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Visual Analytics for Dynamic Evacuation Planning

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Abstract

We use visual analytics to assist human experts in the verification of evacuation schedules and enable them to identify the bottle-necks in building evacuation. The user can change parameters, such as the number of occupants present in the rooms, the parametric settings for fire simulation, the building design, etc. and analyze their effect on evacuation. Visualization of the people flow in the building combined with the computational techniques plays a great role in analyzing the evacuation process. This helps in understanding the movement of the people during evacuation, possible delays in evacuation process, etc. and it provides feedback to the user. We introduce a novel priority based distributed evacuation routing (PDER) algorithm that produces dynamic evacuation schedules and is designed to work smoothly and seamlessly in interactive exploratory environments for visual analysis of dynamically updated evacuation schedules.

Categories and Subject Descriptors (according to ACM CCS):
F.2.2 [Nonnumerical Algorithms and Problems]: Sequencing and scheduling—Routing and layout,
H.5.2 [Information Interfaces and Presentation]: User Interfaces—Graphical user interfaces (GUI)

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1. Introduction

Numerous types of disastrous incidents that occured in the recent past in different hotels [ABC10], shopping centers [ABC11], theaters [NBC11], large residential buildings [Des11] etc., emphasize the need for effective evacuation planning methods. Recent developments on evacuation systems aim to provide more efficient means for alarming and guiding occupants. Existing evacuation systems [Bos12] warn the occupants over the threat in the building through mass media communication, requesting the affected occupants to follow the static evacuation paths. Such systems only react on threat (e.g. the outbreak of fire) and neglect the situation in the building after the alarm is triggered.

In an emergency evacuation, continuous monitoring of the situation in the building is of a critical importance. There is a need for an effective visualization of the situation in the building, through which the safety staff could observe the progress of evacuation in the building, avoiding problems and ensuring a smooth evacuation. It is difficult for the safety staff to find bottle-necks and problems in the evacuation planning and to take decisions based on mere numerical data without the support of visual interfaces, since large amount of available numerical data cannot be analyzed effectively. A human planner needs visual support in such time-critical conditions to plan better and make better decisions.

2. Previous Work

2.1. Evacuation Planning Algorithms

For decades, numerous types of disasters in buildings led to the development of an array of evacuation planning algorithms [HT02], [YAM08] to support evacuation processes with the objective to minimize the evacuation time and to guide the occupants from their initial places to the available exits as safely as possible. Much research has been conducted to optimize the total evacuation time [PG09] and to reduce the computational times [LHS03] of evacuation algorithms.

In general, the existing evacuation algorithms can be divided into two categories: linear programming approaches [HT94] and heuristics approaches [LHS03]. We adopt a heuristic approach—the popular and widely used Capacity

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Constrained Route Planning (CCRP) algorithm [LHS03]—because it leads to "working" solutions to the computationally hard problem of route planning at reasonable compute time. We extend CCRP to the novel Priority based Distributed Evacuation Routing (PDER) algorithm, which allows the user to change relevant simulation parameters like the number of occupants present in the rooms, the heat release rates of fire, the building design, etc. This flexibility of PDER and its support for dynamic updates is critical for successful visual analytics of evacuation planning: it allows the user to analyze the effect of parameter modification on evacuation performance. In contrast, previous evacuation planning approaches focused on devising static, predefined evacuation paths for fixed evacuation plans; this traditional approach may cause serious problems, such as guiding evacuees to the origin of fire, explosions, or chemical releases, or leading them to dead ends with destroyed exits, collapsed ceilings, blocked exits, etc. The recent evacuation planning algorithm by Wang et al. [WZM*11] is an example of dynamic evacuation simulation. However, in contrast to Wang et al., we focus on a couple of different features of the algorithm such as prioritizing evacuees (e.g., in disaster-affected areas) and we also embed the algorithm in the visual analytics process.

2.2. Node-Edge Relational Model

The input to the evacuation planner is a 2D or 3D building model that needs to be transformed to a mathematical model. The Node-Relation Structure (NRS) [Lee01] represents the topological relationships between the 3D spatial objects by a combinatorial data model: a node-edge relational model through which the adjacency and connectivity relationships between various components of buildings can be represented. Each building object (such as rooms, corridors, ladders) is represented as node and the connection between two nodes is represented as an edge. Each node has two parameters: initial occupants in the room and maximum capacity of the room. Each edge has two parameters: the travel time along the path and maximum flow capacity along the path per time unit. The NRS or variants thereof are common to many evacuation planning algorithms (including CCRP and [WZM*11]), we also use it for PDER.

2.3. Visual Analytics for Evacuation

There is much previous work on visual analytics for security and emergency applications. A typical example is the use of visual interfaces to improve situational awareness for first responders, such as the visual presentation on mobile devices for fire evacuation [KMO*08]. Another example is the use of virtual reality for evacuation training [MJC08]. However, such systems typically lack advanced automatic evacuation algorithms.

Another related example is the interactive scheduling of evacuation from disaster-affected areas by using vehicles [AAB08]. This system provides many useful visual analytics techniques, including the appropriate visualization of schedules and the linked views on geographic maps. However, it does not aim at evacuation from buildings and, therefore, does not consider building-oriented evacuation algorithms and their visual representations. Therefore, to the best of our knowledge, our approach is unique in its combination of interactive visual analysis and dynamic evacuation planning algorithm.

3. Visual Analytics for Evacuation Using PDER

The concept of visual analytics is applied to evacuation planning in the following way: We start with an initial evacuation plan automatically generated by PDER. Then, the user views the output from PDER and can analyze the movement of the people, bottle-necks, and problems in the evacuation for a particular set of parameters provided to PDER. In the following step, the user can change parameters involved in the evacuation process like number of occupants, number of exits, the position of exits, parametric settings for fire simulation, the origin of fire, the building design etc., analyze and view their effect on evacuation. The bottle-necks in evacuation planning can be explored, for example, if the number of occupants are increased, the blockage in the evacuation paths due to interference of the occupants can be examined. Depending on the analysis, the building design can be changed, for example, the width of the exits and the evacuation paths could be made wider. By analyzing the total evacuation time, the decision could be made to add some more exits in the building or change the position of exits such that the total evacuation time would become minimal. When applied during actual evacuation, visual analysis could lead to dynamically adapted instructions to evacuees.

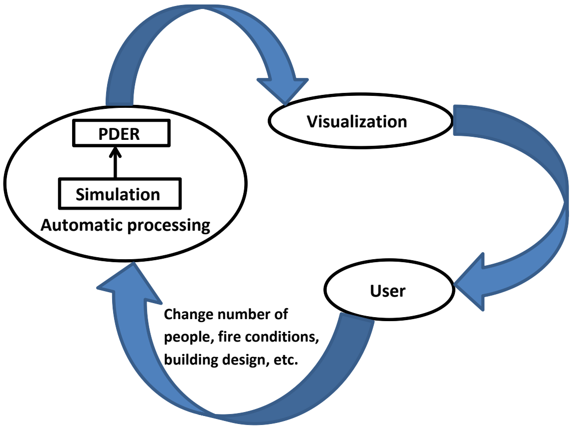

Figure 1: *Visual analytics for evacuation*

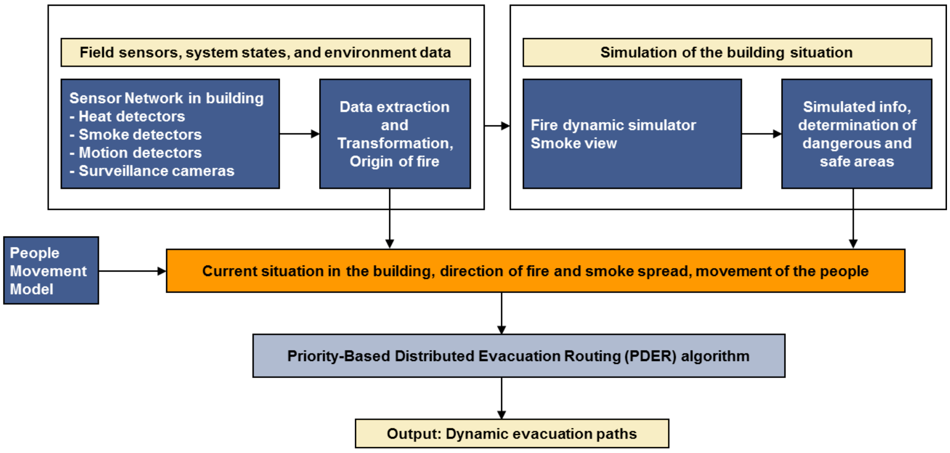

Figure 2: *Overview of priority-based distributed evacuation*

3.1. Priority-Based Distributed Evacuation Routing

The PDER algorithm is based on CCRP [LHS03]. CCRP does not assign priorities during evacuation, cannot take into account information from sensors, and does not integrate people movement models. PDER addresses these issues. Figure 2 gives an overview of the PDER algorithm. Information on the origin of fire and the current situation in the building is monitored and learned by sensor-based monitoring devices (heat detectors, smoke detectors, motion detectors, etc.) installed in the building.

The situation in the building for the next minutes, the fire and smoke spread are simulated using Fire Dynamic Simulator (FDS) [McG00]. A people count model is integrated into PDER from which the number of occupants at the time of evacuation can be estimated. PDER takes into account the simulated information of FDS and the latest available sensor information from the sensor network and generates evacuation paths that can be changed dynamically depending on the real-time changes in the building.

PDER models the building into different areas, the different areas are obtained by the seperations made by the fireproof doors installed as per the building regulations. The areas in the building are categorized into dangerous areas and safe areas depending on the current sensor information and FDS simulation information. The occupants in the dangerous areas are evacuated with high priority compared to occupants in the safe areas. The computational time of PDER is less than for conventional algorithms for two reasons: firstly, the model to be worked on has few nodes and edges, since each area is represented by a small network. Secondly, PDER generates the evacuation paths in parallel for the different available areas in the building.

PDER produces sub-optimal evacuation times since the evacuation process is sequential, but the evacuation planning is safer since the occupants present in the dangerous areas are given priority and evacuated at the earliest possible time.

3.2. Visualization of the Situation in the Building

To support evacuation planning under time-critical situations, the node-edge relational model is visualized to see the movement of people inside various nodes, the maximum capacites of nodes and edges. The user would like to see the number of occupants at a certain point of time, the width of the evacuation paths, the progress of evacuation in the rooms, blockages during evacuation, etc. Figure 3 illustrates the visualization of the node-edge relational model, as used in our visual analytics approach.

In Figure 3, nodes are visualized as function plots. The horizontal axis shows the number of time periods and vertical axis shows the number of occupants. A time period is the duration of time chosen by user to represent a time unit. Each plot contain information of the initial number of occupants and the maximum capacity of the node. The movement of the occupants in the node with respect to time, occupants coming in and going out is found in the plot.

Color coding and varying thicknesses are used to represent time-varying data, in a similar way to the method described in paper by Burch and Weiskopf [BW11]. The movement of people through different nodes during evacuation is visualized. It facilitates the identification of bottle-necks, for example the critical nodes whose capacities reach to maximum level during the evacuation.

The problems of an evacuation plan, such as blocked occupants in a particular node, can be identified. The source nodes in which the evacuation is delayed, the nodes in which the occupant capacities reached its maximum, and the nodes that are not used by the occupants can be observed.

4. Example

We sketch an example of evacuation planning to illustrate how PDER is combined with the visual interface. The test dataset is the three-floor building presented in appendix of evacnet usersguide [TMKN85] of the evacnet program [KF85]. The corresponding node-edge relational model for the building is shown in Figure 3 and the origin of fire is assumed to be in third floor.

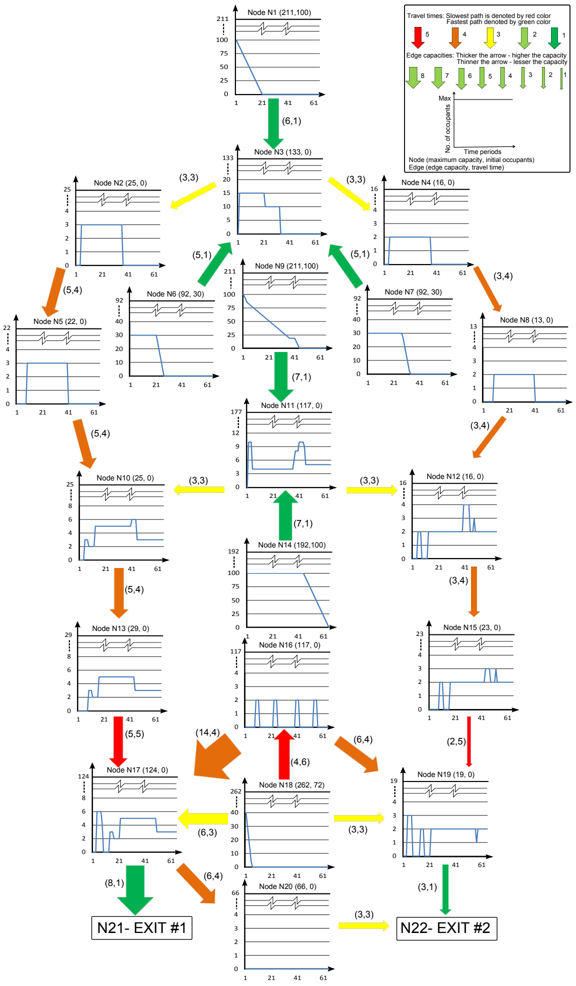

Figure 3: *Visualization of the node-edge relational model: Different colors diverging from red to green are used to represent the different travel times. Red indicates that it takes longer time to travel through the arc and green indicates that the occupants can travel through the arc more quickly. The thickness of the arc indicates the maximum flow capacity through the arc. The thickest arc indicates highest flow capacity and the thinnest arc indicates lowest flow capacity.*

In Figure 3, the nodes that have constant and continuous movement of people can be interpreted as rooms with smooth evacuation of occupants. For example, the nodes N1 and N9 show continuous movement of people during certain time periods. We observe how the nodes that are empty in the beginning are filled with people and finally they become empty during the evacuation. For example, the nodes N2, N4, N5, and N8 were empty in the beginning and are then filled with occupants during the evacuation and becomes empty again as the evacuation progresses.

It can be interpreted that the nodes with initial occupants that become empty very quickly are the nodes that are the nodes that are most affected by the disaster. In this example, the origin of fire is in third floor, hence node N1 is evacuated quickly compared to other nodes. The reason for this is the occupants in the dangerous areas are evacuated at a higher priority compared to the occupants in safe areas. Node N18 became empty in the first few time periods since the occupants are very close to the exits.

The nodes where there is no change in the movement of the people for a certain period of time, although they contain occupants, can be interpreted as the nodes in safe areas. For example, the evacuation of people in node N14 starts after 40 time periods since it is in safe area. Evacuation in the safe nodes starts after the occupants from the dangerous nodes are evacuated. The nodes where the occupants accumulate without further movement indicate blockages in the evacuation paths. In such cases, decisions can be taken to guide the occupants in the paths where there is no blockage.

The behavior of the nodes near the exits can be observed. A continous flow of occupants through the exits indicates a smooth evacuation without blockages. For instance, N17 and N19 are nodes close to the exits. In first few time periods, the flow of occupants was high. Later it is smaller, which shows that there is no blockage at the exits. If the occupants are getting accumulated near the exits, it indicates that the exits are getting blocked and decisions can be made to guide the occupants to other exits which are not blocked.

5. Conclusion

We proposed a visual analytics method for dynamic evacuation planning, where the user can visualize the progress of evacuation and take better decisions in evacuation planning. For example, the user can observe the number of occupants and their flow, the width of the evacuation paths, the progress and delays in the evacuation. The user can verify schedules, discover bottle-necks in evacuation, change the parameters involved in the evacuation, and observe their effect on evacuation. This helps plan the evacuation schedules efficiently. Some problems present in the conventional algorithms like the inability to change the evacuation paths dyamically are addressed and solutions to them are proposed. The CCRP algorithm is improved in PDER by integrating the sensor information, simulation information, and people movement model. This helps in changing the evacuation paths dynamically during evacuation and planning the evacuation in a better way.

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