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On the role of design in information visualization

Andrew Vande Moere[1] and Helen Purchase[2]

Abstract

Every information visualization developer is engaged in a complex process of design – balancing the three requirements of utility, soundness and attractiveness within given constraints. This paper investigates the oft-overlooked requirement of attractiveness (or 'aesthetics') in visualization, and, in doing so, discusses a wider role for the design process which emphasizes the benefits of disseminating design rationale. In presenting a model of three potential roles for design in information visualization, we suggest that the field would benefit from encompassing a broader scope that includes visualizations produced as part of commercial practice or artistic exploration. We conclude with a discussion on the practical consequences to the academic community of adopting our model – consequences that will require a paradigm shift in the way we value, teach and conduct information visualization research.

Keywords

design, visualization, aesthetics, case studies, design studies

Introduction

Information visualization is traditionally viewed as a set of methods for supporting humans to understand and analyse large, complex data sets. Because of its historical roots in scientific reasoning, computer graphics and algorithmic optimization, academic research in information visualization has typically focused on supporting expert users in executing complex data exploration and analysis tasks as efficiently and effectively as possible. Such advanced information visualizations are often interpreted as scientific (and therefore 'neutral') tools. These tools permit the exploration, unanticipated discovery and subjective interpretation of data, but typically present little context or guidance beyond what is directly present within the data, in pursuit of representational primacy and 'faithful' data replication and comprehension.[1] As a result, existing information visualization techniques cover a wide spectrum of application fields, but mostly consist of expert-level solutions that solve well-defined, specialized tasks.

Computer science research in information visualization has largely focused on solving functional requirements, placing less weight on alternative concerns such as aesthetics or user experience. In recent years, however, both the increasing prevalence of software development skills and the increasing public accessibility of data sources has had a significant effect on information visualization practice.[2] With the ability to create representations of freely accessible data sets, an increasing number of artists and designers[3–5] have applied typical information visualization principles as a powerful and even artistic means of expression.[6–8] At the same time, the typical user audience of information visualizations has increased from a limited number of highly skilled and experienced data experts to the large, lay masses.[9] As a result, an increasing number of 'popular' visualizations have been developed, specifically designed to allow non-expert users to reach open-ended, reflective insights about data with personal relevance.[8] Figure 1 shows three examples of 'popular' visualizations that combine artistic influence and personal relevance, and which were created outside the academic information visualization community. Popular works like these are typically presented online and in print media and demonstrate how visualization is turning into a medium in its own right – a popular

[1]K.U. Leuven, Department of Architecture, Urbanism and Planning, Kasteelpark Arenberg 1, 3001, Heverlee, Belgium.
[2]School of Computing Science, Sir Alwyn Williams Building, University of Glasgow, UK. G12 8QQ.

Corresponding author:
Andrew Vande Moere, K.U. Leuven, Department of Architecture, Urbanism and Planning, Kasteelpark Arenberg 1, 3001 Heverlee, Belgium
Email: andrew.vandemoere@asro.kuleuven.be

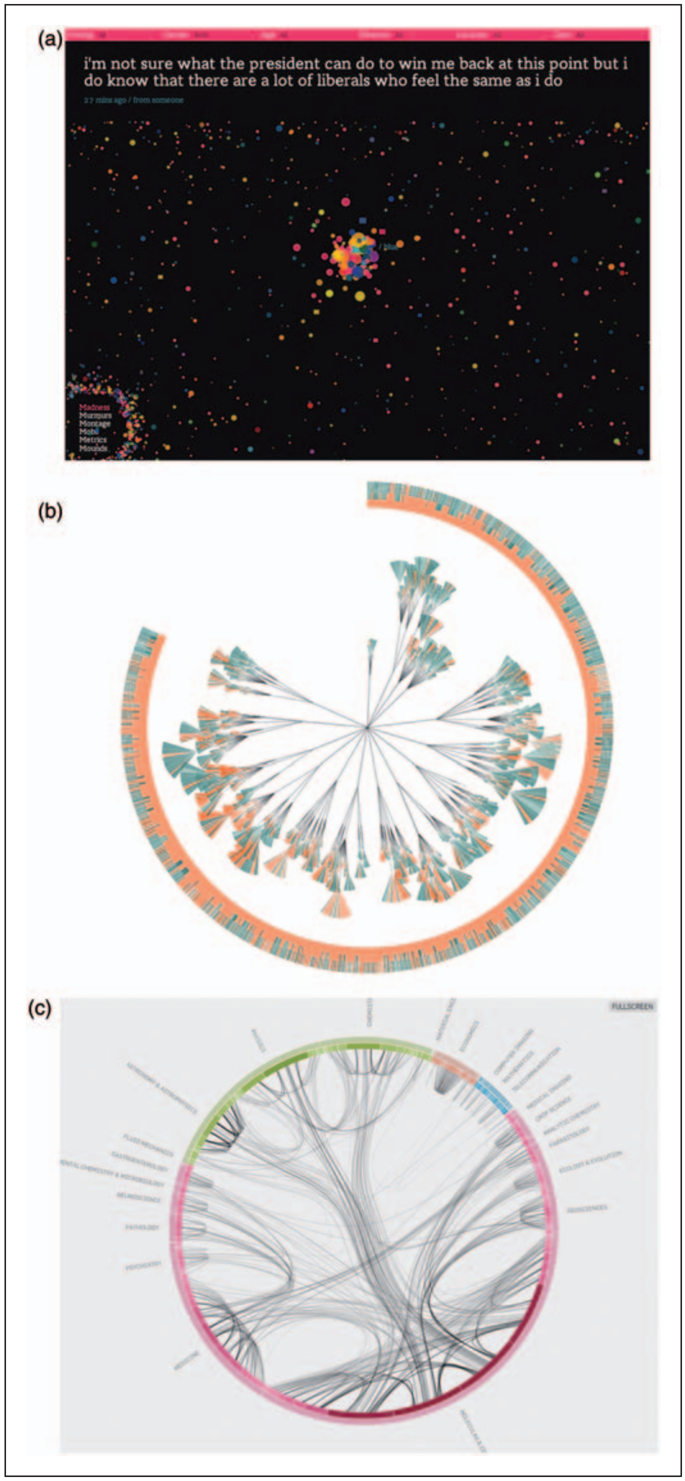

Figure 1. Examples of popular representations created by artists and designers outside of the academic visualization community. (a) *We Feel Fine* by Jonathan Harris and Sep Kamvar.[3] (b) *(En)tangled Word Bank* by Stefanie Posavec.[4] (c) *Well-Formed Eigenfactor* by Moritz Stefaner.[5]

medium without the functional and objective requirements of typical academic or expert visualization tools, and which has the freedom to be artistic and seek an emotional response.

With its inherent ability to represent complex data in understandable form, information visualization has become adopted by large media and news outlets, as well as many educational, governmental and advocacy

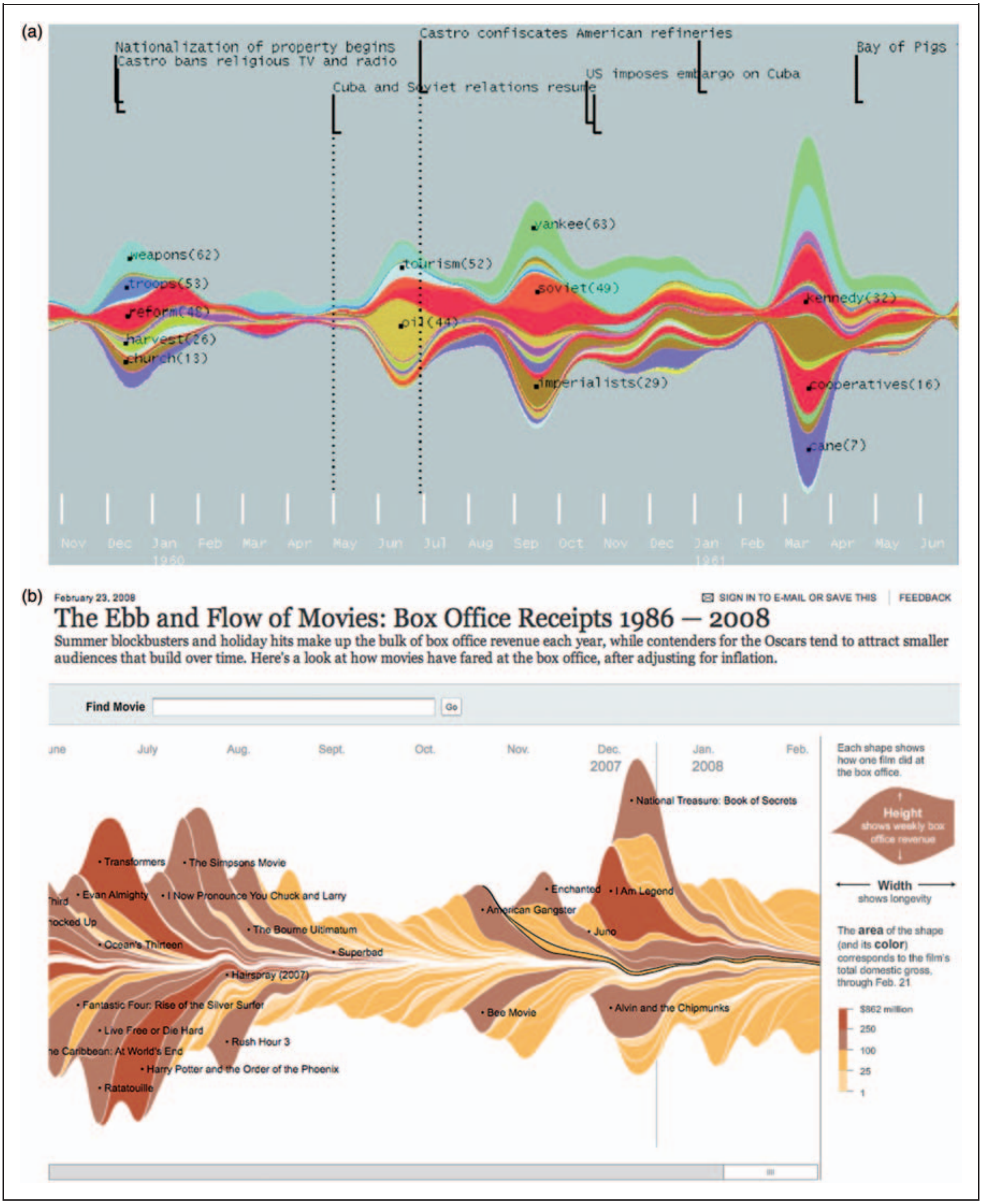

Figure 2. ThemeRiver (a), a scientific contribution originally published in 2002,[15] was the inspiration for a *New York Times* infographic 'The Ebb and Flow of Movies: Box Office Receipts 1986–2008' (b)[14].

organizations. Examples of such visualizations have featured in various prestigious venues, ranging from the cover of the renowned scientific journal *Nature*,[10] through prestigious exhibitions in the New York Museum of Modern Art (MoMa),[11] to attractive coffee-table books.[3,12,13]

There are several examples of the influence of information visualization research on popular media. For example, the Stream Graphs infographic, published in the print and online copy of the *New York Times*,[14] was primarily based on a scientific publication that first proposed the concept of 'ThemeRiver'[15]

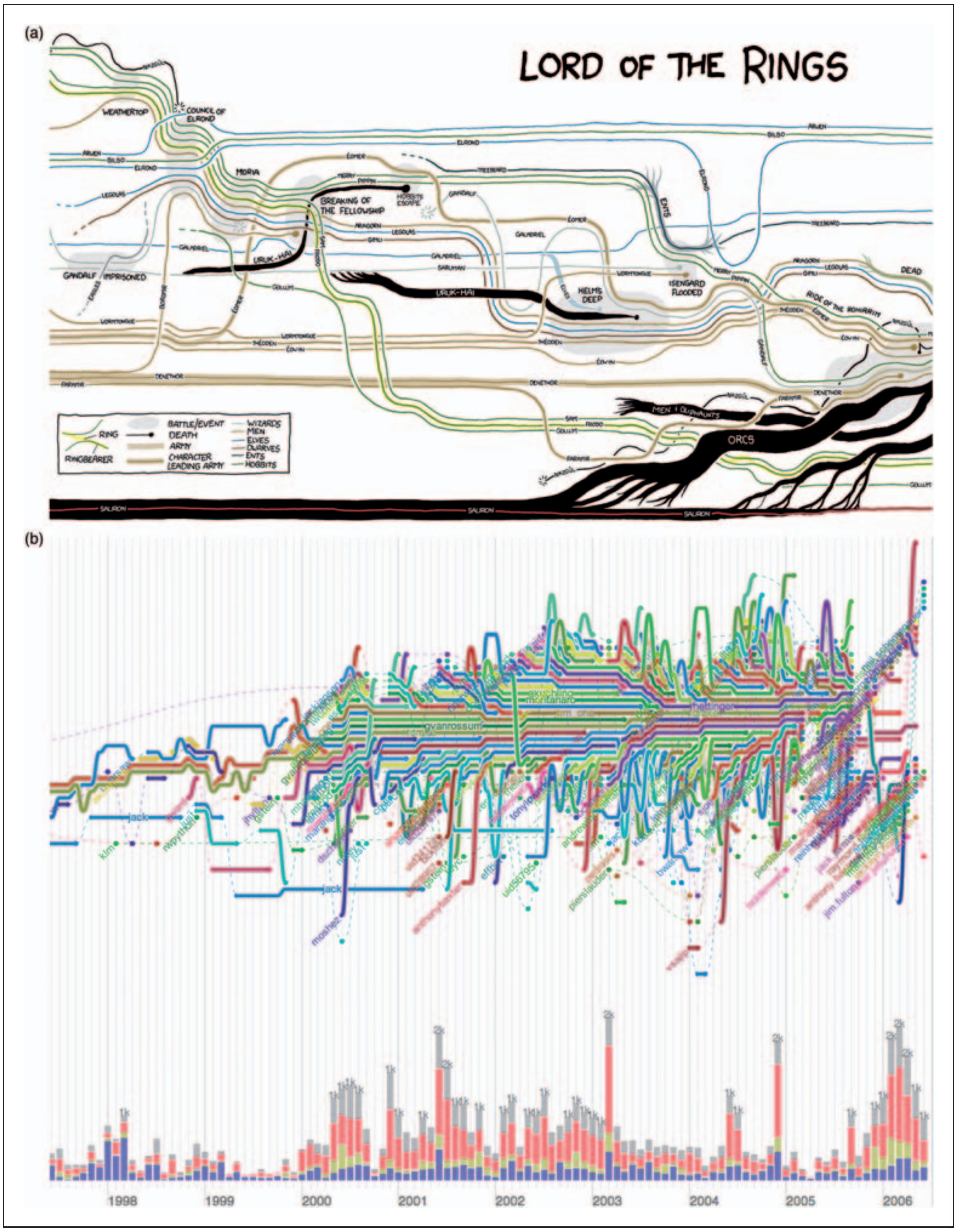

Figure 3. The illustration 'Movie Narrative Charts'[18] (a), published on the popular XKCD web comic website, was the basis for the design study 'Software Evolution Storylines'[17] (b).

(Figure 2). Moreover, the development of Stream Graphs itself resulted in an academic 'design study' publication of its own (Byron and Wattenberg,[16] see also later section, 'The choice of visual mapping').

Conversely, popular media has also influenced some information visualization research. As shown in Figure 3, Ogawa and Ma's[17] representation of software development collaborations over time uses a computational analogy of a compelling hand-drawn comic published on the widely popular XKCD website.[18]

Even in popular media, the role of the design process is more multifaceted than simply affecting an emotional or personal response. Two applications of an identical visualization technique may differ qualitatively in terms of their attention to design. Figure 4 shows two similar treemap representations[19]: on the left, a demonstration application by The Hive Group which categorizes performance attributes of electronic equipment on a popular shopping website; on the right, a 'Newsmap' that summarizes recent news

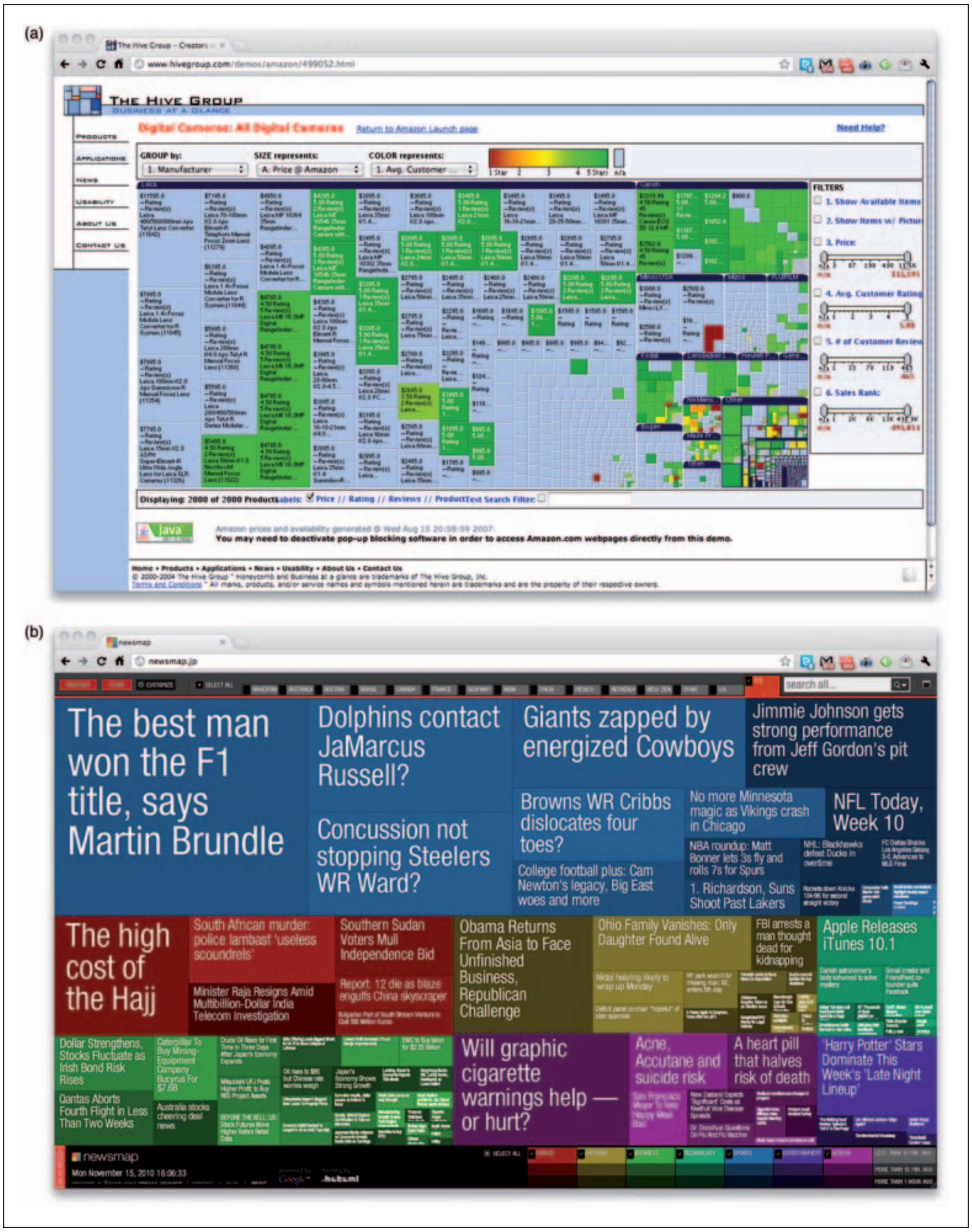

Figure 4. Two treemap visualizations: Amazon digital cameras (http://hivegroup.com/demos/) (a) and Newsmap (http://newsmapjp.) (b).

headlines. While both use a similar mapping algorithm to structure the hierarchical data, they clearly differ in terms of visual design. The most obvious differences include the treatment of visual elements (e.g. colour palette, font type, font size), whereas differences between the more complex features such as the rectangular proportions and the grouping of similar objects require more careful visual analysis. It is probable that The Hive Group chose a typical colour palette to achieve an intuitive data interpretation (i.e. positive for green, negative for red, grey for unknown), although the three-dimensional (3D) effect seems gratuitous. Newsmap, instead, seems to be motivated by a desire to attract the user's attention through no-frills clarity: while being more varied and bright, its colour palette also conveys useful information (i.e. the thematic grouping).

In critiquing and comparing these two treemaps, their functional effectiveness could be objectively measured and compared by way of task-based evaluative studies. However, it is evident that they differ significantly in terms of their visual form, despite the fact that they obviously each have been subject to a process of visual design. It is difficult to objectively discuss critique or compare the overall quality (i.e. appropriateness, attractiveness, beauty, effectiveness, appeal) of the visual form (the 'visual quality') of both works when the rationale behind their design has not been made explicit and can only be guessed.

Like Newsmap, some popular visualization examples enjoy such a wide success that their visibility is arguably much greater than that of most advances in information visualization research, even though they might have shortcomings in terms of usability or, indeed, usefulness. These apparent differences in visual quality between 'popular' and 'scientific' approaches highlight a possible rift between academic research in information visualization, its commercial practice and its artistic exploration, and between the associated stakeholders, researchers, businesses and artists. This divergence is most evident in the attention paid to the explicit roles of the relationships between the concepts of form, function and content (as well as some rather vague characteristics such as aesthetics, appeal and joyfulness). These roles may be obvious to those with design education or practical design experience, but may be less so to members of the academic community. There are clear benefits in crossing these boundaries and taking on board the perspectives and experiences of other communities. Although an academic researcher might be knowledgeable of specific representation techniques that are empirically proven to be task-effective, these techniques might be intrinsically visually unappealing, and therefore not adopted in practice. On the other hand, complex and socially relevant issues might best be communicated to a large audience through popular media using an artistic and engaging visualization (even if its designer knows that such a method is not the most effective or efficient).

We suggest that there needs to be better understanding of how those who engage in the science, art and practice of information visualization can learn from each other. For example, researchers in information visualization do not tend to explicitly acknowledge the role of the design process in their academic publications, despite its value being self-evident for those with a practical or theoretical background in design. Design research has thrived for several decades, even in fields adjoining information visualization (including, but not limited to, human–computer interaction, information design and user interface design), but few academic publications in the area of design specifically focus on issues relating to information visualization research.

In this paper, we introduce design as an introspective approach in which developers are mindful of their design choices and reflect on actions taken in order to improve future methodologies. We report on an increasing involvement of designers in the field of information visualization. We suggest that design is integral to the information visualization development process and that the training, practice, evaluation, and dissemination of information visualization would benefit from a more proactive and explicit consideration of design. By recognizing the value of articulating and sharing design knowledge, we claim that information visualizations that are valued for both their functional effectiveness and their visual quality can become the norm, rather than the exception.

In addressing information visualization design, we focus our discussion on the visual form of a visualization, rather than the interactive or analytical functions that might support it. This is not to dismiss these functions as being irrelevant – indeed, the interactive and analytical features of an information visualization system may themselves have an important and essential aesthetic quality – it is simply to allow us to focus on the most obvious aesthetic quality of a visualization: its visual form. Our primary argument – that mindful articulation of design choices will enable the field of information visualization to develop so as to better stand alongside the complementary areas of commercial and artistic practice – is as applicable to the design of interactive and analytical features as it is to the visual design.

The design of visualizations

Design

Outside of traditional usability metrics, measuring the 'success' of an information visualization is often subjective and highly complex. Notwithstanding some early attempts for design-focused yet still objective 'InfoVis' tests,[20] defining design success is still an open and contested issue that is often addressed during (mostly confidential) judging discussions at open competitions or design challenges. Although the number of sophisticated and novel information visualization techniques is increasing, little is known about the design reasoning behind the best practice exemplars, that is the mindful rationale that drove their design decisions. A design process can be the result of several different approaches,[21] ranging from 'system design' (which structures a logical roadmap of decisions), through 'user-centred design' (UCD, which involves users in capturing their needs and preferences),[22,23] to 'genius design'[21] (in which the designer takes on the role of an absolute authority whose natural instincts produce a considered, desirable experience). Such varied design frameworks typically epitomize a subtle balance between logic and intuition, such as between so-called ‘engineering’ design (i.e. finding a solution within predefined requirements) and ‘creative’ design (i.e. an interplay between problem setting and problem solving).[24,25] Sharing such integrated approaches to design can benefit future visualization designers, who can be guided by understanding how good visualizations are best created, from conceptual decisions such as why a specific visual structure was chosen to apparent trivial choices regarding fonts or colours.

Many definitions of design exist, with varied connotations in different fields. Here, we characterize design as ‘the conception and realization of new things’ which has ‘its own distinct things to know, ways of knowing them, and ways of finding out about them’[26] and describe a designer as someone ‘who devises courses of action aimed at changing existing situations into preferred ones’.[27] Consequently, designing is ‘a pattern of behaviour employed in inventing things of value which do not yet exist’.[28] It consists of various goal-oriented, constrained, decision-making, exploration and learning activities, which all operate within a given context, and which depend on the designer’s perception of that context.[29]

According to these definitions, we claim that designing is an inevitable process in information visualization research, in particular when inventing new representational methods. The design goal is the development of a new technique, which often needs to be the first effective solution for conveying a given data set, or be ‘better’ than existing solutions that represent similar data sets. Such a design process often needs to take into account multiple complex and interrelated constraints, ranging from open-ended specifications of qualitative expectations from users[23] to strict, predefined requirements such as screen resolution, calculation power or data consistency. Arguably the most challenging design constraint is the limit of human visual perceptual and cognitive capabilities which may prevent effective or complete understanding of a highly complex data set.

Design requirements

There are several implicit requirements and constraints involved in information visualization development that reach beyond simply creating a reasonable, working solution. As in most other design-related fields (e.g. architecture, product design, fashion), information visualization seeks to achieve a workable equilibrium between the aspects of *utility*, *soundness* and *attractiveness* – in their original Latin form, *utilitas*, *firmitas* and *venustas*. These are typical design requirements when conceiving, for example, architectural structures; this triangle (Figure 5) was first formulated by Roman architect Vitruvius in his book *De Architectura* in 25BC.

Here we relate this triad of requirements to information visualization.

Utility corresponds to the classic notions of functionality, usability, usefulness and other quantitative performance measures. In visualization evaluation studies, these aspects are generally defined in terms of *effectiveness* (the accuracy and completeness with which users achieve specific tasks) and *efficiency* (the amount of resources expended in relation to the effectiveness criterion). In general, a developer attempts to optimize a visualization to reach the highest level of effectiveness and efficiency. Utility forms the main focus of academic research, allowing objective comparison and benchmarking between different solutions, or deriving empirical knowledge about the influence of specific factors on performance through controlled experimental studies.

The current practice of academic research has an explicit expectation that the utility of a newly proposed visualization technique should be described (usually through usability evaluations).

Soundness is concerned with reliability and robustness. In the context of information visualization (and in accordance with this paper’s focus on visual form), soundness relates to the quality of the visualization presentation algorithm: Does it crash? Does it do what it is intended to do? How efficient is the code? Soundness also refers to the extent of the algorithm’s wider use, outside of its initial presentation: Can it represent a wide range of data sets? Can it be used with different output media? Can it withstand variation in data complexity (e.g. size, dimensionality, time

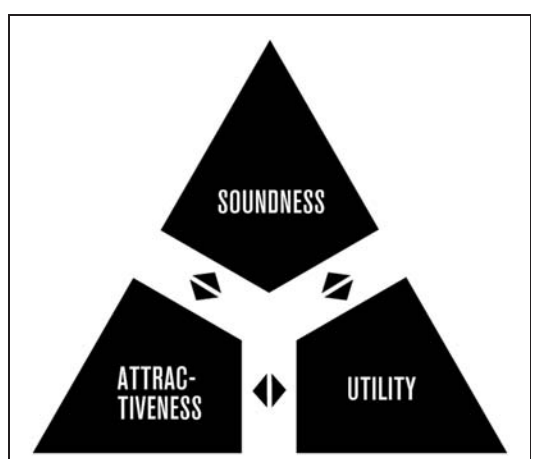

Figure 5. The Vitruvius triangle, based on typical architectural design requirements.

variance) or data inaccuracies? For example, the treemap[19] and parallel coordinates[30] techniques could be considered highly robust ('sound') as they have been widely adopted, optimized and used in several contexts after their initial conception.

The current practice of academic research has an explicit expectation that the soundness of a newly proposed visualization technique should be described in detail (usually by explaining data mapping rules using mathematical algorithms or pseudocode), and thus allowing others to easily reproduce, and eventually improve upon, it.

Attractiveness refers to what we have hitherto called 'aesthetics': the appeal or beauty of a given solution. Aesthetics does not limit itself to the visual form, but also includes fuzzy aspects such as originality, innovation and novelty, and other subjective factors comprising the user experience. Furthermore, aesthetics can apply to more than the designed artefact, for example to the methodology or structure of the solution itself (for instance, how neatly or eloquently a software application has been computed[31]). Although understanding the role of aesthetics has been proposed as an important unsolved problem in the information visualization field,[32,33] investigating the driving factors that contribute to the aesthetics of a visualization is not a current focus of information visualization literature. Some evaluation studies limit themselves to querying users about 'appeal' and 'enjoyability' (as a shorthand way to ascertain its user experience[34]); however, such studies appear to make little contribution in terms of furthering understanding of how a designer can best satisfy aesthetic requirements when creating a new visualization.

The current practice of academic research has no explicit expectation that the attractiveness of a newly proposed visualization technique should be described through explanation of design rationale. Thus, the academic dissemination of compelling 'design studies' is still 'all too rare'.[35]

The 'attractiveness' requirement

In the context of computer interfaces, there is some evidence that the role of aesthetics reaches beyond the experiential or superficial, and might even be useful in supporting 'utility'. For example, some researchers have argued that aesthetics can positively influence task performance and overall user satisfaction in the use of everyday objects.[36] In the context of visualization, highly aesthetic representations may compel the user to engage with the data, enabling more effective communication of the information itself. Salimun et al.[37] recently demonstrated through empirical studies that visual search task efficiency improves with a more classical aesthetic layout of visual objects. Several experimental studies have shown a relationship between subjective aesthetic judgement and apparent usability of computer interface design.[38,39] In addition, people spend more time – and tend to be more forgiving when confronted with errors or software glitches – if the interface is perceived as being aesthetically pleasing. In an online study, Cawthon and Vande Moere[40] presented empirical evidence that latency in task abandonment and the time taken for erroneous responses are correlated to a visualization's perceived visual aesthetic. Recent empirical results show how apparently non-utilitarian 'visual embellishments' in the form of meaningful metaphors do not affect interpretation accuracy, but positively influence long-term recall in simple infographic charts.[41] Whether the same is true for more complex or interactive information visualization techniques is yet unknown.

However, aesthetics can have wider influence than the efficacy or subjective appeal of a visualization. The specific notion of the role of aesthetics in the representation of information was first proposed by media writer Lev Manovich,[42] who coined the term 'info-aesthetics' as a visual quality that inherently exists in commonly used information visualizations, interfaces and analysis tools. He argued that the rise of the information society has resulted in a new type of aesthetic that is conceptually similar to those that exist in traditional design, architecture or art. Just as we can often interpret the time period of an art painting by its genre, technique, subject, or visual style, we can identify the era in which a specific information interface was developed. Accordingly, current 'popular' visualizations reveal a generational zeitgeist of information abundance and data addiction.

Several visualization subfields implicitly recognize the intrinsic value of aesthetics, for example in developing data representations that aim to entice lay user interest or encourage frequent, long-term engagement. The field of *social visualization* has produced visually compelling graphs that attract as much as inform, thus enriching electronic social communities and their interaction processes by making their salient qualities visible in easily understandable and accessible ways.[43] *Ambient displays* represent non-critical information subtly in the periphery of human attention.[44] They explicitly recognize aesthetics to be a key design criterion, ensuring that information displays are as unobtrusive as possible and 'dissolve' into their physical environment.[45] In the field of *informative art*,[46] data representations are deliberately disguised as well-known works of art so as to encourage societal acceptance of information displays in public spaces. The translation of weather and bus schedule data into Mondrianesque paintings[47] demonstrates the explorative process of mapping abstract data into any sort of perceivable form, in particular when deliberately ignoring immediate utilitarian design constraints.

Sack[48] looks beyond whether such enticing and engaging visualizations are pretty, beautiful, or easy to use, and instead recognizes their 'aesthetics of governance': the interpretation and articulation of meaning (rather than information) as a creative response to visual contemporary art. He notes how Manovich's 'anti-sublime' visualization grew out of science and engineering, and ultimately became embraced by conceptual art as a powerful way of creative expression. In turn, Kosara[49] proposes the practice of *criticism* as a tool for identifying differences between 'information visualization' and more artistic forms of visual communication. Pousman et al.[8] coined the term *casual visualization* for visualizations that convey 'increased focus on activities that are less task driven, data sets that are personally meaningful, and built for a wider set of audiences'. While artists may object to the term 'casual' to denote a self-critical subfield, highlighting the difference in audience and the focus on 'personal' meaning is useful. Viégas and Wattenberg,[6] creators of several 'beautiful' visualizations themselves, have used the term 'artistic data visualization' to describe data depictions that employ a 'forceful' point of view as a means of recognizing the inherent power of visualization as a potential mass communication medium. Inspired by Manovich, Lau and Vande Moere[7] proposed the term 'information aesthetics', and listed three potential characteristics that affect the engagement of lay audiences: (1) *design quality* including visual style and user experience in general; (2) *data focus,* where a visualization is focused on communicating meaning instead of facts and trends; and (3) *user interaction*, involving the aspects of fluidity, flow, engagement and social collaboration.

These aforementioned models and definitions attempt to identify why a visualization is attractive by either identifying the *intent* behind its creation or by analysing externally distinguishable *properties* in its visual form (or in its associated interactive features). Key decisions regarding intent and visual properties are made as part of the design process; they contribute to the attractiveness of the visualization, and are motivated by design rationale – whether explicitly stated or not.

Evaluating 'attractiveness'

Many techniques facilitate the objective benchmarking of the 'utility' and 'soundness' characteristics in a visualization. In contrast, measuring aesthetic quality is not trivial, as there are no common and validated aesthetic principles that can be quantified or benchmarked. Determining criteria to assess 'aesthetics' is complex and highly subjective, as it involves a wide range of possible interpretations of what 'aesthetics' actually entails. The notion of defining aesthetic quality as a set of quantifiable and fully deterministic metrics was theorized by Plato: he argued that the recognition of beauty in nature as mathematically definable forms could reflect the existence of a greater and calculable universal aesthetic.[50] Accordingly, many scientific approaches use algorithms that measure and quantify recognizable features relating to the concept of 'order', such as the *proportionality*, *complexity* and *variety* of the discernable elements comprising a visual composition. For example, Ngo et al.[51] proposed 14 different metrics quantifying the classical aesthetic layout of the components of an interface, including concepts such as symmetry, sequence and cohesion.

In contrast, some believe a valid opinion about aesthetic quality can be formed without explicit reference to measurable characteristics.[52] One might believe that an artwork is aesthetically pleasing (or 'beautiful') because of a particular visual quality, but it is equally as valid to believe this *without* providing a specific reason. A component of aesthetics thus seems to be founded in the human experience, rather than in reasoned interpretation. Aesthetics can therefore be addressed non-discursively: people may not understand 'why' they find an object aesthetically pleasing, and do not feel the need to analyse it. The fact that aesthetics is under-represented in academic research might therefore be explained by the difficulties in accurately defining, measuring and quantifying it.

The choice of visual mapping

Many models describe the procedural stages of configuring an information visualization. For example, Card's early model lists four successive steps: (1) the processing of raw data; (2) the transformation of data tables; (3) the mapping of visual structures; and (4) the transformation of the visual results (e.g. zooming, overview).[53] The third stage focuses on the visual form, and implies a high degree of design reasoning: one of the main challenges during the development of new techniques entails inventing novel visual metaphors that represent the structure of, and the relationships within, complex data (while also allowing for its interactive navigation and exploration).

Because the data in an information visualization are 'abstract' and thus lack any spatial layout or physical presence, the representation problem centres on deciding upon an effective way to map intangible data into a perceivable visual form. Typically, each data element (e.g. tuple or row) within a given data set corresponds to a single visual element. Each data attribute (e.g. value) of such a data element is then linked to a unique visual attribute of the corresponding visual element, so that the numerical, ordinal or categorical data value determines its visual appearance. The multitude and variety of existing visualization techniques demonstrates that while this 'graphical grammar' might seem relatively constrained, it still results in an almost infinite design space: the combination of the three dimensionality constructs (i.e. points, surfaces, objects) with their spatial transformations (e.g. position, size, colour, transparency, texture, motion) allows for infinite ways of relating data values with visual form. At some stage during the design of a novel visualization technique, such data-to-form decisions need to be explicitly made.

We suggest that design reasoning is always present and encompasses a wide range of decisions that all influence the final visual form; although this reasoning may happen unconsciously, it is always present. We suggest that it aims to balance the three Vitruvian requirements of utility (e.g. 'Can my users understand the mapping?'), soundness (e.g. 'Can my algorithm handle data complexity?'), and attractiveness (e.g. 'Will people find my visualization beautiful and compelling?'), and requires careful choice of mapping metaphors, depending on design requirements and constraints. From innovative decisions that determine the visual structuring of data attributes to more 'trivial' choices such as colour palettes and font types, the data mapping stage is characterized by design reasoning. In fact, the selection of a specific colour or font type might not be as 'trivial' as it appears: for expert designers, these choices are often the result of years of training and practical experience, and form the basis of an aesthetic craftsmanship that can be difficult to describe or quantify. A visual designer's skill is to be able to manipulate the perception, cognition, and communicative intent of a visualization by carefully applying principles of 'good' design.[54] Design reasoning therefore entails processes as diverse as analysis, conceptualization, idea expression, verification and evaluation of possible solutions, and finally decision-making based on a consistent and internally valid rationale.

This rationale may be supported by established empirical results (such as the Gestalt laws), textbooks that focus on perceptive and cognitive human capabilities,[55] explicit design guidelines,[56] experimental evidence, or by constructive feedback and critique by colleagues, design experts or the users themselves. Design decisions may rely on precedent from best practice and 'successful' exemplars. However, ultimately, when external support material is lacking, they tend to depend on the personal judgement of the developer (or perhaps better called 'the designer') of the visualization.

Design cases in the information visualization literature

We are not the first to call for the academic research community to pay more attention to analysing the decisions behind the mapping of visual structures or to describing the rationale behind design decisions. In discussing the processes and pitfalls of writing academic information visualization papers, Munzer points out that there are few good design studies: she seeks 'well-reasoned justifications' and urges authors to ensure that 'visual encoding choices are appropriate and justifiable'.[35]

A consequence of design decisions not being described and justified in many academic publications is that the creation of novel visualization techniques could be perceived as a sort of *romantic* process[57]: a mystical, unexplainable series of events that does not seem to be supported by logical reasoning, but instead relies on the developer's subjective values and taste. It can appear that new visual metaphors have been simply 'dreamt up', as the visualization developer does not explain the rationale behind their design. This stands in contrast to the other two aspects of the design requirements triangle: both the effectiveness (i.e. 'utility') and algorithmic generation (i.e. 'soundness') of a new technique are typically described in detail, so as to facilitate external scrutiny and constructive critique. The same detailed descriptions of, and reflections on, the 'attractiveness' requirements of a novel visualization are seldom evident.

Accepting that mapping new visual structures involves the process of design reasoning means agreeing that proven design methods can be of value. Typical design activities[58] – such as involving users or experts,[23] exploring original possibilities, navigating the borders of given constraints, redefining predefined requirements, incrementally prototyping solutions and exposing them to critique and evaluation – can all be employed during the development of a new visualization. Even if such design methodologies are in place, operating them explicitly and consciously, and fully documenting and disseminating them, would be of benefit to other researchers. Truthful design documentation is not always straightforward, however, as design activities do not follow a strict, linear process, and no obvious sequence of stages is apparent as analysis, conceptualization and implementation are inextricably interlinked.[26]

Authors of some ‘design studies’ in information visualization refute the romantic notion of design and explicitly present their design reasoning. For example, Keefe et al.[59] described both the process and the results of a collaborative effort involving professors and students of computer science and design departments in developing novel visualization techniques for a virtual reality environment. While they highlighted a lack of design tools allowing for immediate sketching and critiquing, they also concluded that ‘artists [have] key roles in working closely with scientists to design novel visual techniques for exploring data and testing hypotheses’.

Byron and Wattenberg[16] have shown how articulation of design can be a driving force behind the investigation of a novel visualization technique (i.e. the stacked graph), resulting in scientific contributions on both an algorithmic (i.e. ‘soundness’) as well as an aesthetic (i.e. ‘attractiveness’) level. In particular, they revealed their detailed reasoning behind design decisions in terms of shape, ordering, labelling and colour, partly based on a small, informal and qualitative user study, and partly based on their own subjective judgement in terms of reaching an appropriate equilibrium between legibility and aesthetic quality. They also described the design process they followed, such as how the algorithms were carefully fine-tuned through various iterative stages of analysis, synthesis, and evaluation,[57] as well as how seemingly ‘trivial’ decisions such as the choice of colours and text labelling were addressed. The result is a collection of generalizable knowledge, which is meaningful beyond the specific design case described; their detailed description of design rationale is of benefit to other developers, who can follow a similar research-through-design approach.

Segel and Heer[60] presented a post-development analysis of the design reasoning behind several existing visualizations in the context of narrative storytelling. They characterize design differences by comparing the intentions (i.e. design requirements) of the visualization designer (i.e. ‘author’) with the experience of the ‘reader’. The resulting design space analysis reveals gaps, representing underexplored approaches that can direct future narrative visualization strategies. Forsén et al.[61] describe the design reasoning and empirical validation of a new visualization technique called ‘PinPoint’, which supports the networking of people within an organization by similarities of expertise and interest. Calling their research explicitly a ‘design study’, they stress their deliberate focus on learning about the problem space as a design activity, rather than simply providing a definitive answer to a given question. Their contributions are thus reported in a manner that allows other researchers to validate and assess their design decisions, with equal attention paid to the three qualities of utility, soundness and attractiveness. Finally, Agrawala et al.[54] propose that the ‘design’ of visualization systems can be simulated computationally, in three successive stages: (1) identification of design principles (i.e. in hand-designed visualizations and prior work in perception and cognition); (2) instantiation of those principles in automated algorithms; and (3) evaluation of the principles through user studies.

Most ‘design studies’ like these reveal a desire to control the ‘attractiveness’ requirement of the triad, particularly as a potential avenue for innovative design. This relates, unsurprisingly, to similar approaches in interaction design, where creative designers believe ‘aesthetics to be an integral part of functionality, with pleasure a criterion for design equal to efficiency or usability’,[62] and that design should help us create solutions that inspire us to be smarter, more curious, and more inquisitive rather than simply solving complex problems.[63]

These examples from the literature show the potential benefits of presenting design cases within information visualization. Design can be integrated in research, for example by creating visualization prototypes to demonstrate the scientific contributions (i.e. ‘design-oriented research’[64]), or a traditional design process can utilize specific research methodologies, such as when issues cannot be solved using existing development practices (i.e. ‘research-oriented design’). Publications of this type can describe the different ways in which both problems as well as solutions have been analysed, and include a critical reflection on their merits within a given (or possibly reinterpreted) set of requirements and specifications. They can demonstrate how the designed artefact (here the visualization technique) can contribute to scientific knowledge in itself, rather than simply being the outcome of a hidden rationale. Describing the design process allows peers to assess the resultant visualization more completely, and to integrate the design insights into their own existing knowledge framework.

A model of design in visualization research

Our model aims to provide a framework for considering the possible roles of design in information visualization. Inspired by the model of interaction design research as proposed by Daniel Fallman,[65] the model, as shown in Figure 6, includes three design domains by adding both commercial practice and artistic expressions of visualization[6–8] to traditional academic research. We have reinterpreted Fallman’s research model as one of design research as conducted and experienced by stakeholders in the three worlds of commercial practice, research and art, represented by the three extremes of 'visualization practice' (businesses), 'visualization studies' (researchers) and 'visualization exploration' (artists).

The domain of *visualization studies* resembles typical academic research activities, that systematic inquiry, the aim of which is to add meaningful and empirically proven insights to a generalized body of knowledge. Its main goals are to understand, explain and predict. The combination of its historical background in computer science and the use of expert-level application domains means the academic research community has tended to focus on the aspects of 'utility' and 'soundness' in visualization, largely overlooking the role of 'attractiveness'. However, while much typical academic activity in information visualization does not explicitly employ any design methodologies in achieving its research goals, it still is clearly involved in designing (e.g. by proposing, developing and evaluating novel representation techniques). A visualization developer may even consider the design process the goal of the academic research. However, a shift in research focus from analysis or understanding of existing information visualization techniques to the dissemination of novel ideas that aim for reflection and a change in approach may require a significant paradigm shift in how the field is perceived and how research is conducted.

Visualization practice refers to those visualization activities that are mainly accomplished by commercial enterprises, ranging from large data analytical firms to individual freelance 'infographic' designers. Its goals are to create visualizations so as to make them sell. Designing is often a dominant visualization development activity in practice; for example infographic (e.g. Pitch Interactive,[66] Catalog Tree[67]) and mass communication-oriented (e.g. Stamen 'Design',[68] XPLANE Business 'Design' Thinking[69]) commercial ventures are often deliberately set up as creative *design studios*. This phenomenon can be explained partly by the design background of the typical employee, and partly by the commercial attention paid to aspects such as originality and innovation (both of which relate to the 'attractiveness' requirement). In such practical contexts the explicit dissemination of know-how and tacit knowledge is typically rare – this is a consequence of the oral tradition of design studios[70] as well as the intrinsic characteristics of design expertise, which tends to be acquired after years of intense and passionate refined craft mastery, and which cannot be captured by a series of steps. However, a few commercial publications have

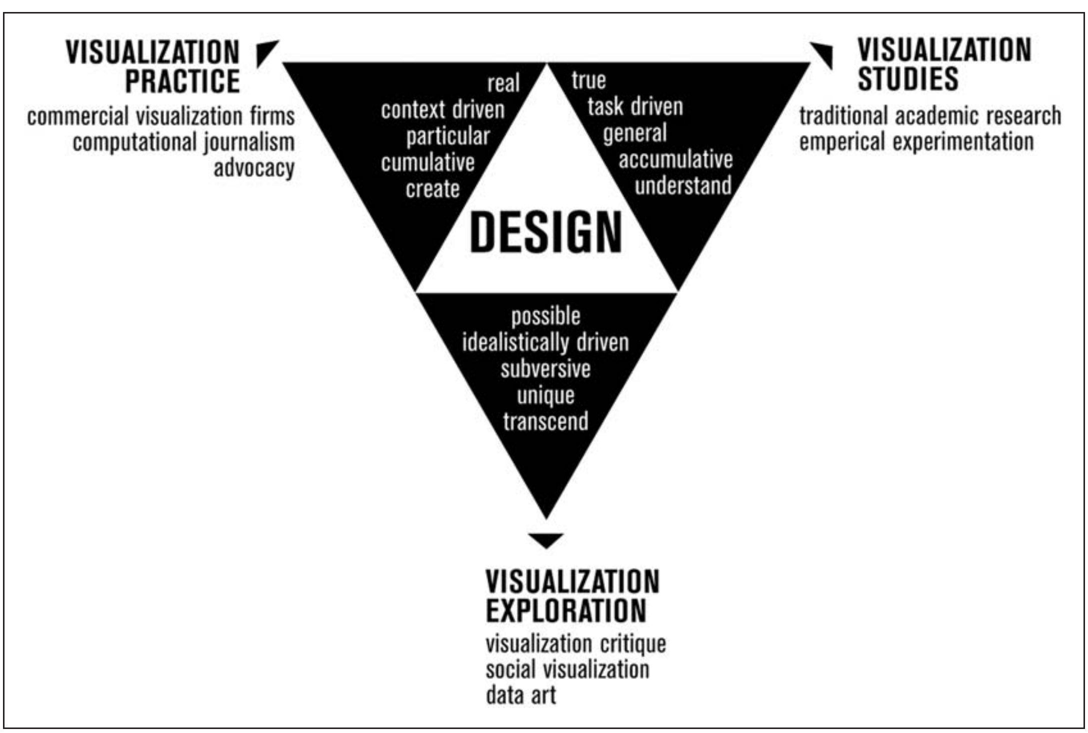

Figure 6. A model of three roles of design in information visualization research (based on ref. 65).

described the design rationale behind successful or particularly compelling visualization projects, showing a recent willingness to be open, share and build upon others' experiences. Books such as *Beautiful Data*[71] and *Beautiful Visualization*[72] are positive examples of how design reasoning can act as a common platform for practical and theoretical knowledge that brings together different disciplines with interest in information visualization. Their description of varying views, as well as 'war stories' and tips and insights from visualization developers, provides a unique view of the range of design approaches and methodologies that are commonly used in practice.

Visualization exploration is similar to design practice in its desire to create workable solutions rather than accumulate knowledge. However, its goals are more idealistic and visionary. Projects in this domain are often self-initiated and driven by the designer's own research agenda.[65] The design reasoning does not focus on addressing the requirements of 'utility' or 'soundness', but rather attempts to demonstrate what is possible, to innovate, and to provoke or critique the current state of affairs. Visualization exploration activities often deliberately create a conceptual space in which they exploit 'attractiveness'. Exemplars of more artistic and avant-garde approaches[7,49] (such as those shown in Figure 1) also belong to this category; they too can benefit the progress of information visualization by provoking and questioning current dogmas.

Although the activities and tools used within the three domains might appear similar in some real-world scenarios, it is useful to recognize their differences in order to accept design as a cross-disciplinary platform that can facilitate the sharing of valuable knowledge. All three domains produce various types of information visualization, each from its own unique perspective. We suggest that most innovation will occur in the mid-section of the triangle, where the three domains overlap.

Discussion: The way forward

The relationship between design and information visualization

We propose some assertions regarding the visualization design process – in doing so, we take the view that articulating knowledge that may appear obvious is always useful.

1. **Visualization design is not an 'add on'.** Design reasoning is not an activity that can be added 'later' after most other decisions have been made; visualization developers need to be conscious of the role of design at the outset. Design often does not follow a streamlined process, but may be iterative,[73] spiralling,[74] non-linear[25] or even chaotic.[57,58]
2. **Visualization design is not a black box.** Design is not a mystic activity, nor is it reserved for those with excellent skills in sketching or innovative thinking. Design reasoning entails making conscious decisions that are consistent, interlinked and internally valid, with each decision grounded on a reasonable and objectively reproducible rationale.
3. **Visualization design is not art.** Although our focus in this paper has been on visual form (rather than interaction or analysis), we acknowledge that design still requires a functional purpose, often specified in a design brief.
4. **Visualization design is not engineering.** When design decisions are made based on predefined rules, norms, or formulae, or founded purely on precedent, there is little research, invention, innovation or progress in the field: design is rather a symbiosis between 'engineering design' (targeting 'tame' problems), and 'creative design' (focusing on 'wicked' problems[24,25]).
5. **Visualization design can be disseminated.** Although practising visualization developers might not recognize the need to articulate their design choices, researchers have a scientific responsibility to be as articulate as they possibly can about their decisions and the processes that drove them.
6. **Visualization design can be learned.** Contrary to the 'romantic' view of design as being a mystic activity, effective design practices can be taught: visualization development requires tacit knowledge and experience that goes beyond simply solving functional requirements.
7. **Visualization design belongs to a wider design community.** Many related fields (e.g. human–computer interaction, user interface development, information design) already incorporate the concept of design research, using such processes and concepts as iteration, user-centred design, constraint satisfaction, and creative exploration.

Practical consequences

Our argument is that information visualization is a design discipline, and that with 'design' we do not simply mean 'attention to aesthetics'. All aspects of a visualization are designed, explicitly or implicitly, consciously or unintentionally. Although we have focused primarily on design within the third stage of Card's model (i.e. mapping visual structures), all stages in the visualization pipeline entail design thinking: the choice of data set and data attributes, as well as the facilities provided for interactive data exploration. While 'good' design sense is often the result of years of training and experience, becoming aware of the rationale behind such choices is not only interesting, but, if well documented and openly disseminated, can benefit the information visualization community as a whole. This would have several practical consequences:

- A wider range of activities and domains should be encompassed within the field of 'information visualization research', potentially including initiatives that address the current gap in academic literature on 'visualization practice' and 'visualization exploration'. For example, academic conferences could explicitly solicit submissions of best practice design case studies or design studio experience reports. They may extend their scope to include externally critiqued provocative data art pieces as well as reflective discussions on the impact of information visualization on applications in science, business and art. However, including such activities may require new critical evaluation methods that do not focus on 'soundness' and 'utility' alone.
- Visualization design experience and practice should be incorporated into the field's body of knowledge, requiring a paradigm shift in its definition, and in the criteria used for public dissemination. It would be impossible to retrospectively collect the design experience that has led to the current state of the field, but recognizing that disseminating and accumulating this experience can enhance its future development is a key initial step.
- The practice of developing a visualization should be executed with design in mind, and with a balanced consideration of 'utility', 'soundness' and 'attractiveness'. Several well-established design tools and techniques can facilitate this, such as user participation, idea exploration and analysis, rapid prototyping and pilot testing, public presentation and external critiquing, and recording and reflecting of rationale. There are at least three implications of this:
  - focusing on the process of design requires additional effort, time and continuous self-reflection; it is likely, therefore, that it will be done only by visualization developers if they see a personal value in doing so. Although some researchers may be internally motivated to be explicit about their processes (recognizing a personal academic benefit), more concrete and direct external motivation will probably be required, typically through peer-reviewed publication.
  - visualization developers require training in design methods, typically learned by studio-based methodologies, in which students 'act out' the role of designer in small projects, and are tutored by more experienced designers.[75] Information visualization education would therefore benefit from looking further than traditional textbook-led instruction and using educative methods typically used in other design domains (e.g. analysing best practice, iteratively creating and prototyping designs, and engaging in public and peer critique). The benefit of investing in the additional resources required for such courses (to both the academic community and the students, our future researchers) would need to be obvious. Such a new educational paradigm would require new assessment methods (not dissimilar to the new requirements for assessing research contributions outside traditional boundaries, as discussed above).
  - research teams will need to be explicitly organized and managed to be explicitly organized and managed so as to foster the design experience: no longer will individual researchers work independently on their visualizations, but the discussion and justification of design choices with colleagues would become part of the day-to-day research activity.
- The 'best practice' examples of the field would need to be revisited, so that they include visualizations that are valued for the detailed description of the design process as well as (or even instead of) the final product.

These suggestions would require a significant paradigm shift, a different way of viewing the information visualization field: widening it and making it more inclusive of associated domains, while still respecting the practice of conducting rigorous and scientific research. Doing so will lead to a greater maturity of the field – a field that is more open to reflection and critique, even for those works that are controversial, unconventional or commercial in nature.

In this paper, we have considered the field of information visualization as having a wider scope than its common, scientifically motivated, definition. Of the three design requirements of 'utility', 'soundness' and 'attractiveness', we have focused on the third, as the former two are already typically included as traditional evaluation criteria for scientific contributions. In reviewing the value of aesthetics in visualization and analysing published design cases, we conclude that design is an inevitable part of creating a visualization, and that, as a scientific field, we tend to overlook the design process and focus on the product. In doing so, we risk losing valuable design knowledge that has the potential to enhance and mature the field. Based on

Fallman's model of interaction design, we have suggested that the field could be extended to include visualizations created as commercial practice, as well as projects that explore and question the visual design space itself. We present a set of assertions about the relationship between information visualization and design, and reflect on the practical consequences for the academic community of adopting our model.

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