From Explanation to Demonstration:
A Conceptual Framework for the Study and Strategic Design of Interactive Visualizations

by

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ABSTRACT

Interactive visualization is a burgeoning class of cognitive and communicative tools that is challenging to define. Typically, interactive visualizations have been evaluated by the multimodal features they are comprised of, or for the communicative tasks they support, but this contributes little to understanding them as semiotic systems.

This thesis offers a conceptual framework with which to further study existing interactive visualizations or to consider during the design phase. By examining the constituent elements of images (static and dynamic) and language, we can see how the relationship between them influences the expression of causality, and consequently narrativity, in information graphics. The added capacity for interaction allows graphics to accept and respond to input from users. However, there is an inherent tension between narrativity and interactivity, and these can be considered end points of an inversely proportional scale. The outcome of the tension is a means of defining the perspective of an interactive—greater degrees of narrativity suggests an author-driven perspective, creating an interactive object that tends towards explaining data, whereas greater degrees of interactivity suggests a user-driven perspective as users explore data, drawing their own conclusions.

DEDICATION

This work is dedicated to the memory of my dear old dad,

Edward Francis Windsor

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1.1 INTRODUCTION

In 1964, Justice Potter Stewart wrote,

> *I shall not today attempt further to define the kinds of material I understand to be embraced within that shorthand description ... and perhaps I could never succeed in intelligibly doing so.* ***But I know it when I see it...*** (emphasis mine) Jacobellis v. Ohio (1964)

Justice Stewart was referring to the definition of hard-core pornography in a threshold test for obscenity applied to the movie *The Lovers*. In this now famous phrase he was attempting to define a category of objects or events whose parameters are too vague and subject to varying interpretations to establish with any precision. Interactive visualizations too are in a category with vague parameters subject to varying interpretations—a vast array of digital entities (that is growing at an accelerated rate) being generated in a wide range of disciplines, that serve different requirements drawing from a large variety of rapidly evolving features and digital affordances. They are often (but not always) found online, can include any combination of text, photography, charts, diagrams, graphics, animation, video or audio with the purpose of conveying or creating meaning. They are hypermedial, participatory and not necessarily linear. Sometimes, especially in journalistic applications, they have a strong narrative quality.

For the purpose of this thesis, I will refer to this broad and vague category of digital entities as interactive visualizations (or just interactives) but in fact there is no agreed-upon name or even widespread recognition that they necessarily belong in the same category. Often they are identified for the particular purpose they serve and have been called, sometimes interchangeably by the same author, data visualizations, interactive information graphics, interactive narratives, explanation scientific visualizations, infoviz, multimedia features, interactive visual explainers, interactive narratives, interactive data displays, data stories and narrative visualizations. In the absence of a conclusive means of defining the nature and scope of interactive information graphics, how can we identify and categorize them? How can we study, discuss and generate them in a meaningful way? The intent of this thesis is to instead establish a conceptual framework with which to enhance examination, greater understanding and strategic design of interactive visualizations as cognitive and communicative tools.

In Chapter 1 I will examine some of the milestones from the rich history of information graphics that led to interactive visualizations as they are today. The concepts of interactivity and data, especially big data, are complex and embody a multitude of concepts—I will attempt to outline a working definition of each for the purposes of this thesis. The intent of Chapter 2 is to survey the literature surrounding interactive visualization research and consider the likely causes of the seemingly deficient theoretical foundations in this area. Building on the preceding chapters, Chapter 3 will deconstruct interactive visualizations to their constituent semiotic modes in order to establish how they function individually and in concert in their new multimodal context. In doing so, I will establish a conceptual framework which will then be applied to a sample group of interactive visualizations in Chapter 4 to test its soundness. Chapter 5 will conclude the thesis.

1.2 INFORMATION GRAPHICS

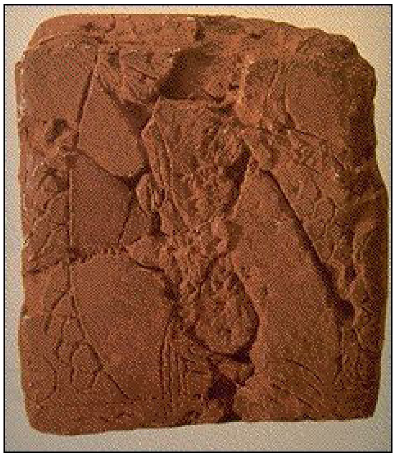
> *To envision information—and what bright and splendid visions can result—is to work at the intersection of image, word, number, art. The instruments are those of writing and typography, of managing large data sets and statistical analysis, of line and layout and color.*
> ~ Edward Tufte, *Envisioning Information*

Maps, diagrams, charts, graphs, timelines: information graphics (or infographics) are a visual expression of data, information and knowledge that is often too unwieldly to present with text alone. They can illuminate that which is otherwise hidden (the interior of the human body), or conceptualize that which is either too large (a country) or too small (a sub-microscopic system) to be photographed. They can provide a means to engage with speculative, intangible, abstract or theoretical material. Whereas all images are depictions or interpretations of aspects of ourselves and our environment, information graphics are often multivariate in nature and focus on comparative or relational aspects in order to highlight significant connections or identify patterns, trends, clusters, outliers or gaps. They can be characterized as an exchange between at least three semiotic systems: image, language and numbers. Infographics are a branch of information design—a cross-disciplinary school of thought that prioritizes efficient and effective communications that lead to knowledge and informed behaviours over aesthetics and artistic expression or persuasive approaches used in practices like advertising. Pettersson (2014) defines it as comprising of "…analysis, planning, presentation and understanding of a message–its content, language and form. Regardless of the selected medium, a well-designed information material will satisfy aesthetic, economic, ergonomic, as well as subject matter requirements" (p. 2). Other branches of information design include signage systems, wayfinding design, standardized international pictograms and icons, information content design and typography.

1.3 A BRIEF HISTORY OF INFORMATION GRAPHICS

In the history of visual communication, the written word is a relatively recent development: ancient humans were outlining bison on cave walls 32,000 years ago but only began using writing to communicate in roughly the past 4,000 years. Images were the dominant method of communicating, teaching and record keeping even prehistorically—maps incised in clay from possibly as long ago as 6,200 BC were found in ruined city of Ga-Sur at Nuzi (Yorghan Tepe), located in modern day Iraq (see Figures 1a and 1b). The ancients—Babylonians, Egyptians, Greeks, Chinese—developed sophisticated information graphics: maps, both celestial and earthly to plot the movements of the stars, plant crops, and develop cities, and later various forms of charts and diagrams to express astrological, medical, scientific, religious thought of the time.

Bertin (1983) observes that early graphics were conceived as reproductions of the visible world, adjusted only for scale and detail. He writes,



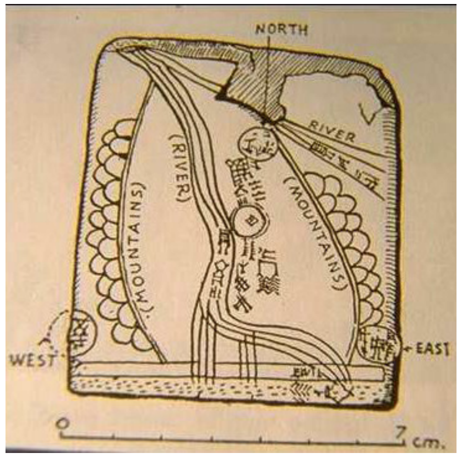


Figure 1a. Clay tablet map from Ga-Sur, 2,500 B.C. (left). (Biblioteca Pleyades, n.d., n.p.).

Figure 1b. Redrawn with interpretation (right) (Biblioteca Pleyades, n.d., n.p.).

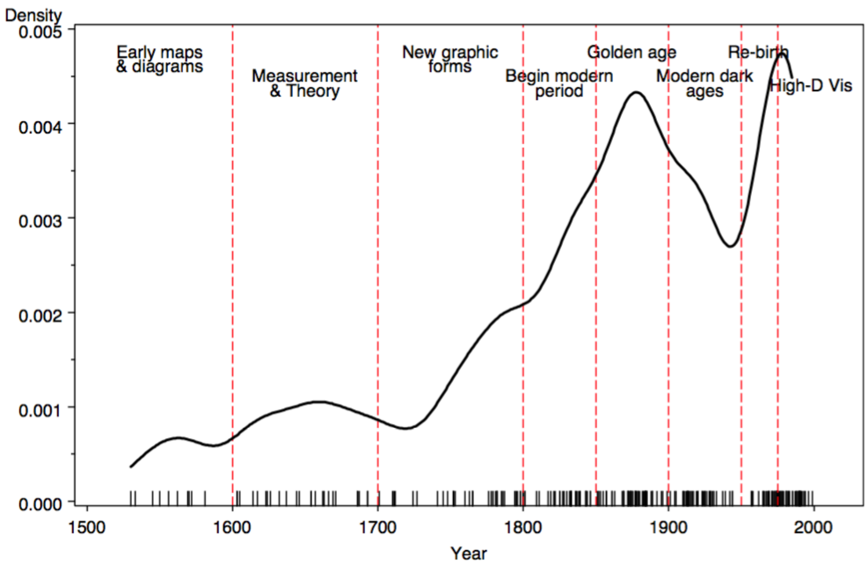


Figure 2. Milestones: Time course of developments. A time distribution of information graphics considered significant to the history of data visualization shown by rug plot and density estimate (Friendly, 2008, p. 18).

> *One had to wait until the fourteenth century to suspect, at Oxford, and until the eighteenth century to confirm … that the two dimensions of a sheet of paper could usefully represent something other than visible space. This amounts to a transition from a simple representation to a "sign system" that is complete, independent, and possesses its own laws, thus falling within the scope of semiology* (p. 4).

Although the individual disciplines of cartography, statistics, astronomy and others each have historical accounts of developments within their own fields, chronicles of information graphics as a discipline in its own right are scarce. Of the existing few, all point to the period around 1800–1850 as the beginning of modern information graphics as made apparent by the steep rise

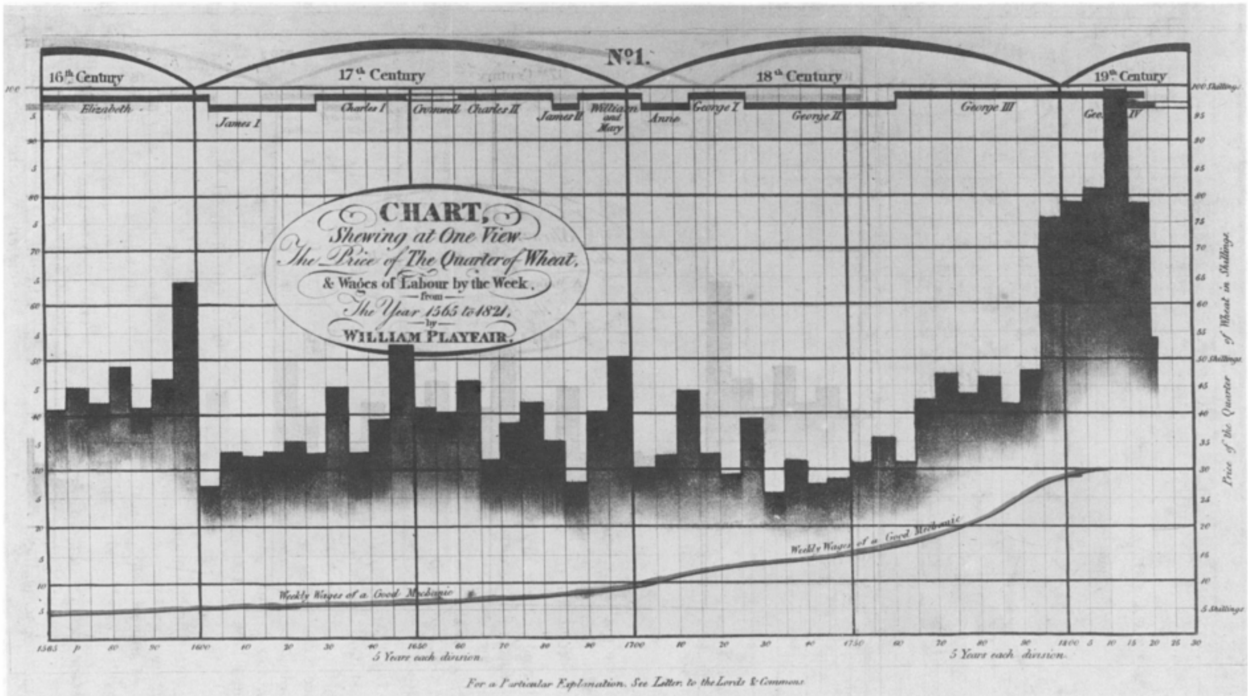


Figure 3. William Playfair's Chart Shewing at One View The Price of The Quarter of Wheat & Wages of Labour by the Week from The Year 1565 to 1821 (Tufte, 1985, p. 34).

and density in the time course of developments of Figure 2. William Playfair (1759–1823), a Scottish political economist, is considered by most scholars to be the inventor of several of the graphical forms we are familiar with today such as line and circle graphs, bar and pie charts (Friendly, 2008, p. 8). Playfair was also known for his time-series graphics, for instance in Figure 3 where we see three parallel time-series of prices and wages over the reign of successive British monarchs. Figure 4a is also a time-series, here taken to the zenith of the genre with what Edward Tufte (1984) considers the finest infographic ever created: French engineer Charles Joseph Minard's map of Napoleon's 1812 march on, and disastrous retreat from, Moscow.

Minard's graphic was created in 1869 during the period Friendly (2008) refers to as the Golden Age of statistical graphics, marked by "unparalleled beauty and many innovations in graphics and thematic cartography" (p. 14). Of this age he writes,

> *By the mid-1800s, all the conditions for the rapid growth of visualization had been established—a "perfect storm" for data graphics. Official state statistical offices were established*

throughout Europe, in recognition of the growing importance of numerical information for social planning, industrialization, commerce, and transportation. Statistical theory … provided the means to make sense of large bodies of data (p. 13).

Minard was a pioneer of thematic cartography and this art "always involves a tension and trade-off between the confines of the map and the representation of data"—when there was conflict between accuracy of geographic representation and representation of data, Minard invariably chose the latter and revised geographical specifics to fit the data rather than vice versa (Friendly, 2002, p. 33). This map is notable for several reasons, not least of which is its break with map-making traditions of the time. Minard succeeded in capturing a remarkable number of data dimensions in a single visualization. First, we see the army's plotted path (brown on the way to Moscow; black on the return) on a map; next, the line width indicates the number of soldiers throughout the duration of the campaign, from those who started through those who break off

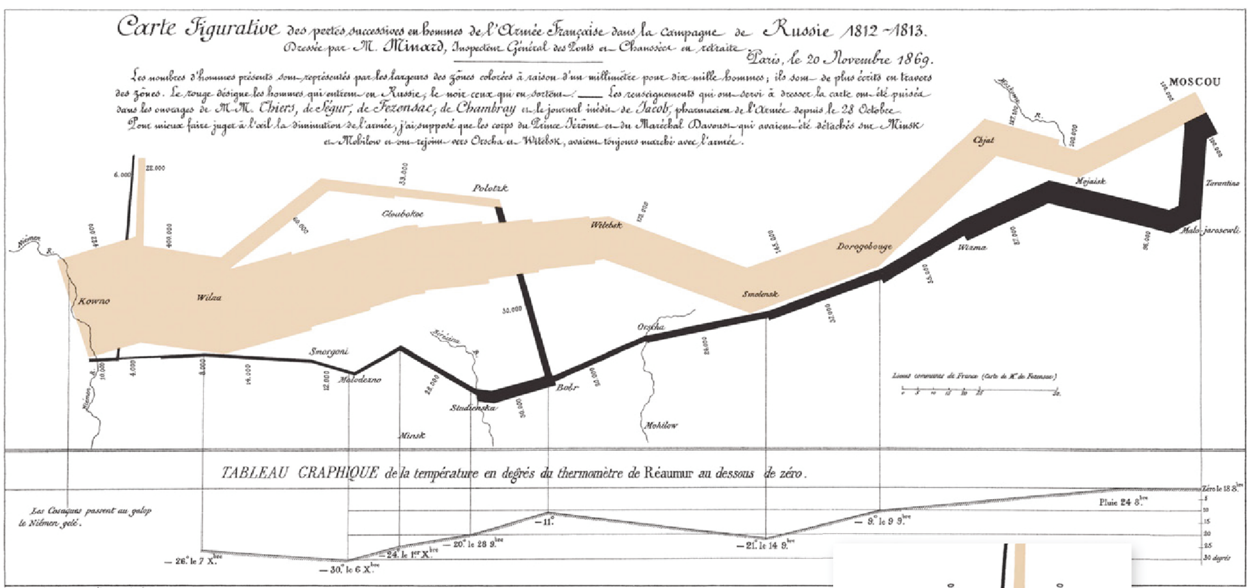


Figure 4a. Charles Joseph Minard's chart, Napoleon's 1812 march on Moscow (above) (Wikimedia Commons, n.d., n.p.).

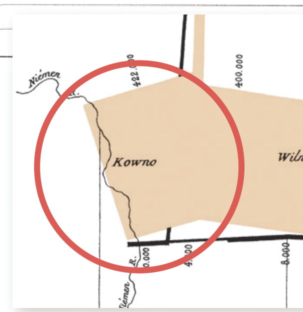


Figure 4b. Detail of Charles Joseph Minard's chart, Napoleon's 1812 march on Moscow (above) (Wikimedia Commons, n.d., n.p.).

to subgroups, to the sad few who returned defeated. A temperature scale points to stages of the journey and, in correlation with the other data represented, indicates where and when troops froze to death for a third dimension. Thin vertical lines signify river crossings, and in correlation with the decreasing width of the troops line, indicates deaths at these events as well. The viewer can clearly see the proportion of lives lost from the start to the finish of the campaign in the bottom left corner of the graphic alone (see Figure 4b).

Two noteworthy information graphics produced during the same period as Minard's map illustrate the power of information graphics as visual arguments—in both cases for medical intervention during health crises: John Snow's untitled map showing cholera cases in the London epidemic of 1854 (see Figure 5) and Florence Nightingale's 1858 "Diagram of Causes of Mortality in the Army in the East" (see Figure 6). Snow created a map of central London marking households with incidences of death from cholera with dots and water wells with x's and in doing so was able to clearly identify the source of disease contaminated water. Nightingale's diagram,

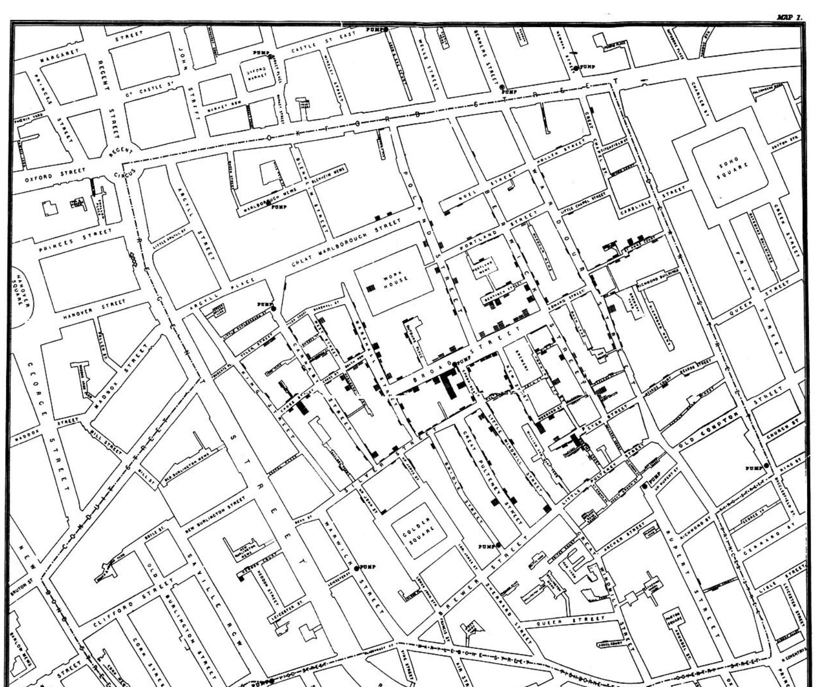


Figure 5. John Snow's map, Dots mark clusters of cholera cases in the London epidemic of 1854. (Wikimedia Commons, n.d., n.p.).

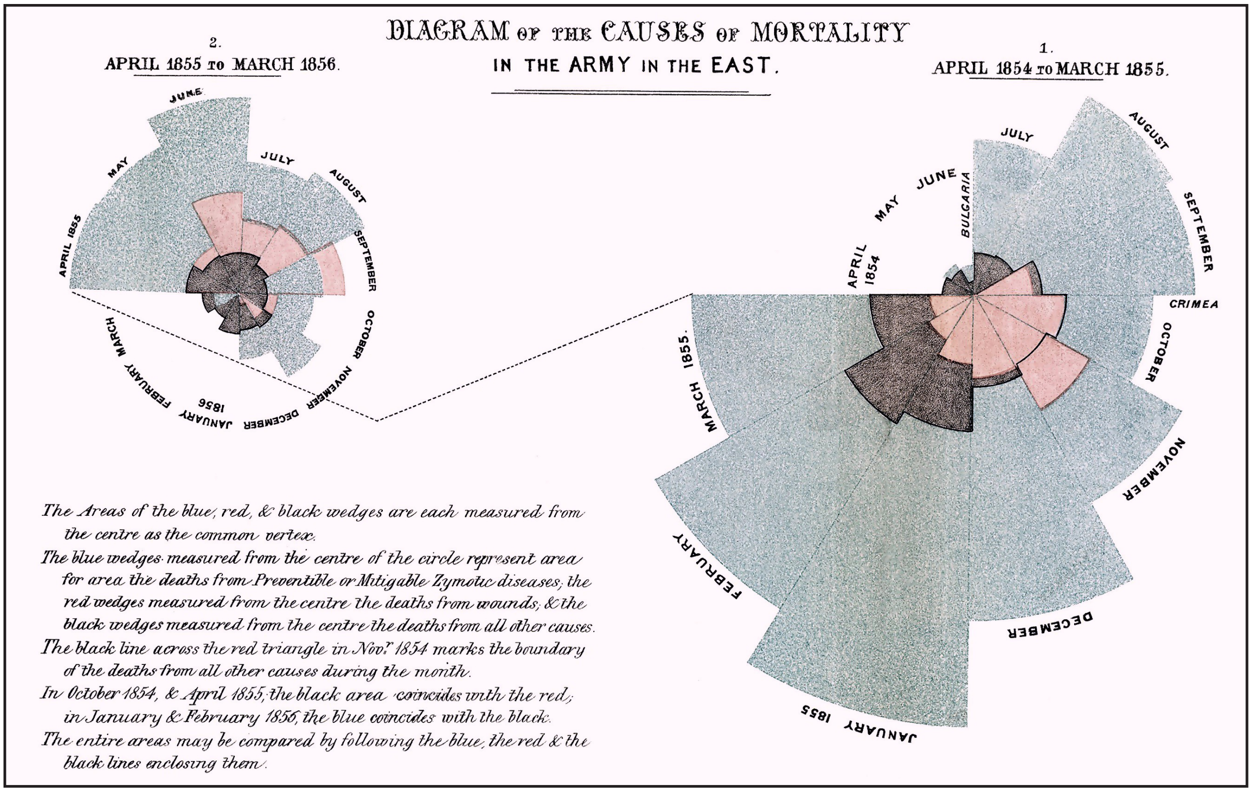


Figure 6. Florence Nightingale, Diagram of the Causes of Mortality in the Army in the East (Wikimedia Commons, n.d., n.p.).

more challenging to read with our current understanding of graphic conventions, convinced Queen Victoria to provide sufficient supplies to improve sanitary conditions for soldiers dying from preventable diseases and infections on the battlefield rather than at the hands of the enemy (Friendly, 2008, p. 15).

In 1931 Harry Beck created another milestone in the history of information graphics: the innovative version of the London Underground map which evolved into arguably the most widely recognized information graphic of all time (see Figure 7). Prior to Beck's redesign, maps of the Underground corresponded faithfully to the physical locations and distances above ground (see Figures 8 and 9) but as the number of train lines expanded the map grew in complexity: a tangle of rail lines and a dense cluster of dots representing stations at the city's centre that diffused dramatically toward the outskirts. Where Minard shifted around geographic accuracy, Beck virtually abandoned it in favour of a restrained geometry of 90° and 45° angles, an expanded core

Figure 7. 1933 London Underground Map, Created by Harry Beck (Wikimedia Commons, n.d., n.p.).

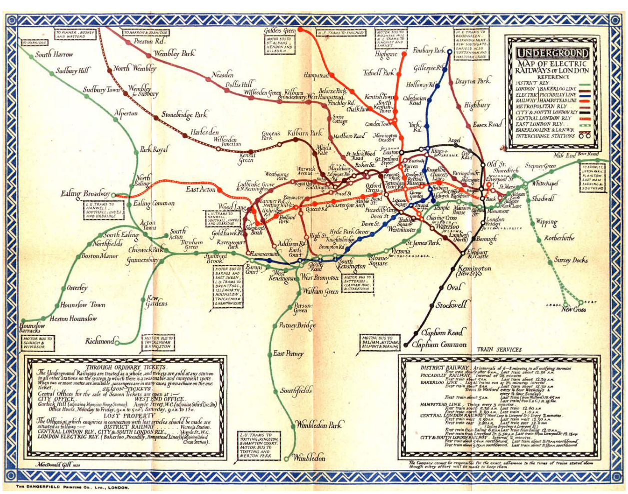


Figure 8. London Underground Map, 1921 (The London Tube Map Archive, n.d., n.p.).

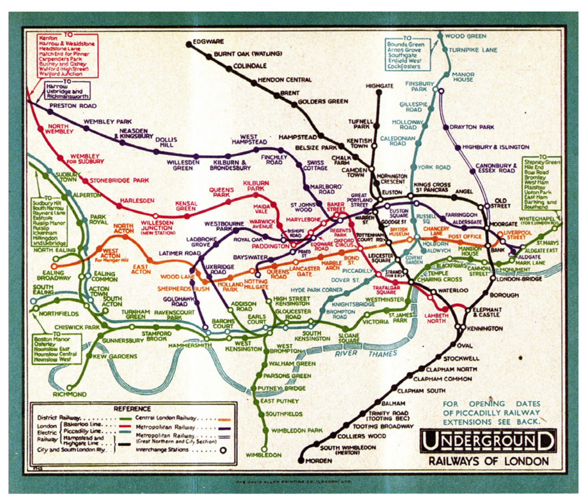


Figure 9. London Underground Map, 1932 (1932 pseudo-geographical pocket map by F.H. Stingemore, n.d., n.p.).

with connections and interchanges at regularly spaced intervals to create not just a simplification of railway routes but "an essential simplification of the city itself" (Bitarello, Ata & Queiroz, 2012, p. 349). Bitarello et al (2012) observed that the London Underground map functions as a cognitive tool for its users: assuming it is impossible to memorize all the lines and correlations between stations, the map becomes an external artifact to distribute the cognitive effort of the user. It is a powerful tool that aids problem-solving in certain contexts and radically changes how users navigate their environment, ultimately making them more suited to their environment. By reducing the similarity between representation and object, Beck increased the efficiency of the map as a cognitive tool (p. 351). Eventually this became a favoured approach to transit maps worldwide.

The most dramatic reduction of detail can be witnessed in the diagram incised into gold anodized aluminum plaques that accompanied the Pioneer spacecrafts in 1972 and 1973 (see Figure 10). The diagram, designed by Carl Sagan and Frank Drake, and illustrated by Linda Salzman-Sagan, can be considered the most ambitious information graphic of all time: a single image to transcend all languages and cultures to communicate rudimentary truths about planet Earth and mankind to extraterrestrial life should the spacecrafts be intercepted. The diagram was based on the assumption that mathematics and drawing are not just international languages but also universal ones. The diagram includes a hyperfine transition of hydrogen to indicate 'standard' units of time and length, the figures of a man and woman with a silhouette of the Pioneer spacecraft behind them

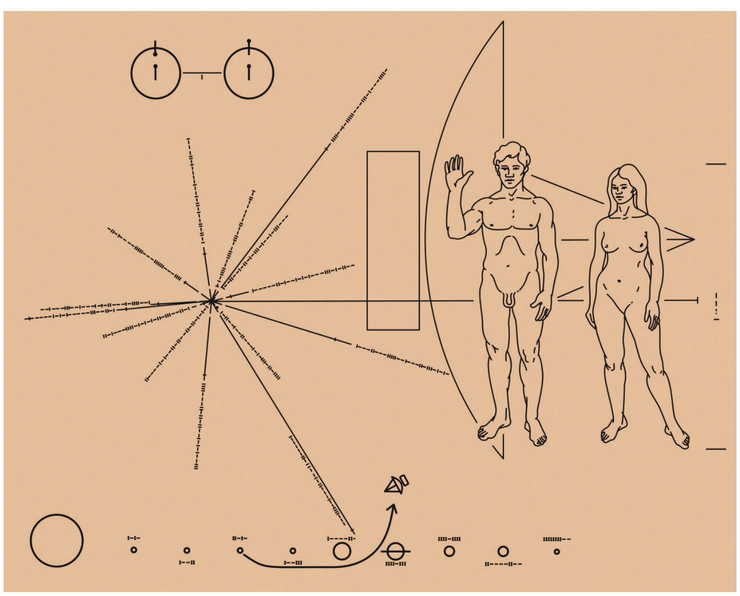


Figure 10. Pioneer plaque, sent with the Pioneer spacecrafts in 1972 and 1973 to communicate with extraterrestrials if intercepted (Wikimedia Commons, n.d., n.p.).

to show scale, the relative position of the sun to the centre of the galaxy and 14 pulsars in binary numbers (to pinpoint where Earth is in the galaxy and precisely when the plaques were launched) and our solar system with the trajectory of the spacecraft (Macauley, 2010, p. 99–113). The plaque will, it is believed by many, long outlive Earth. Macauley writes,

> *According to Drake, the map was universally meaningful because it incorporated objective mathematical properties of astronomical objects and specified the location of the Solar System from which Pioneer 10 was launched. Drake claimed that the meaning of the map was not only universal but was also transhistorical. For him it transcended the limits of human history and would be legible to extraterrestrials in the remote future* (p. 105).

In the 80s desktop publishing software enabled computer-generated information graphics to be created affordably and quickly and they soon became mainstream in a variety of print applications. The 90s saw the seemingly overnight ubiquity of the internet and in the early 2000s Web 2.0, the second stage of the internet, changed static web pages to dynamic and facilitated interactive visualization to flourish. It is important at this point to mention that not all digital information graphics are interactive—some are digital but non-dynamic (other than, for instance, scrolling down to see a long vertical format). To better differentiate between the two, from this point I will refer to both print and non-dynamic digital graphics as static information graphics.

1.4 INTERACTIVITY

Interactivity plays a central role in the examination of the constituent elements of interactive visualizations but it is an elusive phenomenon that researchers have been been trying to explicate for decades and a thorough examination of the different facets and perspectives of interactivity is beyond the scope of this thesis. While there is some agreement as to basic characteristics, there remains a lack of consensus regarding what interactivity is or what it does because, as McMillan (2006) observes, it “means different things to different people in different contexts” (p. 205). In an influential work on the subject, Rafaeli (1988) propose a general definition of interactivity: “an expression of the extent that in a given series of communication exchanges, any third (or later) transmission (or message) is related to the degree to which previous exchanges referred to even earlier transmissions" (p. 111). Some years later, Rafaeli and Sudweeks (1997) elaborated,

> *Interactivity is not a characteristic of the medium. It is a process-related construct about communication. It is the extent to which messages in a sequence relate to each other, and especially the extent to which later messages recount the relatedness of earlier messages. … communication is mostly about and for the purpose of interaction. Interactivity places shared interpretive contexts in the primary role. Interactivity describes and prescribes the manner in which conversational interaction as an iterative process leads to jointly produced meaning. Interactivity merges speaking with listening. And it is a general enough concept to encompass both intimate, person-to-person, face-to-face communication and other forums and forms.* (n.p.)

Liu and Shrum (2002) observed that general definitions of interactivity have transformed over time and can be categorized as either user-machine, user-user or user-message according to what chronological stage of the evolution of interactive technology they corresponded to. Definitions in the user-machine category typically describe the very early development of digital interactive technology—a stage when to be considered interactive a computer system only needed to be responsive to the user's commands. As technology evolved and the internet became increasingly ubiquitous, attention shifted from responsiveness to emerging methods of interpersonal communication (like instant messaging and email) and these definitions of interactivity are consistent with their user-user category. People no longer needed to be in the same place, same time-zone or even speak the same language to connect with one another and definitions of interactivity from this stage focus predominantly on communication. Later, definitions fall within the user-message stage and deal with the user's ability to control and modify the content she is working with and consequently customize the messages she is receiving according to her own objectives (p. 54). McMillan (2005) also notes user-machine, user-user, user-message categories

	Human-to-Human	Human-to-Computer	Human-to-Content
Features	• Instant messaging • E-mail	• Navigational tools such as menus • Search tools	• Tools that facilitate personalized content • Unique content forms
Processes	• Participating in an IM chat • Sending/receiving e-mail	• Navigating a web site • Using a search engine	• Creating a personalized home page • Seeking out news stories in multiple media formats
Perceptions	• Believing that IM and e-mail facilitate communication • May be based in personal interest or involvement with topics of communication	• Finding a web site easy to control and engaging • May be based in experience with the technology as well as interest/ with topic	• Believing that customized and in-depth content is interactive • May be based in time available for viewing content

Figure 11. Putting Together the Parts of Interactivity. (McMillan, S., 2005, p. 1).

(calling them human-to-computer, human-to-human, and human-to-content, respectively), but sees these simply as coexisting parts that fit together to create the greater whole. She also defines interactivity as "being based in features (the characteristics of the communication environment that make it interactive), processes (the actual activity of interacting), and perceptions (whether or not users perceive the communication environment to be interactive)" and provides a framework, Figure 11, for seeing the bigger picture and thinking about interactivity (p. 1).

1.5 WHAT IS "DATA"?

Simply speaking, data is an item, or items, of information, at present largely considered digital in nature: "quantities, characters, or symbols on which operations are performed by a computer, considered collectively or information in digital form" (OED, 2016). In the user-message or human-to-content category of interactivity, data is the raw form of the content or message we are interacting with. At present we are living in a widely acknowledged "data deluge." De Mauro, Greco and Grimaldi (2016) attribute this to the extensive degree to which data are created, shared and utilized, especially since the early 90s when optical character recognition (OCR) tools gave rise to mass digitization projects converting entire libraries, or, notably, the Google Books Library Project digitizing more than millions of print books. Now data is largely "born digital" and the proliferation of personal devices—forecast to be 26 billion by 2020—generate a multiplicity of unstructured data types like video, photos and texts at an escalating pace and this is a major challenge associated with managing big data today (Greco et al, 2016, p. 124–125). In January, 2016 was predicted to be the Year of the Connected Device, with “connected fridges talking to smartphones talking to game consoles talking to connected cars,” all generating data, and accordingly 2016 will be the year the world will start producing more data than it can store (Permabit, 2016, n.p.). We are awash in a world of digital data, but it is all meaningless without some form of interpretation and this always involves a reduction of detail and organizing structure. Once endowed with meaning and purpose, data becomes information.

1.6 CONCLUSION

We are now over two decades in to the most recent generation of information graphics, interactive visualizations that draw on increasing computer processing speed, display resolution and graphic agility to produce dynamic versions of their static predecessors. Information graphics have evolved from the supplemental role they once played in print applications to centre-stage on current digital devices. In the current state of data overload, our reliance on visually-communicated information has never been greater and interactive visualizations are a significant means to manage, access and create knowledge from raw data. They “have the potential to make statistical data truly comprehensible: they can make the data engaging, point out causal relationships, and tell the story behind the data” (Weber and Rall, 2012, p. 1). Where Charles Joseph Minard once amazed with multiple data dimensions in a single graphic, the addition of time-based media presents new possibilities for the visual expression of causal explanations which will be explored further in later chapters.

2. REVIEWING THE LITERATURE

2.1 INTRODUCTION

Despite over twenty years of exponential growth, there is a widely acknowledged need for more substantial theoretical foundations to support endeavours in the field of interactive visualization. Theory is comprised of general principals and systems of ideas that explain phenomenon and advance knowledge and understanding in a discipline and it drives research that results in insights and enables greater innovations in the field. Having briefly looked at the history and several key concepts of information graphics in Chapter 1, I now turn to a survey of the academic literature surrounding research in this area and examine why theoretical development is lagging. Researchers and practitioners need fundamental theoretical support and this survey examines the methods of overcoming the limitations in validating, defending and evaluating interactives in its absence.

2.2 THE MANTRA

In 1996 Ben Shneiderman, an early researcher and practitioner in the field of interactive visualization, proposed the Visual Information-Seeking Mantra: *overview first, zoom and filter then details-on-demand* (n.p.). At that time, computer-supported information graphics were still in a nascent stage and there was a dearth of research in the field. The Mantra was based on Shneiderman's extensive experience in the field and quickly became regarded as a touchstone for designers, developers and researchers. Shneiderman himself referred to the Mantra as descriptive and explanatory, not prescriptive—he intended it to function as just one of several simple guidelines to help streamline the interactive visualization development process. Nearly a decade later, Craft and Cairns observed the continual frequency with which the Mantra was cited in interactive visualization literature and investigated who was referring to it and why it was so regularly referred to. In a 2005 paper they noted that, while the Mantra is useful to many practitioners (and of course utility fully justifies its relevance), it lacks the empirical validation required of a guiding principle in what they, even then, considered a maturing field. In the absence of more rigorous research, the Mantra had become "a prescriptive principle for many information visualization designers, either implicitly or explicitly." They pointed out that, in general, "many practitioners, particularly novices, are finding guidance from fragmented and varied sources [and] applying this knowledge in a patchwork fashion" and so accordingly the "wide appeal and relative scarcity of methodological knowledge may account for the frequency of the Mantra's citation" (Craft & Cairns, 2005, n.p.).

By 2008, researchers were still noting the lack of theoretical foundations in the interactive visualization sphere. *Information Visualization: Human Centered Issues and Perspectives*—a collection of papers from theoreticians and practitioners of information visualization that had gathered at the Information Visualization seminar held in Germany the year prior—was published. In it, an examination of interactive visualization foundations notes that the field was still suffering from the lack of a clear underlying theory, making it difficult to validate, defend or predict the worth of new methods prior to implementation. "There is much unease in the community" wrote Purchase, Andrienko, Jankun-Kelly and Ward (2008), "as to the lack of theoretical basis for the many impressive and useful tools that are designed, implemented and evaluated by Information Visualization researchers" (p. 46). Independently, in the same year, Liu, Nersessian and Stasko (2008) also noted the frequency of reference to Shneiderman's Mantra, and they too attributed it to the absence of more rigorous and powerful formal theories and methodologies. They wrote:

> *As InfoVis designers, we often have only our own intuition and experience to depend on. Even though InfoVis research has matured technically in recent years, an important problem for the field remains the lack of an underlying theory or even a systematic framework for guiding design and investigation* (p. 1173).

2.3 SCARCITY OF THEORETICAL FOUNDATIONS

Why is there so little theoretical knowledge in an arguably mature field? Interactive visualization is an interdisciplinary and multidisciplinary field and combined disciplines are often challenging to research and study (Pettersson, 2014, p. 13). Specialists from diverse fields come together to create complex digital artifacts comprised of text, image, moving image, audio and interactivity—each area of specialization bringing its own theoretical foundations that may not apply in the new multimodal context. For example, information graphics in print have been widely studied, but the frameworks and typologies that apply to that work cannot be transferred to interactive visualization one-to-one. As Weber and Rall (2012) note in instances like this, the differences lie in the information architecture, interactivity, dramaturgy, intermediality and multimodality and this changes the perception, the production and the final product in fundamental ways that theories of print graphic theories are unlikely to be able to account for (p. 2).

Somewhat paradoxically, as interactive visualizations are being developed at an accelerating pace across a wide range of diverse fields such as engineering, biology, cartography, statistical modelling, text analysis and so on, there is a tendency for interactive visualization research to remain discipline-centric and extrapolation from research in other disciplines occurs only infrequently. As Friendly (2008) observed, "practitioners in these fields today tend to be highly specialized and unaware of related developments outside their domain, much less their history" (p. 17). Over time, it is possible that a chicken-and-egg dilemma has arisen: as discipline-specific work accumulates, the more firmly established and unlikely to branch out the body of knowledge becomes and the less likely cross-domain theories offering broader perspectives will be undertaken; the less cross-domain theories of interactive visualization there are to draw from, the more firmly entrenched and unlikely to branch out each area of research becomes. Vickers, Faith and Rossiter (2013) caution, "[t]he danger of neglecting the theoretical foundations is that the discipline will fragment into isolated communities of practice that fail to learn from one another and replicate work unnecessarily" (p. 1048).

2.4 THE NEWSPAPER INDUSTRY

If interactive visualization research and practice were not already siloed enough, the devastating world-wide economic crash of 2008 served to further bifurcate the trajectory of future research into two distinct paths: narrative interactives and all other forms of interactive visualizations. At that time the newspaper industry, which had already been struggling for relevance in the internet age with free online classified ad listing sites like Craigslist and Kijiji decimating its ad sale revenue, found itself hit particularly hard. Many newspapers that were unable or unwilling to adapt were wiped out—over 120 in the United States alone (Chen, n.d., n.p.). In an effort to attract and retain increasingly capricious and impatient digital-age consumers, larger online news providers like The New York Times, The Guardian and the Washington Post began capitalizing where feasible, with online affordances—video, audio, animation, hyperlinks, social networking and interactivity—to create a new incarnation of journalism with an ever more graphic presentation. Interactives with strong narrative aspects proved immensely popular with users. Shortly thereafter, research literature (though still relatively rare) appeared to address these journalistic devices as an emerging class of media in an interactive visualization niche separate to, or removed from, what was sometimes referred to as "scientific" visualization (Burmester, Mast, Tille & Weber, 2010; Segal & Heer, 2010; George-Palilonis & Spillman, 2011; Weber & Rall, 2012).

2.5 CHALLENGES OF VALIDATION

Complex interactive visualizations of the type seen on large news sites can be very expensive to create in terms of time and human resources—they often require the advanced skills of several specialists such as computer programmers, animators, videographers, statisticians, graphic designers, journalists, subject matter specialists and so on. Practitioners are often under pressure to defend the value of their work to supervisors, funders or other stakeholders who need assurance that their investments are well spent (van Wijk, 2005; Fekete et al, 2008). Newsroom editors considering an interactive visualization for a news story must also take its potential longevity before it grows cold into account before allocating resources to it (George-Palilonis & Spillman, 2011). However, defending interactives by quantifying their benefits is inherently challenging. Much of the literature agrees that the traditional goal of interactive visualizations is to *create user insight* or *amplify cognition* (Carpendale, 2008; Card, Mackinlay & Shneiderman; Fekete et al, 2008; Purchase, Andrienko, Jankun-Kelly & Ward, 2008; Tory & Möller, 2004, van Wijk, 2005). Fekete et al (2008) summarize this to mean,

- *Increasing memory and processing resources available*
- *Reducing search for information*
- *Enhancing the recognition of patterns*
- *Enabling perceptual inference operations*
- *Using perceptual attention mechanisms for monitoring*
- *Encoding info in a manipulable medium* (p. 6).

However all are also in agreement this is neither clearly, nor precisely, measurable. Carpendale (2008) writes,

> *Development of insight is difficult to measure because in a realistic work setting it is not always possible to trace whether a successful discovery was made through the use of an information visualization since many factors might have played a role in the discovery. Insight is also temporally elusive in that insight triggered by a given visualization may occur hours, days, or even weeks after the actual interaction with the visualization. In addition, these information processing tasks frequently involve teamwork and include social factors, political considerations and external pressures such as in emergency response scenarios* (p. 21).

Difficulty in quantifying benefits is particularly true in instances of interactives with lesser narrative qualities (I will address degrees of narrativity in the next chapter) where the user may not have a specific question or goal in mind but is investigating the interactive as a means of formulating new questions or ideas.

2.6 GUIDELINES ARE NOT THEORY

Guidelines like Shneiderman's Mantra are useful as general recommendations and a means to simplify processes into steps or best practices, but they are not absolute or enforceable and conflicting recommendations from other guidelines are not uncommon. Theory is knowledge that is still subject to experimentation but is nevertheless a means to describe how or why an interactive visualization is. It can function as a structure to organize and explains known facts, make predictions about new work or information, conceptualize and systematize our knowledge about diverse phenomena. Without it, research into interactives suffers a lack of focus and direction (Pettersson, 2014, p. 6). A theoretical framework determines how a researcher formulates her or his research problem, how she or he proceeds investigating the problem, and what meanings are attached to data arising from the investigation (Imenda, 2014, p. 185). It can provide a structure within which practitioners can understand and interpret their work. Bederson and Shneiderman (2003) summarize the ways theory can enable us to understand interactive visualization research and practice in particular: to describe key concepts; explain relationships and processes; predict performance in existing and new situations; prescribe guidelines and warnings for design; and facilitate creativity and discovery in future practice or research (p. 349). As van Wijk (2005) simply puts it, "[i]n order to make good choices, an understanding of the purpose and meaning of visualization is needed. Especially, it would be nice if we could assess what a good visualization is" (p. 79). Theory enables researchers and practitioners to better establish "what a good visualization is" across various disciplines of study and practice (thus avoiding repetitions in the work) and create a broad-ranging body of knowledge that researchers and practitioners can draw from to better enable them to describe, validate and defend interactives (Purchase, Andrienko, Jankun-Kelly & Ward, 2008, p. 47).

It is widely held that evaluation is important to interactive visualization research, but limiting factors mean conclusions are better suited to correcting design problems than drawing broader meaning from. However, each interactive is a unique configuration and there is an infinity of design possibilities. As such according to Liu et al (2008), evaluation results do not appear to play a significant role in broader research (p. 1178). Carpendale (2008) outlines three desirable factors of a worthwhile evaluation: generalizability (the extent to which it can be applied to work outside of the study); precision (how definite about the measurements that were taken and how controlled factors outside of scope were); and realism (how similar the context of the evaluation matches the context in which the visualization would actually be used). Any two of these factors, she posits, are difficult to manage; three are impossible (p. 22–23). User studies are by far the most common evaluation method and according to Liu et al (2014) offer a scientifically sound method to measure an interactive's performance. User studies range from informal surveys, crowdsourcing user surveys, to small group lab studies (p. 1376). These, however, are not without their challenges. For instance, participants in evaluations are typically few yielding small data sets. Tasks users are asked to perform are simple—limited, with clear objectives in a controlled setting—in order to draw clear conclusions. This means high-level cognitive tasks like understanding trends or causal relationships are not evaluated (Tory & Möller, 2005, p. 8). Carpendale (2008) outlines the difficulty in obtaining appropriate samples of participants: if the interactive is intended for domain experts it is often difficult to obtain their time; if the interactive is of a novel form participants might be attached to previous methods. "Think-aloud" protocols can be useful if carefully done, but she argues it is at the cost of realistic behaviour with the interactive (p. 20). As Liu et al (2008) write,

> *… determining usefulness of new designs is hard and we are still not sure how to best do that. In many traditional experimental methods, some control variables are identified and human subjects are brought in as operators of a system. The goal is to measure and compare system performances by varying control variables. Such an approach is arguably influenced by scientific methods in natural sciences. However we are often left perplexed after these experiments, not able to explain the results obtained. Furthermore, it is not impossible that doing these experiments in another lab with another group of participants could produce distinctively different results. Many have come to realize that using scientific methods does not necessarily mean we are doing good science* (p. 1178).

2.7 TAXONOMIES

Taxonomic studies have become a common approach for researchers desiring to provide a more solid foundation in a rapidly burgeoning field where interactives and interactive visualization categories are being generated at an accelerating pace. As an empirically-driven strategy, taxonomies are useful for creating and organizing a structured space to understand interactives by classifying them, their characteristics and their salient concepts. Taxonomic examinations of note mainly fall into three very general categories: data or data types (Shneiderman, 1996; Card & Mackinlay, 1997; Chi, 2000; Chen & Floridi, 2012); interactivity (Pfitzner, Hobbs & Powers, 2001; Yi, Kang, Stasko & Jacko, 2007); and user tasks, goals or operations (Amar & Stasko, 2005, Card & Mackinlay, 1997; Hobbs & Powers, 2001). Yi et al (2007) offer a comprehensive survey of taxonomies relevant to interaction techniques by taxonomic units. Chen & Floridi (2012) suggest user tasks, goals or operations is also structured further into three general groupings: information retrieval, information analysis and information dissemination. Outside of these general taxonomic groups, Pfitzner et al (2001) also consider a taxonomy of user skill and context of use, and Nichani & Rajamanickam (2003) issued a very simple but much referred to four-category classification of “interactive visual explainers” that has become a touchstone for journalistic interactive visualization research since.

Despite the acknowledged benefits of taxonomic strategies to structure the space of possibilities in interactive visualization research, they are not without limitations. Taxonomies, by their very nature, seek to tame complexity by grouping like features together and pertinent details can be lost. Further, like the blind men describing an elephant, taxonomic studies typically address a singular perspective (like data types or user tasks) with the risk of misrepresenting the compound whole. As Liu et al (2008) explain, taxonomies are a “bottom up” approach that, without a comprehensive theoretical, or “top down” framework, risk being overwhelmed by details and not looking in the right places that must be addressed when developing theory—starting with a theoretical framework, they argue provides important direction and focus required in a maturing field. They write,

> *To reach its full potential, a science of interaction should not be just a taxonomy of interaction techniques or a framework of the abstracted task procedures; it should be a scientific approach to understand how cognition emerges as a property of interaction between external and internal representations. The research problem then, is not to discover, for example, the assumed condition-action schemata that govern human behavior. Instead we need to ask research questions such as the following:*
>
> - *What are the nature and mechanisms of coordination and cognitive coupling?*
> - *How do people develop interaction strategies during sensemaking and analytical reasoning?*
> - *How are external representations created and how do they evolve?*
> - *How does interaction with visual structures enable turning information into meaningful understanding?* (p. 1178)

2.8 THEORIES FROM OTHER DISCIPLINES

As a hybrid form, interactive visualizations have incorporated knowledge, methods, practices, tools and strategies from a wide range of disciplines. Purchase et al (2008), Chen & Jänicke (2010) and Pettersson (2014) also point to the need to likewise incorporate theories, or parts of theories, from other disciplines. Purchase et al (2008) observe,

> *Investigating theoretical approaches used in other disciplines, and their relation to Information Visualization, is an obvious way forward, and can provide a useful way for researchers in the area to present, discuss and validate their ideas […] The more solid theoretical analyses that Information Visualization researchers or tool designers can call on in defending or validating their work, the more secure the discipline will be* (p. 62).

A small but growing body of interactive visualization literature has focused on building theoretical foundations in this manner. Liu et al (2008) point to the distributed cognition theoretical framework, originating largely from the work of Edwin Hutchins and colleagues in the mid 80s.

Distributed cognition, not a new idea to HCI, supports interactive visualization by taking not just a user's internal processes but also their social, cultural and material environment into account in shaping their process of acquiring knowledge: "cognition is embodied, enculturated, situated in local interactions and distributed or stretched across humans and artifacts" (p. 1174).

Purchase et al (2008) argue for a data-centric predictive theory to instruct practitioners how to better select and use the right tools for their data and exploration of it. This work is an initial sketch of a theory that seeks to "define pattern types used to represent relationships between attributes or between phenomena (represented by several datasets differing in structure) such as correlation (co-occurrence) or influence" and highlights the "usefulness of systems which can explore the data model, predict the patterns in datasets, and facilitate the perception of these patterns." They also propose a deeper exploration of formal scientific modelling to describe and predict phenomenon in interactives and facilitate design, arguing that existing models from perceptual psychology and cognitive science provide guidelines but may not be sufficient to address the human and computer context of interactive visualization (p. 48). More recently, Vickers, Faith & Rossiter (2013) combine semiotics and category theory and apply the frameworks of both Saussure and Peirce to visualization processes to explore the relationships between interactive visualization "signs, sign systems, the consumers of those signs, and the systems they represent" (p. 1048). Colin Ware (2008, 2012) has conducted considerable work into two main psychological theories to explain perceptual processing that can be applied to interactive visualization: preventive processing theory that explains what visual features can be processes effectively and Gestalt theory which describes principles used to understand images. Both of these theories will be examined in greater detail in the next chapter.

Information theory, however, has arguably gained the greatest traction in interactive visualization research (Purchase et al, 2008; Chen, 2008; Chen & Jänicke, 2010; Chen & Floridi, 2012; Coppin, 2014; Pettersson, 2014). Widely attributed to Shannon (1948), information theory was first introduced as a model or "pipeline" of a basic communication system and provides a framework for quantifying information, optimizing communication, resolving uncertainty and managing loss of information. Chen and Jänicke (2010) identify aspects of a visualization pipeline that closely resembles a communication pipeline as outlined by Shannon (1948):

- *Data abstraction usually results in data compression;*
- *creating and viewing a visualization is usually an information discovery process;*
- *the messages in a visualization are not guaranteed to be received by a viewer;*
- *the quality of a visualization is often measured by probabilistic experiments;*
  and so forth (p. 1206)

Information theory can explain a range of phenomena in interactive visualizations and contribute to the body of knowledge supporting the field, but according to Purchase et al (2008) no single uniting theory may be possible to encapsulate the whole interactives field. Complexity of the medium and the strong relationship to several other diverse disciplines (cognitive science, graphic design, statistics and so on), they argue, might require the support of several theories, each with a different perspective (p. 62) . Practitioners turning to existing theories for insight, have found no fully-developed theories that are sufficiently able to describe, explain, predict effectiveness of, or generate interactives as of yet.

2.9 CONCLUSION

Today, twenty years after it was first published, Shneiderman's Mantra continues to be referred to with regularity—at the time of this writing, a look at Google Scholar indicates it has been cited over 3,700 times. That it remains a touchstone in this area of endeavour indicates a persistent deficiency of theoretical knowledge with which to better understand, explain, predict phenomena and evaluate work in the realm of interactives. While this survey can not confirm the reason for this scarcity, one likely cause is the current practice of research being conducted in isolated communities of practice or nonacademic settings with little communication between them.

Another possible reason is the hybrid, multifaceted nature of interactives brings researchers and practitioners of diverse fields together and each maintains the perspective of their own background. A theory, or theories, that apply across disciplines involved in interactive visualization research would enable practitioners to extrapolate from the practice of others and open up their work to greater possibilities.

3.THE PARTS OF THE SUM

3.1 INTRODUCTION

Rather than focusing on functional aspects and categories of application, the intent of this chapter is instead to establish a conceptual framework for examination and greater understanding of interactive visualizations as cognitive and communicative tools. By deconstructing interactives to their constituent elements and establishing the ways and means in which these elements relate to one another, key concepts will be formed. Central to this discussion is the presentational and discursive aspects of images (still and motion) and language, the fundamental challenges of creating image-based narratives and an examination of the inherent tension between narrative and interactivity.

3.2 IMAGES

> *Thinking is more interesting than knowing, but less interesting than looking.*
> ~ Johann Wolfgang von Goethe

Images can more clearly represent large amounts of certain types of information in a small space than can otherwise be achieved with text. Information graphics—both static and dynamic multivariate images such as charts, graphs, diagrams and maps—excel at expressing comparative or relational aspects of data in order to highlight significant connections or identify patterns. As Tufte (1991) points out, "highlighting significant differences is the key to information graphics, and at the heart of each is a single question: *compared to what?*" (p. 67). Visual comparisons efficiently enable the identification of clusters, outliers, trends, patterns and gaps. Information graphics also provide a more straightforward expression of relationships that are otherwise difficult to induce—inside, outside, part of, around and so on—that are suggestive of position, either literally or figuratively. Drawing on the relationship between elements, an infographic reveals the structure of what it represents, either that which exists in the original data or that which can be derived from the data (Ware, 2013, p.101). Figure 12 shows a simple example of a management

Jane is Jim’s boss.
Jim is Joe’s boss.
Anne works for Jane.
Mark works for Jim.
Anne is Mary’s boss.
Anne is Mike’s boss.

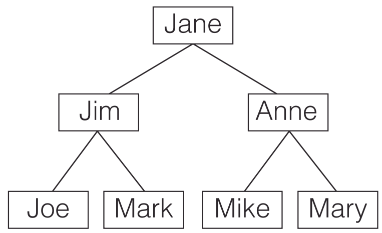


Figure 12. Management structure chart. (Derived from Ware, 2012, p. 330).

structure to demonstrate the ease of perception of the chart on the right compared to the textual notation on the left.

A well-designed information graphic provides the *gist* of the data—the substance or salient aspects of the information and a perceptual shortcut. Indeed, the “overview” of Shneiderman’s (1996) visual information-seeking mantra: “overview first, zoom and filter, then details-on-demand” refers to a conscious strategy to capitalize on the benefits of gist (p. 2). Gist is the ‘macro’ Tufte (1991) refers to when discussing micro/macro readings of infographics: the texture of detail that we don’t need to direct our full attention to that accumulates into larger, coherent structures (p. 38). Gist provides a summary of the data at a low cognitive cost in terms of time and mental energy. Ware (2013) states,

> *Providing context for an object that is perceived is the gist of a scene. Gist is used mainly to refer to the properties that are pulled from long-term memory as the image is recognized. Visual images can activate this verbal-propositional information in as little as 100 msec (Potter, 1976). Gist consists of both visual information about the typical structure of an object and links to relevant nonvisual information. The gist of a scene contains a wealth of general information that can guide our actions, so that when we see a familiar scene (for example, the interior of a car) a visual framework of the typical locations of things will be activated* (p. 385).

Our ability to pick up gist is, in part, because vision has a very high bandwidth—huge amounts of information from our environment can be rapidly perceived, seemingly at once. The reasons for this are complex and beyond the scope of this paper, but Ware (2013) summarizes a model of perceptual processing in three stages. In Stage 1, billions of neurons work in parallel to extract low-level properties such as orientation, colour, texture and movement patterns from every part of the visual field at once, whether we are paying attention or not. This stage is transitory and bottom-up, and sensory in nature. Stage 2 is a dynamic and flexible stage where top-down attentional processes of pattern perception determine structures and regions of colour, texture and movement patterns. As such, it is slightly slower than Stage 1. Stage 3 is the visual working memory that holds a few perceptions long enough for active attention. During this stage, we conduct a series of visual queries that arise from our visual search strategies. When we find an "answer" to a visual query, it will briefly receive our attention. Each movement of our eyes is, in fact, a redirection of attention. At this stage, gist emerges into our consciousness. From here, we can rapidly perform further visual queries based on our expectations or motivations to fill in any further details (p. 22).

3.3 COGNITIVE TOOLS

Consequently, for thinking through concepts that involve comparative relationships and positional concepts, visual representation is an important tool that facilitates cognitive processes and allows analytical thought to become faster and more focused. Indeed, for sighted individuals, it is indispensable to our very thought processes. As Ware (2013) states,

> *...we acquire more information through vision than through all other senses combined. The 20 billion or so neurons of the brain devoted to analyzing visual information provide a pattern-finding mechanism that is a fundamental component in much of our cognitive activity* (p. 2).

Thinking is not something that happens entirely, or even mostly, inside our heads. Sketches, the most basic and informal of all cognitive tools, are ideas made visible—an "external artifact to support decision making" (Ware, 2013, p. 3). Initially, a rough concept is formed in the mind and a loose scribble is drawn on paper, externalizing the concept and providing a starting point for refinements. The designer critiques the scribble by informally executing a series of visual queries. New meanings might be attached or discerned from the sketch and it can be modified accordingly (Ware, 2008, p. 148). Visual tools like paper and pencil do amplify cognition as we can think better with, than without, them. Liu, Nersessian, and Stasko (2008) observe,

> *… artifacts are scaffolds for cognition, i.e. they make cognitive tasks easier or more efficient, and in some instances they provide a means of accomplishing cognitive tasks that could not be performed without the tools. However, cognition involves only the manipulation of information abstracted and represented "in the head", and artifacts serve to assist these processes* (p. 1173).

A person working with thinking tools is more capable of working through complex ideas than someone sitting alone with their thoughts. Cognitive tools support processes like memory and metacognition, support lower level cognitive demands so that mental resources can be applied to higher order thinking, allow users to engage in cognitive activities otherwise beyond their abilities and allow users to problem solve by generating and then testing hypotheses (Lajoie & Derry, 1993, p. 261).

In a similar sense, language can be considered as having tool-like qualities in aiding or perhaps even comprising higher-level cognition. According to Mirolli and Parisi (2009), the traditional view of cognitive science was that cognition is linguistic in itself (as the manipulation of language-like structures) and the function of language is just to express these language-like structures. In other words, language does not significantly affect cognition (p. 518). However, since the 70s these assumptions have been challenged by a number of philosophical views against, and proposed alternatives to, the symbol manipulation paradigm. Mirolli and Parisi argue that, human language is not only used for communicating with others but also to communicate with oneself to guide actions and cognitive processes and this, it is argued "plays a fundamental role in the development of all human psychological processes" by the learned ability to categorize experiences, focus on important aspects of the environment, remember useful information and so on (p. 520). They point to the work of Andy Clark who posits that language is not only for communication but also an "external artifact whose current adaptive value is partially constituted by its role in re-shaping the kinds of computational space that our biological brains must negotiate in order to solve certain types of problems, or to carry out certain complex problems" (Clark 1998, as cited in Mirolli et al, 2009, p. 520). Using computer simulations Mirolli et al (2009) demonstrate that communicating with oneself has a tremendous influence on the development of cognition, including high-level thinking which considers cognition as "environmentally embedded, corporeally embodied, and neurally embrained." (van Gelder, 1999, as cited in Mirolli et al, 2009, p. 526).

The most obvious way language functions as a cognitive tool is by augmenting our memory in the artifactual world with writing books or writing in notebooks, diaries and so on. These objects can then, in themselves, be used as cues for information that is stored in our brains. Linguistic labels typify objects by identifying similarities between them and this cognitively simplifies our environment and reduces mental effort. Language allows problem solving to become a communal and cumulative activity. The physical properties of written language allow ideas from different sources and times to be juxtaposed, rearranged, compared and influence each other in a manner that would be otherwise impossible and as such reinforces intellectual endeavour. Finally, language provides the ability to display second-order cognitive dynamics, that is, thinking about thinking (West, n.d., p. 2).

3.4 SYMBOLS AND LOGIC

Language-based thinking and visual thinking are not the same and the difference is greater than a simple variance of a predominantly spoken (and auditory) mode and a visual mode. As Ware (2008) points out, "a more basic distinction between the mode of expression has to do with symbolization and logic" (p.131). Language, based on assigning arbitrary sounds and corresponding and equally arbitrary graphic marks, is symbolic in nature. He clarified this with an examination of sign-language, which he argues, though predominantly visual in nature, is a natural language in its own right, not merely a visual translation of a spoken language. As a natural language, it too is a socially developed system of shared symbols—in this case physical gestures rather than vocalizations—together with specific grammar. Languages, he points out, are comprised for the most part of arbitrary symbols. Sign language uses arbitrary gestures and verbal language uses arbitrary vocalizations to represent units of thought, expressed in an arbitrary, but consistent, structure. In each there are exceptions: sign languages have some gestures that look like the actions they represent, and spoken languages have onomatopoeic words that sound like the word they represent, but in both instances, the more sophisticated a language becomes, the greater the proportion of arbitrary words (p. 131). Ware (2013) observes that written language, although it "comes in initially through the visual channel, is transformed into a sequence of mentally recreated dynamic utterances when it is read" and is processed in the same part of the brain that processes verbal and sign languages (p. 328). Similarly, the more sophisticated a written language becomes, the greater the proportion of arbitrary letter forms. In Figure 13, for example, the Latin alphabet letter 'A' originated as a pictograph of an ox head, but over millennia, as the language spread geographically and was assimilated by other cultures, the letterform evolved into the abstract symbol that represents a phoneme (a distinct unit of sound) that we are familiar with today.

The arbitrary qualities of language take a long time to learn, are easily forgotten and are culturally-situated, as anyone learning a second language can attest to. It takes a good deal of practice

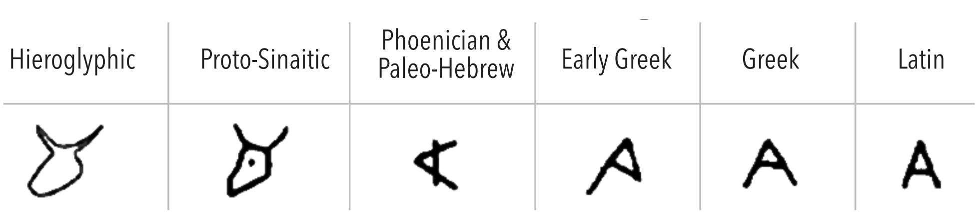


Figure 13. From pictogram to symbol. Evolution of the letter A (Derived from Craig, 2006, p. 11-12).

to become proficient at a language, but it has an advantage over all other means of expression in its ubiquitousness and complexity of expression. It is "by far the most elaborate, complete, and widely shared system of symbols that we have available. For that reason alone, it is only when there is a clear advantage that visual techniques are preferred" (Ware, 2013, p. 331).

There are arbitrary visual symbols such as musical notation, traffic signs, religious symbols or logos, but these function somewhat differently than letterforms. Like letterforms, they must be learned and are reliant on culturally or socially agreed upon meaning. But where letterforms represent units of sound, other visual symbols function like individual words or concepts. They lack the syntax and semantics that is characteristic of a true linguistic system. Visual symbols of this nature can be meaningful and easy to remember and as such are a powerful means of representation, but their range of expression is considerably more limited than linguistic systems.

3.5 NARRATIVE

The arbitrary symbolism of language makes possible the expression of abstract or imprecise mental constructs that have no physical referents. As Rimmon-Kenan (as cited in Ryan, 2004) observed, an image cannot fully convey possibility, conditionality, or counterfactuality (p. 11), although, as we will see, there are visual ways to suggest these types of ideas. Being bound by the sensory, images are unable to fully express abstract temporal concepts either, and Ryan (2004) considered the ability to infer causal relations as essential to narrative. She wrote, "only language can make it explicit that the queen died of grief over the death of the king…" (p. 11). A narrative, in this sense is more than an account of events; it includes an effort to express *why* the event happened. Little (2010) writes,

> *What is a narrative? Most generally, it is an account of the unfolding of events, along with an effort to explain how and why these processes and events came to be. A narrative is intended to provide an account of how a complex historical event unfolded and why. We want to understand the event in time. What were the contextual features that were rele-*

vant to the outcome—the settings at one or more points in time that played a role? What were the actions and choices that agents performed, and why did they take these actions rather than other possible choices? What causal processes—either social or natural—may have played a role in bringing the world to the outcome of interest? (n.p.)

With a commonly used visual symbol, like a line or an arrow, it is possible to denote some kind of relationship between two entities, but not necessarily causality. Although the terms *narrative* and *story* are sometimes used interchangeably, it is important to note here that a story in its simplest form is one thing happening after another without necessarily an explicit element of causality. Weber and Rall (2012) write, "[a] story in an information graphic can be defined as a sequence of facts or factual events that are temporally structured and coherently related to each other" (p. 8).

3.6 TEMPORALITY

When envisioning temporality we have a spatial model or map in our mind of where the past and future lay and what direction time flows, but it is important to remember that this notion was acquired in our childhood and our social and cultural environment had a major influence on it. These thoughts are attached both to the words we use to describe temporality and the spatial orientation of the way we write. Studies conducted by Tversky and colleagues have shown,

> "*…people who wrote from left to right tended to map temporal concepts from left to right and people who wrote from right to left tended to map temporal concepts from right to left. This pattern of findings fits with the claim that neutral concepts such as time tend to be mapped onto the horizontal axis*" (Meirelles, 2013, p. 88).

In English, we describe temporality on a horizontal axis with words like before, after, forward, and backward. Accordingly, Mandarin dialects are traditionally written in vertical columns from bottom right to top left, and Mandarin speakers use the spatial morphemes shàng ('up') to talk about earlier and xià ('down') to talk about later events, weeks, months, semesters and so on (Boroditsky, 2001, p. 5).

Language is necessary to fully express temporality because its very structure is temporal in nature. Language is meted out serially over time—rules of linguistic syntax require words to follow a linear, discursive pattern to form proper sentences and it takes a few seconds to hear or read even a short sentence. This also makes it good for describing procedural information. Images, however, are presentational rather than discursive—there is no particular order to "read" them in (Lester, 2006, n.p.) and as Ware (2013) observed, "in contrast with the dynamic, temporally ordered nature of language, relatively large sections of static pictures and diagrams can be understood in parallel" (p. 328). Causality (used here in the sense of some process giving rise to another process, event or phenomenon) also bears the understanding that these occurred over time, and they occurred serially—first the king died, and then after that happened (and *because* that happened) the queen died of grief.

Ryan (2004) was clear that the passage of time is necessary for narrative to exist. However, she puts forth a case for *degrees* of narrativity. She states,

> *This interpretation of narrative supports the intuitive notion that, within a novel, not every sentence moves the plot forward. The narrativity of a text would be borne by sentences that imply the temporal succession of their referents, as is the case with the evocation of events and actions, as opposed to those sentences that refer to simultaneously existing entities, to general laws, to static properties, or to the narrator's personal opinions. The degree of narrativity of a text could thus be measured by the proportion of properly narrative sentences* (p. 7).

3.7 TEMPORALITY IN IMAGES

A static image cannot tell a full story on its own, because it lacks the means to express temporality and "the ability to articulate specific propositions and to explicate causal relations" (Ryan, 2004, p. 139). However, there are ways visuals can summon a degree of narrativity by evoking a story in the imagination or memory of the viewer by the symbolic representation of passing time.

Moshe Barasch (1997) outlined how narrative can be injected into static images using one or a combination of two strategies to imply temporality—the *pregnant moment*, or with repeating elements (for perhaps a fuller narrative) in what he referred to as the *narrative strip* (p. 257).

Barasch (1997) identifies the term "pregnant moment" as originated in G.E. Lessing's (as cited in Barasch, 1997) essay, Laocoon. Lessing used the term as an explanation for a way the artist depicts a story. Visual clues, often layered, suggest to the viewer what has happened prior to the frozen moment we are witness to in the work of art, and what is about to happen in the future:

> *The [visual] artist can never use of ever-changing reality more than one single moment of time and, if he is a painter, he can look at this moment only from one single aspect. But since their works exist not only to be seen but also to be contemplated...it is clear that this single moment and single aspect must be the most fruitful of all that can be chosen. Only that one is fruitful however that gives free reign to the imagination* (p. 8).

A rich example of a pregnant moment evoking a degree of narrativity can be found in William Holman Hunt's 1853 painting *The Awakening Conscience* (see Figure 14). The painting captures the instant a young woman comes to realize that she may be in moral peril. Every element in the abundantly detailed painting symbolically represents what led to this moment, and what her future may hold for her if she does not change her ways. Terry Riggs (1998) summarizes the painting:

> *A gentleman has installed his mistress (known to be such because of her absence of a wedding ring) in a house for their meetings. As they play and sing to Thomas Moore's* Oft in the Stilly Night*, she has a sudden spiritual revelation. Rising from her lover's lap, she gazes into the sunlit garden beyond, which is reflected in the mirror behind her. The mirror image represents the woman's lost innocence, but redemption, indicated by the ray of light in the foreground, is still possible. Intended to be 'read', the painting is full of such symbolic elements. The cat toying with the broken-winged bird under the table symbolises*

the woman's plight. A man's discarded glove warns that the likely fate of a cast-off mistress was prostitution. A tangled skein of yarn on the floor symbolises the web in which the girl is entrapped. Indeed, as Ruskin wrote to the Times on 25 May 1854, 'the very hem of the poor girl's dress, at which the painter has laboured so closely, thread by thread, has story in it, if we think how soon its pure whiteness may be soiled with dust and rain, her outcast feet failing in the street'. The frame, designed by Hunt, also contains various symbolic emblems; the bells and marigolds stand for warning and sorrow, the star is a sign of spiritual revelation (William Holman Hunt section, para. 1).

Figure 14. Hunt, *The Awakening Conscience*. 1853, Oil paint on canvas, 762 x 559 mm.

The major drawback of the pregnant moment, according to Ryan (2004), is a loss of narrative determinacy. Depicting a single instant on the narrative trajectory is not a story but rather a variety of narrative possibilities that a viewer will plot their own way through. The story tends to "fray toward the edges, since the network of possibilities increases in complexity the farther one moves away from the climactic moment" (p. 141). As noted earlier, visual symbolism is reliant on culturally or socially agreed upon meaning, and visual elements such as a discarded glove warning of prostitution or marigolds representing sorrow in *The Awakening Conscience* might only be relevant to a limited number of viewers: those familiar with the time period and cultural milieu the painting was created in.

If the pregnant moment expresses some degree of narrativity by imbuing a composite image with symbols or suggestions of temporality, multiple image techniques are on the other end of the spectrum, plotting several points on a narrative trajectory and illustrating each one individually. Barasch (1997) stated that where the pregnant moment (or composite type) may be described as a spatialization of time, the narrative strip creates a dynamization of space (p. 260). A familiar example of the narrative strip can be seen in cartoon strips and graphic novels. These images succeed in expressing the passage of time when scenes of each frame are connectable, significant to the story and represent a change. Ryan (2004) wrote,

> *The approach prefigures the frames of moving pictures, but, instead of depending on a projector to animate the show, it uses the eye of the spectator moving from panel to panel to keep narrative time running. The reader (for eye movement amounts to an act of reading) constructs a story line by assuming that similar shapes on different frames represent common referents (objects, characters or setting); by interpreting spatial relations as temporal sequence (adjacent frames represent subsequent moments); and inferring causal relations between the states depicted in the frames* (p. 141).

The dynamization of space is at the heart of what Tufte (1991) referred to as *small multiples*, series of "information slices ... positioned within the eyespan, so that viewers make comparisons at a glance—uninterrupted visual reasoning. Constancy of design puts the emphasis on changes in data, not changes in data frames" (p. 67). Small multiples are adept at expressing change over time. Even a time axis on a simple chart is a rudimentary form of small multiple: in Figure 15 each vertical slice represents a unit of time that we can then compare with adjacent slices. A more detailed example, Figure 16, shows the comparison in quantities of air pollutants over time. However, because we are not witness to what event caused the change, the graphic has a negligible degree of narrativity. As Tufte (1991) stated, "[t]he problem with time-series is that the simple passage of time is not a good explanatory variable; descriptive chronology is not causal explanation" (p. 37)—in other words, a sequence is not a story. Figure 17, however, imparts an element of narrativity because a degree of causality is apparent: Ware (2008) asserted, "assembly instructions have the classic form of a narrative in that a problem is posed (assembling something), elaborated (the detailed steps), and hopefully resolved (the fully assembled object)" (p.143).

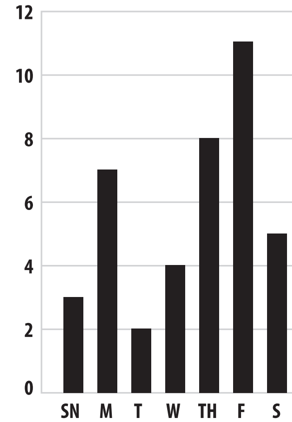


Figure 15. A simple bar chart.

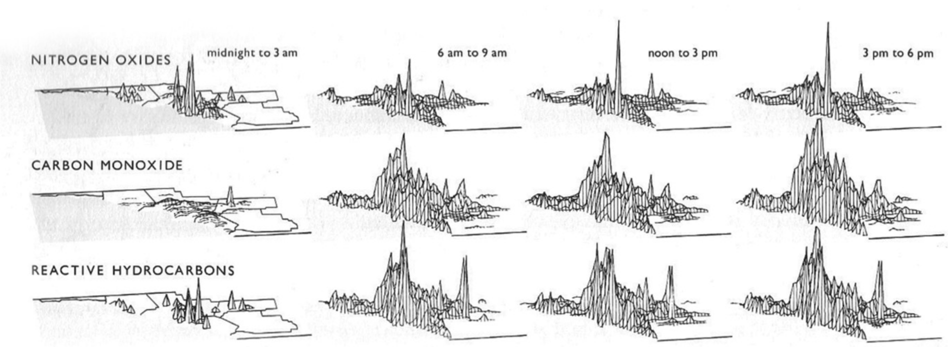


Figure 16. Time series. Quantities of air pollutants over time (Tufte, 1991, p. 28).

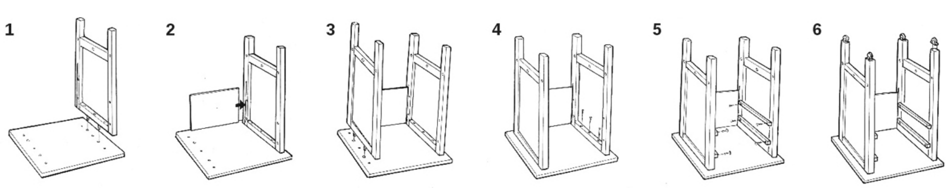


Figure 17. Assembly instructions. Putting together a desk (edutexts.org, n.d., n.p.).

3.8 MOTION IMAGES

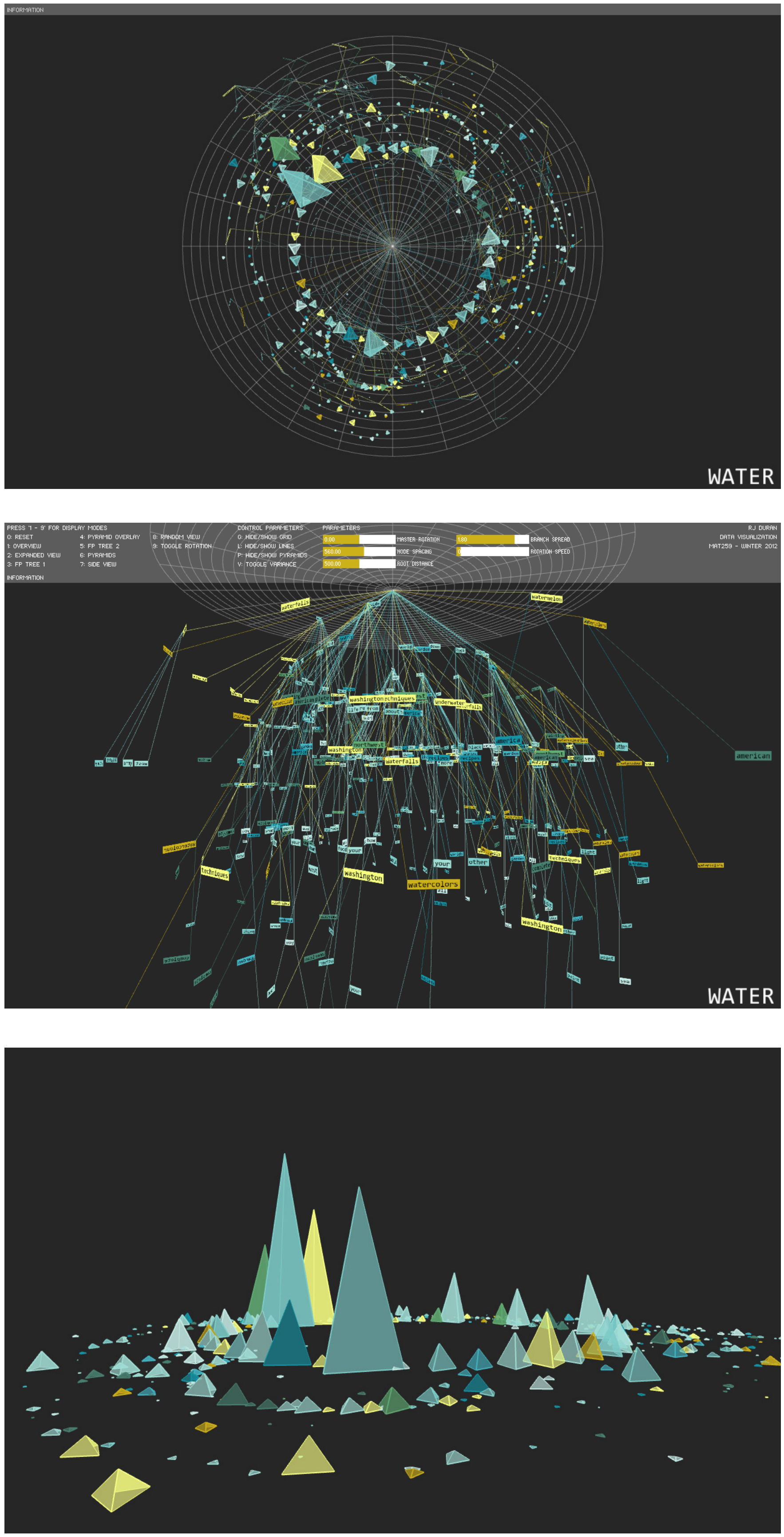
Derived from sequentially viewed images, motion images are the most significant way we visually represent the passage of time. While capable of recording movement in real-time, motion images are also temporally fluid: depictions of time can appear to speed up, slow down, reverse and reorder with flashbacks and flash forwards. Filmmakers use a seemingly limitless variety of symbolic means to express time: montage sequences that show calendar pages flipping, spinning hands of a clock, or quick edits of seasons changing at the same location for example, but more often than not depictions of temporality in film are a result of post-production editing.

Contemporary movies are an established and ubiquitous method of storytelling, but even silent movies illustrate that language is not necessary for narrative to be conveyed as long as there is a degree of cause and effect: filmmakers design actions and camera shots to guide the attention of viewers and ensure that their working memories will retain sequential information that carries the plot forward (Ware, 2013, p. 340). In motion images, the perception of physical causality requires precise timing: "for causality to be perceived, visual events must be synchronized within at least one-sixth of a second. Given that virtual-reality animation often occurs at only about 10 frames per second, events should be frame accurate for clear causality to be perceived" (Ware, 2013, p. 234). Once the temporal sequencing of a traditional motion image has been established by the filmmaker and the film is determined to be complete, it is temporally self-contained. Of course viewers are free to manipulate it by watching it backwards, speeding it up, and so on, but that is rarely the intent of the filmmaker.

3.9 INTERACTIVE VISUALIZATIONS

Interactivity is the central defining attribute of interactive visualizations. As established in Chapter 1, interactivity can be considered a conversation between the user and the content. Evolving digital technologies have given rise to interactive visualizations—hybrid, multimodal cognitive tools that have the sensory, high bandwidth perceptual advantages of static images, the

Figure 18a–Figure 18c.
WATER. Screen captures showing explorable interactive environment (blog.rjduran.net, n.d., n.p.).



dynamic temporal quality of motion images, and varying degrees of user control and web-based hyperlinks. Weber and Rall (2012) define interactives as "an independent visual representation of information or knowledge with different modes: e.g., images (still and moving, diagrams, maps), written texts, audios, and design elements are combined in such a way that they create a new hybrid form" (p. 4). As digital processing speed and display resolution increase, and data source opportunities increase, interactives are able to draw on almost unimaginably vast amounts of data for display. Like static information graphics, they enhance pattern finding and comparative and relational aspects, but rather than a single presentation, interactive visualizations also enable the expression of time and motion, and interactivity provides options for exploration. Tours through visualized data can be organized in a linear sequence or they can be nonlinear "inviting verification, new questions, and alternative explanations" (Segal & Heer, 2010, p. 1139).

In Figures 18a to 18c, we see an example of this: screen captures from the interactive *WATER*, designed to explore connections between words associated with the word "water" in book titles from the Seattle Public Library database from 2006 to 2011. Here we see the incoming book title words visually represented as both tree structures and volumetric pyramids in a polar plane (2012). Exploration consists of filtering connections and "moving" around the structure to better examine connections, comparisons, clusters and outliers.

WATER has a high degree of interactivity and the user plots his or her own way through the visualization as "a director who composes his own story" (Burmester, Mast, Tille, & Weber, 2010, p. 361). However, because *WATER* has no structurally incorporated elements of causality—that is, no evidence as to why the data reveals itself as it does—any narrative, or notion of narrativity, arises from the user's memories and imagination only. As open-ended cognitive tools, interactives like *WATER* are particularly useful when a user doesn't yet know what questions to ask about the data or when he or she wants to find aspects to examine more closely. Kerren, Stasko, Fekete and North (2008) describe this type of interactive:

> *Information Visualization is still an inductive method in the sense that it is meant at generating new insights and ideas that are the seeds of theories, but it does it by using human perception as a very fast filter: if vision perceives some pattern, there might be a pattern in the data that reveals a structure. Drilling down allows the same perception s ystem to confirm or infirm the pattern very quickly. Therefore, information visualization is meant at "speeding up" the process of filtering among competing theories regarding collected data by relying on the speed of the perception system* (p. 4).

In contrast, some interactive visualizations function less as open-ended cognitive tools and more as self-contained story-telling devices. Figures 19a to 19c are screen captures from a non traditional and informationally rich interactive called *inequality.is*, which outlines the problems

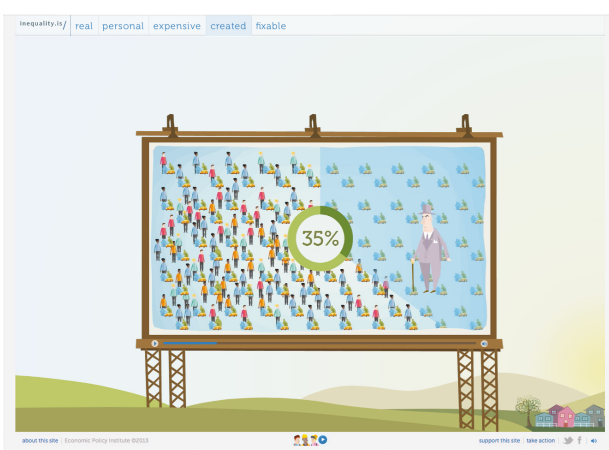


Figure 19a–Figure 19c. *Inequality.is.* An interactive examining income, wealth, wages and opportunities in the U.S. (inequality.is, n.d., n.p.).

with the United States becoming increasingly unequal in terms of income, wages, wealth and opportunities. It does this by asking the user to participate and answer questions like "how would you split up income between the top 10% and the other 90%?" and enter in basic data about themselves to see how they fare economically compared with others and with a vision themselves if circumstances had been different. Short animations throughout enrich the narrative and explain how the situation came to be, how it could be better and what the user can do to fix it. Opportunities for interaction are limited but strategic, creating engagement for the user.

Inequality.is follows a narrative format that *WATER* does not—it has an author-driven perspective with several linearly-ordered chain of causally-related events in the form of animations throughout. Even though the user is free to click through the events in any sequence she chooses, the chronology of the storyline, as determined by the author, remains intact. Like a traditional narrative, events expressing causality occur in a chronological order, but they are not always revealed in a chronological order. To use our earlier example, an author can begin a story with the queen dying and only reveal at the end of the story that it was from grief because the king had died, usually in order to serve some artistic or dramatic intent.

Hazel (2008) explored the ways narratives are central to human understanding, both individually and across cultures. Because human experience occurs over time and our memory encoding system is episodic, we are predisposed to stories and our brains are hardwired to learn, process and remember in a narrativized way better than in a logico-scientific way. He looked to cognitive psychology and neurobiology to give an overview of the connection between the parts of the brain that manage time-based experiences and executive functions, and how this connection is at the core of learning. In the context of interactives for pedagogical application, Hazel asked, what benefit do narratives afford? The answer he arrived at was better comprehension, retention, and enjoyment (p. 203).

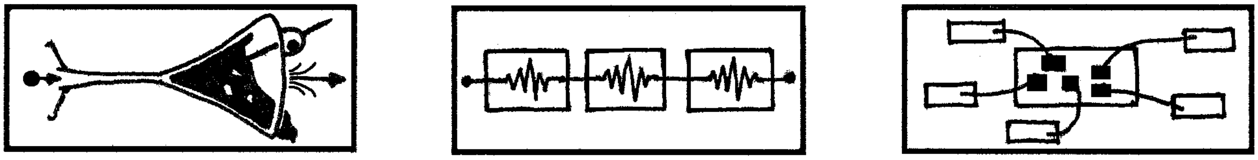
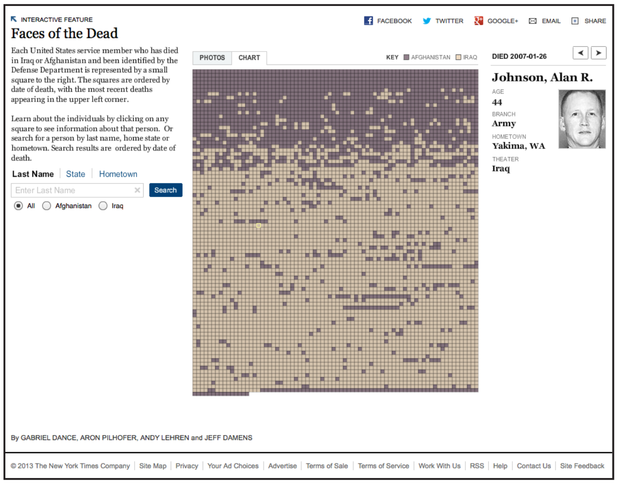


Figure 20. Interactive narrative structures (derived from Segel and Heer, 2010, p. 1146).

In "Narrative Visualization: Telling Stories with Data," Segel and Heer (2010) examined interactive visualizations like *inequality.is* with a goal to enhancing storytelling qualities in these devices. By analyzing the balance between narrative flow and interactive story discovery, they defined a spectrum ranging from author-driven (where there is a linear ordering of scenes, heavy messaging and limited interactivity) to reader-driven (which has no prescribed order, little messaging and free interactivity). Where an interactive falls on this spectrum suggests which of three general interactive narrative structures it is built on (Figure 20). The most common, the delightfully named Martini Glass Structure, favours an author-driven approach (typically beginning with a question, observation or article) to introduce the visualization and then opens up to an interactive stage. The Interactive Slideshow features greater levels of interactivity where each slide incorporates interaction like a succession of mini Martini Glass structures. And finally there is the Drill-Down Story, where the author first presents a general theme and then allows readers to dictate what stories they will pursue in greater detail (p. 1146).

Segel and Heer were studying narrative interactives specifically, and central to their definition of narrative is "the notion of a chain of causally related events" (p. 1139). Therefore, even an interactive described as inhabiting the far 'reader-driven' end of their spectrum "still requires significant amounts of authoring to determine the possible types of user interactions, what candidate stories to include, and the details included for each story" (p. 1146). As such, interactives like *WATER* cannot figure anywhere on their spectrum because their open-ended, user-driven format precludes the author-driven sequencing required for the expression of causality. It is this incongruity between author and user control that underscores the inherent tension between narrative and interactivity. However, returning to Ryan's case for degrees of narrativity, that is, that not all



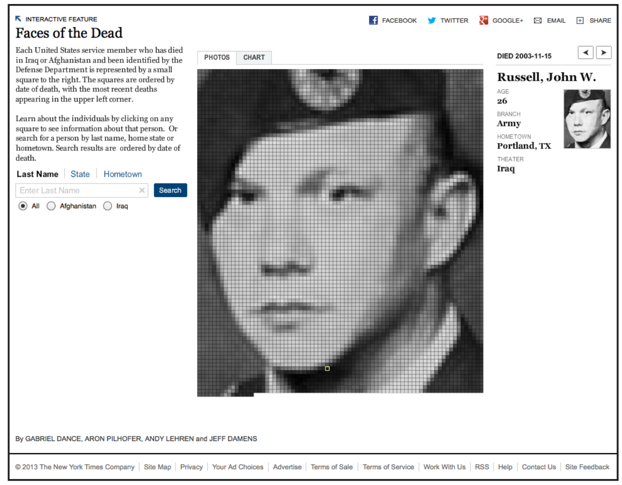


Figure 21a and Figure 21b. Screen captures from the interactive *Faces of the Dead* (Dance,Pilhofer, Lehren & Damens, 2013, n.d.).

elements must necessarily move the plot of a story forward as long as some do, it is also feasible to have corresponding degrees of interactivity that also allows user control on an inversely proportional scale.

An example of an interactive that is neither fully narrative nor fully interactive (but which exhibits degrees of both) can be seen in the New York Time's online interactive *Faces of the Dead* (Figures 21a and 21b) which invites users to explore a United States Defense Department data set of service members who have died in combat in Iraq and Afghanistan. The "Photos" section (Figure 21a) displays a grid of small squares, each of which represents one person killed. On selecting an individual square, the entire grid displays that person's portrait with name, age and other details on the right. The "Chart" section (Figure 21b) functions similarly, but here the larger grid shows which theatre the service member was killed in. Both sections provide the means to search by name, state or hometown. Though users have a vast number of options for how they choose to proceed through the interactive, interactive features themselves are quite modest: selecting squares, selecting one of two sections and using the search box. Likewise, each selection moves the plot of the narrative forward in tiny cumulative increments to contribute to a poignant but incomplete narrative: many young lives were lost, but we are left to wonder why.

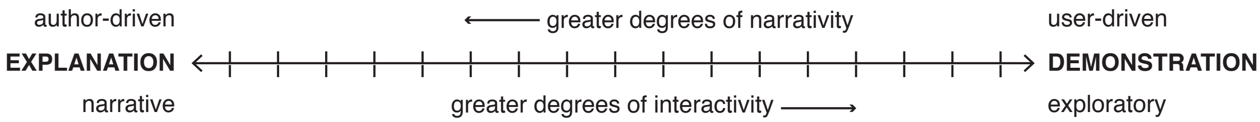


Figure 22. Explanation to demonstration. Interactive visualization spectrum.

Since greater degrees of interactivity challenge a linear narrative progression and gradually shift the perspective from an author-driven narrative to that of the user, we can say that narrativity and interactivity are on a spectrum; an inversely proportional scale, operating by degrees rather than in binary opposition (see Figure 22). Interactive visualizations with greater degrees of causality function as cognitive tools that tend to provide an explanation of the data, that is, they express the causes, consequences and perhaps even context of the information at hand. Segal and Heer's narrative structures and interactives like *inequality.is* would lean toward this end of the spectrum. Meanwhile, as degrees of interactivity increase and causality necessarily decreases toward the other end of the spectrum, we find data visualizations like *WATER*. Defined by a high level of visual information, visualizations at this end demonstrate (in the sense of substantiate or provide visual evidence for) information rather than explain it, and as such, support cognitive tasks like conceptualizing data structures and generating hypotheses. *Faces of the Dead*, which could be seen as having roughly equal degrees of narrativity and interactivity, would fall somewhere in the middle.

It is important to bear in mind that an interactive cannot be either 100% explanation or 100% demonstration. All narrative interactives require some small degree of user control in order to be considered interactive in the first place; an extreme example might present as a self-contained narrative animation with at least a means of stopping and starting. By the same token an interactive on the extreme demonstration end of the spectrum still requires the choice of visual arrangement that best directs the user to significance in data and as such is subject to the developer's perspective of what data is, in fact, significant.

3.10 CONCLUSION

Although this spectrum falls short of a concise definition for interactive visualizations, it provides a framework with which to conceptualize them as a single category of digital entities. Though they vary widely in format, purpose and application, to conceive of interactives as constructs along a single continuum provides an entry point to studying, discussing and designing them. Accordingly, this provides a direct relationship between theoretical and practical application. For researchers the framework offers a structure against which assessment and predictions can be made in further study, a reference point from which to launch research questions and a basis for discussion of the differences and similarities between interactives. For designers it offers a means to understand how altering the variables of time representation, causality and interactivity can significantly impact the nature and communicative objectives of the interactive and provide a jumping-off point for strategic design.

4. APPLYING THE FRAMEWORK

4.1 INTRODUCTION

Having established a conceptual framework with which to understand, describe and discuss interactive visualizations, I now turn to systematically apply it in an examination of the fundamental properties of a sample group. Liu et al (2008) note that, arguably, the design field takes a pragmatic attitude toward theoretical exploration, and considers the true value of theory not in whether it provides an objective picture of reality or not, but whether it informs design practice and is able to do work in the world (p. 1174). With this in mind, and harkening back to the underlying purpose of theoretical knowledge as summarized in Chapter 2, the aim of this section is to better understand, explain, predict phenomena and evaluate work in the realm of interactive visualizations.

4.2 EXAMPLES

The eight interactive visualizations chosen for this examination were selected to meet criteria both individually and as a group. They represent a fairly wide variety in terms of sources, formats, types and amounts of data presented, while maintaining a manageably-sized selection for the scope of this examination. I chose samples that display a wide range of visual formats: a timeline, a map, diagrams and charts; and various semiotic modes: graphics, photographs, film, animations and audio. Half are chosen from online news providers; half from other sources. They represent a variety of kinds of data: very large datasets, user generated data, self-contained, tweets scraped from Twitter and so on. This selection is by no means meant to represent a conclusive survey of interactive visualizations but rather a starting point for discussion. I will use the term 'author' to describe the originator(s) and/or producer(s) of the interactives—this includes designers programmers, editors, journalists, writers and any or all others involved with deciding on the format and bringing it to life. I begin with a brief description of each interactive.

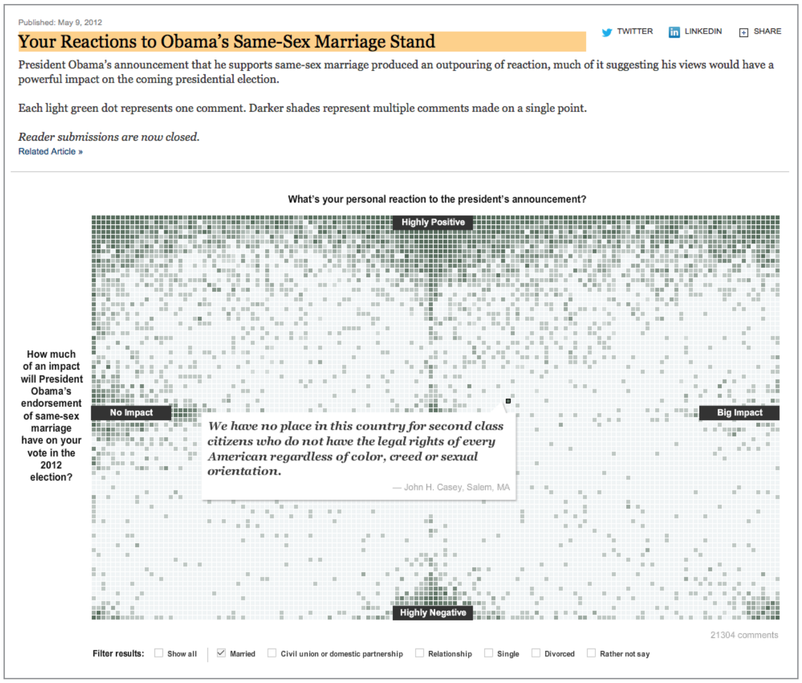


Figure 23. Screen capture of interactive *Your Reactions to Obama's Same-Sex Marriage Stand* (Huang & Lavallee, 2012, n.p.).

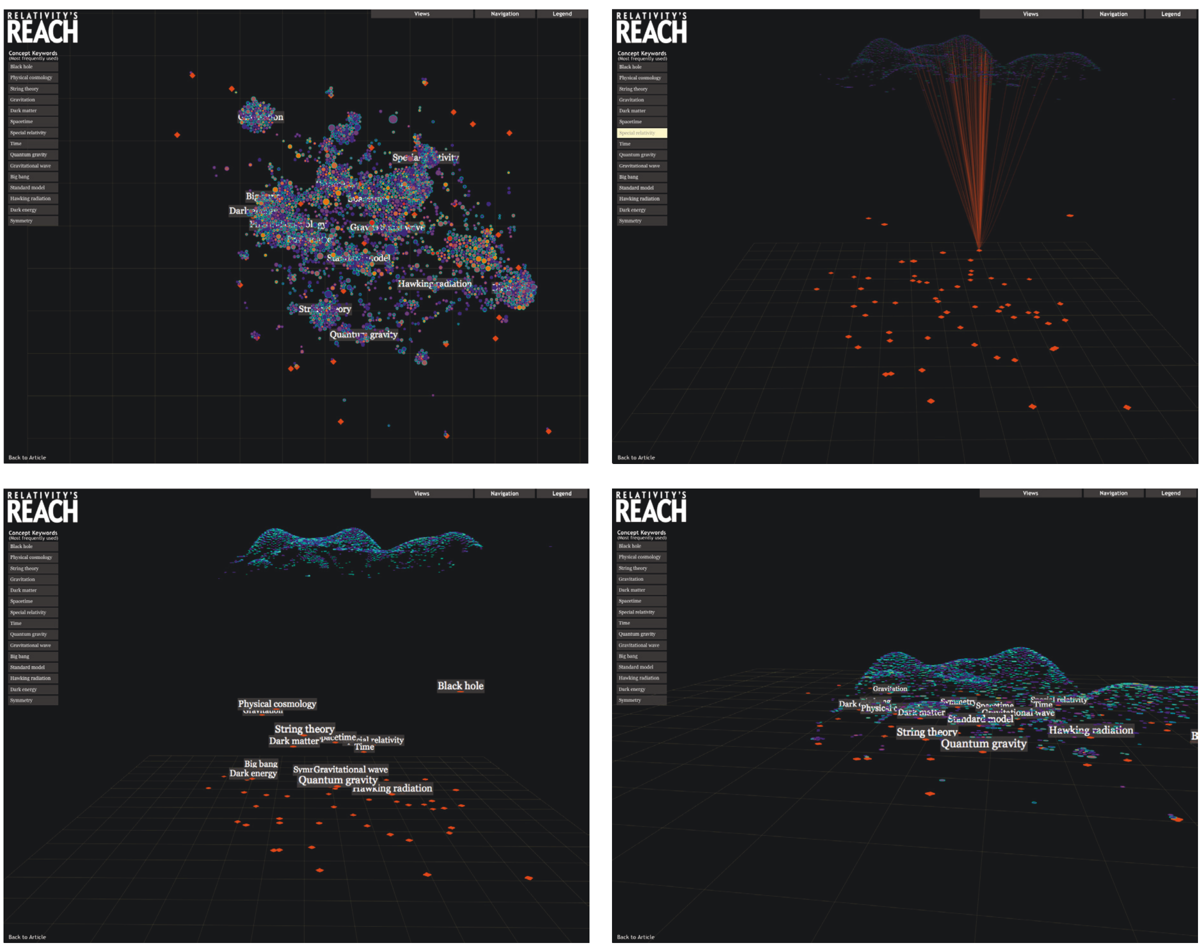
4.2.1 *Your Reactions to Obama's Same-Sex Marriage Stand*

Figure 23 shows a Cartesian coordinate plane graph that was featured on nytimes.com in response to President Obama's announcement of support for same-sex marriage. As a journalistic interactive story, it includes a title, a subhead, a brief explanation of the graphic and labels on the chart coordinates and filter options. Readers had previously been invited to mark where on the vertical scale (from highly negative to highly positive) and horizontal scale (from no impact to big impact) best indicated their thoughts regarding President Obama's announcement of support for same-sex marriage and what effect they felt this would have on the 2012 election. They were also able to enter a limited amount of text which displays in a pop-up box either randomly or upon selecting one of the squares. Darker coloured squares indicate more placements at those coordinates; lighter colours indicate less. Users can select individual squares to read random reactions, or random reactions are displayed automatically for a few seconds each. Options at the bottom allow current users to filter for opinions from those with various self-identified marital statuses.

4.2.2 *Relativity's Reach*

Drawing on research trends from arXiv.org, an online scientific paper database, this interactive (Figures 24a to 24d) visualizes the influence of the general theory of relativity on present day physics papers one hundred years after Einstein first described how gravity works. Each coloured circle represents one of 2,435 papers and rolling over each reveals its title, authors and and number of citations. Larger circles represent papers of greater influence (measured by citations); the smallest circles have not been cited. Right-clicking opens the paper in a new window. Red diamonds represent keywords and a selection of the most common concept words are available to choose from in a list on the left. Colours of circles represent numbers of authors—the warmer the colour, the more authors. Outlines around circles indicate publication status: blue outlines have been published; purple outlines await peer review. Placement of circles both according to the base

Figure 24a to 24d. Screen captures from *Relativity's Reach* (2016, n.p.).

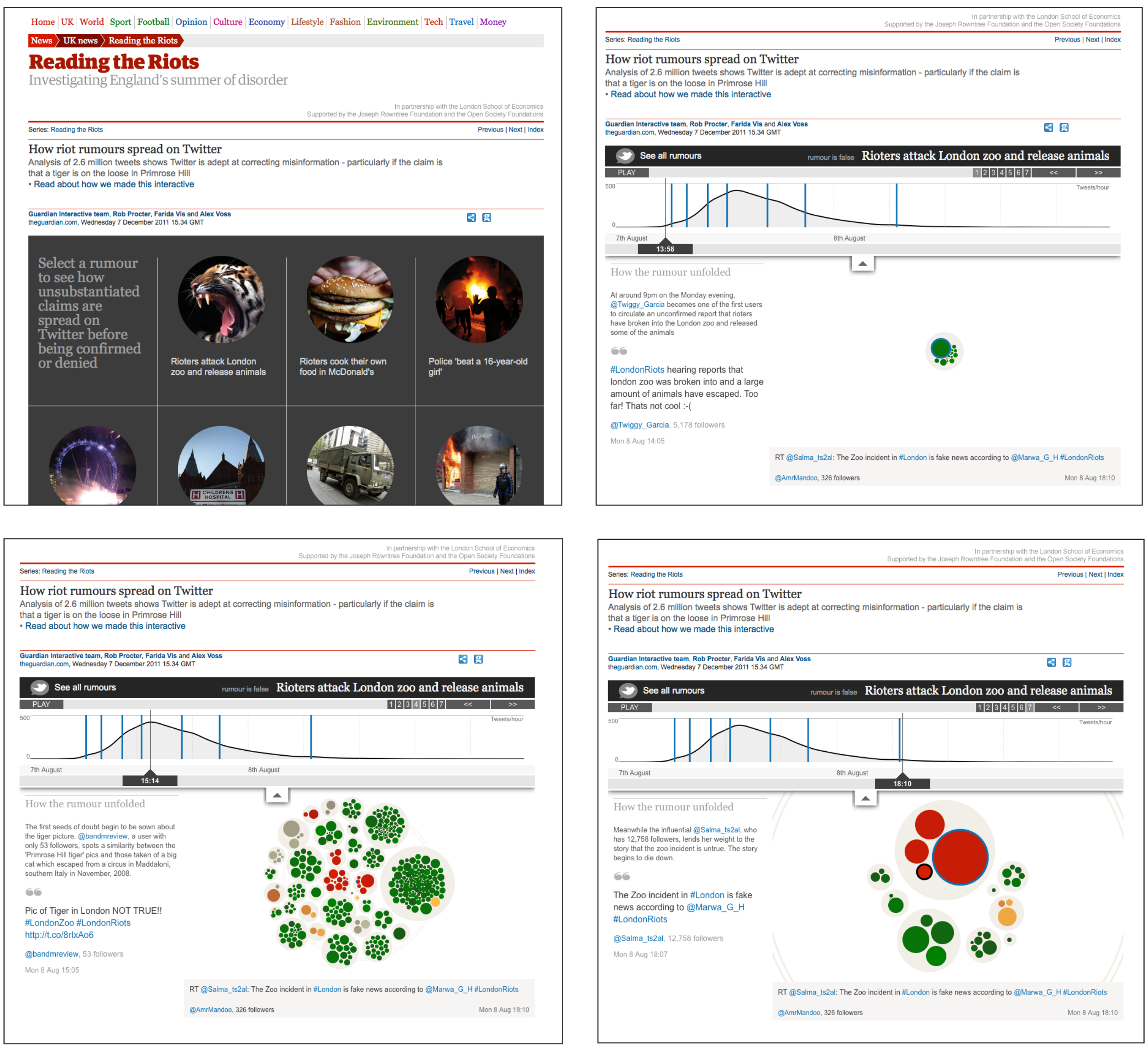


grid and in the space above it is calculated by proximity to keywords of which each article may have several.

4.2.3 *How riot rumours spread on Twitter*

The Guardian UK analyzed 2.6 million tweets relating to at least one of a selection of hashtags during and immediately following the UK riots of August 8, 2011. From the collected data, they identified seven key rumours, and then distilled these down to a series of subsets with which

Figure 25a to 25d. Screen capture from *How riot rumours spread on Twitter* (Guardian Interactive team, Procter, Vis & Voss, 2011, n.p.).

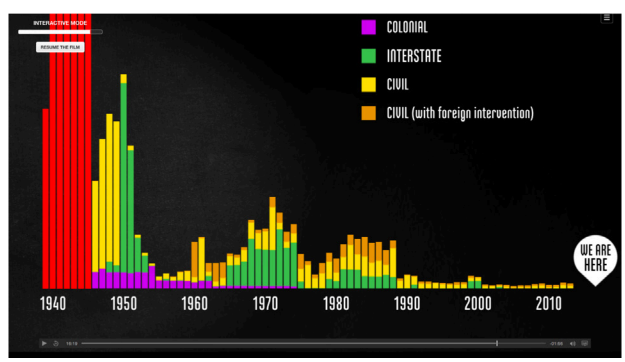


they created *How riot rumours spread on Twitter* (Figures 25a to 25d). The format is the same for each rumour. The interactive is on a news site, theguardian.com, and is part of a larger story detailing the August 2011 riots in England. As is common messaging in journalistic settings, the interactive has a title, subhead, story byline, date and time. There is also a link to a detailed account of how the data for this interactive was collected and processed and how the interactive was designed. Opportunities for interaction include navigating the timeline several ways and selecting bubbles to reveal tweets to read. A key at the bottom tells users how to interpret the representation of data: individual tweets are represented by bubbles (shades of green indicating support of the rumour; shades of red opposing it; and queries in orange) grouped together in larger bubbles—a set of retweets for a given tweet. Larger bubbles enclosing the others can be clicked and tweets can be read beneath. The larger a bubble appears, the more influential it is, measured by retweets. Watching the bubbles develop, grow and die down gives an overall gist of how rumours start, grow and, most interestingly, are self-corrected on Twitter.

4.2.4 *The Fallen of WWII*

This interactive documentary (Figures 26a and 26b) uses animations, graphics (timelines, histograms), photographs, narration and music to chart the devastating human cost of WWII, breaking the deaths down by country, continent, various battles and comparing data to other large scale wars in human history. It is presented in two formats: interactive and film. For the purposes of this discussion I am examining the interactive version only, however even this

Figures 26a and 26b. Screen capture from *The Fallen of WWII (Halloran, n.d., n.p.).*



version is mostly film itself: 18 minutes, with two spots at 7:24 and at 16:16 where users can pause and explore interactive data, presented in simple histograms, by selecting elements with popup labels. Text is limited: a title, credits and labelling of graphic elements. The film segments are narrated and this is how the of the story progresses—graphics and photographs play a supporting role in moving the plot forward.

4.2.5 *Racial Dot Map*

Perhaps the most visually straightforward of all the interactives examined here, the *Racial Dot Map* (Figure 27) draws on the largest dataset. One colour-coded dot per each of 308,745,538 people placed according to geographic referents provides “an accessible visualization of geographic distribution, population density, and racial diversity of the American people in every neighbourhood in the entire country” (Cable, n.d., n.p). Where dots are smaller than one pixel, the visualization shows “smudges”—colour-adjusted aggregations of groups of dots. Messaging is limited to labelling and a colour key in the lower right corner and a link to a broader description of the visualization. The user can zoom in to the interactive to the neighbourhood level and chart their own course as they navigate to different areas of the country exploring the data.

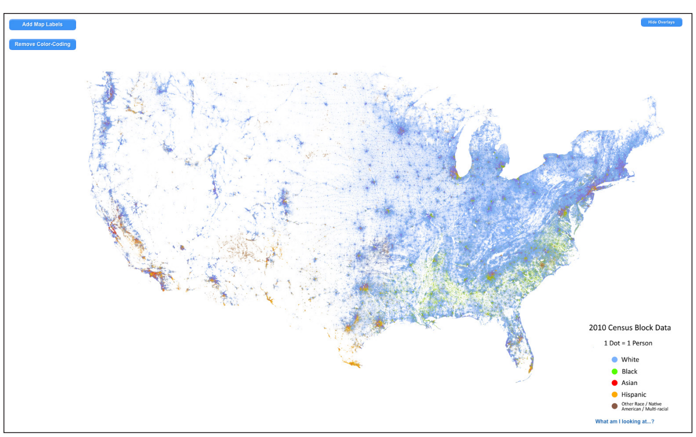


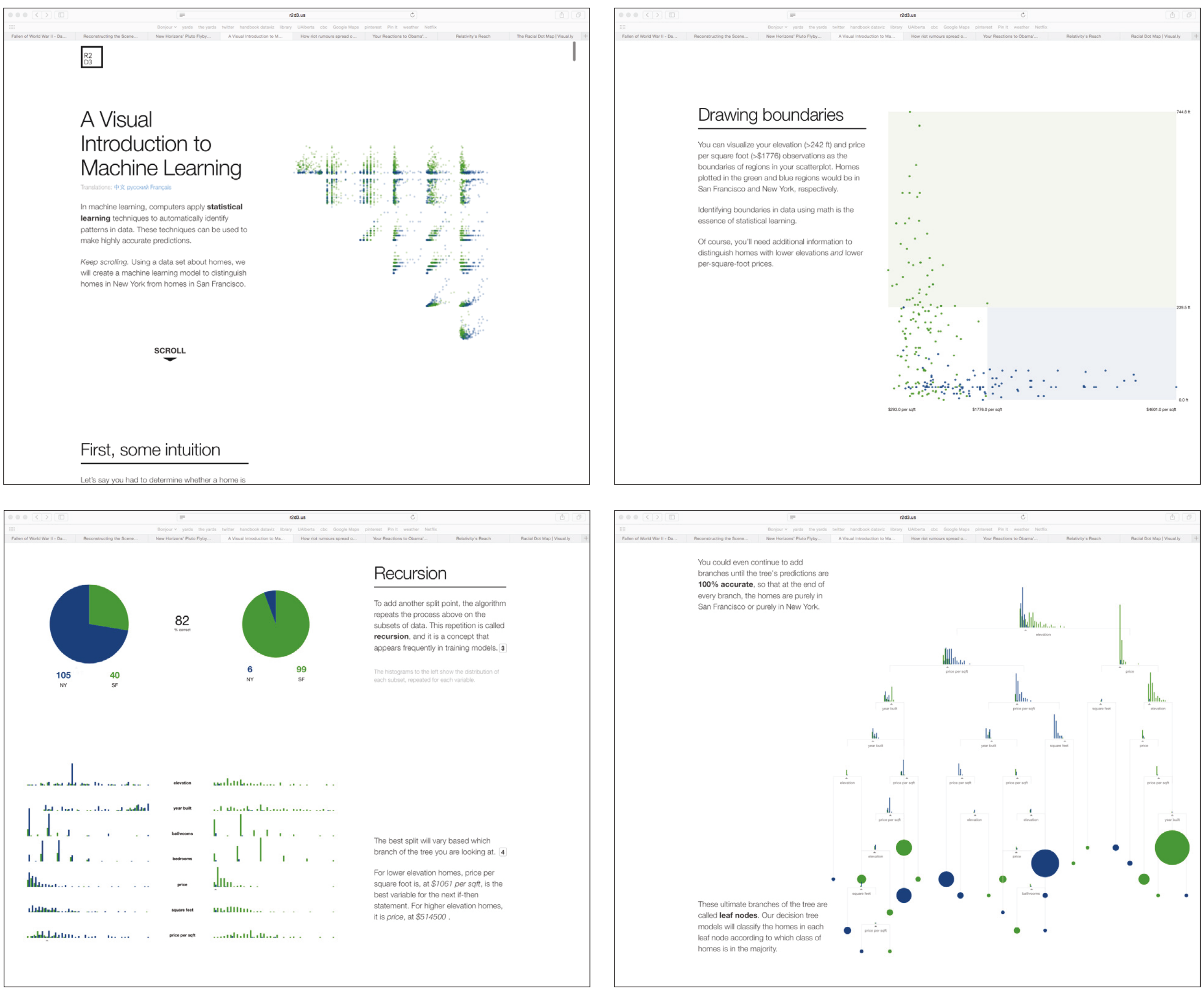
Figure 27. Screen capture from the *Racial Dot Map* (Cable, n.d., n.p.).

Figure 28. Screen capture from *New Horizons’ Pluto Flyby* (Corum, Grondahl & Parshina-Kottas, 2015, n.p.).

4.2.6 *New Horizons' Pluto Flyby*

Figure 28 is a screen capture of an animated slideshow documenting the few hours in which the New Horizons spacecraft flew past Pluto and its five moons—a critical point in its journey. Text consists of the typical title, subhead and byline often seen in news site interactives, and each slide also has brief messaging that provides additional information. Options for interactivity are modest: a row of navigation dots the user can select that linearly roll out the story or an advance arrow (bottom right) that does the same thing. Transition sequences from one frame to the next are animated.

Figures 29a to 29d. Screen capture from *A Visual Introduction to Machine Learning* (Yi & Chu, 2015, n.p.).



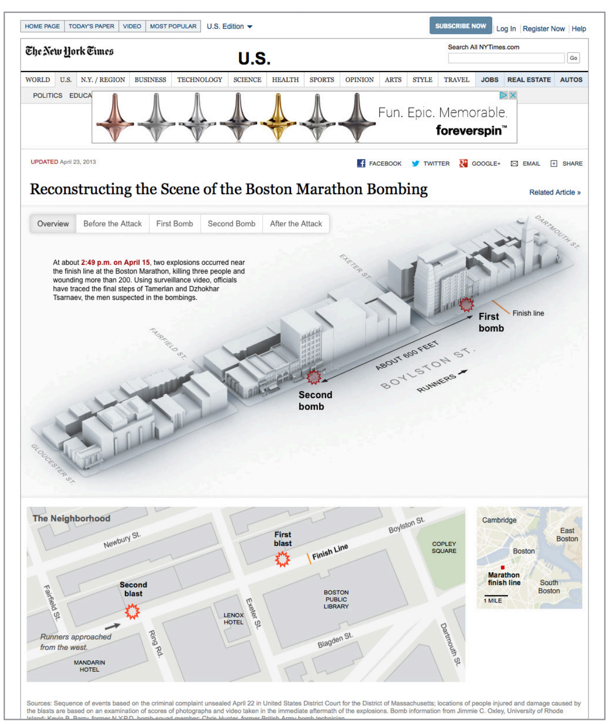
4.2.7 *A Visual Introduction to Machine Learning*

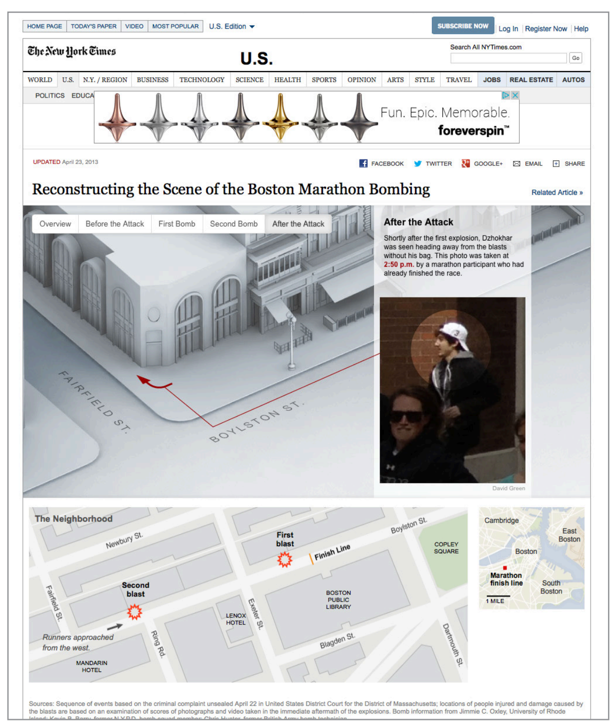
This scroller (Figures 29a to 29d) is a parallax interactive explaining machine learning. Messaging is extensive—images support the text and illustrate concepts challenging to describe with language alone. The user's only opportunity to initiate interaction is to scroll up or down—this essentially 'drives' the interactive, like manually turning a crank on a machine. Images like histograms, scatter plots, pie charts and decision trees are animated and brought to life by scrolling. The interactive has a linear format.

4.2.8 *Reconstructing the Scene of the Boston Marathon Bombing*

This news site interactive is an overview of the affected urban area where the Boston Marathon bombing took place April 15, 2013 (Figures 30a—30b). A diagram of the three block area is labeled with relevant details such as bomb blast locations and distance between explosions, and messaging in text panels augments the visuals and enriches the story. Static maps below provide locational context as the view above changes from scene to scene. Modest options for interactivity

Figures 30a and 30b. Screen capture from *Reconstructing the Scene of the Boston Marathon Bombing* (New York Times, 2013, n.p.)..





in the form of a row of buttons that correspond to a chronological order of events from left to right direct users with an animated transition to relevant locations and times.

4.3 ORDERING

Segal and Heer (2010) describe a “design analysis space” of narrative structures genres and design elements for interactive visualizations and central to it is the concept of narrative structure or ordering—the path users navigate through an interactive. They identify three general methods: linear, random access and user-directed, each aimed at producing a different type of outcome (p.1145). Weber and Rall (2012) call these dramaturgic structures, reasoning that not all interactives are narratives. Narratives, or degrees of narrativity, as discussed in Chapter 3, require an element of causality. Weber et al rather use the more general term story, defining it as “a sequence of facts or factual events that are temporally structured and coherently related to each other” (p. 8). All narratives are stories; not all stories are narratives.

According to Segal and Heer, linear ordering can be prescribed by the author in order to ensure users follow an established progression through the interactive when sequencing is important for interpretation or revelation of the material (p. 1145). Of the examples at hand this is seen most obviously in *The Fallen*, an interactive with a format not unlike a film (aside from two planned breaks for exploration of interactive histograms and a curious tendency for certain illustrations, such as a waving flags, to remain in motion even when it is paused). The user selects ‘play’ and the interactive progresses until a decision point arises to pause and explore or continue on. In *Machine Learning*, the only instruction the user receives is to scroll down, and as she does text appears and visual events occur in a prescribed sequence from top to bottom. *Pluto Flyby* and the *Boston Marathon Bombing* interactives use very similar navigational formats—a row of implicitly arranged (and in the case of *Boston Marathon Bombing*, explicitly labelled “overview, before the attack, first bomb, second bomb, after the attack”), buttons guiding the user in the order established by the author for maximum comprehensibility of the material. In each of these examples we see a format that metes out material sequentially, with each new time slice or revelation building on those previous. It is possible to view the material in any order, but there is no incentive to view it out of order as it compromises the story.

In user-directed ordering, the author provides multiple alternatives for the user to choose from when navigating through an interactive and *How Riot Rumours Spread on Twitter* has aspects of this. While the event the interactive represents unfolded chronologically, in the interactive the user is offered multiple methods to explore the chronology: playing through it like a video from beginning to end, dragging a time slider back and forth, and two methods of clicking forward and backward between key events that mark critical junctures in the unfolding of events. It is possible for meaning to be conveyed by the user clicking anti-chronolgically, for instance when a bubble expands rapidly in the chart section it is worthwhile for the user to drag the time slider backward to read what tweet sparked the sudden expansion. It is possible for the same interactive to exhibit more than one ordering type and *Riot Rumours* presents linear ordering elements (in the time line) and random access ordering (clicking any of the bubbles to read tweets) too. Here the authors have created opportunities for the user to plot their own course through the interactive.

Random access ordering occurs when there is no path suggested, either implicitly or explicitly, and the user is free to explore undirected according to her own interests. *Relativity's Reach*, *Your Reactions to Obama's Same-Sex Marriage Stand* and the *Racial Dot Map* are all examples of this type of ordering. *Relativity's Reach* provides a simulated three-dimensional environment for the user to navigate within, with options to select articles to view—what Shneiderman (1996) referred to as details-on-demand (p. 2). Although the concept keywords are in a top to bottom arrangement they too are arbitrarily arranged. The content of these interactives does not have a sequential imperative or storyline to maintain; the material is presented democratically (although, of course, there is always an element of authorial bias regardless of format) for the user to explore and potentially attribute their own meaning to.

4.4 LEVELS OF INTERACTIVITY

Of course the heart of the concept of ordering in interactive visualizations is the question of who has greater control of the course of the message as it unfolds—the author or the user—and this is where levels of interactivity come into discussion. Smuts (2009) argues that the concepts of control and interactivity are often used interchangeably in discussions of new media (p. 55), a phenomenon Rawlins and Wilson (2014) characterize as the "tension between individual volition and structural constraints" (p. 308). Ultimately, the author of the interactive determines the amount of agency the user can have, but at the point of connection between the author, the interactive and the user, "[d]iscussions of interactivity shift the focus from a broadcast model of communication to a collaborative effort between the designer and user, with technology as an enabling tool" (p. 308). They observe,

> *When users are allowed to interact with the visualizations, they become active participants who can shape, refine, and construct meaning, ultimately becoming co-creators of the visualization with the designer. The users move from perception to participation, from consumption to creation. In the process, users gain at least some control over the data, design, and rhetorical message. Users form temporary collaborative partnerships with designers they have never met and who are separated from them by time and space. The results of these collaborations are new, individualized data visualizations. Rather than being handed a single fish, users are able to explore an entire ocean (with the designer's expert guidance) to catch the fish that fits their appetite* (p. 305).

Differing levels of interactivity represent levels of opportunities for users to influence the message of the interactive. Weber et al (2012) describe three levels of interactivity, low, medium, and high, though distinction between levels blurs somewhat. Low levels limit the amount of agency the user has with the material and higher levels open the material up to greater manipulation and exploration. Low levels include object and linear interactivity: object interactivity refers to devices within the interactive that can activated with a cursor or other pointing device and provide some kind of audio-visual response. Linear interactivity, related of course to linear ordering, enables users to move forward and backward through a predefined framework like the timeline buttons in Boston *Marathon Bombing* and *Pluto Flyby*. Of relevance is that each click must provide access to new information to be considered an interactive feature—clicking to, say, enlarge a thumbnail does not constitute interactivity. A medium level of interactivity is indicated by hierarchical and hyperlinked activity. A high level of interactivity is achieved when users can influence content or choose their own route to explore the interactive (p. 3–4). Here again we see levels of interactivity correlated with levels of ordering: in *Relativity's Reach, Your Reactions* and the *Racial Dot Map* users are given the reins to take a certain amount of control and create their own rhetorical message from the interactive.

4.5 PERSPECTIVE

Borrowing a term from the world of literature, authorial perspective is the lens through which we observe and come to understand events. For interactives there is a direct correlation between levels of interactivity (or control), ordering and perspective. All interactives display at least the lowest level of object and/or linear interactivity and accordingly provide at least a modest amount of control to the user. *The Fallen* is the example with the lowest level of interactivity and the least flexible ordering—users can only start or stop the film and explore limited histograms at two points. The voice-over is a proxy for the author and literally narrates the story, it also represents the perspective of the author as the productive force creating the message.

At the opposite end of the spectrum, The *Racial Dot Map* has the greatest freedom to explore and, as such, user-directed ordering. Meaning arises from the user's exploration of the material and through this engagement perspective shifts to that of the user. This is also the case for *Relativity's Reach* where the visualization takes on the users perspective as they browse the material.

Your Reactions is interesting in that the author created a framework onto which users affixed their message effectively transforming users into authors creating content for other users—not unlike a bulletin board. In this case, it is more challenging to pin down whose perspective the interactive represents: the authors that created the framework, the user's as they explore the interactive or the user-author's that provided the content. *Riot Rumours* has a medium level of interactivity and user-directed ordering. The author has made the full collection of tweets available, but directs users to seven in particular that can chart the rise and fall of sentiment if the user reads no others. As Rawlins and Wilson (2014) note, interactives like *Riot Rumours* "represent cooperation, collaboration, co-creation, or even co-authorship between the designer and the user. The user, who is an interpretive agent in static displays, becomes a creative agent who actively makes decisions and participates in the creation of the data, design, and rhetorical message" (p. 308). *Pluto Flyby, Boston Marathon Bombing* and *Machine Learning* shift the perspective among these examples from user to author by exhibiting lesser options for interactivity and a more structurally linear ordering.

4.6 EXPRESSIONS OF TEMPORALITY

As discussed in Chapter 3, indications of the passage of time is a necessary feature to build a story, and elements of causality is necessary to form a fuller narrative. It is important to note here that expression of time has a relationship to, but is different from ordering, which was discussed earlier. Where ordering [regards] how sequential the path users can plot through the interactive is, expression of time is how obvious the passage of time within the internal logic of the interactive is. So for example, in *Boston Marathon Bombing*, the order the user progresses through the interactive is also labelled to suggest chronology: Before the Attack, First Bomb, Second Bomb, After the Attack. But in other instances, ordering and indications of the internal chronology of the story are not so closely linked, as in *Riot Rumours* where the internal logic of the passage of time is critical to the story of the interactive: a rumour swells up, opposition arises, and the rumour dies down, in chronological order. However, the user is able to manipulate that timeline by several different means, not to in any way alter the unfolding of the narrative, but rather to more closely examine the cause and effect of events unfolding. Our eight examples can tidily be divided into two groups:

With expressions of time	**Without expressions of time**
Riot Rumours	*Your Reactions*
Pluto Flyby	*Relativity's Reach*
Boston Marathon Bombing	*Racial Dot Map*
Machine Learning	
The Fallen	

Those without expressions of time exist in a perpetual and persistent realm. Those with expressions of time show varying degrees of beginning, middle, and end, which are necessary elements in traditional storytelling (Gershon & Page, 2001, p. 36). *Riot Rumours, Pluto Flyby* and the *Boston Marathon Bombing* interactives all have graphic timelines—symbolic representations of time that run from the past (left) to future (right). *Pluto Flyby* also has the option to advance backward or forward in perceived time using arrows pointing left and right, and these most minimal symbols of also appear *Machine Learning* and *The Fallen* to direct users only forward temporally.

4.7 MESSAGING

In the context of interactives, messaging refers to the text, or in the case of *The Fallen*, narration, that works alongside the visuals: titles, labels, sidebars and, in the case of *Machine Learning*, the dominant content of the interactive. For the purposes of this discussion messaging does not refer to additional text the interactive might link to like related articles, how the interactive was made or directions of use, nor does it refer to the detail-on-demand content of the interactives like the tweets in *Riot Rumours* or user comments in *Your Reactions*. With this in mind, the most heavily messaged examples are *The Fallen* and *Machine Learning*. As explicated in Chapter 3, language makes possible the expression of much that images cannot fully convey and in these two examples we see the narration and text tell the bulk of the story, using animated information graphics and photographs only to illustrate complex concepts when more efficient or engaging than language alone.

There is a direct relationship between the amount and nature of messaging in an interactive and the perception of whose perspective it conveys. For example, a heavily messaged interactive like *The Fallen* is clearly the perspective of the author whereas The *Racial Dot Map*, with only enough text to label the colour key, is more ambiguous: the author created the interactive, but the user's takeaway has more to do with their own viewpoint of what they have looked at and what they were looking for.

4.8 DISCUSSION

Ordering, levels of interactivity, perspective, expressions of temporality, messaging and the interconnections between all of these are the components that determine the degrees of narrative or explorability in an interactive visualization. Going back to Figure 22 in Chapter 3, a distribution of the interactive examples on the spectrum from explanation to demonstration might look something like Figure 31.

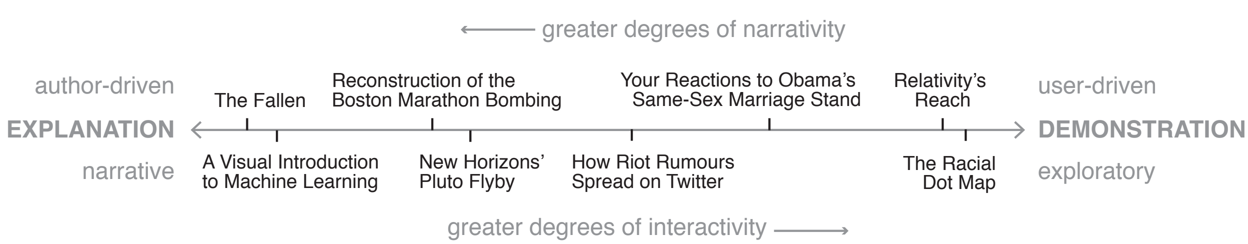


Figure 31. Applying example interactives to the explanation-to-demonstration spectrum

The Fallen and *Machine Learning* are the most narrative of the examples examined here. The linear ordering and limited interactivity point to an author-driven perspective. *The Fallen* uses cinematic story-telling techniques as well as charts, photographs and messaging in the form of voice-over narration tells the story of the casualties of WWII and explains the causes of who died where, under what circumstances and ultimately why there has been a decline in battle deaths in the wars since WWII. *Machine Learning* has less messaging and though both contain animations, the passage of time is more obvious and purposeful in the narrative of *The Fallen*. Both have a strongly author-driven perspective.

The *Boston Marathon Bombing* and *Pluto Flyby* interactives are author-driven perspectives with low levels of linear interactivity, but their ordering is perhaps slightly looser. It is in the messaging that somewhat lesser degrees of narrativity are detected compared with the first two examples. The *Boston Marathon Bombing* story has implicit elements of causality—for instance it is strongly implied, but never stated, that the suspects detonated the bombs. The story, as is typical in journalism, unfolds as a sequence of factual events and this slightly counteracts a completely author-driven perspective as in the first two examples. In *Pluto Flyby* less messaging merits a position somewhat closer to the demonstration end of the spectrum.

Riot Rumors is neither strongly explanation nor strongly demonstration. Elements of linear and user-directed ordering open the interactive up somewhat. Levels of interactivity may be low, but there are more options than the previous examples. There is a rudimentary story with a small degree of causality ("the rumours died down because these tweets were in opposition"), but like the previous two examples it remains mostly sequence of factual events. Messaging is very limited and between this and the choice of ways to interact with the graphic the perspective seems slightly more user-driven than author-driven.

Your Reactions is further toward the demonstration end of the spectrum. Random access ordering, little messaging and no temporal indicators move it well away from being an explanation graphic, but low levels of interactivity while still being able to explore content and, as discussed earlier, an ambiguous perspective prevent it from being fully a user-driven, demonstration interactive. *Relativity's Reach* and *The Racial Dot Map*, however, achieve a position much closer to demonstration with higher levels of interactivity, no expressions of the passage of time, and a more completely user-driven perspective.

4.9 APPLICATION FOR DESIGN

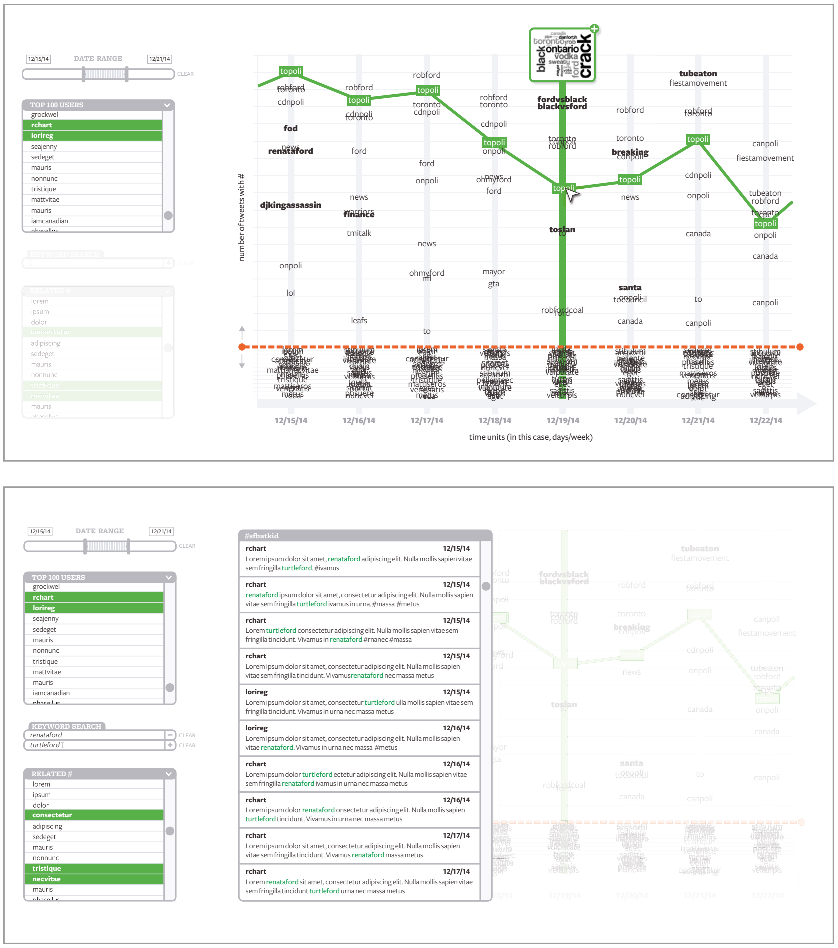
As demonstrated above, theories like the explanation-demonstration conceptual framework enables explanations leading to greater understanding of phenomenon in interactive visualizations. The design field is also guided by theory: design involves high degrees of planning and making decisions based on accurately predicted outcomes leads to stronger solutions with more intentional consequences. Designing interactive visualizations relies on pragmatism and so the value of a theory is whether it is able to productively inform practice and "do work in the world" (Liu et al, 2008, p. 1172). Design as a process sees a problem and addresses it with a solution. Cairo (2013) writes,

> *"The fact that an information graphic is designed to help us complete certain intellectual tasks is what distinguishes it from fine art. Rather than serving as a means for the artist to express her inner world and feelings, an infographic or visualization strives for objectivity, precision, and functionality, as well as beauty. In short: The function constrains the form"* (p. 25).

After the top-down approach of examining existing interactives through the structure of the explanation-demonstration framework, I now turn briefly to the design process using the framework in a bottom-up approach in creating new interactives. I will look at three interactive visualizations I have designed: *TweetVis*, *Colorectal Cancer Outcomes in Alberta*, and the *Phenomenological Timelines* project. I will touch briefly on the design process, as informed by, and supported by the framework for each of these projects.

4.9.1 *TweetViz*

After scraping twenty gigabytes of twitter data surrounding an ongoing conversation on Twitter,



Figures 32a and 32b. Sketches for the interactive visualization *TweetViz*

we created *TweetViz* (Figures 32a and 32b) as a way to investigate the topic and the massive number of conversation threads running through it. We were looking for ways to best reveal clusters, outliers, patterns and trends within this large body of data. Because the data set was so large it was unexplorable in any other meaningful way beforehand so we had no knowledge as to what it might reveal or how to best to present it.

We needed to design a tool that presented the data as neutrally as possible for the user to then explore and draw their own conclusions. As such, we decided on a high degree of interactivity and a random-access ordering with the intention of creating a user-driven perspective. Because we didn't know in advance how the data might present, we also built in mechanisms for managing potential cases of data occlusion in the display: Figure 32a is an early sketch showing the slider bar (in orange) that "presses down" the majority of hashtags to allow greater visibility of the top ten tweets of each day (the x-axis shows the temporal range and hashtag frequency is on the y-axis). A highlighted line charting frequency of top or individually selected hashtags from day to day provides a macro view of a conversation arc over time and does present a slight indication of a story. We also decided to highlight outliers to gain a glimpse into perspectives outside of occurring trends. If desired, the user can zoom in to details-on-demand and read the individual tweets that comprise the visualization macros. Messaging was deemed unnecessary and distracting to the users visualization experience. In designing *TweetViz* we determined a position very close to the demonstration end best suited the data, and how we wanted our users to experience it (Figure 33).

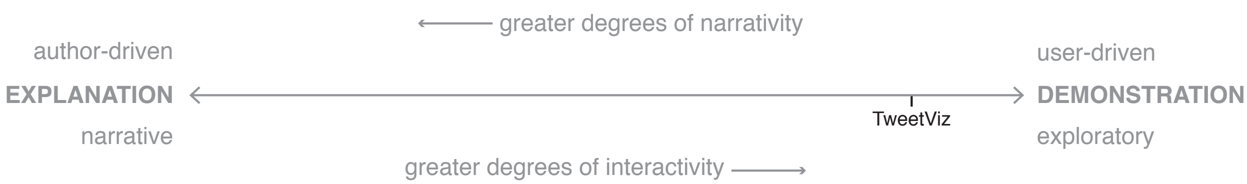


Figure 33. Applying *TweetViz* to the explanation-to-demonstration spectrum.

4.9.2 *Colorectal Cancer Outcomes in Alberta (CCOA)*

Alberta Health Services data revealed that during a three-year period only half of Albertans with advanced state colorectal cancer had received recommended care and as a consequence mortality rates were much higher than other provinces. The client, the Physician Learning Program, had tried other methods of communicating this information to cancer physicians but had met with resistance regarding the interpretation of the data. CCOA (Figures 34a to 34d) was conceived of as a method of data delivery, a learning resource and a meaningful tool for self-reflection for these physicians with the ultimate goal of changing health outcomes for this group of patients.

CCOA was designed as a discoverable storytelling device and as such was situated close to the explanation end of the explanation-demonstration spectrum as a jumping off point for subsequent design considerations. After a brief animation with heavy messaging, ordering was user-directed: three paths (Alberta, My Hospital and My Practice) were offered for the user to choose

Figures 34a to 34d. Sketches for the interactive visualization *Colorectal Cancer Outcomes in Alberta.*

from, with a modest amount of filtering for cancer type and stage. In keeping with the goal of self-reflection, users could enter their own IDs to access data about their own and their hospital's patients outcomes to compare with provincial averages. After a brief period of interacting with the visualization users would quickly reveal the underlying author-driven narrative: regardless of other factors, lower rates of adjuvant therapy caused higher rates of mortality. We placed in on the explanation-demonstration as seen in Figure 35.

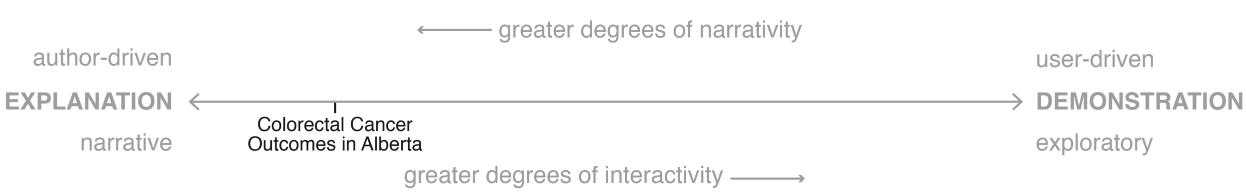


Figure 35. Applying *CCOA* to the explanation-to-demonstration spectrum.

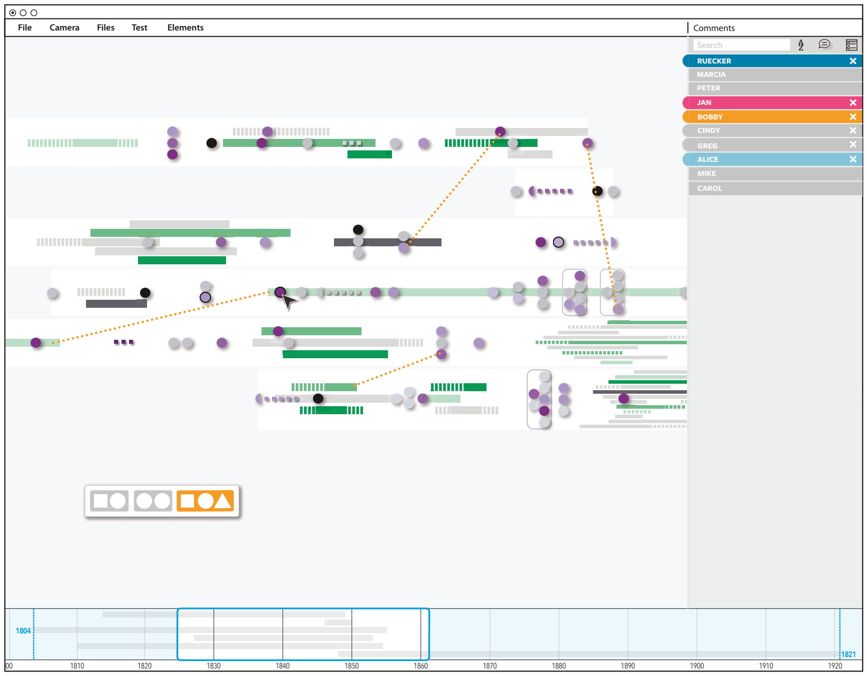


Figure 36. Sketch for the interactive visualization *Phenomenological Timeline.*

4.9.3 *Phenomenological Timeline*

This timeline interactive (Figure 36) was conceived of to represent certain, uncertain and approximate events and periods in history, and chart the effect these had or may have had on other historical events and periods. The data used for the prototype was the life histories of the three Brontë sisters, Emily, Charlotte and Anne. Events in their lives are marked by colour-coded "objects" on a 3-dimensional timeline, and events are depicted as ribbons. As well as exploring the lives of the sisters, users can tokenize events and durations with levels of importance and draw connections between events in one sister's life, or between the lives of the three sisters, attaching comments, saving "sets" and sharing with other scholars. The underlying concept was to reveal subjective perspectives, interpret the "strength" of events (how important it was to the overall timeline and other events), or record possibly changing recollections and predictions.

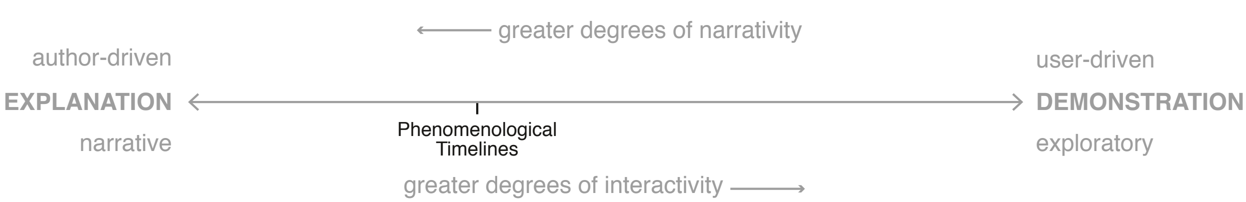


Figure 37. Applying *Phenomenological Timelines* to the explanation-to-demonstration spectrum.

Although the timeline/story is a dominant metaphor in the interactive, a design decision was made early on to counteract its linearity with a non-linear, random-access ordering and a high level of interactivity. We wanted users to be able to explore the data freely and move around it, both figuratively and perceptually to create their own perspectives. Messaging within the interactive itself was as minimal as possible—labelling life events—with the goal to place the user in the position of applying as much of their own meaning as possible. Situating the *Phenomenological Timeline* on the explanation-demonstration spectrum (Figure 37) reveals the deliberate midpoint between the linearity of the timeline and the interactive freedom to explore it from any angle.

4.10 SUMMARY

Interactive visualizations are complex, multi-faceted, multi-modal artifacts. They often require multiple skill-sets, significant man-hours and a great deal of thought and energy to produce and this, of course, has implications for the design process. In short, they are expensive in terms of time, energy, and consequently, money. Strategic design minimizes over-expenditures in all areas. While we have seen the explanation-demonstration spectrum as a way to examine, characterize and discuss interactives, it also has potential as a tool for strategic design: when facing the initial stages of a design project it's often useful to have a place to start, and something to refer back to at different stages of the process. The spectrum provides an interpretive context for those involved in producing the interactive to align their objectives and reach consensus on possible outcomes. It enables designers to position where on the explanation-demonstration spectrum they are targeting and adjust elements of ordering, interactivity, perspective, expressions of temporality and messaging until the optimum balance for the project is achieved.

CONCLUSION

Drawing insights from the rich information graphic past, we can look at interactive visualizations as the most recent development in a long history of what we have seen to be powerful cognitive and communicative tools. However, hybridization of semiotic modes, structures and genres mean existing theories from information design may not always apply to this new incarnation. Having considered and confirmed the generally held belief that there is a scarcity of theoretical knowledge in the field of interactive visualization in Chapter 2, some possible reasons became evident: firstly, research is taking place in various discipline-specific communities of research and knowledge and practice is not always being extrapolated across disciplines. Secondly, interactive visualizations are complex digital artifacts that often require a multidisciplinary approach in their design and production and each area of specialization often brings its own theoretical knowledge which may or may not apply in the new multimodal context.

A discipline-specific body of knowledge for interactive visualizations, as opposed to a single overriding theory, is a means of providing generalization to researchers and practitioners working across a wide range of areas of specialty to draw from, and it can provide ways to describe and structure ideas across a large class of observations from multiple perspectives. This thesis serves to provide a conceptual framework that can function as both an analytical tool and a way to organize the design space for both research and practice, but that is not to suggest that it encapsulates anything other than one small facet of the study and design of interactive visualizations as cognitive and communicative tools.

Card, Mackinlay and Shneiderman (1999) define interactive visualization as “the use of computer-supported, interactive, visual representations of abstract data to amplify cognition” (p. 637), and Friendly (2008), describes it as “the science of visual representation of ‘data’, defined as information which has been abstracted in some schematic form, including attributes or variables for the units of information” (Friendly, 2001 as cited in Liu et al, 2012). Nichani and Rajamanickam

(2003) on the other hand, describe interactives in categories of *narratives, instructives, exploratives* and *simulatives* with the objective of conveying an account of connected events (n.p.). To Nichani et al's categories, George-Palilonis and Spillman (2011) add *serious games* which, in addition to a highly immersive experience "go a step further by actually applying traditional gaming strategies to serious storytelling" (p. 173). The intent of this thesis is to take steps in advancing the notion that Card et al, Friendly, Nichani et al and George-Palilonis et al are not describing unlike things, but rather that the differences between what they are describing is, as I have presented, no greater than a balance of degrees of ordering, levels of interactivity, perspective, expressions of temporality and causality, and messaging.

Finally, as Tufte (1985) writes,

> *Design is choice. The theory of the visual display of quantitative information consists of principles that generate design options and that guide choices among options. The principles should not be applied rigidly or in a peevish spirit; they are not logically or mathematically certain; and it is better to violate any principle than to place graceless or inelegant marks on paper. Most principles of design should be greeted with some skepticism, for word authority can dominate our vision, and we may come to see only through the lenses of word authority rather than our own eyes. What is to be sought in designs for the display of information is the clear portrayal of complexity. Not the complication of the simple; rather the task of the designer is to give visual access to the subtle and the difficult—that is, the revelation of the complex* (p. 191).

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