Interactive Visualization of Hospital Contact Network Data on Multi-touch Displays

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ABSTRACT

Hospital infections cost the lives of more than 100,000 people in the United States every year. Understanding how infections spread in hospitals is critical to reducing this problem. To help in this endeavor, we developed an interactive, multi-touch hospital contact-network visualization and disease spread simulation. The system visually animates healthcare workers as they move through a hospital building based on a very large, real world dataset of electronic medical record login sessions. Users control the visualization and infection spread simulation by direct manipulation using multi-touch interactions and on screen controls. Through our implementation, we explore how infection control experts might use visual analytics and multi-touch user interfaces to explore such large datasets. We share the feedback gathered from three domain experts, who tested our application and suggested additional use cases for similar systems or potential datasets.

Categories and Subject Descriptors

H5.m. Information interfaces and presentation (e.g., HCI)

General Terms

Design, Human Factors.

Keywords

Information visualization, multi-touch, contact-networks, epidemiology, visual analytics, healthcare

1. INTRODUCTION

In 1854 a terrible cholera epidemic is haunting London. On Broad Street, where the outbreak is worst, John Snow's research suggests the local water pump to be the origin of the epidemic [17]. Snow later plots the deaths claimed by cholera and local water pumps on a map of the Broad Street neighborhood (see Figure 1). His map becomes an essential tool in communicating his (at the time) controversial hypothesis as Snow pioneers the field of epidemiology. Since then, Snow's map has also become a classic example of information visualization [18]. This point emphasizes how beneficial visualization techniques can be to the study of infectious disease.

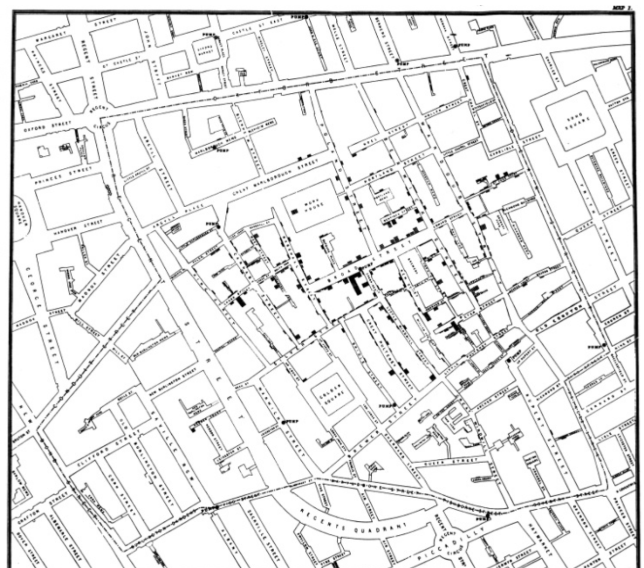

Figure 1. In 1855 John Snow plots cholera deaths and water pumps on a map of Soho, London. A clear clustering is evident around a specific water pump.

Regretfully, more than 150 years later, visualizations to track infections in places like hospitals have not made much progress with health professionals still relying largely on static plots (e.g., [14]). This is of grave concern given the high rates of infection at hospitals, costing the lives of more than 100,000 people a year in the United States [2]. Epidemiologists are beginning to explore computation, modeling and automatic data collection to study how diseases spread in hospitals. Recent approaches to model the social contacts involved in the spread of an infection include *Contact Network Epidemiology* [12].

Hospital Contact Networks are based on geographic maps of hospitals and spatiotemporal records of social contact between healthcare workers and patients. They are valuable tools in modeling and simulation of infection spread; especially with the ability to construct sufficiently large datasets through advances in data acquisition [10].

In the research presented in this paper, we use a large dataset of electronic medical record (EMR) login sessions [4][10] to construct an interactive visualization of such contact-networks and a simplified simulation of disease spread. Although our system is not accurate in terms of spatiotemporal information or simulation of infection spread, it does provide a plausible scenario based on real world data. We use this system to explore possible ways for infection control professionals to interact with this kind of data. We use their feedback to identify novel applications that will be enabled as such data becomes available.

The main contributions of the paper to human-computer interaction are the successful application of multiple techniques developed within human-computer interaction to an important problem with a potentially large impact. Through the experiences presented in this paper, we further knowledge about the appropriateness of these techniques to hospital epidemiology and related disciplines.

2. BACKGROUND AND RELATED WORK

There is a long history of using information visualization techniques in the study of (spatial) epidemiology or medical geography. Oppong et al. [14] emphasize the impact and utility of Geographic Information Systems (GIS) on research about the geography of health. An example of an interactive epidemiology visualization is discussed in [3]. This visualization environment encapsulates epidemiological models and displays results of spatial analysis of West Nile Virus, including demographic, environmental, and clustering data on a large display. Such visualization efforts for epidemiological purposes have mostly been limited to macro scale geographic contexts.

Visualizations involving the spread of disease within buildings usually consist of simple plots on a schematic or architectural drawing, much like John Snow's map of 1855 [14]. This is in part due to the lack of the kind of high-resolution spatiotemporal data that is now becoming available [10]. As Oppong et al. point out; "while GIS has enabled Medical Geographers to address previously inconceivable complex health-related phenomena, their ability to deal with the dynamic processes of disease transmission among population groups, which usually requires complex interactions among numerous variables, is quite limited."

As new methods in data collection and computational epidemiology respond to these challenges [4][10][12], the need for visualizing this data arises and poses its own challenges. For example, traditional information visualization techniques for spatiotemporal data such as the space-time cube [1][11] or time-series graphs linked to maps [1] cannot encapsulate efficiently the large number of independent agents involved in the kind of hospital contact-graphs visualized in this work.

Appropriate interaction techniques are a vital component of interactive information visualization. Multi-touch user interfaces have become popular, not only with HCI researchers, but also with consumers as commercial devices such as the iPhone, Microsoft Surface, the Smart Table, and multi-touch capable tablet computers become more widely available.

GIS and spatial data offer compelling applications for large horizontal surfaces. Forlines and Shen investigated multi-user spatial data exploration with DTLens [6]. They noted the inherent appeal of large horizontal surfaces for spatial data by pointing out that groups have traditionally inspected maps and other spatial media on tabletops. Various applications for the iPhone and other mobile devices have demonstrated the utility of multi-touch user interfaces for geospatial data on small displays as well.

Schöning et al. [16] explored multi-touch combined with additional modalities (foot gestures) to navigate and manipulate spatial data on large vertical display. Nóbrega et al. [13] used multi-touch displays to interact with their Flood Emergency Interaction and Visualization System. There is also much work on navigation and camera control using multi-touch interactions for 3D user interfaces (e.g., [5][8]).

3. DATASET

Our visualized dataset comes from a University research hospital in the United States. In this hospital, every time a doctor or nurse sees a patient, they have to login to a computer and logout when they are done. There are computers in every room where doctors or nurses see patients.

The dataset consists of 19.8 million de-identified computer login records (22 months, 15,595 users, 4,379 login locations/rooms), and a graph based model of the hospital building containing location and adjacency information of 19,554 nodes (rooms or room segments).

Each record contains information about user, date, time and location. Because healthcare workers login multiple times a day at different locations, the login records can be used to infer contact based on spatiotemporal proximity and estimate movement through the building. For example a physician might go from one patient room to the next, before returning to his office; logging in at each step to pull up patient information and record history and treatment.

4. USER INTERFACE AND VISUALIZATION

4.1 Design Process

We partnered with a Medical Doctor who specializes in infectious diseases, and more particularly in hospital epidemiology, to design our application. Our design partner had been looking for ways to analyze the data described in the previous section. He found that descriptive statistics and static maps were not sufficient to understand the motion of healthcare workers around the hospital, or the way infections could spread.

To address these issues, we decided to design an interactive visualization application. We took advantage of the information we had in the existing data and added some simple ways of simulating an infections spreading in the hospital. We decided to make use of multi-touch displays to provide easier manipulations of the three-dimensional hospital view than those that would be available through a single-point interaction. We implemented the visualization using PyMT, a cross-platform, open source research toolkit for prototyping multi-touch applications [9].

4.2 Overview

Our current visualization is intended to provide information on how infections may spread in the hospital. The visualization allows users to see and manipulate the view of the hospital building, and see how healthcare workers move around the building. Users can then "infect" a healthcare worker and see how the infection spreads throughout the hospital based on criteria such as vaccination rates and chance of infection.

More specifically, our implementation presents the user with a three-dimensional orthographic rendering of the hospital's floors. Each room (hallways are divided into multiple room segments) is rendered as a point and connected to adjacent rooms with a simple line. Healthcare workers are displayed as colored dots that move through the hospital as the simulation progresses. Green dots represent uninfected healthcare workers while red dots represent infected healthcare workers.

We animate the position of healthcare workers based on the date, time and location of computer login and logout records. We use Dijkstra's shortest path algorithm to interpolate location information for times between logouts and subsequent logins. Although this does not produce accurate results, it provides at the very least a plausible scenario.

4.3 Manipulating Views

To explore specific areas of interest, users can adjust the viewpoint using multi-touch interactions. Constraints on adjustment allow easily locking the viewpoint in 2D modes to inspect the visualization in cross section or traditional map format.

A global overview of the hospital (see Figure 2) can provide users with useful information to decide whether and where to concentrate their attention. For example, if they see healthcare workers being infected in a particular hospital wing, the can zoom into it (see Figure 5).

Other situations may call for different views. For example, to better understand how infections move from floor to floor, a horizontal cross section view can be used to highlight the movement of workers between floors. See Figure 3.

To better understand how infections spread within a specific floor, users can touch one of the numbers to the right of the display to highlight a specific floor, and then turn the visualization to see a tradition floor map. See Figure 4.

Additionally, 2D user interface controls with buttons and sliders are used to highlight individual floors and control simulation parameters like simulation speed, chance of infection and number of vaccinated people. The floor controls are on the right side of the screen. Figure 6 shows an instance when a user selected one floor to visualize.

The other 2D simulation controls are rendered inside a semi transparent frame, which can be moved, resized and rotated so that users can enlarge the controls or move them out of the way when not needed.

We implemented three multi-touch interaction techniques for viewpoint adjustment (See Figure 7). Dragging a single finger across the screen, pans the view across the display. Using two fingers rotates the 3D hospital around a vertical axis and scales the model simultaneously; this lets users zoom in and out while adjusting rotation in a similar fashion as the widely disseminated "pinch" gesture for 2D interfaces. Holding or "pinning down" the hospital with two fingers, users can control the angle of rotation around the horizontal axis by using a third finger sliding up or down. The angle of rotation around the horizontal axis is constrained from 0° to 90°. The constraint allows fast transition to 2D views by gross application of the three-finger interaction technique and prevents users from getting disoriented by turning the building on its head or attaining otherwise confusing viewpoint positions.

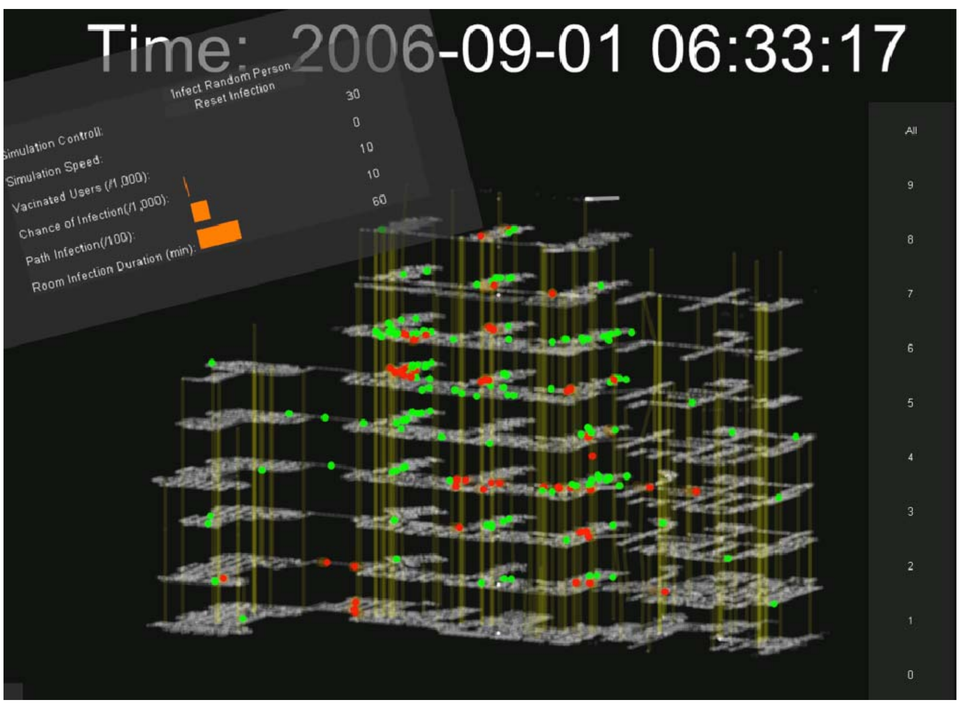

Figure 2. Default view of the hospital, with red dots representing infected healthcare workers, and green dots representing uninfected workers. The numbers to the right can help users see activity in only one floor. The movable control on the top left can be used to adjust simulation settings.

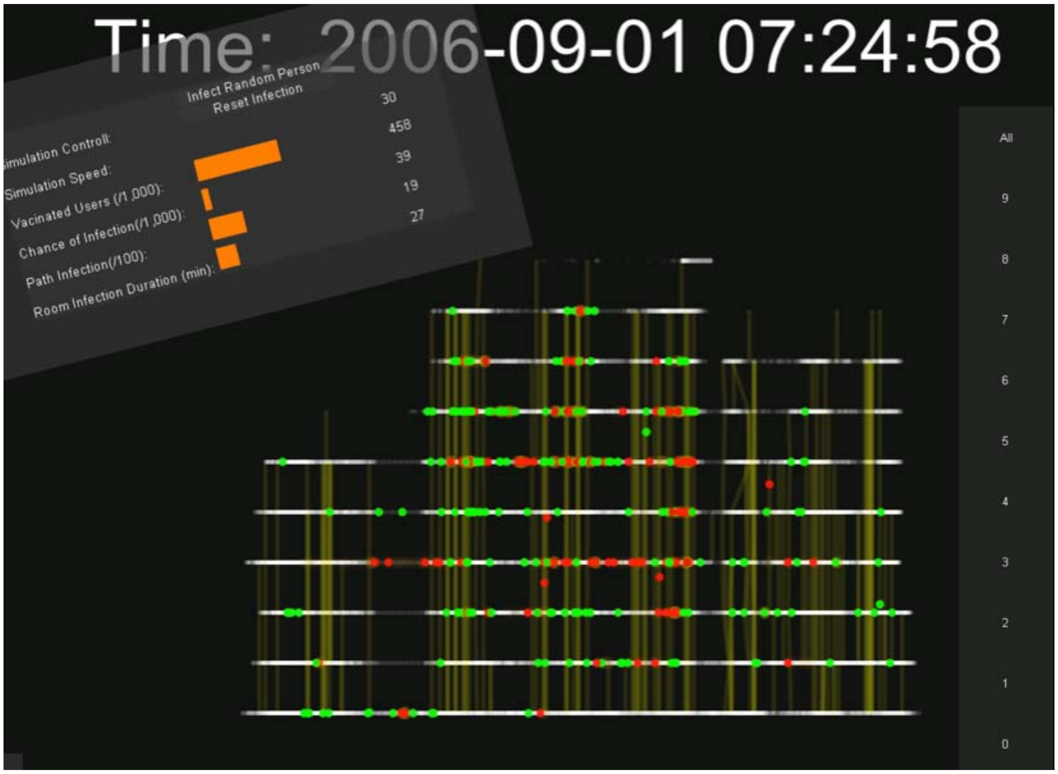

Figure 3. A horizontal cross-section of the hospital, highlighting movement between floors.

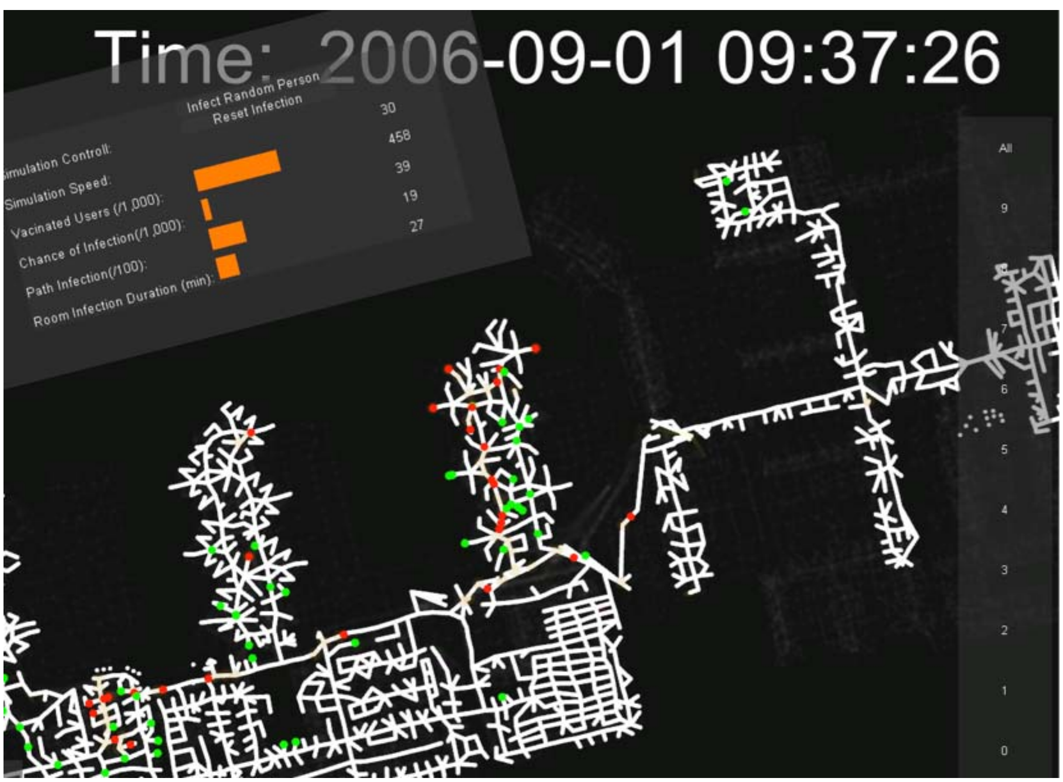

Figure 4. Visualization showing a traditional floor plan to study movement within a floor.

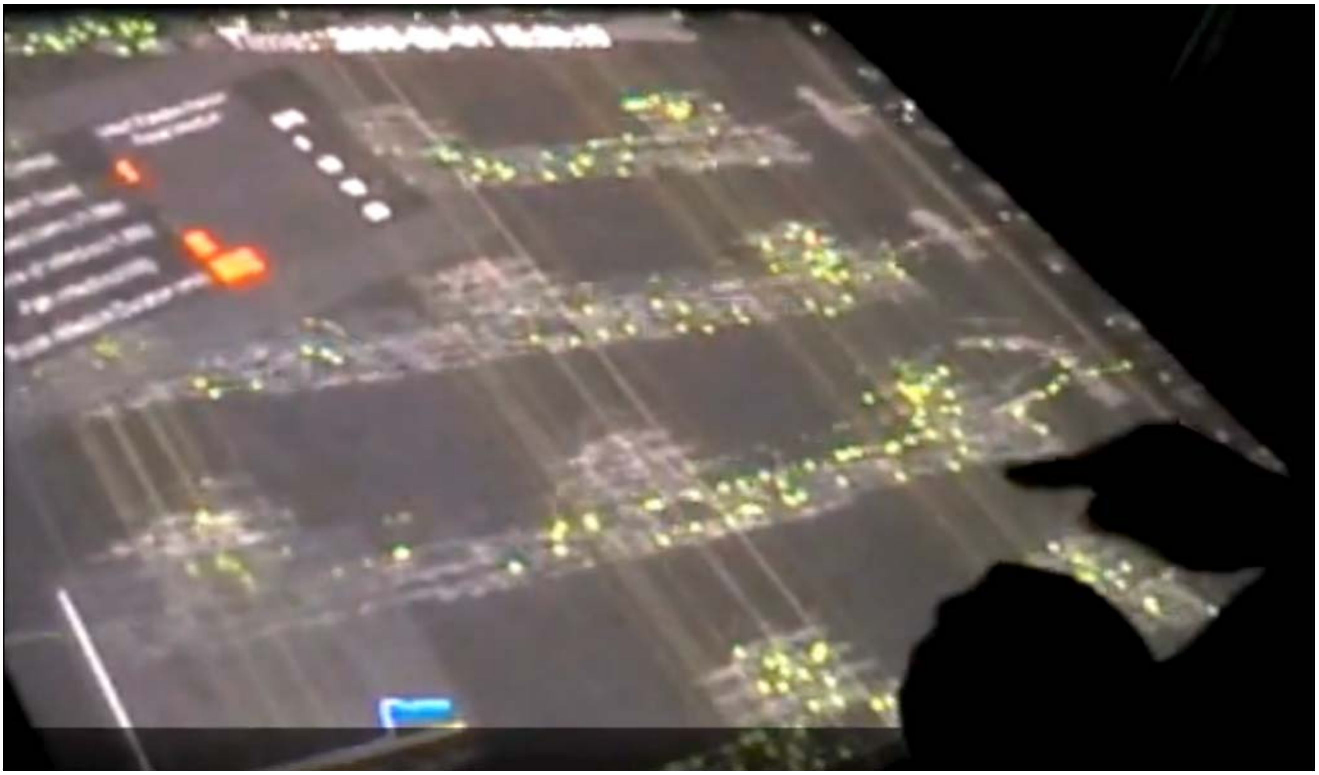

Figure 5. Visualization running on our tabletop display, in this case, with a close-up view of one area of the hospital.

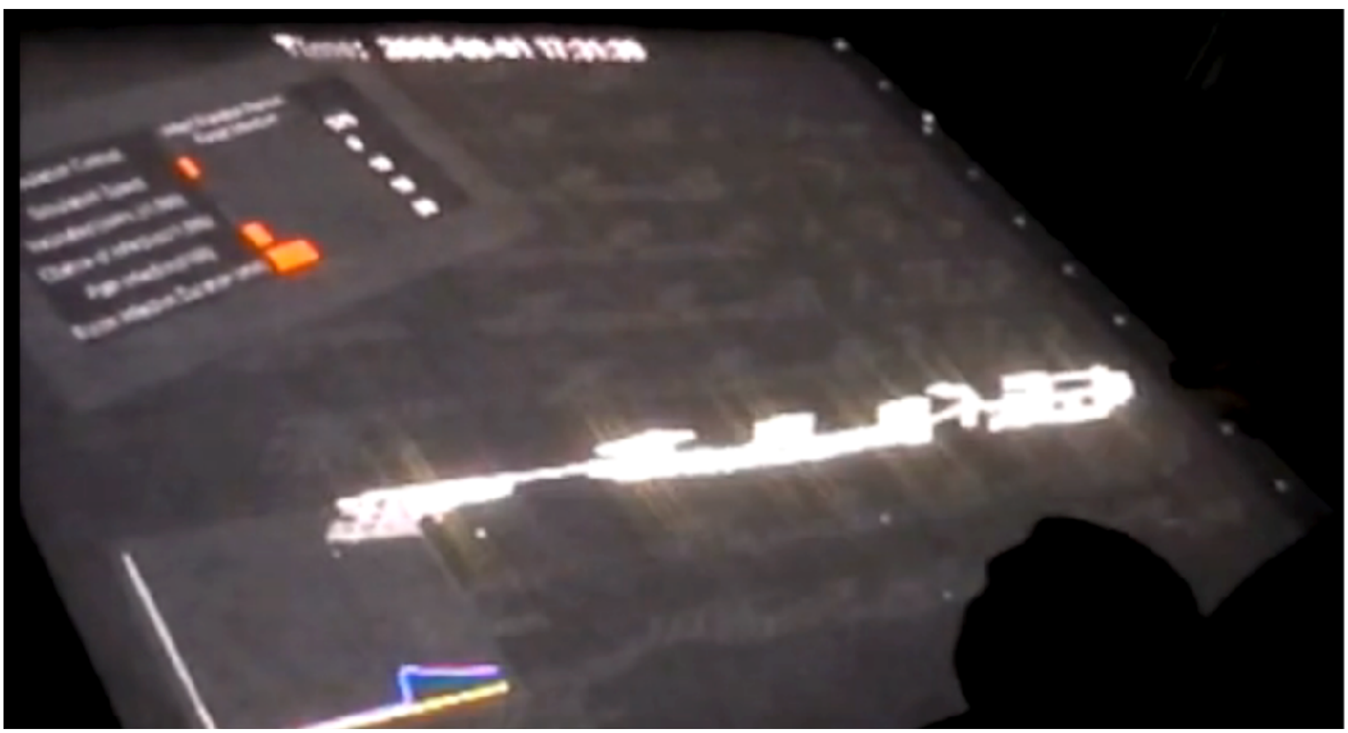

Figure 6. Selecting one floor on our tabletop display. The graph on the bottom left shows infection trends for the floor.

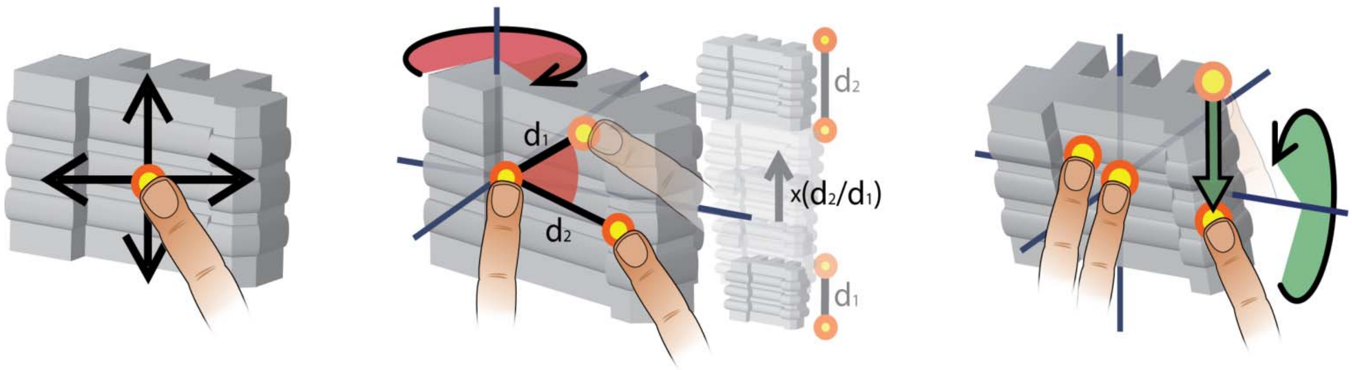

Figure 7. Gestures for manipulating the visualization. On the left, panning with one finger. In the middle, rotation around the vertical axis. On the right, rotation around the horizontal axis. In addition, users can zoom in or out using a two-finger pinch gesture.

5. FEEDBACK FROM DOMAIN EXPERTS

Instead of relying on traditional usability studies, we decided to evaluate our application by obtaining feedback from domain experts. In particular, we were interested in learning about the insights they could obtain from using our application and to get their ideas on how it could be modified to better serve their needs. In looking for experts, we selected people with different backgrounds and jobs from our design partner, but who share an interest in the dataset.

We thought this would provide advantages over traditional usability testing in that it would better help us obtain insight from experts who are already familiar with the hospital and the challenges that need to be addressed. In addition, many information visualization tasks do not lend themselves well to traditional usability testing that emphasizes efficiency and effectiveness, since it is unclear when a task would be completed and whether it was completed accurately.

Similarly, there were no clear competitors to our application. We could have asked experts to pour through the data gathered from logins, but that would have been unfair to them and would have taught us little.

We met with three domain experts from the hospital at which the data was collected (a large University research hospital); the Assistant Vice President for Operational Excellence and Quality/Safety, a quality management coordinator (infection control professional / nurse epidemiologist), and the Director of Capital Management. Each of them was given a brief introduction to the visualization, its context, and user interface. The domain experts were invited to explore the visualization, discuss their thoughts and possible applications to their work. Two of the meetings where conducted in the experts' offices using a HP Touchsmart TX2 multi-touch laptop to run the visualization. The Director of Capital Management joined us in our research lab, where the visualization was available both on the laptop and on a custom-made 32”x24” FTIR multi-touch table.

Overall, our interactive visualization was well received. We received both positive feedback and constructive criticism about it. The discussions also identified several potential use cases and applications enabled by the availability of similar datasets and this type of interactive visualization.

In the rest of this section we briefly outline the work responsibilities of the experts and their specific feedback about the system and possible applications to their work.

5.1 Assistant Vice President for Operational Excellence and Quality/Safety

The first expert to review our application focuses on achieving institutional excellence in all areas as well as operational improvement. To accomplish this, this expert is responsible for clinical quality safety and performance improvement, materials management and the supply chain. He is also an adjunct instructor at the University's College of Public Health.

This expert noted that the system would provide tremendous utility if the data were relayed in real time, especially if augmented with additional data, such as hand washing and facilities (water lines). He emphasized the importance of and difficulty of convincing healthcare workers of pursuing proper hand hygiene. Even without real-time data, he said the tool could be used to “influence new residents.” Making them afraid of the possible consequences in terms of infection in the hospital could lead to better results. “I don't see hand hygiene going up without a fear factor,” said the expert.

The expert also noted our application would be useful for tracking patients for time-lapse studies, investigating where patients spend their time at the hospital when they are not seeing a doctor. “We spend a tremendous amount of effort physically seeing those things,” he said.

Other possible uses for the application identified by this expert include:

- Identifying persons who came into contact with carrier/pathogen
- Tracking patients' stay in hospital to optimize operations
- Evaluating the outcome of emergency or quarantine drills by recording activity and being able to replay /analyze or show results
- Running response scenarios based on accurate models for disease spread

In terms of the implementation of the interactions, this expert had “fat finger” problems when using the multi-touch tablet, and thought he would prefer to use the application on a large tabletop display instead.

In spite of these issues, he had positive comments about the software. "On a level of ease, it is very good; you really don't have to do any calculations; you can just see it

5.2 Infection Control Professional / Nurse Epidemiologist

Our second expert performs daily surveillance for hospital-associated infections. This expert investigates outbreaks and clusters of infections at the hospital and associated clinics. In addition, this expert is responsible for safety education and presents data and activities that improve the safety of the hospital environment. Part of this responsibility involves printing maps of the hospital on a regular basis to plot infections, the way Snow did 150 years ago.

This expert thought the tool would be great for facilitating discussions and doing safety presentations for educational purposes. The expert also thought the tool would be very useful for tracing the path of an infection. Currently, this is very difficult to do and is largely based on anecdotal evidence from nurses and doctors.

5.3 Director of Capital Management

This expert manages the planning, design, construction and commissioning of capital projects (e.g., buildings). These projects include renovations, construction, interior design, and move management. This position also requires reviewing and analyzing building codes.

This expert was confused by the three-dimensional interface and said he would have preferred preset two-dimensional views. In particular, the expert was interested in examining specific sections of the hospital, such as a wing or department, instead of the whole hospital. "I'm typically looking at much small sub-systems," he said. If the application were to provide such preset views, it would be more useful given the expert's responsibilities.

Part of this expert's complaints had to do with the way we rendered the floor plans, as lines connecting nodes. This looked different from the floor plans the expert is used to working with, which caused him difficulty interpreting the data. Certainly, a more advanced implementation would use correct architectural renderings.

He also gave us specific ideas for improving the application for his needs. He said that as is, it provides "far too much data." He is more interested in "what is the movement within the neighborhood.". He said "all I really want to see is what is happening within each unit." He could use this information to maximize operational efficiency, trying to shorten the distance a healthcare worker needs to cover on a daily basis.

If seeing the entire hospital, this expert said he would prefer to see overviews of what is happening within each unit (e.g., bar charts showing infection rates), instead of seeing dots representing individual healthcare workers. He thought this more detailed information could be revealed if he were to zoom into a unit. This suggestion is in line with the concept of "semantic zooming", previously discussed by Furnas and Bederson [7].

6. DISCUSSION

We are pleased with the overall feedback we obtained and the many possible applications of our visualization software for improving safety at hospitals. In particular, there seems to be great potential for using the software to track infection spread, improve the experience of patients, assess drills and conduct presentations on safety.

We have also learned that it would likely have to be customized for experts with different work responsibilities, something that does not surprise us. For example, it became clear that some experts found the three-dimensional views useful and necessary, while others preferred two-dimensional visualizations. An additional challenge as tracking technologies improve is to enable their use to improve safety while guarding the privacy of those being tracked.

There is also room for improving the visualization and simulation by making it more complex and adding more variables to manipulate. Likewise, features to replay a simulation, in particular to go back in time to see how something happened would be useful.

Similarly, the visualization could be augmented with various ways to aggregate data. An example would be the suggestion of our third expert of using semantic zooming to provide an overview of what happens in each hospital unit as opposed to showing the detailed animations of all healthcare workers.

6.1 Limitations

As mentioned earlier, our current dataset has clear limitations in terms of providing accurate data. Likewise, privacy and practical concerns may limit the quality and amount of data available in the future. Privacy concerns are likely to cause issues with data on healthcare workers. Practical concerns will be added if the intent is to track patients at the hospital.

6.2 Future Work

In the future, we plan to customize the application to better serve those most interested in using it. We also expect to be able to use it with more accurate and reliable data, which may lead to more direct impacts on how hospitals are managed.

7. ACKNOWLEDGEMENTS

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