Spatial Analysis of Employee Safety Using Organizable Event Quiltmaps

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Abstract—We present a web-based visualization for the analysis of event-based movement of individuals within a building, as well as for the observation of groups, patterns, and outliers in a population of employees. The visualization comprises a novel organizable event quiltmap, and a 3D spatial heatmap. The quiltmap can be used to cluster similar event trajectories based on a spatial metric. The 3D view reveals employee movements throughout a day in the context of building sensor data. A small multiple display supports the browsing of multiple intervals, and individual event sequences can also be compared for the same employee across multiple days through individual quiltmaps. We demonstrate the approach on a VAST contest dataset of event and sensor measurements and show that it can capture complex and subtle aspects of the event spatiotemporal data.

1 Introduction

To safeguard a company's employees, many energy and engineering companies instrument their office buildings with sensors that have the ability to identify everything from building properties to employee's behaviors. Analyzing the data acquired from these sensors helps the company to identify potential employee issues, operational issues, and security issues. Typically, observing employees and maintaining building operations have been conducted through the use of surveillance footage and daily check-ups on building HVAC (heating, ventilation, and air conditioning) properties. However, the ability to analyze these components becomes difficult as, often times, companies can not find anomalies within their employees or HVAC data by simply observing a day's worth of data or footage. Approaching this issue through spatiotemporal event visualization can lead to more meaningful results and discoveries.

In this work, we introduce a spatiotemporal visualization of employee event data. The visualization introduces event quiltmaps, an organizable, jagged cell-based representation which captures both the temporal activity of employees and spatial relationships in the data through the use of textures and a spatial metric. The quiltmaps are further linked to a spatial heatmap representation which captures sensor data and details employee trajectories.

2 Related Work

Cell-based displays in the form of heatmaps are often used to display an overview of spatiotemporal data and assist in discovery tasks [2, 4]. Zeng et al. [13] further use ribbons mapped to heatmaps. The quiltmaps we propose differ from these encodings (and heatmaps in general) through the use of ribbons to encode categorical spatial locations, rather than non-spatial quantitative features [10, 11]; and through the use of textures to capture spatial relationships. Furthermore, a spatial metric backbone allows the quiltmaps to be organized into clusters of employees with similar trajectories.

None of the existing HVAC visual analysis works [12, 14] display the spatial layouts of the buildings associated with the HVAC system, which is an important factor in this work. We extend these works by overlaying HVAC heatmaps on a 3D spatial building map. Our 3D view approach is similar to Han et al.'s [7], who display a building heatmap (not HVAC, though) to show location-based feature values.

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Manuscript received xx xxx. 201x; accepted xx xxx. 201x. Date of Publication xx xxx. 201x; date of current version xx xxx. 201x. For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org. Digital Object Identifier: xx.xxxx/TVCG.201x.xxxxxxx

Previous works in movement visualization have either used a volume heatmap to show ensemble movement in an outdoors area [9], or nesting line charts to track multiple subject motion on a 2D floor map [5]. However, the first approach can not show multiple areas inside a building, and the second approach discards the spatial information. Ivanov et al. [8] use linked views to show temporal security data and the space layout of a two-story infrastructure, with color-coded lines depicting worker trajectories on a flat 2D floor plan. Their approach does not track a person between different levels. Unlike the 2D movement data discussed in the works above, the movement data in our study is in three dimensions, and we choose a 3D representation of the building to capture movement between floors.

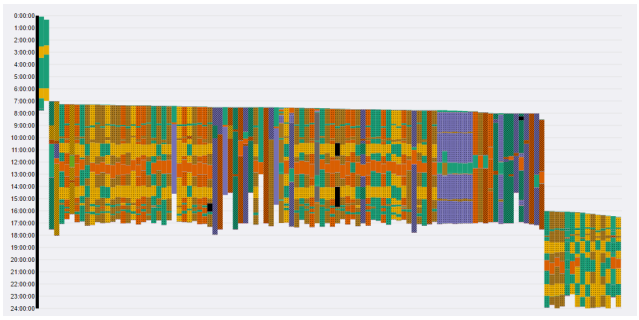

Fig. 1. Event quiltmap, unclustered, showing all employee events in a single day. Each vertical element of the quilt—called a ribbon—abstracts an individual employee. Each ribbon cell stretches vertically for the duration of time under which the employee did not move zones, and thus did not trigger an event. The cells use color to encode the zone number consistently across the building floors, and texture to encode the building floor level, which gives the map the appearance of a quilt. Employees are lined up along the horizontal axis in order of their first logged event of the day. The map can be organized through a custom spatial metric as shown in Fig. 2.

3 Methods

3.1 Data and Task Analysis

Employee security datasets typically span buildings with multiple floors, in which each floor is divided into zones with different purposes—for example office spaces as opposed to break rooms. The zone codes can be used to track employee movement throughout the building. A second set of zones encodes HVAC zones, each with individual HVAC system properties. Employee movement data are captured as a set of event logs, generated whenever an employee moves from one zone in the building to another. Each log contains the ID of the employee as

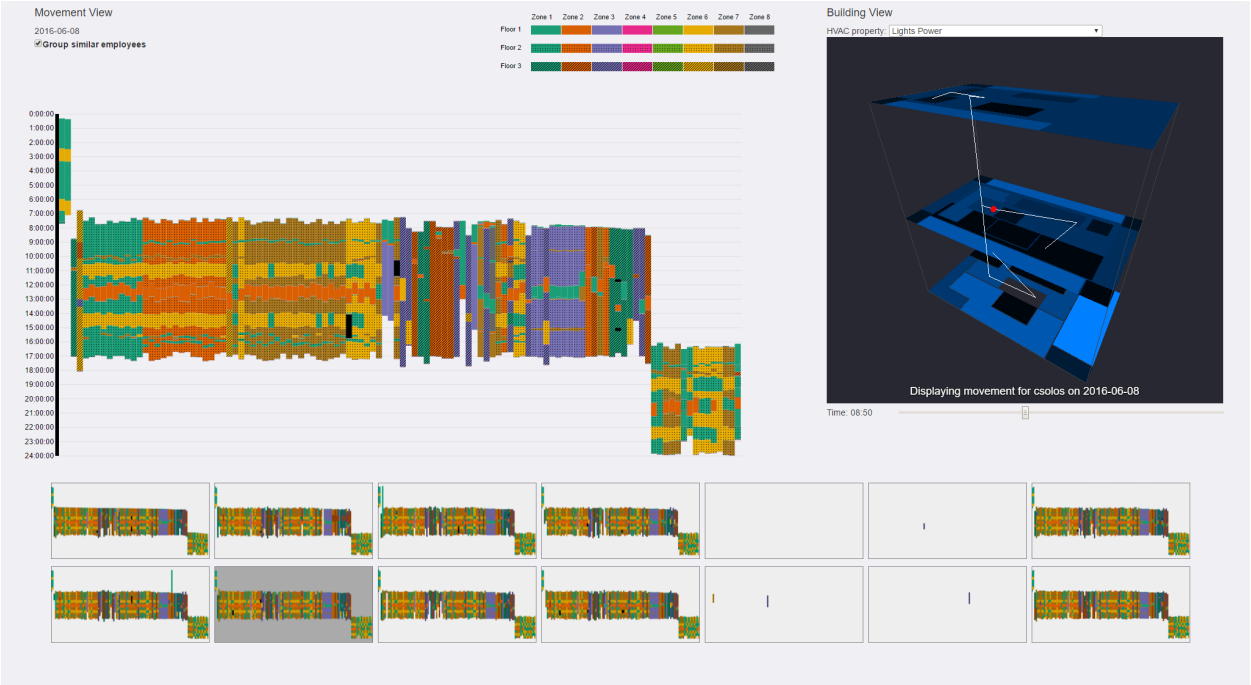

Fig. 2. Clustered quiltmap capturing spatiotemporal relationships in the data over a single day, 3D building view with sensor data and employee trajectory overlaid, and small multiple of quiltmaps showing larger trends over multiple days. Textured ribbons in the quiltmap capture similar locations across building floors, while a trajectory similarity metric clusters similar event sequences together. In the small multiple at the bottom, note the larger trends such as employees not coming in on weekends (nearly empty boxes), or maintenance crews operating after hours (lower right green patches on weekdays). In the organized event quiltmap (left), note the outliers with short and/or unusual ribbons. In the 3D view on the right, note the HVAC measurement distribution, and the multi-floor trajectory of a single individual. Suspect behaviors include erratic trajectories which do not make use of either stairs or elevators when transitioning floors.

well as the floor and zone being entered and the time of the transition. Such logs can be recorded over several weeks, and when so, they are labeled chronologically.

The HVAC data for buildings is typically collected at regular intervals, at which the numeric values of various HVAC properties are reported. These properties may then be grouped per floor. Goals of interest include discovering typical patterns in employee movement data, as well as investigation to determine what typical behavior looks like across all employees. Other tasks are finding anomalies in both the employee movement and HVAC data, and any potential relationships that may exist between these different datasets.

3.2 Visualization and Interaction

Our visualization entails two linked components: an Event Quiltmap spatiotemporal representation, and a 3D Building View. The event quiltmap captures employee movement throughout a single day, and can show the employee movement for all days through the use of small multiples. The 3D building display shows the building sensor data on multiple floors, as well as employee trajectories throughout a day.

3.2.1 Event Quiltmap

The event quiltmap (Fig. 1) enables the summarization and comparison of employee movement activity over periods of time. Each vertical element of the quilt—called a ribbon—abstracts an individual employee. Each ribbon cell stretches vertically for the duration of time under which the employee did not move zones. The cells use color to encode the zone number, and texture to encode the building floor level. The color coding is cross-registered and consistent across the multiple floors of the building, so that, for example, stairs and elevator zones have the same color regardless of their specific floor. The mixed color and texture encoding allows us to capture spatial relationships among different zones, and gives the map its quilted appearance.

Because of their compact cell-based approach, quiltmaps scale well. Ribbons progress vertically in a top to bottom fashion between the start and end time of an employee's shift, while individual employees (respectively individual days in the individual map) are lined up along the horizontal axis.

Brushing over individual ribbons displays the tabular information for the particular employee. Selecting any of the ribbons displays an individual quiltmap for that employee. Here, ribbons encode the activity over the course of each day throughout the selected period. Finally, similar movement patterns and activities between employees are explored through clustering of employee behavior.

3.2.2 Event-Trajectory Clustering and Spatial Metric

In order to group similar individual employees, we extract first zone boundaries from the building data. We next process the employee movement data to determine sets of employees with similar behaviors over these zone boundaries. Employees are grouped using a clustering algorithm with a custom distance between each pair of employees over the course of each period. The clustering groups together employees who have been relatively close in proximity, and thus exhibit similar behavior.

For every pair of zones in the building, the distance value was determined based on the minimum number of zones that one would need to pass through to travel from one to another. Once we compute the distance between two employees at a given time, we weigh it by the amount of time the employee pair had maintained that distance. By totaling all weighted distance values between an employee pair over a given period, we obtain an overall distance value that indicates how much the behavior of two employees differs.

$$distance_{overall} = \sum_{i=0}^{n} d(L_A, L_B, t_i) * (t_{i+1} - t_i)$$

where i goes from 0 to n movement events, $d()$ returns the minimum distance between location A (L_A) and location B(L_B) for the event at

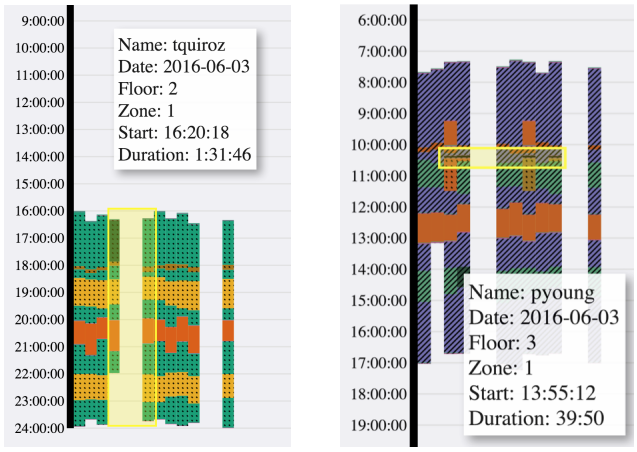

Fig. 3. Two individual event quiltmaps. (Left) Detail of individual quiltmap for employee Quiroz, showing early departure on a Tuesday (the top Tuesday cell is currently selected, leading to the details box) and a return on a later day with a new prox card. The employee typical behavior does not change. Vertical ribbons here correspond to individual days for this employee. The overlay yellow box (not part of the visualization) highlights the gap in days. (Right) Detail of the quiltmap for employee Young, showing suspicious activity. Young also leaves early one day (second ribbon from left) and returns with a new prox card. However, unusual behavior emerges on the return day as early as 9:15am (brown cell around 9am on third ribbon). In the area highlighted in yellow, the original card has entered and remains in the server room, while the new card enters an office space on a different floor, indicating unauthorized use by different individuals.

t_i, which is multiplied by the number of seconds for which the two employees were at the retrieved distance.

By empirically choosing a proximity threshold of 31000, below which employees' behaviors could be considered similar, an employee network is built, in which employees with sufficiently low distances between each other are grouped together.

3.2.3 3D Building View

To complement the event quiltmap, the 3D Building View allows users to view a heatmap of the building sensor data over time, as well as inspect an overlaid trajectory of employee movement. This view supports panning and zooming. A slider below the 3D Building View allows scrubbing over time, and a control box controls the building data parameter shown. A trail marks the trajectory of the current employee in the 3D view, with a red marker indicating the position at the current timestep.

Selecting any employee quilt ribbon displays their 3D trajectory over the course of the day. Further selecting one of the time blocks of that employee displays the employee's location at that time, while also changing the time shown in the 3D Building View's HVAC data. The 3D view, the daily quiltmap, and a small multiple of quiltmaps for multiple days are all linked through brushing and filtering.

4 Results

Our web-based application is implemented using D3 [3] and three.js [6]. We demonstrate our approach on the VAST 2016 Contest dataset [1]. The dataset describes a three-floor building in which each floor is divided into zones. Two unique sets of zones are utilized, one for the tracking of employee movement throughout the building (prox zones), and the other for the HVAC system. The dataset includes floor plan images for the building, as well as images indicating the locations of the various zones on each floor. Event logs for 114 employees are provided over a period of two weeks.

Event Quiltmap. From the aggregated event quiltmap, we discovered that a facilities employee named Twana Quiroz leaves early on a Tuesday and returns the following day with a new proximity card (Fig. 3). There were about 6 employees that experienced the same issue but there was one employee that particularly stood out, Patrick Young. Thus, the event map provided insight into an employee with suspicious activity.

While further analyzing Young's individual map, we discovered that Young's movement pattern on a particular day did not match the movement patterns from previous days. From the map, Young appears to have left early on Wednesday June 1, but further investigation reveals that he had in fact misplaced his tracked prox card: pyoung001. The next day, he returns to the job with a new card: pyoung002. It appears Young follows his normal pattern for the first half of the day using his new prox card, but irregular behavior arises as early as 9:14 AM. While Young's 002 prox card was going around Patrick Young's usual business, the misplaced 001 card reappeared and was used to enter and exit zones that Young had previously left untouched. The 001 card ventures into the server room while pyoung002 enters an office. The quiltmap not only alerted us to a change in behaviour, leading us to discover that Young had misplaced his first prox card and registered another, but also displayed suspicious zone entries on those days when the 001 prox card would return. The results show that the individual quiltmap can reveal if employees are participating in movement that does not correspond to their normal patterns of movement.

Small Multiples. The small multiples proved useful in observing larger trends such as employees not coming in on weekends, or maintenance crews operating after hours (Fig. 2 bottom).

3D Building View. The building view (Fig. 2 right) allowed us to investigate the concentration levels of hazium, a fictitious chemical in the contest. We discovered not only high levels of hazium concentration on Floor 2, Zone 2, but also inconsistent high levels of CO2 in zones from the return outlets (Fig. 4). Using the building view time slider gives us the ability to see which locations had greater CO2 concentration levels during the day. These high levels of concentration are potentially dangerous to employee health. However, what was most interesting was that analyzing the quiltmap revealed that the hazium concentration spikes were occurring when no employees were in the building or shortly after employees had left for the day.

Trajectory Analysis. As previously mentioned, we discovered that an employee named Patrick Young was participating in suspicious activity. On those days during which Young's card was seen exhibiting suspicious behavior, the trajectory view becomes appropriately distorted. Young can be seen making impossible transitions from one floor to another without using the building's stairs or elevator (Fig. 5), further confirming our suspicion that someone else had gotten hold of his original prox card and possibly made copies of it as well. While a visible change in activity had occurred on the quiltmap, the trajectory view gives us a better understanding of the spatial element of the movement, allowing us to spot inconsistencies such as movement between non-contiguous zones.

5 Discussion and Conclusion

Evaluation on a complex dataset shows that our event quiltmap and 3D view visualization successfully supports the discovery of typical patterns in employee movement data, as well as the investigation of typical behavior across all employees. The visualization was further successful in finding anomalies in the employee movement and HVAC data, and correlations between these different datasets. Through the integration of spatiality in both metrics and visual encodings, our hybrid visualization provided insight into intricate and subtle aspects of the spatiotemporal data.

The approach meets successfully the original tasks we have identified in the context of employee safety, from pattern discovery to outlier detection in spatiotemporal data. While we have tested our encodings on a single domain dataset, the event quiltmaps are visually scalable with respect to both time and the number of event sequences analyzed, thanks to a compact cell-based design. Scalability with the

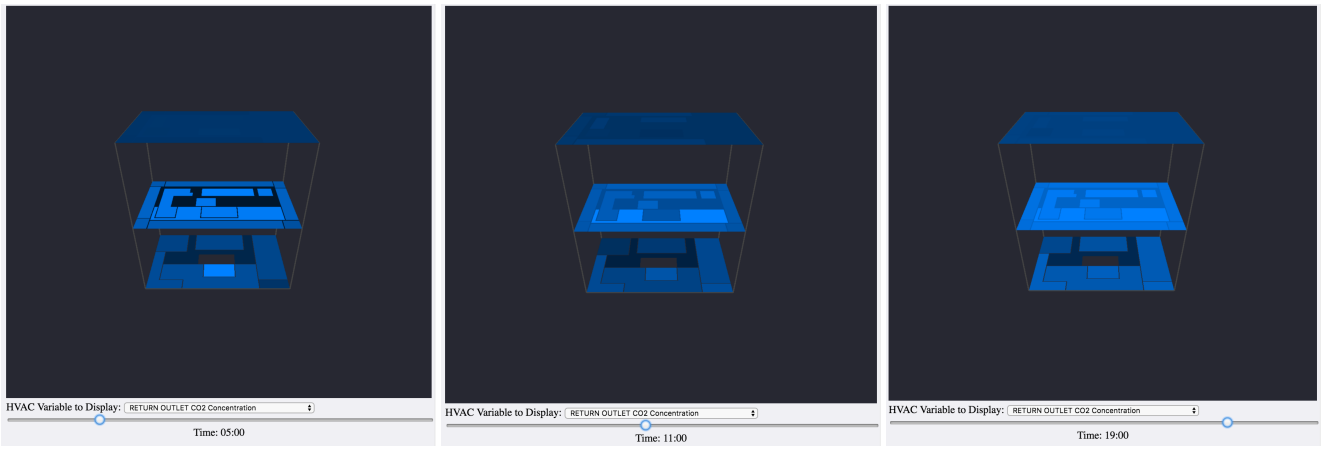

Fig. 4. Inconsistent high levels of CO2 in zones from the return outlets, as recorded at 5am, 11am, and 7pm. The three planes shown in each figure correspond to the three building floors in the test dataset. Each floor is divided into zones, with color intensity being mapped to CO2 concentration.

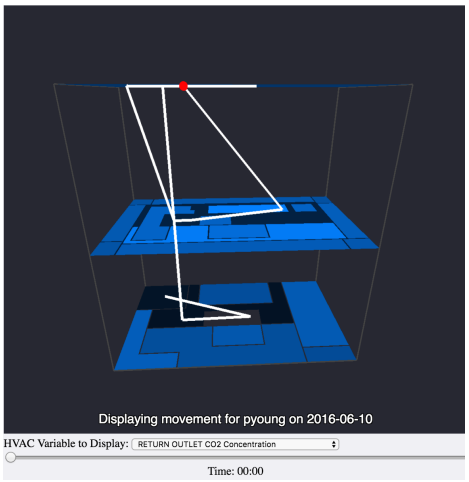

Fig. 5. Employee Young can be seen making impossible transitions from one floor to another without using the building's stairs or elevator.

number of event types, zones or floors may be limited by colormap size, respectively by the maximum recognizable number of distinct textures.

Our approach is novel through the use of ribbons to encode categorical spatial locations, through the use of textures to capture spatial relationships, and through the use of a spatial metric to organize similar ribbons together. This work is also, to the best of our knowledge, the first to tackle 3D motion sequences with between-plane transfers.

In conclusion, we introduced a novel web-based visualization which comprises an organizable event quiltmap and a 3D spatial heatmap. Through the use of a spatial metric, the quiltmap can cluster similar event sequences, while the 3D view captures building measurements and individual trajectories. When linked together in our visualization, these components can be used for the analysis of event-based movement of individuals within a building, as well as for the observation of groups, patterns, and outliers in a population of employees.

Acknowledgments

This publication is based on work supported in part by the National Science Foundation (NSF), award NSF IIS-0952720-CAREER. We thank the NSF REU program for supporting Dennis, Jackie, and Andrew, and the NSF Graduate Research Fellowship Program for supporting Tim. We acknowledge the VAST 2016 contest for making the dataset available (the deadline was too early for this work). We further thank our colleagues at EVL for their support and help.

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