A Visual Tool for Tracing Users' Behavior in Virtual Environments

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ABSTRACT

Although some guidelines (e.g., based on architectural principles) have been proposed for designing Virtual Environments (VEs), several usability problems can be identified only by studying the behavior of real users in VEs. This paper proposes a tool, called VU-Flow, that is able to automatically record usage data of VEs and then visualize it in formats that make it easy for the VE designer to visually detect peculiar users' behaviors and thus better understand the effects of her design choices. In particular, the visualizations concern: i) the detailed paths followed by single users or groups of users in the VE, ii) areas of maximum (or minimum) users' flow, iii) the parts of the environment more seen (or less seen) by users, iv) detailed replay of users visits. We show examples of how these visualizations allow one to visually detect useful information such as the interests of users, navigation problems, users' visiting style. Although this paper describes how VU-Flow can be used in the context of VEs, it is interesting to note that the tool can be also applied to the study of users of location-aware mobile devices in physical environments.

Author Keywords

Evaluation tools, virtual reality, virtual environments, users' flow.

ACM Classification Keywords

I.3.6. Computer Graphics: Methodology and Techniques - *Interaction techniques*. H.5.2. Information Interfaces and Presentation: User Interfaces – *Interaction styles, evaluation.* H.1.2. Models and Principles: User/Machine Systems – *Human factors.*

INTRODUCTION

A commonly used technique to study how people use a computer application is based on recording and analyzing users' interaction with the application. For example, recordings can involve different interfaces for the same system and the analysis can indicate if and how an interface is more usable compared to the other ones, or they can involve the study of different classes of users and the analysis can identify usage preferences for the considered system or highlight which contents are more interesting for a user class. However, it is not trivial to choose what users' actions to record (to avoid recording a lot of unuseful information) and how to analyze them.

In our research, we focus on 3D Virtual Environments (VEs), whose study brings new challenges to usability research. Indeed, the concepts and technology involved with VEs lead them to be significantly more difficult to design, implement and use than conventional interfaces [9].

In VEs, users move through a three dimensional space causes frequently suffer navigation problems, such as disorientation and difficulties in wayfinding [6]. To face these problems, guidelines for environment design (e.g., [4][18]) and electronic navigation aids (e.g., [6]) have been proposed. However, experiments have shown that the effectiveness of a navigation aid depends on the specific environment and the specific task that the user has to carry out.

For traditional 2D interfaces, there are well-known techniques (and commercial tools) that help to carry out a usability evaluation based on the analysis of users' actions, and a significant research effort is aimed at improving those techniques and tools. For example, WebRemUSINE [14] is a recent tool that accepts as input a task model and the log files recorded during test sessions, and performs an automatic evaluation of a Web site. It provides the evaluator with a set of measurements to identify usability problems derived from a lack of correspondence between how users perform tasks and the system task model. Helms et al. [8] extended traditional logging approaches to collaborative multi-user systems, showing how data captured at an higher level of abstraction can categorize user-system interaction more meaningfully. The design of 3D environments would greatly benefit by the availability of tools specifically devoted to their peculiar features. To this purpose, this paper proposes a tool, called VU-Flow

(Visualization of Users' Flow), that records users' data, such as position and orientation, and visualizes them at an higher level of abstraction to derive information about VE usage. This solution helps designers to evaluate VEs by visually analyzing how users actually navigate the VE. The tool can be also used to identify most viewed objects in the VE and to visually detect particular behaviors such as *visiting style* [19]. Moreover, the opportunity to replay visits of single or multiple users also helps the evaluator to contextualize verbal data acquired through think-aloud protocols [3].

Although we focus on applications of VU-Flow in the context of VEs, it is interesting to note that the tool can be also used to visualize how users move in a physical environment. Identifying user's position in physical space requires additional technologies such as: infrared for indoor environments, or the Global Positioning System (GPS) for outdoor environments.

USER'S INTERACTION IN VES

Sweeney et al. [15] proposed a classification of possible user's interactions, identifying five main categories: on-line behavior/performance, off-line nonverbal behavior, cognition/understanding, attitude/opinion and stress/anxiety. In this paper, we consider the on-line behavior/performance category, that allows one to obtain usability data from the automatic recording of user interactions with the system. Several UI toolkits (e.g., Macintosh OS, Microsoft Windows, X Windows, Java AWT,…) are capable of automatically recording user interface events (UI events), that can be used as a fruitful source of information regarding application usage and usability. In traditional 2D interfaces, the recorded data are usually an ordered sequence of events such as clicks (referred to graphical or textual components) or key-press actions. However, since the size of the recording is typically huge and rich in detail, automated support is generally required to extract information at a level of abstraction that is useful to analyze application usage and evaluate usability.

Some typical problems experienced by users in a VE are disorientation, perceptual misjudgement and difficulty of finding and understanding available interaction [5]. User's interactions in VEs can be classified into two main categories [9]: i) *navigation* and *viewpoint control* and ii) *object interactions*, such as picking, grabbing, rotating and moving objects. Unlike traditional 2D applications, VEs allow one to derive what areas have been visited by users and where a user looked at, simply using the data obtained from the recording of user position and orientation.

For example Mourouzis et al. [12] record users' interactions and propose the concept of Virtual Prints (ViPs), the digital counterpart of real-life tracks that people live behind.

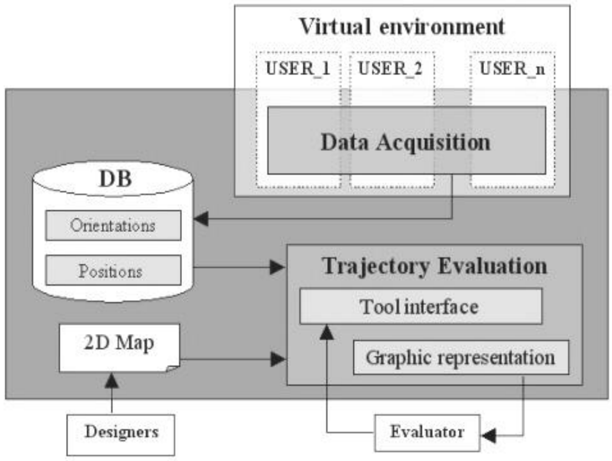

Figure 1 - Tool Architecture

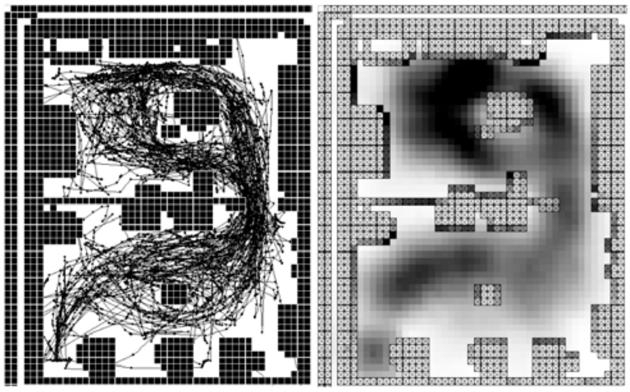

Figure 2 - Two different visualizations of the same data

Although the proposed tool can record all user-VE interactions, this paper is especially focused on the navigation category and concentrates on users that move into the VE in "walk" mode (i.e., the most frequently adopted kind of movement in VEs).

TOOL ARCHITECTURE

The tool we propose is mainly composed by two modules (as shown in Figure 1): the *Data Acquisition module* and the *Trajectory Evaluation module*. The first module records the position (e.g., x and z coordinates) and orientation (e.g., the vertical rotation) of each user at constant time intervals and stores them into a database. The second module analyzes the recorded data and derives more abstract representations of it that are visualized on a map of the VE. The 2D map of the environment required for visualization can be provided by VE designers or automatically obtained (e.g., using rasterizing graphics hardware [11]). In particular, the technique we used for automatic map derivation is described in [10].

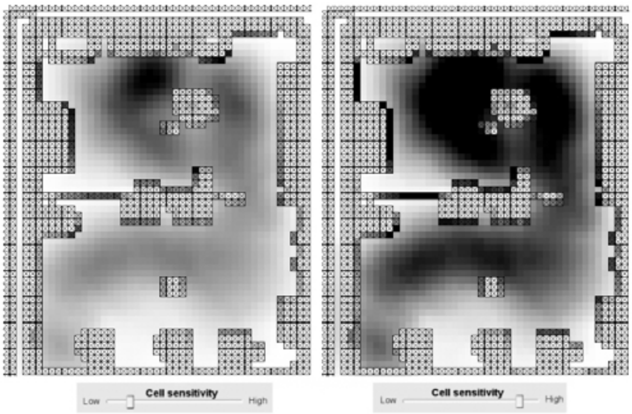

Figure 3 - The same recorded data visualized using two different cell sensitivities

By interacting with the tool interface, the evaluator can change the visualization to highlight different information on the map. Figure 2 shows two different visualizations of the same data: on the left map, each of the trajectories followed by different users in a VE is traced on the map, while the right map shows how much different areas have been travelled by users with a color coding mechanism (black corresponds to most travelled areas).

Data Acquisition Module

The Data Acquisition module samples users' interactions in the VE and stores them into an appropriate data structure. In particular, the module samples both the position and the orientation of each user at constant time intervals to track her movement. The sample rate can be set by the evaluator according to the accuracy required; an high sample rate guarantees an accurate acquisition of users' movements, while a low sample rate allows one to save memory required to store sampled data. The module stores all recorded data into a database, together with information about the sample rate and the *id* of the specific user.

Trajectory Evaluation Module

The Trajectory Evaluation module represents at an high level of abstraction the recorded information, providing visual representations of this data based on points, lines, and colored areas. The module is able to: i) draw the detailed paths followed by single users or groups of users in the VE, ii) identify areas of maximum/minimum users' flow, iii) identify the parts of the environment more/less seen by users, and iv) replay users' visits.

Colored lines and points are employed to represent the paths of different users. The map of the environment is discretized in cells of equal size: hereinafter, we call *free cells* those where the VE space is left free and *taken cells* those where space is taken by solids such as objects or walls. The module assigns a color to each cell according to the evaluator's requirements for the visualization.

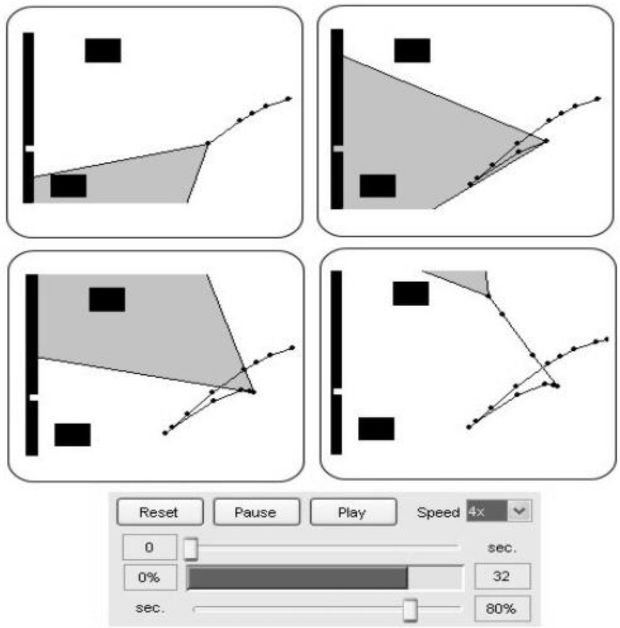

Figure 4 - Replay of user's movements

For example, when the evaluator needs to identify areas more travelled by users, the value associated to each free cell indicates how many times users walked on the cell, and the evaluator can change the sensitivity of cells to users' movement, by interacting with a slider in the tool interface (see Figure 3).

VU-Flow provides both grayscale and color visualizations; figures in this paper refer to grayscale version.

MAIN FUNCTIONALITIES OF VU-FLOW

VU-Flow offers four main types of visualization. The first allows one to replay movements of single users or groups of users, employing points on the map to identify the recorded positions and using colored lines to draw users' paths. The second and the third visualizations use color to identify respectively the areas more/less *travelled* in the VE and the areas where users *stayed* for more/less time. In the fourth visualization, taken cells of the map are colored in a way that highlight parts of the environment more/less *seen* by users.

The four visualizations can be classified in two different categories: *time-dependent visualizations* take into account the temporal dimension of recorded data, e.g. maintaining information on different walking speeds of users during the visit; *time-independent visualizations* maintain only information on paths followed by users, regardless of speed and time spent by users in different positions. The visualization that identifies more travelled areas is time-independent, while the other three visualizations are time-dependent.

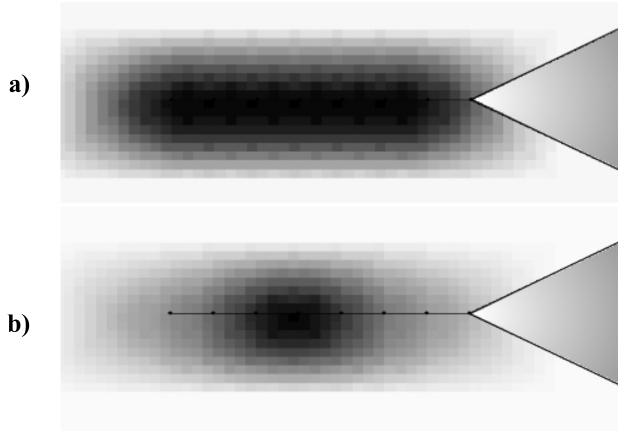

Figure 5 – (a) Time-independent and (b) time-dependent visualization of user's movement

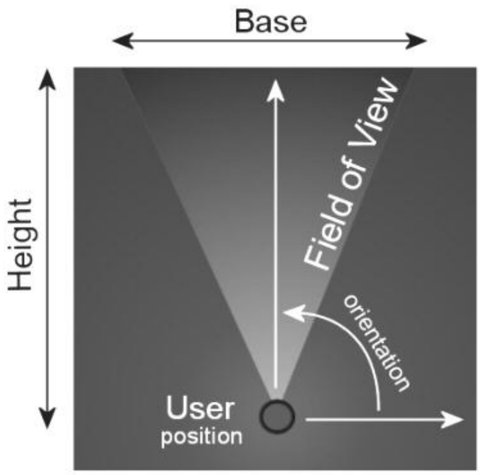

Figure 6 - User's field of view

Replay users' movements

Starting from a sequence of recorded positions, the tool is able to draw the paths followed by users on the map, marking each single trajectory with a different color. From the list of recorded data and the sample rate, VU-Flow is able to determine the instant in which the user was in a specific position and orientation. This information is used by VU-Flow to replay movement of users: current position of the user is drawn on the map as a point, while current orientation is represented by means of two lines that delimit the field of view of the user (see Figures 4 and 6). The evaluator is thus both able to observe user's positions in time and know where the user looked at during the visit.

To control the replay, VU-Flow interface includes the typical functions of a VCR, such as play, fast forward rewind, pause, fine tuning of the speed (see control panel in Figure 4). Moreover, one can choose to visualize the entire path followed by users until the current instant (as shown in Figure 4) or only the current position and orientation.

Identify more/less travelled areas

Visualizing detailed users' paths on the map might help one in identifying more/less travelled areas, but the result is too visually confusing (see Figure 2). Therefore, to better support an evaluator in studying the behaviour of a population of users in VEs, we introduced the more suitable visualization based on color-coded areas.

Colors on the map indicate how many times users travelled different free cells: in the grayscale visualization black highlights areas more travelled, while white identifies the areas less travelled. Different shades of gray are used to identify intermediate situations.

This visualization is time-independent, since the color of each area on the map depends only on the number of times the area has been travelled by users, and it is not affected by the speed of users and by the amount of time spent in different position.

Identify areas where users stayed for more/less time

By using the sampled data, VU-Flow is able to derive information concerning the different moving speeds of users. If two subsequent positions are relatively distant from each other, this obviously means that the user moved quickly from one position to the next one (remember that in this paper we are considering users moving in "walk" mode; less common solutions like "teletransport" can be however taken into account because the activation of "teletransport jumps" is easily recorded).

This visualization highlights areas of the VE where users stayed for more/less time. The walking speed of users is thus taken into account: the more slowly users walk, the more the travelled areas will shift to black. On the contrary, if the user walks through an area very quickly (even more than once) the color of the area will shift from white to black more slowly. To understand the substantial difference between this representation and the previous one, it is sufficient to look at Figure 5, that shows the two different visualizations on the same data. In this simple example, the user followed a straight path, at the middle of the trajectory the user slowed down, stopped and then started to walk again. While the first visualization (upper image in the figure) identifies the path followed, regardless of speed changes, the black color in the second representation (lower image in the figure) clearly highlights the area where the user spent more time.

Identify more/less seen objects

The two previously described visualizations provide useful information by coloring free cells of the VE. Another functionality offered by VU-Flow concerns taken cells: the tool is able to draw these cells in a color that indicates how much users looked at the corresponding parts of the VE. In the figures of this paper, we use black to highlight more seen parts, while white identifies the less seen areas. Different shades of gray identify intermediate situations.

To determine what areas have been viewed by users, for each user and for each of her positions and orientations, the system identifies the taken cells that fall in the user's field of view. The shade of gray for the taken cell is chosen to be: i) directly proportional to the distance from the user, ii) inversely proportional to the centrality of the taken cell into the user's field of view. Given the position and the orientation of the user, her field of view is obtained as a triangle (Figure 6) oriented according to the recorded orientation; parameters of the triangle, such as height and length of the base, can be changed by the evaluator.

To precisely identify more/less seen areas of the VE, VU-Flow takes into account possible occlusions of the sight; if an obstacle (i.e. a taken cell) stands between the user and the considered cell, VU-Flow does not count that cell as seen by the user.

Although it is not always guaranteed that user's attention is focused in the center of her field of view, we consider that a reasonable assumption.

Time spent looking towards taken cells is taken into account. This visualization can be synergically paired with the visualization that identifies areas where users stayed (we will see examples in the section on users' visiting styles).

USING VU-FLOW TO IDENTIFY NAVIGATION PROBLEMS

In this section, we show practical examples of how our tool helps evaluators to identify navigation problems in VEs. In particular, the examples refer to multi-rooms VEs (that is the typical structure of virtual museums and virtual exhibitions). We consider some cases were VU-Flow proved to be useful.

The more suitable visualization to identify navigation problems of a VE is the time-dependent one. For example, it can be effectively used to point out a navigation problem (i.e. flow congestion) that often occurs when an originally single-user VE is converted into a multi-user VE. As an example, we consider a virtual exhibition (composed by three rooms and a corridor) where several exhibits are hanged on the walls. Users are free to navigate through the VE and look at the different exhibits. VU-Flow, as shown in Figure 7, identifies an higher flow of users near the passages connecting the rooms; among all available passages, it identifies the highest flow of users near the room on the upper right. This is mainly due to the fact that the room has only one entrance. While in a single-user visit, the width of passages was sufficient to move conveniently, in the multi-user context behaviors aimed at avoiding proximity and collision with other visitors increased users' activity near the passages. VU-Flow indicates how serious is the problem at each passage; the designer could choose to increase the width (or the number) of passages.

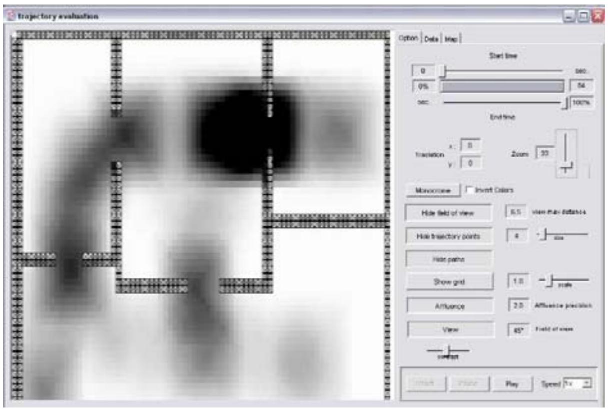

Figure 7 - Example: identification of areas of congestion

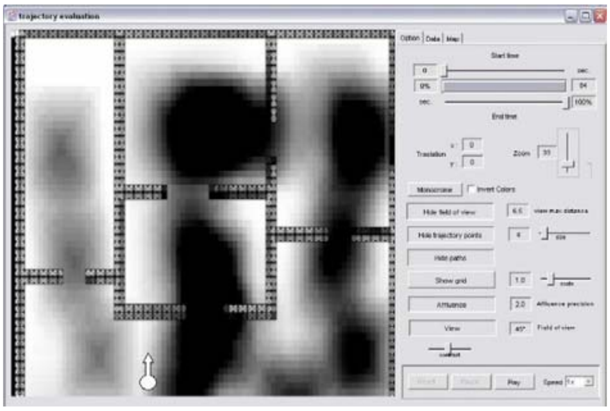

Figure 8 - Example: identification of less visited rooms

When the evaluator intends to study how the architecture of the VE influences the path followed by users during their visit, she is not interested to take into account the time spent by users into single rooms, considering it as a possibly confusing aspect because it can depend on the users' interest towards room contents. In this situation, the more suitable visualization is the time-independent one.

The time-independent visualization can be effectively used by the evaluator to easily identify the parts of the VE less visited by users, and how different rooms were visited, without being heavily affected by users' interests. Consider, for example, the visualization in Figure 8: since the shape of black areas on the map gives an estimation of how many users travelled that part of the environment, one can easily notice that the top left room is the less visited, although in this VE the initial position of users was close to its entrance. The visualization also highlights other aspects of users' behavior, e.g. the fact that a majority of users started the visit by taking the closest available door (the white arrow in Figure 8 represents the initial position and orientation of users).

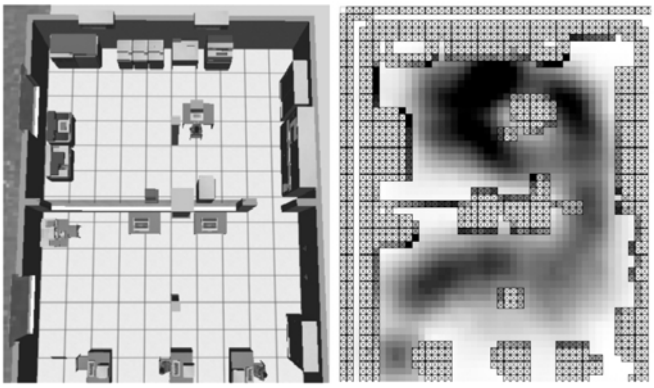

Figure 9 - Example: identification of interesting objects in a virtual museum

USING VU-FLOW TO IDENTIFY VISITING STYLES AND USERS' INTERESTS

Evaluations of visitor's movements, acquired using active or passive radio-frequency localization technologies in physical environments, have been proposed in the context of mobile indoor applications [16]; in this section, we first consider an application in the context of real exhibitions and museums, then we describe how this approach can be transferred to the context of VEs.

The considered application [7][12] relies on the classification proposed by Veron and Levasseur [19] who categorize visitors according to style of stereotypical movements (*visiting styles*).

Oppermann and Specht [12] designed a location-aware nomadic exhibition guide, that presents information according both to the current visitor's position and to her visiting style. This information is automatically acquired [1] by localization technologies that are able to track visitors' movements. Visitors' movements are used to i) identify the kind of visiting style of the current visitor and ii) infer which sequence of exhibits (a tour) can be proposed to visitors. VU-Flow allows one to transfer some of these considerations into the context of VEs. The time-dependent visualizations offered by VU-Flow allow one to identify both more interesting exhibits and the visiting style of the user (or a group of users, if considering the behavior of the average group member gives meaningful results).

Identify more interesting exhibits

Oppermann and Specht [12] discuss the potential of localization to evaluate users' interests during navigation in physical space. The position of the user and the time spent in that position are the first indicators of attention in the particular exhibit. These considerations can be applied also to VEs: in the context of virtual museums, a measurement of how much time the user spent in front of a specific exhibit can be an indicator of interest (Figure 9 shows an example of this usage in a virtual museum we analyzed). If the time spent by an user in front of an exhibit is very short, one could assume that the exhibit was not considered very interesting. This information can be used to help the designer of the virtual exhibition to propose guided tours.

In the evaluation of which exhibits can be considered interesting, the factors that have to be considered are both the time spent near an object, and the direction where the user was looking at. So an interesting exhibit can be identified when i) it is colored in dark gray in the visualization and ii) there is an area colored in black in front of it. The evaluation of users' interests can be enriched by identifying whether users view an exhibit from a single area or whether they choose multiple areas to see different views and details.

Identify users' visiting styles

Users' behavior in artistic environments has received particular attention in ethnography [17][19]. Veron and Levasseur [19] identified four categories of visitors, briefly summarized in the following. *The ant visitor* spends quite a long time to observe all exhibits, she stops frequently and usually moves close to walls and exhibits, avoiding empty spaces. *The fish visitor* moves preferably in the center of the room, walking through empty spaces. She does not look at details of exhibit and makes just a few or no stops; most of the exhibits are seen but for a short time. The *grasshopper visitor* sees only exhibits she is interested in; the visit is mostly guided by personal interests and pre-existing knowledge about the contents of the exhibition. The grasshopper crosses empty spaces, and the time spent to observe single selected exhibits is quite long. *The butterfly visitor* changes frequently the direction of visit, usually avoiding empty spaces. The butterfly sees almost all the exhibits, stopping frequently, but times vary for each exhibit.

Tracing the trajectories followed by a user and identifying where the user stayed for more time, VU-Flow allows one to categorize a visitor (or a group of visitors) depending on visiting style. A user can be classified as a fish visitor (see example in Figure 10) when the center of most rooms on the map is colored in black and there are no large differences concerning how long the different exhibits have been seen. With ant visitors, there are one or more black areas near each exhibit and almost all exhibits are colored in a similar color (see example in Figure 11). Fish and ant usually differ also in the length of the followed paths and in the time spent for the visit.

While it is easy to categorize a visitor as a fish or ant, it is more difficult to identify the grasshopper and the butterfly, due to the fact that these visitors follow paths that are heavily influenced by personal interests and by the time available for the visit. However, for both visiting styles, it is possible to identify some typical color arrangements that help in their identification.

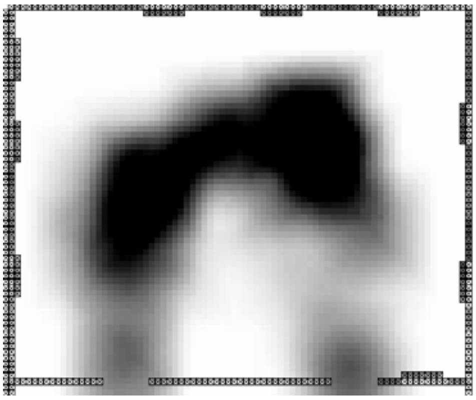

Figure 10 - Fish visiting style

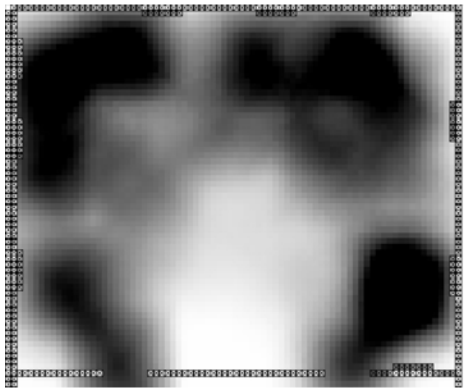

Figure 11 - Ant visiting style

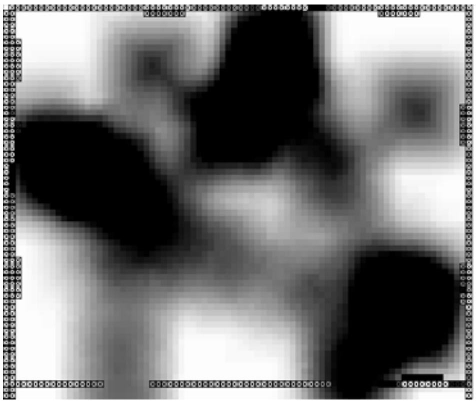

Figura 12 - Grasshopper visiting style

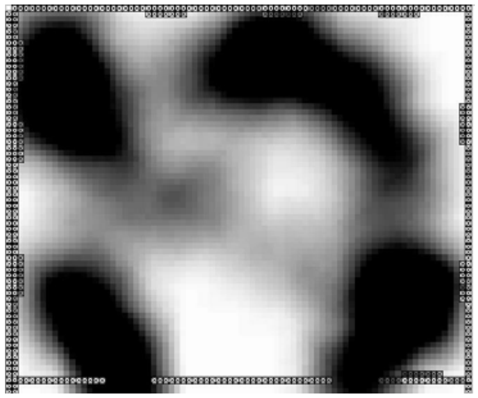

Figura 13 - Butterfly visiting style

The visualization of a grasshopper visitor (see example in Figure 12) is characterized by areas near exhibits that are colored with highly variable shades of gray, due to the fact that this visitor spends a variable time to observe different exhibits. The different shades of gray on the exhibits can be used to confirm this visitor's behavior. Moreover, by increasing cell sensitivity, the central area of the room generally becomes (partially) black.

With a butterfly visitor (see example in Figure 13), it is possible to notice that all parts of the VE corresponding to exhibits are colored in different shades of gray; the black areas are approximately placed near walls (or exhibits), but less regularly than the ant visiting style. The duration of the visit helps to distinguish the behavior of an ant visitor with respect to the butterfly visitor: visits of ants are generally longer and tend to result in more sharply shaped dark areas near the exhibits.

VU-Flow also allows one to identify an average visiting style, deriving general information about a set of visitors. Loading data concerning different users, VU-Flow highlights on the map the more viewed exhibits and the more followed paths.

Since there are relations between the visiting style and the information more suitable way of presenting exhibits (e.g. long and detailed presentations are more suitable for an ant visitor, while short presentations are more suitable for a grasshopper visitor), VU-Flow, helping to identify the predominant visiting style, may be used in the context of a virtual exhibition to improve the degree of satisfaction of visitors.

USING VU-FLOW WITH THINK ALOUD

The information obtained from the monitoring of user's interactions can be integrated with think-aloud protocols [3]. VU-Flow, by recording users' movement and allowing to replay it later, can be used to improve the understanding of the information obtained with the think aloud protocol. For example, the evaluator can find a relation between a recorded user opinion and the corresponding position and orientation. This way, it is possible to understand sentences such as "What is this?", "How can I open it?" (identifying where and what the user really was looking at), "Where I am?", allowing one to identify the specific area of the VE where the user encountered the disorientation problem.

CONCLUSIONS

This paper proposed a tool, called VU-Flow (Visualization of Users' Flow), that is able to automatically record usage data of VEs and then visualize it in formats that help the VE designer to understand the effects of its design choices. We illustrated the tool functionalities also by providing practical examples of its application to real VEs.

Future goals for our research are the following. First, we plan to introduce visualizations based on 3D maps of the VE. These 3D visualizations will provide very detailed information about user's behavior in space, but will not be an alternative to the 2D map that will still be used as the main overview. Second, we plan to extend the architecture of the system, by adding a module to record (audio) users' comments during navigation; the audio will be automatically synchronized with user's movement. Third, we will study how to extend VU-Flow to employ it in VEs where users are able to move in "fly" mode. Finally, we plan to test VU-Flow with VE designers; the experimental evaluation will allow us both to test the effectiveness of our tool, and to elicit possible new requirements.

ACKNOWLEDGEMENTS

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