C-Flow: Visualizing Foot Traffic and Profit Data to Make Informative Decisions

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ABSTRACT
"Business intelligence", a term first coined in 1958 [11], has been evolving for almost 60 years. With recent advancements in data collection [15, 2, 8, 13], companies are looking for new ways to gain insight into customer behavior. In this paper, we present C-Flow, a novel system that allows mall and store owners to reason about consumer foot traffic with respect to store profits. This is done with an integrated heat map and overlaid footpaths on a mall map. Through two rounds of usability studies, we also provide evidence that rendering abstract paths may be more useful than rendering raw path data. See video at `http://goo.gl/mBXjKd` for reviews, slides and demonstration.

Author Keywords
Information Visualization; Data Mapping; Indoor Visualization; Business; Usability Testing

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Thousands of shoppers pass through shopping malls every day [14]. With the advent of dynamic ads in the form of electronic screens (televisions, projections, touch screens, etc.), there is an increasing demand to select consumer-relevant, time-sensitive advertisements. To meet this demand, old technologies are being used in new ways: Closed Circuit Television (CCTV) screens and cell phones are now being used to track consumer movements. [13, 2].

With the variety of consumer data now available, there are many new opportunities for visual analytics. While we were not able to locate specific works for malls, more generally, there has been some research involving overlaid temporal heat maps and geospatial data points. Our design and analysis of our tool, C-Flow, provides evidence that intelligent aggregation of this data may lead to more understandable and actionable business decisions.

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C-Flow, a proof-of-concept web application, allows mall owners and supervisors to reason about temporal consumer path data. It combines a heat map, a geo-spatial map, and consumer flows, using modern libraries such as *D3.js* and *Kinetic.js* for responsive interaction.

Mall owners can use C-Flow to visualize foot traffic overlaid on floor plans, quickly spot profit fluctuations among stores for several time periods, and locate high impact areas in order to variably price advertisement space throughout the mall. Even store owners can use C-Flow to make informed decisions on advertisement locations, allowing them to better reach their target audience. Though C-Flow is still a prototype, we firmly believe that it could boost the development of business intelligence for mall and store owners.

PREVIOUS WORK
Many previous efforts visualize individual data points [3, 6, 4, 9]. While these visualizations provide a global understanding, it is difficult to glean specific insights that would help businesses. We instead pre-aggregate data to provide a more manageable, yet sufficiently actionable visualization.

Other previous work [12, 16, 17, 7] try to reduce the screen space devoted to visualizing edges in a connected network through line simplification via clustering and minimizing crossing edges.

Instead of using clustering algorithms to reduce the lines on our visualization and showing every individual data point in our data, we propose a smart aggregation and simplification of data prior to display. This simplification aims to allow the user to make more sense of the data without losing critical details that would lead to insights. To explain this simply, much in the way that [1] simplifies map data to route paths, we simplified the individual x,y coordinates with stores that were visited.

To the best of our knowledge, we are the first to visualize foot traffic data through the use of abstract connections in an indoor setting.

DATA GENERATION
For most projects MicroStrategy creates in-house synthetic data in order to test their products before releasing them to their customers. Synthetic data is typically used in the business intelligence industry if the company is offering a tool that will be used in-house. Once you start working with real data, you have to deal with privacy concerns and interaction

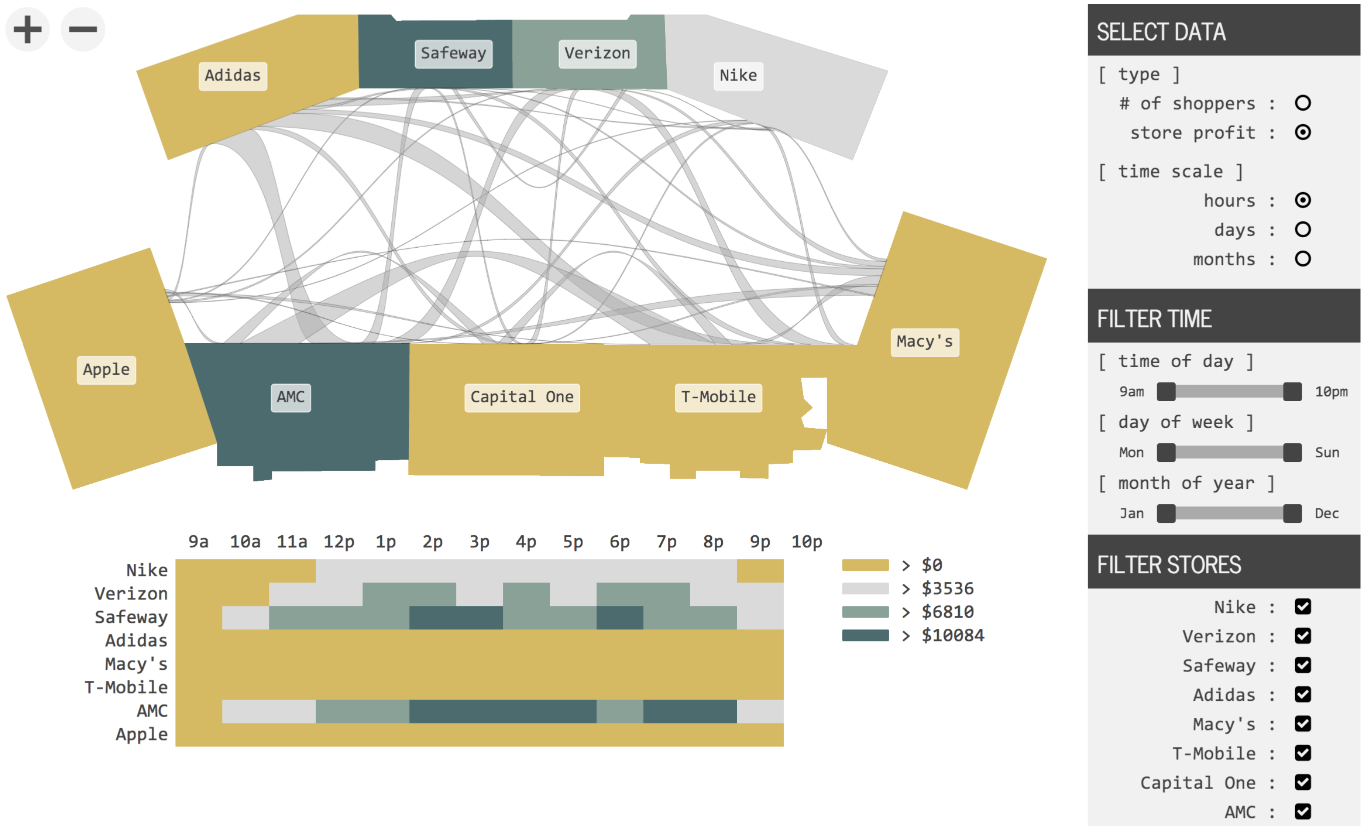


Figure 1. Overview of the Floor Plan Visualization

with the data can potentially reveal trade secrets. Furthermore, the issue of tracking consumer habits in malls [5] has become a point of contention amongst consumers.

In order to quickly develop a tool without having to get our hands on real data, MicroStrategy provided initial suggestions on data generation and some randomized data. We used these insights to create data to fit the needs of our tool. The synthetic mall data for C-Flow consists of four parts: a floor plan, shopper visiting patterns, number of shoppers in a store at a given time, and the amount of profit in a store at a given time.

In order to provide a realistic experience for our tool we selected Tyson's Galleria in McClean, VA as our floor plan. Data was extracted from the website, layered in Adobe Illustrator and stores were individually exported as support vector graphic (SVG) images. The floor map of the mall includes nine stores. In order to spend the maximum amount of time on our visualization, we did not automate the process of converting an AutoCAD file to an SVG graphic. While we did not further any efforts in this area, MicroStrategy is actively exploring this automation.

Two types of foot path data were created in the development of our tool: the raw (x,y) consumer path coordinates and a simplification of the data that only included the stores that a shopper visited. The raw (x,y) consumer data consisted of sets of points for each shopper. The points for each shopper were arranged in sequential order so that, for each time step (defined to be one second), each position represents a shopper's location at that second. Furthermore, each shopper was instantiated with randomized preferences for store categories. The simplified foot path data was generated for 1,000 shoppers in a year time-frame with a limit of visiting all nine stores in one day. Stores were randomly chosen on a multiplicative weighting scale and number of stores they visited were randomly decided from a value of one to the maximum, nine. Restrictions placed on shoppers included not being able to visit a store outside of the given time frame, 9AM to 11PM and shoppers could not go back into a store after leaving it in one time step.

Shopper data was generated off of the visiting patterns described above and profit data was randomly determined, giving each shopper present in the store at a given time-period the ability to make a purchase between $20 and $200.

The map aggregates all of the data for profit and shoppers, and the heat map shows the hourly separation of values. Both derive their data for a given filtered time period selected in the control panel. The goal behind our synthetic data generation was to create realistic synthetic data in order to potentially gain insights in areas where our tool is especially effective.

C-FLOW COMPONENTS

In this section we will describe the different components of C-Flow. More specifically we will discuss the organization of the back-end and front end components: geo-spatial map, flows, control panel and heat map.

Overview

Fig.1 shows the entire C-Flow interface. C-Flow is implemented as a web application with a Node.js back-end serving the data. The tool is made up of two views and a control panel. The first view is the floor plan view, and the second is the heat map view.

Back-end

C-Flow uses a remotely hosted RESTful back-end implemented in Node.js, a modern server-side implementation in JavaScript for real-time web applications. The REST request to the server supports ten parameters, which are described as follows.

- `type`
  Indicates the type of data to return - store data or path data. Store data consists of profit or shopper data. Path data consists of aggregated paths which are represented as a store start point and a store end point with a number of shoppers within the path.

- `name`
  The name of the store to query.

- `value`
  Indicates whether the data returned should consist of shopper or profit data.

- `timeType (hour, day, month)`
  Indicates how to aggregate results.

- `time parameters (hour1, hour2, day1, day2, month1, month2)`
  Indicates time ranges for filtering the data specified by the time-based filters.

Using these parameters, the front-end specifies the desired data from the server with a single REST request through AJAX. The server queries the database with the parameters, aggregates them based on `timeType`, and then returns them in a format easily usable for the front-end.

Front-end

The front-end is HTML5/CSS/Javascript (JS). We use two different JS libraries for the two main views: Kinetic.js, an HTML5/JS canvas framework for high-speed drawing and animations, for the floor plan view; *D3.js*, a popular JavaScript library to manipulate documents based on data, for the heat map view. We also use *jQuery* for general-purpose utilities and event-based coordination and a customized *jQuery UI*'s range slider for the sliders in the control panel.

Control Panel

The rightmost slice is the control panel. It is the main interactive component, though it contains little information itself. From top to bottom, the controls are as follows:

- Data type toggle
  Toggles whether the heat map displays shopper or profit data, and whether stores are colored based on profit or shopper data.

- Time selector
  Changes time granularity (hour, day, month). Filters heat map cells and floor plan footpaths.

- Time filters
  Filters heat map cells and floor plan footpaths by hour, day, or month.

- Store filters
  Toggles whether the heat map displays data for a given store. Effectively adds or removes heat map rows.

Map View

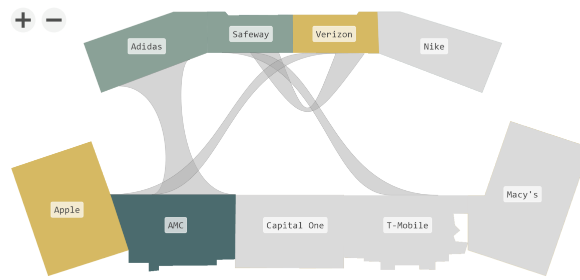


Figure 2. The map view with store heat map and C-Flow visualization

The bulk of the interface consists of the floor plan of the mall, as well as a display of the consumer flows between stores. In Figure 2, we can see that Tyson's Galleria consists of two rows of stores. Each store has a label (its name) and a color (describing either profit level or foot traffic popularity, depending on the data toggle mentioned previously).

The gray curves with a 50% opacity represent consumer flows between stores. Figure 2 shows the latest version, which employs a simpler footpath model (motivated largely by the results from the first usability study). Initial prototypes rendered raw footpath data, which are almost random paths distributed in the entire mall. When hovering over a particular store, only the consumer flows out of that store would be displayed.

C-Flow Rendering

To generate the curve of the path flow, we used a *Weighted Bézier Curve Model*. Suppose there are N stores, for each store i, the leftmost and the rightmost point in the entrance is labeled as L_i to R_i; the number of shoppers from store i to j is noted as $f_{i,j}$, where $i, j \in [1, N]$. $f_{i,j}$ is dynamically loaded from the server by filtering on the control panel. We define the entrance vector $\overrightarrow{E_i}$ as $\overrightarrow{L_i}$ to $\overrightarrow{R_i}$, i.e. $\overrightarrow{E_i} = \overrightarrow{L_i R_i}$. Finally, the total number of shoppers flowing out of store i is defined by $F_i = \sum_j f_{i,j}$. Afterwards, we calculate the number of shoppers λ corresponding to a unit pixel length:

$$\lambda = min_i\{\frac{F_i}{|E_i|}\} = min_i\{\frac{\sum_j f_{i,j}}{|\overrightarrow{L_i R_i}|}\}$$

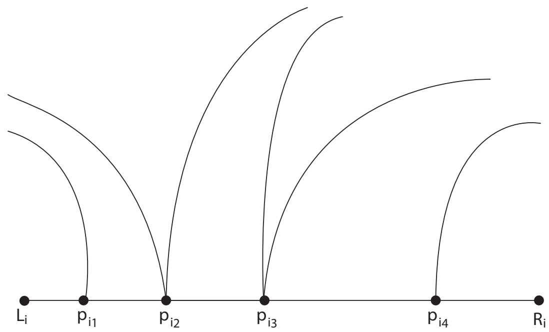


Figure 3. Control points are distributed along the store entrance by the traffic flow.

As illustrated in Figure 3, for each flow from store i to j, the position of the flow $p_{i,j}$ is given by:

$$p_{i,j} = \sum_{k=1}^{j-1} p_{k,j} + \lambda \cdot f(i,j)$$

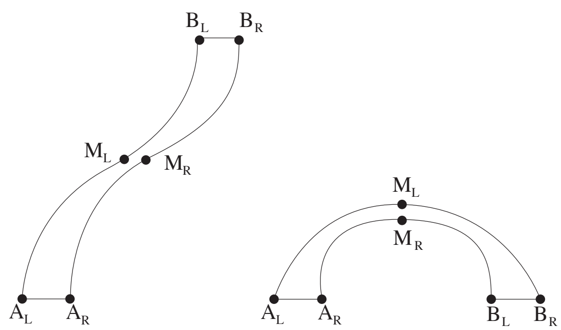


Figure 4. Control points used in Bézier Curve

In Figure 4, for one flow from store A to store B, we also define two corresponding control points to render the curve $\mathbf{M}_L = \frac{1}{2}(\mathbf{A}_L + \mathbf{B}_L)$, $\mathbf{M}_R = \frac{1}{2}(\mathbf{A}_R + \mathbf{B}_R)$. For cases where two entrances are parallel, the positions for $\mathbf{M}_L$ and $\mathbf{M}_R$ are defined orthogonal to the line between store A and store B and the distance between $\mathbf{M}_L$ and $\mathbf{M}_R$ is half of the width of the flow. Thus, we have

$$\mathbf{M}_R = \frac{1}{2}(\mathbf{A}_R + \mathbf{B}_L) \pm \mathbf{j} \cdot (\mathbf{A}_R + \mathbf{B}_L)$$

$$\mathbf{M}_L = \mathbf{M}_R \pm \mathbf{j} \cdot \frac{1}{2}\lambda \cdot f_{i,j}$$

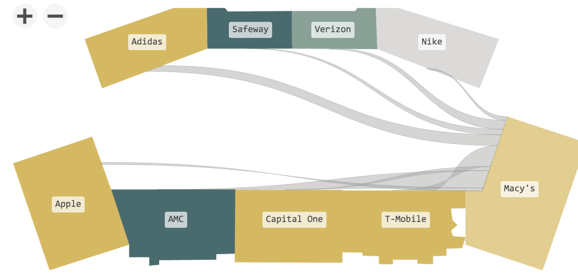
For every three continuous control points, a quadratic Bézier curve[10] is applied for C-Flow. Given points $\mathbf{P}_0$, $\mathbf{P}_1$ and $\mathbf{P}_2$, we have

$$\mathbf{B}(\beta) = (1-\beta)^2\mathbf{P}_0 + 2(1-\beta)\mathbf{P}_1 + \beta^2\mathbf{P}_2$$

Finally, in order to avoid overlapping as much as possible, we propose to sort the consumer flows according to the angle ϕ between the store entrance $\overrightarrow{E_i}$ and the simplified flow vector $\overrightarrow{M_iM_j}$ where

$$\phi_{i,j} = arccos(\frac{\overrightarrow{E_i} \cdot \overrightarrow{M_iM_j}}{|\overrightarrow{E_i}| \cdot |\overrightarrow{M_iM_j}|})$$

As illustrated in Fig.5. The layout of traffic flow is impressively improved after the sorting algorithm.



(a) Naive Traffic Flow Layout

(b) Sorted Traffic Flow Layout without Overlap

Figure 5. (a)Naive traffic flow (b)New layout without overlap

Heat Map

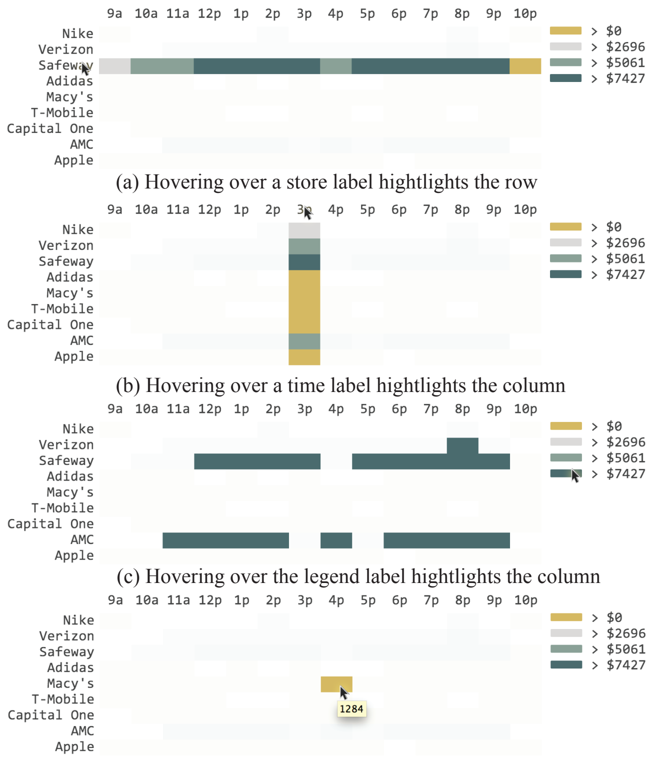
The bottom section is a heat map that displays profit or consumer data over time. Each row represents a store and each column represents a unit of time binned by hour, day, or month. A four-color legend sits off to the right.[1]

As is illustrated in Figure 6, hovering over a store label highlights that row, fading all other rows and triggers a hover event for the store on the map. Hovering over the legend focuses on cells that fall into the hovered bucket, fading out all other cells. Hovering over a time label focuses on that column, fading all other columns. Hovering over a cell highlights that cell and fades out others and triggers a tooltip that shows the actual value of the cell. Additionally, hovering over a store in the C-Flow view, described above, highlights the relevant heat map row allowing coordination between the two views.

EVALUATION

We designed a two-round usability study: the first for the initial prototype (with raw footpaths) and the second for the revised prototype (with abstract flows). 11 volunteers were drawn from friends and family, whose ages ranged from 19 to 55 and professions ranged from business student to industry computer scientist. None of the participants were familiar with the interface prior to the study. The first six studies were

[1]Technically, there are five colors: white, yellow, gray, light green, dark green. The legend only describes non-zero buckets, however.



(a) Hovering over a store label hightlights the row

(b) Hovering over a time label hightlights the column

(c) Hovering over the legend label hightlights the column

(d) Hovering over a cell returns the actual profit in the tooltip

Figure 6. Interactions of the heat map

conducted across three days, and the latter five studies were conducted across two days.

Procedure

All of the participants took part in the usability test in either a meeting room or office setting, or the observer went to the home of the user and observed the participant's interaction.

The usability study began with a brief introduction of C-Flow. Firstly, we explained the general problem to the participant (ad placement) in 2 minutes. No training procedure is provided during the introduction session. Afterwards, the user was asked to complete the specific tasks (3 tasks, about 5 minutes each). Lastly, there was a brief questionnaire and time for general comments. They were told they could stop at any time. We asked them to think aloud, and we quietly took notes.

The three tasks were arranged from simple to complex, straightforward to open-ended, and they were designed to exercise the most important aspects of the prototype available at that time. We chose not to introduce the tool, hoping to gain insights from the participant's learning process. These insights would help us understand novice user behavior and help us modify the interface so that it is easily adaptable for any type of user. If the participant took less time than allotted for any particular phase, we allowed them to proceed to the next task and allowed them to work at their natural pace. The usability test follows:

Task 1: Basic navigation

Find Safeway.
(Prompt them if they flounder: it's towards the right.)
Goal: store identification. May trigger panning.

Do people visit Safeway?
Goal: path identification. Is the term "path" clear?

Where's the first store most people visit when they leave Safeway?
Goal: path direction identification.

Task 2: Detail

Find Macy's. Do a lot of people visit at 11:00?
(Prompt them if they linger on the map.)
Goal: heat map legibility. Heat map use.

Do more people visit Macy's at 11:00 or 3:00?
Goal: heat map legibility. Value comparison.

Task 3: Ad placement (putting it all together)

Pretend you own Macy's. Suppose you want to place an ad for women's perfume. There are two open spots: one at point P1 (center of the map, where the paths intersect; point to it), at time 4:00 PM; another at point P2 (entrance by Apple, point to it), at time 10:00 AM. Which spot would be better? Why?
Goal: data synthesis.

The first task evaluates C-Flow's most basic visual representations: the floor plan and the footpaths. The second task evaluates the heat map: what it displays, and how it's interpreted. The third task examines whether both can be meaningfully combined, testing how well the interface supports higher-level reasoning.

The concluding survey given, designed to gauge subjective reactions, follows.

Basic Demographics

Gender? M / F
Age? —

Computer use:
Once or twice a month Once or twice a week
Several times per week Several times per day

Please indicate the degree to which you agree with the following statements.

1. The interface was easy to navigate.

2. It was easy to figure out where people went.

3. It was easy to figure out when people went to various stores.

4. Buttons, text, and so on were easy to read.

5. The interface was aesthetically pleasing.

Results: Usability Study #1

Some elements of the first C-Flow prototype performed well; many others under performed.

Results: Survey

The averaged results of the usability test survey may be seen in Fig. 7. From this we may conclude that our participants seemed to receive the overall aesthetics well. They found the interface simple to navigate and buttons were easy to discern. On the negative side, our participants seemed to find it difficult to understand consumer movement. This is particularly problematic, as it is one of the key components of C-Flow.

Task One

Task one, as previously mentioned, existed to test participants' understanding of the basic layout of C-Flow. The starting state of C-Flow was to display profit data; however, for this task, foot traffic data was far more useful. Many participants did not notice the toggle between foot traffic and profit data in the control panel. Users tended not to use the path implementations to solve this problem, seeming to become confused when attempting to grasp their meaning. Overall, participants seemed to identify stores in both views of C-Flow quickly and without trouble.

Participants completed this task with ease; however, we had expected them to attempt to use the paths to solve problems of shopper location. Instead they resorted to using the heat map in foot traffic mode. We did not expect the heat map to be so quickly understood; however, participants very quickly grasped the inherent time series data. This was encouraging. While participants seemed to avoid the footpath data, they were drawn to the heat map.

Task Two

Task two existed to test participants' ability to discern details from the footpath and profit data. For this test we fully expected the participants to utilize the heat map, as it comprised our finest granularity view. Users were very successful at task two solving all questions with ease.

We received several comments that our color palette was too subtle, making it difficult to differentiate different values. Some participants suggested that we might adopt a more traditional red/green gradient. Participants requested additional time controls for the paths, allowing them to filter out paths that occurred before and after a time.

Task Three

Task three was meant to test participants' ability to perform the actual task for which C-Flow was designed. Using all tools available, participants were told to choose one of two advertisement placements. Again for this task we saw participants drawn to the heat map over the raw footpath map. For this task; however, the raw footpath data was more necessary. Users had difficulty understanding the paths, stating that they were too cluttered and confusing.

All participants eventually came to the same conclusion for ad placement, placing the ad near a large cluster of intersecting paths near the middle of the map. Several cited an uptick in nearby store foot traffic in the heat map for their choice. Others chose this point because it was a more central location with more paths on the raw path map. Feedback for this task suggested that the current implementation of paths was more confusing than helpful.

Subject Feedback

Participants used the time following the three tasks to provide suggestions and helpful feedback. Almost universally, participants requested path data be drawn directionally. Several participants noticed a glitch in the initial implementation of C-Flow, which caused path colors to be inconsistent. Participants also universally reported that the current implementation of paths was overwhelming. From this feedback we decided to work on a second iteration of C-Flow incorporating several of the ideas suggested by the usability test participants. Additionally, for this new version of C-Flow we sought out different ways to visualize path data. We will discuss our new C-Flow and the numerous changes we made in the following section.

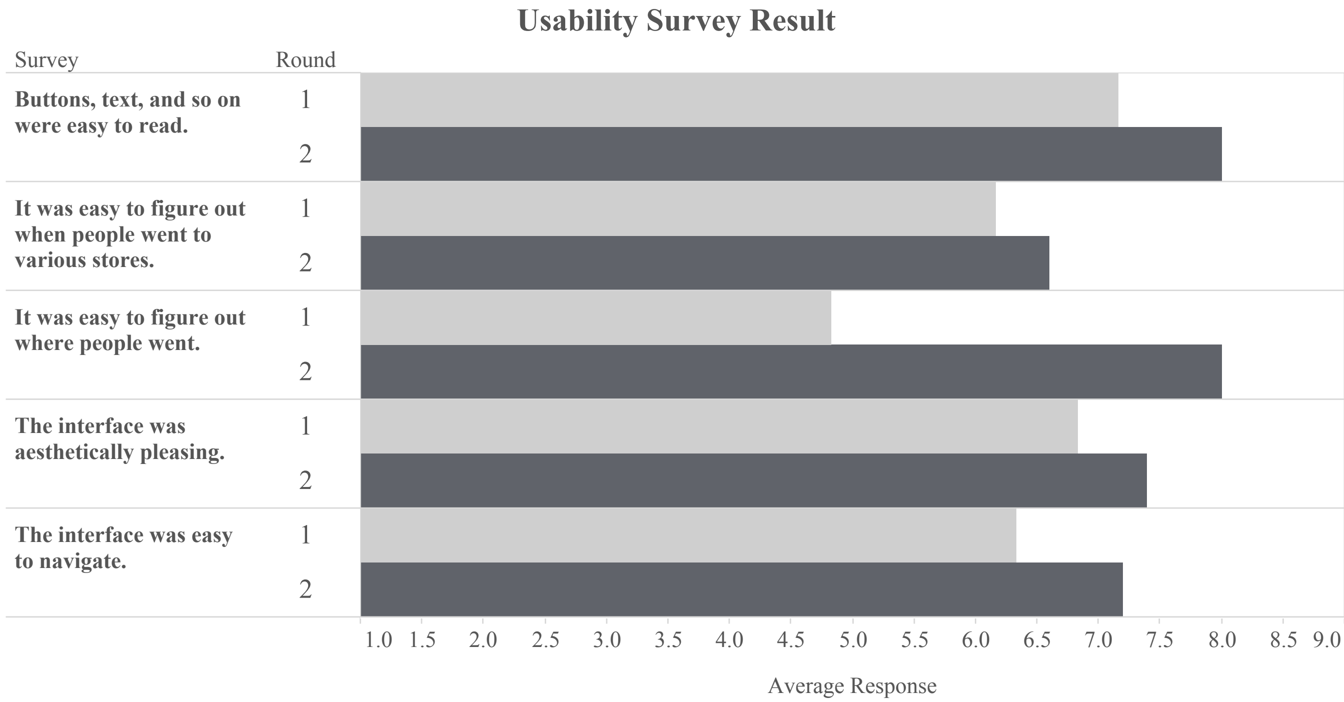


Figure 7. Averaged usability survey responses

Discussion of Usability Study

We considered the results of our usability studies carefully, taking into account both our participants' comments, and their usage patterns. We found that there were several areas that required improvement in our design. Each of our two usability studies furthered the design of C-Flow; leading to what, we believe, is a compelling visualization of consumer traffic flow between stores.

Insights from Round 1

Our first round of usability studies alerted us to three major issues. These issues were, readability of data, raw path incomprehensibility, and clear heat map usage. The first two were negative discoveries, while the third was a positive discovery.

Readability of Data

Multiple participants alerted us to elements in our color scheme being inconsistent and, worse, that several elements were mistakenly consistent. In particular, for the first version of C-Flow, the colors of our paths data were drawn from the same color palette as our heat map. Even though the paths and the heat map shared a color palette, there was no intended equation in values.

Additionally, several participants reported that it was difficult to see the labels for stores on the map view, because the store labels blended in with the background colors of the stores.

In order to address these issues we decided to add a neutral gray color to our palette to indicate a lack of numerical data. We used this gray to draw our paths in the second version of C-Flow. Additionally, we use this gray as a transparent backing for the labels on our stores.

Raw Path Incomprehensibility

Universally, our participants avoided the raw path data we presented in C-Flow. The main reasons for this seemed to be the fact that the data was too cluttered, and that the data was directionless. This made it impossible to tell if a shopper was arriving or departing a store. We expected participants to make heavy use of these paths for Tasks one and three of our usability study, and they circumvented this element.

To reduce the clutter of the raw path data, we made the decision to abstract our path data down to simple curves, indicating which stores shoppers travel after leaving a given store and maintaining the overall understanding of the flows of shoppers from store to store.

Heat Map Use

Our participants seemed unable to utilize the raw footpaths presented in the original C-Flow, but they managed to solve tasks one and three despite this handicap by making use of the heat map. One example: To find where most shoppers traveled after leaving Safeway, participants examined time periods of peek Safeway traffic in the heat map, and then which locations saw an increase in foot traffic at the next time bucket. When examining the results from our usability study we were surprised at how versatile the participants found the heat map, preferring it over the path view. We bore this in mind when going forward with version two of C-Flow.

Insights from Round 2

Our second round of usability studies supported the changes we made after our first round. We found that participants began using paths to attempt to solve tasks one and two. Participants still found issues with our path displays. Additionally, participants found it difficult to find details in C-Flow. Lastly, participants still showed some hesitancy in terms of selecting an advertisement location.

Paths in Version Two

Participants were more willing to work with the paths in version two of C-Flow. They seemed to utilize the map view for solving tasks one and two. This was in stark contrast to our first round of usability studies, in which the participants did not utilize the map view. Several participants again cited issues of directionality, not understanding that, when hovering over a store, all paths were outflows. To solve this problem we have implemented a flow direction graphic, which indicates the directionality of the currently displayed flows.

One issue that some participants reported was that they no longer felt as though the paths were indicative of the actual paths taken by the consumers. The abstraction detracted from participant belief that the paths represented an actual guide for where to place advertisements. This is an issue we have considered and we believe that an additional view of the data might help address this issue, showing how crowded areas of the mall are, explorable by time. Unfortunately, this insight will have to wait until a future version of C-Flow.

Color Scheme

Participants voiced concerns about our color palette for the data. It was not intuitive that the data was double ended, both extremes more interesting than the intermediate values. We found that participants seemed to think of the intermediate values in the heat map as lower than the low values. This is due to our particular choice of color. We believe that, for double ended data, this color scheme is appropriate; however, we believe that an important feature that might help alleviate this confusion is the ability to define custom colors for each of the data ranges in our legend. This will also help usability for color blind users.

Detail Difficulties

When asked to compare two values in task 2, some participants were unable to discern differences between similar values. This was due to these similar values being binned into the same color values. C-Flow's heat map supports built in tooltips, but participants did not seem to notice these. Participants felt as though they would like the ability to delve into the values under the visualization. Currently version two does not have this functionality (beyond the built in tooltips).

FUTURE WORK

There are many possible expansions to our current project. Our mall representation is a bit smaller than the average mall, though our framework could be easily be scaled to support larger maps and multiple floor views. We envision a tile-based approach, in which we load only the sections that are visible on the screen and create points on the map that represent flows between regions. The visualization also makes several data requests to the server; we would like to experiment with making one data request and filtering all the data in memory with the larger representation, similar to SpotFire.

Another natural extension would be splitting or filtering paths based on demographics in order to more effectively target consumers. Specifically, we would like to explore the dichotomy of abstract and raw path data, potentially developing a hybrid solution that incorporates fine-grained details.

Our usability study participants were very helpful with providing future improvements to C-Flow. We would like to explore these suggestions in greater detail. Participants had requested that individual cell hovering in the heat map should not fade out the other cells completely so that a user can maintain a contextual window when exploring the data. Participants would also like to see further coordination of the heat map and map components. This would include adding store hovering, which activates the heat map row hover feature and the heat map time hover activating a filter for the map.

Some further minor feature updates gleaned from our usability study could include: adding titles to legends, adding a image showing the directionality of flow, making fixed intervals for the heat map range, displaying store logos, giving a user greater flexibility for color selection, adding options to explore specific events by date, and customizing sort order of the heat map rows.

Finally, given the ubiquity of mobile devices, it would be particularly beneficial to extend our implementation so as to include iPad development. We designed the interface for a mouse/keyboard paradigm; however, the added functionality of touch gestures gives rise to new opportunities, new challenges, and perhaps, unaddressed design ramifications.

CONCLUSION

C-Flow is a robust means of visualizing foot traffic data and combining that data with store profit data. The changes we made between versions one and two of C-Flow were drastic; however, we believe that they were all for the better. Although we sacrificed displaying the true paths that the shoppers followed, we feel that the source/destination implementation we alighted upon is an elegant abstraction of that data. This tool helps solve a newly emerging problem in a world of dynamic advertisements, allowing users to reason about the demographics and shopping habits of consumers via the paths they walk throughout a shopping center.

CREDITS

C-Flow was developed as a group. Tiffany worked primarily on styling, as well as the control panel and general coordination. Kent worked equally on data generation and heat map development. Ruofei focused on the map view including the floorplan rendering and Bézier curve algorithms. Jonathan worked on raw path data generation, as well as paper and video production. Hitesh implemented C-Flow's Node.js backend, working with everyone to provide necessary query support.

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