An Evaluation-Guided Approach For Effective Data Visualization On Tablets

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ABSTRACT

There is a rising trend of data analysis and visualization tasks being performed on a tablet device. Apps with interactive data visualization capabilities are available for a wide variety of domains. We investigate whether users grasp how to effectively interpret and interact with visualizations. We conducted a detailed user evaluation to study the abilities of individuals with respect to analyzing data on a tablet through an interactive visualization app.

Based upon the results of the user evaluation, we find that most subjects performed well at understanding and interacting with simple visualizations, specifically tables and line charts. A majority of the subjects struggled with identifying interactive widgets, recognizing interactive widgets with overloaded functionality, and understanding visualizations which do not display data for sorted attributes. Based on our study, we identify guidelines for designers and developers of mobile data visualization apps that include recommendations for effective data representation and interaction.

Keywords: Visualization, mobile, touch screen, user interaction, user evaluation

1. INTRODUCTION

Worldwide sales of tablets totaled 195 million in 2013 and are projected to reach 370 million by 2017.[1] The number of apps available on the Android market is presently 675,000, with 25 billion downloads to date while Apple's App Store has 700,000 available apps, with over 30 billion downloads to date. Mobile devices and the apps that run on them are becoming increasingly popular and ubiquitous. Recent research suggests that users are increasingly using tablets for data visualization tasks for financial management and quantified self-type tasks.[2] This, however, does not necessarily imply that users are capable of using mobile apps to efficiently explore and better understand data. In light of the extreme popularity of mobile devices, we identify guidelines for developers of visualization apps based on a user evaluation that investigates how users *interpret and interact* with a visualization app on a tablet.

This research topic is especially relevant in consideration of the growing popularity of interaction interfaces such as multi-touch screens. Specifically, tablets offer the versatility and portability of a mobile device but with a larger screen size than phone-sized devices. Although a tablet display size is constrained when compared to standard desktops for visualization, it is sufficient to permit interactive visualizations. Tablets differ from standard desktop PC's in a variety of ways, including limited display size, reduced computational power, different user input methods, slower connection speeds, increased likelihood of user distractions,[3] varying work environment conditions, and power supply limitations.[4] Tablets present unique opportunities and challenges to the visualization developer. In order to make visualizations on tablets effective, it is first helpful to understand the features and limitations of tablets, as simply porting visualizations intended for desktop computers to tablets can result in a system that is confusing, cumbersome, or even unusable.[5]

To specifically investigate challenges that users face when using an interactive visualization for data exploration tasks on a tablet we conducted a user study. Through observing and recording users interacting with

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varied visualizations on a tablet, we were able to gain insight regarding the tasks and specific problem areas that users were having trouble with. Additionally, we were able to find tasks (and corresponding visualizations) that users were able to perform correctly regardless of their age group or familiarity with a touch-screen device. The results of the user evaluation significantly improved our understanding of the interaction challenges that users face when performing analytical tasks using interactive visualizations on a tablet. With this increased understanding, we propose guidelines for mobile visualization app designers and developers, focused on improving the user's overall interaction experience.

2. RELATED WORK

Much of the research regarding mobile data visualization is focused upon data representation on small mobile devices, such as phones. There is a dearth of research investigating effective visualizations and user interaction methods on larger devices, such as tablets. Recent advances in mobile graphics research[4] and mobile graphics tools/APIs[6] have made the field of mobile visualization not only possible, but very promising. Yet despite the relatively short period of time during which mobile devices have included advanced graphics technology, researchers have been exploring and investigating the field of mobile visualization for decades.

A variety of mobile device characteristics must be considered, including limited display size, reduced computational power, different user input methods, slower connection speeds, increased likelihood of user distractions,[3] varying work environment conditions, and power supply limitations.[4] Pattath et al. [7] discuss some of these challenges as they relate to mobile visual analysis and present some solutions, explained by way of example systems for networking monitoring and a conference information system.

Visual representations which allows users to see, explore, and understand large amounts of information are extremely valuable and important.[8] Mobile devices which provide these visual representations can more effectively support mobile workers in making important decisions.[3] Yet despite the utility and importance of mobile visualization, there remains a lack of understanding in terms of the interaction and visualization capabilities of tablet users.[9]

2.1 Displaying Visualizations on Small Screens

There are a variety of published approaches and strategies that relate to presenting and interacting with visualizations on small, phone-sized devices. Karstens et al. [10] discuss the importance of avoiding excessive scrolling and panning on small devices. Instead, they present an approach to visualize hierarchies using *Rectangular View*, which consists of a radial layout where the levels are arranged as squares, in order to more efficiently utilize the limited screen space. Yoo and Cheon[11] use a circular radial layout to display hierarchical data on a small screen. Hao and Zhang [12] also present a method for visualizing hierarchical data on small mobile devices. The approach, called *Radial Edgeless Tree* (RELT), recursively partitions the display area to maximize usage of the limited display size. Burigat et al. [13] evaluate three techniques to support user navigation of large information spaces on small screen devices. The authors compare a scroll and zoom approach, a drag and zoom approach, and an approach whereby an overview outline is superimposed over the detail view, called *Zoom-Enhanced Navigator* (ZEN). Sadana and Stasko[14] recently presented a tablet-based dynamic scatterplot implementation for tablets that allows interactive filtering and zooming. The Kinetica system[15] presents a physics-based technique for interaction with data on a multi-touch system. They showed that users were able to explore multi-dimensional data quickly using their system.

Another approach which increases the amount of information displayed on a small mobile device screen by adding a third dimension of depth, presents the user with a 3D spatial overview of the data.[16] Dykes et al. [17] compare different approaches to presenting route instructions to a user, including textual/spoken instructions, 2D maps, and 3D maps. Recently, Wiehr et al.[18] presented a visualization system for navigation that varies the amount of detail presented to the user based on the context.

2.2 Addressing Mobile Device Constraints

Some approaches to visualizing data on mobile devices with limited computational power involve performing a portion of the computation on other devices with greater resources. Ehret et al. [19] present a scalable visualization system, in which the client device information is collected, and based upon the capabilities of the client device, visualization computations are performed by the most appropriate available resources. Chittaro[20] presents an approach to showing multiple visualizations on a small screen in an overview fashion either by displaying the visualizations in different areas of the same screen or by allowing the user to rearrange the visualizations to possibly overlap. Schmeiß et al.[21] present an approach to support temporal information in mobile visualizations in an integrated way by use of a time slider widget. With this functionality, mobile visualizations display events and points of interest at a user-specified time.

Another approach to efficiently use limited screen space involves *filtering* geographic query results and decreasing the amount of information displayed on a small, mobile device screen. This approach involves quantifying object relevance, omitting less relevant objects, aggregating objects, and displaying aggregation symbols.[22] Pattath et al.[23] present another system to visualize and analyze data on a mobile device. The authors discuss in detail the user interface design, with the goal of displaying essential information in different correlated modes efficiently and effectively.

With the limited display space of mobile devices, it is even more important to consider the information that should be included in visualizations and the information that should be excluded. Rukzio et al.[24] present research demonstrating the fact that displaying confidence values in mobile applications does not necessarily improve usability of the system. A user study showed that system certainty values were mostly not used and not considered helpful by test subjects.

By virtue of the fact that mobile device users are mobile, there is a greater likelihood of user interruption when using a mobile device.[3] To compensate for the user's decreased attention, user interaction tasks should be *minimized and simplified*. Our user evaluation led us to similar conclusions, where users performed poorly on tasks requiring multiple interaction steps.

2.3 User Interface and User Interaction

User input methods on mobile devices differ from those used on PC's since there is no right-click or hover functionality when using a touch interface. Thus, in addition to the challenges related to displaying visualizations on mobile devices, there are also challenges related to defining user interaction techniques with visualizations on mobile devices. Chittaro[25] emphasizes that the design of mobile device interaction mechanisms must be driven by user needs *more* so than technology, especially considering the limited input facilities available. Oviatt[26] discusses the importance of considering users' intuitive and natural behavior in designing interfaces so as to reduce the cognitive load on the user, thus allowing improved performance.

Gong and Tarasewich[27] reconsider Schneiderman's interface design guidelines in light of mobile device technology[28] and the unique usability challenges that mobile devices present. Specific guidelines include designing mobile device interface appearance to be similar to that of a desktop and also implementing context awareness and self-adaptation to the user's current environment. There were no guidelines mentioned for tasks that require the use of a data visualization application.

Nichols[29] presents an exploration of touch screen technology and mentions the importance of developing software interfaces designed to accommodate a user's finger. Touch screen interfaces should not contain small controls designed for a cursor or stylus-based system. The author also discusses the promise of certain touch screen capabilities, such as incorporating simultaneous input from multiple users and applying tactile sensations (such as vibration) to interactions. Wobbrock et al.[30] conduct a user study focused upon finding the most appropriate tabletop hand gestures for specific actions. The study results identify gestures that non-technical users find most applicable to perform specified tasks. Willett et al.[31] conducted a similar user study to identify gestures that users would prefer to perform (to show peaks, downward trends, etc.) when interacting with visualizations on a 32-inch multi-touch device.

3. USER EVALUATION

At present, there is a lack of guidelines that explain how to design visualizations on tablet-sized touch screen devices and develop effective interfaces when interacting with data on tablets. Our user evaluation was designed to gain a better understanding of the most effective means of displaying data and facilitating interaction with varied types of data (ordinal/nominal, quantitative, hierarchical, time-series, etc.)

The goals of our user evaluation were as follows:

- to identify tasks and activities which present challenges to users on touch screen devices
- to identify methods of data interaction/representation that result in *misinterpretation* of data
- to identify interface components that consistently hinder effective user interaction/exploration
- to identify specific visual representations that *frustrate* users on touch screen devices

Figure 1. Interactive Visualizations: Sales Cube Analytics (top left), Consumer Electronics (top right), Pharmaceutical Trends (bottom left), Sales by Store (bottom right).

For the user evaluation, we used Roambi,[32] a comprehensive, flexible, and popular commercial visualization system. Currently, Roambi is only available for the iPad (Apple tablet computer) and thus, our user evaluation testing was performed on an iPad. We identified sample visualizations that encompassed a wide range of features and data types. Four of the interactive visualizations used in our evaluation are displayed in Figure 1.

Here are the interactive visualization scenarios that we used for the user evaluation:

- The *Sales Cube Analytics* scenario (top left) displays multivariate, time-series sales data for different products, customers, regions, and dates via interactive bar graphs.
- The *Consumer Electronics* scenario (top right) displays hierarchical and time-series sales data by product, city, and country, including micro charts and "swipeable" summaries.
- The *Pharmaceutical Trends* scenario (bottom left) displays hierarchical and time-series pharmaceutical data for various drug categories and classes via interactive bar charts and line charts.

- The *Sales by Store* scenario (bottom right) displays hierarchical sales data by store and store type via micro charts which drill down to detailed summaries.
- The *Top 200 Companies* scenario (not in Figure 1) was chosen since it displays multivariate company data in *tabular* form.

All of the visualization scenarios except *Pharmaceutical Trends* provide some mechanism for sorting and all visualizations except *Consumer Electronics* provide some filtering functionality.

For each visualization scenario, we identified a set of 7-8 questions that required interactive exploration to correctly answer the question. The questions were designed to test a wide range of the interactive functionality available on a tablet from basic (observe representation) to advanced (sort, filter, change modes in a dataset, etc.). Additionally, we used a program that was run on a laptop to administer the test. The program was used to obtain consent from the user, collect demographic information, and collect answers as well as qualitative feedback. For each question, we compute the time required to answer the question as well as record the user's confidence level for the provided answer. Confidence was measured on a Likert scale (1: not at all confident, 5: extremely confident). The test was administered to 24 participants, consisting of 16 males and 8 females in the 18-50 age group.

In addition to age range and gender, users were also asked to specify their level of experience using tablets and iPads from the following choices: novice, beginner, competent, proficient, and expert.

A *section* consisted of an visualization scenario (as shown in Figure 1) followed by 7-8 questions. At the end of each section, the user was given an opportunity to provide qualitative feedback on that section and evaluate the visualization. The user was required to rate the *level of difficulty* in understanding the visual representation of the data and interacting with the visualization. The user was also required to rate her/his level of *frustration* in finding answers to the test questions. The level of difficulty and frustration too were measured on a Likert scale (1: not at all difficult/frustrating, 5: extremely difficult/frustrating). Lastly, the user could optionally enter a free-form text response to provide any other comments, thoughts, or ideas.

Figure 2. User Evaluation Testing Setup

The first test section (the series of questions for the first visualization scenario) was a training section. Before the training section was administered, users were given basic instructions regarding the testing procedure, the training section data set, and the training section visualization. If the user had any questions during the training section, the test administrator was available to help the test participant. For all subsequent test sections, which were presented in random order, participants were not provided with instructions beforehand. Although the order of the test sections was randomized, the order of the questions within any test section was not randomized. Questions within a testing section *increased in difficulty* over time. Easier questions were presented earlier and more difficult questions were presented later within a testing section. We utilized this approach in order to reduce test participant frustration and increase test participant confidence. The test setup is shown in Figure 2.

4. USER EVALUATION RESULTS AND ANALYSIS

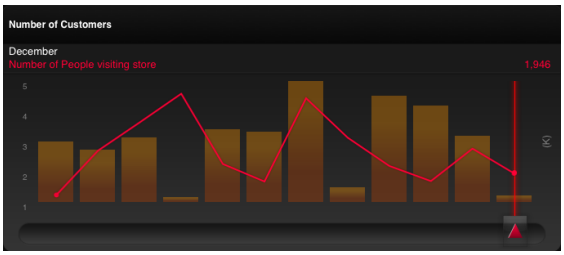
The aim of the user evaluation was to *identify guidelines for effective data visualization* on tablets. To identify these guidelines we took a user performance based approach. Our assumption is that if a large majority of the users answered a question incorrectly, or took a long time to answer a question incorrectly, or confidently answered a question incorrectly, then the visual representation or interaction setup is misleading and should be avoided. On the other hand we also noticed things that worked well, when a significantly high majority of the users answered a question correctly, or took a short amount of time to correctly answer a type of question, or confidently answered a type of question correctly.

Based on the user evaluation data analysis, in the following sections we shall provide guidelines (pitfalls and recommendations) and provide our rationale for the guidelines.

Pitfall 1: Avoid widget overloading

Based on the accuracy of the answers, we found that overloading functionality onto a widget caused the most confusion for the users. One such task, with a low percentage of correct answers in our user evaluation, included a visualization widget with multiple types of interactivity. The test question asked the user for the number of people who visited a particular store in a particular month (December). Users had little difficulty locating the customer information for the store in question, but only 18.75% of the users were able to answer the question correctly. Most users found the correct visualization, shown in Figure 3(a), which displays the number of customers for the store in question over a 12 month period. However, as the question asked was about the number of people *visiting* the store, not the number of customers. The visualization required user interaction to display the desired data. By tapping on the slider widget (orange triangle) at the bottom of the visualization (Figure 3(a)), the display changes to show the number of people visiting the store as shown in Figure 3(b).

(a) The number of customers for a store over a 12 month period.



(b) The number of people who *visited* a store over a 12 month period.

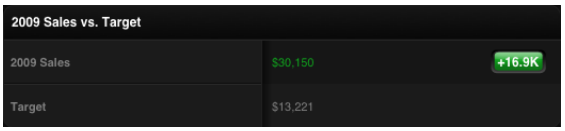
Figure 3. Tapping on the slider widget toggles between the two figures above.

Although users understood the sliding functionality of the widget, very few recognized that the widget was "overloaded" and needed to be tapped in order to display the desired data. We hypothesize that perhaps in this situation, a tabbed display would lead to higher accuracy rates.

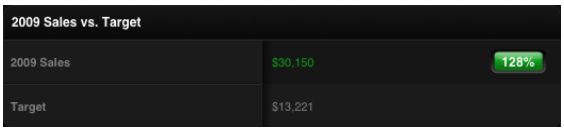
Another question upon which users fared poorly pertained to determining a numerical value as a percentage. The question asked the user to determine by what percentage a sales amount exceeded the corresponding target. In general, users were able to display the sales amount, the target amount, and the difference between the two amounts without difficulty. It is worth noting at this time that users were informed in the pre-test instructions that no calculations were *required* to find answers to the test and that all answers were available in the visualizations.

Although users were able to find the difference between the sales amount and the target amount in dollars, they had difficulty determining how to interact with the visualization in order to display this value as a percentage. We hypothesize that this difficulty arose from the fact that the user needed to interact with a widget that was not perceived as *interactable*. By tapping on the displayed dollar amount (Figure 4(a)) (representing the difference between the sales amount and the target amount), the displayed value would change to a percentage (Figure 4(b)). However, 56.25% of test participants were unable to determine how to change the displayed value to a percentage and subsequently answered the question incorrectly. Tapping on the green text on the right

toggles between the two displays (dollar amount and percentage), however users were not able to recognize this interactivity. We hypothesize that if the green widget appeared more like an interactable widget, more users would have discovered this toggle functionality and answered the question correctly. Another solution would be to display both values simultaneously, as this particular display is uncluttered and has sufficient area to do so.



(a) Sales exceeded the target by 16.9K dollars (displayed in green widget on right).



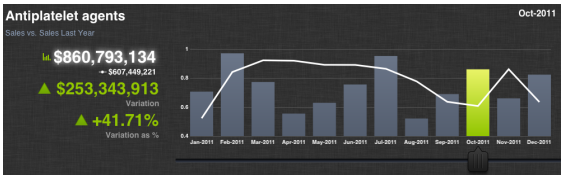
(b) Sales exceeded the target by 128% (displayed in green widget on right).

Figure 4. Tapping on the green widget on the right toggles between the two figures above.

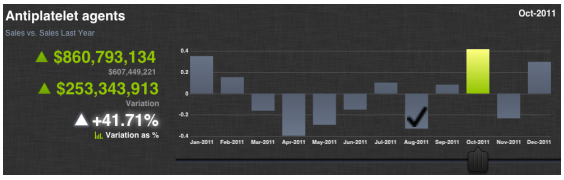
Pitfall 2: Avoid adding interactive functionality to numeric quantities

In other instances, numerical quantities were not perceived as interactable. One such question asked the user to determine in which month the percentage by which sales exceeded previous year sales was the greatest. Most users located the correct information but could not determine how to change the bar chart to display results as a percentage rather than a dollar amount. Figure 5(a) shows a bar chart displaying the monthly sales amount (and previous year sales amount denoted by a superimposed white line chart) and Figure 5(b) shows a bar chart displaying the monthly percentage by which sales exceeded the sales amount from the previous year. In both images, October (the correct answer) has been selected with the slider widget.

In order to change from one of these displays to the other, the user must tap on the appropriate numerical value on the left of the bar chart. For example, to display the percentage values, the user must tap on the numerical value representing variation as a percentage (in this case, the number *+41.71%* to the left of the bar chart). When a user performs this action, the bar chart display changes as appropriate and the color of the selected numerical value changes from green to white. Almost 40% of participants did not discover the interactive functionality of these numerical values and subsequently answered incorrectly. We surmise these numerical values were perceived by the user as a quantity, not as an interactive widget.



(a) Bar chart representing monthly sales amount for the previous year. (October has been selected with the slider widget.)



(b) Bar chart representing monthly percentage by which sales amount exceeded previous year sales amount. (October has been selected with the slider widget.)

Figure 5. Tapping on the numerical values on the left changes the displayed visualization from dollars to percentage.

Pitfall 3: Avoid "hidden" user interfaces

Users struggled at answering questions that required interaction with a "hidden" user interface. In one such question, users were required to sort hierarchical data. In order to sort the data, the required user interaction was very difficult for many participants to locate, resulting in almost 40% of participants answering incorrectly. The default display is shown in Figure 6(a). Since most viewers cannot locate the interactive widget, Figure 6(b) shows the default display again and upon the default display, we have superimposed a red circle drawing the viewer's attention to the interactive widget which exposes the "hidden" functionality. After the user taps on or drags this widget, the resulting display is shown in Figure 6(c). At this point, the user must select the hierarchical category upon which to sort, *Countries* in this case, leading to the display in Figure 6(d). The user may now select the appropriate sort attribute and tap on the *Apply* button on the left and the data will be sorted appropriately.

(a) Default display.

(b) Superimposed red circle indicates the interactive widget which exposes "hidden" functionality.

(c) Display after user taps on or drags interactive widget, exposing "hidden" functionality.

(d) Display after user selects the hierarchical category upon which to sort, *Countries* in this case.

Figure 6. "Hidden" user interface.

Pitfall 4: Avoid excessive scrolling to locate a page

Users provided feedback regarding their experience interacting with the visualizations. In some visualizations, multiple pages were displayed with page dots (see Figure 7) and several users noted **significant frustration** with page switching when trying to identify a specific page. Without knowledge of the specific location of a page, users must scroll through many pages looking for the desired visualization. Perhaps a tabbed window with labels or a drop-down widget would allow faster, more efficient page selection.

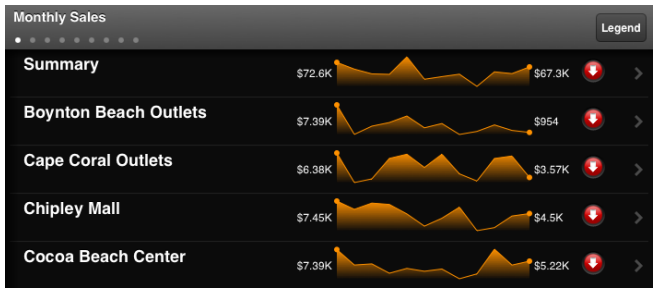
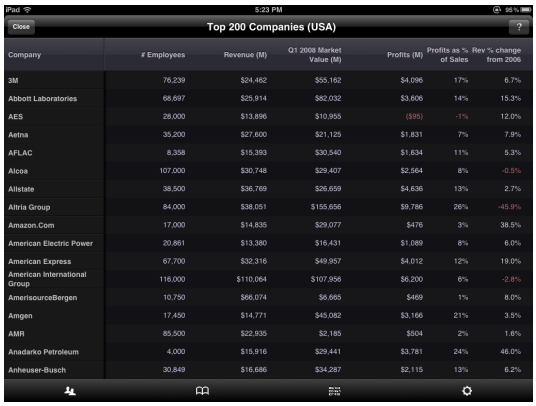


Figure 7. Without knowledge of the specific location of a page, users must scroll through many pages looking for the desired page. Figure here shows the *Monthly Sales* page.

Recommendations

In terms of recommendations, there were nine questions where **100%** of participants completed every task accurately. Overall, users had high success rates when working with **tables** and **line charts**. Although users did suggest some improvements, the visualization corresponding to the highest participant accuracy was a table, which appeared similar to a typical spreadsheet layout, shown in Figure 8. Despite the fact that answers to visualization questions for the table required interaction to perform sorting and filtering, users still rated the table as the *easiest* to understand and *least frustrating* of all the visualizations.



Company	# Employees	Revenue (M)	Q1 2006 Market Value (M)	Profits (M)	Profits as % of Sales	Rev % change from 2006
3M	76,239	$24,462	$55,162	$4,096	17%	6.7%
Abbott Laboratories	68,697	$25,914	$82,032	$3,606	14%	15.3%
AES	28,000	$13,896	$10,955	($95)	-1%	12.0%
Aetna	35,200	$27,600	$21,125	$1,831	7%	7.9%
AFLAC	8,358	$15,393	$30,540	$1,634	11%	5.3%
Alcoa	107,000	$30,748	$29,407	$2,564	8%	-0.5%
Allstate	38,500	$36,769	$26,659	$4,636	13%	2.7%
Altria Group	84,000	$38,051	$155,656	$9,786	26%	-45.9%
Amazon.Com	17,000	$14,835	$29,077	$476	3%	38.5%
American Electric Power	20,861	$13,380	$16,431	$1,089	8%	6.0%
American Express	67,700	$32,316	$49,957	$4,012	12%	19.0%
American International Group	116,000	$110,064	$107,956	$6,200	6%	-2.8%
AmerisourceBergen	10,750	$66,074	$6,665	$469	1%	8.0%
Amgen	17,450	$14,771	$45,082	$3,166	21%	3.5%
AMR	85,500	$22,935	$2,185	$504	2%	1.6%
Anadarko Petroleum	4,000	$15,916	$29,441	$3,781	24%	46.0%
Anheuser-Busch	30,849	$16,686	$34,287	$2,115	13%	6.2%

Figure 8. The table visualization corresponding to the highest participant accuracy.

Recommendation 1: Provide descriptive labels for category widgets when exploring hierarchical data

Another problem that users encountered involved changing categories of hierarchical data. The user was asked to identify the month with the greatest sales target for a particular drug class for the Pharmaceutical Trends scenario as shown in Figure 9(a). The drug class shown by default is the *Cardiovascular* class (see top right in Figure 9(a)) Changing the drug category to another proved more difficult than we expected, resulting in 47.37% of test participants answering the question incorrectly.

(a) Default display.

(b) Display after user selects the *Pain and Inflammatory* drug category from the list.

Figure 9. Widget to change category labeled with currently selected value.

It appears that this problem is related to the fact that the text for the widget which allows the user to change drug categories indicates the currently selected value, not the category name. The default display is shown in Figure 9(a). To change the drug category, the user must tap on the button in the upper-right corner, labeled

with the current drug category - *Cardiovascular*. At this point, the user would need to select the *Pain and Inflammatory* drug category from the list, resulting in the display shown in Figure 9(b).

We propose that a more descriptive label for this button would have been helpful for users who had a difficult time changing the drug category. If a static label immediately to the left of the button displayed text such as *Drug Category:* for example, we believe that users would have answered this question with greater accuracy. This example also illustrates the importance of a *show all* option for 2-level data. If the visualization was capable of displaying all drug classes (for all of the drug categories), the user would not have been required to perform the additional interactive step of changing drug categories, a task which clearly posed problems for many users. In this case, the addition of a *show all* option would result in increased efficiency and we presume, increased accuracy.

Recommendation 2: Ensure that a data column for a sortable attribute is visible

Another question which only a small percentage of users (37.5%) answered correctly involved sorting a list of stores by a particular attribute (net profit). Most users were able to successfully sort the list and locate the second item in the list, as the question asked for the store with the *second highest net profit*. However, many users incorrectly sorted the list in ascending order and then selected the second item from the top (which would be the store with the second *lowest* net profit), rather than sorting the list in descending order. We initially assumed that the widget (shown in Figure 10) was causing confusion in terms of conveying the sorting order - ascending or descending. However, when examining questions in which a large percentage of users answered *correctly*, we noticed that answers to a similar question which required sorting in a similar way had a *very high accuracy rate*. Upon further examination, we recognized that in the former question, a data column for the sort attribute was not actually displayed in the visualization (whereas it was in the latter). Therefore, although the user was sorting by total net profit for the year, the visualization only displayed data columns for net profit for each of the four quarters *individually*, not total net profit for the year. Therefore, after sorting the data, a user would not be able to see data for the sorted attribute. We hypothesize that if the user were able to see a data column for the sorted attribute, s/he would easily detect whether the data had been sorted in ascending or descending order, and would quite easily be able to identify the second highest value in the sorted list.

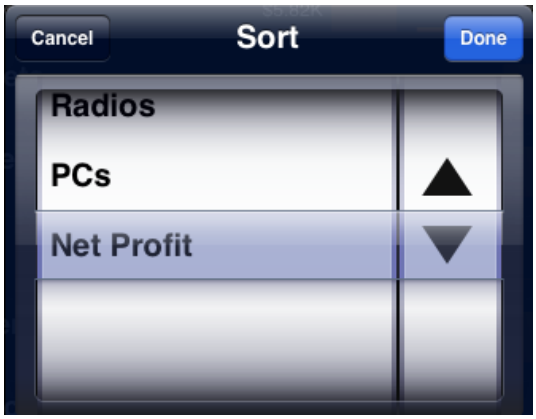


Figure 10. Setting the sort order by Net Profit, in descending order (indicated by the triangle pointing downward).

Recommendation 3: Simplify process and minimize steps for filtering

Users were able to add a single filter and visualize the data, but for some reason we found that the interface would not allow intuitive specification of multiple filters. Participants repeatedly mentioned this in their survey as a source of significant frustration.

Visualization App Guidelines

Our guidelines were identified based on the user performance on the tasks, their feedback with respect to difficulty level, and frustration and free form thoughts at the end of each section. Based upon our analysis of the user evaluation, we present tablet-based visualization app guidelines in the list below and in summary form in Table 1.

Table 1. Visualization App Guidelines

	Pitfalls:
1.	Avoid widget overloading.
2.	Avoid adding interactive functionality to numeric results.
3.	Avoid "hidden" user interfaces.
4.	Avoid requiring excessive scrolling to locate a desired page.
5.	Inconsistent highlighting of data values causes confusion.

	Recommendations:
1.	Provide descriptive labels for category widgets when exploring hierarchical data.
2.	Ensure that a data column for a sortable attribute is visible.
3.	Ensure that interactable widgets appear interactable.
4.	Simplify process and minimize steps for filtering.
5.	Include a *show all* option for 2-level data.
6.	If displaying data in row or column form, highlight user-selected rows or columns.
7.	Consider displaying data in the form of a table or line chart.
8.	Simplify visualization display and interactive functionality as much as possible.

5. CONCLUSIONS AND FUTURE RECOMMENDATIONS

We have presented guidelines for effective data visualization on tablets. These guidelines were identified based on the tasks performed by the users in our user study. The user performance in the user study was the metric that gave us insight into common pitfalls and consistent successes when interacting with the visualizations on a tablet.

We envision future research focused on expanding the proposed guidelines based on evaluating advanced interactive visualizations such as treemaps, heatmaps, geographic visualizations and so on. Also, performing similar evaluations on mobile devices with different display sizes would provide an opportunity to compare and contrast guidelines for differing display sizes. It is not clear whether all guidelines would remain consistent for phone-sized devices, small tablets (7"), large tablets (10"), and even larger touch screen displays.

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