

## Spatiotemporal Analysis of Circulation Behaviors Using Path And Residing Time display (PARTY)

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**Abstract**—Spatiotemporal data displayed in a spatial layout are not the best visualization for simultaneously exploring visitor paths and comparing their residing time. A challenging problem is the visual analytics of circulation patterns in varying layouts commonly found in both real and virtual environments. A circulation pattern is defined as how visitors move within space regarding a sequence of visited items. Understanding and discovering the circulation patterns has received much attention from space designers for increasing visitor satisfaction. This paper proposes a layout-independent visualization approach that transforms the four dimensional data of visitor trajectories (3D-position + time) into time series data. One time series datum represents a visitor path and his/her time spent residing in each particular region. In our visualization, we encode a time interval residing in an item boundary into a line segment. The length of a segment is in proportion to the total time spent in the layout. The time segment is placed in the row corresponding to its item boundary. A path of visited items is illustrated by connecting the time segments with vertical lines. The resulting visualization technique, called Path And Residing Time display (PARTY), enables users to find trends of circulation behaviors in a consistent fashion regardless of the targeted layout. The scalability of PARTY can be enhanced by a clustering technique which we enable PARTY to handle real data of more than two thousand visitors. We demonstrate the effectiveness of PARTY on these datasets. First, we show circulation behaviors of visiting styles in a 3D virtual museum. Second, we illustrate a flow of people who escaped from an explosive in a building. Third, we analyze players' patterns in a massively multiplayer online game, named Angel Love Online.

**Keywords**-layout-Independent visualization; visual analysis; spatiotemporal data; visitor circulation; virtual environment;

### I. INTRODUCTION

Visualization of spatiotemporal data is an interesting and challenging research area. Most visualization techniques using traditional two-dimensional maps present the paths of and the time spent therein of visitors directly over spatial layouts. In this paper, we call *layout-dependent* visualization for any visualization technique using the spatial layout of a targeted area as its graphical background in visualization. Three challenging problems of layout-dependent visualization are as follows:



Figure 1. Map of in use of Angel Love Online (ALO) where eight resources in four locations are distributed apart.

- 1) Understanding of the visualization results requires the familiarity with the targeted layout.
- 2) Examining of a set of selected items placed apart from each other is easily interfered by the other items placed in the layout.
- 3) Presentation of circulation patterns in the visualization is done in an inconsistent fashion.

The layout-dependent visualization approach burdens users by a cost of requiring them to recognize the layout of items and routes by themselves. Some additional symbols indicating the position and boundary of items as well as arrowheads indicating representative routes must be placed in layout-dependent visualization. However, these symbols and arrowheads conceal visitor traces from users.

Such a situation, in which users examine items placed in different areas, is disruptive since a layout-dependent visualization must display all areas covering those items. Areas of no interest will enlarge the size of that visualization, and the items and areas of consideration will be de-emphasized. If an item group of interest (denoted by orange rectangles) are located far apart others as shown in Fig. 1, the circulation patterns of players' avatars among the item group will be hidden away by the layout context.

A circulation pattern is defined as how visitors move within space with respect to their common sequences of

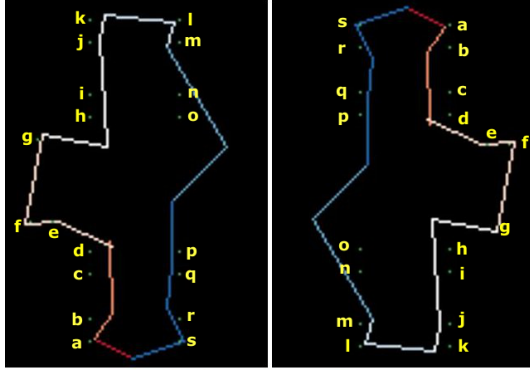


Figure 2. Similar circulation patterns in observing a set of items  $a - s$ , i.e., the circulation ring starting with a left turn, in two different item layouts whose routes are colored from red to blue; (Left) Original; (Right) Different orientation.

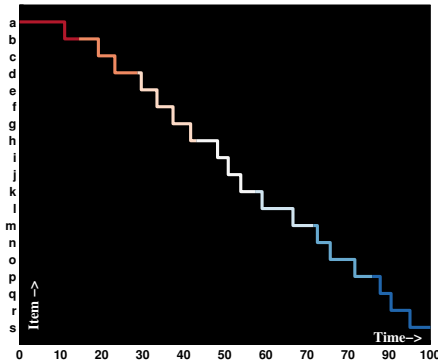


Figure 3. PARTY produced the invariant visualization of the visitor path obtained from both the left and right routes of Figure 2.

visited items. As a result, the visitor trajectories shown in Figure 2 are considered the same circulation patterns whose visitor trajectory explores an exhibition following the same predefined route, where its beginning and ending segments are represented by starting with red and blue, respectively. However, visual presentations in varying layouts are substantially different in shape, size, and orientation as found in a number of environments such as convenient stores, department stores, World's Fairs. Those visitor trajectories are distorted by the shape and size of spatial layouts as well as the orientation of items therein.

In this paper, we introduce both local and global visualization approaches that are independent of the space layout, naming them Path And Residing Time display (PARTY). PARTY can be used to analyze the circulation patterns of movement data in a number of environments. Applicable analysis targets include visitors in an exhibition, people who evacuated during an incident, or virtual characters in virtual space. Figure 3 is a use of PARTY for presenting the visualization of a single visitor exploring a set of items in a

museum.

We applied PARTY to three use cases where one uses real data from an online game and the others use synthesized data. The first one is a dataset of real users playing a popular massively multiplayer online game in Taiwan, named Angel Love Online (ALO), where the targeted map is shown in Figure 1. The second one is a dataset of 36 synthesized visitors with the concrete definition of four visiting styles as addressed in [1]; this data set is generated in a virtual museum environment as shown in Figure 1. The third one is a dataset of trajectories of 82 people in a building as shown in Figure 4 who were escaping from an explosive; this data set is synthesized for the VAST 2008 challenge.

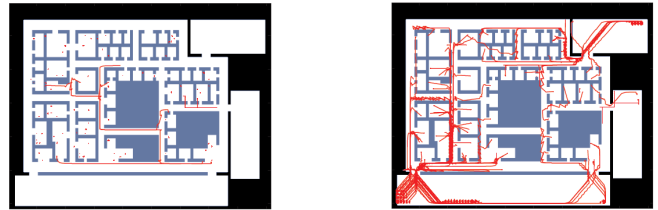


Figure 4. Trajectories of people denoted by red lines in a building; (a) Before an explosive; (a) After the explosive.

## II. RELATED WORK

This Section is organized to explain the motivations for developing PARTY. We review techniques dealing with visualizing the visitor trajectories mapped on a spatial layout and describe the approach and application of proximity-based visualization where a visitor path and the corresponding time spent are presented in a 2D dimensional view.

### A. Visualizations of Visitor Trajectories

A simple presentation of a visitor trajectory containing temporal and spatial information is a set of colored polylines overlaid on the place map in which visitors traveled. The color shades and polylines enhance a local visualization of a visitor trajectory in [2] for exploring the corresponding time spent. A path is in the form of connecting segments from red to blue. The session is equally divided in time into 7 periods in the ascending order from red to blue. The color of a particular segment indicates the passage of time. Its visualization is more complicated in such a case shown in Figure 7 (a).

To explore the trajectories of multiple visitors, Boörner and Penumathy [3] plotted the trajectories as colored polylines that interconnect discrete positions and used distinct colors distinguishing between different visitors. The aggregated trails were shown in their visualization based on the concept of a leader and her/his followers. Their group movement can be visualized by determining the coordinate of the centroid of all group members at a time unit and then drawing the connecting lines of these centroids.

Exploiting the color intensity illustrates either the time spent or the traveled area as proposed by Chittaro et al. [4]. First, the time spent visualization uses a color intensity to indicate how much time was spent by visitors in each area of the targeted layout. It takes into account the speed of entities, because the slower they move, the longer the time to pass through an area is. Second, the traveled areas visualization uses a color intensity to represent the frequency of visitor passing through each area of the layout.

Visualization of frequent traveled regions [5] is conducted by spatial partitioning of all visitor trajectories. A k-mean algorithm was applied to the trajectory data to divide the space into k areas. Therefore, a more crowded point is likely to be the center of a cluster, and an uncrowded point is likely to be the periphery of a cluster. As a result, the targeted layout is automatically partitioned into a number of regions based on the global information. Afterward, each visitor trajectory can be illustrated by painting a passed region with a shade. A distinct shade present different time spent. The darker color indicates that a visitor staying longer in a particular region while the brighter one shows the shorter residing in this region.

In addition to the aforementioned 2D visualization approaches, many visual analytics of visitor trajectories [6], [7], [8], [9] provide in 3D display by using the human geographers' technique of space-time paths. These approaches are called Space-Time-Cube that the cube consists of a representation of the geography (along the X- and Y-axis) and the time (Z-axis). The space time-paths are an instance in the cube. Although the 3D visualizations are able to include a geographical map where items are indicated by symbols and colors, the 3D displays introduce ambiguity and are hard to navigate.

### B. Visualization with Proximity Distance

Using a proximity distance introduced by [10] is an alternative approach to visualize visitor trajectories in a fashion regardless of the spatial layout. A proximity data is a distance between a visitor position and a given reference location. A visitor trajectory is transform into a collection of the proximities by the Euclidean distance metric. The advantage of using this approach is to view spatiotemporal information in a 2D display by reducing spatial information from 2D to 1D and retaining time in the other dimension.

This visualization approach focuses on the proximity distance to a set of reference points versus time. As used a single fixed reference point, the proximity distance does not distinguish regions A from B as shown in Figure 5. To solve this problem, multiple reference points are applied as described by [10]. The authors do not limit their proximity-based visualizations to a single distance dimension. It means that the distance to multiple points of reference can be defined. Since their visualization is in a form of a 2D display, the multidimensional proximity data point must be projected

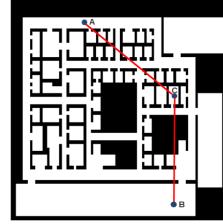


Figure 5. Regions *A* and *B* having the same proximity distance from a fixed reference location *C*.

to a single dimension that the other dimension is retained for time. However, the projected data is difficult for humans to understanding.

In our paper, we use a path of residing regions rather than proximities versus time. The decomposed regions in a spatial layout are systematically fixed by items of interest, for example, we use the boundaries among items residing in a museum as regions. It is possible to specifically define regions by users in order to find the desired solution, for example, we divide the layout of a given building floor into small blocks depending on their investigation questions. A path of residing regions is represented on a vertical axis of PARTY.

### III. DESIGN DECISIONS

Designers of museum space and online games as well as investigators of a terrorism situation require several types of information for examining the circulation behavior of visitors. These include (1) locations, regions, or item boundaries, (2) a time interval in each visited region, (3) a path of visited regions, (4) information about multiple visitors residing in a particular region or time spent therein, and (5) a degree of their interest depending on applications. All of these data types are computed from (a) a log file of visitors' positions including x-y coordinates and time and (b) the map of a museum or a floor plan including the item locations or the room positions.

The design of PARTY aims to represent three dimensional entities, i.e., a time unit, a visited item, and a visitor. The horizontal and vertical axes of PARTY represent time and items which the visitor resides within the close proximity to the items. A stack of visitor stripes is put inside an item block (row). As shown in Fig. 6, there are five items of interest and three visitors. The stack of three visitor stripes places inside each item row. The order of the three visitor stripes is consistent thorough the five item rows.

We arrange the visitor stripes in every stack in the same order and rank them by the similarity among their circulation patterns. Then, we use a hierarchical clustering technique for finding the similarity of all pairs of visitor paths. To handle hundreds of visitors, the representative of each group of visitors can be used rather than a single visitor. The representative is derived from the generalized median

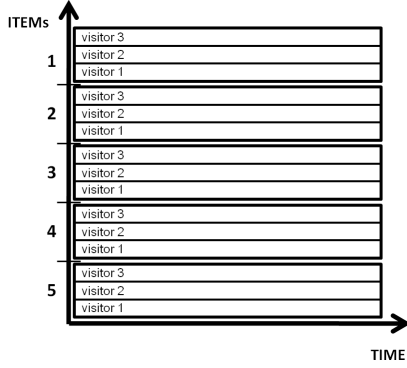


Figure 6. Structural design of PARTY.

defined as the visitor path having the nearest distances to the others in the same group.

Besides a path of nearest items versus time, the proximity distance to the nearest item can be displayed in PARTY as a degree of visitor’s interest to each exhibit item. A displaying color is computed using the observation distance and range based on the locations of all items. For example, given a visitor trace as shown in Fig. 7(a), Fig. 7(b) represents the visitor trace as our observation-based time series. The visualization in Fig. 7(b) consists of the horizontal axis corresponding to the visit time, the vertical axis indicating an item belonging to the observation range at a particular time, and the shades of red showing the observation distances. This visualization is produced by using the observation distance and range in the application of a 3D virtual museum in Section 5.1.

#### A. Visitor Interest as Observation Distance

The consistent color scheme using ColorBrewer’s nine-level sequential shades [11] is applied throughout PARTY. The shades from the brightest white to darkest red present the decreasing degree of visitor interest. The interesting degree is transformed from the visitors’ movement approaching to each item. It implies that visitors pay attention to an item whenever these visitors move closer to that item. In our visualization, the colors from darkness to brightness indicates that visitors are approaching to an exhibit item of interest.

With respect to the physical properties of varying exhibition items, the best observation area is not always nearest to those items. The best observation areas, which are colored by the white color, are simply defined by exhibition designers or curators in charge. The other positions far from the best area are the second three brightest shades. These color shades are mapped to the farther distance from the best area. The darkest red shows that the visitor is approaching to or passing that exhibit. Last, the black indicates that a visitor does not approach to that exhibit.

An example is shown in Figure 8 (a), which is a map

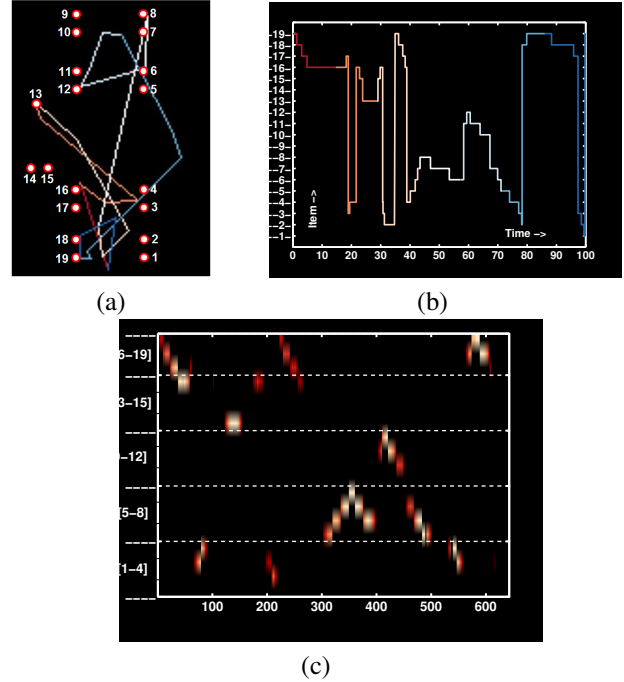


Figure 7. Transformation of a single visitor trace for PARTY; (a) Representation of a visitor trace tracked in a 3D virtual museum; (b) PARTY of a single visitor that represents a path of visited items (Y-axis) and his/her spending time; (c) Representation of the visitor interest to items by using color shades from brightness to darkness as highest to lowest degrees.

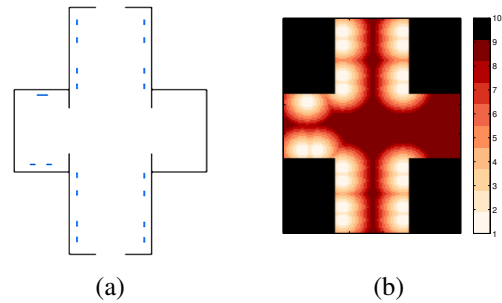


Figure 8. Example of observation distance map; (a) RDAP map; (b) Observation distance map.

of RDAP (Ritsumeikan Digital Archiving Pavilion). RDAP is a virtual gallery displaying the kimono textiles of 19 objects. At all locations, kimono textiles are hung against the wall; therefore the brightest shade, white, is displayed near the border except the right wing as shown in Figure 8 (b). Inversely, the hallway and the middle area are illustrated with the darkest shade of red. The black color is used for area outside the gallery.

#### B. Observation Range as Voronoi Diagram

In our visualization, shading colors against time present the direction approaching to/ leaving from a particular exhibit item. For this purpose, the observation range of each item is calculated by using Voronoi diagram. The decom-

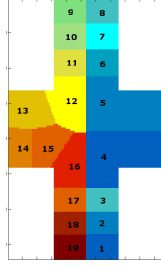


Figure 9. Item boundaries derived by using Voronoi diagram in accordance with Figure 8.



Figure 10. Stack of three visitor stripes in the first item row where the red color denotes their residing time intervals near item 1.

position of exhibition space is determined by distances to a set of exhibit items in the space. For example, the layout of RDAP is partitioned into 19 regions derived from the locations of items as shown in Figure 9.

### C. Time Interval in an X-Axis

PARTY represents a whole route of a single visitor spending his/her time in a targeted environment. A time interval represented by PARTY is a relative value with a relationship of his/her total time. In other words, a time unit along the X-axis of PARTY indicates a percentage of the total time spent. Therefore, PARTY can analyze log files of any visitors regardless of their real visit time.

### D. Item Ordering in a Major Y-Axis

The order of items can be automatically arranged by using a conventional Genetic Algorithm (GA) with the objective function that minimizes the total length of all paths drawn on PARTY as well as the number of crossing lines among paths. GA starts with an initial population where each chromosome represents an order of items. The best ordering of Items will result in PARTY with the optimal total length of all paths and the least number of crossing lines.

### E. Stack of Visitor Traces in a Minor Y-Axis

PARTY represents all visitors trajectories as a set of stacks each of which provides information about the residing time intervals corresponding to an item. The visitor information in a stack is represented as a stripe. For example, Fig. 10 represents the stack of the first item row showing visitor 1 resided near item 1 at the beginning and end of his/her route. Visitors 2 and 3 have the same visiting pattern at item 1 where they stopped near it for a long period of their visit time. The stack representation allows users to visually

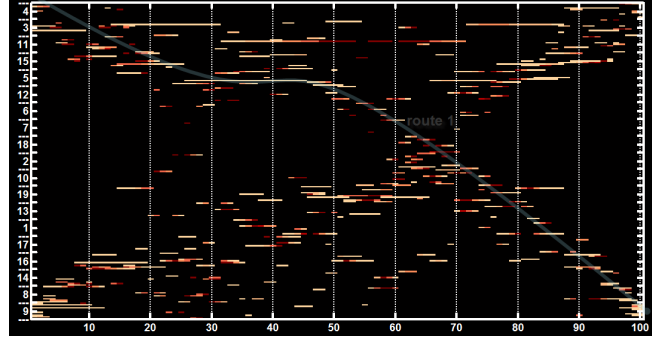


Figure 11. PARTY of the museum data set showing both degree of visitor interest, most common time periods of visited items, and also the flow of visitors for one journey session in the RDAP museum the layout of which is shown in Figures 8 and 9.

analyze the visitors' trajectories in aspect of global and local visualization.

All stacks in PARTY have the consistent order of visitor stripes. The ordering can be in accordance with the dissimilarity matrix that is the distance between every pair of time series data that are derived from visitor trajectories. Otherwise, users can explicitly specify their order. There are many techniques to calculate the dissimilarity matrix. In this paper, we compute the dissimilarity matrix by using the dynamic time warping and the Euclidean distance and then sort the time series data in an ascending or descending order.

### F. Group-based Stack of Visitor Traces

The structural design of a stack of visitor stripes allows users to visually find similarities of visitor paths and residing time intervals. This can enhance PARTY to handle a large number of traces. The discovered trends can be represented as a new definition of the visitor stack. Unlike the stack of all visitors, a group-based stack shows only representatives of similar time series data while PARTY in a fashion of the all-visitor-based stack is shown in Section 5.1 and 5.2. The width of stripes in the group-based stack is proportional to the total number of visitors. The wider stripe, the larger number of similar time series are found in this cluster

## IV. APPLICATIONS

### A. Application to a 3D Virtual Museum

This section presents an application of PARTY analyzing the avatars' trajectories and finding trends of circulation behaviors in the 3D virtual museum, RDAP. RDAP, owned by the Global Center of Excellence in Digital Humanities Center for Japanese Arts and Cultures, of Ritsumeikan University, is built in Second Life. An objective of RDAP is to disseminate Japanese costumes, Kimonos, preserved in a digital achieving system. We synthesize the visitor trajectories based on the metaphor of the four animals as mentioned in Section 2.1. The total number of synthesized trajectories is 36.

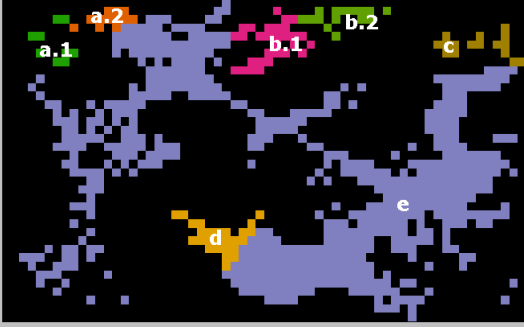


Figure 12. Decomposition of the ALO map associated with the resources as shown in Figure 1.

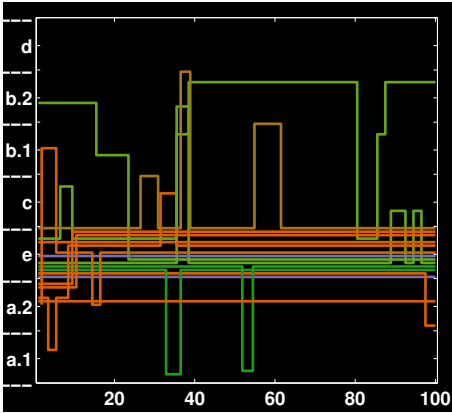


Figure 13. PARTY of the ALO dataset showing the most typical circulation patterns among the locations of the six resources as shown in Figure 1; Six colors was used for indicating trace patterns that resides in one particular resource longer than the other resources.

As shown in Figure 11, PARTY displays two typical pattern routes: one starting from the top left to the bottom right and the other starting from the bottom left to the top right. For example, one typical route 1 (denoted by a gray curve drawn) starts from items 4 followed by the other items along the Y axis with ending at 9. Following route 1, visitors walk slower in the first half and then the visitors hurries up in the second half. The typical pattern routes imply that the re-arrangement of the item order in the museum can a) avoid visitors to miss some importance exhibits and b) encourage visitors to observe all exhibits in order.

### B. Application to Angel Love Online

For the second use case, PARTY presents the most typical circulation behaviors derived from the ALO data set. ALO was developed by UserJoy Tech. Co. Ltd, a leading game designer and publisher in Taiwan. Our target layout is the most popular island because of its inclusion of the resources for increasing the fighting skill of players. There are four different types of resources located separated in the map as denoted by *a*, *b*, *c*, and *d*. The landscape of the island is two sides connected via a small strip of land in the center

surrounded by water. The sea (denoted by black color in Figure 12) is an area players cannot access. In the data set, there are 122 unique players with 2,231 total sessions that was collected from this map for about 70 hours.

At the beginning, we decomposed the map into the main regions by using the ISOMAP technique to partition the space so that any distances among the connected locations were considered as the shortest path in the Euclidean distance set. This decomposition technique results in seven regions corresponding to the locations of the resources as shown in Figure 12. Then, all trajectories are transformed into time series data for the PARTY representation as explained in Section 4. PARTY as shown in Figure 13 uses the strategy of a group-based stack of visitor traces as explained in Section 4.6. Using PARTY, users can explore the following information

- 1) Typical circulation patterns of players collecting resources
- 2) Circulation patterns residing in the particular location for seeking resources
- 3) Most popular locations for collecting resources

### C. Application to an Evacuation Situation

Evacuation patterns when an explosion occurs in an office building are considered to be another type of circulation patterns. Exits or safe areas in the building are the destination in this situation. For the investigation of an incident, an analyst uses PARTY for:

- 1) Describing flows of evacuating people through safe areas
- 2) Identifying when and where the explosion occurred
- 3) Finding potential suspects or witnesses to the event

We apply PARTY to the evacuation data set from the IEEE VAST 2008 Challenge [12], [8]. Such a situation is that the detonation of an explosive was set off at a Department of Health (DOH) building, Miami, Florida. All people in the building wore badges enabling their location to be recorded during the time of the incident. The data recorded is approximately 15 minutes and contains 82 people traces. The coordinates are mapped to a  $91 \times 61$  grid space as the map is shown in Fig. 14.

For analysis of evacuation patterns, the decomposition of regions appearing on PARTY is systematically and recursively computed as follows. The recursive decomposition can proceed in a particular region for discerning movements within it. We decompose the DOH map into 16 regions consisting of three safe regions, two walking area outside the rooms, and 11 blocks of rooms inside the building.

Our numbering procedure of decomposed regions is derived from the designer's idealized paths. In a evacuation situation, it is supposed that the flow direction of circulation patterns is a straight line to the nearest exits. For the sake of simplicity, two main evacuation patterns are considered

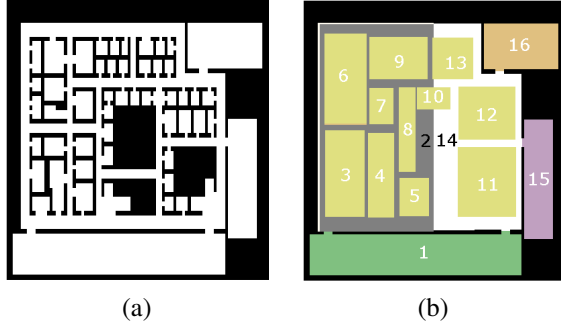


Figure 14. Building layout and its decomposed regions; (a) Binary image of the building layout; (b) Decomposed regions by using a recursive partition.

as (a) flow to the green exit and (b) flow to the violet and orange exits. The flow to the green exit is assigned to the first number 1; the others are set to the two last numbers 15 – 16. Then, the walking paths are divided into two regions: left and right parts. Basically, most of people on the left part escape to the green exit; therefore, the left region of the walking paths is assigned with number 2. In the same manner, the right region is set to number 14. For all blocks inside the building, the proximity from a block to the nearest exit is used for the numbering procedure. After the decomposition and numbering procedure, PARTY in Fig. 15 shows the evacuation patterns of people moving from their location before the incident to the exits. Green, violet, and orange lines confirm the people who were able to escape from the explosion thorough exits 1, 15, and 16. The other lines colored with yellow show that a number of people were stuck inside. Visual analytics of the evacuation patterns by using PARTY can discover the following facts:

- 1) The majority of evacuation patterns were flows to exit 1 followed by exit 15 and 16, respectively. These are easily identified by comparing the width of stripes at the ending time.
- 2) People were stuck in regions 10, 12, and 13 as well as in the hallway regions 1 and 14.
- 3) Most people left for the hallway regions 1 and 14 at time interval 381-480 second as seen by the width of dense vertical lines.
- 4) The approximate explosion time happened 10 seconds before they arrived the hallway regions by second 381 as noticed by the beginning of the dense vertical lines suddenly flowing through either row 2 or 4. Therefore, The incident may happened by 371 because PARTY represents the residing regions where visitors have already arrived.
- 5) The suspected bomber was detected from his/her movement before the incident.
- 6) The location of bombs was possible in either regions 11 or 12.
- 7) There were bottlenecks in regions of walking paths

that caused people to be still inside the building at the ending time.

## V. DISCUSSIONS AND CONCLUSIONS

In this paper, we propose PARTY which is a 2D visualization of the residing time intervals and regions of multiple visitors as well as the visitor paths. Our main goal is to design 2D layout-independent visualization for visual analyzing circulation behaviors commonly found in a number of environments and situations. Through the three applications, we showed how PARTY supports visual analysis of visiting styles and trends in a 3D virtual museum, a game online and investigation of an explosion incident in an office building.

In the first and second applications, PARTY is beneficial to visitor as well as game player satisfaction and comprehension of items being observed. The main beneficiary of PARTY is a person who is in charge of efficient design of space. For example, curators must design an efficient exhibition with the understanding of the factors that determine circulation behavior. For this purpose, PARTY of visitor traces in exhibition space represents the following information:

- 1) Sequence of observed items along their visit time
- 2) Observing time and position at each item during their visit time
- 3) Comparison among multiple visit traces
- 4) Trend of visiting patterns within a particular time period
- 5) Majority of visiting patterns in given exhibition space

In the third application, PARTY is a power visual analytics tool to assist officers to conduct a comprehensive investigation after the incident. The main view of PARTY allows its users to answer important questions such as:

- 1) What are the typical evacuation patterns?
- 2) Which individuals might be suspects?
- 3) Where are locations of explosive setting devices?
- 4) When did the explosion incident occur?
- 5) What are the approximate number of casualties?

There are three issues we consider for future work. First, we have described that the best observation location may not be the nearest position to an item. We plan to employ the visual analytics approach to find the best observation location introduced in [13]. Second, we have described the decomposition approach of a spatial layout into a number of regions when we applied PARTY to the evacuation incident. We will adopt the dynamic space division based on the quadtree representation addressed in [14] for the automatically recursive partition of the targeted layout. Third, we plan to enhance PARTY functionality with the recommendation approaches, such as predictions for the next items to be observed by a visitor in museum space.

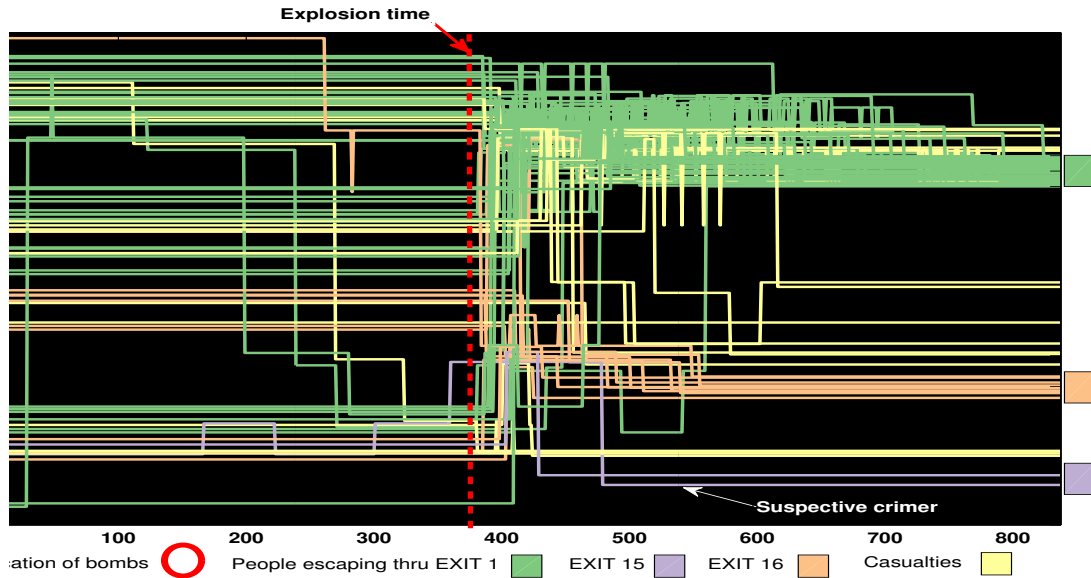


Figure 15. PARTY of 82 visitor trajectories where lines are colored following their destination; Four colors are used for discerning between the visitors moving through exits, numbering with 1, 15, and 16, and the others staying inside the building.

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