Surveying the World of Visualization

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Introduction[1]

The great strides in computing, graphics and information technology, and the widespread use of the web and communications technologies have rapidly changed the landscape for conveying and analyzing data and other information. From a technological perspective, the possibilities for identifying ways to generate and project images seem boundless. From a user perspective, individuals are consuming and absorbing information in far more diverse ways, and, regardless of personal cognitive styles, they are more familiar with hypermedia technology and new ways to convey visual information. Indeed, the field of "visualization" has been taking shape, with research institutes, university courses, web sites, and practitioner and scholarly conferences, and textbooks proliferating, with great enthusiasm and considerable momentum.

The practice of visualization, though of great interest to many people, can mean very different things and the field has many streams, even though scholars and practitioners often look back to similar sources of inspiration in mapping, graphing, and more. Some of these visualization streams overlap, but there are distinct areas flowing from inputs, visualization technologies, goals, and even proximate target audiences. Some areas of visualization streams rely heavily on securing, transforming and projecting data, while others are focused more on visual means for facilitating analysis or dialogue without necessarily relying on data.

The purpose of this paper is to provide an overview and survey of the rapidly growing field of "visualization" as background for the HC Coombs Roundtables on "Grappling with Complex Policy Challenges: Exploring the Potential of Visualization Technologies for Analysis, Advising and Engagement" and as a complement to the primary discussion paper. The discussion paper is best understood as considering the "demand-side" possibilities and challenges for selecting and working with different visualization technologies, while this paper focuses on the "supply-side" seeking to give a sense of the evolution, diversity, and key issues of this field. Having a

[1] I would like to acknowledge Irene Huse, who provided excellent research assistance in support of this paper.

broad sense of the visualization landscape should assist roundtable participants with exchanging their department and agency experiences with different visualization technologies.

This paper is organized as follows. The first part provides a brief overview of visualization, the key antecedents, and its many areas of practice. The next three sections delve into each of the primary areas of information visualization and data analytics, graphic and information display, and visual approaches in support of dialogue and strategy along with the related approaches of systems thinking, simulation, and scenarios – identifying key themes, concepts, contributors, and resources. The fifth section stands back to identify key issues that arise from all of the streams of visualization research and practice, and points to issues for public sector executives and policy analysts undertaking analysis, advising and engagement on complex policy issues.

1. Brief Overview of Visualization: Data, Graphics, Facilitation/Strategy

Visualization is a broad, diverse and relatively new field, really an amalgam of distinct yet overlapping approaches: information visualization and data analytics, graphics and information display, and visual facilitation for thinking and strategy. Each approach has its own focus, different origins, and a unique mix of scholarly or practitioner communities, who typically attend different conferences. The "what" of visualization for each of these communities differs: for those focused on information visualization, it is the fidelity to and prospect of making sense of and representing often considerable volumes of data; for the graphics and information display community the goal is to produce aesthetically pleasing visualizations, often informed by interesting data; and for those engaged in graphics recording and strategic facilitation, the goal is to assist organizations, stakeholders, and communities to share perspectives and context with encompassing visual diagrams in order to develop a broader sense of collective interest and the possibilities for moving forward. For government leaders, it is important to appreciate these approaches to visualization and which might fit best with different strategic needs.

Delineating and juxtaposing different approaches to visualization usefully serves to clarify their essential foci and approaches, but, along with the different techniques and issues associated with each approach, the overlaps and cross-fertilization across the broad approaches need to be appreciated. For example, Tufte's (1990, 1997, 2001) pioneering work on visual display is universally considered seminal, itself informed by exemplary maps and graphs, often produced decades and even centuries in the past. However, despite some intersections, each approach has its own streams of literature, conferences, and textbooks or manuals. That said, some of the most interesting research resists easy categorization, and often involves efforts to array and work across the different traditions in visualization.

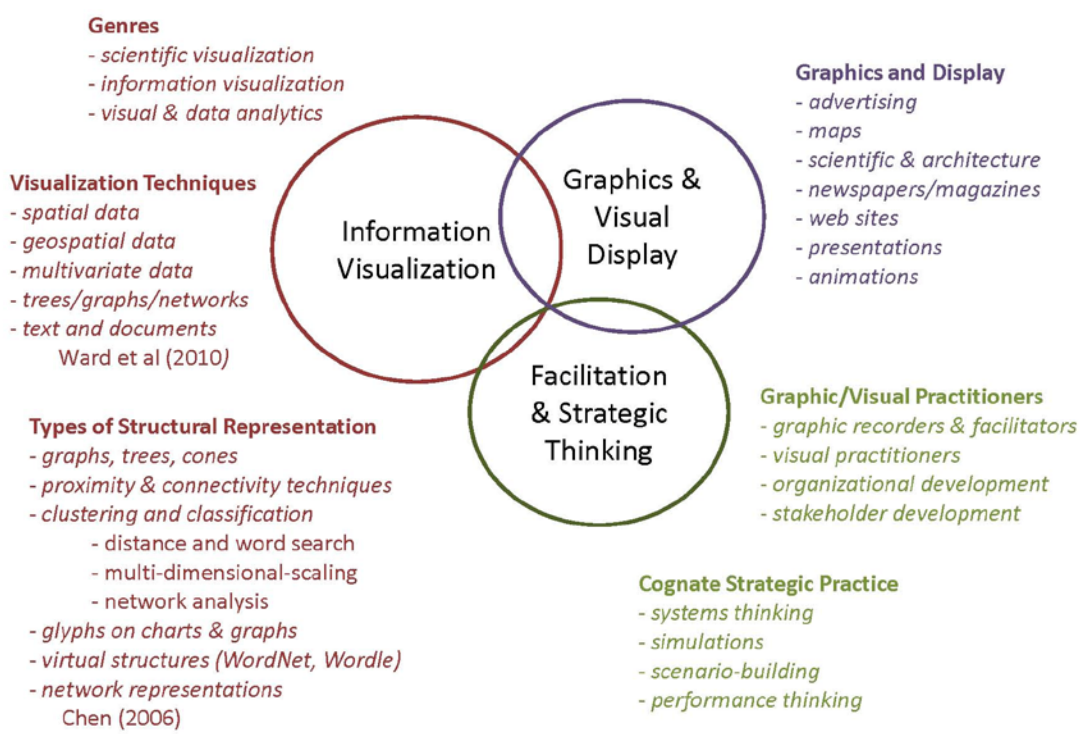
The first and briefest part of this paper begins with a high-level overview of three different visualization domains. The next three parts of this paper successively take up each of the visualization approaches, considering their origins and their key focus, approaches, and issues:

- *information visualization and data analytics:* this interdisciplinary field has emerged out of computing and graph-making, motivated by the need to visually represent increasingly large data-sets found it the sciences, as well as digital communications and records, to enhance how humans can analyze and learn from this information;

- *graphics and information display:* this field celebrates the beauty and diversity of design and representation of data for the purposes of communication, marketing, and illumination, and has roots not only in the worlds of graphics and map-making for prepared for architecture, advertising, newspapers, magazines, and web sites; and
- *visual facilitation for thinking and strategy:* this field uses diagramming to assist with facilitating groups to better understand each other and their challenges, and includes a large circle of approaches for strategy development – systems thinking, simulation, scenarios, and performance thinking – which rely heavily on visual techniques.

A high-level way to think about the differences among these approaches is to consider (a) the extent to which their primary goal is to represent raw data versus ideas, and (b) the extent to which they seek to raise awareness of audiences versus directly facilitate decision-making.

Fig. 1 – Three Visualization Domains



In parsing out these approaches, it will be important to recall not only the overlaps, but also the commonalities: scholars and practitioners in all of the approaches are wrestling with and trying to make sense of complexity; they all believe that visualizing data and challenges are typically more effective for sharing information than more linear, text-based renderings; and they all have a commitment to increasing the impact of visualizations for illumination and judgement.

2. Information Visualization and Data Analytics

The field of "information visualization" is a relatively new and rapidly growing, driven by the latest developments in information and communications technologies, but tracing its origins to early mapping and graphing techniques (e.g., Friendly 2008; Tufte 1990). It has been developing at the intersection of well-established disciplines such as computing, engineering, graph analysis, data management, cognitive psychology, software development, human-computer interface, etc., with engagement from a host of scientific, social science and humanities disciplines where visualization technologies are applied. The "InfoVis" field is only beginning to institutionalize, as evidenced by an expanding number of conferences, journals, research centres at universities, courses, and programs. Although the field is breathtaking in diversity, it is driven by the premise that access to different kinds of data, which – when found, accurately transformed, well represented, and then properly matched with other streams of data – will help inform and improve awareness of issue, analysis, and decision-making.

Entire books have recently been written attempting to provide overviews of the new field of information visualization (e.g. Chen 2006; Spence 2007; Mazza 2009; Keim et al 2010). Since it is not possible to provide a full account of the field in just a few pages, what follows provides a sense of the evolution, scope and issues taken up in the literature, with attention directed to issues of relevance to those interested in exploring the potential of information visualization for addressing complex policy challenges. The goal is also to give readers a sense of where to look for more detailed accounts and explanations. Accordingly, the first section outlines the genesis, scope, and state of the field, while the second section provides a high-level itemization of some of the main techniques and outputs associated with information visualization. The final section identifies key issues, emerging research directions, and overlaps with the other domains of visualization taken up in the next two parts of this paper.

Information Visualization: Emergence and Growth of a Field
Card et al (1999b) provides a useful survey of the origins of information visualization. They identified several streams of overlapping interest:

- *data graphics*, which concerned how to use graphs and maps to visually represent data, including setting out historical and contemporary examples and principles for good design (Bertin, 1967, 1977; Tufte 1983/2001).
- *statistics and visualization*, which focused more on different ways to more efficiently and rapidly allow viewers to distil findings from statistical data-sets, particularly multi-variable and large-n data (e.g., Tukey 1977; Cleveland & McGill 1988).
- *scientific visualization*, established in 1985, an National Science Foundation panel set a research agenda on "visualization and computer graphics" involving computational scientists (including physical and life sciences, economics, medicine, much of applied mathematics, etc.) and engineers, visualization scientists and engineers, systems support personnel, artists, and cognitive scientists (McCormick et al 1987, p.11);

- *computer graphics and artificial intelligence*, where researchers, informed by principles like those developed by Bertin and Tufte, sought to automate the transformation and matching of data, as well as creating graphical and other visual representations, with communications goals in mind; and
- *user-interface research*, which explored different ways to facilitate users sifting through and exploring large amounts of data, as well as different streams of data. Card et al (1999b) note that the "concern was again not so much the quality of the graphics as the means for cognitive amplification." (p.8)

According to Card et al (1999b) this last stream of research produced the first known use of the phrase "information visualization" (Robertson et al 1989), although terms such as 'scientific visualization', 'visual display', and 'visualization' were already in use.

These early tributaries to the contemporary "river" of information visualization research and practice explain, in part, some of the different broad definitions of the field. Early on, when the National Science Foundation panel saw visualization as a sub-field of computing, but with great potential for many other fields, it intriguingly suggested that "Visualization offers a method for seeing the unseen." (McCormick et al 1987, p.3) Card et al (1999) suggested that information visualization is "the use of computer-supported, interactive visual representations of abstract data to amplify cognition" (p.7), having made a distinction from scientific visualization based on physically-based data. When introducing a new journal for the field, Chen (2002) declared that

> "information visualization can be broadly defined as a computer-aided process that aims to reveal insights into an abstract phenomenon by transforming abstract data into visual-spatial forms. The intention…is to optimize the use of our perceptual and visual-thinking ability in dealing with phenomena that might not readily lend themselves to visual-spatial representations." (p.1)

Later, after the field has further evolved and expanded, Ward et al (2010) defined visualization as "as the communication of information using graphical representations" (p.1). They also emphasize that visualization is not the same thing as computer graphics, arguing that it is the connection to data that is crucial and not making a firm distinction between information and scientific visualization. Likewise, Chen (2010) defines information as "computer generated interactive graphical representations of information." (p.387) However, rising above all of these perspectives, Shneiderman (2006) declares that "the essence of information visualization is more ambitious and more compelling [than finding appropriate representations of relationships, patterns, trends, clusters, and outliners]; it is to accelerate human thinking with tools that amplify human intelligence."(p.vii) This declaration authentically captures the sense of mission that pervades this rapidly growing field.[2]

Despite the many disciplinary and sub-disciplinary strands of research feeding into information visualization, it did not start to galvanize as a field until the late 1990s and early 2000s. The first

[2] Spence (2007) notes that to "visualize" means "to form a mental model or mental image of something" and then observes that "visualization is solely a human cognitive activity and has nothing to do with computers." (p.5) Information can be secured in a variety of ways. Hegarty (2004) defines visualization as "any display that represents information in a visual-spatial medium" (p.1), with this and other research exploring the effects of external representations on internal representations in the mind.

collection of key articles and other resources, as well as an account of the evolution of the field, was published as *Information Visualization: Using Vision to Think* (Card et al 1999), and was soon complemented by Chen's *Information Visualization and Virtual Environments* (Chen 1999) Ware's *Information Visualization: Perception for Design* (2000), and Spence's *Information Visualization*. (2001). The journal *Information Visualization* was started in 2002, later joined by the *Parsons Journal of Information Management*, which added to a portfolio more specialized journals that various contributors had and continue to publish in. There has since been a profusion of books and collections (e.g., Bederson and Shneiderman 2003; Thomas and Cook 2005; Chen 2006; Few 2006; Chen et al 2008; Fry 2008; Few 2009; Keim et al 2010; Steele and Iliinsky 2010; Ward et al 2010), along with university courses around the world dedicated to grooming the next generation of practitioners and researchers in this field.

An international community of scholars has rapidly emerged to explore information and data visualization. Reflecting the precursors to the field, the IEEE (International Electrical and Electronic Engineering) Computing Society has been an important vector for the exchange and publication of ideas and research. Perhaps the most important annual event is InfoVis or the IEEE Symposium on Information Visualization, but it has been joined by the Visual Analytics Science and Technology (VAST) conference and the International Conference on Information Visualization (IV), with these meetings collectively referred to as VisWeek. Gatherings with colleagues in cognate fields and other regions, have led to a bewildering menu of events such as SoftVis, BioVis, EuroVis, PacificVis, etc.(Chen 2010) There is an ever-expanding number of research institutes at universities and corporations specializing in information visualization.

Finally, there is no shortage of web sites collecting and celebrating noteworthy visualizations, which in some cases are commercial. A sample includes the following web sites and blogs:

- Online Library of Information on Visualization Environments at www.otal.umd.edu/Olive
- Datavisualization.ch at http://datavisualizaton.ch/
- Many Eyes at http://www-958.ibm.com/software/data/cognos/manyeyes/
- Tableau Public at http://www.tableausoftware.com/public
- Flowing Data at http://flowingdata.com/ (see "Visualization" in the Archives section)
- Infosthetics at http://infosthetics.com/
- Simple Complexity at http://simplecomplexity.net/
- Visual Complexity at http://www.visualcomplexity.com/vc/ (focus on network applications)
- Dynamic Diagrams blog "Information Design Watch" at http://dd.dynamicdiagrams.com/
- The Big Picture at www.public.iastate.edu/~CYBERSTACKS/BigPic.htm
- Junk Charts at http://junkcharts.typepad.com/

While the literature on information visualization focuses more on techniques, algorithms, issues, challenges, and theories, these web sites and blogs celebrate (and market) the outputs that emanate from the field, often starkly beautiful. The excitement from finding and engaging visualizations is palpable when visiting these and other sites, but also animates the literature.

What is Information Visualization? Inputs, Outputs, Domains

It is tempting to review information visualization outputs, which can be stimulating and aesthetically pleasing, and forget that not only are they are based on data inputs of one kind or another, but they are representations of that data. Data can be scientific measurements or other streams of data (like information packets), abstract numbers buttressing variables (such as social or economic data), or images, text, and documents. In a seminal contribution, Shneiderman (1996) identified seven kinds of data – one-dimensional (1D), two-dimensional (2D), three-dimensional (3D), temporal data, multi-dimensional data, tree data, and network data – noting that different data can be used in varying combinations. Indeed, a recurring and more fundamental theme in the data is that the quality of information visualizations – and the judgments they inform – are only as good as the underlying data. Not surprisingly, as is the case with statistics more generally, a fundamental precursor to good information visualization is ensuring that data either comes from a reliable and accurate source, or spending time to ensure that the data becomes so, or appreciating the extent of reliability and gaps when analyzing it (Ward et al 2010, pp.423-4).

With reliable data in hand, Bederson and Shneiderman (2003) identify seven tasks information visualization specialists must typically grapple with: overview, zoom, filter, details-on-demand, relate, history, and extract. Fry (2008) offers a somewhat different list: acquire, parse, filter, mine, represent, refine, and interact. The need to provide an “overview” and “zoom” presumes a certain threshold in volume of data, which requires seeing the whole and then focusing on different areas, levels of analysis or dimensions, or detail. The notion of filtering suggests that, with sufficiently large amounts of data on hand, aggregating or filtering out certain data might best inform analysis. There may be different ways to represent the same data in a visually pleasing and more accessible way to users. Underpinning these typologies, and the field more generally, is the expectation that arriving at robust and effective visualizations will necessarily be an iterative process, involving lots of experimentation with the data, filtering, and so on. Indeed, the very activities of mining, parsing, zooming, relating different streams of data, etc., are not only part of *building* visualizations, but often what a completed visualization capability might allow with end users. The extent of the visualization challenge depends on the amount, type, and diversity of the data streams at hand and, in turn, the audiences for the information.

A survey of the web sites noted above will quickly show that there are many different ways to represent data, which may be conditioned by type and range of data.[3] Ward et al (2010) divide visualization techniques into six broad categories: spatial data, geospatial data, multivariate data, trees/graphs/networks, and text/documents. Chen (2006) identifies many different forms

[3] Ward et al (2010) provide a detailed discussion of different types of data, ranging from whether they constitute ordinal, nominal or scalar data, to the various elements of syntax and semantics associated with data, and the extent to which data has explicit or implied geometric structure and/or connectivity with other data sources. They identify several examples of structured data: magnetic resonance imagery, computational fluid dynamics, financial, computer-aided design, remote sensing, census, and social network.

of “structural” representation: graphs, trees, and cones; proximity and connectivity techniques (such as semantic distance and word search, multi-dimensional scaling, and network analysis); clustering and classification (e.g., dividing data into sub-sets and taxonomies, cluster-seeds);[4] use of glyphs (e.g., using symbols on charts to convey additional information); creating virtual structures (e.g., WordNet, Wordle, etc.); and creating networks (scale, small or large, topological, nodes, etc.). Arriving at relatively easy-to-digest and relatively uncluttered diagrams, despite the volume and complexity of data, requires sifting through and organizing the data. Considerable research has focused on how to display network renderings without too many “edge-crossings”, or to use colour and line-density to show flows and relationships of certain volumes and intensities, or hyperbolic and fish-eye views to allow readers to see more detail in focused areas, all to make it easier for users to absorb despite rich and often dense data patterns. A challenge for observers is making sense of the many proprietary software packages, which may vary only modestly with respect to essential features of data manipulation but offer many different features for filtering and display.

In his survey of the state and evolution of the field, Chen (2006) argued that, while great strides had been made with many visualization techniques, most focused on ascertaining “structure” from available data. He argued that the next round of research would focus on extracting and displaying the dynamic and evolutionary properties of data. This partly reflects his interest in tracking the evolution of knowledge domains through citation data which display seminal contributions, linkages among researchers, and competing scientific worldviews (e.g., Chen and Cribben 2002). It also more generally captures the increasing interest in Rosling’s GapMinder web site and other efforts to show how data and variables intersect and change over time.

A significant development has been the emergence of the field of *visual and data analytics*. Driven by the availability of increasingly large and multiple data-sets – but also the real-time needs of governments, corporations, and scientific disciplines – there has been increasing interest in “data-mining” and the challenges of assembling, representing, linking, and analyzing diverse data in real-time contexts. For example, since 9/11 attacks, the US Department of Homeland Security invested considerably in exploring the potential of visualization technologies (Thomas and Cook 2004; Wong et al 2005) and supported leading-edge research in this field, and firms like Google analyze user patterns to develop new products and advertising streams. What makes visual analytics different from information visualization broadly understood are the specific challenges of: how to represent and use information from unstructured sources, how to facilitate developing hypotheses about potential linkages and behaviours, how to develop and test scenarios and hypotheses, how to display and assess diverse streams of

[4] Ward et a (2010) identify several topics in this regard: metadata and statistics; missing values and data cleansing; normalization; segmentation; sampling and subsetting (using interpolation); dimension reduction; aggregation and summarization; smoothing and filtering; and raster to vector conversion.(pp.50-66) The key point here is that information visualizations are often based on various ways of converting and representing data. They warn that understanding “the types of transformation the data has undergone can help in properly interpreting it.” (p.66)

information,[5] and how to share and analyze such information in group contexts, often in real-time and distributed decision-making environments (a variation on the challenges of meshing human-factors with computer-interface design).[6] Keim et al (2008) identify other areas for applications: physics and astronomy; environmental monitoring; disaster and emergency management; software analytics; biology, medicine and health; engineering analytics; personal information management; and mobile graphics and traffic. (pp.82-87)

Evaluating Visualization Techniques

An important premise of the field is that, in a complex world with a surfeit of data, visualization techniques are more effective than more traditional ways of sharing information. Bederson and Shneiderman (2003), for example observe that:

> "The attraction of visual displays, when compared to textual displays, is that they make use of the remarkable human perceptual ability for visual information. Within visual displays, there are opportunities for showing relationships by proximity, by containment, by connected lines, or by color coding. Highlighting techniques (for example, bold-fact text or brightening, inverse video, blinking, underscoring, or boxing) can be used to draw attention to certain items in a field of thousands of items. Pointing to a visual display can allow rapid selection, and feedback is apparent. The eye, the hand, and the mind seem to work smoothly and rapidly as users perform actions on visual displays." (Bederson and Shneiderman 2003, p.5)

In contrast, despite his enthusiasm and central role in a rapidly growing field, consider Chen's (2006) worry about where it might add genuine value:

> "The 1990s witnessed leaps and bounds in the field of information visualization with increasingly powerful techniques and visually appealing information visualization artifacts. Research in information visualization has been traditionally dominated by sophisticated and eye-popping innovations of visual representations and technical mechanisms. In contrast, empirical evaluations of information visualizations are often overshadowed by the enthusiasms for what can be done rather than for what should be done." (Chen 2006, p.173)

Which visualizations are superior to others, for what purposes, and under what circumstances? Is it the visualization or the hardware/software interface that affects the ability of users to consume and manipulate information as efficiently as possible? One strand of the literature has sought to provide answers to these questions (Chen and Czerwinski 2000).

Chen (2006, Ch.6), reviews studies that have sought to assess accuracy and effectiveness from the standpoint of users (i.e., a variety of cognitive factors, gender, prior knowledge), tasks (i.e., search, scanning, finding shortest paths, judgement), visual features (focus-context balance, 2D vs. 3D, glyphs,[7] etc.), and information (e.g., website hyperlinks and networks of documents).

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[5] For example, Reis et al (2010) consider the challenge of integrated assessment modelling (IAMs) for air pollution and climate change. This involves assembling and working across data collected for different purposes and with different time horizons, variables, and degrees of resolution.

[6] Ham (2010) lists several software tools for facilitating data analytics and source web sites, several of which are described in further detail in Ward et al (2010, Ch.14).

[7] Brath (2010) and Few (2009) present different ways to use the degrees of freedom offered by dots and spaces on graphs to convey more information (with a "glyph" or symbol), rather than numbers essentially adding another dimension or more in scientific and information visualization.

For example, 2D views seem to outperform 3D visualizations for exploring hierarchical data structures, but it is not clear why (Cockburn & McKenzie 2000). Others have compared kinds of tree map visualizations (Bederson et al 2001; Bederson and Shneiderman 2003; Satasko et al 2000; Plaisant et al 2002; Bevington and Anderson 2010), hyperbolic (focus + context) and fisheye views, as well as different kinds of graphs. Chen (2006) reports that 3D renderings of tree-maps do not out-perform 2D visualizations. Priolli et al (2003) developed the idea of "information scent", and sought to assess the effectiveness of display cues when users completed various tasks. Chen (2006) reviews several studies which show that, in different ways, the cognitive style of users makes a significant difference, which has important implications for design, training and education (p.202-210). Another area for research is focusing on the utility of dashboards and other interfaces in real-time decision-making in organizations with rapidly expanding stocks of information (Hamzah et al 2010).

A related line of research has recently emerged, examining the effectiveness of visualizations utilized for strategic purposes,[8] a practice field developed without much contact with diagram scholars (Blackwell et al 2008). The dimensions for comparison include: visual impact, clarity, perceived finishedness, directed focus, facilitated insight, modifiability, and group interaction support (Bresciani et al 2008a, 2008b; Bresciani & Eppler 2010). Bresciani and Eppler (2009b) use a quasi-experimental methodology to ascertain whether groups worked more effectively with different kinds of visualization, and controlling for no visualization. They found, regardless of perceived increased effectiveness, visualization-enhanced collaboration was more effective (and never inferior), even if the match of visualization approach for the tasks was not optimal. Blackwell et al (2008) suggest that assessments of effectiveness likely depend on whether the purpose was goal achievement vs. general orientation and visioning. Eppler et al (2009) consider the merits and risks of visual ambiguity, noting the benefits include analytic flexibility and allowing for diverse perspectives.[9] However, while this work is reported in InfoVis proceedings and journals, it is not focusing on data-driven visualization projections, but rather, on "strategic visualizations" that will be reviewed in more detail later in this paper.

Taking Stock: Key Issues and Research Priorities

A noteworthy feature of field of information visualization is that it regularly sets aside time to reflect on progress and to identify the next areas for research exploration. Indeed, the field received an enormous kick-start from the National Science Foundation panel that shaped it for years to come (McCormick et al 1987). This sensibility has been carried on over the years.

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[8] These include: flowcharts, idea fireworks visual metaphor, system dynamics, Venn diagrams, road maps, Forrester's wave, graphs, quadrant diagrams, cube diagrams, decision tables, pre-sketches, sketches and templates with post-it notes, embedded graphs in slide presentation, icebergs, mountain trails, slide rulers, bridges, metaphors, along with causal loops, timelines, and argument maps. Dansereau and Simpson (2009) call for more visual displays relying on node-link diagrams (including information maps, guide or template maps for facilitated dialogue, and freestyle maps arising from collaborations) for a variety of task-specific and client-oriented activities, and organizational development. They point to concept mapping (Novak 2002) and mind mapping (Buzan 1974).

[9] Categorizes types of ambiguity: the visual (iconic, symbolic, indexical); the people interpreting the visual (background, familiarity); and the interaction among the people interpreting the visual (focus, scope).

Ward et al (2010) provide a good overview and commentary on issues and challenges arising from several key reports, discussions, and lists developed by others (Johnson 2004; Johnson et al 2006; MacEachren and Kraak 2001; Thomas and Cook 2004; Grinstein et al 2008). There is not the space to review their survey in detail, but the key headings provide a sense of the span and the current research frontiers of the field of information visualization:

- *issues of data:* handling increased scale and scalability of data-sets (Chen 2010: 398); addressing and representing different types of data (static vs. dynamic, special vs. non-spatial, nominal vs. ordinal, and structured vs. nonstructured); dealing with time as variable and attribute; and variable quality;
- *issues of cognition, perception, and reasoning:* more research into how people undertake problem-solving with visual displays (clustering, identifying patterns, building and testing hypotheses, etc.), and how displays and systems can be improved to increase higher-level functioning, learning, interpretation, and use of memory with greater volumes and more streams of data (see also Hargarty 2010);
- *issues of system design:* achieving increased integration of computational analysis with interactive visual analysis, which would allow, depending on the challenge, for analysis to proceed either from visual analysis into computational manipulation, or vice versa; developing new interaction tools to assist with higher-order tasks when using visualizations; and designing systems that rely less on expert users.
- *issues of evaluation: t*o measure the yields of different kinds of visualization in terms of how individuals react and take in information, but also impacts on the quality of analysis and decision-making (Chen and Yu 2002; Plaisant 2004);
- *issues of hardware:* taking advantage of new technologies to share and display visualizations and information, such as hand-held displays, display walls, immersive environments, taking advantage of available computational hardware, and richer and more subtle interaction devices (voice, more tactile controls, and learning from gaming devices, etc.).
- *issues of applications:* depth-based innovations (how to take advantage of the latest or most appropriate visualization techniques by fostering good collaboration with domain experts) vs. breadth-based innovations (extending the reach of visualization, multiple types of data, and domain-specific innovation into other domains).

More generally, Ward et al (2010) call for a “science” of visualization to buttress the learning and yields from what has been essentially an inductive field. (p.424) Many of these topics and challenges stand as enduring themes of information visualization, with the strides in technology creating new issues or finally allowing for possibilities previously imagined to be taken up.

Interestingly, one theme from Chen (2005) not picked up by Ward et al (2010) was his call for more education and training in information visualization for users and practitioners alike. To be sure, there has been a significant proliferation of courses and textbooks since 2005, including Ward et al (2010)! In a more confrontational tone, Few (2008) criticizes contributors to the information visualization and data analytics for having been too scholarly, technology-driven, and inaccessible; insufficiently focused on the needs of generalist users. Conversely, Chen (2010) wonders whether enough thought has been given to striking the right balance between aesthetics and utility (pp.391-2). This latter concern is taken up in the next part of this paper.

3. Graphics and Information Display

The field of information visualization overlaps with writing and practice on information and graphics design in two directions: (1) towards the broad field of graphics, which has long explored and celebrated innovative ways to convey information for scientific, professional and advertising; and (2) the increasing number of magazines (e.g., *Wired*, *Scientific American*, *Popular Mechanics*, etc., to name only a few) and newspapers (e.g., *Wall Street Journal*, *The New York Times*, the *Globe and Mail*, etc.) investing in visual renderings of issues and stories. Websites and books have been multiplying on this subject, as well as gurus like McCandless (2009) and (Baer 2008) who generate and/or convey the best and most intriguing of these efforts. However, this broad and diverse area of graphics and information display should not be confused with the academic and professional work in visualization described in the previous section: the latter is wholly data-driven, whereas in varying degrees, information and graphics design places more of a premium on aesthetics, beauty and impact as points of departure.

This literature is breath-taking in its diversity, ranging from the exploration of new programs and algorithms for producing visualizations, to showcasing the remarkable and beautiful examples of visualization, to exploring their application in an ever-increasing array of fields, to developing theoretical constructs, and to exploring the cognitive dimensions of processing and interpreting visualizations. Many tip their professional and scholarly hats to Tufte (1990; 1997; 2001). Given that some visualization here is dedicated to “marketing” of ideas and products, it often generates concerns about the implications for how the cognate field of information visualization might be used in policy analysis, advising, and engagement, and therefore it is important to understand what it encompasses. What follows considers some of the different areas of application (print, graphic displays, presentations, etc.), and focuses on themes arising in the literature on topics like presentations, story-telling, animation, and the meaning of beauty, all relevant to addressing complexity and policy issues.

Displaying Information: Scope, Application, Media

In a wide-ranging compendium, Baer (2008) reports that the field of information design is broadly defined as “the translating [of] complex, unorganized, or unstructured data into valuable, meaningful information.” (p.12) Information-design practitioners can be found in many fields, and include graphic designers, information architects, interaction designers, user experience designers, usability and human-factors specialists, human-computer interaction specialists, and plain language experts (pp.14-15). Practitioners work with diverse media, ranging from printed matter (signs, guides, marketing, etc.), to information graphics produced for magazines and newspapers, to interactive web sites and screen-based projects, to various types of animation and advertising.

Baer (2008), like Steele and Iliinsky (2010), do a wonderful of job of displaying the diverse domains for information visualization: social and market network analysis (Krebs 2010; Holloway 2010; Perer 2010); voting patterns in legislatures (Odewahn 2010; Kinnaird et al 2010); aviation flight patterns (Koblin and Klump 2010) and subway maps (Jabbour 2010); text-related applications such as Wordle, searching New York Times data-bases, and monitoring the editing of entries in Wikipedia (Feinberg 2010; Thorp 2010; Wattenbery and Viegas 2010); and even autopsies! (Persson 2010) But these applications could easily be multiplied to include advertising, designs, and renderings in almost any field, like engineering, natural sciences, etc.

Steele and Iliinsky (2010) provide useful accounts of the design processes for very different kinds of visualizations (Chs. 2, 5, 8-9, 12-13). Some key themes that surfaced include: getting data and metrics right, simplifying the complexity that exists around thematic issues, achieving elegance and balance in the presentation of the visualization, moving from the specific to the whole, and anticipating considerable iteration, experimentation, and prototyping in order to arrive at workable and innovative visualizations. Many of these ideas are not new, and some have been long understood in research on specific aspects of visualization.

Cleveland and McGill's (1984) outlined a theory of graphical perception based on experimental data about how eye and brain take in and assess data contained in different charts (perceptual tasks). They considered the strengths and weaknesses of different displays, and how they might be improved with respect to, for example, the distribution and concentration of data, the angle of lines and trends, etc. Their ultimate goal was to find out how best to array information to facilitate basic perceptual task activity of users so as to improve the accuracy of their judgement. The seminal books are from Ware (2000; 2004; 2008). More recently, Blackwell et al (2008) reviewed strategy roadmaps as a genre of diagram approaches with respect to relative effectiveness, how they differ from each other, and what makes them succeed or fail (this is part of the research program of Bresciani, Eppler and Blackwell, *op.cit.* on diagrams).

Visualization: Presentations, Story-Telling, Animation

Another focus of some literature concerns designing visual displays of information for the purposes of engaging audiences as part of real-time presentations (which, of course, can be recorded and shared at other times). There are many publications that seek to improve presentations with respect to pacing, visuals and impact (e.g. Atkins 2007), but Duarte's recent *slide:ology* (2008) and *Resonate* (2010), interestingly, take this to new levels by *using visuals* to analyze how speakers can create emotional and intellectual impact by tapping into good visuals, adroit timing and scripting of presentations, balancing oral and visual information flows, and linking data and presentations to good stories and overriding messages to broaden horizons, encourage commitment, and stimulate change. Such assessment and instruction is clearly focused on *persuasion*, and, this leads some observers, who are not familiar with the other visualization approaches, sceptical about how visualization can add value to policy analysis, advising, and engagement.

A related theme concerns the importance of storytelling in communicating the relevance of data to audiences. Shapiro (2010), though identifying what sort of intellectual expertise is required to produce compelling visualizations,[10] argues that the key talent involves storytelling, and most information visualizations "will make themselves a pivotal point in a story or narrative within the viewers' (or users') minds." (p.16) Indeed, although Duarte (2010) identifies many exemplary speakers, she draws attention to the work and performances of Hans Rosling and his GapMinder visualizations, which can show the evolution of statistics over time, but, while the graphics can intriguingly be manipulated by users themselves, equally important are his performances that impart meaning, and mesmerize and stimulate audiences. Segel and Heer (2010) undertook an empirical study of the extent to which and modalities for how information visualizations were used in newspaper stories. Drawing on narrative analysis, they considered whether visualizations were used to support narrative structures developed in articles by the author (author-driven), or, moving in the opposite direction, providing the reader with more opportunity to develop their own interpretations and narratives (user-driven).[11] They identify three hybrid types of articles with visualizations: 'martini-glass' visualizations, interactive slideshows, and articles with 'drill-down' organization. This study leads to some important questions: what is the appropriate balance to strike between narratives projected by the author versus the exploration of the reader? Is the goal to support worked-out narrative structures or support more exploration?

Considering the possibilities of animation is a logical step after considering the proliferation of visualization packages, particularly those allowing users to manipulate data over time and with different filters, and how story-telling might assist with interpreting data. There are many types of animation (Heer & Robertson 2007), including computer-generated animation for movies, gaming, simulations, advertising, and more scientific-architectural-engineering applications. However, where users are concerned, the literature suggests animation does not out-perform static representations of data, such as graphs. Tversky et al (2002) reviewed close to a hundred studies on animation and visualization, concluding that, while animation outperformed textual representations, they did not do better than "rich static" diagrams. Others suggest animations do not help understand the theory behind algorithms, but understanding the theory (causal linkages) did help in learning more from them, and one way to do so involved manipulating the animations (Hundhausen et al 2002). Fisher (2010) explored how users respond to static versus dynamic (or animated) visualizations, and how to move across different kinds of visualization relying on the same data. He, like others, argues that evidence shows a limited pay-off to animation, which only provides benefits under certain circumstances. Those using scientific visualization tend to be more comfortable with dynamic representations than those using information visualizations, likely because the former have a shared knowledge base and work with real-world objects, while the latter often work with abstract data. (p.331)

[10] "The best visualizations tend to be dreamed up and executed by either single individuals with abilities across a wide range of disciplines, or small teams working very closely together. In these small, agile environments, the full range of talents can intersect and produce a stunning image or interactive product that can communicate a concept in a way that is more natural to human comprehension than a string of insights." (p.15).

[11] See also Gershon and Page [12] paper.

Fischer (2010) observes that even GapMinder – which is not a full animation technology – relies heavily on Hans Rosling's narratives, and because the dimensions of the charts remain constant and the data generally move in similar directions over time (p.333) Consistent with Segel and Heer (2010) reviewed above, Fisher (2010) makes a distinction between using animation for the purposes of presentation versus exploration (and learning), reporting that users would take longer to explore and play with animations, and that, when responding to questions they were less accurate with animation as opposed to static diagrams. Here I would like to observe that much of this literature has focused on animations seeking to convey a data-field of some sort, as opposed to animation that creates impressions free from, but with fidelity to, the data.[12] The latter case is Segel and Heer's (2010) narrative story-telling. Intriguingly, Fisher (2010) notes that cartoon animators often used distortion to create movement and catch the eye, and raise the possibility that modern animators may inadvertently suggest linkages where none empirically exist (p.331-2; see also Zongker & Salesin 2003). There is a modest consensus on principles for guiding animation: congruence with actual data; ease of apprehension or take-up for users, staged changes to different time or other dimensions, compatibility with previous visualizations, and only use necessary and meaningful motions (Fisher 2010, p.348-9; also see Tversky et al 2002, Heer & Robertson 2007, Zongker & Salesin 2003, Freidrich & Eades 2002).

Conclusion: Balancing Beauty and Utility in Visualization

The quality of "beauty" is a dominant and recurring theme. A review of the representations of flight patterns across North America in Koblin and Klump (2010) or the fact-driven visualizations in McCandless (2009), let alone myriad scientific visualizations in various articles and collections, make this apparent. Indeed, as Steele and Iliinsky (2010) in the introduction to their collection *Beautiful Visualization* observe:

> "This book found its beginnings as a natural outgrowth of Toby Segaran and Jeff Hammerbacher's *Beautiful Data* (O'Reilly), which explores everything from data gathering to data storage and organization and data analysis. While working on that project, it became clear to us that visualization – the practice of presenting information for consumption as art – was a topic deep and wide enough to warrant a separate examination...Andy Oram and Greg Wilson's *Beautiful Code* (O'Reilly), defined beauty as a simple and elegant solution to some kind of problem. But visualization – as a combination of information and art – naturally combines both problem solving and aesthetics, allowing us to consider beauty in intellectual and classical senses." (p.xi)

Illinsky (2010) argues that "For a visual to qualify as beautiful, it must be aesthetically pleasing, yes, but it must also be novel, informative, and efficient" (p.1) and suggests there is often a tension between the goal of conveying what is already known versus assisting the process of discovery (p.8). Putnam et al (2010), when describing their efforts to provide surround-sound-and-visual experiences, comment that "Our challenge and opportunity in composing beautiful visualizations is thus to strike a balance of both mathematical truth and perceptual expression, and to introduce a new form of art and research as epistemological experiment." (293) Indeed,

[12] **EAL**: There is good advice on design sensibilities, it does not deal with the challenge of multiple levels of analysis and streams of information. However, perhaps the place to go is Fry (2008) on dashboard designs.

despite the adage “beauty is in the eyes of the beholder”, both elegance and proportionality in design are highly valued across disciplines and professions for addressing the purposes at hand.

A big question concerns the extent to which such visualizations, no matter how compelling and intriguing, are also relevant, useful and economical. Beauty, of course, is not inconsistent with utility, and often arises from its correspondence and assistance to the tasks hand. The idea that beautiful visualization can contain a mix of elegance and utility is compelling but, even when beauty predominates as a goal and effect of visualization, such “play” can lead to greater interest in visualization, more facility with associated technologies, and to discovering other more practical applications.[13] So, in this sense, beautiful visualization – just like information visualization and data analytics reviewed earlier, and different kinds of strategic visualization discussed in the next section – is part of a broader spectrum of exploring possibilities for more effective ways to present and interpret information.

4. Visual Approaches to Thinking and Strategy

The first two streams of information and graphics visualization are essentially driven by data, with varying degrees of emphasis on the data-sets and presentation. This section reviews a third stream of visualization comprising two distinct but, to my mind, overlapping streams of visualization both involving direct engagement with and facilitation of decision-makers. Of all the visualization streams, this “free-hand” work – though not short of method and technique – comes the closest to grappling with the more general challenges confronting policy-makers and advisors, even if they involve coming to grips with information and perspectives supplied by other visualization practitioners. We begin with the practitioners who most readily see their work as “visualization”, and then turn to others who work with clients to strategically address complexity, but who can be seen as highly visual in approach.

Visualization and Facilitation

When the term “visualization” is uttered, another equally engaged and enthusiastic set of practitioners might step forward: a growing community of visual and graphics artists who assist clients in grappling with complexity by means of sketching, often involving elaborate renderings of challenges and strategies. Their work proceeds under different labels – graphic recorders, graphic facilitators, and visual practitioners – but essentially they sketch in an engaging manner the evolution and key conclusions of meetings and conferences over a day and more, often in substantial and dynamic diagrams attempting to capture the movement, enthusiasm and vision of participants. Visual practitioners either work as – or in collaboration with – consultants who are variously providing services as facilitators and/or recorders for strategic and organizational development retreats, collaborative visioning processes, and community and stakeholder engagement exercises.

[13] Feinberg (2010) emphasizes that Wordle was developed for pleasure and play, but it has acquired more aesthetic qualities for impact and art. He notes that research reveals that, even when people don’t use Wordle for analysis, they feel creative and experience “delight and surprise” (Viegas, Wattenberg and Feinberg 2009).

The vector for this visualization community is the International Forum of Visual Practitioners (IVFP) founded in 1995 and anchored by its web site www.ifvp.org and an annual conference. Another vector for this community is the VizThink web site at www.vizthink.com, which seems to range somewhat more broadly to include providing advice on compelling presentations with different visual technologies and monitoring different techniques for telling stories, but this difference may seem more apparent than real, since there seems to be considerable overlap in approach, gurus, and literature. Once again, many take inspiration from the work of Edward Tufte, but also Peter Senge, a leader in systems thinking and organizational development (see below). In addition to the community's sense of momentum in terms of events and the blogosphere, external validation and interest recently came from the more traditional *Harvard Business Review* (McGinn 2010).

A review of the IFVP web site reveals that many of the practitioners have similar styles, but varying degrees of vertical integration: some are exclusively "recorders", others are equally engaged in facilitation, and still others may be more fully immersed in the broader process of organizational development and stakeholder engagement. Nevertheless, there seems a great deal of convergence in approaches and techniques, which can be found in several books and guides (Margulies and Valenza 2005; Hyerle 2009; Sibbet 2010; Blackwell et al 2008) and include the following: Venn diagrams, concept mapping, bubble maps, mind maps, thinking maps, systems feedback loops, mind-scaping, thinking hats, visual journeys, assumption trees, icebergs, influence circles, etc.[14]

Some approaches, however popular, are more focused, such as Roam's (2009) focus on "back-of-the-envelope" sketching for individuals and groups, and Osterwalder and Pigneur's (2010) survey of approaches to innovation and design – both seek to quickly stimulate creativity and problem-solving by sketching and a variety of visual techniques. Others are broader, moving into the realm of facilitating better presentations for audiences by means of more effectively using visualization, intriguingly including developing a better understanding how presentations work through a variety of visual means (Duarte 2010; Atkinson 2008).

Stepping back, these contributions all convey a strong sense of mission and pragmatism, typically centred on the suite of approaches valued by specific authors, and thus do not constitute reviews of the state of the literature and practice that one would find of the fields of information visualization and data analytics. And, it would be a mistake to suggest that this community, while not heavily vested in data-driven information visualization, is not interested in technology; rather, they appear interested in the challenges posed by technological change

[14] Sibbet (2010) was authored by the founder of The Grove Consultants International group at www.grove.com, well-known for its dynamic, complex drawings that capture facilitated events, most notably "story-mapping" and a host of other visualizations. This book provides an eclectic history, advice and templates developed over the years, and points to other sources of tools and inspiration, including, among others, David Snowdon's work at Cognitive Edge at www.cognitive-edge.com, the Institute for the Future, Tony Buzan and his mind mapping at www.thinkbuzan.com, and the Society for Organizational Learning at www.solonline.org Peter Senge's *The Fifth Discipline*, which relies on visual thinking in the form of systems thinking.

for organizations and communities, and actively seek ways to use technology to assist with their work (using tablets, sharing information at events, displaying and sharing diagrams, etc.).

To conclude, it is worth drawing attention to the work of Robert Horn, one of the gurus in the field, who authored (drew!) a classic in the field: *Visual Language: Global Communications for the 21st Century* (Horn 1998). Horn's approach is interesting because not only does he argue that visual language has its own semantic elements and structure, and he uses visualization with sketches and clip-art to assist policy-makers and citizens to comprehend and think about how to address complex policy challenges and 'wicked problems' (Horn 2001). Like the broader family of visual practitioners, he developed various techniques to assist in coming to grips with different facets of challenges. These included maps for identifying strategy, options, scenario, argumentation, cross-boundary causality and dynamics, stakeholder considerations, and unknown territory, as well as agreement templates, visual timelines, quantitative charts and graphs, and process and procedure flow charts, and what he called "visual cognitive" maps, including "mythosphere", media, public rhetoric, worldview, dilemmas and paradox maps. Many visual practitioners might see more generic techniques under these labels, but what stands out is his effort to capture the challenges confronting policy-makers.

Related Approaches: Systems, Simulation, Scenarios, and Performance Thinking
An interesting feature of visualization practice literature is that many authors and facilitators tap into approaches that many observers would associate with "systems thinking", and, with the exception of Sibbet (2010), this is not acknowledged. This may be partly attributable to the fact that the modern systems thinkers did not conceive of themselves as "visualists", but rather as bringing more systematic analysis to organizations and sometimes communities to address complexity and wicked problems, even if they relied on visual methods. Moreover, there are other approaches for analyzing complexity which are not ordinarily thought of as part of the family of "visualization" methodologies, but ought to be included. What follows briefly reviews some essential systems thinking contributions and its relationship with visualization, and then flags simulation, scenario, and performance thinking as candidates as *de facto* practitioners of visualization, albeit working with different methodologies.

A widely recognized approach for helping decision-makers and affected stakeholders explore, comprehend, and grapple with complex policy and management problems is that of "systems thinking", particularly the soft systems approach – developed by Peter Checkland in the 1970s and later popularized by Peter Senge and others in the 1990s. These formulations modified and extended of the early ideas associated with general systems theory, which performed better with more mechanistic systems (Checkland 1999; Senge 1990). We do not have the space here to review systems thinking in detail, but in essence its practitioners seek to work with decision-makers and stakeholders to better understand in the context of problems and interventions the issues, surrounding complexity, diverse interests and perspectives, the task and institutional factors at play, and, through dialogue, identify pragmatic ways for improving the situation (Checkland 1999; Checkland & Poulter 2010; Senge 1990; Chapman 2004; Chapman et al 2009). Chapman sees systems thinking as ranging from different mixes of sense-making to developing action plans in complex situations (Checkland 1999, A29).

A key feature of systems thinking involves encouraging participants do commit perspectives, perceptions, and even emotions to paper in the form of diagrams, such as 'rich pictures' and other sketches, which can be shared and debated with others. Reflecting on the emergence of the diagramming in soft systems methodology, Checkland (1999) observed:

> "...an intangible, aesthetic point, but an important one—its fried-egg shapes and curved arrows begin to undermine the apparent *certainty* conveyed by straight arrows and rectangular boxes. These are typical of work in science and engineering, and the style conveys the implication: 'this is the case'. The more organic style...is meant to indicate that the status of all these artefacts is that they are working models, currently relevant *now* in *this* study, not claiming permanent ontological status. They are also meant to look more human, more natural than the ruled lines and right angles of science and engineering." (A13)

> "Making drawings to indicate the many elements in any human situation is something which has characterized SSM from the start. Its rationale lies in the fact the complexity of human affairs is always a complexity of multiple interacting relationships; and pictures are a better medium than linear prose for expressing relationships. Pictures can be taken in as a whole and help to encourage holistic rather than reductionist thinking about a situation...we have found them invaluable as an item which can be tabled as the starting point of exploratory discussion with people in a problem situation. In doing so we are saying, in effect 'This is how we see this situation at present, its main stakeholders and issues. Have we got it right from your perspective?'" (A16)

> "...although the stages can be carried out on a computer screen, there is a good case, as long as you can manage it from a good visual style, for producing the final model in hand-drawn form. The reason for this is psychological, and is the same as that for drawing egg or cloud shapers rather than rectangular boxes: it acknowledges the models' roles as pragmatic devices, not definitive once-and-for-all statements." (A27)

Chapman (2004) observes that, when trying to capture messy situations, a free-hand picture is superior to a more formal diagram because by "making a picture rather than using words most people will express more of their emotional reaction to the mess." (pp.46-47). *Beyond making the case that systems thinking relies heavily on visualization in how it engenders engagement and dialogue, these observations will be worth reflecting on more generally when we consider how individuals react to pre-formed visualizations of information and strategic thinking*.

There are many other approaches that assist with sense-making and strategic dialogue and planning within and across organizations and communities. These include, but are not limited to simulations, scenario-building, and performance thinking. I do not have the space to delve into each of these rich traditions, but I want to make the argument that each essentially relies on visualization to achieve its purpose, each with costs and benefits:

- *simulations*. Models of how a variety of market, social, organizational, and natural systems are developed, with the capability of altering different input and external variables as a way to understand the properties of complex systems. This allows users to consider the resulting trajectories of other variables over time and decision-making quandaries, constraints, and trade-offs. The point is that, no matter how mathematical the underpinning models, the altered intersections and trajectories of key variables are often conveyed visually (think of how economists use charts to display different "runs" of a model) to engage analysts and audiences. Other examples are more elaborate: it suffices to think of airplane cockpit, climate-change, or multi-actor game simulations.

- *scenario-building*. There is a considerable literature on scenario-building, encouraging participants to imagine diverse futures comprised of diverse variables and based on key contingencies, and how these futures might be connected to the present, with the goal of creating "shared mental maps" (Rosell et al 1995; Ringland 1998; Staley 2009). Scenarios are intended to assist users to think broadly and creatively about future possibilities, but are also ways to get a handle on dynamic, complex environments. What is not sufficiently well understood is the *visuality* of scenario-building, even if the more elaborate exercises can be informed by speakers and background documents: participants are typically encouraged to share ideas on walls and whiteboards, to explore the interconnections among variables, to develop coherent narratives and images of future states (often capturing their essence with diagrams and labels).
- *performance thinking*. With the advent of the New Public Management, performance thinking has swept across the government sector around the world. Most observers undoubtedly understand the crucial steps of developing "logic models" linking inputs and activities associated with programs to outputs and desired outcomes (short, medium and longer term) as a basis for developing performance measurement and management systems (McDavid & Hawthorn 2006). However, they would typically not see logic models as visualization, in part because of the resulting diagrams are linear. And yet, any practitioner would agree that the delineation of logic models is a highly visual and iterative process: often balancing the needs of parsimony and detail to arrive at a "model" that is a representation of much more complex reality, usually leaving out details that others might think important for assessing likelihood of achieving success, such as about the state of organizational capabilities and culture, political dynamics and commitment, resource allocation, client perspectives, and environmental change.

All of these approaches – systems thinking, simulations, scenario-building, and performance thinking – seek to make sense of complexity and assist decision-makers and others to develop strategic interventions. Each, in vary degrees, relies heavily on facilitation of group processes for the purposes of sense-making and strategic dialogue, and on visualization in order to capture complexity at different stages and levels of analysis. To the extent that such processes do not engage a broader circle of organizational, network or community participants, they in the end are seen as 'top-down' and fail to resonate more broadly.

Conclusion: Visualization for Thinking and Strategy in Perspective

The family of sketching and systems "strategic" visualization practitioners are perhaps the closest of all the visualization experts to the specific challenges of decision-makers; their goal to assist clients with capturing the nature of problems and developing workable strategies for addressing them. They contrast with the other traditions reviewed earlier in two ways:

- they <u>are</u> focused on the challenges of decision-makers, as opposed to supplying them with data or perspectives driven by data, and strive to assist them in discovering what they know and don't know; and

- they do <u>not</u> rely on computer-mediated visualizations (simple or complex) of findings from data-sets (larger or small), instead relying on hand-sketched renderings to move conversations along.

However, strategic visualization practitioners and their clients can be informed by data and rendering from the other visualization practitioners. All of these practitioners, though working with different goals and methodologies, often have similar intellectual interests, intrigued by TED events, animation, etc. Collectively, they are in search of better ways to foster individual, organizational, and societal learning.

Intuitively and through practice, strategic visualization practitioners have arrived at similar conclusions of their data-driven and graphics-enhanced colleagues: *users of visualizations can only handle so much complexity, prefer to have images in certain forms, and often learn better with tactile engagement with frameworks and data, often resisting pre-formed charts and figures*. With the exception of those seeking to evaluate different approaches to information visualization, data analytics, and human-computer interface from a user perspective, the strategic visualization practitioners seem more acutely aware of the challenges that decision-makers as users have with respect to making sense of information, developing strategic interventions in light of this information, and then implementing them, because they see and hear more about these challenges. These are all important considerations for thinking about how potential of information visualization, graphics, and strategic visualization can be better factored into analytic, advising, and engagement processes in government.

5. Stepping Back: Looking Across the Visualization Domains

The three visualization domains reviewed above vary with respect to: their focus and the problems addressed, the visual techniques applied, the intended audiences, the kind of data driving the visualization, etc. Although each visualization domain provides interesting contrasts – implicitly or explicitly – to the others, there are overlaps across them, and no hard and fast boundaries. Indeed, those working in all of the domains seem equally inspired by Tufte's work and earlier efforts at mapping and drawing; all see visualization as having great promise as a superior way to render information for illumination and decision-making; and all try to balance and improve the aesthetic and practical qualities of visualizations, albeit in varying ways.

Rather than summarize the similarities and differences across these visualization domains, the goal of this section is to step back and consider some broad messages arising from the full body of inquiry, practice, and innovation. These include the following:

- *holism, scaling, zooming*. Although easily taken for granted, a key reason for adopting visualization techniques is to see the "whole" in order analyze the parts. This advantage creates challenges: analyzing the whole requires delving into the parts, filtering across parts, and seeing connections. This requires the ability to zoom in and out, to rotate, and to use images as point of departure for further exploration and re-integration.

- *representations involve trade-offs*. Although well understood in the literature, the very ability of visualizations to represent considerable complexity – whether it involves data, images, networks, voices or conclusions – obscures the fact that the depictions are often simplifications of complexity, distillations of information, and not showing underlying detail that might be critical for interpretations and strategies.
- *visualizations may (or may not) promote exploration*. Visual images and imaging can arise out of an iterative and often from group processes, and users may well have their mental horizons broadened by them, but it can be an open question as to whether the ultimate audience can manipulate the variables underpinning the visualizations.
- *dynamic visualization rocks*. Static data and representations are important, and will continue to be, but displaying trends and evolving relationships is highly desirable as a basis for better understanding phenomena and arriving at strategic interventions.
- *more data streams and perspectives are better*. Whether as an input into different kinds of representations, or even as an activity and output, it is considered superior to have multiple lines of data, diverse perspectives on their semantics, and/or the wherewithal to appraise the final results from different vantage points. However, the extent to which this is essential also depends on the nature of task (e.g., analysis, security, strategizing).
- *users lag and react differently to visualizations*. Despite the advances that have been made in computer-generated visualization, the evidence suggests that humans may not take-up more sophisticated renderings due to cognitive limitations, preferences, or prior knowledge of interfaces or substance. The disposition of different user audiences – expert or novice, and primary and secondary – ought to be considered when designing visualizations and supporting systems and technologies (this also applies to drawing!).
- *story-telling enhances visualizations*. There is widespread acknowledgement that even the best visualizations require parallel story-telling in order to draw out interesting facts and interesting issues. The audiences for visualizations are human: needing context, narrative, and often a guide to parse information. This suggests that, for visualization to reach its full potential, the larger context of utilization must be appreciated.
- *accessibility matters*. Increasing accessibility to visualization technology and products from non-experts is an important goal, and a greater challenge for those in information visualization and data analytics, but necessary for anyone seeking to interpret outputs of visualizations from any of the three domains, and critical if more non-experts are to be give greater opportunity to work with and manipulate visualizations.
- *designers and users should interact*. There is considerable agreement that the best and most relevant visualizations as result of dialogue and interaction between the designers and the users, with the former needing a nuanced appreciation of users' needs.
- *innovation, re-discovery and re-packaging*. Regardless of the domain, one can see instances of where a technique developed for one purpose either gets applied to another, is incorporated as a sub-set of another suite of technologies, is "invented" in another substantive or scientific domain, or is branded as part of proprietary software

or facilitation package. This creates confusion but also augers for cross-fertilization and cross-cutting reviews and assessments of techniques and applications.

- *education and training increasingly essential*. Even in the InfoVis community, where the leading technical researchers have pushed the boundaries of technology and imaging, there is broad agreement on expanding the circle of users – primary and secondary – literate in visualization techniques (Chen 2006; Few 2008) and this requires experts to meet them more than half way (Plaisant 2005; Grammel et al 2010).

These are high-level themes, rising above the often intriguing and sophisticated observations, lessons, and research findings that can be easily found in specific visualization domains. In the next and final section we consider whether this literature explicitly or implicitly deals with the use and potential of visualization for dealing with the complex challenges in the worlds of policy analysis, advising, and engagement.

6. Conclusion: Implications for Complexity and Policy Visualization?

This paper has provided a review of the literature on information visualization, graphics and information display, and visual facilitation for thinking and strategy. We have considered their contrasting and common features. Individually and collectively, the fields of visualization are diverse and exciting, generating considerable enthusiasm among practitioners, particularly as applications spread to different disciplines and policy areas, with an aspiration of relevance for the public, decision-makers in organizations and communities, and policy-makers. However, as discussed below, the literature does not have well-developed ways for understanding how visualization fits into policy-making. Conversely, many public service executives and policy and public administration scholars I have chatted with about visualization are sceptical about the potential for applying information and other visualization approaches to public policy matters precisely because they assume visualization is about marketing and persuasion – they are not familiar with its potential for providing data and ways to capture complexity.

To understand the gaps and misapprehensions here, let us first briefly re-visit the orientations of the visualization domains. The information and graphics visualization movements have both been focused on making use of available data, presuming that, if represented well, it will be useful to users, while understanding limits and potential misuses arising from poor data and presentation techniques, and even intentional misrepresentation. However, aside from understanding how visualizations might be more authentically and better displayed (as well as improving hardware and software interfaces for manipulating them) for specific users, little attention has been directed to considering how visualization products fits into sense-making, strategic development, advising, and communications in policy-making environments, nor how organizations and decision-makers more generally grapple with complexity. *This is intriguing because the third stream of visualization for thinking and strategy explicitly works in this area*. Approaches such as drawing, modern systems thinking, soft systems methodology, concept mapping, strategy maps, and performance models are dedicated to capturing and analyzing complexity as a basis for strategic assessments and organizational and policy interventions.

There has been little effort to work systematically across the visualization domains; nor is there much evidence of cross-fertilization across the InfoVis and VisThink communities.

Why would such a gap exist across these domains, when there are overlaps across visualization domains, and each claims Tufte as a guru? All of the visualization domains have been growing rapidly: there is a lot on the respective agendas of already broad, interdisciplinary scholarly and practice fields. The irony, though, is that the most recent stream of "evaluative" information visualization research has focused on strategy mapping and related approaches (see work by Bresciani, Blackwell, and Eppler), even if it does not appear to be informed by a more general framework about how data and visualization might fit into broader policy-making dynamics. Taking a much broader perspective, there appears to be little, if any, awareness in any of the visualization fields of the knowledge and research utilization literature, which has long sought to understand whether and how research influences policy-making, or more recent work on evidence-based policy-making (for a primer, see Nutley et al 2007). As far as I am aware, there are no studies that seek to assess the relative yields and cost of information and other types of visualization, nor how they, in turn, might compare to other ways of presenting information for insight.[15] And, despite evidence of appreciation of how well-presented visualizations can inform sense-making, there is little, if any, discussion of how any of the products from any of the visualization domains would fit in, enhance or compete with other forms of information used in policy-making.[16]

We should never be overly critical of fields of practice and inquiry that were never intended to deal with other questions that we bring to the table. The visualization domains reviewed in this paper have been largely technology-driven and practice-based fields; they have yet to produce an encompassing and uniting framework, let alone address questions about the salience and performance of visualization techniques in policy-making contexts. Conversely, it appears that none of the major academic and professional journals on public policy and public management have systematically explored the potential of visualization for improving analysis, advising, and engagement,[17] but reviews of policy-specific professional and academic journals would likely identify several instances of use of visualization techniques. This suggests that the HC Coombs Policy Forum roundtables on "Grappling with Complex Policy Challenges: Exploring the Potential of Visualization Technologies for Analysis, Advising and Engagement" may provide an opportunity not only to explore how visualization can inform policy-making but also stimulate the fields of visualization to develop a more encompassing perspective which may inform the theorization that some contributors have suggested is overdue.

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[15] A parallel gap exists for the literature on citizen engagement, which has not systematically compared the costs and benefits of different consultation and engagement instruments (Lindquist 2005).

[16] This criticism has been made of the evidence-based policy movement, which does not consider the many other streams of information converging on policy-makers (Lindquist 2006), but see Campbell et al (2007).

[17] Some attention has been paid to policy argumentation, narrative policy analysis, etc. (e.g., Majone 1989; Fischer and Forrester 1993; Roe 1994; McBeth et al 2007), and to different teaching methodologies (see the Journal of Public Affairs Education and the teaching notes section of the *Journal of Policy Analysis and Management*).

References

Arnheim, Rudolf, *Visual Thinking* (Berkeley: University of California Press, 1969).

Atkinson, Cliff, *Beyond Bullet Points*. Redmond, WA: Microsoft, 2008.

Baer, Kim (with Jill Vacarra), *Information Design Workbook: Graphic Approaches, Solutions, and Inspiration + 30 Case Studies* (Beverly, Mass.: Rockport, 2010).

Bederson, BB, B Shneiderman, and M Wattenberg, "Ordered and quantum treemaps: Making effective use of 2D space to display hierarchies" in *ACM Transactions on Graphics*, v.21, n.4 (2002), pp.833-854.

Bederson, B.B., and B. Shneiderman (2003). *The Craft of Information Visualization: Readings and Reflections*. San Franciso: Morgan Kaufman.

Bevington, William M., and William A. Anderson, "Complications and Adjacencies: An Organizing Logic for Information Graphics", *Parsons Journal for Information Mapping*, v.11, n.3 (Summer 2010), pp.1-13.

Bevington, William M., "PIIMPaper 01, Part One: A Visualization-based Taxonomy for Information Representation: Introduction and Overview" (New York: Parsons Institute for Information Mapping, 2007), accessed at http://piim.newschool.edu./media/pdfs/PIIM-PAPER_01-Pt3_Bevington-William.pdf.

Blackwell, Alan. F., et al, "Strategy Roadmaps: New Forms, New Practices" in G. Stapledon, J. Howse, and J. Lee (eds.), *Diagrams 2008* (Springer-Verlag, 2008), pp.127-140.

Brances, Ulrik, and Steven R. Carmen, "Visual Unrolling of Network Evolution and the Analysis of Dynamic Discourse", *IEEE Symposium on Information Visualization 2002*, pp.1-7.

Brandes, Ulrik, Patrick Kenns, Jorg Raab, Volker Scheider and Dorathea Wagner, "Explorations into the Visualization of Policy Networks", *Journal of Theoretical Politics*, v.11, n.1 (1999), pp.75-106.

Brandes, Ulrik, Patrick Kenns, and Jorg Raab, "Explanation Through Network Visualization", *Methodology*, v.2, n.1 (2006), pp.16-23.

Brath, Richard, "Multiple Shape Attributes in Information Visualization: Guidance from Prior Art and Experiments", Proceedings 2010 14th Conference Information Visualisation. Washington, DC: IEEE Computer Society, 2010).

Bresciani, Sabrina, Alan Blackwell, and Martin Eppler, "Choosing visualisations for collaborative work and meetings: A guide to usability dimensions", Darwin College Research Report, DCRR-007. Cambridge University, 2008a.

Bresciani, Sabrina, Alan F. Blackwell, and Martin Eppler, "A Collaborative Dimensions Framework: Understanding the Mediating Role of Conceptual Visualizations in Collaborative Knowledge Work", Proceedings of the 41st Hawaii International Conference on System Sciences – 2008. Washington, DC: IEEE Computer Society, 2008b.

Bresciani, Sabrina, and Martin J. Eppler, "The Risks of Visualization: A Classification of Disadvantages with Graphic Representation of Information", ICA Working Paper #1/2008, University of Lugano, Institute for Corporate Communication (February 2008).

Bresciani, Sabrina, and Martin J. Eppler, "Beyond knowledge visualization usability: toward a better understanding of business diagram adoption", Proceedings of 2009 13th International Conference Information Visualisation. Washington, DC: IEEE Computer Society, 2009a.

Bresciani, Sabrina, and Martin J. Eppler, "The Benefits of Synchronous Collaborative Information Visualization: Evidence from an Experimental Evaluation", IEEE Trans Vis Comput Graph. v.15, n.6 (Nov-Dec 2009b), pp.1073-80.

Bresciani, Sabrina, and Martin J. Eppler, "Choosing Knowledge Visualizations to Augment Cognition: the Managers' View", proceedings of 2010 14th International Conference Information Visualization. Washington, DC: IEEE Computer Society, 2010, pp.355-360.

Campbell, Siobhan, et al, *Analysis for policy: evidence-based policy in practice* (London: HM Treasury, 2007).

Card, Stuart K., Jock D. Mackinlay, and Ben Schneiderman (eds.), *Readings in Information Visualization: Using Vision to Think*. San Francisco: Morgan Kaufmann, 1999a.
- "Information Visualization", Ch. 1, 1999b, pp.1-34.
- "Applications", Ch. 8, 1999c, pp.625-636.
- "Conclusions", Ch. 9, 1999d, pp.637-640.

Carpendale, Sheelagh, "Evaluating Information Visualization" in Andreas Kerren, John T. Stasko, Jean-Daniel Fekete, and Chris North (eds.), *Information Visualization: Human-Centered Issues and Perspectives* (London: Springer-Verlag, 2008), pp.19-45.

Chabris, Christopher F., and Stephen M. Kosslyn, "Representational Correspondence as a Basic Principle of Diagram Design" in S.-O. Tergan and T. Keller (eds.), *Knowledge and Information Visualization* (Springer-Verlag Berlin Heidelberg 2005), pp. 36-57.

Chapman, Jake, *System Failure: Why governments must learn to think differently,* 2nd Edition. London: Demos, 2004).

Chapman, Jake, Charlie Edwards, and Simon Hampson, *Connecting the Dots*. London: Demos, 2009.

Checkland, Peter, and John Poulter, "Soft Systems Methodology" in M. Reynolds and S. Howell (eds.), *Systems Approaches to Managing Change* (London: Open University, Springer-Verland, 2010), 191-242.

Chen, Chaomei, *Information Visualization and Virtual Environments* (London: Springer, 1999).

Chen, Chaomei, *Mapping Scientific Frontiers* (2003).

Chen, Chaomei, *Information Visualization: Beyond the Horizon*, 2nd Ed. (London: Springer-Verlag, 2006).

Chen, Chaomei, "Top 10 Unsolved Information Visualization Problems", *IEEE Computer Graphics and Applications* (July/August 2005), pp.12-16

Chen, Chaomei, "Overview: Information Visualization", *WIREs Computational Statistics*, v.2 (July/August 2010), pp.387-403.

Chen, Chaomei, and Timothy Cribben, "Visualizing and Tracking the Growth of Competing Paradigms: Two Case Studies", *Journal of the American Society for Information Science and Technolog*y, v.53, n.8 (2002), pp.678-689.

Chen, Chaomei, and M. Czerwinski, "Empirical evaluation of information visualizations: An introduction", *International Journal of Human-Computer Studies*, v. 53 (2000), pp.631-635.

Chen, C. and Y. Yu, "Empirical studies of information visualization: A meta-analysis", *International Journal of Human-Computer Studies*, v.53, n.5, (2000), pp.851-866.

Chen, Chun-houh, Wolfgang Hardle, and Antony Unwin (eds.), *Handbook of Data Visualization* (London: Springer-Verlag, 2008).

Chin Jr., George, Olga A. Kutcher, and Katherine E. Wolf, "Exploring the Analytical Processes of Intelligence Analysts", *ACM CHI 2009 ~ Understanding Information* (2009), pp.11-20.

Cleveland and McGill, "Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods", *Journal of the American Statistical Association*, v.79, n.387 (September 1984), pp.531-554.

Cohen, C. A. & Hegarty, M. (2007). Individual differences in use of an external visualization while performing an internal visualization task. *Applied Cognitive Psychology, 21,* 701-711

Conklin, Jeff, *Dialogue Mapping: Building Shared Understanding of Wicked Problems* (West Sussex, England: John Wiley & Sons, 2006).

Danserau, Donald F., and D. Dwayne Simpson, "A Picture Is Worth a Thousand Words: The Case for Graphic Representations", *Professional Psychology*, v.40, n.1 (2009), pp.104-110.

Duarte, Nancy, *slide:ology: The Art and Science of Creating Great Presentations.* Sebastopol, CA: O'Reilly Media, 2008.

Duarte, Nancy, *Resonate: Present Visual Stories That Transform Audiences*. Hoboken, NJ: John Wiley and Sons, 2010.

Fayyad, Usama M. Andreas Wierse, and Georges G. Grinstein (eds.), *Information Visualization in Data Mining and Knowledge Discovery*. London: Academic Press, 2002.

Feinberg, Jonathan, "Wordle", Ch. 3 in Steele & Iliinsky (eds.), *Beautiful Visualization* (Cambridge: O'Reilly, 2010), pp.37-58.

Fekete, Jean-Daniel, Jarke J. Van Wijk, John T. Stasko, and Chris North, "The Value of Information Visualization" in Andreas Kerren, John T. Stasko, Jean-Daniel Fekete, and Chris North (eds.), *Information Visualization: Human-Centered Issues and Perspectives* (London: Springer-Verlag, 2008), pp.1-18.

Few, Stephen, *Information Dashboard Design: The Effective Visual Communication of Dat*a. O'Reilly, 2006.

Few, Stephen, "What Ordinary People Need Most from Information Visualization Today", *Perceptual Edge: Visual Business Intelligence Newsletter*, August 2008.

Few, Stephen, *Now You See It: Simple Visualization Techniques for Quantitative Analysis* (Oakland, CA: Analytics Press, 2009).

Fikkert, Wim, Marco D'Ambros, Torsten Bierz, and T.J. Jankun-Kelly, "Interacting with Visualizations", Ch. 4 in Andreas Kerren, Achim Ebert, and Jorg Meyer (eds.), *Human-Centered Visualization Environments* (London: Springer-Verlag, 2007), pp.77-162.

Fisher, Danyel, "Animation for Visualization: Opportunities and Drawbacks", Ch. 19 in Steele & Iliinsky (eds.), *Beautiful Visualization* (Cambridge: O'Reilly, 2010), pp.329-352.

Fischer, Frank, and John Forrester (eds.), *The Argumentative Turn in Policy Analysis and Planning.* Durham, NC: Duke University Press, 1993).

Freidrich, C., and P. Eades, "Graph drawing in motion", *Journal of Graph Algorithms and Applications* v.6, n.3 (2002), pp.353-370.

Friendly, Michael, "A Brief History of Data Visualization" , Chapter II.1 in Chun-houh Chen, Wolfgang Hardle, and Antony Unwin (eds.), *Handbook of Computational Statistics* (Berlin: Springer 2008), pp.15-56.

Gershon, N., and W. Page, "What storytelling can do for information visualization". *Communications of the ACM*, 44(8) (2001), pp.31-37

Gilbert, John K., Miriam Reiner, and Mary Nakley (eds.), *Visualization: Theory and Practice in Science Education* (London: Springer-Verlag, 2008).

Grammel, Lars , Melanie Tory, Margaret-Anne Storey, "How Information Visualization Novices Construct Visualizations," *IEEE Transactions on Visualization and Computer Graphics*, vol. 16, no. 6, Nov./Dec. 2010, pp. 943-952.

G. Grinstein, D. Keim, and T. Munzner, "Grand Challenges for Information Visualization", IEEE VisWeek 2008.

Hamzah, M.; Sobey, A.; Koronios, A.; "Supporting decision making process with information visualisation: A theoretical framework", The 2nd IEEE International Conference on Information Management and Engineering (ICIME), 2010 , pp.267 – 271.

Hanson, Charles D., and Christopher R. Johnson (eds.), *The Visualization Handbook* (Elsevier, 2005).

Hargarty's 2010 keynote address not been published yet...

Ham, Dong-Han, "The State of Visual Analytics" in J.H. Lee (eds.), *EU-Korea Conference on Science and Technology, SPPHY*. Berlin Heidelberg: Springer-Verlag, 2010, pp.213-222.

Heer, Jeffrey, and George G. Robertson, "Animated transitions in statistical data graphics", *IEEE Transactions on Visualization and Computer Graphics* v.13, n.6 (2007), pp.1240-1247.

Heer, Jeffrey, Frank van Ham, Sheelagh Carpendale, Chris Weaver, and Petra Insenberg, "Creation and Collaboration: Engaging New Audiences for Information Visualization" in Andreas Kerren, John T. Stasko, Jean-Daniel Fekete, and Chris North (eds.), *Information Visualization: Human-Centered Issues and Perspectives* (London: Springer-Verlag, 2008) pp.92-133.

Hegarty Margaret. "Diagrams in the mind and in the world: Relations between internal and external visualizations" in A. Blackwell, K. Mariott, and A. Shimojima (eds.), *Diagrammatic Representation and Inference. Lecture Notes in Artificial Intelligence 2980* (pp. 1-13). Berlin: Springer-Verlag, 2004).

Horn, Robert E., *Visual Language: Global Communication for the 21st Century* (Bainbridge Island, WA: MacroVU, 1998).

Horn, Robert E., "Knowledge Mapping for Complex Social Messes**"**, presentation to the "Foundations in the Knowledge Economy" at the David and Lucile Packard Foundation, July 16, 2001 http://www.stanford.edu/~rhorn/SpchPackard.html.

Hundhausen, Christopher D., Sarah A. Douglas, and John T. Stasko, "A meta-study of algorithm visualization effectiveness", *Journal of Visual Languages & Computing*, v.13, n.3 (2002), pp.259-290.

Hyerle, David, *Visual Tools for Transforming Information into Knowledge*, 2nd Edition. Thousand Oaks, CA: Corwin, 2009.

Iliinsky, Noah, "On Beauty", Ch. 1 in Steele and Iliinsky (eds.), *Beautiful Visualization* (Cambridge: O'Reilly, 2010), pp.1-13.

Irani, Pourang, Dean Slonowsky, and Peer Shajahan, "Human perception of structure in shared space-filling visualizations", *Information Visualization*, v.5 (2006), pp.47-61.

Johnson, Chris, "Top scientific visualization research problems", *Computer Graphics and Applications, IEEE* (July-Aug. 2004), v.24:4, pp.13-17.

Johnson, Chris, Robert Moorhead, Tamera Munzner, Hanspeter Pfister, Penny Rheingans, Terry S. Yoo, *NHI-NSF Visualization Research Challenges Report* (July 2006).

Keim, Daniel, Jorn Kholhammer, Geoffrey Ellis, and Florian Mansmann, *Mastering the Information Age: Solving Problems with Visual Analytics*. Goslar, Germany: Eurographics Association, 2010.

Keim, Daniel A., Florian Mansmann, Jorn Schneidewind, Jim Thomas, and Hartmut Ziegler, "Visual Analytics: Scope and Challenges" in S.J. Simoff et al (eds.), *Visual Data Mining* (London: Springer-Verlag, 2008), pp.76-90.

Kerren, Andreas, Achim Ebert, and Jorg Meyer (eds.), *Human-Centered Visualization Environments* (London: Springer-Verlag, 2007).

Kerren, Andreas, John T. Stasko, Jean-Daniel Fekete, and Chris North (eds.), *Information Visualization: Human-Centered Issues and Perspectives* (London: Springer-Verlag, 2008).

Kinnaird, Peter, Mario Romero, and Gregory Abowd, “Connect 2 Congress: Visual Analytics for Civic Oversight”, presented to CHI 2010: ACM Conference on Human Factors in Computing Systems, April 10-15, 2010, Atlanta. XXX: ACM, pp.2853-2862.

Koblin, Aaron, with Valdean Klump, “Flight Patterns: A Deep Dive”, Ch. 6 in Steele & Iliinsky (eds.), *Beautiful Visualization* (Cambridge: O’Reilly, 2010), pp.91-102.

Krebs, Valdis, “Your Choices Reveal Who You Are: Mining and Visualizing Social Patterns”, Ch. 7 in Julie Steele and Noah Iliinsky (eds.), *Beautiful Visualization: Looking at Data Through the Eyes of Experts* (Cambridge: O’Reilly, 2010), pp.103-122.

Kriz, S. and M. Hegarty (2007). “Top-down and bottom-up influences on learning from animations.” *Int. Journal of Human Computer Studies, 65*, 911-930.

Kulyk, Olga, Robert Kosara, Jaime Urquiza, and Ingo Wassink, “Human-Centered Aspects”, Ch. 2 in Andreas Kerren, Achim Ebert, and Jorg Meyer (eds.), *Human-Centered Visualization Environments* (London: Springer-Verlag, 2007), pp.13-75.

Laramee, Robert S., and Robert Kosara, “Challenges and Unsolved Problems”, Ch. 5 in Andreas Kerren, Achim Ebert, and Jorg Meyer (eds.), *Human-Centered Visualization Environments* (London: Springer-Verlag, 2007), pp.231-254.

Lindquist, Evert, “Organizing for Mega-Consultation: HRDC and the Social Security Review”, *Canadian Public Administration*, v.48, n.3 (2005), pp.348-385.

Lindquist, Evert, “Building Evidence-Based Policy Capabilities in the Context of Results-Based Management”, a paper prepared for Human Resources and Skills Development Canada, June 2006).

Liu, Zhicheng, and John T. Stasko, “Mental Models, Visual Reasoning and Interaction in Information Visualization: A Top-Down Perspective”, *IEEE Transactions on Visualization and Computer Graphics*, v.16, n.6 (Nov/Dec 2010), pp.999-1008.

MacEachren, Alan M., *How Maps Work: Representation, Visualization, and Design* (New York: Guilford, 1995).

MacEachren, Alan M., and Meno-Jan. Kraak, “Research Challenges in Geovisualization”, *Cartography and Geographic Information Science*, xxxxx v.28, n.1 (2001), pp.3-12.

Majone, Giandomenico, *Evidence, Argument, and Persuasion in the Policy Process*. New Haven, CT: Yale University Press, 1992.

Margulies, Nancy, and Christine Valenza, *Visual Thinking: Tools for Mapping Your Ideas*. Bethel, Connecticut: Crown House, 2005.

Martin J. Eppler, Jeanne Mengis, Sabrina Bresciani, "Seven Types of Visual Ambiguity: On the Merits and Risks of Multiple Interpretations of Collaborative Visualizations," Proceedings of the 2008 12th International Conference on Information Visualisation. Washington, DC: IEEE Computer Society, 2009, pp.391-396.

Mazza, Riccardo, *Introduction to Information Visualization* (London: Springer-Verlag, 2009)

McBeth, Mark K., et al, “The Intersection of Narrative Policy Analysis and Policy Change Theory”, *Policy Studies Journal,* v.35, n.1 (2007), pp.87-108.

McCandless, David, *Information is Beautiful* (London: Collins, 2009). Also published as *The Visual Miscellaneum: A Colorful Guide to the World’s Most Consequential Trivi*a (2009).

McCormick, Bruce H., Thomas A. DeFanti, and Maixne D. Brown, *Visualization in Scientific Computing*. Report of the Panel on Graphics, Image Processing and Workstations (Washington, DC: National Science Foundation, July 1987).

McCormick, Bruce H., and Thomas A. DeFanti, “Visualiation is Computer Graphics”, *Computer Graphics* 21:6 (November 1987).

McDavid, James C., and Laura Hawthorn, *Program Evaluation and Performance Measurement: An Introduction to Practice*. London: Sage, 2006.

McGinn, Daniel, “Tired of PowerPoint? Try this Instead”, *Harvard Business Review*, v. 88, n.9 (Sep 2010), pp.30-31.

Novak, Joseph D., and D.B. Gowin, *Learning How to Learn* (Cambridge University Press, 1984.

Novak, Joseph, and Alberto J. Canas, “The origins of concept mapping and the continuing evolution of the tool”, *Information Visualization*, v.5 (2006), pp.175-184.

Nutley, Sandra M., Isabel Walter, and Huw T.O. Davies, *Using Evidence: How research can inform public service*s. Bristol, UK: Policy Press, 2007.

Odewahn, Andrew, “Visualizing the U.S. Senate Social Graph (1991-2009)”, Ch. 8 in Steele & Iliinsky (eds.), *Beautiful Visualization* (Cambridge: O’Reilly, 2010), pp.123-142.

Osterwalder, Alexander, and Yves Pigneur, *Business Model Generation*. Hoboken, NJ: John Wiley & Sons, 2010.

Pirolli, P., S.K. Card, and M.M. van Der Wege, “The effects of information scent on visual search in the hyperbolic tree browser” in ACM Transactions on Computer Human Interaction, v.10, n.1 (2003), pp.20-53.

Plaisant, C., Grosjean, J., Bederson, B., SpaceTree: Supporting Exploration in Large Node Link Tree, Design Evolution and Empirical Evaluation, *Procedings of IEEE Conference on Information Visualization*, Boston, (2002), pp. 57-64.

Plaisant, C., “The Challenge of Information Visualization Evaluation” in *Proceedings of the Working Conference on Advanced Visual Interfaces* (2004) pp.109-116.

Catherine Plaisant, “Information Visualization and the Challenge of Universal Usability”, Ch. 3 in J. Dykes, A.M. MacEachren, M.-J. Kraak (eds.), *Exploring Geovisualization*, Elsevier, 2005, pp 53-82.

Pretorius, A. Johannes, and Jarke J. Van Wijk, “What does the user want to see? What do the data want to be?” *Information Visualization*, v.8, n.3 (2009), pp.153-166.

Purchase, Helen C., Natalia Andrienko, T.J. Jankun-Kelly, and Matthew Ward, “Theoretical Foundations of Information Visualization” in Andreas Kerren, John T. Stasko, Jean-Daniel Fekete, and Chris North (eds.), *Information Visualization: Human-Centered Issues and Perspectives* (London: Springer-Verlag, 2008), pp.46-64.

Ringland, Gill, *Scenario Planning: Managing for the Future*. New York: Wiley, 1998.

Robertson, George, Roland Fernandez, Danyel Fisher, Bongshin Lee, and John Stasko, “Effectiveness of Animation in Trend Visualization”, *IEEE Transactions on Visualization and Computer Graphic*s, v.14, n.6 (Nov/Dec 2008).

Robertson, George, David Ebert, Stephen Eick, Daniel Keim, and Ken Joy, “Scale and complexity in visual analytics”, *Information Visualization* v.8, n.4 (2009), pp.247-253.

Roe, Emery, *Narrative Policy Analysis*. Durham, NC: Duke University Press, 1994.

Roam, Dan. *The Back of the Napkin: Solving Problems and Selling Ideas with Pictures*, Expanded Edition. New York: Portfolio, 2009.

Roese, Neal J., and Kathleen D. Vohs, “The Visualization Trap”, *Harvard Business Review* (May 2010), pp.26.

Rosell, Steven, et al., *Changing Maps: Governing in a World of Rapid Change*. Ottawa: Carleton University Press, 1995).

Segel, Edward, and Jeffrey Heer, “Narrative Visualization: Telling Stories with Data”, *IEEE Transactions on Visualization and Computer Graphics*, v.16. n.6 (Nov-Dec 2010), pp.1139-48.

Senge, Peter M., *The Fifth Discipline: The Art & Practice of the Learning Organization*. New York: Doubleday, 1990).

Shapiro, Matthias, “Once a Time a Stacked Time Series” in Steele and Iliinsky (eds.), *Beautiful Visualization: Looking at Data Through the Eyes of Experts* (Cambridge: O’Reilly, 2010), pp.15-36.

Shneiderman, Ben, “The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations”, paper prepared for the Proceedings of the Visual Languages 1996 Conference (September 1996).

Shneiderman, Ben, “Foreward” in Chaomei Chen, *Information Visualization: Beyond the Horizon* (London: Springer-Verlag, 2006).

Sibbet, David, *Visual meetings: How Grahpics, Sticky Notes & Idea Mapping Can Transform Group Productivity*. Hoboken, NJ: John Wiley & Sons, 2010.

Sinclair, S., S. Ruecker, and M. Radzikowska, “Information Visualization for Humanities Scholars”, forthcoming.

Skeels, Meredith, Bongshin Lee, Greg Smith, and George G. Robertson, “Revealing uncertainty for information visualization”, *Information Visualization*, n.9, n.1 (2010), pp.70-81.

Simoff, Simeon J., Michael Bohlen, and Artuas Mazeika (eds.), *Visual Data Mining*. Berlin-Heidelberg, Springer-Verlag, 2008.

Simoff, Simeon J., and John Galloway, “Visual Discovery of Network Patterns between Attibutes” in Simeon J. Simoff, Michael Bohlen, and Artuas Mazeika (eds.), *Visual Data Mining*. Berlin-Heidelberg, Springer-Verlag, 2008, 172-195.

Spence, R. *Information Visualization*, 2nd Edition. London: Addison-Wesley (2007).

Stasko, John, Richard Catrambone, Mark Guzdial, and Kevin McDonald, "An Evaluation of Space-Filling Information Visualizations for Depicting Hierarchical Structures", *International Journal of Human-Computer Studies*, Vol. 53, No. 5, November 2000, pp. 663-694.

Stasko, John, Carsten Goig, and Zhicheng Liu, “Jigsaw: supporting investigation analysis through interactive visualization”, *Information Visualization*, v.7 (2006), pp.118-132.

Stasko, John T. and Zhang, Eugene, "Focus+Context Display and Navigation Techniques for Enhancing Radial, Space-Filling Hierarchy Visualizations", *Proceedings of IEEE Information Visualization 2000*, Salt Lake City, UT, October 2000, pp. 57-65.

Steele, Julie, and Noah Iliinsky (eds.), *Beautiful Visualization: Looking at Data Through the Eyes of Experts* (Cambridge: O’Reilly, 2010).

Thomas, James J., and Kristin A. Cook (eds.), *Illuminating the Path: The Research and Development Agenda for Visual Analytics* (Washington, DC: Dept. of Homeland Security, 2005).

Tufte, Edward R., *Envisioning Information* (Chesire, Conn.: Graphics Press, 1990).

Tufte, Edward R., *Visual Explanation: Images and Quantities, Evidence and Narrative* (Chesire, Conn.: Graphics Press, 1997).

Tufte, Edward R., *The Visual Display of Quantitative Information*, 2nd Ed. (Chesire, Conn.: Graphics Press, 2001).

Tversky, Barbara, Julie B. Morrison, and Mireille Betrancourt, “Animation: Can it facilitate?”, *International Journal of Human-Computer Studies*, v.57 (2002), pp.247-262.

van der Heijden, Kees, *Scenarios: The Art of Strategic Conversation*. New York: Wiley, 1996.

van Wijk, Jarke J., “the Value of Visualization”, *IEEE Visualization* (2005).

Viegas, Fernanda B., Martin Wattenberg, and Jonathan Feinberg, “Participatory visualization with Wordle”, *IEEE Transactions on Visualization and Computer Graphics*, v.15, n.6 (Nov-Dec 2009), pp.1137-1144.

Ward, Matthew, George Grinstein, and Daniel Keim, *Interactive Data Visualization: Foundations, Techniquies, and Applications* (Natick, Mass.: AK Peters, 2010).

Ware, Christopher. *Information Visualization: Perception for Design*. San Francisco: Morgan Kaufmann, 2000; 2nd Edition, 2004.

Ware, Christopher, *Visual Thinking for Design*. San Francisco: Morgan Kaufmann, 2008.

Wong, Pak Chung, et al., “Walking the path: a new journey to explore and discover through visual analytics”, *Information Visualization* (2006), pp.237-249.

Zongker, Douglas E., and David H. Salesin, “On creating animated presentations”, *Proceedings of the 2003 ACM SIGGRAPH/Eurographics Symposium on Computer Animation*. New York: ACM Press, 2003.