ChartMaster: a Tool for Interacting with Stock Market Charts using a Screen Reader

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ABSTRACT
Stock market charts guide investors in making financial decisions. Online stock market charts are largely interactive, driven by real-time financial data. However, these are not easily accessible via a screen reader. To enable screen reader users to query and effectively use interactive online stock market charts, we are developing a tool called ChartMaster. In this paper, we describe an early study conducted with sixteen visually impaired persons, most of whom were financial novices, for co-designing the interaction interface for ChartMaster. An inclusive design exercise was undertaken to discover alternative interfaces using non-visual modalities to interact with stock market charts. A user-centered process of co-design using HCI methods was carried out to iteratively evaluate and refine three input solutions: audio input, text input and dropdown menu. While the users ultimately declared the dropdown menu to be the most useful of the three solutions, they wanted all possible options to choose from based on task contexts and personal preferences. User feedback confirmed that a one-size-fits-all design is not ideal for accommodating diverse user needs within the widest possible range of contexts. It was also found that the ChartMaster tool with dropdown menu interface holds potential educational value for financial novices.

Categories and Subject Descriptors
H.5.2 [User interfaces]: Evaluation/methodology, User-centered design, Theory and methods.

General Terms
Performance, Design, Human Factors.

Keywords
Stock market charts; screen reader; non-visual; multi-modal; inclusive design; usability; accessibility; visual impairment; financial literacy.

1. INTRODUCTION
The Global Economics of Disability 2014 annual report indicates that a total of 1.3 billion people with disabilities, including seniors, control $8 trillion in annual disposable income worldwide [10]. Again, between 1983 and the end of 2007, the capitalization of the world stock markets grew by 1,800% and the volume of share trading increased almost a hundred fold, from $1.22 trillion in 1983 to $111.2 trillion during 2007 [14]. However, people with disabilities, despite their financial promise, are disadvantaged in making use of online investment instruments such as stock market charts due to their low accessibility.

Over the last few decades, the stock market has seen dramatic changes, featuring a rapid growth in capitalization and trading activities, as well as increase in the number of self-directed investors worldwide. Making effective and responsible investment decisions requires research about a financial product's features and risks and the overall financial context [2]. With advances in technology, the stock market chart, one of the major tools investors use to predict the future trend of stocks, has gone through a major makeover in the past decades. Static charts have been replaced with interactive charts that enable investors to perceive, compare and analyze data points with merely a few clicks. These interactive charts are dynamic, rendered based on streaming data according to the parameters chosen by users, such as time frame, providing both real-time and historical data instantly.

Figure 1: A typical stock market chart (Google Finance)

All interactive stock market charts are similar in structure (Figure 1) and have five components:

1. A line graph on the top of the chart presenting the change in price.
2. A bar graph at the bottom presenting the change in volume.
3. Options to define the time frame through which the chart will be rendered.
4. Identifiers for events such as dividend payout, split, or quarterly financial report release.
5. Functions to enable comparison with other stocks or indices.

However, stock market charts are particularly challenging for screen reader users due to sensory, cognitive and emotional barriers. Sensory barriers are caused by the visual design of the chart. For example, some interactive charts use Flash or advanced scripting, that is not always compatible with the user's computer, browser settings, or the assistive technology installed, making it difficult for the user to perceive the charts. Cognitive barriers manifest when users attempt to evaluate, analyze, and comprehend a chart in textual format, such as in a summary or a numeric data table. Such barriers that reduce sensory and cognitive capabilities could also aggravate negative emotional reactions caused by the uncertainty and risk inherent in financial transactions.

In addition, some other features of stock market charts add to problems with accessibility. For example, when sighted users hover over the chart, specific values appear: such as day low, day high, closing, and open price. However, screen reader users can only access these data when presented in a numeric table format. The user must memorize and calculate these values based on the data stream. And, unfortunately, the way screen readers interact with numeric tables doesn't provide enough flexibility for them to get the data they are interested in. The challenge, therefore, is to make the data stream behind the charts easier to access.

This study explored ways to improve the accessibility of stock market charts for screen-reader users. While the overall goal is to develop a tool, ChartMaster, that makes it easier to access stock market charts using a screen reader, the goal of the current study is to design an optimal interface for users to query stock market charts.

This paper first presents a design challenge situated in the context noted above, and outlines the approach and methods adopted to respond to it. It then describes the different steps of the response: preliminary usability inspection, survey of related research, iterative design of alternative interaction interface solutions through four rounds of evaluative refinement, description and discussion of the findings. The contributions of this study, implications for inclusive design and human-computer interaction (HCI), and future work planned are given in the conclusion of the paper.

2. DESIGN CHALLENGE

Information and Communication Technologies (ICT) play a critical role in providing access to not only the web interfaces where transactions are made, but also the financial research tools and information needed for investment decisions. It is often that ICT acts as the only means of accessing or participating in important financial and investment functions and services [24]. In recent years, many studies have analyzed the barriers to financial literacy from cultural, social, and structural perspectives. However, little attention has been paid to the barriers individuals face from an HCI perspective. The design challenge undertaken in this study was to develop an interaction interface to improve the usability and accessibility of stock market charts, with a focus on screen reader users with visual impairments. Adopting an inclusive design approach, this study used an iterative co-design process with target users involving methods from the HCI domain.

2.1 Inclusive Design Approach

The British Standards Institute defines inclusive design as "the design of mainstream products and/or services that are accessible to, and usable by, people with the widest range of abilities within the widest range of situations without the need for special adaptation or design" [17]. This definition clearly suggests that design must accommodate the needs of a diversified user base without the implementation of separate, specialized or segregated solutions.

The Inclusive Design Research Centre (IDRC) in Toronto, Canada, provides a variant of the social approach in their reframing of disability within the design context. Rather than a personal characteristic or a binary state (disabled vs. non-disabled), IDRC frames disability as "a mismatch between the needs of the individual and the design of the product, system or service" [15]. Thus, disability is no longer considered a medical or health condition associated with the individual, but rather the result of social, physical, or political barriers that prevent or hinder an individual's ability to participate fully in society. This shift reflects a common recognition and appreciation of diversity, and in turn helps to drive the design and implementation of inclusive policies, services, and products that fit the needs of a "full range of human diversity with respect to ability, language, culture, gender, age and other forms of human difference" [15].

The IDRC recognizes three dimensions to inclusive design. First, it suggests that the optimal inclusive design should integrate personalization and flexible configurations while supporting "self-determination and self-knowledge." Second, it defines an inclusive design process as one that enables diverse designers and "extreme" users to participate in the design process through accessible and usable processes and tools. Third, it urges designers to look beyond the intended beneficiary and create a design that can trigger a "virtuous cycle of inclusion," which, in turn, will lead to both social and economic equality [15].

Guided by the above three dimensions of inclusive design, this design challenge developed multiple solutions, involved participants with visual impairments who used assistive technologies, and looked beyond screen reader users to include a consideration for novice financial tool users. Insights drawn from the inclusive design domain acted as the guiding principles throughout the research process, from the initial empathic design requirements gathering to the above co-design and evaluation process with user participation.

2.2 Human-Computer Interaction Methods

This study employed usability inspection, usability testing, think-aloud protocol, and iterative user-centered processes. The concept of usability is central to the study of HCI. According to Eason [11], a system should provide utility that is easy to use and learn, thus benefitting the user. For determining usability, the following criteria drawn from the work of noted HCI researchers [19, 23, 4] were used: usefulness (users achieve goals), effectiveness (users operate the system productively), learnability (system provides training) and likeability (users derive high subjective satisfaction).

User-centered design (UCD) is a philosophy that is based on the needs and interests of the user, with an emphasis on making products usable and understandable [19]. This study undertook an iterative UCD process through which the user requirements and design were continuously evaluated and refined. The study implemented the following user-centered design methods and techniques:

1. On-site observation: Collecting information by conducting usability testing in an environment in which the design artifact will be used.
2. Simulations (Wizard of Oz): Evaluating design concepts and gaining insights about users' needs and preferences without creating a working prototype.
3. Usability testing: Collecting user feedback using usability criteria mentioned above.

The design process consisted of three parts:

1. Manual usability inspection of 10 investment research websites using a screen reader.
2. Survey of related research on non-visual approaches to reading charts and graphs.
3. Iterative co-design of three solutions—audio input/audio output, text input/audio output, and dropdown menu—through evaluation and refinement with screen reader users.

These are described in Sections 3, 4 and 5 below, followed by discussion of the findings in Section 6 and concluding remarks.

3. MANUAL USABILITY INSPECTION USING A SCREEN READER

During June and July 2014 an analysis of the accessibility of existing stock market charts in terms of their compliance with the Web Content Accessibility Guideline (WCAG 2.0) was conducted to identify issues that need to be addressed. Manual examination was preferred over the use of automated accessibility checking tools because human judgment ensures accuracy and helps in observing the challenges from the user's perspective [27]. The objectives were:

1. To examine the compliance of current stock market charts with the four WCAG principles: perceivable, operable, understandable, and robust for screen reader users;
2. To specifically check if the stock market charts support accessibility of non-text content by providing both short and long text alternatives that "serve the same purpose and present the same information as the original non-text content." (Technique G92 of WCAG 2.0)

Ten popular investment research websites of comparable functionality (Yahoo Finance, Google Finance, Bloomberg, Wall Street Journal, Morning Star, The Street, CNBC, MSN Money, Financial Post, and The Globe and Mail) were chosen. All of these sites provide interactive charts that allow the user to acquire specific data, such as price, volume, and event in any given time frame, as well as comparison with other symbols/indices.

Usability inspection was conducted using the Jaws screen reader Version 15 from Freedom Scientific along with an HP laptop with Windows 7 operating system. The Jaws screen reader was chosen because a series of studies by WebAIM [28] reported it to be the most popularly used screen reader. The accessibility and usability issues discovered for stock market charts in terms of the four principles of WCAG 2.0—Perceivable, Operable, Understandable and Robust—are described below.

Not perceivable: All ten stock market charts exhibited difficulties in perception via the screen reader. The screen reader could only detect six out of the ten charts; this meant that the users might not even know about their existence. For the remaining four charts, the screen reader could only render the chart legend. In addition, nine out of the ten charts failed to provide a short text description. Yahoo Finance, the only website that provided alternative text for the stock market chart, merely stated, "This is an interactive chart". This terse statement is meaningless to visually impaired users.

WCAG 2.0 recommends providing chart data in a numeric table in the form of a long text description as an accessible equivalent for visual charts. Four out of the ten websites placed the numeric table on a separate page, accessible only through the navigation menu. The other six websites did not include a numeric table at all, which means visually impaired users are completely excluded from acquiring critical information about the price and volume of a stock.

Not operable: The stock market charts were not operable. Advanced scripting enables sighted users to hover the mouse over the chart and acquire specific data points. However, such mouse hovering is not possible using a screen reader. Therefore, the charts are not optimally operable using a screen reader.

Not understandable: It is common practice for a stock market chart to use abbreviations for the legends in the chart. However, when a screen reader read out abbreviations missing appropriate <abbr> attributes, they would often sound like other totally unrelated words. For example, 'Jun' was read as Jone, and 'min' as mean. In addition, where the sequence of the codes did not align with the logical order of content, information read out by the screen reader based on the order of the codes produced confusing output. For example, the following text string, which is part of the chart indicating four variations of the stock price of the Globe and Mail—"Open: 91.11, High: 91.40, Low 90.85, Close 90.92"—was read out as "90.92 close 90.85 low 91.40 high 91.11 open"; this was completely impossible to understand, especially because there were no pauses between data elements. Further, stock market charts were hard to understand even when represented through a numeric table where the information for each data point could be accessed. If each data cell in the numeric table does not include appropriate "ID" or "headers" to associate the data with the corresponding column header, the screen reader will be unable to communicate the table in a meaningful way because all one would hear is number after number without knowing what the number is meant to represent. Thus, the stock market charts were not understandable.

Not robust: Even without testing across different technologies and versions to test robustness, it was apparent from the above three results that stock market charts are not robust enough to be interpreted reliably by the screen reader.

4. SURVEY OF RELATED RESEARCH

A critical examination of literature on non-visual approaches to reading charts and graphs revealed research in the areas of natural language interfaces, haptic interfaces, sonification, and hybrid interfaces. However, these studies focus primarily on how the system can provide information to the user and not so much on enabling the users to query the system randomly to get the information they want.

4.1 Natural language interface

iGraph [12] and SIGHT [9] emerged as the two recent, most popular systems using natural language output. They use pattern recognition technology to generate a summary that enables visually impaired individuals to grasp the salient points from charts and graphs. A typical summary generated by SIGHT would be: "This bar chart titled 'Credit-card debt leaps higher' shows that there is an increase in Jan '99 in the dollar value of 6-month growth in consumer revolving credit in contrast with the decreasing trend from July '97 to July '98".

These tools provide an overview that captures the key features of static graphs (such as line graphs and bar graphs). However, they do not provide a mechanism for users to interact and access data according to their needs and interests [22]. On the other hand, they offer some useful features and analysis, such as a summary, which could be built into the ChartMaster tool.

4.2 Haptic interface

Haptic devices enable users to 'touch and feel' the simulated objects with which they interact through tactile sensations, such as the texture of surfaces, temperature and vibration [3]. For example, Ina proposed a TSR (Terminate and Stay Resident) hard-copy system that translates colour pixels on the screen into embossed dots on paper by Braille printer plotter [16]. Krufka, Barner and Aysal developed an application to automatically convert vector-based graphics into raised-line images based on a graphic's hierarchical structure [18].

While this method improves discrimination, identification, and comprehension, it might not be suitable for interacting with stock market charts for the following reasons. It requires special software and hardware, such as a Braille printer, Tactile Printer, swell-touch paper, etc., which could prove expensive for ordinary users. Further, it focuses on conveying the shape of the graph, rather than the underlying data [20] and it is constrained by the complexity of the graphs and the tactile sensitivity of individuals [20, 30]. The output is not only static and impossible to update [29] but it is also not sustainable as it could "fade" after use [20]. Finally, it is time consuming for users to perceive the graph [27].

Another method to enable haptic interfaces is by utilizing force feedback, such as through a joystick. This method is normally used in combination with audio (non-speech sonification or speech), and will be discussed in the Hybrid Interface Section.

4.3 Sonification

Sonification involves "translation" of graphical information into music or varying sound frequencies [5, 8, 13]. Although it is possible to enable users to identify trends or compare different sets within a graph, interpreting graphs through sonification generally takes more training, time and effort on the user's side. From the perspective of interactive stock market charts, sonification might not help in acquiring accurate and precise information.

4.4 Hybrid interfaces

To overcome the limitations inherent in using natural language, haptic, or sonification methods by themselves, more recent works [1, 6, 25, 28, 30] have focused on developing a multimodal visualization system to assist users in perceiving graphical information using a combination of audio, synthesized speech (both speech and non-speech sound) and haptic (forced feedback), which demonstrates that using multiple sensory modalities enables users to perform tasks such as comparing graphs or identifying the largest maximum better. Hybrid interfaces are seen to help in accomplishing tasks much faster and more accurately than using swell-paper alone. However, this approach might require additional, more expensive forced feedback devices that are not normally accessible or familiar to many users with visual impairments.

4.5 ChartMaster Design Goals

Based on the preliminary usability inspection and review of related work, the following four design goals, which influenced the form and functionality of the proposed design solutions, were adopted for ChartMaster:

1. The system should be able to have the flexibility to accurately communicate both high-level information (i.e., overall trend) and particular data points (i.e., closing price on a certain day).
2. The system should be usable by screen reader users regardless of the browser or operating system used.
3. The system should be integrated into an existing stock market research interface without the need for the end user to install any additional program.
4. The system should not require the use of any special external equipment so as to not impose extra financial burden on individuals with visual impairments.

5. ITERATIVE INTERFACE CO-DESIGN

A user-centered, iterative design process was carried out from August 2014 to February 2015 with eighteen participants. Description of the participants is given in section 5.1 and an overview of the procedure is provided in section 5.2. In addition to the interaction option of numeric data table currently recommended by WCAG 2.0 as an accessible way to present charts, three interface options–audio input/output, text input/audio output, and dropdown menu–were designed and evaluated. The dropdown menu option was tested using two methods, Wizard of Oz and working prototype, leading to a total of four iterations of interface design and user evaluation as described in sections 5.3 through 5.6. For each of the iterations, users were given the same set of tasks to complete (for example, finding the volume of a stock on a given day or finding the highest price in the past 6 months) by interacting with different alternative solutions. Users' feedback was sought in each stage and used in the design of the next iteration of the interface. Figure 2 illustrates the four sessions, showing details of the method of testing (Wizard of Oz or working prototype), and participants involved.

5.1 Participants

Ten male and eight female participants of ages ranging from the 20s to 60s were recruited. Sixteen participants had visual impairments while two did not. Of the 16 visually impaired individuals, nine used only a screen reader, six used both screen readers and screen magnifiers, and one used only a screen magnifier. Twelve of the visually impaired participants had more than 15 years of hands-on experience with the primary assistive technologies they were using, while the remaining three participants each had 10-15 years, 5-10 years, and less than three years of experience respectively.

Participants also had various levels of financial and investment experience. Of the 16 visually impaired participants, one had advanced stock market knowledge and worked as a customer service representative in an investment brokerage, while four others had moderate understanding of personal financial management and investment (e.g., they conducted currency exchange, bitcoin trading, and stock market trading either online by themselves or through an investment advisor). The remaining 11 visually impaired participants had little or no financial literacy. The two sighted participants had high financial literacy levels and trading experience as they work in an investment brokerage. Participants were mainly recruited through various mailing lists that specifically focused on visually impaired individuals. Participants were paid $15 for each session as compensation for their time and effort.

5.2 Procedure

There were a total of 18 sessions, each lasting approximately one hour. Participants were encouraged to choose a location of their preference. Fifteen chose their home, one chose a public library, one chose his office, and one chose the researcher's home. All participants used their own computer and the assistive technology they typically use to participate in testing, except the participant who did the testing in the public library. All but one participant used the Windows operating system.

The usability testing session followed a semi-structured script with spontaneous modifications based on context. Think aloud protocols were recorded where users were encouraged to speak out loud while interacting with stock market charts and graphs. Observational notes on participant behavior during the session were recorded.

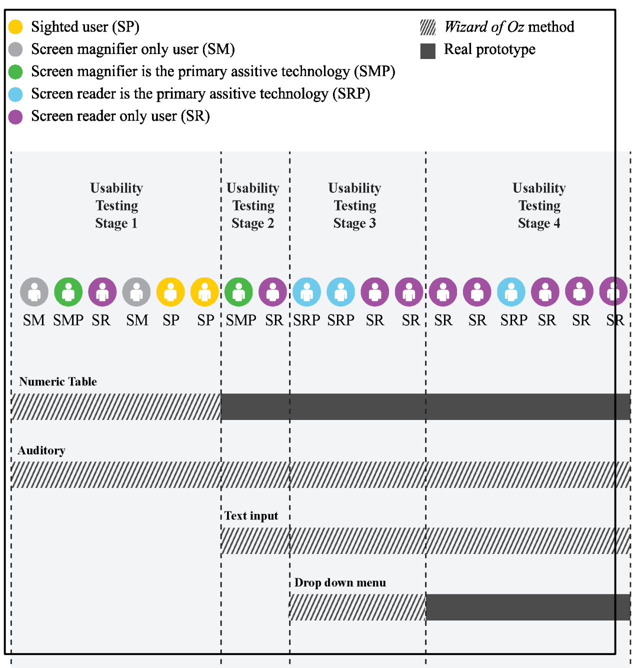

Figure 2: Usability testing: participants, materials & methods.

5.3 Iteration 1: Audio Input/Output

The first design involved audio input and audio output where the users were able to ask questions regarding information they needed from a stock market chart and the system would return an auditory answer. The interaction mechanism of this auditory solution was intended to be much like Siri used in the iPhone. However, the processing will be based on ChartMaster's own logic, which will be worked out in the next stage of development. Figure 3 shows the main process of the auditory input, inspired by Dean Rutter's diagram *How Siri works*.

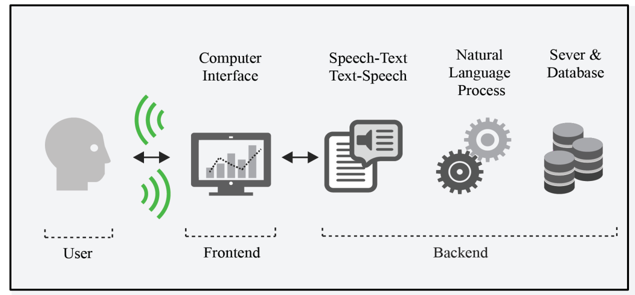

Figure 3: Main process of the auditory input.

This iteration used six participants, two of whom were sighted; three had low vision, using a screen magnifier; and one was blind, using a screen reader. A *Wizard of Oz* method was used to quickly collect feedback on the initial interface design solution (audio input/output) before commencing a full cycle of development.

This session initially evaluated the accessibility and usability issues of a numeric data table built based on a stock market chart. Screen reader users use the numeric table to learn about the chart, which they cannot perceive visually. The numeric table normally includes all of the data points used to generate the chart. The screen reader reads the table once it detects it. The participants were asked to complete a set of tasks that involved "asking" the system questions, such as "Highest price in the past 6 months?" The researcher then read out the data table as a screen reader would read it, and the participants identified the answers to the queries.

Next, in order to evaluate the audio input/output interface, the above tasks were repeated with the researcher acting like the computer and speaking out the correct answers to the participant's questions directly. For example, if the participant asked, "What is the average volume during last week?" the researcher would answer, "The average volume during last week is …"

5.4 Iteration 2: Text input/audio output

During the first iteration, several participants suggested using text input instead of voice input. "Can I type my question?" asked one participant. "I think the computer should be able to understand my typed question as well. Probably it will be more accurate." Based on this, the second iteration was designed. Instead of speaking out their query, this solution enabled users to acquire information about a chart by typing in their questions through a keyboard. The mechanism of this text input solution is very much like IBM's Watson Supercomputer, an artificial intelligence (AI) system that gained wide public attention through the popular TV quiz show Jeopardy [26]. Similar to the IBM Watson, the text input solution provides system responses as audio output. Here again, the processing logic will be considered in the next stage of development of **ChartMaster**. Figure 4 shows the main process of the text input/audio output solution.

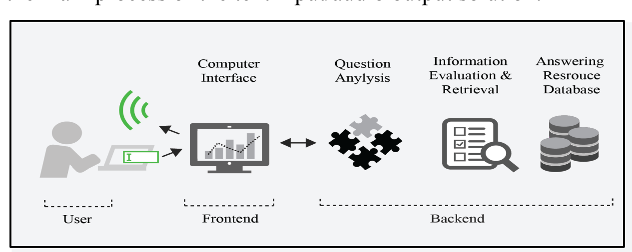

Figure 4: Main process of the text input solution.

This iteration used only two participants, both of whom used screen readers, one of whom was blind and the other with low vision. Similar to the first iteration, the researcher used the *Wizard of Oz* method to evaluate the text input/audio output design. The audio input/output design and the numeric table design were also comparatively evaluated. However, the numeric table alone used a working prototype that comprised a webpage developed with a static image of a chart and a numeric table that included all the data used to generate the chart. Appropriate visual treatment and HTML attributes were assigned to the static image chart and the numeric table to ensure they met WCAG accessibility standards.

5.5 Iteration 3: Dropdown menu/audio output

During iteration 2, both the participants suggested using a dropdown menu input to counter some drawbacks they sensed in the audio and text input methods. "Is there a filter I can use without me asking questions?" one participant asked after expressing his unwillingness to talk to a machine. The other participant asked, "How about using dropdowns? For example, I can first select 'Price,' and then start typing a symbol in the box…. It will be very fast and accurate."

A dropdown menu solution that enabled users to acquire key data points of a stock market chart, such as price, volume and events (i.e., dividend payout or stock split) for one or multiple stocks was then designed. At this stage, the focus was on simultaneous evaluation and comparison among the numeric table, auditory input, text input, and the new dropdown menu. Again, the *Wizard of Oz* method was used for all tasks as in the previous iterations except for the numeric table, where a prototype was used. Four screen reader users participated in this iteration.

5.6 Iteration 4: ChartMaster

The feedback for the dropdown menu was overwhelmingly positive. Users were thrilled after trying the prototype: "This is so cool!" "That is great! I can't believe that nobody has developed something like this before!" "I think that's it!" Participants found the drop-down menu to be an effective way to filter down and navigate through the huge quantities of data. When asked to compare between the numeric table and dropdown menu, many users simply thought these two approaches were not even comparable. In view of the above feedback, a prototype of the dropdown menu solution was designed as illustrated in Figure 5. This comprised a frontend interface generated using HTML; a backend data retrieval and calculation system controlled by JavaScript; and a Java ArrayList to store the data underlying a stock market chart.

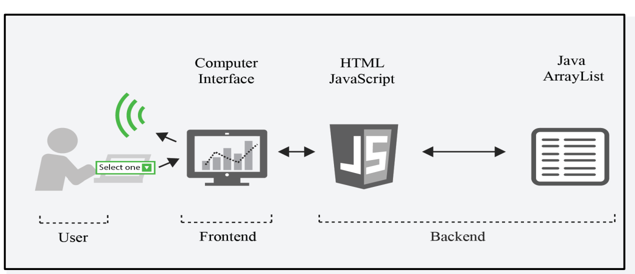

Figure 5: Main process of the dropdown menu solution

Based on the above design, an early version of the **ChartMaster** tool was developed as illustrated in Figure 6, and evaluated in the final iteration. Audio and text input solutions were also tested and compared with the dropdown menu; however, these features were tested using The *Wizard of Oz* method. The numeric table was integrated into the interface where the dropdown menu was featured, so that the users could compare both solutions using one interface. Six screen reader users evaluated the above interfaces.

The **ChartMaster tool** is designed as a link grouped with other commonly used stock market chart tools and placed at the top of a stock market chart. Once activated through the keyboard, the tool expands, pushing the chart down on the page and enabling the user to acquire information by interacting with a series of dropdown menus. When a user submits a query, the answers are displayed as a text summary at the bottom of the dropdown menu.

The dropdown menus are grouped into three categories: Information type (as shown using label "Ask for"); Time frame; and Specific data set. The information type dropdown menu is where users decide what type of information they want to acquire. The time frame dropdown menus allow users to define a time frame for the data. When combined with text input fields, these dropdown menus provide options, from which users can choose one particular day, or pick from a preset time frame, such as 5 days, 1 month, 6 months, etc., or define a random custom time frame. The specific data category provides 4 dropdown menus: Price (i.e., open, close, day high, day low), Volume (i.e., latest, highest, lowest, and average), Event (i.e., split, dividend), and Trend (i.e., overall trend, technical pattern). Currently, **ChartMaster** only allows the user to select one option from each specific data category, however, the function of selecting multiple options will be developed in future versions.

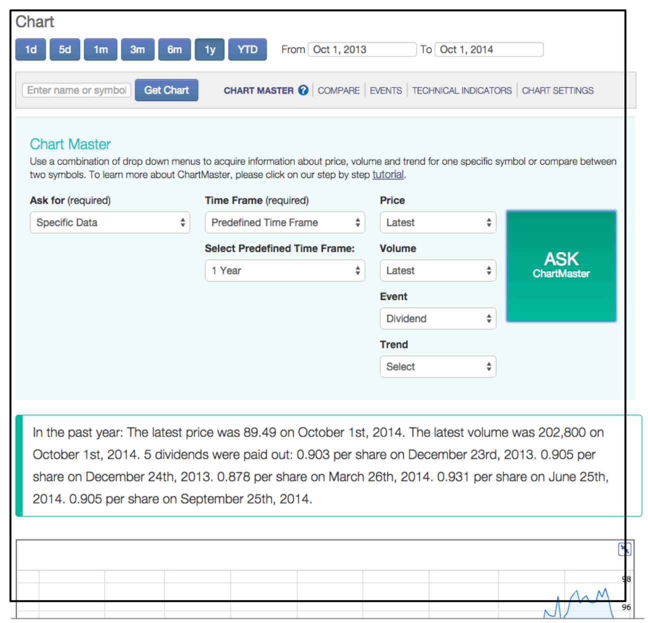

Figure 6: Expanded ChartMaster tool with dropdown menus

The **ChartMaster** includes almost all key information provided by a typical stock market chart (Figure 1), such as price, volume, events, time frame, comparison, etc. The following section demonstrates how the dropdown menu provides great flexibility for users to acquire accurate and precise information according to their needs and interests. Options within each dropdown menu are dynamic according to a hierarchy that makes sense of stock market data: the choice of information type will determine the options within the time frame, while the selection of the time frame will define the options available from the specific data set. For example, when Specific Data is selected as the information type, there are three options under time frame: Predefined Time Frame, Custom Time Frame, and Specific day;

whereas if “Compare with Current Symbol” is selected as the information type, then the options under “timeframe” will change to: Different Days and Different Months. Similarly, when “predefined time frame” or “1 year” are selected as the time frame, the options under price will then be: Latest, Highest, Lowest, Median, and Average; however, if specific day is selected, then the option under price will change to: Open, Close, Day High, Day Low.

Once the choice is made for information type, time frame, and specific data set, the user can then click on the “**ChartMaster**” button and receive a text summary of the information acquired, which will also be read out by screen reader software. Below are a few answers generated by the system demonstrating that **ChartMaster** provides great flexibility for users to acquire information according to their needs and interests.

- *One data point for one stock on a particular day*: “For May 27th, 2014: The closing price was 91.02”.
- *Multiple data points for one stock on a custom defined time range*: “Between June 27th, 2014 and December 10th, 2014: The highest price was 97.61 on September 18th, 2014. The highest volume was 427,000 on August 28th, 2014”.
- *Compare data points for two stock on a particular day:* “For May 27th, 2014: The closing price for ABC was 91.02. The closing price for XYZ was 100.96. The volume for ABC was 95,300. The volume for XYZ was 5,124,900. No dividends were paid out for ABC [name of the symbol]. No dividends were paid out for XYZ [name of the symbol being compared]”.

These answers are composed using three key components: the data entered by the user through the dropdown menus and associated text input fields, such as “6 months” and “average price”; the data pulled or generated by the system according to the data entered by the user; and a template (including the wording and punctuation marks) which arranges and presents all of the data mentioned above in a meaningful and grammatically-correct way to the user.

The system is smart enough to give clear explanations when there is no data available according to users’ request. For example, when user requires data for a day that has no trading activities, the system will inform the user, “Sorry, there was no trading activity on September 21st, 2010”. And when the user asks for certain events that are not applicable to the chosen timeframe, the system will return, “In the past 6 months: No stock splits occurred.”

One point worth mentioning is that the participants did not offer suggestions for designing the drop down menu options, such as the categorization of the information or the specific items in each drop down menu. It was not possible to involve the participants with visual impairments in forming the questions because as screen reader users they had not been able to interact with stock market charts and so were not having the required expertise. The first author, who is a domain expert, in consultation with two expert colleagues, designed the options and questions. While these questions are fundamental to the understanding of any stock market chart, the set of questions will be refined in a future research step with financial experts as well as novices.

6. DISCUSSION

This study aimed to design the interaction interface for the ChartMaster tool that is being developed for screen reader users to query stock market charts by making the data that is used to create the stock market charts more accessible. The tool will use a drop down menu as a structured way to query the chart to get key information from a stock market chart. A screen reader generally does not allow random access to information. It reads information, such as a chart summary, serially. The ChartMaster will allow random access to chart information.

6.1 Numeric table

W3C’s Web Content Accessibility Guidelines (WCAG) recommends using numeric tables as a visual equivalent for charts. The usability testing, however, revealed that although accessing data points through a numeric table is a “fairly straightforward task,” it can be “very time consuming,” and take “enormous cognitive effort” especially when the task involves analyzing information based on a comparison of multiple data points. Including appropriate “ID” or “headers” for each cell as recommended by WCAG as the best practice did little to improve the usability of the numeric table. Although users could differentiate data points in the same row, it still took a huge cognitive effort to process data. Furthermore, the shortcut keys that enable quick navigation through the numeric table were seen to be too complicated and hard to master.

Users’ expertise and technical constraints of the screen reader such as linear reading and the enormous amount of data in stock market chart numeric tables had a negative impact on the usability of the numeric table. Along with technical constraints, users’ expertise with assistive technology, interface elements, and financial literacy were key factors impacting the usability of the numeric table. For example, participants who could use screen reader commands were able to accomplish the activity much faster and more accurately than those who did not have the same skill level. Similarly, participants who in general skip reading tables in real life were having a hard time to even figure out the structure of a table, thus failing to complete any task during the usability testing. Participants with a higher financial literacy level or with stock market experience were more comfortable in using the table than those who did not have that knowledge.

Users’ language level was another important factor that impacted the efficiency of the numeric table. For example, two of the participants with 18 years of screen reader experience and advanced computer experience were able to use Jaws hot key for tables; however, it took one of the participants much less time to find the answer, because, being a native English speaker, he was able to set the screen reader speed much faster than the other user.

6.2 Audio input/output

The audio input/output approach was considered a “robust” and “more effective” approach than the traditional numeric table. Despite the initial excitement, many users, especially those with speech disabilities and those who spoke English as a second language, expressed concerns about the capability of the voice input system to recognize their voice. Many users also expressed their frustration when the system could not recognize their question. Users questioned the system’s capability to provide answers as well.

The second user concern was the uncertain and unpredictable nature of the auditory solution. When the system failed to provide an answer, the users had no idea of the reasons behind it; it could be that they didn’t phrase the question appropriately, or that the system was unable to interpret the question, or simply that the answer was not in the database. Users would not know how to solve the problem unless the system would detect and display the actual cause for the error.

The third concern raised by participants was that the tool might not be apparent to users. The users also implied that they would only use the tool if "it is easy to get and easy to install," and ideally the system should be able to automatically run when it detects a numeric table.

In addition, users pointed out that the machine-like synthetic speech is not "pleasant to hear," and also could cause challenges for users who speak English as a second language. Another disadvantage that was pointed out by almost all participants is that the auditory approach could potentially interfere with their privacy, especially in public places. Environmental context can also potentially hinder a user from using the tool. Finally, some users just did not feel comfortable talking to a machine.

6.3 Text input/audio output

User feedback confirmed that text input not only improved the accuracy, but also provided privacy and could be implemented in a way that users are familiar with. However, as was the same with voice input, users were still not sure if the system was able to successfully "decode" the text that was input in various formats and sometimes in grammatically incorrect form. The system's limitations in answering were also not apparent.

6.4 Dropdown menu/audio output

Iterative co-design provided a perfect platform to discover new ideas. One of the most surprising findings is that users thought the dropdown menu approach to be educational, enabling them to discover information or look at the data in ways they were not hitherto aware of. As one participant said, "This is a way to educate the user about what this tool can do, what kind of questions they can ask and what kind of answers they can get."

Secondly, dropdown menus solved three key issues that users encountered regarding the numeric table, audio input/output approach and text input/audio output approach, which are: cognitive load, accuracy, and predictability. Users don't need to manually go through each data point and try to memorize and calculate in order to acquire the information related to the stock market chart. The system will "filter" out the data based on the selection they made using the drop down menu. In addition, if users are to ask questions by speaking or using free-form text, they would not know whether or not the questions they are asking are within the scope of the system. The drop down menu avoids these problems by specifying the valid questions that the system can handle. This is good both for the user and for the system since only a subset of possible questions can be implemented.

Thirdly, users confirmed that the dropdown menu maintained the flexibility that the audio and text input approach have; this allows users to perceive and acquire information based on their needs and interests.

Finally, the concept of using dropdown menu was found to be very easy to understand. "I get it!" said another participant right after a short initial exploration of the prototype. In addition to the consistent positive feedback demonstrated above, users also provided constructive feedback to improve the accessibility and usability of the dropdown menu solution.

6.5 No single winning solution

One of the most profound discoveries in this study is that users wanted several options instead of one winning solution. During the entire course of testing, users were asked to compare numeric table, auditory approach, text input approach, and dropdown menu. They preferred the inclusion of as many options as possible to accommodate different individual preferences, learning styles and contexts of use. This finding is in conformance with previously reported research [1] where users denoted preferences in intertwining aural, speech and haptic methodologies to gain understanding of the content of charts.

7. CONCLUSION

7.1 Contributions

This study came up with an interaction interface design for the **ChartMaster** tool we are developing to enable querying of interactive stock market charts using a screen reader. Better informed investment decisions have the potential to lead to greater returns, more spending power, greater shareholder influence, more economic opportunities and better participation in design decisions, which will, in turn, improve the design of financial monitoring instruments leading to a virtuous (rather than vicious) systemic cycle of economic inclusion [23].

With **ChartMaster**, users would be able to access data points quicker and easier. And for users who don't have much investment background, this tool can guide them to look for information that they might have overlooked. Thus, the tool has educational use for both sighted as well as visually impaired investors; as well, we highlight the preference of the participants for multiple options as another curb-cut illustration. The outcomes were seen to also benefit financial novices in understanding and using stock market charts.

Compared to other related systems, **ChartMaster** has the following advanced features:

- **ChartMaster** is able to provide accurate and precise data points regardless of the complexity of the chart.
- **ChartMaster** works with underlying real data stored in a java ArrayList that is used to generate the graph instead of the graph image, allowing the system to return as many data points as possible with reduced chances for errors.
- **ChartMaster** also provides additional, yet critical, computed data points such as average, unusual value, median, highest, and lowest. These provide a benchmark for users while analyzing and comparing data.
- **ChartMaster** provides users with great flexibility to acquire information about a chart based on their needs and interests.
- **ChartMaster** could be compatible with a wide range of browsers, operating platforms, and screen reader applications as it is developed using simple and straightforward java script and commonly used interface elements (dropdown menus and text input fields).
- **ChartMaster** can be integrated into any existing interface by the stock market chart provider, without additional installation on the part of the end user.
- **ChartMaster** is easy to learn and use because it does not require extra shortcuts to operate the tool.

7.2 Implications for inclusive design

We will be adding three levels of educational materials in the form of contextual help to the design to cater to the learning needs of users at diverse knowledge levels – novice, moderate or advanced - in the form of tool tips, glossary and education centre. This enhancement echoes with the inclusive design principle that the design needs to include various options to support users' "self-determination and self-knowledge" [15].

Use of **ChartMaster** would improve the accessibility and usability of charts for visually impaired users, enabling them to participate more fully in investment activities, become financially literate and make informed financial decisions. Owing to the curb-cut effect, it could also benefit users who have speech, mobility, and learning disability, or those whose activity might be constrained by the environment, or sighted people with low financial literacy. Such curb-cut advantage results when a design is: "aware of the context and broader impact of the design and striving to effect a beneficial impact beyond the intended beneficiary of the design" [15].

The study demonstrated that users prefer a flexible configuration that provides several options enabling them to make personalized adjustments according to context. This finding confirms the importance of promoting personalization rather than finding a universally accessible, 'one-size-fits-all' solution [15]. Future designs will need to explore the possibility of integrating all four options (numeric table, auditory solution, text input solution, and dropdown menu solution) into one design. Options should be easily found and easily switched. In addition, users will be able to save their preference settings, such as search criteria that they are particularly interested in or solutions they prefer to use.

The study demonstrated the power of the inclusive design approach that derives from co-design with users. Through the iterative design process, users were getting involved during several stages of the design: they helped identify the problem, evaluated the initial concept, and provided design suggestions. One blind participant even assisted in writing the code for an accessible numeric table. Getting users involved in the design process proved extremely effective in terms of generating and refining ideas. In fact, two out of three design concepts, the text input and the dropdown menu, were directly inspired by usability testing participants' recommendations.

The experience of conducting usability testing at the users' home also had a profound impact on the design. It allowed the researcher to have a much more realistic view of how the design artifact will be used within a particular environment unique from user to user. It helped capture customer needs that otherwise could be missed in a standard testing room.

7.3 Implications for HCI

From an HCI perspective, this research clearly demonstrated the sensory, cognitive and emotional barriers that visually impaired users face while interacting with stock market charts. In her doctoral dissertation, Chandrashekar [7], states that online interaction proficiency (for screen reader users) is a composite concept closely tied to the user's 'expertise', 'experience', 'training' and 'trouble shooting skills' in using the computer, the Internet, and the screen reader. This research discovered two other aspects related to online interaction proficiency of screen reader users: 'language proficiency', or the level of English knowledge when English is not the first language, and 'domain proficiency', or the knowledge level related to the content or topic communicated through the interface.

7.4 Future work

- **ChartMaster** is now able to provide information for "historic" stock market charts, meaning a chart that represents data for past trading days; the capability could be expanded to provide information for a "live" chart with real-time data streaming in when the market is open.
- A customizable **ChartMaster** API solution will be developed that enables the creator of any chart or graph to create their own **ChartMaster** module by simply uploading a data spreadsheet to the system. This module could then be plugged into a Webpage, a PowerPoint presentation or an electronic report to allow visually impaired readers to access the charts and graphs.
- The **ChartMaster** provides textual information to visually impaired screen readers. Haptic solutions for tactile presentation of some stock market chart elements for deaf-blind users could be explored.
- Visually impaired participants, who were novice investors, emphasized the educational aspect of the ChartMaster. Given this educational potential of **ChartMaster**, sighted novice investors should be involved in future studies to expand the application of the design to a much boarder audience base. Expert investors reactions will also be sought.
- In addition, to specific data points, future versions of **ChartMaster** will communicate the visual characteristics of the chart, such as the structure of the chart, technical patterns, and the overall trend of the chart. This information requires sophisticated mathematical algorithms that have not been fully developed in the current version. However, these more difficult issues with answering the questions will be dealt with in future work.
- Two usability improvements are proposed: (1) shift the focus of the screen reader to the results when user clicks on Ask **ChartMaster** button to allow the screen reader to automatically read the answer; (2) reorganize the drop down menus so that the 'high-level summary' dropdown menu is placed before 'price', 'volume', and 'event'. This will mentally prepare the user before drilling down to detailed information.
- So far, there is little investigation of the information architecture of ChartMaster, specifically, the categorization of the different drop down menus and each data point included in each drop down menu. Future work should examine the adequacy of the current question set and modify it. It should also examine how the system could accurately and effectively answer questions.

Advances in ICT enable users to access charts and graphs today through multiple modalities: visual, textual, audio, tactile and haptic. **ChartMaster** presents an optimal inclusive design solution for most screen reader users by allowing transformation from graphical to nonvisual through a wide range of options to fit users' contextual needs. In making these charts accessible, people who use screen readers should be able to get whatever the sighted people get out of them. So, they should also be able to learn to get better at asking the questions relevant to making their investment choices. The tool might also be helpful to novice, sighted users. Inclusive design benefits everyone and provides value. As one participant remarked, "Accessibility is for everyone, not just for people with disabilities."

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