SketchStory: Telling More Engaging Stories with Data through Freeform Sketching

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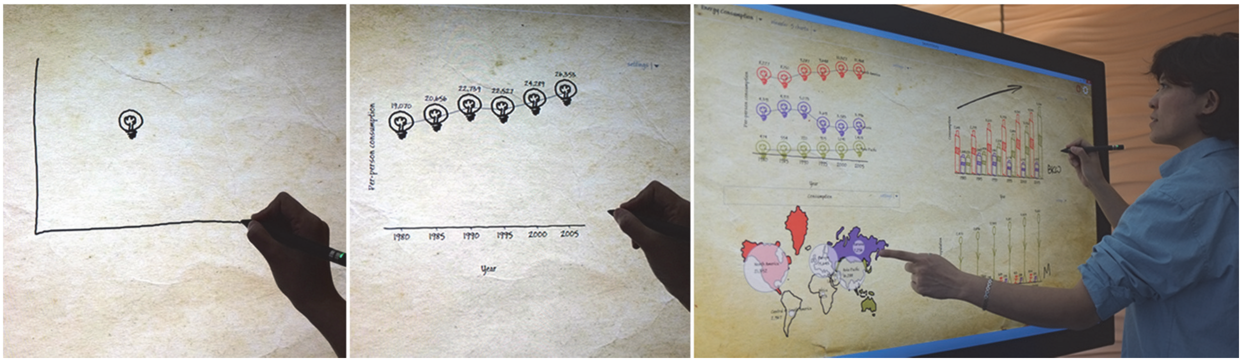

(a) (b) (c)

Fig. 1. Telling a story using SketchStory: (a) A presenter sketches out an example icon and chart axis, (b) Upon recognition of the chart axis, SketchStory completes the chart with underlying data by synthesizing from example sketches, and (c) The presenter interacts with the charts.

Abstract—Presenting and communicating insights to an audience—telling a story—is one of the main goals of data exploration. Even though visualization as a storytelling medium has recently begun to gain attention, storytelling is still underexplored in information visualization and little research has been done to help people tell their stories with data. To create a new, more engaging form of storytelling with data, we leverage and extend the narrative storytelling attributes of whiteboard animation with pen and touch interactions. We present SketchStory, a data-enabled digital whiteboard that facilitates the creation of personalized and expressive data charts quickly and easily. SketchStory recognizes a small set of sketch gestures for chart invocation, and automatically completes charts by synthesizing the visuals from the presenter-provided example icon and binding them to the underlying data. Furthermore, SketchStory allows the presenter to move and resize the completed data charts with touch, and filter the underlying data to facilitate interactive exploration. We conducted a controlled experiment for both audiences and presenters to compare SketchStory with a traditional presentation system, Microsoft PowerPoint. Results show that the audience is more engaged by presentations done with SketchStory than PowerPoint. Eighteen out of 24 audience participants preferred SketchStory to PowerPoint. Four out of five presenter participants also favored SketchStory despite the extra effort required for presentation.

Index Terms—Storytelling, data presentation, sketch, pen and touch, interaction, visualization

1 Introduction

One of the main goals of Information Visualization (InfoVis) is to help people gain insights—finding underlying patterns and relationships between bits of data hidden by raw quantity—more easily through their innate perceptual and cognitive capabilities. Accordingly, over the last two decades, the InfoVis research community has focused on developing techniques and systems that facilitate gaining insights by representing abstract information in interactive, visual forms. Although effectively presenting or communicating these insights to others is often one of the main end-goals of data exploration, until recently insight presentation and communication has been relatively less explored by the InfoVis research community. But there is now a growing interest in novel forms of storytelling techniques with data, commonly known as narrative visualization [39]. As an emerging medium, narrative visualization can borrow techniques from existing storytelling sources (e.g., comics, posters, etc.) [39], and extend them to develop a more engaging form of storytelling.

In a form of narrative visualization called whiteboard animation (also known as video scribing) [36], the presenter produces a sequence of dynamic sketches along with synchronized narration to vividly tell a story. There is anecdotal evidence that this may be more effective for delivering information than traditional presentations. LectureScribe allows people to create animated whiteboard lectures by capturing handwriting along with voice [10]. Dean has used LectureScribe to develop supplementary content for undergraduate and graduate algorithms courses in the computer science department. Informal feedback from his students in these courses suggests that these animated whiteboard lectures were very effective as a learning aid. Rom also claims that people like seeing other people's pictures, and that, in most presentation situations, audiences respond better to hand-drawn images than to polished graphics [35]. The narrated, animated content creation and expressive graphic style makes whiteboard animation a very unique and engaging form of storytelling. As such, it has attracted both audiences and artistically-inclined presenters, and has become increasingly popular in domains such as advertising and education (e.g., [24][36]). However, producing high-quality whiteboard

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animation is time-consuming and potentially expensive; furthermore, its power to communicate with data is limited by its reliance on the presenter's numeric and artistic ability to formulate and depict the underlying numbers in a visually compelling way during a live performance.

To create a novel and more engaging storytelling tool with data, we explore how to leverage and extend the narrative storytelling attributes of whiteboard animation using pen and touch interactions. In this paper, we present SketchStory (Figure 1), a data-enabled digital whiteboard specifically designed to support telling more engaging stories with data through freeform sketching. It facilitates the creation of charts in real-time by synthesizing from the presenter's sample sketches, preserving the expressiveness and organic style of visual graphics. SketchStory helps the presenter stay focused on telling her story by eliminating the burden of manual data binding. It allows the presenter to record a sequence of charts along with example icons before the presentation, and to invoke them with simple sketch gestures in real-time. Furthermore, it enables the presenter to add freeform annotation and to interact with the charts created during the presentation. This helps invite discussion, explanation, and further exploration.

Pursuing an iterative design strategy, we first conducted a formative study with six presenter participants. This helped us understand the usability and unique affordances of the SketchStory approach for presenting a story with data. We improved the system based on the lessons learned from the usability study. We then conducted a controlled experiment to compare SketchStory with Microsoft PowerPoint [34], one of the most commonly used presentation tools, for both audiences and presenters. Results show that the audience is more engaged with the presentation done with SketchStory than PowerPoint. Eighteen out of 24 audience participants preferred SketchStory to PowerPoint. Four out of five presenter participants also favored SketchStory even while acknowledging the extra presentation effort it required. In addition to these promising results, we identified future research directions gleaned from both studies.

2 Related Work

2.1 Storytelling with Information Visualization

Storytelling allows visualization to reveal information effectively [13]. Conversely, as Wojtkowski and Wojtkowski pointed out, it can be very effective to tell stories with data visualization [49]. Therefore, storytelling with data has begun to gain more attention as storytellers integrate visualizations into their narratives. The InfoVis research community organized a workshop "Telling Stories with Data" two years in a row (2010 and 2011), focusing on exemplars of stories told with data and the techniques used to construct the stories. Recently, Segel and Heer reviewed the design space of this emerging class of visualizations called narrative visualizations [39]. They identified seven genres of narrative visualization—magazine style, annotated chart, partitioned poster, flow chart, comic strip, slide show, and video—from an analysis of 58 examples. Within this characterization, SketchStory spans the genres of annotated chart, partitioned poster, and video.

Several visualization systems have been incorporating storytelling into their design, primarily through graphical history and annotation. For example, the sense.us system provides bookmark trails, a graphical list of bookmarks, with graphical annotation to support storytelling [17]. Tableau's graphical histories allow people to review, collate, and export the main insights of their visual analysis [16]. Recently, Tableau Public supports the publication of interactive visualizations on the web, enabling storytelling with data visualization [42]. GeoTime Stories enables analysts to create and present annotated stories within visualizations using a customized text editor for a story document containing links to visualization snapshots [11]. These systems augment their exploration function by providing storytelling capabilities through an extension, mainly for asynchronous storytelling. However, SketchStory was specifically designed with more engaging, real-time storytelling as its main goal.

2.2 Sketch-based Interaction for Communication, Design, and Information Visualization

Ever since Sutherland introduced the Sketchpad concept in 1960s [41], sketch-based interaction has been extensively studied. Given the central role of sketching in design process and visual thinking, previous research on sketch-based interaction has infused a wide range of graphical applications for supporting pre-productive, exploratory activities. For example, sketch-based interaction has been explored for communicating early design ideas [27], 3D graphics modelling [1][20], animation authoring [9], interactive interface prototyping [25][28], texture illustration [22], and in special purpose applications such as MathPad^2 [26] and VectorPad [3].

In the context of InfoVis, sketch-based interaction was first used to support data queries with sketches. For example, QuerySketch [47] and QueryLines [37] enable people to specify queries of time-series data by drawing a freeform line graph as a target pattern. Recognizing the benefits—promoting thinking, insight, and inspiration—of the act of sketching [43], the InfoVis community has recently started to employ sketch-based interaction for data exploration. For example, NapkinVis uses pen gestures to support fast and effortless visualization construction [6] and SketchVis leverages hand-drawn sketch input to quickly explore data in simple charts without using menus or widgets [4]. To further advance these approaches, Walny et al. investigated the use of pen and touch for data exploration on interactive whiteboards [46]. Their study on the distinctive role of pen and touch interaction shows that people can transfer knowledge from interaction with the physical world, leading to more natural and learnable interaction techniques. SketchStory continues the efforts of SketchVis [4] and Walny et al.'s study [46] in exploring pen and touch interaction for creation and manipulation of data charts. However, it is specifically designed for narrative storytelling with data, leveraging the expressiveness and freeform nature of sketch for the creation of interactive, organic data charts.

2.3 Non-Photorealistic Rendering for Visualization

Apart from the role of sketching in rapid visual design, Non-Photorealistic Rendering (NPR) or sketchy rendering styles have been explored extensively to illustrate 2D shapes and 3D objects across a wide range of domains for practical and aesthetic advantages [40]. In addition, NPR techniques are found to affect viewers emotionally [15][38]. Sketchy renderings are preferred for depicting early design results, as they elicit higher engagement, participation, greater clarity, and active discussion [38]. More recently, Wood et al. [51] demonstrated the use of NPR specifically in statistical data visualizations and hypothesize its potential role in constructing visualization narratives. Compared to traditional data visualizations, their study indicated increased engagement and active participation with NPR data charts. The ability to evoke emotional response and to provoke active participation, and the distinct visual appeal of NPR are encouraging to our work as we pursue similar goals with our narrative storytelling tool. Therefore, SketchStory employs integration of sketching and data chart rendering, where the sketched input is used for rendering the data charts.

3 SketchStory Design

Our main goal was to explore a novel genre of narrative visualization technique specifically for real-time storytelling and presentation. Hence we assume that the presenter has already found a story during a prior exploration phase. Target users of SketchStory are people who want to present a story that can be told with a set of data charts. Even though good sketching skills may result in better presentations, they are not required. We looked into the strengths and limits of popular and pervasive storytelling techniques with data, and explored ways to harness the strengths and to overcome the limitations.

3.1 A New Form of Storytelling with Data

Data visualization melds the skills of computer science, statistics, artistic design, and storytelling to make massive amounts of data more easily accessible. However, it remains an open question how to support richer and more diverse forms of storytelling with data [39]. In this section, we identify three desirable properties of storytelling with data; *expressiveness*, *narrative sketching*, and *interactivity*.

3.1.1 Expressiveness in Infographics

Information graphics (or infographics) are graphical representations of information, data, or knowledge. Infographics are commonly used by reporters, computer scientists, and statisticians for communicating conceptual information in a broad range of domains. To clearly communicate complex information in an aesthetically pleasing way, they often employ icons and other visual elements that are customized to the dataset (Figure 2).

We believe the communicative power of customized infographics stems from two key factors. First, a close mapping between the graphical representations and the underlying data helps people make connections between them and facilitates understanding. Prior neurological studies indicate that fictional, metaphoric representations of facts and narratives activate many parts of the brain [30]. Despite some criticisms [12] of Bateman et al.'s methodology, their study suggests that people's recall of embellished charts (after a two- to three-week gap) is significantly better than that of plain charts without sacrificing description accuracy [2]. Second, a custom visual design allows presenters the artistic freedom to create a unique, personalized chart taking full advantage of an innate visual language that is largely universal.

Often created with sophisticated graphical tools such as Photoshop and Illustrator, these visualizations can be both aesthetically pleasing and highly expressive. On the other hand, they are largely static, missing out on the full breadth of communicative power available to a live storyteller.

3.1.2 Narrative Sketching in Whiteboard Animation

Whiteboard animation is another compelling visual communication technique, where the presenter simultaneously narrates and sketches a sequence of line art elements to vividly tell a story (Figure 3). Like infographics, whiteboard animation builds on visual explanation with expressive graphics, yet it augments the storytelling aspect by linearly and verbally developing the graphical elements. Viewers consume the content one step at a time, following a logical sequence that makes the story easier to understand. Whiteboard animation is increasingly attracting audiences and storytellers and getting more popular in commercials, communications, presentations, and tutorials (e.g., [24][36]).

Several attributes of whiteboard animation make it a memorable, effective, and engaging method for visual communication. First, the dynamic re-enactment of a presenter's sketch (or whiteboard presentation) conveys the order of action sequences by directing viewer attention from one object to the next, building anticipation as in a story. Second, skilled hand-drawn sketches generate organic and expressive graphics, allowing a personal, unique storytelling process. Viewers of sketched drawings are inclined to focus on the high-level aspects such as the overall structure and flow since they tend not to focus on unnecessary details (e.g., precise font size, alignments) [5][14]. Third, as with other performance art media [21], the process of creation drives attraction and aesthetic appreciation. The storytelling attributes of whiteboard animation go beyond entertainment to engagement, making it an effective medium to plant ideas, emotions, and thoughts in viewers' minds [19]. Fourth, the use of real-time narration and a canvas displaying the full visual interaction history provides constant contextual information to augment the communicative process.

However, creating traditional whiteboard animations is expensive and labour intensive; individual lines and text all need to be manually drawn, requiring intensive editing and post-processing of the recorded video. Any quantitative data presented visually is, in effect, "made up" by the artist during the drawing process rather than being backed by the underlying numbers in a more formal way. Finally, even though whiteboard animation is perceived to be more engaging than the regular video, it is still not interactive.

3.1.3 Interactivity in Information Visualization

Interaction plays a critical role in InfoVis particularly for exploring large and complex datasets. For example, dynamic queries [48] are one of the most commonly used interaction techniques for interactive visualizations. They enable people to formulate queries by manipulating embedded widgets (e.g., check boxes, range sliders), and immediately see the query results. Also, InfoVis systems often combine multiple views through interactive brushing and linking to enhance the individual visualizations [29]. Since changes made in one visualization are automatically reflected in other linked visualizations, more information can be gleaned than considering the component visualizations independently [23].

Furthermore, interactivity in storytelling with data invites verification, further questioning, and exploration of alternative explanations [39]. Recognizing the importance of this interaction, there are on-going efforts to make infographics interactive. For example, news organizations such as the New York Times and Washington Post employ dynamic infographics on their websites. Also, tools like Many Eyes [45] and Tableau Public [42] enable publishing interactive visualizations on the web more easily. But these efforts do little to aid narrative communication of the story. While general purpose, low-level rendering APIs (e.g., Java2D, Processing) are also available, construction of even simple charts is tedious and they lack narrative communication as well.

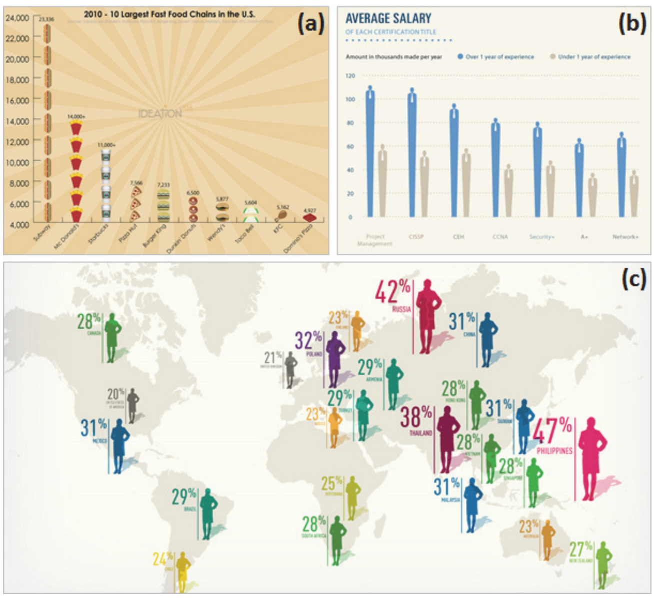


Fig. 2. Examples of expressive and iconic data representation in infographics: (a) A tally chart shows the consumption of fast foods using food icons that represents each food type [31], (b) A bar chart uses a corporate executive icon instead of the traditional rectangle to represent average salaries [44], and (c) Custom icons representing geographic data overlaid on a map [50].

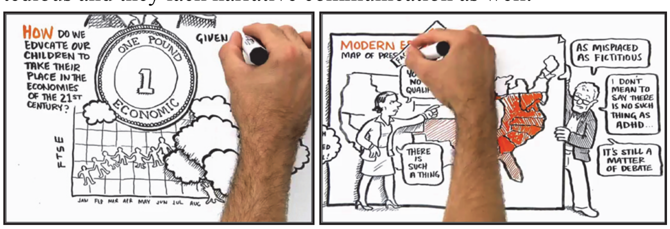


Fig. 3. Manual sketching of data representation in whiteboard animation [36].

3.2 Design Rationale

Our goal was to create a new, more engaging way of telling stories with data by inheriting and extending the advantages of the successful storytelling techniques described in the previous section. In this section, we describe our design rationales behind the design of SketchStory. These reflect the lessons learned from recent previous research (SketchVis [4] and Walny et al.'s study [46]) and the usability study we conducted with the initial SketchStory design, which will be described in Section 5.1.

3.2.1 Support Real-time Content Creation with Animated Sketch

With traditional presentation tools such as Microsoft PowerPoint and Apple Keynote, the audience is often visually exposed to content significantly before the presenter verbally presents it unless she uses sub-slide appearance animations. To attract attention and create anticipation, SketchStory uses a real-time approach to content creation like many other performance art techniques do [21]. In addition, SketchStory combines the expressive visual language of infographics and dynamic sketch with narrative communication of whiteboard animation. To enable the presenter to generate expressive and custom representations that can be better aligned with her narration (i.e., story), SketchStory lets the presenter provide any desired representation as an example visual element (Figure 5a). It then synthesizes a full chart from the example sketch. Furthermore, SketchStory completes the chart with animation to make it look like the presenter is sketching the chart at a faster speed.

3.2.2 Aid Narrative Communication by Reducing Manual Burden

It is burdensome to manually draw an entire presentation or to interactively specify settings (e.g., chart type, axis, etc.) for each chart during the presentation. To alleviate this burden, SketchStory's design enables the presenter to pre-specify a sequence of charts and invoke each one with sketch interaction in real-time. Furthermore, to reduce the burden of manually drawing each icon during the presentation, SketchStory allows the presenter to optionally pre-record an example icon for each chart and save it with the other chart settings. The presenter can focus on narration while SketchStory takes care of the visual presentation at whatever level of detail the presenter wishes.

SketchStory recognizes a small number of simple, easy-to-remember sketch gestures for creating (or invoking) different types of pre-specified charts. For example, the presenter can draw an 'L' shape to invoke a chart with x and y axes, or draw a circle to invoke a pie chart (Figure 4). SketchStory also recognizes touch gestures for moving and resizing charts. For example, the presenter can resize a chart with a one- or two-hand pinch gesture. Previous research shows that, when both pen and touch interactions are supported, people clearly distinguish between appropriate pen and touch interactions [18][46]. SketchStory leverages this by using the pen for drawing charts or annotations and touch for manipulating them, thereby avoiding having two explicit modes for sketching and manipulation.

3.2.3 Provide Interactivity and Contextual Information through a Canvas

In contrast to most traditional presentation tools, SketchStory uses the notion of a canvas to present information, and supports freeform annotation anywhere on the canvas for emphasis and decoration (Figure 6b). This is to help the audience understand the context of the whole story and derive relationships between the visual components. Furthermore, to make storytelling more dynamic and responsive, SketchStory supports interactivity—missing from most infographics and whiteboard animations—by tightly coupling all the charts on a canvas and allowing data filter changes in real-time.

3.3 Choice of Data Charts in SketchStory

To help us decide the design of data charts in SketchStory, we informally examined the common data charts used in infographics; a more formal survey was beyond the scope of this paper. There are disparate sources for infographics examples including data art websites, visualization blogs, newspapers, and scientific articles. To avoid subjective selection, we extracted the first 100 image search results for the keyword "infographics," from two search engines (Bing and Google, dated 24th December, 2012). Of the resulting 187 infographics (13 appeared in both results lists), 149 (79.6%) of them depict numeric data. Each infographics consists of one or multiple graphical elements representing data: charts, symbols, stylized text, or customized visuals. We tabulated each of these elements; a total of 795 graphical data representations were logged in these 149 infographics (on average, 5.3 data representations per infographics).

We grouped the elements into 9 categories—*bar* (20.8%), *pie* (18%), *tally* (9.4%), *scale* (8.8%), *stacked bar* (6.8%), *map* (5%), *line* (2.9%), *area* (2%), and *tag cloud* (1.1%). The remaining 25% were too customized to fit into any of these categories; they were tabulated as *custom*. For all data charts, we also logged them as custom iconic vs. standard representation. Despite the fact that iconic data charts require graphical tools (Photoshop, Illustrator, etc.) and can be laborious to create, we found 24% of the data charts to be iconic, which further motivates our design goal to facilitate the creation of iconic data charts.

We began by incorporating the three most popular chart types (bar, pie, and tally) into SketchStory, and then included line chart and scatterplot because they were straightforward variants of the bar chart. We also included map both because we wanted to explore the particular expressiveness of maps and because we wanted to be able to use maps as interactive objects for dynamic filtering.

4 SKETCHSTORY

4.1 Story Preparation

Once a presenter finds a data-based story to tell with existing data exploration tools, the story can be recorded within SketchStory as a sequence of charts in an XML metadata file, where each chart specifies settings such as a chart type, data columns, and potentially a pre-recorded example icon. Once saved, to make a change in the story the presenter has to manually edit the metadata file using a text editor. For example, a chart or example icon could be removed, a chart type or data columns could be changed, and the sequence of charts could be changed. During presentation, the recorded sequence is available to the presenter as a dropdown of chart thumbnails, where the next chart in the sequence is indicated by a visible check mark (Figure 4, right).

To support dynamic filtering during presentation, SketchStory enables the presenter to create *visual keywords*: a mapping between a set of strokes and a textual keyword. Visual keywords are recorded as separate XML files and referenced in the story metadata file. For example, Figure 6c shows the creation of visual keywords to represent the two genders, female and male. The two selected strokes for a female head and body (shown with green highlighting) are about to be mapped to the "Female" attribute value. To make drawing visual keywords easier, SketchStory allows people to trace their strokes on top of an imported background image.

4.2 SketchStory Interaction[1]

4.2.1 Creation of Expressive Data Charts

The interaction for chart generation consists of two simple steps; the presenter 1) sketches an example icon (Figure 5a) and then 2) draws the sketch gesture (Figure 5b, Figure 4, left) in the desired size and location for the chart. SketchStory recognizes the sketch gesture and automatically completes the chart according to the chart settings specified in the presentation sequence (Figure 5c). To support the

[1] Our supplementary video demonstrates SketchStory interaction.

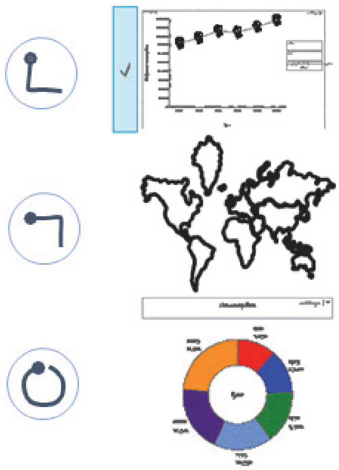


Fig. 4. Preview of the part of the sequence of charts for the energy consumption story (right) and sketch gestures to invoke them (left).

case where the presenter does not want to use an iconic representation, the first step is optional. If the presenter does not provide an example icon either during the presentation or in the chart settings, SketchStory creates a standard chart (Figure 5d).

The four chart types that involve x and y axes (bar chart, tally chart, line chart, and scatterplot) are invoked using an “L” sketch gesture; the pie chart is invoked with a circle gesture; and the map is invoked with a rotated “L” gesture (Figure 4, left).

4.2.2 Interactivity through Visual Keywords

SketchStory supports dynamic filtering, a very common interaction technique in InfoVis, through visual keywords (i.e., shaped strokes or icons). Visual keywords can depict an existing geographical map, or an iconic representation of keywords, to preserve the expressive graphical style of the visuals. For example, Figure 6a shows six visual keywords to represent six different regions (e.g., Almia, Parador, etc.). The presenter can perform dynamic filtering during presentation by interacting with the strokes instead of entering the keyword. For example, when the presenter selects a visual keyword by tapping the icon (Figure 6a), SketchStory updates other charts on the canvas according to the keyword associated with that selected icon (Figure 6b). SketchStory toggles the selection when the presenter taps the visual keywords.

4.2.3 Freeform Annotation and Chart Management

SketchStory supports freeform annotation anywhere on the canvas because it is useful for explanation, emphasis, and decoration. For example, the presenter can write down the unit for data values or draw an arrow to emphasize the trend (Figure 6b). SketchStory also allows the presenter to move and resize charts with touch interaction. For example, the presenter can make a chart bigger with pinch gestures to focus on the chart. When the presenter moves a chart, the annotations drawn within the chart boundary move with the chart.

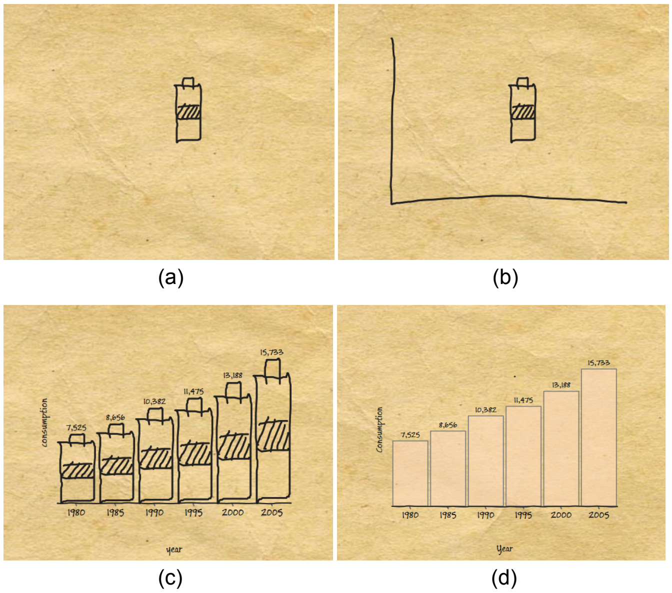


Fig. 5. Creation of a chart: (a) Drawing an example icon, (b) Drawing an axis, and Automatic completion of the chart by SketchStory with an example icon (c) and without an example icon (d).

4.3 Implementation Details

SketchStory is implemented in C# using WPF (Windows Presentation Foundation) and handles both pen and touch input. It runs on any pen and touch enabled Windows device since it relies on standard input event handlers.

On initialization, SketchStory loads all data files in a designated folder (which can be changed) and provides the available data stories with their friendly names in a listbox control on the toolbar. SketchStory consumes a tab-delimited format for its raw data files, where each row of input is one data item and the tab-separated values represent the item’s column values. Each data file requires an additional companion XML metadata file that describes the ordering, name, type (e.g., ordinal or numeric), and optional mapping files for each column. This metadata file also contains a presentation sequence, where individual settings are serialized, specifying chart type, chart data columns, chart icon strokes, and other visual chart options (e.g., show or hide x/y axis, legend, outline, etc.) for each chart in the sequence. A mapping file is an additional XML document consisting of a series of pen strokes with associated visual keywords that correspond to column values for a particular data column. Strokes for both icons and visual keywords are persisted in the form of XML polyline objects as a sequence of x, y points.

Once the data is loaded, whenever the presenter adds a stroke to an empty area of the canvas with the pen, SketchStory attempts to segment the stroke into a polyline using a corner-finding algorithm [7] and then matches the stroke against the chart-invocation gesture set. If there is a match, SketchStory fills in the chart’s data according to the next settings object in the current data story’s chart sequence and renders the completed chart with animation. If the chart invocation gesture surrounds an existing set of strokes on the canvas, that set is cloned and used as the example chart icon.

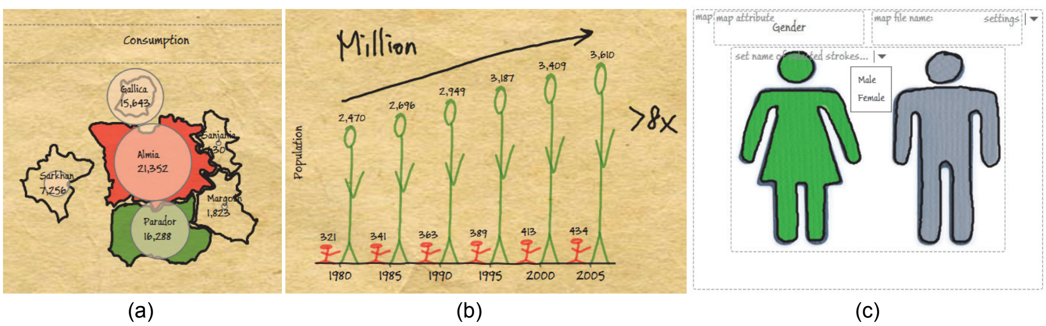


Fig. 6. Visual keywords—mapping between strokes and keywords—for dynamic filtering, and annotation: (a) scale chart overlaid on a fake region map used for the controlled experiment, (b) chart with annotation, and (c) creation of visual keywords for a gender map.

5 Evaluation

We conducted two studies to evaluate SketchStory. We first ran a preliminary usability study to identify major usability issues and to investigate unique affordances of SketchStory for presenters. We improved the SketchStory interaction based on the lessons learned from the first study. We then conducted a controlled experiment to compare SketchStory with PowerPoint, a traditional presentation system, in terms of subjective level of engagement for both audiences and presenters.

5.1 Usability Study

5.1.1 Initial SketchStory Prototype

SketchStory initially focused on stories about trends (i.e., changes over time), relying on time (e.g., year) as the default x-axis. The SketchStory interaction for chart generation consisted of three modal steps. First, the presenter selected the desired value attribute (i.e., the numerical data for the y-axis) from the data attribute menu; the currently selected data attribute was shown under the menu. Second, the presenter switched to an example icon mode and sketched one or more example icons. Finally, the presenter switched to a chart axis mode and drew the baseline for the desired chart.

SketchStory initially supported four types of data charts; tally chart, bar chart, line chart, and map. After the presenter sketched the baseline in the third step, SketchStory clustered the example strokes into icons. Based on the example icon and baseline stroke, SketchStory automatically generated a chart using heuristics (e.g., a line chart if a single icon does not intersect with the baseline or a bar chart if the single icon intersects with the baseline).

5.1.2 Participants and Study Setup

We recruited six participants (3 females) comfortable with sketching from an industrial company. P1, P2, and P5 were UX (user experience) designers; P3 and P4 were program managers; and P6 was a researcher. Participants were also proficient with digital design and presentation tools such as Photoshop and PowerPoint. They received $20 worth of lunch coupons for their participation. We conducted the study on a 3.2 GHz Windows 7 desktop machine with 12 GB RAM and a 27" Perceptive Pixel Display [32] that supports both pen and touch interaction at a resolution of 2560x1440.

5.1.3 Procedure

At the start of each session, we asked participants to fill out a pre-experiment questionnaire to collect their background about sketching, design, and presentation skills.

Then we gave the participants a brief introduction to SketchStory with a printed tutorial. The 10–15 minute training was broken into two phases. In the first phase, the participants sketched different types of charts and visual elements, following the step-by-step illustration of the tutorial. This phase familiarized the participants with the interface, features, and different types of visual elements and data charts within the scope of SketchStory. In the second phase, the participants replicated an example presentation to convey a simple story to the experimenter with a training dataset. This phase familiarized the participants with the storytelling aspects of SketchStory. The experimenter did not intervene unless the participants had trouble using the system.

After the training, we directed the participants to a new story we prepared with a dataset–global energy consumption data between 1980 and 2005 [33]. We asked the participants to tell a story with this data around the following key points:

1. Global energy consumption doubled.
2. Global population increased but less than 50%.
3. Per-person energy consumption has also increased.
4. North America and Asia-Pacific are the top two consumers.
5. While Asian population is more than 8 times higher than North America's, on average American person consumes more than 7 times more energy than Asian person.

In order to familiarize with the data and facts, the participants first practiced the presentation once without narration. Then we asked them to tell the story to the experimenter with narration. This presentation phase took 40–65 minutes.

Finally, we asked participants to fill out a post-experiment questionnaire about their experience with SketchStory. We also asked a few open-ended follow-up questions about their experience. Sessions lasted an average of an hour with a maximum of 1.5 hours. We captured video and audio of the participants presenting the story.

5.1.4 Results and Discussion

Overall, participants liked SketchStory as a way of telling stories with data, and found it to be easy to learn and use. In a 7-point Likert scale, with 1 = strongly disliked and 7 = strongly liked, the average rating was 5.5. Participants also rated it 5.2 for ease of learning (1 = very difficult to learn and 7 = very easy to learn) and 4.7 for ease of use (1 = very difficult to use and 7 = very easy to use). In particular, participants liked the notion of using a data-enabled canvas instead of sequential slides. The underlying data and synthesis techniques made it easy for them to create charts and aided the narrative storytelling. For example, P3 said *"This is my canvas, and it is preloaded with my data, and I can create charts and interact with them with a few strokes, which is very helpful for real time storytelling."* P3 also acknowledged the ease of content creation: *"Having the dataset embedded with the tool made me comfortable destroying elements as they were no longer needed because I can create them so easily later. When something takes a long time to create, you are not comfortable removing it from the canvas."*

Participants also liked the interactivity and connection between the data charts created with sketching. P3 commented, *"I like the fact that the visual elements are connected to each other. Interacting with the maps affects other charts in the canvas."* P2, a UX researcher with a design background, explained the benefits of interactivity by comparing SketchStory with Photoshop; *"I spend so much time in Photoshop or Illustrator meticulously drawing my graphs but I can't go back and change the graph if someone asks a question. But, here my drawings can change according to their questions."*

The freeform aspect of sketching facilitated the creation of expressive and personalized data representation. For example, P5 commented that *"The iconic data representation helps me to connect with the viewers."* Participants also liked the organic graphic style and visual feel of the data charts.

5.1.5 Improvements based on the Usability Issues

Participants found it challenging to create content and perform narration simultaneously, especially the first time. Four participants suggested some preparation beforehand would facilitate the storytelling by reducing real-time sketching burden and cognitive load (and stress) during storytelling. Specifically, one participant (P3) pointed out that the nuances (i.e., heuristics) used for chart generation were confusing and he found himself unsure what chart the system would generate from his sketches. We observed that this was mainly due to the three modal steps for chart creation. Participants often forgot to switch to appropriate mode while sketching example icons and axis baselines. To address this problem, we removed the manual mode switching; we enabled the presenter to record the sequence of charts before the presentation, and to invoke them with the simple sketch gestures during the presentation.

Three participants expressed concerns about their sketching quality in real-time and wanted the system to beautify their sketches. Two participants were concerned that sketching in real-time would create cognitive load and opined that they would like to record the icons for data charts before the presentation. Therefore, we also enabled the presenter to pre-record the example icon as part of the chart specification. Sketch beautification remains future work.

Finally, two participants indicated that annotations should move with the data charts during move operations. As described above, in the new version of SketchStory, the annotations drawn within the chart boundary move along with the chart.

5.2 Controlled Experiment

Our goal was to examine the subjective level of engagement of SketchStory for both the audience and presenters as compared to a traditional presentation system, PowerPoint. In addition, we wanted to explore how well presenters could learn and use SketchStory.

5.2.1 Datasets and Stories

To compare two systems, we prepared two stories with two datasets [8][33] downloaded from the web. One is the story about global energy consumption we used for the first usability study. The other story is about global income statistics between 1985 and 2010. To ensure that both stories had comparable length, structure, and complexity, we extracted parts of the datasets and tweaked some numbers. To avoid participants using prior knowledge, we also created two fake region maps and replaced the region names with fictitious country names. For example, Figure 6a shows a region map used for the energy consumption story. Both datasets consist of 5 data columns (country, year, population, energy consumption/gross national income, and per-person consumption/GDP per-capita), with 30 rows in total (5 regions and 6 time points per country).

Both stories had six key messages to convey. For the income statistics story, we had the following six key points:

1. Gross national income has increased overall.
2. Global population has increased steadily and linearly.
3. GDP per-capita has also steadily increased overall.
4. Celtica and Aslan are the two countries with most gross income.
5. While Celtica's population is more than double of North America's, Aslan's GDP is more than double of Celtica's.
6. Celtica and Aslan's national income was once flipped in 2000.

For the SketchStory condition, we used three chart types—bar chart, line chart, and map—for four charts with annotation, filtering, and zooming capabilities. We also recorded an example icon for one chart; presenters had to draw two example icons during their presentations. We suggested possible annotations but did not force presenters to use them. For the PowerPoint condition, we embedded standard charts created with Microsoft Excel; each slide contained one chart except for one page comparing and contrasting the difference between two charts (for the key point #5). Because PowerPoint and Excel do not support maps by default, we instead used a pie chart, and greyed out slices of the pie chart right before drilling down into two countries to help the audience follow the transition in the PowerPoint condition (Figure 7).

5.2.2 Participants, Study Design, and Equipment

We recruited 24 (14 males) audience participants fluent in English. The average age was 38.7, ranging from 28 to 47 years of age. In addition, to examine presenters' reactions to SketchStory, we recruited 5 (4 males) presenter participants. The average age was 34.6, ranging from 31 to 43 years of age. We required presenter participants to be native English speakers and comfortable with giving presentations. Furthermore, they were screened to be already familiar with PowerPoint and to give presentations regularly (at least once a month). Both audience and presenter participants were screened for color-blindness and deafness, and required normal or corrected-to-normal eyesight. They were also required to be able to read basic charts such as line chart, bar chart, and pie chart. Participants were given a software gratuity for their participation.

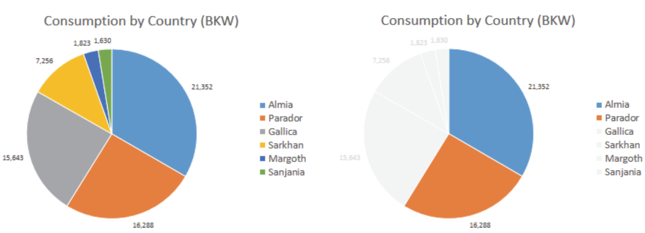


Fig. 7. For the PowerPoint condition, we greyed out slices of the pie chart right before drilling down into two countries to help the audience follow the transition.

We conducted the study as a within-subjects design in a small conference room. Each presenter gave a presentation with both systems—SketchStory and PowerPoint—to an audience; the audience watched both presentations as a group. The audience size was four or five participants. To avoid an ordering effect, we counterbalanced the order of the two systems, but we fixed the order of stories. To measure the level of engagement, we collected participants' subjective ratings for each system.

Each presenter gave both presentations on an Intel Xeon W3550 3.07 GHz Windows 8 desktop machine with 12 GB RAM and a 55" Perceptive Pixel Display [32] that supports both pen and touch interaction at a resolution of 1920x1080; both presentations were not projected onto the wall.

5.2.3 Procedure

Presenter participants arrived an hour earlier than audience participants because they needed to learn the SketchStory system as well as both stories. At the start of each session, we explained the goal and overall procedure of the study and how datasets were prepared. We then asked the presenters to fill out a pre-experiment questionnaire to collect their background about presentation skills.

We then trained the presenters for two stories. As for the story, we explained a storyline and the six key messages to convey during their presentations. We gave the presenters printout notes that had the sequence of screenshots or slides with the key messages, and allowed them to write down their own notes. As for the system training, since all presenters were already familiar with PowerPoint, we trained them only SketchStory. However, for the PowerPoint condition, the presenters practiced the touch swipe gestures because they were not familiar with the touch-enabled large screen. They practiced both presentations multiple times, spending about 30~40 minutes for SketchStory and about 10 minutes for PowerPoint.

When the audience arrived an hour later, we first explained the goal of the study and how datasets were prepared to the audience in a separate room. We then brought the audience to the conference room where the presenter was waiting. Before the first presentation, we emphasized that we wanted to evaluate the system, not the presenter, even though it might be difficult to separate the two.

Then the presenters told the first story to the audience. After the presenter finished the story, both the audience and presenters were given a short questionnaire about the presentation they just watched and gave, respectively. The same procedure was repeated with the second story and system. On average, the presenters spent about 3 minutes for the SketchStory presentation and about 2 minutes for the PowerPoint presentation.

At the end of the session, we asked both the audience and presenters to select which system they preferred overall and explain why. In addition, we asked the presenter participants to select which system required more efforts and explain why. We captured video and audio of the session. The experiment took about one hour for the audience participants and two hours for the presenter participants.

5.2.4 Results and Discussion: Audience

After each presentation, audience answered four questions intended to measure the subjective level of engagement using a 7-point Likert scale, with 1 = Strongly disagree and 7 = Strongly agree for Q1 (enjoyment) and Q4 (perception about presenter's enjoyment), and with 1 = Not engaged at all and 7 = Highly engaged for Q2 (engagement with the story) and Q3 (engagement with the system). Figure 8 shows the average subject responses from the audience for both systems. We analyzed these subjective responses using Friedman Chi-Square tests, and found significant differences in all four questions. Audience indicated that they enjoyed the presentation more with SketchStory than PowerPoint ($\chi^2(1, N = 24) = 14.73$, $p < .001$), and they felt the presenter enjoyed giving the presentation more with SketchStory than PowerPoint ($\chi^2(1, N = 23) = 8.90$, $p = .003$). In addition, they were more engaged with the story ($\chi^2(1, N =$

24) = 6.37, p = .012) and system ($\chi^2(1, N = 24) = 10.89$, p = .001) with SketchStory than PowerPoint. We also analyzed the response to Q2 for both stories and did not find a significant difference between them ($\chi^2(1, N = 24) = 1.32$, p = .25). This indicates that the perceived engagement of both stories was the same, but SketchStory made the audience feel more engaged for the same story.

In addition, 75% (18 out of 24) of our audience participants chose SketchStory as their preferred presentation system. When asked why, their reasons were: more engaging, interactive, dynamic, better storytelling, more organic, more personal, annotation, and one screen. Their comments upheld our design rationale to achieve more engaging presentations. For example, P10's comment touches many of these: *"I liked how he [the presenter] could draw a picture to have the graph present itself. The view of all the data presented on one screen, options to choose to focus on a particular piece of data. Being able to add text as you go—specifically highlighting what is being discussed. It's much more interactive and able to keep my attention more interesting than a static presentation."*

More specifically, P2's comment demonstrates that SketchStory's real-time content creation successfully created anticipation: *"The system makes you want to see what was next. I felt it kept your attention better."* In addition, P24's comment shows that interactivity on a canvas helped people follow the story: *"The ability to interact with the data and the more organic presentation made it easy to follow the story. Having the entire presentation on one screen allowed greater context in understanding the story."*

Interestingly, several audience also commented about presenters' perspective. For example, P7 stated that *"It allowed the presenter opportunities to engage his audience, not just present to them."* P11 stated his desire to try SketchStory: *"I enjoyed watching the presentation, and I would be eager to give a presentation using this system [SketchStory]."*

It seems that low-quality sketching can cause distraction, hindering the audience from being more engaged. Six audience participants chose PowerPoint as a preferred system mainly because of the readability. They mentioned that PowerPoint was "easier to read," "legible," and "easier to see and read." Another reason by two audience participants was familiarity. For example, P14 stated that *"The ease of visibility understanding the flow, the cleanness of the graphics in each slide the boldness of the fonts much easier to follow along with it as I was more familiar with it."*

5.2.5 Results and Discussion: Presenter

After each presentation, presenters answered five questions measuring subjective ease of learning, ease of use, and engagement; they answered only four questions for PowerPoint because we did not ask about ease of learning. We again used a 7-point Likert scale, with 1 = Strongly disagree and 7 = Strongly agree. Figure 9 shows the average subject responses from presenters for both systems. Since we did not have enough presenters for statistical analysis, we report only descriptive statistics. For SketchStory, presenters tended to agree with the statement "It was easy to learn" (Q5: 6.0 average; higher than 5.2 from the first study). For both SketchStory and PowerPoint, they also tended to agree with the statement "It was easy to give a presentation with this system" (Q1: 5.8; higher than 4.7 for ease of use for SketchStory from the first study). Presenters' reaction was similar for Q4: "I am satisfied with my presentation with this system." However, SketchStory tended to be ranked higher for Q2 (fun) and Q3 (perception of audience engagement).

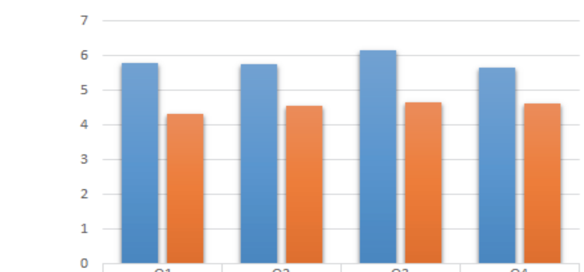
Four out of five presenters chose SketchStory as their preferred presentation system even though all five presenters indicated that SketchStory required more effort. They seem to think that SketchStory helped keep the audience more engaged. For example, PP1 stated that *"It felt as though I was bringing the audience with me on a journey versus 'presenting to (at)' them."* PP5 mentioned that *"It is almost like I'm telling a story rather than stating facts, which is more fun/entertaining/informative/memorable for everyone involved."* Not surprisingly, the most common reason given for more effort was the fact that they had to draw the icons to populate the graphs. Two presenters also commented that, for SketchStory, they had to be more familiar with the content.

6 Discussion and Future Work

The encouraging results of the controlled study indicate that the SketchStory design supports more engaging storytelling. The results from both studies also point out the unique affordances and potential of the approach, and provide exciting possibilities in the direction of novel and engaging storytelling with data.

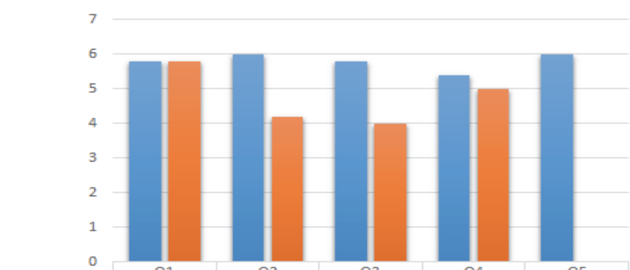
Integration with Exploration and Better Authoring Capability: Participants commented about the capabilities of data-bound sketching for data exploration. For example, two participants in the first study mentioned that they would like to change the chart type dynamically (e.g., from bar chart to line chart). We have extended SketchStory to support chart type changes for the charts with x and y axes through simple sketch gestures. For example, you can draw a bar and an 'M' shape in the chart area to switch to a bar chart and line chart, respectively. However, an example icon good for one chart type is not necessarily right for the other. For example, thin-and-tall icons are good for bar charts but not so great for line charts.

To ease the problem of mode switching, SketchStory enables the presenter to record a sequence of charts before the presentation, and to invoke them with simple sketch gestures during the presentation. However, SketchStory currently does not support editing of the recorded story, requiring the presenter to manually edit the metadata file with a text editor. Since this is tedious and error-prone, a logical next step is to support a better authoring capability within SketchStory. We believe incorporating exploration capabilities will facilitate story authoring. For example, the presenter could create a story from a canvas during the exploration phase by dragging a chart into a separate story pane. The order of charts could be changed with simple drag-and-drop interaction. In addition, changes in chart settings on a canvas could be easily reflected to the story. We have been expanding SketchStory accordingly to provide a seamless experience from fluid data exploration to engaging presentation.



	Q1	Q2	Q3	Q4
SketchStory	5.79	5.75	6.17	5.65
PowerPoint	4.33	4.54	4.67	4.63

Fig. 8. Average subjective responses from the audience to 7-point Likert scale questions; 1 = Strongly disagree or Not engaged at all and 7 = Strongly agree or Highly engaged. All differences are significant.



	Q1	Q2	Q3	Q4	Q5
SketchStory	5.8	6.0	5.8	5.4	6.0
PowerPoint	5.8	4.2	4.0	5.0	

Fig. 9. Average subjective responses from presenters to 7-point Likert scale questions; 1 = Strongly disagree or Not engaged at all and 7 = Strongly agree or Highly engaged.

Burden vs. Control: Interestingly, most presenter participants preferred SketchStory even though it required more work. This means that lowering perceived workload does not always lead to the optimal experience. We suspect this is because of the trade-off between burden and control. For example, we could minimize the burden during the presentation by allowing presenters to record additional chart settings such as the size and location of the charts, and then to invoke them with simple click-through. However, presenters then lose an additional measure of control during the presentation, and the experience approaches that of the traditional presentation. It is important to note that some presenter participants liked having the control and believed that it helped them keep the audience more engaged.

In the current implementation, the presenter can see the chart sequence in a dropdown list and change the order at any time by selecting a different thumbnail. However, for fluid presentations, presenters need to remember the sequence without interrupting their flow. Existing commercial presentation tools like PowerPoint and Keynote provide a presenter view mode, where the presenter could preview the next slide along with a current slide on a computer screen. It would be useful to explore how to help presenters better remember or recall the flow.

Sketch Rendering: During the implementation of tally chart rendering for initial SketchStory, we had a trade-off between data precision and aesthetics. For instance, in Figure 10, data values of 307 and 365 have an equal number (five) of icons. We originally decided not to clip or distort icons for two reasons. First of all, we wanted to provide more aesthetically pleasing drawings; clipped icons looked untidy. We identified similar practices by infographics designers during our analysis phase, preferring aesthetics to precision (e.g., Figure 2a). Ultimately, our main goal was to support storytelling scenarios that demonstrate major trends without depending on exact precision. Second, given the imprecise nature of sketching, we believed that people would be more forgiving of imprecision in sketched content. In fact, during our first usability study, participants did not complain about imprecision. Rather, they used annotations to point out major trends. However, how the sketchy and iconic rendering of data charts affect the perceived accuracy requires further investigation.

Regarding the sketchy rendering style, one participant commented that SketchStory would be more useful for less business-based presentation, such as art or gaming. People may infer a sketchy style to be more fun and entertaining rather than official and serious. It would be interesting to investigate the possible connotations for sketchy rendering more formally in future work.

Some audience participants preferred PowerPoint because SketchStory looked untidy and cluttered for them. Furthermore, one major issue with SketchStory for the audience was readability; each chart did not have a title like a PowerPoint slide and the fonts for the numbers and labels were too small. An audience participant mentioned that it would be nice to have the capability of maximizing one chart since it would alleviate the readability problem. It could be helpful to incorporate existing sketch beautification algorithms and to support adaptive font size.

Scalability: The current SketchStory design is not scalable in terms of the complexity of data and types of story. It currently handles only tabular datasets with simple data charts and is suitable for a short, simple story but not sufficient for long, complex ones. SketchStory also works best when presenters can find and draw icons that best match their story. To enable richer presentations covering broader types of stories, we need to add a more powerful data layer that can handle more complex data and extend the gestures and interactions to support additional chart types (e.g., scale charts, stacked bar charts, etc.) and more sophisticated visualizations. A scrollable or zoomable canvas could help SketchStory support a longer story. However, it may lose the one-page overview of the story. How to extend SketchStory to support more complex stories remains future work.

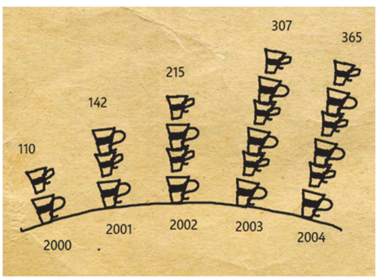


Fig. 10. Example tally chart generated by initial SketchStory.

Limitations of Controlled Experiment: As an initial step, our controlled experiment compared only the live presentation aspect of SketchStory with PowerPoint, excluding the story preparation (e.g., authoring) aspect. Further comparisons with presentation tools with more flexible storytelling features would shed more light on the strengths and weaknesses of the SketchStory design. As briefly mentioned above, we have been extending SketchStory to incorporate data exploration along with authoring of the sequence of charts. Further evaluations on the usability and effectiveness of the chart sequence authoring would help us better understand the feasibility of the SketchStory approach.

In addition, our experiment does not address whether the main effect of participants' preference is due to the sketchy rendering style, due to the interactive, animated generation of charts, or due to the combination of both. Also, presenter participants spent more time practicing SketchStory because they already felt comfortable with PowerPoint. This could have made differences in their presentation quality. Furthermore, our experiment could not control the novelty effect; people might have preferred SketchStory because it is new and different than existing presentation tools. Therefore, future research is needed to tease out these factors.

Participants acknowledged that SketchStory's capability of digitizing whiteboards could be useful in other domains. For example, they mentioned that the SketchStory approach would be great for lectures and group meetings because it allows for dynamic group interaction. In the controlled experiment, we mainly investigated the subjective level of engagement for stories with data. It would be useful to investigate effectiveness of the SketchStory approach for content understanding or idea generation, not just in data story presentations but also in other contexts such as education.

7 Conclusion

Inspired by successful storytelling techniques, we explored a novel approach to telling stories with data by melding the expressive visual language of infographics with the narrative storytelling attributes of whiteboard animation. We presented SketchStory, an interactive whiteboard system integrating real-time freeform sketching capabilities with the fluid synthesis of interactive, organic data-bound charts. We first conducted a usability study to understand how people would use this new form of storytelling. We improved the system based on the lessons learned from the first study. For example, to reduce the burden of manual manipulation during the presentation, SketchStory allows the presenter to record a sequence of charts before the presentation, and invoke them with simple sketch gestures in real-time. We then conducted a controlled experiment to compare SketchStory with Microsoft PowerPoint, one of the most commonly used presentation tools. Results show that the audience is more engaged with the presentation done with SketchStory than PowerPoint, and that most presenters favored SketchStory even though they acknowledged the extra effort required to present with SketchStory. In addition, our results provide new possibilities for future work in sketch-based narrative storytelling with data.

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