Storytelling and Visualization: A Survey

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Abstract: Throughout history, storytelling has been an effective way of conveying information and knowledge. In the field of visualization, storytelling is rapidly gaining momentum and evolving cutting-edge techniques that enhance understanding. Many communities have commented on the importance of storytelling in data visualization. Storytellers tend to be integrating complex visualizations into their narratives in growing numbers. In this paper, we present a survey of storytelling literature in visualization and present an overview of the common and important elements in storytelling visualization. We also describe the challenges in this field as well as a novel classification of the literature on storytelling in visualization. Our classification scheme highlights the open and unsolved problems in this field as well as the more mature storytelling sub-fields. The benefits offer a concise overview and a starting point into this rapidly evolving research trend and provide a deeper understanding of this topic.

1 INTRODUCTION AND MOTIVATION

"We believe in the power of science, exploration, and storytelling to change the world" - Susan Goldberg, Editor in Chief of National Geographic Magazine, from "The Risks of Storytelling", October 2015 [Goldberg, 2015].

"In a world increasingly saturated with data and information, visualizations are a potent way to break through the clutter, tell your story, and persuade people to action" [Singer, 2014]. -Adam Singer, Clickz.com, "Data Visualization: Your Secret Weapon in Storytelling and Persuasion", October 2014.

Throughout history, storytelling has been an effective way of conveying information and knowledge [Lidal et al., 2013]. In the field of visualization, storytelling is rapidly developing techniques that enhance understanding. Many communities have commented on the importance of storytelling in data visualization [Segel and Heer, 2010]. Storytellers tend to be integrating complex visualizations into their narratives in growing numbers.

As contributions, we present a survey reviewing storytelling papers in visualization and present an overview of the common and important elements in storytelling visualization. We also describe the challenges in this field and present a novel classification of the literature on storytelling in visualization. Our classification highlights both mature and unsolved problems in this area. The benefit is a concise overview and valuable starting point into this rapidly growing and evolving research trend. Readers will also gain a deeper understanding of this rapidly evolving research direction.

Definition and Storytelling Elements Story can be defined as "a narration of the events in the life of a person or the existence of a thing, or such events as a subject for narration" [Reference, a] or "a series of events that are or might be narrated" [Dictionary, a]. Storytelling is a popular concept that is used in many fields, such as media [Segel and Heer, 2010], education [Zipes, 2013] and entertainment [Schell, 2008]. Storytelling is a technique used to present dynamic relationships between story nodes through interaction. According to Zipes [Zipes, 2013], storytelling can involve animation and self-discovery, incorporating models, ethical principles, canons of literature, and social standards. In education, a storyteller can improve and strengthen the literacy of students. Also, the storyteller can engage audiences so they feel a desire to read, write, act, and draw. Audience members can learn to express themselves critically and imaginatively with techniques they may learn from the storyteller or teacher.

Classification of Literature and Challenges in Storytelling and Visualization Although storytelling has been developing in other fields for years, storytelling is a relatively new subject in visualization. As such, it faces many challenges. In this survey we have extracted the fundamental characteristics of storytelling both as an entity and as a creative process. Our literature classification is based on the logical notions of *who are the main subjects involved in storytelling for visualization* (authorship and audience), *how are stories told* (narratives and transitions), *why can we use storytelling for visualization* (memorability and interpretation). From these characteristics we have then developed the following dimensions which are common to storytelling in visualization.

Authoring-Tools: Authorship addresses *who* creates the story and narrative. Authorship commonly refers to the state or fact of being the writer of a book, article, or document or the creator of a work of art [Dictionary, b] and its source or origin [Reference, b]. Central to this definition is the writer or author. Rodgers [Rodgers, 2011] defines an author as "an individual solely responsible for the creation of a unique body of work."

User-engagement: Engagement is about the audience and also concerns *why* we use storytelling. How can we ensure that the message comes across to the audience? Can we measure engagement?

Narratives: Narrative concerns *how* an author tells a story. Narrative structures include events and visualization of characters. Narrative visuals contain the transition between events. This entails, "Using a tool to visually analyze data and to generate visualizations via vector graphics or images for presentation," and then deciding "how to thread the representations into a compelling yet understandable sequence." [Hullman et al., 2013b]

Transitions: Transitions are about *how* authors may tell the story. Transitions seamlessly blend events within a story and are key to its flow. Successful transitions vary actions as little as possible to strengthen overall coherence. Transitions in visualization can be either dynamic or static.

Memorability: Memorability addresses *why* authors present data in the form of a story. Memorability is an important goal of storytelling. A good visualization technique draws the viewer's attention and increase a story's memorability [Bateman et al., 2010].

Interpretation: Data interpretation refers to the process of critiquing and determining the significance of important data and information, such as survey results, experimental findings, observations or narrative reports.

When examined in the context of storytelling in visualization each dimension raises interesting questions: Are current storytelling platforms taking into account the role of the author and supporting the authorship process? What forms of narrative structures and visuals best apply to storytelling in visualization? Are static transitions or dynamic transitions more effective for storytelling in visualization? Can visualization increase the memorability of data information or knowledge? Does storytelling and visualization aid with data interpretation? What is the most effective way to engage an audience? Data preparation and enhancement is another challenge for which there is currently no literature. Thus we include it as a future research direction but not in our classification.

Starting from the logical notions of who, how, why, and these open questions we have chosen these dimensions to form the basis of our literature classification on storytelling in visualization. See Table 1. It is important to note that some papers address multiple topics in Table 1 and in our classification. We placed papers in what we determined to be the main focus on element of the paper. This is very useful for obtaining an overview. However some papers address more than one theme, e.g. authorship and narratives.

Classification of Literature: the Second Dimension In addition, the literature is also classified by the ordering or sequence of events, which refers to the traversal the path viewer takes through the visualization. This dimension is adapted from Segal and Heer [Segel and Heer, 2010]. It forms our second categorization for Table 1. The classification includes:

Linear: A story sequence path in linear order is prescribed by the author.

User-directed path: The user selects a path among multiple alternatives or creates their own path.

Parallel: several paths can be traversed or visualized at the same time.

Random access or other: There is no prescribed path. There is currently no literature prescribing random order. Therefore we replace this with a column called "overview".

Literature Search Methodology We search both the IEEE and ACM Digital libraries for the terms "storytelling", "narrative visualization", "memorability", "transitions in visualization", "user-engagement", and various combinations of these phrases. We focus primarily on the IEEE TVCG papers. We check the references of each paper and looked for related literature on storytelling. We also

Table 1: Our classification of the storytelling literature. The y-axis categories fall into who-authoring-tools and user-engagement, how-narrative and transitions, why-memorability and interpretation. See section 1 and 1 for a complete description. See table 2 in the appendix for an alternative classification.

		Linear	User-directed/Interactive	Parallel	Overview
Who	Authoring-Tools	Gershon et al. 2001 [Gershon and Page, 2001] Lu and Shen, 2008 [Lu and Shen, 2008] Cruz et al. 2011 [Cruz and Machado, 2011]	Wohlfart, 2006 [Wohlfahrt, 2006] Wohlfart et al. 2007 [Wohlfahrt and Hauser, 2007] Lidal et al. 2012 [Lidal et al., 2012] Lee et al. 2013 [Lee et al., 2013] Lidal et al. 2013 [Lidal et al., 2013] Lundblad et al. 2013 [Lundblad and Jern, 2013] Fulda et al. 2016 [Fulda et al., 2016] Amini et al. 2017 [Amini et al., 2017]	Eccles et al. 2007 [Eccles et al., 2008] Kuhn et al. 2012 [Kuhn and Stocker, 2012]	
	User Engagement		Figueiras, 2014 [Figueiras, 2014a] Boy et al 2016 [Boy et al., 2015] Borkin et al,2016 [Borkin et al., 2016]		Mahyar et al.,2015 [Mahyar et al., 2015]
How	Narrative	Hullman et al. 2013 [Hullman et al., 2013a] Hullman et al. 2013 [Hullman et al., 2013b] Gao et al. 2014 [Gao et al., 2014] Amini et al. 2015 [Amini et al., 2015] Bach et al. 2016 [Bach et al., 2016]	Viegas et al. 2004 [Viégas et al., 2004] Hullman et al. 2011 [Hullman and Diakopoulos, 2011] Figueiras, 2014 [Figueiras, 2014a] Figueiras, 2014 [Figueiras, 2014b] Nguyen et al, 2014 [Nguyen et al., 2014] Satyanarayan et al. 2014 [Satyanarayan and Heer, 2014] Gratzl et al. 2016 [Gratzl et al., 2016]	Akashi et al. 2007 [Akaishi et al., 2007] Fisher et al. 2008 [Fisher et al., 2008] Hullman et al. 2011 [Hullman and Diakopoulos, 2011] Bryan et al. 2017 [Bryan et al., 2017]	Segel and Heer, 2010 [Segel and Heer, 2010] Lee et al. 2015 [Lee et al., 2015]
	Static Transitions		Ferreira et al. 2013 [Ferreira et al., 2013]	Robertson, 2008 [Robertson et al., 2008] Chen et al. 2012 [Chen et al., 2012] Tanhashi et al. 2012 [Tanahashi and Ma, 2012] Liu et al. 2013 [Liu et al., 2013] Ferreira et al. 2013 [Ferreira et al., 2013]	
	Animated Transitions	Heer et al. 2007 [Heer and Robertson, 2007] Liao et al. 2014 [Liao et al., 2014]	Bederson and Boltman, 1999 [Bederson and Boltman, 1999] Akiba et al. 2010 [Akiba et al., 2010]		
Why	Memorability	Bateman et al. 2010 [Bateman et al., 2010] Borkin et al, 2016 [Borkin et al., 2016]		Saket et al. 2015 [Saket et al., 2015]	
	Interpretation		Ma et al. 2012 [Ma et al., 2012]		Kosara and Mackinlay, 2013 [Kosara and Mackinlay, 2013]

search the visualization publication data collection [Isenberg et al., 2015] for these major themes in visualization and storytelling. Google scholar is also used as part of our search methodology.

In summary, our literature search includes:

1. IEEE EXPLORE Digital Library
2. ACM Digital Library
3. Visualization publication data collection [Isenberg et al., 2015]
4. the annual EuroVis conference
5. the Eurographics Digital Library

Several other papers were discovered by looking at the related work section of the papers we found.

Survey Scope The storytelling visualization papers summarized in this survey include the subjects of scientific visualization, information visualization, geospatial visualization, and visual analytics. In order to manage the scope of this survey, storytelling papers from other fields are not included, such as:

Virtual reality and augmented reality: For example, Santiago et al. [Santiago et al., 2014] present "mogre-storytelling" as a solution to interactive storytelling. This tool provides different functionalities for creating and the customization of scenarios in 3D, enables the addition of 3D models from the Internet, and enables the creation of a virtual story using multimedia and storytelling elements.

Education: For example, Cropper et al. [Cropper et al., 2015] address the extent of how scientific storytelling benefits our communication skills in the sciences, and the connections they establish with the information itself and others in their circle of influence.

Gaming: Alavesa et al. [Alavesa and Zanni, 2013] describe the development of a small scale pervasive game which can take storytelling from camp-fire sites to modern urban environments.

Multi-media and Image Processing: For example, Chu et al. describe a system to transform any temporal image sequence to a comics-based storytelling visualization [Chu et al., 2015]. Correa and Ma present a narrative system to generate dynamic narrative from videos [Correa and Ma, 2010]. Image processing falls outside the scope of this survey. Video processing also falls outside the scope of the survey [Amini et al., 2015].

Language processing: Theune et al. [Theune et al., 2006] develop a story generation system. It can create story plots automatically based on the actions of intelligent agents living in a virtual story world. The derived plots are converted to natural language, and presented to the user by an embodied agent that makes use of text-to-speech.

There are other fields that study storytelling as well. In the next sections we describe the literature on storytelling in visualization. Our classification is presented in Table 1.

2 Authoring-tools for storytelling and visualization

Authorship refers to writing or creating a book, article, or document, or the creator of a work of art according to The Oxford English dictionary [Dictionary, b] , especially with reference to an author, creator or producer [Reference, b]. For our purposes, we will adopt a definition of author described by Rodgers [Rodgers, 2011], "An author is best described as an individual solely responsible for the creation of a unique body of work." Hullman [Hullman et al., 2013b] et al. state, "Story creation involves sequential processes of context definition, information selection, modality selection, and choosing an order to effectively convey the intended narrative".

All papers in this section focus on authoring-tools for storytelling. Wohlfart and Michael [Wohlfahrt, 2006] create new volume visualization stories for medical applications. Gershon [Gershon and Page, 2001] and Cruz [Cruz and Machado, 2011] present general storytelling for information visualization. Kuhn [Kuhn and Stocker, 2012], Lee [Lee et al., 2013] and Plowman [Plowman et al., 1999] all develop unique creator tools for storytelling visualization.

Authoring-tools for Linear Storytelling Gershon and Page state that storytelling enables visualization to reveal information as effectively and intuitively as if the viewer were watching a movie [Gershon and Page, 2001].

Lu and Shen propose an approach to reduce the number of time steps that users required in order to visualize and understand the essential data features by selecting representative datasets [Lu and Shen, 2008].

Lu and Shen [Lu and Shen, 2008] is based on the previous work of time-vary visualization [Hansen and Johnson, 2011] and design a general method for comparing data dissimilarities.

Cruz et al. [Cruz and Machado, 2011] present generative storytelling as a conceptual framework for information storytelling.

Authoring-tools for User-directed and Interactive Storytelling A large body of research has been carried out for authors wishing to create their own user-oriented or interactive stories. This literature focuses on interactive, user-driven authorship (as opposed to automatic or semi-automatic authorship). Storytelling is a relatively new form of interactive volume visualization presentation [Wohlfahrt, 2006]. Wohlfart presents a volumetric storytelling prototype application, which is based on the RTVR (real time volume redering) Java library [Mroz and Hauser, 2001] for interactive volume rendering. Each story action group stores the scene changes relative to its preceding action group (or story node) [Wohlfahrt, 2006, Wohlfahrt and Hauser, 2007].

Wohlfart is based on previous work of volume visualization [Gooch et al., 1998, Haber and McNabb, 1990, Viola, 2005] and interactive visualization [Donald, 1993] and combine these concepts together to develop a storytelling model for volume visualization. Lidal et al. [Lidal et al., 2012] [Lidal et al., 2013] present a sketch-based interface for rapid modelling and exploration of various geological scenarios.

Lidal et al. is based on a previous storytelling model [Wohlfahrt, 2006] for scientific visualization [Ma et al., 2012] and develops a storytelling model for geological visualization.

Lee et al. present SketchStory, a data-enabled digital white board to support real-time storytelling. It enables the presenter to stay focused on a story and interact with charts created during presentation [Lee et al., 2013]. Lee et al. is based on previous work for storytelling of information visualization [Gershon and Page, 2001, Segel and Heer, 2010] and sketch-based interaction [Li et al., 2012], and develops the SketchStory system to enhance storytelling in a presentation.

Lundblad and Jern [Lundblad and Jern, 2013] present geovisual analytics software with integrated storytelling.

Lundblad and Jern is based on the previous work of the storytelling concept [Gershon and Page, 2001] and work of web-based geovisual tools, integrates storytelling with geovisual analytics software.

Authoring-tools for Parallel Storytelling In this category of literature, authors create stories in parallel. In other words there may be multiple authors working in parallel i.e. simultaneously for the final outcome. This is opposed to a single author as in the previous subsection.

Eccles et al. [Eccles et al., 2008] presents the GeoTime stories prototype that combines a geo-spatial map with narrative events to produce a story framework.

This system uses a similar approach to Sense.us [Heer et al., 2007a].

The CodeTimeline visualization by Kuhn and Stocker [Kuhn and Stocker, 2012] enables developers who are new to a team to understand the history of the system they are working on.

Prior to Kuhn and Stoker, Ogawa [Ogawa and Ma, 2010, Ogawa and Ma, 2009] presents "software evolution storylines" and "Code Swarm", which focus on the interactions between developers on projects but do not focus on telling a story about the software history. Codebook, a concept presented by Begel et al [Begel et al., 2010], outlines a social network that connects software engineers with their shared code base.

3 User Engagement

The literature in this category addresses an important but less developed research topic, namely user engagement. In other words, who do we engage with storytelling and how can we engage an audience?

Mahyar et al. [Mahyar et al., 2015] address how prior research in different domains define and measure user engagement. Their work is based on previous work of Bloom's taxonomy [Bloom, 1974] and adapts it to information visualization.

User Engagement for User-directed visualization The literature in this subsection focuses on interactive, user-driven visualization for user engagement. Engagement specifically focuses on each user's investment in the exploration of a visualization [Boy et al., 2015]. Boy et al. use low-level user interaction e.g. the number of interactions with a visualization that impact the display to quantify user engagement.

Boy et al is based on previous work on narrative visualization [Hullman and Diakopoulos, 2011] and user-centred metrics [Gotz and Wen, 2009].

4 Narrative Visualization and Storytelling

Narrative structures include events and visualization of characters. An example narrative can be a simple interface that presents trends in keywords over time [Fisher et al., 2008]. Narrative visuals contain the transition between events. It involves "using a tool to visually analyze data and to generate visualizations via vector graphics or images for presentation" to decide "how to thread the representations into a compelling yet understandable sequence" [Hullman et al., 2013b]. Plowman et al [Plowman et al., 1999, Eccles et al., 2008] report that a narrative specifically refers to the macro-structure of a document in contrast to the term story which refers to both structure and content. This structuring of evidence, combined with the choice of appropriate rhetorical strategies, is referred to as "the art of storytelling" among literary scholars [Plowman et al., 1999]. Research in narrative visualization points to visualization features that afford storytelling including guided emphasis and structures for reader-driven storytelling. It also includes the principles that govern effective structuring of transitions between consecutive visualizations in narrative presentations, and how different tactics for sequencing visualizations are combined into global strategies in formats like slideshow presentations. We separate transitions into their own section, section 4 and section 5, because of their importance.

All papers in this section develop methods or structure on how to improve narrative storytelling visualization. Viegas et al. [Viégas et al., 2004] present methods for improving data memorability. Fisher et al. [Fisher et al., 2008] present ways for tracking narrative events over time. Segal and Heer [Segel and Heer, 2010] investigate the design of narrative visualizations and identify techniques for telling stories with data. Hullman et al. [Hullman and Diakopoulos, 2011, Hullman et al., 2013a, Hullman et al., 2013b] design the structure of a visualization to present storytelling. Figueiras [Figueiras, 2014b, Figueiras, 2014a] studies how to incorporate narrative elements as storytelling elements. Again, these papers may cover more than one topic in Table 1. The borders between categories are not 100% black & white. We place papers in the category reflective their main focus.

Narrative Visualization for Linear Storytelling The literature in this sub-section focus on narrative visualization using linear automatic or semi-automatic approaches (as opposed to interactive approaches). The research here involves tools and techniques with an emphasis on how stories are created.

Hullman et al. describe a system called contextifier, which automatically produces custom, annotated visualizations from a given article [Hullman et al., 2013a].

Hullman et al. is based on previous work in storytelling in visualization [Segel and Heer, 2010] and Kandogan's automatic annotation analytics [Kandogan, 2012].

Hullman et al. [Hullman et al., 2013b] outline how automatic sequencing (the order in which to present visualizations) can be approached in designing systems to help non-designers navigate structuring decisions in creating narrative visualizations. This paper is based on previous work of narrative sequencing [Black and Bower, 1979] and narrative visualization [Hullman and Diakopoulos, 2011, Segel and Heer, 2010], and demonstrates that narrative sequencing can be systematically approached in visualization systems.

Amini et al [Amini et al., 2015] identify the high-level narrative structures found in professionally created data videos and identify their key components. Amini et al is based on previous work on storytelling [Gershon and Page, 2001] and storytelling in information visualization [Hullman et al., 2013a].

Bach et al. [Bach et al., 2016] develop graph comics for data-driven storytelling to present and explain temporal changes in networks to an audience.

Bach et al. is based on previous work on network exploration [Herman et al., 2000] and data-driven storytelling [Gershon and Page, 2001].

Narrative Visualization for User-Directed and Interactive Storytelling The literature in this subsection focuses on interactive, user-driven narrative visualization (as opposed to automatic or semi-automatic). In other words, the papers focus on techniques that enable users to create narratives interactively. Viegas et al. [Viégas et al., 2004] summarize two methods of visualizing email archives with the aim of improving memorability of the data.

Previous visualizations of online social interaction data have been focused on unravelling the data from the researchers' perspective, whereas these visualizations are for the benefit of the user [Boyd et al., 2002, Donath, 1995].

Hullman and Diakopoulos state that narrative information visualizations are a style of visualization that often explores the interplay between aspects of both exploratory and communicative visualization [Hullman and Diakopoulos, 2011]. Hullman and Diakopoulos is based on the previous work of Segel and Heer [Heer et al., 2007b].

A narrative-based visualization attempts to create a natural flow whereby the data has an obvious progression and therefore permits easier understanding and memorability [Figueiras, 2014b].

Figueiras is based on previous work of storytelling [Hullman and Diakopoulos, 2011] [Ma et al., 2012] [Segel and Heer, 2010] and narrative visualization [Fisher et al., 2008], and develops a model to add storytelling in narrative visualization [Figueiras, 2014b].

Storytelling aims to simplify concepts, create emotional connection, and provides capacity to help retain information [Figueiras, 2014a]. Figueiras presents the results of a focus group study on collecting information on narrative elements.

Figueiras is based on previous work of narrative visualization [Segel and Heer, 2010], and storytelling visualization [Kosara and Mackinlay, 2013, Ma et al., 2012].

Nguyen et al. [Nguyen et al., 2014] develop a new timeline visualization, SchemaLine, to gather, represent, and analyze information. Their work is based on previous work of timeline visualization [Ma et al., 2012, Tanahashi and Ma, 2012] and sensemarking with timeline [Pirolli and Card, 2005].

Narrative Visualization for Storytelling in Parallel In this category of literature, the structure of events is layed out in parallel. The research here focuses on tools and techniques that create multiple narratives at once, in other words simultaneously. These can be useful for groups.

Information visualization systems enable users to find patterns, relationships, and structures in data which may help users gain knowledge or confirm hypotheses [Akaishi et al., 2007].

Fisher et al. [Fisher et al., 2008] present narrative as a way of presenting temporally dynamic data. In this case, narratives help the user by tracking concepts found in news stories that change over time. Fisher et al. show how to piece together complex information and examine multiple variables, See Figure **??** [Fisher et al., 2008].

Fisher et al. is based on previous work in topic detection and tracking [Dubinko et al., 2007] [Swan and Jensen, 2000], and temporal visualization [Van Wijk and Van Selow, 1999], and presents narrative as a new technique in visualization [Fisher et al., 2008].

Narratives Visualization Overviews Segel and Heer state that storytelling is revealing stories with data and using visualization to function in place of written story [Segel and Heer, 2010]. They also discuss directions for future reader-centric research [Heer et al., 2007b].

Segel and Heer is based on previous work of narrative structure, visual narratives, and storytelling with data visualization [Heer et al., 2007b] and observes the storytelling potential of data visualization and drawn parallels to more traditional media.

5 Static Transitions in Storytelling for Visualization

A transition refers to the process or a period of changing from one state or condition to another according to the Oxford English Dictionary [Dictionary, d]. In the visualization literature, transitions may be the focus of visualization and include both dynamic and static which are alternatives of presenting visualization. Static visualizations are those that do not rely on animation. Transitions may be considered part of narrative storytelling. However, we designate the literature here in its own category to reflect the importance of transitions and to keep related literature on this topic together. Several research papers focus on the transitions in storytelling. This is why they are separated into a special group.

In this section, the visualization of transitions is generally static. The authors focus on presenting the trend of data along timelines. Robertson et al [Robertson et al., 2008] evaluate three approaches of using bubble charts and attempts to discover which one works best for presentation and analysis. Tanahashi and Ma [Tanahashi and Ma, 2012] presents a storyline visualization which consists of a series of lines, from left to right along the time-axis. Liu et al. [Liu et al., 2013] design a storyline visualization system, StoryFlow, to generate an aesthetically pleasing and legible storyline visualization. Ferreira et al [Ferreira et al., 2013] propose a method of visualizing a large amount of taxi data consisting of both spatial and temporal dimensions.

Static Transitions for User-directed and Interactive Storytelling The literature in this subsection focuses on interactive user-driven transitions. The user creates static transitions interactively, i.e. using a process they have some control over(as opposed to automatically).

TaxiVis proposes a method of visualizing a large amount of taxi data consisting of both spatial and temporal dimensions [Ferreira et al., 2013].

Taxi behaviour is a popular focus of research. Among others, Veloso et al. explored patterns and trends in taxi ride data looking at the relationship between pick up and drop off points [Veloso et al., 2011a, Veloso et al., 2011b]. Liao et al. developed a visual analytics system to error check GPS data streamed from taxis [Liao et al., 2010].

Static Transitions for Parallel Storytelling In this category of literature, the static transitions are shown in parallel. In other words, many transitions can occur simultaneously. Robertson et al. [Robertson et al., 2008] define a trend in data as an observed general tendency.

The gapminder trendalyzer uses a bubble chart to show four dimensions of data, life expectancy is mapped to the x axis, infant mortality is mapped to the y axis, population is mapped to bubble size and continent is mapped to color [Rosling, 2006].

An alternative multi-dimensional trend visualization provides the user with the ability to select particular bubbles such that the animation shows a trace line for the selected bubble as it progresses [Rosling, 2007]. They are further grouped by continent and ordered alphabetically within each group [Tufte, 1990]. Robertson et al. is based on earlier work by Tversky et al. [Tversky et al., 2002] and Baudisch et al. [Baudisch et al., 2006].

Visual Storylines, by Chen et al. is designed to summarize video storylines in an image composition while preserving the style of the original videos [Chen et al., 2012].

Chen et al. is based on the work of video summarization [Yahiaoui et al., 2001] and first clusters video shots according to both visual and audio data to form semantic video segments.

Storyline visualization is a technique that portrays the temporal dynamics of social interactions by projecting the timeline of the interaction onto an axis [Tanahashi and Ma, 2012]. Tanahashi and Ma [Tanahashi and Ma, 2012] is based on the idea of XKCD's hand-drawn illusion "Movie Narrative Charts" [Ogievetsky., 2009] and develops an algorithm for general storyline visualization.

Liu et al. [Liu et al., 2013] design a storyline visualization system, StoryFlow, to generate an aesthetically pleasing and legible storyline visualization. Liu et al. is based on previous work of Tanahashi et al. [Tanahashi and Ma, 2012].

6 Animated Transitions in Storytelling for Visualization

Gonzalez and Cleotilde define animation as a series of varying images presented dynamically according to user actions, in ways that help the user to perceive a continuous change over time and develop a more appropriate mental model of the task [Gonzalez, 1995].

Animated Transitions for Linear Storytelling The literature in this sub-section focuses on animated transitions using automatic, or semi-automatic approaches(as opposed to interactive techniques to animated transitions).

Heer and Robertson investigate the effectiveness of animated transitions in traditional statistical data graphs, such as bar charts, pie charts, and scatter plots [Heer and Robertson, 2007]. Heer and Robertson is based on the previous work of Bederson and Boltman [Bederson and Boltman, 1999] but builds upon it by testing different transitional events.

Animated Transitions for User-directed and Interactive Storytelling The literature in this subsection focuses on interactive, user-driven transitions. The user or users create animated transitions interactively (as opposed to automatically as in the previous section). Bederson and Boltman examine how animating a viewpoint change in a spatial information system affects a user's ability to build a mental map of the information in the space [Bederson and Boltman, 1999]. Bederson and Boltman is based on Gonzalez [Gonzalez, 1996b] and Donskoy and Kaptelinin [Donskoy and Kaptelinin, 1997] which address the relationship between animation and users' understanding.

Akiba et al. introduce an animation tool named: AniVis for scientific visualization exploration and communication [Akiba et al., 2010]. Akiba et al. is based on previous animation support [Childs et al., 2005] and an animation enhanced system [Correa and Silver, 2005] and develops template-based visualization tools for animation.

7 Memorability for Storytelling and Visualization

Memory refers to the faculty by which things are remembered; the capacity for retaining, perpetuating, or reviving the thought of things past according to the Oxford English Dictionary [Dictionary, e]. Memorability is an important goal of storytelling. A good visualization technique engages the viewer's attention and increases a story's memorability [Bateman et al., 2010].

All papers in this section evaluate the effects of visualization on memorability. Bateman et al. [Bateman et al., 2010] explore the effects of embellishment on comprehension and memorability. Saket et al. [Saket et al., 2015] illustrate that map-based visualization can improve accuracy of recalled data comparing with node-link visualization.

Borkin et al. [Borkin et al., 2013] develop an online memorability study using over 2000 static visualizations that cover a large variety of visualizations and determine which visualization types and attributes are more memorable.

Memorability for Linear Visualization The literature here shows and tests visual designs in linear order. Users are asked to compare the visual designs (e.g. standard bar charts) verses embellished bar charts. In other words, users are tested on their ability to recall one visual design at a time in linear fashion.

Bateman et al. examine whether embellishment is useful for comprehension and memorability of charts [Bateman et al., 2010].

Fourteen embellished charts are selected from Nigel Holmes' book Designer's Guide to Creating Charts and Diagrams [Holmes, 1984], and converted to plain charts.

Previous studies have suggested that minor decoration in charts may not hamper interpretation [Blasio and Bisantz, 2002], and work in psychology has shown that the use of imagery can affect memorability [Gambrell and Jawitz, 1993], but there is very little work that looks at how chart imagery can affect the way people view information charts.

Borkin et al. [Borkin et al., 2016] present the first study incorporating eye-tracking as well as cognitive experimental techniques to investigate which elements of visualizations facilitate subsequent recognition and recall. Borkin et al. is based on previous work on perception and memorability of visualization [Bateman et al., 2010] and eye-tracking evaluation visualization [Blascheck et al., 2014].

Memorability for Parallel Visualization In this subsection, users are presented with a large number of relation data in parallel (as opposes to one at a time). Users are tested on their ability to process relationship data in parallel (all relationships simultaneously). This is distinct from memorability for linear visualization where recall focuses on one visual design at a time in linear order.

Saket et al. [Saket et al., 2015] illustrate that different visualization designs can effect the recall accuracy of data being visualized. Saket et al. is based on previous work of visualization memorability [Bateman et al., 2010] and a recalling experiment [Isola et al., 2011]

8 Interpretation for Storytelling and Visualization

Interpretation refers to the action of explaining the meaning of something, according to the Oxford English Dictionary [Dictionary, f]. Martin [Martin, 1997] refers to interpretation as a process to reach a deep cognition level which contains the fundamental values of a story. To find out the fundamental oppositions and transformations underlying the story, interpretation has to reduce all the oppositions found on the figurative and narrative levels to one or two basic umbrella oppositions.

Interpretation for User-directed Visualization The literature in this subsection focuses on interactive, user-driven interpretation. In this class of literature, a user interprets visual design interactively. In other words, the observer chooses the order in which they view and interpret visual designs. This is as opposed to a prescribed or automated order of visual designs. Ma et al. [Ma et al., 2012] state that a story that is well paced exhibits deliberate control over the rate at which plot points occur. Ma et al. is based on previous scientific visualization work at NASA, based in the scientific research center and scientific museum and describe how visualization can be used to tell a good story, and tell it well. This is a topic that the scientific visualization research community paid little attention to at that time.

Overviews of Interpretation for Visualization and Storytelling The literature in this subsection provides overviews on the topic of interpretation for visualization and storytelling.

Kosara and Mackinlay define a story as an ordered sequence of steps with a clearly defined path through it [Kosara and Mackinlay, 2013]. This paper presents a selection of previous work on storytelling in visualization and postulates storytelling as a fruitful area of future research [Kosara and Mackinlay, 2013]. Kosara and Mackinlay is based on the previous history of storytelling, definition and model of Segel and Heer [Segel and Heer, 2010] and outlines a research program to develop storytelling as a visualization task of equal importance to exploration and analysis.

9 Unsolved Problems and Conclusion

This survey provides a novel up-to-date overview of storytelling in visualization. The most important recent literature is included and discussed. Since storytelling in visualization is a recently new subject, we expect an increase in research in the coming years. Moreover we believe it will evolve into a popular topic in the field of visualization.

By reviewing Table 1 and Table 2, we can see storytelling visualization focuses on information visualization more than scientific visualization, which conveys that more challenges are left unsolved in this field. However, by refining a storytelling model for scientific visualization [Wohlfahrt and Hauser, 2007], the implementation of storytelling in scientific visualization could increase in the future. We can also see that storytelling in visualization concentrates more on exploration than on presentation. Like Kosara and Mackinlay [Kosara and Mackinlay, 2013] state: "visualization techniques address the exploration and analysis of data more than presenting data".

In future work, there are many directions and unsolved problems. Storytelling will gain importance in data presentation and data exploration. Here is a summary of some unsolved problems in storytelling for visualization.

It is clear that objective measures of user-engagement is a relatively unexplored area of research. Can we derive a mature classification of user engagement activities? Is user engagement something we can clearly define?

Data preparation and enhancement: Virtually no one has addressed the challenge of data preparation and enhancement for storytelling. Moreover, is storytelling data best captured or derived from an existing data set or software system? Can a standard data file format be developed?

Narrative visualization for scientific and geo-spatial visualization: Why has there been such an imbalance of research narrative visualization for information visualization but virtually none for scientific and geo-spatial visualization.

Transitions for scientific visualization: The benefits of static transition versus dynamic transitions in visualization still remains relatively immature.

Memorability for visualization: What are the key elements for making a memorable visualization? This is still an immature research direction.

Animated transitions for geo-spatial visualization: Animated transitions for geo-spatial visualization remains an open research direction. This is surprising given the popularity and importance of geo-spatial visualization.

Interpretation for scientific information, and geo-spatial visualization: Although we included two papers that arguably touch upon the topic of effective interpretation of stories, this topic remains largely unexplored.

The classification of literature, we present makes it clear that many future research directions remain open in storytelling and visualization.

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