

Narrative Visualization: Telling Stories with Data

Edward Segel and Jeffrey Heer

Abstract—Data visualization is regularly promoted for its ability to reveal stories within data, yet these “data stories” differ in important ways from traditional forms of storytelling. Storytellers, especially online journalists, have increasingly been integrating visualizations into their narratives, in some cases allowing the visualization to function in place of a written story. In this paper, we systematically review the design space of this emerging class of visualizations. Drawing on case studies from news media to visualization research, we identify distinct genres of narrative visualization. We characterize these design differences, together with interactivity and messaging, in terms of the balance between the narrative flow intended by the author (imposed by graphical elements and the interface) and story discovery on the part of the reader (often through interactive exploration). Our framework suggests design strategies for narrative visualization, including promising under-explored approaches to journalistic storytelling and educational media.

Index Terms—Narrative visualization, storytelling, design methods, case study, journalism, social data analysis.

1 INTRODUCTION



In recent years, many have commented on the storytelling potential of data visualization. News organizations including the New York Times, Washington Post, and the Guardian regularly incorporate dynamic graphics into their journalism. Politicians, activists, and television reporters use interactive visualizations as a backdrop for stories about global health and economics [10] and election results [9]. A recent feature in *The Economist* [6] explores the proliferation of digital data and notes that visualization designers are “*melding the skills of computer science, statistics, artistic design and storytelling*.”

Static visualizations have long been used to support storytelling, usually in the form of diagrams and charts embedded in a larger body of text. In this format, the text conveys the story, and the image typically provides supporting evidence or related details. An emerging class of visualizations attempts to combine narratives with interactive graphics. Storytellers, especially online journalists, are increasingly integrating complex visualizations into their narratives.

Crafting successful “data stories” requires a diverse set of skills. Gershon and Page [12] note that effective story-telling “*require[s] skills like those familiar to movie directors, beyond a technical expert’s knowledge of computer engineering and science*.” While techniques from oration, prose, comic books, video games, and film production are applicable to narrative visualization, we should also expect this emerging medium to possess unique attributes. Data stories differ in important ways from traditional storytelling. Stories in text and film typically present a set of events in a tightly controlled progression. While tours through visualized data similarly can be organized in a linear sequence, they can also be interactive, inviting verification, new questions, and alternative explanations.

Currently, most sophisticated visualization tools focus on data exploration and analysis. Applications such as spreadsheets and visualization tools support an array of analysis routines and visual encodings, but beyond exporting images for presentation typically provide scant support for crafting stories with analysis results. As such, they provide powerful vehicles for discovering “stories”, but do little to aid narrative communication of these findings to others. As tools mature and more richly integrate with the web (e.g., Many Eyes [25], Tableau Public [22], GeoTime Stories [8]), they are enabling the publication of dynamic graphics with variably constrained levels of interactivity. It remains an open question how the design of such tools might be evolved to support richer and more diverse forms of storytelling.

In this paper, we investigate the design of narrative visualizations and identify techniques for telling stories with data graphics. We take an empirical approach, analyzing visualizations from online journalism, blogs, instructional videos, and visualization research. After reviewing related work, we share five selected case studies which highlight varied design strategies and illustrate our analytic approach. We then formulate a design space constructed from an analysis of 58 examples. Our analysis identifies salient dimensions of visual storytelling, including how graphical techniques and interactivity can enforce various levels of structure and narrative flow. We describe seven genres of narrative visualization: magazine style, annotated chart, partitioned poster, flow chart, comic strip, slide show, and video. These genres can be combined with interactivity and messaging to produce varying balances of author-driven and reader-driven experiences. Finally, we discuss the implications of our framework, noting recurring design strategies, promising yet under-utilized approaches to integrating visualization with other media, and the potential for improved user interfaces for crafting data stories. By focusing on the graphical and interactive elements of narrative visualization, our approach gives less attention to the cognitive and emotional experience of the reader. We recognize the importance of these elements, however, and describe directions for future reader-centric research in our conclusion.

2 RELATED WORK

Storytelling and visual expression are integral parts of human culture; storytelling has even been referred to as “*the world’s second-oldest profession*” [12]. Without summarizing millennia of achievement, we describe a few of the key concepts informing narrative visualization.

2.1 Narrative Structure

The Oxford English Dictionary defines *narrative* as “an account of a series of events, facts, etc., given in order and with the establishing of connections between them.” Central to this definition is the notion of a chain of causally related events. Stories of this form often have a beginning, middle, and end [3, 24]: an introduction to the situation, a series of events often involving tension or conflict, and a resolution.

Since ancient times, people have tried to understand and formalize the elements of storytelling. For example, writers (e.g., [5, 19, 21]) have developed typologies of dramatic situations and identified plot lines common to many narratives, such as the “hero’s journey” [5]. This research typically distinguishes between the content of the story and the form in which it is told. While stories often concern interacting characters, they may also present a sequence of facts and observations linked together by a unifying theme or argument.

Storytelling strategies vary among media and genre. For instance, stories told through writing have access to a different set of formal mechanisms and narrative structures (e.g., stream of consciousness) than stories told through film (e.g., split-screen sequences [3]). Blundell [2] describes narrative devices for journalism such as the *anecdote*.

• The authors are with Stanford University, Stanford, CA 94305.
E-mail: {esegel, jheer}@stanford.edu.

Manuscript received 31 March 2010; accepted 1 August 2010; posted online 24 October 2010; mailed on 16 October 2010.

For information on obtaining reprints of this article, please send email to: tvcg@computer.org.

tal lead—an initial story, often involving dialogue and characters, that presents a microcosm of the larger news story—and the *nut graf*—a paragraph explicitly describing the news value of an article. These devices are largely unique to journalism, as opposed to literary fiction or film. Visualizations themselves may incorporate a variety of media, including text, images and video, and can also be interactive, **enabling stories whose telling relies as much on the reader as on the author.**

2.2 Visual Narratives

Artists, designers, and psychologists have all explored ways in which visual media can be organized to engender a narrative experience. They have developed nuanced techniques for sequentially directing a viewer's attention and keeping viewers oriented across transitions. While a full treatment of these devices is beyond the scope of this paper, we present some salient principles here.

Many narratives are rooted in a clear starting point. In visual media, an establishing shot or overview [3, 19] is often used to introduce the scene. Of course, not all elements in a scene are of equal importance throughout a story, and so authors often manipulate a scene to direct attention to a point of interest. Psychologists have extensively studied phenomena of visual salience [11, 17, 23], showing that outliers among visual features such as color, size, and orientation preferentially attract one's attention. The strength of this attraction is modulated by multiple factors [17], including the scene itself (e.g., a brightly colored object is less salient when surrounded by other brightly colored objects) and by the viewer's task (e.g., expectations and top-down search can affect what is perceived as most salient).

Cultural factors, particularly reading order (e.g., left-to-right) naturally bias where people look first and how they scan an image [19]. Visual techniques can further establish the order in which the eye visits elements in the scene. For example, gestalt grouping [26] via features such as spatial proximity, containment, or connection may bias one towards first perceiving the grouped content. Vectorial reference [18, 24], most commonly in the form of arrows, is a powerful technique for sequentially directing attention.

Visual media often involve changes of scene, such as between the panels of a comic or across cuts in edited film. A number of devices have been developed to orient a viewer during transitions. Continuity editing techniques in film [3], such as matching on objects or actions, suggest the connection between scenes and may sustain a focus of attention. Similarly, animation design [14, 24] often relies on object constancy and de-emphasizes secondary details to keep viewers oriented; animators may also subdivide a transition into stages to facilitate apprehension. Within comics, McCloud [19] proposes a taxonomy of transition types consisting of *moment-to-moment* (one subject, short time period), *action-to-action* (one subject, longer time period), *subject-to-subject* (different subjects, same scene), *scene-to-scene* (change of scene), *aspect-to-aspect* ("aspects of a place, idea, or mood"), and *non-sequitur* (logically unconnected) transitions. In addition to continuity of objects or actions, extra-pictorial elements [24] such as callouts (e.g., insets or lines to denote zooming) and annotations are used to enrich a narrative. Not surprisingly, we will see that many of these techniques are also applicable to narrative visualization.

2.3 Storytelling with Data Visualization

Though data visualization often evokes comparisons to storytelling [6, 7], the relationship between the two is rarely articulated clearly. Jonathan Harris, the creator of *We Feel Fine* and *Whale Hunt*, considers himself a storyteller first and a visualization designer second: "*I think people have begun to forget how powerful human stories are, exchanging their sense of empathy for a fetishistic fascination with data, networks, patterns, and total information... Really, the data is just part of the story. The human stuff is the main stuff, and the data should enrich it.*" Yet when pressed to describe what he means by "story," he responds with only a rough approximation: "*I define 'story' quite loosely. To me, a story can be as small as a gesture or as large as a life. But the basic elements of a story can probably be summed up with the well-worn Who / What / Where / When / Why / How.*"

Others have tried to articulate the connection more concretely. Ger-shon and Page [12] observe that stories communicate information in a psychologically-efficient format, also a central goal of visualization design. Using the script of a fictional military scenario as a case study, they examine tactics used to communicate narrative events, including continuity editing, highlighting (e.g., flashing), and redundant messaging across media (e.g., audio and video). Still, a deeper understanding of narrative visualization remains elusive, as "*we need to further understand the characteristic interactions of each genre with each particular audience, its advantages and disadvantages, and how it might affect content and learning.*" Wojtkowski and Wojtkowski [27] further argue that what makes data visualization different from other types of visual storytelling is the complexity of the content that needs to be communicated. They conclude that "*visual storytelling, in turn, might be of critical importance in providing intuitive and fast exploration of very large data resources,*" but again stop short of detailing how we might best "*tailor visualization systems to accommodate storytelling.*"

Some visualization systems have begun to incorporate storytelling into their design. For example, GeoTime Stories [8] enables analysts to create annotated stories within visualizations using a text editor and bookmarking interface. The sense.us [15] system allowed users to create trails of visualization bookmarks that were regularly used for storytelling. Tableau's graphical histories [13] lets users review, collate, and export key points of their visual analysis. More recently, Tableau Public [22] supports the construction and web-based publication of interactive visualizations, supporting storytelling in data-rich domains such as finance and sports journalism. Such systems provide the first steps toward making richer storytelling capabilities accessible.

In short, many have observed the storytelling potential of data visualization and drawn parallels to more traditional media. However, a thorough understanding of the design space for narrative visualization has yet to emerge. In the meantime, practitioners such as artists and journalists have been forging paths through this space, and we might hope to gain insight from their explorations. Here we seek to further our understanding of narrative visualization by analyzing and contrasting examples of visualizations with a story-telling component. We then generalize from these examples to identify salient design dimensions. In the process, we hope to clarify how narrative visualization differs from other storytelling forms, and how these differences introduce both opportunities and pitfalls for its narrative potential.

3 CASE STUDIES OF NARRATIVE VISUALIZATION

We collected visualizations with narrative components, and then attempted to identify and categorize the design features that effectively tell stories with data. We gathered examples from sources such as online journalism, blogs, visualization books, research papers, and software packages. Our primary source was online journalism, including visualizations produced by the New York Times, the Guardian, the Financial Times, the Washington Post, and Slate. Additional visualizations were found through visualization blogs such as Flowing Data, Infosthetics, and Visual Complexity. For completeness, we also examined visualizations that do not explicitly tell stories but nonetheless contain relevant storytelling components. We analyzed the narrative and interactive devices used in each example. The accumulated data reveals recurring patterns, leading to our analysis in Section 4.

In this section, we present five selected case studies of narrative visualization. Our goal is to highlight both exemplary and problematic approaches, as well as give the reader a sense of our method of analysis. Throughout, recurrent design strategies are marked in **bold face**. The examples were chosen to provide a diverse sample of points in the design space of narrative visualization. These case studies also highlight the potential application of narrative visualization in fields ranging across journalism, sports, public policy, and finance.

3.1 Steroids or Not, the Pursuit is On

Baseball star Barry Bonds points to the sky; his goal, 755 home runs, hovers over his head—"Steroids or Not, the Pursuit is On" [A36]. Shadowing Bonds' attempt were allegations of steroid use, and many sports statisticians turned to the numbers to investigate these claims.

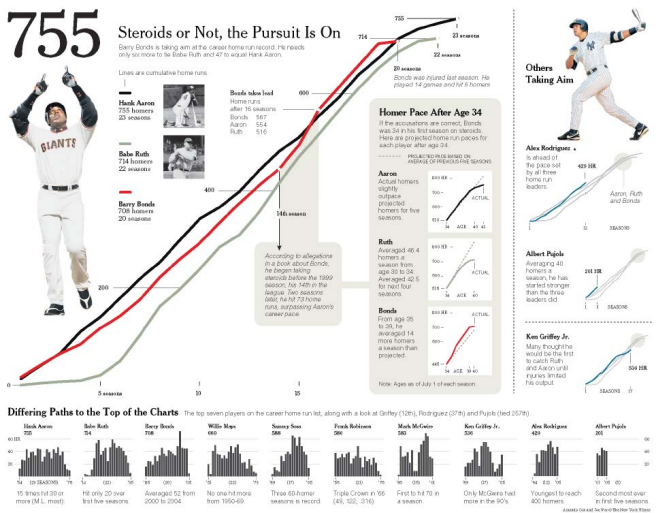


Fig. 1. Steroids Or Not, the Pursuit is On. New York Times.

Sized prominently and placed in the upper left corner of the page, the image of Bonds grabs the eye and points the viewer towards the title, establishing the topic for the rest of the graphic. A legend consisting of photos and text introduce Hank Aaron and Babe Ruth, previous home run leaders whose careers provide points of comparison for Bonds' career. A line-chart of accumulated home runs shows the three hitters' careers in alignment, with Bonds' home runs accelerating at a time when the other hitters slow down. A shaded **annotation** notes that the acceleration coincides with the first reports of steroid use in Bonds' 14th season, accompanied by a second annotation just two years later when Bond takes the lead over Ruth and Aaron. The shaded path then flows to a similarly-colored inset to the right containing a comparison of each player's home run pace after age 34, emphasizing the suspicious acceleration in Bonds' hitting so late in his career.

The viewer may then move to other sections. On the right, the eye is invited by a large image of a swinging Alex Rodriguez and a bold caption noting "Others Taking Aim." Here we see the other current players who are chasing the career home run record. The bottom section ("Differing Paths to the Top of the Charts"), devoid of color and consisting of smaller plots, is given minimum visual priority but completes the story. Small multiples show the home runs per season for top players on the career home run list, each captioned by a factoid.

The visualization resembles a poster one might see at a science fair, with the space subdivided into smaller sections, each telling its own sub-story with charts, pictures, and text. The three sections are linked together graphically through the use of color, shape, and text. For example, the largest section introduces the hitters according to their order on the career home run list: Hank Aaron (black line), Babe Ruth (green line), and Barry Bonds (red line). Subtly **matching on content**, the inset in this section maintains this same scheme, presenting the players in the same order with their associated colors. This allows the viewer to immediately discern the reference to the larger image. The section below also begins in the same order (Aaron, Ruth, Bonds) before proceeding to the other players. This order not only carries informational content (i.e., who has the most home runs) but also prevents the viewer from having to reorient while switching between sections. Finally, the section to the right charts the performance of current players over a shadow of the initial chart, a shape we immediately identify as belonging to Aaron, Ruth, and Bonds.

While these elements provide seamless transitions between sections, they do not dictate the order in which the viewer explores the visualization. Rather, a path is accomplished through the use of **visual highlighting** (color, size, boldness) and connecting elements such as arrows and shaded trails. When looking at the visualization, the viewer begins with the largest image, in part because of its size, central positioning, and coloring, but also because it is capped with a large headline and a picture of Bonds himself telling the viewer where to look.

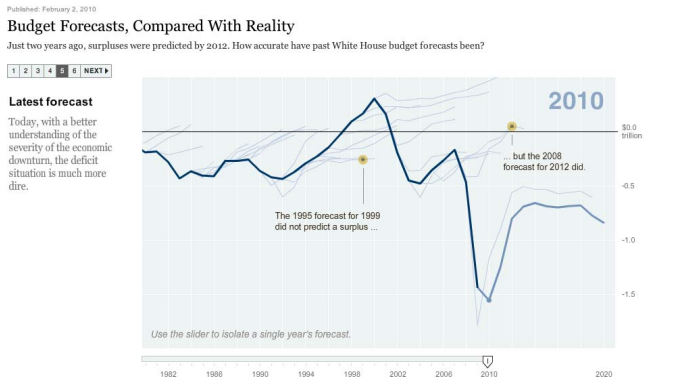


Fig. 2. Budget Forecasts, Compared With Reality. New York Times.

3.2 Budget Forecasts, Compared With Reality

When deteriorating economic conditions forced a downward revision in the 2010 White House budget forecast, the New York Times published this visualization [A53] to explore the accuracy of past budgets' predictions. A large headline is followed by a brief prompt introducing the visualization. Below are two panels side by side. The left panel contains another bold headline accompanied by a short paragraph of text, while the right panel contains a line chart showing budget surpluses and deficits between 1980-2020, with the estimates distinguished from actual data using annotations and coloring. Just above these panels is a **progress bar** indicating the length of the visualization and providing the user with a mechanism to navigate between slides.

As the user steps through the presentation, the visualization maintains a **consistent visual platform**, changing only the content within each panel while leaving the general layout of the visual elements intact. Each new slide alters the text in the left panel, while updating the chart in the right panel with animated transitions. A narrative is communicated clearly through the interaction of the text in the left panel with the annotations and graphic elements in the right panel, each enriching the narrative through **multi-messaging**, providing related but different information [20]. In this way, the presentation guides the viewer through historical budget forecasts, explaining patterns in the data (*80% of deficit forecasts have been too optimistic*) and highlighting key events (*surpluses under Clinton were generated in part by a stock market bubble*). Users can discover additional statistics by mousing-over the chart, revealing **details-on-demand** with the years and estimates of past forecasts. Halfway through the presentation, a **timeline slider** appears above the dates on the horizontal axis, with the slider position updating along with the chart above. Text on the fifth slide explicitly encourages the user to interact with this slider to isolate forecasts for a single year. The presentation ends with the current budget forecasts for 2012, letting the user see how these predictions change under different economic assumptions.

At its core, this visualization is a typical slide-show presentation augmented by two important features. First, it allows the user to determine the pace of the presentation by using the provided progress bar. And second, it allows the user to interact with the presentation by mousing-over areas of interest and by using the slider to explore different time windows. We call this structure an **interactive slideshow** that uses **single-frame interactivity**, meaning that interaction manipulates items within a single-frame without taking the user to new visual scenes. These devices encourage the user to explore the data within the structure of an overarching narrative. The narrative functions in two ways, both communicating key observations from the data, as well as cleverly providing a **tacit tutorial** of the available interactions by animating each component along with the presentation. By the time the presentation encourages the user to investigate budget forecasts for specific years, it is already clear to the user how to do this.

This presentation style can be compared to a narrative pattern called the **martini glass structure** [4], following a tight narrative path early on (the stem of the glass) and then opening up later for free exploration (the body of the glass). Different features of the visualization

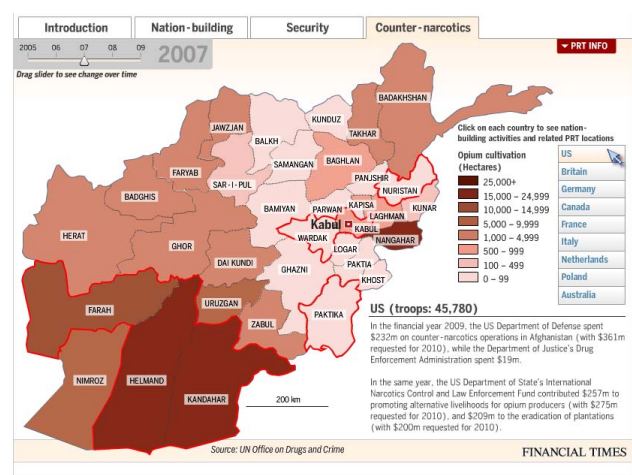


Fig. 3. Afghanistan: Behind the Front Line. Financial Times.

ensure that the viewer does not lose his place in the narrative during this exploratory stage, with orientation provided by the consistency of the visual platform, the updating progress bar, and the timeline slider.

3.3 Afghanistan: Behind the Front Line

In an effort to draw popular support away from the Taliban, NATO deployed groups of soldiers and civilians known as Provincial Reconstruction Teams (PRTs) to Afghanistan to implement nation-building development projects. People began to question the effectiveness of these groups amidst escalating violence in the region. This visualization [A45] begins with a traditional newspaper headline and brief article introducing the PRT's mission. The article then states the intended purpose of the graphic: to establish indicators of success by which to evaluate the development work being done in Afghanistan.

The graphic starts with its own introduction as well, occupying the first of four tabs the user can select. This starting tab contains only introductory text and a photograph of a US soldier. The remaining tabs (Nation-building, Security, Counter-narcotics) each contain an identical map of Afghanistan subdivided by province. A different hue (green, blue, red) is used to color the map for each tab, providing a **semantically consistent** color encoding; brightness encodes the values for each province. To the upper left of the map is a legend which changes according to the tab's content. The "Nation-Building" tab tracks the overall cost of activities for each province, "Security" tracks the severity of insurgent activity, and "Counter-Narcotics" tracks opium cultivation. This last tab also contains a **timeline slider**, allowing the user to explore how opium cultivation has changed over the past five years of the PRT's efforts.

Each tab contains an interactive list of NATO countries on the right. A short message and mouse pointer indicate the list is interactive. Clicking an individual country highlights the provinces in which that country has troops deployed, outlining their borders with a flashing red line. A paragraph of text appears in a panel below, providing facts about that country's involvement, and in some cases allowing the user to isolate particular activities (Education, Health, Economic Development, etc.). Finally, a button labeled "PRT INFO" slides down a new window containing additional background about the PRTs in Afghanistan, with **details-on-demand** for each country involved.

The visualization maintains the same graphical layout across tabs, modified only slightly for the different content. This **consistent visual platform** provides easy transitions between tabs, and the colors serve as an indication that a switch has occurred. The visual highlighting of provinces serves to draw the viewer's eye to the relevant areas, a necessary feature given the density of the map. Finally, each interactive component is clearly adorned with **markers of interactivity**, explicitly pointing out the potential for interaction.

However, we believe that some aspects of the visualization could be improved. Most importantly, the overall structure does not sufficiently

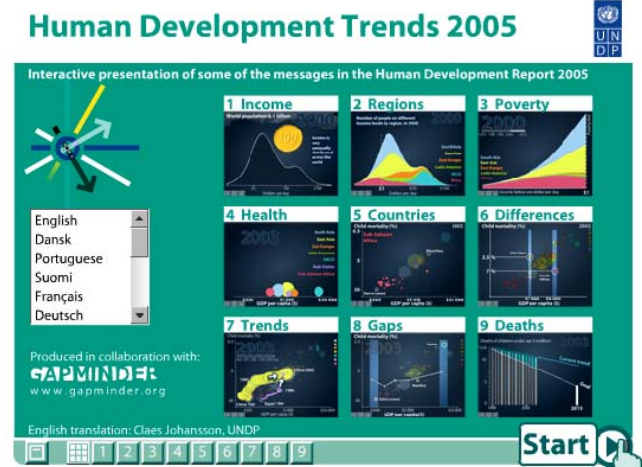


Fig. 4. Human Development Trends. Gapminder.

guide the viewer through the data, making it hard to draw meaningful conclusions from the large amount of information available. Why do some regions cost more than others? (Annotations are needed on the map.) Which countries provide the best aid? (Comparisons are needed between countries.) What projects exist in a particular region? (Regions cannot be selected.) Moreover, too much information is provided for each country in terminology-heavy paragraphs that are difficult to parse. While this may be useful for a trained analyst, a general audience would be better served by replacing the vast quantity of information with memorable factoids. The graphic may suffer by putting exploratory power into the hands of the viewer without sufficient guidance. A **synthesis or summary** could be very useful toward this end.

3.4 Gapminder Human Development Trends

This **interactive slideshow** [A47] surveys trends in global income and health. The visualization begins with a grid of screenshots from different sections of the presentation (Figure 4), with each image labeled with its respective topic (Income, Poverty, Health, Deaths, etc.). This **checklist structure** [20] provides an establishing shot of the content to be covered and serves as a reminder of what each section contains once the presentation is finished. It also enables navigation to particular segments. A **progress bar** at the bottom of the screen mirrors the grid above, while a large "Start" button in the lower right corner, highlighted by an animated pointer, tells the viewer how to begin the presentation. This button turns into familiar browser-style "forward" and "back" buttons when clicked, letting the user navigate between slides at his own pace. A second progress bar also appears upon entering each individual section. Both progress bars also serve as navigation tools, allowing the user to skip around the presentation without relying on the stepwise navigation provided by the browser buttons.

The presentation contains three basic kinds of charts: histograms, scatter plots, and bar charts. However, no individual section utilizes more than one chart type. Importantly, changes between chart types are made explicit in order to avoid confusing the viewer. For example, when the presentation transitions from histograms to scatterplots between Sections 3 and 4, a staged **animated transition** morphs the chart types across several patient steps (see Figure 5). Even manipulations within a single chart receive this same attention: in Section 3, a comment "*Zooming in below the poverty line*" alerts the viewer to the upcoming manipulation before it occurs.

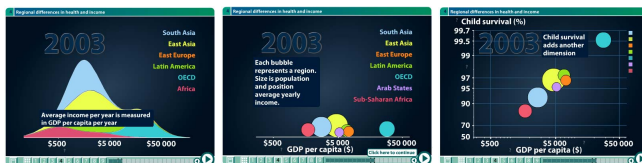


Fig. 5. Staged animated transitions between chart types.

Each section walks the user through a visualized dataset, pointing out key observations along the way. These explanations rely on a combination of **annotations**, **highlighting**, **animated transitions**, and **single-frame interactivity**. Typically, the data is not presented all at once. Rather, each chart is constructed in a stepwise fashion, with annotations and animations explaining each stage of the process. In Section 1, the x-axis initially appears without the rest of the chart, introduced with the comment, “*Daily income is measured in dollars per day.*” In Section 2, the graphic incorporates the data for each geographic region individually, reserving the pauses between animations to offer facts about the region (*Africa: Population 630 million*). At any point in these lessons, the user can mouse over different graphical elements for **details-on-demand**.

Beyond simply introducing graphical features, the annotations convey a narrative for each section, providing observations that the viewer would unlikely identify on his own. For example, Section 3 explains “*In the 1970s most poor lived in South and East Asia.*” Then, as the timeline moves forward and the chart changes, a new comment states, “*The last 30 years changed the face of global poverty. Now Africa is the home of one third of all poor.*” A final animation updates the chart even further, this time with the comment, “*In 2015 Africa will account for the majority of the world poverty.*” These narratives crucially allow dense information to be quickly comprehended by the user, and the graphical elements play an important role in making this possible: animations highlight relevant sections of the charts, color schemes remain **semantically consistent** between slides, and arrows and labels regularly appear to clarify elements mentioned in text.

Periodically the presentation allows increased user interactivity with the display, typically after a narrative segment is complete, again following a **martini glass structure**. In this presentation, the increased interactivity occurs most frequently in segments using time-series data, as a **timeline slider** appears to let the user return to previous years. Importantly, the exposed interactivity is part of the narrative, not merely an afterthought. For instance, Section 3 explains “*The global goal of halving poverty by 2015 will be met because of fast progress in Asia. But on current trends Africa and Latin America will not meet that goal.*” At this point, additional interactive components appear on the display and a prompt appears with the message “*Use the timebar to see people in Asia moving out of poverty.*” In this way, the interactivity is actually a continuation of the story, emphasizing the same themes and encouraging the user to use the story as a starting point for his own personal exploration of the data.

3.5 The Minnesota Employment Explorer

Months before the stock market crash of September 2008, many observers noted that the economy was slowing down; unemployment was rising while gas and food prices neared record highs. In January 2008, Minnesota’s state economist had seen enough to say the state was in recession. In response, in July 2008 Minnesota Public Radio (MPR) released a feature on their website on the “Minnesota Slowdown.” The page links to stories detailing the state’s economic malaise and shares interviews with residents hit hard by the downturn.

At the bottom of the page lies an interactive visualization of state unemployment data: The Minnesota Employment Explorer [A19], a joint effort of MPR and the UC Berkeley Visualization Lab. Small multiples of time-series charts show normalized unemployment data by industry from 2000 to 2007. Both long-term trends and seasonal oscillations are apparent. For example, the Health sector exhibits steady growth, while agriculture, construction, and education show strong seasonal patterns. Mouse-hover provides **details-on-demand**; double-clicking an industry triggers a drill-down into that sector, with an **animated transition** updating the display to show sub-industry trends.

Notably, the visualization also includes social interaction features. A list of comments associated with the current view enables journalists and readers to share observations and discuss trends. Commentary and visualization are linked together: one can select a data series to highlight it in the view; the highlight is subsequently saved with the comment. Selecting a comment reveals these annotations. Conversely, selecting a series highlights related commentary.

Minnesota Quarterly Employment (by Industry) 2000-2007

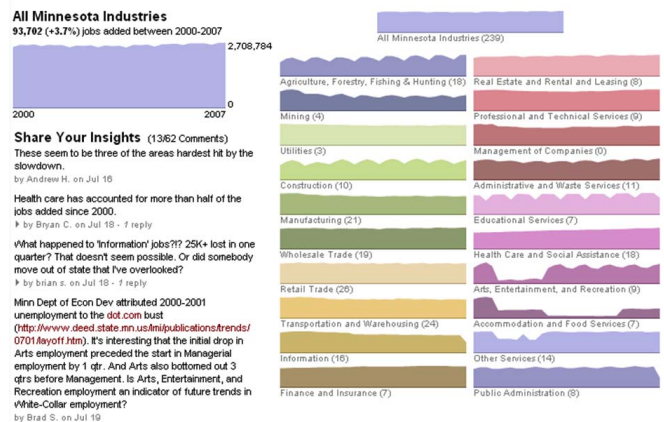


Fig. 6. Minnesota Employment Explorer. Minnesota Public Radio.

The goal of the visualization was to engage readers in finding and telling their own stories in the data. It was hoped that residents in various occupations would engage in social data analysis [15], sharing expertise from their respective industries. Despite good intentions, the visualization largely failed in this goal. A total of 23 people submitted 62 comments, with 25 of these comments being posted by the producers of the visualization. Other guests pointed out trends of interest and shared pointers to other related data sets; for example, a registered nurse shared his first-hand experiences in the Health sector. However, the majority of posters were not citizens of Minnesota; they were visualization and statistics enthusiasts drawn by the technology (the piece was mentioned on a popular visualization blog) and not by the story.

A post-mortem analysis reveals multiple areas for improvement. Some issues revolve around usability: the visualization was placed below-the-fold on the web site, and thus possibly overlooked by MPR readers. The visualization also lacked a **tacit tutorial**—it dropped readers into the data with little orientation and no example of a rich, emergent story. Seed comments served to highlight interesting patterns and raise questions, but did not develop a larger narrative.

Most importantly, the graphics are disconnected from the narrative. While unemployment statistics are topically relevant to the feature, they were not related to any of the other news stories. Moreover, only unemployment data from 2000-2007 was available from the state at that time—yet the main concern of the feature is the economic woes of 2008. Though the Employment Explorer was designed with the hopes of having people *annotate data with stories*, this example suggests that it may be more fruitful to first *annotate stories with data*. By immersing readers in a narrative and providing a tacit tutorial, readers may become invested in exploring new perspectives of a story—and perhaps branch out in search of new stories of their own.

4 DESIGN SPACE ANALYSIS

We seeded our choice of design space dimensions using related work in film, comics, and art. In particular, McCloud’s “Making Comics” [20] provides a robust taxonomy of visual elements that contribute to storytelling. Our ideas evolved as we analyzed more examples and observed emerging patterns. These observations allowed us to further organize the design features into increasingly coherent categories, such as genre types for narrative visualizations and different methods of integrating visualizations with accompanying text. Our final categories depict unique patterns for narrative visualization, distinguishing itself from other forms visual storytelling. For example, interactive visualizations allow users to manipulate the display, introducing design decisions that do not apply to non-interactive media.

We represent the design space in a table that relates each example to specific design strategies observed across the dataset. In total we analyzed 58 visualizations using the case study method illustrated in Section 3. The examples were taken from online journalism (71%), business (20%), and visualization research (9%). We optimized our

		Genre		Visual Narrative							Narrative Structure													
				Visual Structuring		Highlighting		Transition Guidance		Ordering		Interactivity		Messaging										
Visualization Description	Source	Magazine Style	Annotated Graph / Map	Partitioned Poster	Flow Chart	Comic Strip	Slide Show	Film / Video / Animation	Establishing Shot / Splash Screen	Consistent Visual Platform	Progress Bar / Timebar	"Checklist" Progress Tracker	Close-Ups	Feature Distinction	Character Direction	Motion	Audio	Zooming	Familiar Objects (but still cuts)	Viewing Angle	Viewer (Camera) Motion	Continuity Editing	Object Continuity	Animated Transitions
Architecture and Justice (Brooklyn Crime Blocks)	Columbia Univ. STL	+								+			+											
John Snow's Chart of Deaths from Cholera	Edward Tufte	+																						
Politicians Abuse their Free-mailing Privileges before Elec	Visual Complexity	+																						
Football Drawings	Washington Post	+																						
Pedestrians Crossing the Street	Visual Complexity	+																						
The Climate Agenda	Washington Post		+																					
When Did Your Country's Jobs Disappear?	Financial Times		+																					
Academics: House Price Index	Financial Times		+																					
Bank's Earnings: How Compensation Relates to Performa	Financial Times		+																					
Deadly Offensive: Taliban Attacks in Pakistan	Financial Times		+																					
GDP Moves by Sector	Financial Times		+																					
UK Economic Data	Financial Times		+																					
Budget 2010: Reaction from around the UK	Guardian		+																					
Formula One 2010: Driver's Rankings	Guardian		+																					
Lighting Up Hadrian's Wall	Guardian		+																					
Mapping Hydropower: Hotspots across the UK	Guardian		+																					
Moscow Metro Bombs: Interactive map	Guardian		+																					
The World Economy Turns the Corner	Guardian		+																					
Minnesota Employment Explorer	Minnesota Public Radio		+																					
A Map of Olympic Medals	New York Times		+																					
All of Inflation's Little Parts	New York Times		+																					
Paths to the Top of the Home Run Charts	New York Times		+																					
The Ebb and Flow of Movies: Box Office Receipts 1986 -	New York Times		+																					
The Jobs Rate for People Like You	New York Times		+																					
Advertisement: Bus	United Technology		+																					
Advertisement: Helicopter	Washington Post		+																					
Analyzing Obama's Schedule	Guardian		+																					
Oscars 2010: The Best Picture Nominees	Guardian		+																					
The Consumer and Retail Price Indices since 2006	Guardian		+																					
UK Voting Intentions	Guardian		+																					
Comparison of Bear Markets	New York Times		+																					
Faces of the Dead	New York Times		+																					
How Americans Spend Their Day	New York Times		+																					

collection to include visualizations that contained clear sequences of narrative events, a diversity of visualization genres (e.g., flow charts, slide shows), and a range of interaction strategies (e.g., filtering, time-lines). Using these criteria, we sampled from our initial larger pool of examples to arrive at the resulting 58 items featured in Fig. 7. However, we do not claim that our sample is exhaustive, as we did not canvas other potential sources such as video games or e-learning tools.

The table uses dark blue and a plus-sign (+) to indicate the presence of a particular feature; light blue and a minus-sign (-) indicate that an example does not use that feature. In some cases a cell is colored grey to indicate that a design feature is precluded by the medium rather than omitted by explicit design choices. For instance, we did not analyze visualizations on printed paper with respect to interaction or animation. That said, some workarounds to medium limitations are possible: comics can use a multi-panel series of increasing close-ups to convey the same effect as camera zoom [20], and static visualizations might employ a choose-your-own-adventure format to allow viewers to determine their own path through the content.

We arrived at our categories after much iterative organization (e.g., affinity diagramming [11]) of individual design features. We attempted to be consistent in our evaluation of each example. As our categories evolved, we reconsidered previous examples, re-categorizing as appropriate. We acknowledge there is some inevitable subjectivity when imposing a taxonomy over a diverse set of designs.

4.1 Design Space Dimensions

Our organization of the design space contains three divisions of features: (1) genre, (2) visual narrative tactics, and (3) narrative structure tactics. The first division identifies the *genre* of each visualization, a taxonomy of visual narrative types described later in section 4.3.

The second division identifies *visual narrative* tactics: visual devices that assist and facilitate the narrative. This division is subdivided into three sections: (i) visual structuring, (ii) highlighting, and (iii) transition guidance. *Visual structuring* refers to mechanisms that communicate the overall structure of the narrative to the viewer and allow him to identify his position within the larger organization of the visualization. These design strategies help orient the viewer early on (establishing shot, checklist, consistent visual platform) and allow the viewer to track his progress through the visualization (progress bar, timeline slider). *Highlighting* refers to visual mechanisms that help direct the viewer's attention to particular elements in the display. This can be achieved through the use of color, motion, framing, size, audio, and more, which augment the salience of an element relative to its surroundings. Many of these strategies are also used in film, art, and comics. *Transition guidance* concerns techniques for moving within or between visual scenes without disorienting the viewer. A common technique from film is continuity editing, though other strategies (e.g., animated transitions, object continuity, camera motion) also exist.

The third division identifies *narrative structure* tactics used by each visualization, or non-visual mechanisms that assist and facilitate the narrative. This division is further divided into three sections: (i) ordering, (ii) interactivity, and (iii) messaging. *Ordering* refers to the ways of arranging the path viewers take through the visualization. Sometimes this path is prescribed by the author (linear), sometimes there is no path suggested at all (random access), and other times the user must select a path among multiple alternatives (user-directed). *Interactivity* refers to the different ways a user can manipulate the visualization (filtering, selecting, searching, navigating), and also how the user learns those methods (explicit instruction, tacit tutorial, initial configuration). Finally, *messaging* refers to the ways a visualization communicates observations and commentary to the viewer. This might be achieved through short text fields (labels, captions, headlines, annotations) or more substantial descriptions (articles, introductions, summaries).

4.2 Design Space Observations

Three important patterns stand out from the data: (1) the clustering of different ordering structures, (2) the consistency of interaction design, and (3) the under-utilization of narrative messaging.

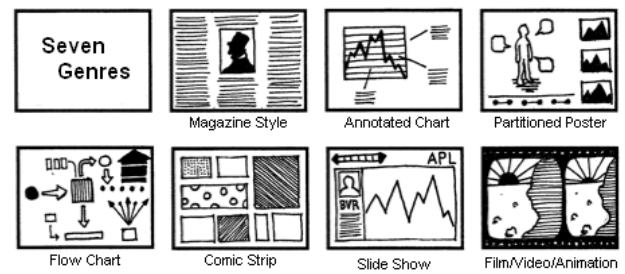


Fig. 8. Genres of Narrative Visualization.

The first pattern can be observed by the clusters of dark blue in the ordering section, suggesting clear differences between how visualizations guide the viewer through their content (Figure 7(1)). These clusters correspond to narrative formats such as slide shows, comic strips, annotated graphs, and others. We use these ordering types to identify distinct genres of visual narratives in Section 4.3.

The second pattern highlights the consistency in interaction design choices made by visualizations. Across the examples, we see the same interactive techniques being used (Figure 7(2)): hover highlighting and details-on-demand, limited interactivity, explicit instruction for interactive functionality, and navigation buttons when the visualization contains more than one frame (e.g., slideshows). The table also shows the consistent under-utilization of “tacit tutorials” and “stimulating default views” (Figure 7(3)). Tacit tutorials introduce a visualization’s interactive functionality by animating the interactive components along with the presentation to make it clear how to manipulate the display. As a result, the user becomes familiar with the interactive capabilities of the visualization without requiring explicit instructions. Stimulating default views provide initial presentations of data and analysis intended to excite the user, a device analogous to journalistic leads. These views can then be used as jumping off points for further exploration. Both these techniques can be seamlessly incorporated into the visualization’s design while simultaneously engaging the user in the interactive functionality.

The third pattern shows the under-utilization of common narrative messaging techniques such as repetition of key points, introductory texts, and final summaries and syntheses (Figure 7(4)). In particular, the data shows that interactive graphs do not include sufficient commentary for narrative purposes, with little use of repetition, multi-messaging (i.e., text, images, and audio working together), or annotations to emphasize key observations from the data. Note that narrative messaging techniques are more frequently used in Slideshows and Videos, as these genres put more effort into communicating the narrative intended by the author. This may explain why qualitatively these visualizations feel more like “stories” and less like data tools.

4.3 Genres of Narrative Visualization

We found that our examples can be characterized by the 7 basic *genres* shown in Figure 8: magazine style, annotated chart, partitioned poster, flow chart, comic strip, slide show, and film/video/animation. These genres vary primarily in terms of (a) the number of frames—distinct visual scenes, multiplexed in time and/or space—that each contains, and (b) the ordering of their visual elements. For example, an image embedded in a page of text (“magazine style”) has only a single frame, while a comic may have many frames. A multi-view visualization (“partitioned poster”) may suggest only a loose order to its images, while a comic strip tends to follow a strict linear path.

These genres are not mutually exclusive: they can function like building blocks, combining to produce more complex visual genres. The Barry Bonds visualization (§3.1) is part Partitioned Poster and part Flow Chart, presenting multiple images simultaneously while using Flow Chart tactics to suggest a path to the viewer. Both the Budget Forecast (§3.2) and the Gapminder (§3.4) examples use Annotated Graphs but within a Slide Show format.

Though each of these genres can be used to tell a story, we note that different genres work better for different story types. Choosing the appropriate genre depends on a variety of factors, including the

Table 1. Properties of Author-Driven and Reader-Driven Stories. Most visualizations lie along a spectrum between these two extremes.

Author-Driven	Reader-Driven
Linear ordering of scenes	No prescribed ordering
Heavy messaging	No messaging
No interactivity	Free interactivity

complexity of the data, the complexity of the story, the intended audience, and the intended medium. There are clear cases in which a genre is more appropriate for a particular purpose. Business presentations typically use Slide Shows instead of Comic Strips, and television commercials use Videos instead of Flow Charts. These are common and intuitive cases, but not all instances are so clear cut. For example, it is not obvious whether students might learn best from a Slide Show or a Video or even a Comic Strip. The right choice also depends on the content being presented and the students' background. In general, there will be no "right answer" *a priori*, but several possible candidates, each with advantages and disadvantages.

Both messaging and interactivity can be layered on top of these genres. Messaging is the use of text to provide observations and explanations about the images. Typically this text takes familiar forms such as headlines, captions, labels, and annotations. For some visualizations, messaging can also include audio. Note that messaging is optional for any of the genres above, and can vary widely between instances of the same genre. Interactivity allows the visualization to be manipulated by the viewer. There are many possible types and degrees of interactivity, though common forms in narrative visualization include navigation buttons, hover highlighting, hover details-on-demand, filtering, searching, drill-down, zooming, and time sliders. Importantly, the appropriate use of messaging and interactivity will depend on a variety of factors. Messaging might clarify visual elements but produce clutter. Interactivity might engage the user but detract from the author's intended message. Again, these tradeoffs require context-specific consideration and judgment.

4.4 Balancing Author-Driven and Reader-Driven Stories

The visual narrative genres, together with interaction and messaging, must balance a narrative intended by the author with story discovery on the part of the reader. We thus place narrative visualizations along a spectrum of **author-driven** and **reader-driven** approaches (Table 1).

A purely author-driven approach has a strict linear path through the visualization, relies heavily on messaging, and includes no interactivity. Examples include film and non-interactive slideshows. A strongly author-driven approach works best when the goal is storytelling or efficient communication. We see this approach used in comics, art, cinema, commercials, business presentations, educational videos, and training materials.

A purely reader-driven approach has no prescribed ordering of images, no messaging, and a high degree of interactivity. Examples include visual analysis tools like Tableau or Spotfire. A reader-driven approach supports tasks such as data diagnostics, pattern discovery, and hypothesis formation.

Historically, many visualizations fall into the author-driven or reader-driven dichotomy. However, as we have seen throughout our case studies, most examples of narrative visualization fall somewhere in-between, and an important attribute of narrative visualization is its flexibility in balancing both elements. Visualizations are increasingly striking a balance between the two approaches, providing room for limited interactivity within the context of a more structured narrative. This is a relatively recent development, with most mainstream examples coming from online journalism.

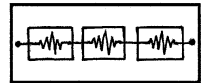
All the interactive examples in our dataset use a mix of the author-driven and reader-driven approaches. Despite the range of possible combinations, a few hybrid models have become most common. Below we discuss three common schemas. The first structure prioritizes the author-driven approach, the second structure promotes a dialogue between the two approaches, while the third structure prioritizes the reader-driven approach.

4.4.1 Martini Glass Structure



The Martini Glass visualization structure begins with an author-driven approach, initially using questions, observations, or written articles to introduce the visualization. Occasionally no text is used at all, as the visualization instead relies on an interesting default view or annotations. Once the author's intended narrative is complete, the visualization opens up to a reader-driven stage where the user is free to interactively explore the data. The structure resembles a martini glass, with the stem representing the single-path author-driven narrative and the widening mouth of the glass representing the available paths made possible through reader-driven interactivity. Using this image, we can think of varying degrees of authoring (question, observation, article) as corresponding to different stem types (short, long), and varying degrees of readership (highlighting, filtering, path-choosing) corresponding to different mouth shapes. With all these permutations, the general structure remains intact, with the author-driven narrative functioning first, then followed separately by the reader-driven interactions. The authoring segment may function as a jumping off point for the reader's interaction, with questions, observations, and themes suggesting the types of issues a reader might explore on his own. This structure is the most common across the interactive visualizations we examined.

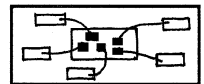
4.4.2 Interactive Slideshow



The Interactive Slideshow structure follows a typical slideshow format, but incorporates interaction mid-narrative within the confines of each slide. This structure allows the user to further explore particular points of the presentation before moving ahead to the next stage of the story. We saw this structure in both the Budget Forecasts (§3.2) and Gapminder (§3.4) case studies. Contrary to the martini glass, an interactive slideshow allows for interaction mid-narrative, a more balanced mix of author-driven and reader-driven approaches. However, individual slides often function in the martini glass style, again communicating author-intended messages prior to prompting the user to interact with the display.

Interactive slideshows work well with both complex datasets and narratives. For complex datasets, this structure allows the author to walk the user through data-dimensions and manipulations step-by-step. This ensures that the user only moves forward in the presentation when he is ready to do so, and allows the user to repeat steps if desired. For complex narratives, this format allows the author to draw discrete boundaries between different story segments, similar to a cut in film.

4.4.3 Drill-Down Story



The Drill-Down Story visualization structure presents a general theme and then allows the user to choose among particular instances of that theme to reveal additional details and backstories. For instance, the theme might be "Historical Bear Markets" [A31] and the visualization will allow the user to drill-down to a particular bear market to learn more about its history. Or a map showing "North Korean Prison Camps" [A38] may allow the user to learn more about individual camps by clicking on a specific location on the map. This structure puts more emphasis on the reader-driven approach, letting the user dictate what stories are told and when. Nevertheless, it still requires significant amounts of authoring to determine the possible types of user interaction, what candidate stories to include, and the details included for each story.

5 DISCUSSION

In this paper, we conducted a design space analysis of narrative visualization—visualizations intended to convey stories—based on a corpus of 58 collected examples from online journalism, graphic design, comics, business, art, and visualization research. Our analysis highlights visual and interactive devices that support storytelling with data, and we identify distinct genres of visualization using narrative structures such as the martini glass, interactive slideshow, and drill-down story. In particular, we note a central concern in the design of narrative visualizations: the balance between author-driven

elements—providing narrative structure and messaging—and reader-driven elements—enabling interactive exploration and social sharing. These results help identify successful design practices. By explicitly naming effective techniques (e.g., “tacit tutorials”, “semantic consistency”, “matching on content”) we hope to facilitate their reuse.

Narrative visualizations differ in important ways from traditional forms of storytelling. In journalism, one presents related material and sources together in a “block progression” to have clear and logical transitions, and digresses “often, but not for long” [2]. Interactive stories present difficulties for these recommendations, as giving narrative control to the reader permits lengthy unordered digressions. The design structures we identify help counter these pitfalls. Generalizing across our examples, data stories appear to be most effective when they have constrained interaction at various checkpoints within a narrative, allowing the user to explore the data without veering too far from the intended narrative. That said, further exploration of transitions between author- and reader-driven elements presents an exciting area for researchers and practitioners.

Our analysis also helps identify under-explored regions of the design space. For example, the “magazine style” genre is the most common genre for static visualizations, but has not been as richly utilized with interactive visualizations. How might multiple media be better integrated for storytelling? For example, a martini glass structure for a visualization may be weaved into a text story: static images might first support the text and introduce the visualization; an embedded interactive visualization may appear later, perhaps with links in the text setting visualization parameters to highlight points made within the prose; finally, at the article’s end, the visualization may open up to enable free exploration. Likewise, our data shows that interactivity is not yet common in flowcharts, comics, or videos, and that few visualizations currently use tacit tutorials or stimulating default views. In this manner, our framework facilitates reasoning about novel juxtapositions of genres and narrative devices.

As our understanding of narrative visualization improves, it also opens up new opportunities for visualization tool research. How should we extend visual analysis applications to enable storytelling? Interfaces that combine visualization construction with the specification of narrative structure, textual/graphical annotation, visual highlighting techniques, transitions, and interactive controls could have a transformative impact on the medium, so long as they can be used by data domain experts, not just technology experts. We believe that our results identify important features for these future tools. By identifying recurring design patterns, we hope to help catalyze novel tools and explorations of narrative visualization.

However, we must acknowledge that we are not experts in the study of narrative. Rather, we are visualization designers and technologists seeking to better understand the potential of the medium. Inevitably, there is much that remains to be understood. For instance, what mix of author-driven and reader-driven elements is best for different purposes? How does this vary based on the data at hand, the desired story form, and the audience? How critical is it to provide either explicit instruction or tacit tutorials to introduce interactive features? Will these elements become less necessary as viewers become more accustomed to narrative visualization? The topic is ripe for future work, and would further benefit from the input of artists, educators, and journalists.

By investigating the narrative devices used in a corpus of visualizations, our analysis has focused primarily on the design decisions made by visualization creators. A promising direction for future research is to focus squarely on readers’ experiences when viewing and interacting with narrative visualizations. Eye-tracking studies of newspaper reading [11, 16] have found that readers regularly skim by scanning graphics, headlines, and initial paragraphs before intermittently stopping to read an article. Based on these results, Garcia & Stark [11] define newspaper design as the challenge “to give readers material that is worthy of their scan, that makes them stop scanning and start reading.” How do such behaviors apply to visualization? Further research is needed to characterize how readers perceive narratives presented via visualizations. Such studies could provide insights for design, such as how viewers might best “skim” a narrative visualization.

A related topic is reader engagement. The examples we analyzed tended to have “hard leads”—brief summaries describing the content of the visualization—whereas journalism often adopts more mysterious leads [2] to promote engagement. How can “stimulating default views” for visualizations best capture readers’ attention and personally engage them in the world of the narrative? Moreover, narrative visualizations put data at the forefront of storytelling, yet others [2, 7] have noted that a myopic focus on data may be a stumbling block to narrative flow and reader engagement. The strategies discussed above suggest ways to incorporate statistics in concert with narrative, potentially enhancing readers’ engagement with data. As Blundell [2] notes, “We’re supposed to be tellers of tales as well as purveyors of facts. When we don’t live up to that responsibility we don’t get read.”

ACKNOWLEDGMENTS

The authors thank Sarah Cohen, Len de Groot, Andrew Haeg, Geoff McGhee, and anonymous reviewers for their constructive feedback.

REFERENCES

- [1] H. Beyer and K. Holtzblatt. *Contextual Design: Defining Customer-Centered Systems*. Morgan Kaufmann, 1998.
- [2] W. E. Blundell. *The Art & Craft of Feature Writing*. Plume, 1988.
- [3] D. Bordwell and K. Thompson. *Film Art: An Introduction*. McGraw-Hill, 2003.
- [4] S. Buttry. The Elements and Structure of Narrative. <http://www.notrain-nogain.org/train/Res/write/sbnar.asp>, 2010.
- [5] J. Campbell. *The Hero with a Thousand Faces*. New World Library, 1949.
- [6] K. Cukier. Show Me: New ways of visualising data. <http://www.economist.com/node/15557455>, 2010.
- [7] L. Danzico. Telling stories using data: An interview with Jonathan Harris. <http://bit.ly/jh-int>, 2008.
- [8] R. Eccles, T. Kapler, R. Harper, and W. Wright. Stories in geotime. In *IEEE VAST*, pages 19–26, 2007.
- [9] P. Farhi. CNN hits the wall for the election. <http://bit.ly/cnn-wall>, 2008.
- [10] Gapminder. <http://www.gapminder.org>, 2010.
- [11] M. R. Garcia and P. Stark. *Eyes on the News*. The Poynter Institute, 1991.
- [12] N. Gershon and W. Page. What storytelling can do for information visualization. *Commun. ACM*, 44(8):31–37, 2001.
- [13] J. Heer, J. Mackinlay, C. Stolte, and M. Agrawala. Graphical histories for visualization: Supporting analysis, communication, and evaluation. *IEEE Trans. Vis. and Comp. Graphics*, 14(6):1189–1196, 2008.
- [14] J. Heer and G. G. Robertson. Animated transitions in statistical data graphics. *IEEE Trans. Vis. and Comp. Graphics*, 13(6):1240–1247, 2007.
- [15] J. Heer, F. B. Viégas, and M. Wattenberg. Voyager and voyeurs: Supporting asynchronous collaborative information visualization. In *Proc. ACM CHI*, pages 1029–1038, 2007.
- [16] K. Holmqvist, J. Holsanova, M. Barthelson, and D. Lundqvist. Reading or scanning? a study of newspaper and net paper reading. In J. R. Hyönä and H. Deubel, editors, *The Mind’s Eye: Cognitive and Applied Aspects of Eye Movement Research*, pages 657–670. Elsevier, 2003.
- [17] L. Itti and C. Koch. Computational modeling of visual attention. *Nature Reviews Neuroscience*, 2(3):194–203, 2001.
- [18] G. Kress and T. van Leeuwen. *Reading Images: The Grammar of Visual Design*. Routledge, 1996.
- [19] S. McCloud. *Understanding Comics*. Kitchen Sink Press, 1993.
- [20] S. McCloud. *Making Comics*. Harper, 2006.
- [21] G. Polti. *The thirty-six dramatic situations*. The Editor Company, 1916.
- [22] Tableau Public. <http://tableausoftware.com/public>, 2010.
- [23] A. M. Treisman and G. Gelade. A feature-integration theory of attention. *Cognitive Psychology*, 12(1):97–136, 1980.
- [24] B. Tversky, J. Heiser, S. Lozano, R. MacKenzie, and J. Morrison. Enriching animations. In R. Lowe and W. Schnotz, editors, *Learning with animation*. Cambridge University Press, 2007.
- [25] F. B. Viégas, M. Wattenberg, F. van Ham, J. Kriss, and M. McKeon. Many Eyes: a site for visualization at internet scale. *IEEE Trans. Vis. and Comp. Graphics*, 13(6):1121–1128, 2007.
- [26] C. Ware. *Information visualization: perception for design*. Morgan Kaufmann, San Francisco, CA, 2004.
- [27] W. Wojtkowski and W. G. Wojtkowski. Storytelling: its role in information visualization. In *European Systems Science Congress*, 2002.

APPENDIX: NARRATIVE VISUALIZATION EXAMPLES

- [1] E. Cadora and L. Kurgan. Architecture and Justice (Brooklyn Crime Blocks). Columbia University's Spatial Information Design Lab, 2006. http://www.spatialinformationdesignlab.org/MEDIA/PDF_04.pdf.
- [2] E. Tufte. John Snow's Chart of Deaths from Cholera. Visual Display of Quantitative Information, 2001.
- [3] E. Tufte. Politicians Abuse their Free-mailing Privileges before Elections. Visual Display of Quantitative Information, 2001.
- [4] S. Rosenthal. Football Drawings. Visual Complexity. <http://www.susken-rosenthal.de/fussballbilder/indexen.html>.
- [5] T. Laureyssens. Pedestrians Crossing the Street. Unknown, 2005. http://www.visualcomplexity.com/vc/project_details.cfm?id=255&index=7&domain=Pattern%20Recognition.
- [6] W. Andrews, A. Cypress, J. Kazil, T. Lindeman, and K. Yourish. The Climate Agenda. The Washington Post. <http://www.washingtonpost.com/wp-srv/special/climate-change/global-emissions.html?ad=inv>.
- [7] C. Wilson. When Did Your County's Jobs Disappear? The Washington Post/Slate, 2009. <http://www.slate.com/id/2216238/?ad=ins>.
- [8] Acadametrics House Price Index. Financial Times. http://www.acadametrics.co.uk/house_prices_June10.swf.
- [9] S. Wheeler and S. Bernard. Banks' Earnings: How Compensation Relates to Performance. Financial Times, 2010. <http://www.ft.com/cms/s/0/4ce7a094-1c9e-11df-8456-00144feab49a.html>.
- [10] H. Warrell, C. Jones, and J. Thompson. Deadly Offensive: Taliban Attacks in Pakistan. Financial Times, 2009. <http://www.ft.com/cms/s/0/1ae8621b-b993-11de-abac-00144feab49a.html>.
- [11] R. Birkett. GDP Moves by Sector. Financial Times, 2010. <http://www.ft.com/cms/s/0/14cc2e70-04e6-11df-9a4f-00144feabdc0.html>.
- [12] V. Bevins and R. Birkett. UK Economic Data. Financial Times, 2010. <http://www.ft.com/cms/s/0/bd7b628c-2068-11df-bf2d-00144feab49a.html>.
- [13] P. Allen, J. Ridley, and C. Levene. Budget 2010: Reaction from around the UK. Guardian, 2010. <http://www.guardian.co.uk/interactive/2010/mar/24/budget-2010-case-studies-map>.
- [14] P. Allen. Formula One 2010: Driver's Rankings. Guardian, 2010. <http://www.guardian.co.uk/sport/interactive/2010/feb/02/formula1-championship-points-2010>.
- [15] C. Oliver and M. Wainwright. Lighting Up Hadrian's Wall. Guardian, 2010. <http://www.guardian.co.uk/culture/interactive/2010/mar/12/hadrians-wall-lights-500-torches>.
- [16] Mapping Hydropower Hotspots across the UK. Guardian, 2010. <http://www.guardian.co.uk/environment/interactive/2010/mar/09/map-hydropower-hotspots-uk>.
- [17] P. Allen. Moscow Metro Bombs: Interactive Map. Guardian, 2010. <http://www.guardian.co.uk/world/interactive/2010/mar/29/moscow-metro-bombs-terror-map>.
- [18] C. Oliver. The World Economy Turns the Corner. Guardian, 2010. <http://www.guardian.co.uk/business/interactive/2010/jan/26/recession-gdp>.
- [19] J. Heer, A. Haeg, and M. Agrawala. Minnesota Employment Explorer. Minnesota Public Radio, 2007. http://minnesota.publicradio.org/projects/2008/07/16_minnesota_slowdown/.
- [20] L. Byron, A. Cox, and M. Ericson. A Map of Olympic Medals. The New York Times, 2008. http://www.nytimes.com/interactive/2008/08/04/sports/olympics/20080804_MEDALCOUNT_MAP.html.
- [21] M. Bloch, S. Carter, A. Cox, and J. Ward. All of Inflation's Little Parts. The New York Times, 2008. http://www.nytimes.com/interactive/2008/05/03/business/20080403_SPENDING_GRAPHIC.html.
- [22] S. Carter and A. Cox. Paths to the Top of the Home Run Charts. The New York Times, 2007. http://www.nytimes.com/ref/sports/20070731_BONDS_GRAPHIC.html.
- [23] M. Bloch, L. Byron, S. Carter, and A. Cox. The Ebb and Flow of Movies: Box Office Receipts 1986-2008. The New York Times, 2008. http://www.nytimes.com/interactive/2008/02/23/movies/20080223_REVENUE_GRAPHIC.html.
- [24] S. Carter, A. Cox, and K. Quealy. The Jobless Rate for People Like You. The New York Times, 2009. <http://www.nytimes.com/interactive/2009/11/06/business/economy/unemployment-lines.html>.
- [25] Advertisement: Bus. United Technology. http://www.pewclimate.org/docUploads/UTC_fuel_cell%20ad_0.pdf.
- [26] Advertisement: Helicopter. United Technology. http://farm4.static.flickr.com/3030/2572980233_0339ee260a.jpg.
- [27] N. V. Kelso, M. Lebling, K. Yourish, R. O'Neil, W. Andrews, J. Kazil, T. Lindeman, L. Shackelford, and P. Volpe. Analyzing Obama's Schedule. The Washington Post, 2010. <http://projects.washingtonpost.com/potus-tracker/?ad=inv>.
- [28] X. Brooks and C. Oliver. Oscars 2010: The Best Picture Nominees. Guardian, 2010. <http://www.guardian.co.uk/film/filmblog/interactive/2010/mar/03/oscars-2010-best-picture-nominees>.
- [29] P. Allen. The Consumer and Retail Price Indices since 2006. Guardian, 2010. <http://www.guardian.co.uk/business/interactive/2009/mar/24/rpi-inflation>.
- [30] P. Allen, J. Glover, and W. Woodward. UK Voting Intentions. Guardian, 2010. <http://www.guardian.co.uk/politics/interactive/2009/jan/26/icm-polls-uk-voting-intention>.
- [31] A. Cox, X. G.V., and D. Leonhardt. Comparison of Bear Markets. The New York Times, 2008. http://www.nytimes.com/interactive/2008/10/11/business/20081011_BEAR_MARKETS.html.
- [32] G. Dance, A. Pilhofer, A. Lehren, and J. Damens. Faces of the Dead. The New York Times, 2010. <http://www.nytimes.com/interactive/us/faces-of-the-dead.html>.
- [33] S. Carter, A. Cox, K. Quealy, and A. Shoenfeld. How Americans Spend their Day. The New York Times, 2009. <http://www.nytimes.com/interactive/2009/07/31/business/20080801-metrics-graphic.html?ref=multimedia>.
- [34] G. Dance and E. Goodridge. Michelle Obama's Family Tree. The New York Times, 2009. <http://www.nytimes.com/interactive/2009/10/08/us/politics/20091008-obama-family-tree.html?ref=multimedia>.
- [35] M. Bloch, A. Cox, J. C. McGinty, and K. Quealy. Netflix Rentals. The New York Times, 2010. <http://www.nytimes.com/interactive/2010/01/10/nyregion/20100110-netflix-map.html?ref=multimedia>.
- [36] Steroids or Not, the Pursuit is On. The New York Times, 2006.
- [37] S. Carter, M. Ericson, and J. Ward. Vancouver's Olympic Venue. The New York Times, 2010. <http://www.nytimes.com/interactive/2010/02/09/sports/olympics/2010-olympics-venue-map.html?ref=multimedia>.
- [38] K. Downs, B. Harden, L. Heron, L. Karklis, and F. Uenuma. On the Map: Five Major North Korean Prison Camps. The Washington Post. <http://www.washingtonpost.com/wp-srv/special/world/north-korean-prison-camps-2009/?ad=inv>.
- [39] S. Anderson, G. Calabro, and M. H. and Ryan Thornburg. Spheres of Influence: The Bush Campaign Pioneers. The Washington Post, 2004. http://www.washingtonpost.com/wp-srv/politics/pioneers/pioneers_spheres.html.
- [40] J. Bachman. A Visual Guide to the Financial Crisis. Flowing Data, 2008. <http://flowingdata.com/2008/11/25/visual-guide-to-the-financial-crisis/>.
- [41] P. S. Ng. Economic Meltdown of 2008-2009. Flowing Data, 2008. <http://bit.ly/SBAAb>.
- [42] E. Klimiuk. Where Did All the Money Go? Flowing Data, 2008. <http://bit.ly/SBAAb>.
- [43] E. Tufte. Life Cycle of a Beetle through a Year. Visual Display of Quantitative Information, 2001.
- [44] S. McCloud. Making Comics, 2006.
- [45] M. Green, H. Warrell, S. Tarling, S. Bernard, and M. Formentini. Afghanistan: Behind the Front Line. Financial Times, 2009. <http://www.ft.com/cms/s/0/663b649e-b7e6-11de-8ca9-00144feab49a.html>.
- [46] J. Soble. Toyota Timeline: A Company History. Financial Times, 2010. <http://www.ft.com/cms/s/0/1f8f077c-2301-11df-a25f-00144feab49a.html>.
- [47] Gapminder. Gapminder Human Development. Gapminder, 2005. <http://www.gapminder.org/downloads/human-development-trends-2005/>.
- [48] P. Allen. Earthquakes: Why They Happen. Guardian, 2010. <http://www.guardian.co.uk/world/interactive/2008/jan/23/earthquakes>.
- [49] G. N. Guardian Science Team. Iran's Nuclear Programme. Guardian, 2010. <http://www.guardian.co.uk/world/interactive/2003/jun/19/iran>.
- [50] Shaun White's Double McTwist. Guardian, 2010. <http://www.guardian.co.uk/sport/interactive/2010/feb/19/winterolympics2010-vancouver>.
- [51] P. Allen and G. News. Toyota's Stick Accelerator Problem. Guardian, 2010. <http://www.guardian.co.uk/business/interactive/2010/feb/04/toyota-automotive-industry>.
- [52] J. Ward, S. Carter, G. Roberts, X. G. V., M. Gröndahl, K. Quealy, and A. Cox. Alpine Skiing, from Technical Turns to Tucks and Speed. The New York Times, 2010. <http://www.nytimes.com/interactive/2010/02/20/sports/olympics/downhill-overview.html?ref=multimedia>.
- [53] A. Cox. Budget Forecasts vs. Reality. The New York Times, 2010. <http://www.nytimes.com/interactive/2010/02/02/us/politics/20100201-budget-porcupine-graphic.html>.
- [54] K. Quealy, G. Roth, and R. Schneiderman. How the Government Dealt with Past Recessions. The New York Times, 2009. <http://www.nytimes.com/interactive/2009/01/26/business/economy/20090126-recessions-graphic.html>.
- [55] Mac Orientation Video. Apple. <http://www.apple.com/findouthow/mac/#anatomy>.
- [56] Delta Airplane Safety Video. Delta Airlines, 2008. http://www.youtube.com/watch?v=MgpZUo_kbFY.
- [57] A. Leonard. The Story of Stuff. Story of Stuff Project, 2008. <http://www.storyofstuff.com/>.
- [58] WILDBRAIN. Virgin America Airplane Safety Video. Virgin America, 2007. <http://www.youtube.com/watch?v=eyygn8HFTCo&feature=channel>.