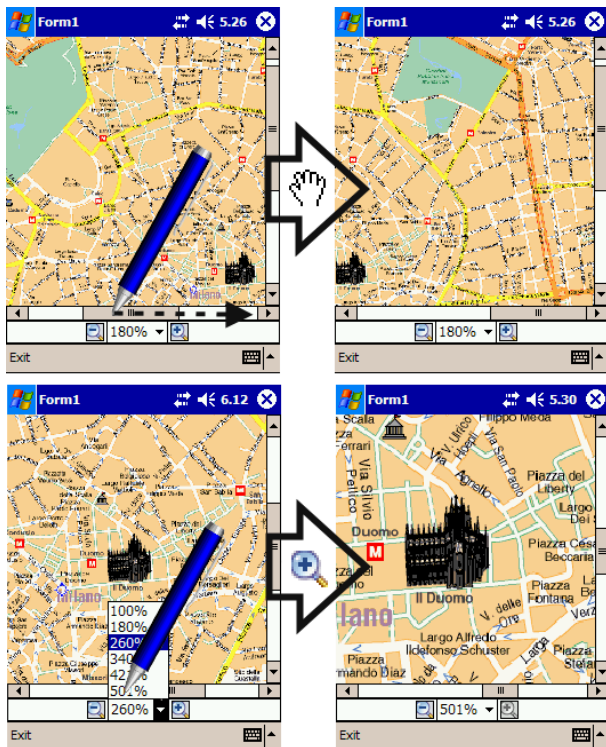
portion of information space is currently displayed on screen.

The second technique (hereinafter, *Grab&Drag*) allows users to perform panning by dragging the portion of information space displayed in the viewport (Fig. 5). On a PDA, dragging is carried out by moving the stylus in any direction while keeping it in contact with the screen. Zooming can be performed by operating a slider (Fig. 5). The zoom level is incremented (decremented) by dragging the slider thumb towards the plus (minus) sign and the currently selected zoom level is displayed as a percentage.

The third technique, called *Zoom-Enhanced Navigator* (ZEN), is an evolution and adaptation to mobile screens of Overview&Detail approaches, which are based on displaying an overview of an information space together with a detail view of a portion of that space. ZEN is composed by three graphical elements (Fig. 6): a black rectangular outline plays the role of overview, providing information about the proportions of the information space; a red rectangular outline (hereinafter, *viewfinder*) within the overview highlights the portion of space displayed in the detail view and can be manipulated to browse the information space; a gray circle inside the viewfinder highlights the area the user can tap to perform panning on the information space. If the user taps instead the viewfinder area comprised between the circle and the red outline, she becomes able to change the size of the
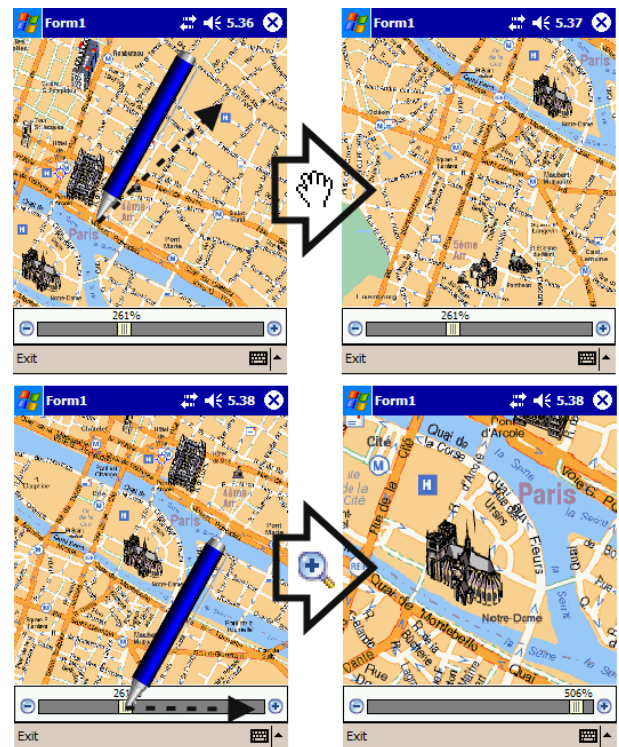


**Fig. 4.** Panning with DoubleScrollbar is carried out by using separate vertical and horizontal scrollbars. Zooming is carried out by choosing a specific zoom level among a predefined set, either through a menu or by tapping the two icons depicting a magnifying glass.



**Fig. 5.** Panning with Grab&Drag is carried out by grabbing and dragging the portion of information space displayed in the viewport. Zooming is carried out by operating the slider at the bottom of the interface.
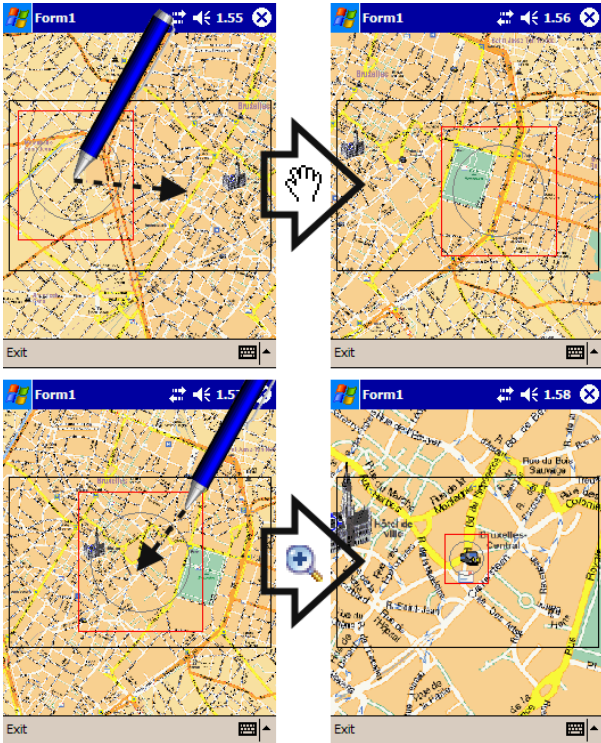
**Fig. 6.** Panning with ZEN is carried out by tapping the area inside the gray circle in the viewfinder and dragging in the desired direction. Zooming is carried out by tapping the area between the viewfinder border and the inner gray circle border and dragging inwards (to zoom in) or outward (to zoom out).

viewfinder: dragging outwards increases the size of the viewfinder, and thus decreases the scale of the information space, while dragging inwards decreases the size of the viewfinder and increases the scale of the information space (Fig. 6).

### *Discovering information*

The dataset we consider concerns 120 browsing sessions (a total of about 63000 sampled data) collected from 20 users who carried out two different tasks on three large city maps. In the first task (MapTask1), users had to browse the map to identify a specific street, while in the second (MapTask2) they had to identify the shortest path (in terms of distance to be traveled) between two specific underground stations on the map. In all tasks, users started their browsing session at the center of the map.

One of our interests was to identify the strategies employed by users to carry out their search tasks with the different techniques. To this end, we first studied each session by using the controls provided by Mobrex to replay browsing sessions. In this way, we identified three main strategies.

Fig. 7(a) illustrates an example of the first strategy, a structured *lawnmower* search that alternates horizontal and vertical panning actions spanning all the considered map. In Fig. 7(a), the user moves first from the center to a corner of the map (by first browsing towards the right

border and then towards the upper right corner). Then, he starts the structured search, mixing horizontal panning actions along the whole width of the map with short vertical panning actions at the left or right borders. We found this behavior to be typical of users employing DoubleScrollbar and ZEN.

The second strategy we visually identified is an *unstructured* search, illustrated by the example in Fig. 7(b). As one can notice, the user mixes short and long panning actions, often inverting the browsing direction without having fully explored an area (e.g., the leftmost part of Fig. 7(b)) or moving through the same area multiple times (e.g., the two areas in the upper left and lower right of Fig. 7(b)). We found this unstructured search to be widespread among users employing Grab&Drag and much less common with the other two techniques.

The third strategy is a mix of the previous ones, usually starting with structured panning actions and changing over time into an unstructured search. For example, Fig. 7(c) shows the structured portion (first 60 seconds) of the search displayed in Fig. 7(d). After having explored all the map during the structured phase, the user resorts to an unstructured search to complete the task.

Aggregated visualizations allowed us to identify a difference in the way users browsed maps in MapTask1 compared to MapTask2. Typically, users thoroughly explored all map areas in the former while they focused on the specific areas that contain underground station symbols in the latter. This is illustrated in Fig. 9, where most of the areas are green-red for MapTask1 (Fig. 9(a)) while there are large blue areas (less browsed) and green-red areas (more browsed) for MapTask2 (Fig. 9(b)).

Another difference becomes evident by comparing aggregated speed visualization for ZEN (Fig. 8(a)) with aggregated speed visualization for Grab&Drag (Fig. 8(b)). The homogeneous dark blue area in Fig. 8(a) reveals that users explored the map at a constant speed with ZEN, while the light blue and green areas in Fig. 8(b) reveal that users moved at faster speed with Grab&Drag and that their browsing speed in the center area was slower than elsewhere (especially along the vertical borders). We also found the same pattern when comparing ZEN and DoubleScrollbar, regardless of task and map considered.

To perform the comparison, we employed the same color scale (i.e., we associated the same values to the endpoints) for each group of aggregated visualizations we considered.

Detailed visualizations provided interesting information about the browsing behavior of individual users and groups of users. For example, Fig. 10(a) shows the spatio-temporal visualization of the zoom level for a group of users employing Grab&Drag. As one can notice in the timeline, there is a quick increase of the zoom level at the beginning of the browsing session for most of the users and the average zoom level (highlighted by the
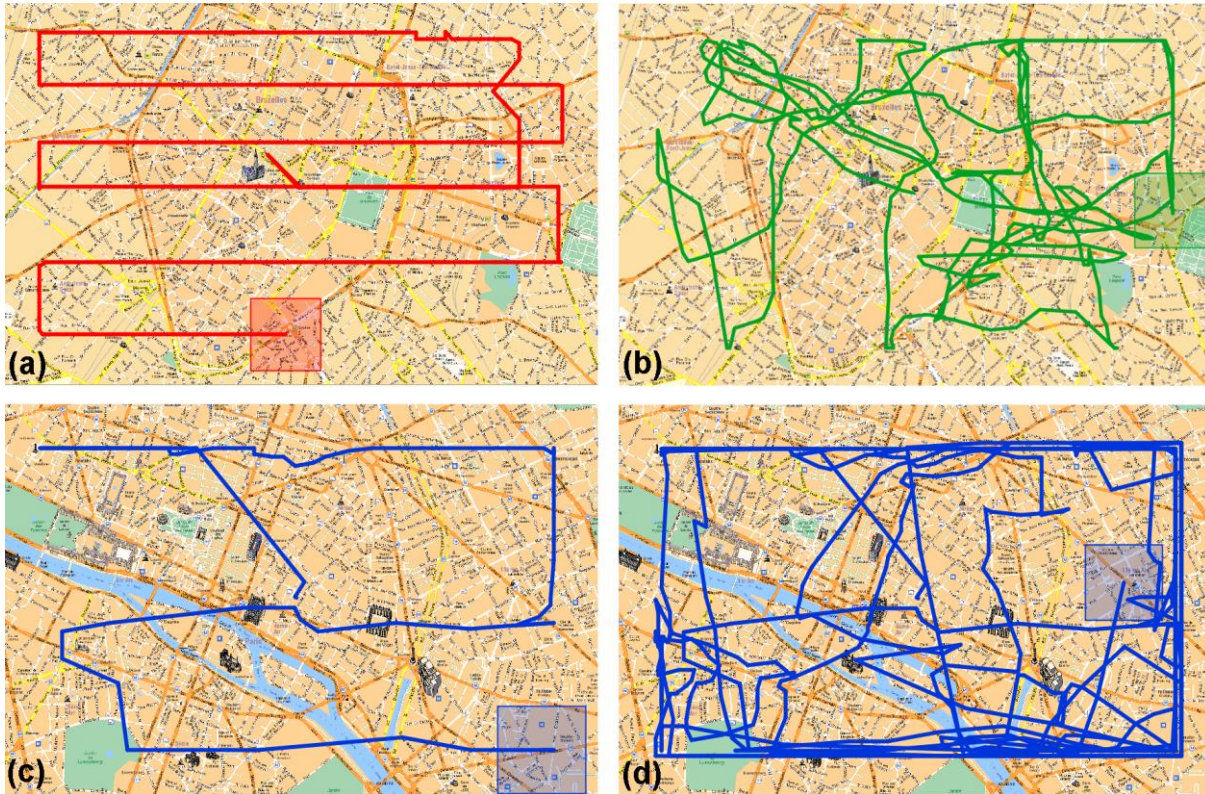
**Fig. 7.** Browsing strategies employed by users in our study: lawnmower search (a), unstructured search (b), structured portion of a mixed search (c), mixed search (d).

shaded area) remains high in the first 3 minutes (the time by which all but one of the users completed their browsing task). However, one user (whose timeline has been highlighted in bold) employed a lower zoom level. This is probably a reason for the bad performance of this user, who took longer than the others to complete the browsing task. By examining the zoom level visualization for each browsing session, we found such a correlation between zoom level and task completion time to be common for users of all three techniques.

The browsing direction visualization allowed us to better analyze when and where users performed horizontal, vertical or diagonal panning actions. The example illustrated in Fig. 10(b), where blue lines are associated to horizontal direction, red lines to vertical direction and intermediate color lines to other directions, was typical of all MapTask1 browsing sessions. As one can notice, horizontal and vertical movements dominate over diagonal movements. This is an indication of a general preference of users for regular grid-based movements, regardless of the flexibility provided by Grab&Drag and ZEN. Interestingly, horizontal dominates over vertical movement, especially in the center area of the map. Vertical movements are indeed performed almost exclusively nearby the vertical borders of the map. This finding, common to all three techniques, shows that users preferred to browse each map by moving along

horizontal bands that span all the map length and that are connected by vertical movements at both ends.

The browsing speed visualization revealed that all users typically moved at a constant and slow pace, as illustrated by the example in Fig. 2(a), where most of the trails in the spatial visualization are blue and the mean speed in the timeline does not vary much. Speed peaks in the timeline are associated to zoom actions performed near the border of the map. Indeed, such actions typically lead to a change of the center point of the viewport, thus being considered as a very fast panning action.

The browsing freedom visualization allowed us to better analyze the behavior of those users who took more time to complete tasks. An example of this visualization is illustrated in Fig. 2(b). As highlighted by the yellow-coded portions of trails, the considered user often browsed along the borders of the map (especially the bottom). This behavior, which was very common for users employing Grab&Drag, is also observable in the timeline, where one can notice how the user browsed for a long time along the borders at the end of the session. Probably, this decrease in the number of possible browsing directions helped Grab&Drag users to reduce the disorientation due to the unavailability of orientation cues (such as the scrollbars in DoubleScrollbar or the viewfinder in ZEN).
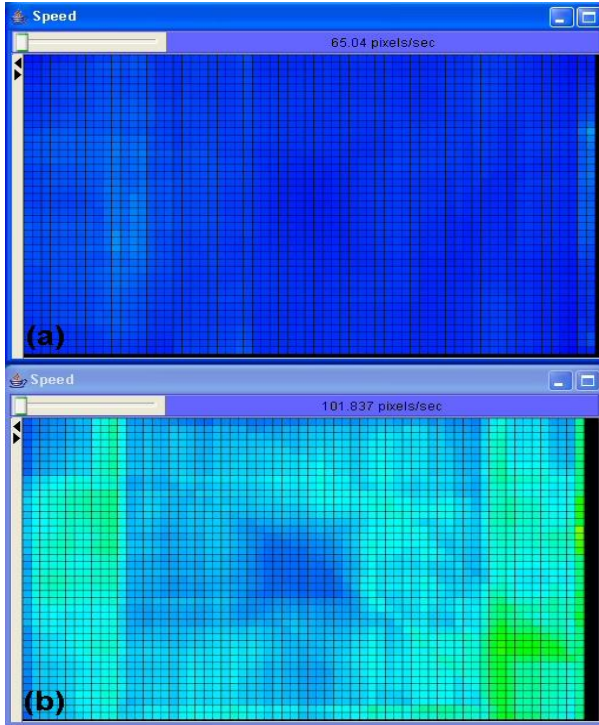
**Fig. 8.** Speed visualization for ZEN (a) and Grab&Drag (b).



**Fig. 9.** Browsed areas visualization for MapTask1 (a) and MapTask2 (b).

## Conclusions

Visualization can help interface designers to understand how users interact with their applications, leading to the discovery of interesting behavior or problems. The tool we propose allowed us to derive insights into user browsing strategies with mobile devices and how these strategies relate to each one of the three browsing techniques we analyzed. Moreover, we were able to identify possible explanations for the unique behavior of some of the users (such as those taking a long time to complete a task), an activity that would have been less straightforward with other means, such as statistical analysis of the browsing logs.

To get a more comprehensive view of user browsing behavior, we plan to employ our tool for the analysis of additional browsing techniques as well as take explicitly into consideration other variables that can affect browsing (e.g., degree of detail in the map, user familiarity with the real locations).

We will also design additional visualizations to complement the current ones. For example, current visualizations of the temporal evolution of browsing parameters are suited to highlight the unique behavior of some users or a global trend concerning a specific browsing parameter. However, they are not particularly suited to highlight temporal patterns in the browsing behavior of users. Similarly, current aggregated visualizations can highlight the overall behavior of users but cannot identify clusters of users showing similar behavior. F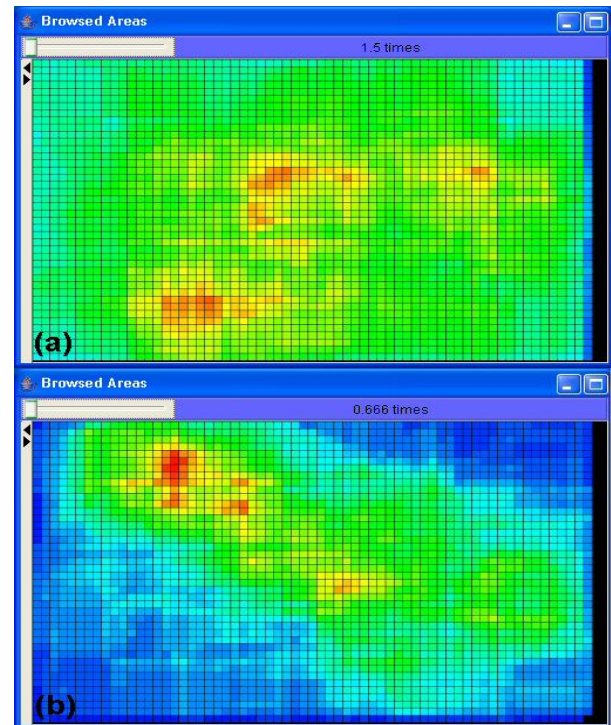or example, if half users move from left to right on a map and the other half move in the opposite direction, the flow visualization shows an overall neutral direction, failing to identify the two clusters. The provision of descriptive statistics and the integration with data mining algorithms would thus be useful to improve these visualizations, providing the analyst with additional information to better understand the behavior of users.

## Acknowledgments

## References

1. Arroyo, E., Selker, T., and Wei, W. "Usability tool for analysis of web designs using mouse tracks", in *Proc. Conference on Human factors in computing systems (CHI 2006)*, ACM Press, pp. 484-489, 2006.
2. Börner K. and Penumarthy S., "Social Diffusion Patterns in threedimensional virtual worlds", *Information Visualization*, Vol. 2, pp. 182-198, 2003.
3. Chi, E. H. "Improving Web Usability Through Visualization", *IEEE Internet Computing*, issue 2, pp. 64-71, 2002.
4. Chittaro, L. "Visualizing Information on Mobile Devices". *IEEE Computer*, Vol. 39 No. 3, pp. 40-45, 2006.
5. Chittaro L., Ranon R., Ieronutti L., "VU-Flow: A Visualization Tool for Analyzing Navigation in Virtual
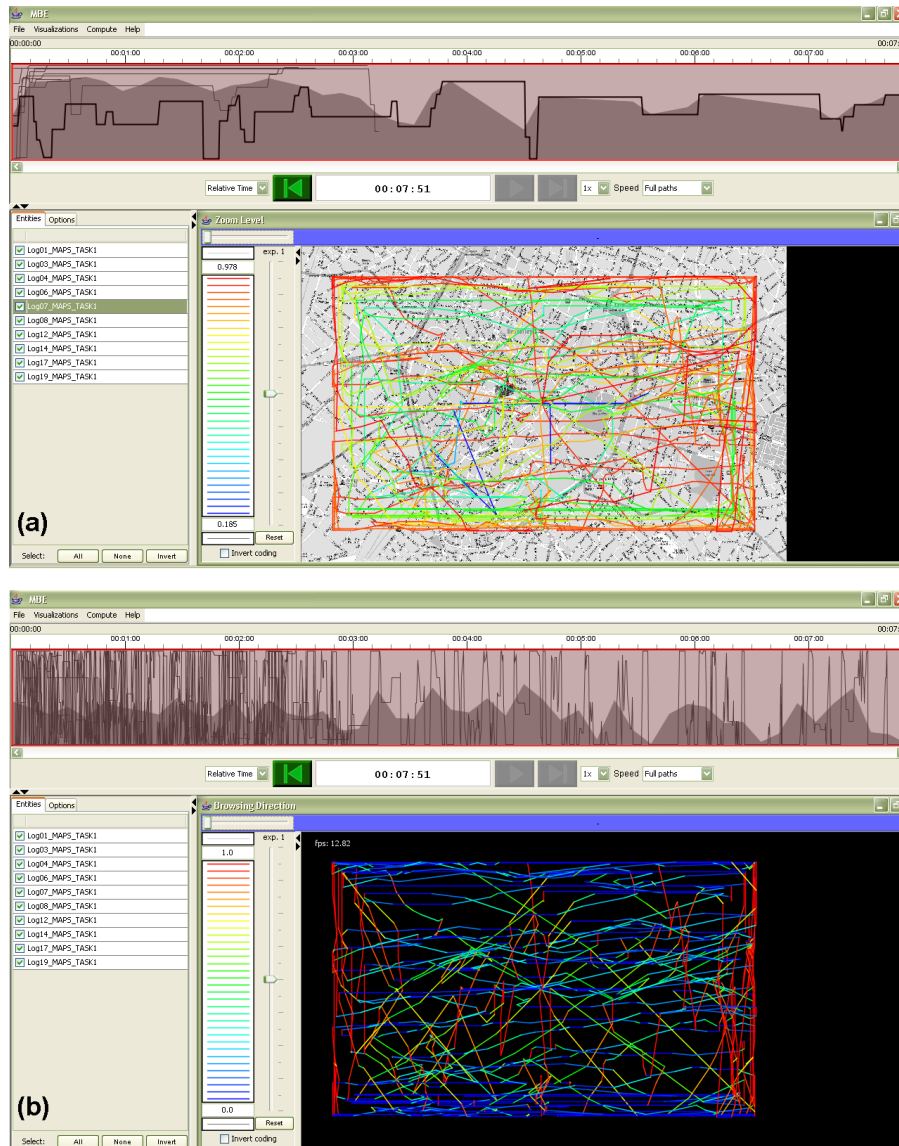
**Fig. 10.** (a) Zoom level visualization: the segmented line highlighted in bold in the timeline belongs to the user that took most time to complete the browsing task among the selected users. (b) Browsing direction visualization: color of trails is used to encode the direction in which users are browsing the map. In this example, blue lines are associated to horizontal direction, red lines to vertical direction and intermediate colors to other directions.

Environments", *IEEE Transactions on Visualization and Computer Graphics*, Vol. 12 No. 6, pp. 1475-1485, 2006.

6. Herder E. and Weinreich, H. "Interactive Web Usage Mining with the Navigation Visualizer", in *Proc. Conference on Human factors in computing systems (CHI 2005),* ACM Press, pp. 1451-1454, 2005.

7. Hoobler N., Humhpreys G., and Agrawala M., "Visualizing Competitive Behaviors in Multi-User Virtual Environments", in *Proc. Conference on Visualization 2004*, IEEE Press, pp. 163-170, 2004.

8. Jones, S., Jones, M., Marsden, G., Patel, D. and Cockburn, A. "An evaluation of integrated zooming and scrolling on small screens", *International Journal of Human-Computer Studies*, Vol. 63 No. 3, pp. 271–303, 2005.

9. Robbins, D.C., Cutrell, E., Sarin, R. and Horvitz, E. "Zonezoom: Map navigation for smartphones with recursive view segmentation", in *Proc. Conference on Advanced visual interfaces (AVI 2004)*, ACM Press, pp. 231–234, 2004.

10. Robinson, A.C. and Weaver, C. "Re-Visualization: Interactive Visualization of the Process of Visual Analysis", in *Proc. Workshop on Visual Analytics and Spatial Decision Support at GIScience 2006*, Muenster, Germany, September 2006.

11. P. Schulze-Wollgast, C. Tominski, H. Schumann, "Enhancing Visual Exploration by Appropriate Color Coding", in *Proc. Conference in Central Europe on Computer Graphics, Visualization and Computer Vision 2005*, pp. 203-210, 2005.

## Bios

**Stefano Burigat** received the PhD degree in Computer Science from the University of Udine, Italy, in 2007. Since 2003, he actively works at the HCI Lab (http://hcilab.uniud.it) of the University of Udine. His research interests are in human-computer interaction, particularly in mobile devices and services, geographic data visualization, and 3D virtual environments. He is author of 11 internationally refereed publications on these topics.

**Luca Chittaro** is full professor in the Department of Mathematics and Computer Science at the University of Udine, where he heads the HCI Lab (http://hcilab.uniud.it). His research interests are in human-computer interaction, particularly in information visualization, mobile devices and services, and 3D interfaces. He is the author of more than 140 publications. He is chair of the Italian chapter of the ACM Special Interest Group on Computer-Human Interaction.

**Lucio Ieronutti** received the PhD degree in Computer Science from the University of Udine, Italy, in 2006. Since 2003, he actively works at the HCI Lab (http://hcilab.uniud.it) and the Software Engineering and Information Systems lab (http://users.uniud.it/pighin/soften g.htm) of the University of Udine. His research interests are in 3D virtual environments, information visualization, and information systems. He is author of 16 publications on these topics.

## Contact information

**Stefano Burigat**
HCI Lab, Department of Mathematics and Computer Science, University of Udine, Via delle Scienze, 206, 33100, Udine, Italy
Tel: +39 0432 558457
e-mail: stefano.burigat@dimi.uniud.it

**Luca Chittaro**
HCI Lab, Department of Mathematics and Computer Science, University of Udine, Via delle Scienze, 206, 33100, Udine, Italy
Tel: +39 0432 558450
e-mail: luca.chittaro@dimi.uniud.it

**Lucio Ieronutti**
HCI Lab, Department of Mathematics and Computer Science, University of Udine, Via delle Scienze, 206, 33100, Udine, Italy
Tel: +39 0432 558457
e-mail: lucio.ieronutti@dimi.uniud.it