The Pitfalls of Visual Representations: A Review and Classification of Common Errors Made While Designing and Interpreting Visualizations

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Abstract
A large body of research has addressed the benefits of visualization, whereas the analysis of the pitfalls has not received systematic attention. We aim to provide an overview of the common pitfalls and potential disadvantages of visual representations based on a multidisciplinary literature review. Subsequently, we develop a theoretically grounded classification of common cognitive, emotional, and social risks of visualization and populate it with a comprehensive list of visualization pitfalls. The aim of this research is not to diminish the potential of visualization, but rather to improve visual literacy by structuring our understanding of the possible limitations of graphic representations.

Keywords
visualization risks, visualization mistakes, disadvantages, visual representation negatives, graphic representations, graphic design improvement

Introduction: Why Examine the Pitfalls of Visualization?
The rise of visualization’s use on the Web, in social media, in education, and in management calls for a systematic understanding of the limitations of graphic representations and of potential mistakes that are committed when designing or viewing information and knowledge visualizations. Examining the potential risks and common mistakes committed in the interpretation and in the creation of visualization is relevant to enhance scholar understanding of an important aspect of visual literacy. In this article, the word visualization refers to the graphic display of information and knowledge. From a pragmatic point of view, a compilation and classification of pitfalls of visuals can be used as an instructional tool, to provide a comprehensive list, a vocabulary and definition of relevant terms related to the risks of visualization. Practitioners could profit from such a classification by using it as a checklist, against which they can test images and improve document design, infographics, or digital images.

Despite the notable number of publications on the benefits of using visual representations in a variety of fields (Meyer, Höllerer, Jancsary, & Van Leeuwen, 2013), few studies have systematically investigated the possible pitfalls that exist when creating or interpreting visual representations. Some information visualization researchers, however, have raised the issue and called to action: “Articles on limitations and pitfalls [of visualization] are scarce. For the advancement of the field, more such reports would be highly beneficial” (van Vijk, 2006, p. 426). Presently, a clear overview and classification of the risks and disadvantages associated with visual depictions of information has not been provided. Thus, as evaluated by Pauwels (2010), “Due to a lack of integrative efforts, we are in danger of constantly ‘reinventing’ knowledge about the visual and its workings” (in Meyer et al., 2013).

Such a synopsis could provide a comprehensive theoretical overview based on prior research findings, to assist researchers in investigating systematically the effects and the boundaries of visual representations of information (Eppler, 2006; Fong, Valerdi, & Srinivasam, 2007). This article aims to provide an instructive schema that contains prior research findings from a variety of fields related to visualization.

The goal of this article is to identify and classify the key problematic issues and risks inherent in visual representations,
as well as to provide a structure to guide work in visualization production and quality assessment. We argue that this is an important step in visualization research to use as a basis for the future development of guidelines and rules for visualization developers and users, and for instructors. To compile a list of risks of visualization, we have screened studies from multiple related research domains. We have focused on the visual representation of information and thus did not analyze areas such as fine arts, photography, film, or scientific imaging.

We structure the article by starting with a review of visualization literature. In the third section, we provide a classification populated with reported disadvantages of visualizations. We then present examples of how to utilize the classification for evaluating and improving graphic representations of information. We end with the conclusions and an outlook for future research.

Our aim with the present work is not to diminish the potential of visualization. It is rather an attempt to deepen and structure our understanding of its possible limitations and constraints. This is relevant not only to avoid or detect mistakes in the production and interpretation of visualization applications, but also as a teaching tool to foster visual literacy.

### A Review of Literature

To survey the current state of research on the pitfalls of visualization, we have analyzed 51 articles published in peer-reviewed journals and books in 6 main fields of research related to visual representations: (a) statistical graphic representations, (b) visual literacy and visual communication, (c) information visualization and human–computer interaction (HCI), (d) management studies, and (e) cross-cultural studies related to visualization. These fields have been selected for their coverage of characteristics of visual representations. Although several other fields have addressed the effects of visualization—such as film studies, sociology, architecture, or education—we have consciously chosen to set the boundaries of this classification to those areas that are closely related to the graphical displays of information. In Table 1, we have compiled a list of all the pitfalls of visualization found in the research reviewed in these fields. A brief description of each disadvantage is provided in the Table 2.

We witness the earliest and most comprehensive collection of visual representation pitfalls in the area of statistical graphic representations. The main approach in this area has been to showcase particularly bad examples of visualized statistical information and to learn from them. This has been elegantly demonstrated in Edward Tufte’s (1986, 1990, 1997, 2007) popular books in which he highlights numerous ways in which visualization falls short of its potential. In his works, he uses several anecdotal examples of graphics that fail to tell the truth. He goes on to explain why and how they fail, for example, by measuring their “lie factor” (given by the size of the effect shown in the graph divided by the size of the actual effect found in the data). Similarly, Wainer points out 10 typical pitfalls in visualizing information in his article, “How to display data badly” (Wainer, 1984). His ironic counter-recommendations are as follows: (a) Minimize the data density, (b) minimize the data–ink ratio, (c) ignore the visual metaphor altogether, (d) only order matters, (e) graph data out of context, (f) change scale in mid-axis, (g) ignore the important, (h) jiggle the baseline, (i) Austria first! (ordering graph items alphabetically), and (j) label illegibly, incompletely, incorrectly, and ambiguously. Other similar publications in the field, as the popular book, “How to Lie with Statistics” (Huff, 1993), emphasize how information visualization can be used to mislead.

In the fields of Visual Literacy and Visual Communication, authors have discussed the heterogeneous interpretation of visual material due to differing prior experience (Avgerinou & Pettersson, 2011; Dwyer, 1972), including the knowledge of visual conventions (Avgerinou, 2007), and different cultural backgrounds (Avgerinou, 2007; Forsythe, 2011). At the same time, Knox’s (2007) study has shown emerging conventions in visual design, whereas Machin and Van Leeuwen (2007) have discussed the increasing institutionalization of visual cues in global media (in Meyer et al., 2013).

In the rich and rapidly evolving domain of Information Visualization, we can find a broad discussion on the properties of graphic representations and their positive use, but fewer considerations of their potential drawbacks. In particular, Ware (2004) identifies the underlying mechanisms of information visualization perception and brings to light potential issues of visualization use, including change blindness, wrong salience, wrong use of color, visual stress, cultural differences, and breaking conventions. Conversely, psychologist Kosslyn (2006) focuses on specific formats of graphic design (e.g., pie charts, bar and line graphs) and discusses graphic representation dangers such as defocus (distraction) and over-complexity. Van Vijk’s (2006) “Views on Visualization” is one of the few articles that explicitly considers “consequences and limitations of visualization.” He finds that visualization can have high initial cost to be understood (when new techniques are developed), is at times subjective, and can be wrong and misleading. Cawthon and Vande Moere (2007) studied the aesthetics of data visualization and found that information visualizations may trigger unwanted emotions or distractions. Few (2006) has extensively addressed the pitfalls of graphic dashboards used in organizations, addressing issues such as wrong use of color, low accuracy, useless decoration, and so on. Also in the specific area of visual analytics (Thomas & Cook, 2005) and collaborative visual analytics (Heer & Agrawala, 2008), the positive and negative mechanisms underlying the effectiveness of visualizations are examined. In the subdomain of Visual Languages, researchers have examined disadvantages of diagrams and of notations, as for example, unevenness (Blackwell et al., 2001; Green & Petre, 1996) or over-reliability appearance (Crilly, Blackwell, & Clarkson, 2006). In the study of diagrams, authors have discussed the...
limitations and possible restrictions of a specific format, for example, in the seminal study by Larkin and Simon (1987) and in the study on visualization over-determinism by (Shimoijima, 1996). In the related field of HCI, a few authors have considered the potential drawbacks of interactive visualizations, but only in the context of user interfaces—and how they inform or confuse users (Shneiderman, 1998).

The recent stream of management focusing on boundary objects and sociomaterial practices explores the potential (and to a much lesser extent, the risks) of using visualization in organizations (Buergi & Roos, 2003; Eppler, 2004; Eppler & Burkhard, 2005; Eppler, Mengis, & Bresciani, 2008; Henderson, 1995; Lurie & Mason, 2007; Meyer et al., 2013, Al-Kassab, Ouertani, Schiuma, & Neely, 2014; Roos, Bart, & Statler, 2004). These studies typically highlight visualization advantages through case evidence. A subset of management studies analyzes specifically the positive and negative effects of visualization for collaboration (Ewenstein & Whyte, 2007; Fong et al., 2007; Mengis, 2007; Nicolini, 2007; Oliver, 2007; Tversky, 2005; Whyte, Ewenstein, Hales, & Tidd, 2007), also in computer-mediated settings (DeSanctis & Gallupe, 1987). For instance, the political use of images in collaborative setting may provide unequal possibilities to contribute to the discussion (Henderson, 1995; Nicolini, 2007; Whyte et al., 2007), or it may affect the typical behavior of the discussants (Nicolini, 2007) who might pay more attention to the visual rather than to the facial expressions of the group participants.

Cross-cultural studies have also addressed the differing interpretation of visual representations caused by cultural variations: Already in 1966, Segall, Campbell, and Herskovits (1966) have described the influence of culture on visual perception. Nisbett (2003) and Nisbett and Miyamoto (2005) have shown through eye-tracking studies how Westerners and East Asians look at images differently, with Westerners focusing on the main central objects and East Asians paying attention also to the background. Chan, Li, Diehl, and Terlutter (2007) have described cross-cultural variations in consumers’ response to emotional images. A comprehensive review of cultural factors influencing the reception of visual representations of information has recently been published (Bresciani, 2014), which include, among others, the different meaning of colors and symbols across cultures, the appropriate use of visual humor in diverse cultural setting, and reading direction (right to left for Arabic and some Asian languages).

In total, we have identified more than 50 articles and books that discuss the potential pitfalls of graphic representations of information and knowledge. We have consciously not considered disadvantages related to the mere functionalities of specific visualization environments or software packages, instead concentrating our compilation of disadvantages on a higher level of granularity (e.g., more conceptual shortcomings). From this literature review, a number of concepts have emerged (see Table 1 for the complete list), with differing levels of abstraction and scope. In the next section, we cluster the results in a $3 \times 2$ classification.

Proposed Classification of Visualization Pitfalls

In this section, we propose a classification of visualization errors or disadvantages to structure the many factors that can make a graphic representation dysfunctional, and we populate it with the pitfalls that we have found in the literature. A classification of the large quantity of concepts that we have collected is necessary to structure them in an efficient and relevant way, as well as to make them usable and accessible.

The classification that we propose, shown in the following table (Table 1), is a matrix based on two causes of pitfalls, the designer or the user, and three types of (negative) effects: (a) cognitive, (b) emotional, and (c) social (Buergi & Roos, 2003). The concepts we have collected from the literature are classified and referenced in the six resulting cells. A short definition of each concept can be found in Table 2.

More specifically, the cause of a visualization problem can be twofold: the encoding (that is, caused by the designer/developer) or the decoding (that is, caused by the reader/user; Avgerinou, 2007). In the latter case, the person who reads the image makes a mistake in the interpretation (Tufte, 1986). The designer can intentionally or unintentionally introduce mistakes or drawbacks in a visual representation. Today’s interactive technologies have substantially contributed to empowering everyone to become a designer and swiftly create visual representations: The classification is thus useful especially for non-professional creators of visual representation who might not be familiar with design principles. These digital technologies, especially when utilized in social media platforms, allow users to both consume and create visual representations: Nevertheless, the classification is still valuable because a person can be either the user or the creator of a specific visual representation at a given time (although on a platform, a person can be both a user and a developer but of different visuals). The distinction between producer and user becomes even more meaningful when images are shared on social media (Neher, 2013) because different meaning can be attributed to the same visual by different users. It is thus important to find the origin of the potential problems (that is, the visual or the viewer). The distinction between designer and user-induced mistakes is particularly valuable in pragmatic terms, as it can give immediate insights for the producers and for the evaluators of visualizations, respectively. Visualization designers should look at the encoding section of the schema in Table 1, while users should pay attention to the pitfalls in the decoding section (or column) of the schema.

Conversely, the distinction between intentional and manipulative (Huff, 1993; Tufte, 1986; Wainer, 1984) or unintentional pitfalls is at times difficult to classify, as it is not always possible to discern intentionality by merely observing a visualization. Thus, intentionality cannot be used for
Table 1. A Classification of Visualization Pitfalls.

| Cognitive                  | Decoding (User-induced)                          |
|----------------------------|--------------------------------------------------|
| The visualization may negatively affect the viewer’s thinking | The viewer may not get the meaning of the image |
| Ambiguity (Eppler & Burkhard, 2005; Eppler, Mengis, & Bresciani, 2008; Heer & Agrawala, 2008; Tufte, 2007) | Change blindness (Ware, 2004) |
| Breaking conventions (Ware, 2004) | Channel thinking (Mengis, 2007) |
| Confusion (Eppler & Burkhard, 2005; Few, 2006) | Depending on perceptual skills (Nisbett, 2003; Tufte, 1986; van Wijk, 2006) |
| Cost to make explicit (Larkin & Simon, 1987) | Difficult to understand (Buergi & Roos, 2003; Cawthon & Vande Moere, 2007) |
| Cryptic encoding (Tufte, 1986) | Focus on low relevance items (Lurie & Mason, 2007) |
| Defocused (Few, 2006; Kosslyn, 2006; Tufte, 1986; Ware, 2004) | High requirement on training and resources (Chen, 2005; van Wijk, 2006) |
| Hiding/obscuring (Few, 2006; Kosslyn, 2006; Tufte, 1986; Wainer, 1984) | Knowledge of visual conventions (Avgerinou, 2007; Knox, 2007; Machin & Van Leeuwen, 2007) |
| Inconsistency (Cawthon & Vande Moere, 2007; Tufte, 1986) | Misuse (Eppler & Burkhard, 2005) |
| Low accuracy (Few, 2006; Kosslyn, 2006; Tufte, 1986; Wainer, 1984) | Overload (Eppler & Burkhard, 2005; Eppler et al., 2006; Tufte, 1997, Ware, 2004) |
| Misleading/Distorting (Tufte, 1986; van Wijk, 2006; Wainer, 1984) | Reification (Whyte et al., 2007) |
| Not respected gestalt principles (Tufte, 1986) | Wrong salience (Al-Kassab et al., 2014; Few, 2006; Green & Petre, 1996; Ware, 2004; Mengis, 2007) |
| Over-determinism (Shimoijma, 1996) | |
| Over/under-reliability appearance (Crilly, Blackwell, & Clarkson, 2006; Green & Petre, 1996; Henderson, 1995; Whyte, Ewenstein, Hales, & Tidd, 2007) | |
| Over-complexity (Few, 2006; Kosslyn, 2006; Tversky, 2005) | |
| Over-simplification (Eppler & Burkhard, 2005; Nicolini, 2007) | |
| Redundancy (Few, 2006; Tufte, 1986) | |
| Task-visualization fit (Al-Kassab, Ouertani, Schiuma, & Neely, 2014) | |
| Technology/template driven (Few, 2006; Tufte, 1986) | |
| Time-consuming to produce (van Wijk, 2006) | |
| Unclear (Cawthon & Vande Moere, 2007) | |
| Unevenness (Blackwell et al., 2001) | |

| Emotional                  | The viewer may suffer because of the image |
|----------------------------|-------------------------------------------|
| The visualization may cause inappropriate feelings in the viewer | Visual stress (Ware, 2004) |
| Disturbing (Cawthon & Vande Moere, 2007; Tufte, 1990) | Personal likes and dislikes (Tversky, 2005) |
| Boring (Cawthon & Vande Moere, 2007) | Prior knowledge and experience (Al-Kassab et al., 2014; Avgerinou & Pettersson, 2011; Chen, 2005; Dwyer, 1972) |
| Ugly (Cawthon & Vande Moere, 2007) | |
| Wrong use of color (Few, 2006; Tufte, 1986; Wainer, 1984; Ware, 2004) | |

| Social                     | The viewer may be prone to miscommunication because of the image |
|----------------------------|------------------------------------------------------------------|
| The visualization may interfere with communication | Altered behavior (Eppler et al., 2006; Mengis, 2007; Nicolini, 2007) |
| Affordance conflict (Nicolini, 2007) | Cultural and cross-cultural differences (Al-Kassab et al., 2014; Avgerinou & Pettersson, 2011; Bresciani, 2014; Ewenstein & Whyte, 2007; Forsythe, 2011; Henderson, 1995; Nisbett, 2005; Segall, Campbell, & Herskovits, 1966; Ware, 2004) |
| Hierarchy, exercise of power (Ewenstein & Whyte, 2007; Henderson, 1995; Nicolini, 2007; Whyte et al., 2007) | |
| Inhibit conversation (Nicolini, 2007; Oliver, 2007) | Defocused from non-verbal interaction (DeSanctis & Galuppo, 1987) |
| Rhythm of freezing and unfreezing (Whyte et al., 2007) | Different (Heer & Agrawala, 2008) |
| Turn taking alteration (Eppler, 2004) | Hiding differences of opinion (Eppler et al., 2006) |
| Unequal participation (Mengis, 2007) | Recency effect (Nisbett, 2003; Tufte, 1986) |
|                            | Time-consuming to agree (DeSanctis & Galuppo, 1987) |
| Disadvantage                  | Author(s)                                                                 | Description                                                                                                                                 |
|------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Cognitive: Encoding          |                                                                           |                                                                                                                                              |
| Ambiguity                    | (Eppler & Burkhard, 2005; Tufte, 2007)                                    | Visual notations may contain unlabeled symbols that may be ambiguous and thus difficult to interpret.                                     |
| Breaking conventions         | (Ware, 2004)                                                              | A visualization may use different visual rules or symbols than normally expected.                                                               |
| Confusion                    | (Eppler & Burkhard, 2005; Few, 2006)                                      | Visualizations that do not have a clear overall logic or accompanying text may confuse the viewers.                                              |
| Cost to make explicit        | (Larkin & Simon, 1987)                                                    | “Diagrammatic representations typically display information that is only implicit in sentential representations and that therefore has to be computed, sometimes at great cost, to make it explicit for use” (Larkin & Simon, 1987). |
| Cryptic encoding             | (Tufte, 1986)                                                             | The visual format used to represent data may not be universally understandable and confuse some audiences.                                    |
| Defocused                    | (Few, 2006; Kosslyn, 2006; Tufte, 1986; Ware, 2004)                        | Visualization may distract a person from the main goal he or she tries to achieve or emphasize, at the same time, using multiple items.      |
| Hiding/obscuring             | (Few, 2006; Kosslyn, 2006; Tufte, 1986; Wainer, 1984)                     | A visualization may hide important insights contained in data by the way that data are represented graphically (e.g., covarying height and width, changing the starting point, or varying the aspect ratio, etc.). |
| Inconsistency                | (Cawthon & Vande Moere, 2007; Tufte, 1986)                                | A visualization may make inconsistent use of certain symbols, for example, changing their function or meaning without signaling this change.   |
| Low accuracy                 | (Few, 2006; Kosslyn, 2006; Tufte, 1986; Wainer, 1984)                     | Visualization generally depicts information less precisely than number and tables.                                                             |
| Misleading/Distorting        | (Tufte, 1986; van Wijk, 2006; Wainer, 1984)                               | Some visualizations are drawn in a way that may lead to incorrect conclusions.                                                               |
| Misuse of figure ground      | (Tufte, 1986)                                                             | The figure ground and layer contrasts are not illustrated properly.                                                                           |
| Not respected gestalt        | (Tufte, 1986)                                                             | Some visualizations do not group related information (proximity principle) or do not represent the same kind of information with the same symbols (similarity principle). |
| principles                   |                                                                           |                                                                                                                                              |
| Over-determinism             | (Shimoijma, 1996)                                                         | A visualization is, by its nature, inherently more specific than text in depicting concepts and relations.                                    |
| Over/under-reliability       | (Crilly, Blackwell, & Clarkson, 2006; Green & Petre, 1996; Henderson, 1995; Whyte, Ewenstein, Hales, & Tidd, 2007) | Highly polished visualizations might prevent users from criticizing the content whereas more provisional sketches encourage suggested revisions.     |
| appearance                   |                                                                           |                                                                                                                                              |
| Over-complexity              | (Few, 2006; Kosslyn, 2006; Tversky, 2005)                                 | The visualization depicts elements in a more complex manner than necessary.                                                                     |
| Over-simplification          | (Eppler & Burkhard, 2005; Nicolini, 2007)                                 | Some graphic depictions leave out essential elements to simplify information, which leads to a distortion of the information.               |
| Redundancy                   | (Few, 2006; Tufte, 1986)                                                  | In some graphic representations of information, the information is visualized in superfluous ways that clutter the visualization unnecessarily. |
| Task-visualization fit       | (Al-Kassab, Ouartani, Schiuma, & Neely, 2014)                             | The lack of an appropriate fit between the task and the visual representation can be misleading.                                                 |
| Technology/template driven   | (Few, 2006; Tufte, 1986)                                                  | Some visualizations are based on pre-defined forms or templates that are not adequate for the communication task at hand or the information to be represented. |
| Time-consuming to produce    | (van Wijk, 2006)                                                         | Producing a visualization may take a disproportional amount of time for the information that is communicated.                                   |

(continued)
Table 2. (continued)

| Disadvantage               | Author(s)                                         | Description                                                                                     |
|----------------------------|---------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Unclear                    | (Cawthon & Vande Moere, 2007)                     | A graphic depiction may leave too much room for interpretation regarding its purpose or main message. |
| Unevenness                 | (Blackwell, 2001)                                | A visualization can typically not be used in many different ways. It may privilege some activities while making others harder, thus constraining users’ thoughts in one direction. |
| **Cognitive: Decoding**    |                                                   |                                                                                                |
| Change blindness           | (Ware, 2004)                                     | Important changes in pictures may go unnoticed by the viewers.                                  |
| Channel thinking           | (Mengis, 2007)                                   | The visualization can direct thinking in an inappropriate direction (caused by a metaphor or familiarity level). |
| Depending on               | (Nisbett, 2003; Tufte, 1986; van Wijk, 2006)     | People see differently, depending on physical (e.g., color blindness) and cultural factors (attention to foreground or background). |
| perceptual skills          |                                                   |                                                                                                |
| Difficult to understand    | (Buergi & Roos, 2003; Cawthon & Vande Moere, 2007) | Some visualizations are inherently difficult to understand because they depict many complex relationships that may not be optimally represented. |
| Focus on low relevance     | (Lurie & Mason, 2007)                            | Visual representations may accentuate biases in decision making by increasing attention to particular attributes or less diagnostic information. |
| items                      |                                                   |                                                                                                |
| High requirement on        | (Chen, 2005; van Wijk, 2006)                     | The use of certain images or visual applications requires extensive training and support.       |
| training and resources     |                                                   |                                                                                                |
| Knowledge of visual        | (Avgerinou, 2007; Knox, 2007; Machin & Van        | Knowing the visual conventions (e.g., reading from left to right or in a clockwise direction) is a learned skill, not a natural ability. |
| conventions                | Leeuwen, 2007)                                   |                                                                                                |
| Misuse                     | (Eppler & Burkhard, 2005)                        | A visualization may be used for a purpose for which it was not intended or adequate.            |
| Overload                   | (Eppler & Burkhard, 2005; Eppler et al., 2006;    | Some graphic depictions overload the senses of a viewer by presenting too many visual elements at the same time. |
| Tufte, 1997; Ware, 2004)   |                                                   |                                                                                                |
| Reification                | (Whyte et al., 2007)                             | Tendency to consider an abstract concept as concrete, for example, attributing properties of a material object to that concept. |
| Wrong salience             | (Al-Kassab et al., 2014; Few, 2006; Green &      | The user concentrates on the wrong issue, for example, on the tool or on the visual appearance, instead of on the task. |
| Petre, 1996; Mengis, 2007; |                                                   |                                                                                                |
| Ware, 2004)                |                                                   |                                                                                                |
| **Emotional: Encoding**    |                                                   |                                                                                                |
| Disturbing                 | (Cawthon & Vande Moere, 2007; Tufte, 1990)        | Some images may cause emotional harm to the viewer because of their shocking or repellent content. |
| Boring                     | (Cawthon & Vande Moere, 2007)                     | Some graphic representations are perceived as uninteresting and do not help to focus attention for an appropriate amount of time. |
| Ugly/unappealing           | (Cawthon & Vande Moere, 2007)                     | Some graphic representations may reduce the motivation to explore them in spite of their informative content due to a sub-optimal, non-aesthetic form. |
| Wrong use of color         | (Few, 2006; Tufte, 1986; Wainer, 1984; Ware,     | The inadequate use of colors or their combinations may make an image confusing or unappealing. |
|                            | 2004)                                            |                                                                                                |
| **Emotional: Decoding**    |                                                   |                                                                                                |
| Visual stress              | (Ware, 2004)                                     | Some kind of patterns (striped or flickering) may cause illness in the viewer.                   |
| Personal likes and         | (Tversky, 2005)                                  | Some visualizations may get more attention than others, not because of their importance, but because they fit the cognitive preferences of a particular viewer. |
| dislikes                   |                                                   |                                                                                                |
| Prior knowledge and        | (Al-Kassab et al., 2014; Avgerinou & Pettersson,  | Previous domain knowledge on how to interpret the content and positive or negative experience with a specific visualization influences the willingness of people to use it. |
| experience                 | 2011; Chen, 2005; Dwyer, 1972)                   |                                                                                                |

(continued)
Table 2. (continued)

| Disadvantage | Author(s) | Description |
|--------------|-----------|-------------|
| **Social: Encoding** | | |
| Affordance conflict | (Nicolini, 2007) | A visualization may signal the wrong kind of required (inter-)activity to its viewers. |
| Hierarchy, exercise of power | (Ewenstein & Whyte, 2007; Henderson, 1995; Nicolini, 2007; Whyte et al., 2007) | The political use of images in collaborative settings by certain people may result in unequal possibilities to contribute (e.g., through manipulative use of visualization provisionality, facilitator choice, sequence of contributions, etc.). |
| Inhibit conversation | (Nicolini, 2007; Oliver, 2007) | Having one’s contributions visualized (for example, in a group context) may lead to participants being less outspoken about certain issues. |
| Rhythm of freezing and unfreezing | (Whyte et al., 2007) | A visualization may make a certain viewpoint or idea too rigorous and too fixed, thus not leaving adequate conditions to invent alternative views or options. |
| Turn taking alteration | (Eppler, 2004) | Using a graphic representation to guide a team conversation can affect the natural turn taking within a group in favor of those who can directly change that visualization. |
| Unequal participation | (Mengis, 2007) | The use of visualizations in group contexts may lead to unequal participation on behalf of the participants. |
| **Social: Decoding** | | |
| Altered behavior | (Eppler et al., 2006; Mengis, 2007; Nicolini, 2007) | The use of visuals in group interaction may affect the typical behavior of the user. |
| Cultural and cross-cultural differences | (Al-Kassab et al., 2014; Averinou & Pettersson, 2011; Bresciani, 2014; Ewenstein & Whyte, 2007; Forsythe, 2011; Henderson, 1995; Nisbett, 2003; Segall, Campbell, & Herskovits, 1966; Ware, 2004) | The meaning of symbols and colors is not universal, and hence, some graphic representations may be misinterpreted in other cultural contexts. |
| Defocused from non-verbal interaction | (DeSanctis & Gallupe, 1987) | A group’s focus on a central visualization on a board or screen can take away the participants’ attention from their body language and gestures, which give important information on how to interpret verbal contributions. |
| Different perspectives | (Heer & Agrawala, 2008) | Different people look at issues from different points of view (e.g., people from different organizational levels). |
| Hiding differences of opinion | (Eppler et al., 2006) | The use of one visualization in a group context may hide individual differences of opinion because of the need to find one common representation. |
| Recency effect | (Nisbett, 2003; Tufte, 1986) | The meaning of a visualization is not interpreted in a vacuum but as part of a broader context that depends on user’s previous exposure. |
| Time-consuming to agree upon | (DeSanctis & Gallupe, 1987) | Group discussion based on visualization requires more time than verbal discussion. |

classification purposes, as it is often impossible to determine whether a designer or author has made a genuine mistake, or whether he or she intended to mislead.

Considering the second criterion of the classification, the effect of visualization drawbacks, we adopt the threefold distinction of cognitive, emotional, and social effects (Buergi & Roos, 2003; Kernbach, Bresciani, & Eppler, 2015; Roos et al., 2004). Similar categorizations include Norman’s classification of the design field (Norman, 2004): He distinguishes the visceral level (corresponding to emotions), the behavioral level (corresponding to usability), and the reflective level (regarding the meaning of things, or the self-image). This classification is also consistent with social interdependency theory, developed in the educational context, which distinguishes cognitive, behavioral, and social dimensions (Johnson & Johnson, 2005). Our proposed classification includes the often neglected “social” effects of visualization following the emerging trend on collaborative information visualization (Bresciani, Blackwell, & Eppler, 2008; Keel, 2007) in which visuals are considered supports for collaborative sense-making and understanding. Along the same line of thought, Heer and Agrawala (2008) state that
although most research to date assumes a single-user focus on perceptual and cognitive processes, in practice, sensemaking is often a social process involving parallelization of effort, discussion, and consensus building. Thus, to fully support sensemaking, interactive visualization should also support social interaction. (p. 49)

We can observe that in Table 1, the list of cognitive disadvantages is the most extensive section. Most of the studies have focused on the cognitive effects of visualization, neglecting its social or emotional consequences. In the context of visualizing organizational strategy, Roos et al. (2004) also confirmed this impression: “While social and emotional modes of experience are involved in strategy process, in general they are suppressed in favour of cognitive elements” (p. 551). The emotional category is referring to the most visceral impact of visualization on the user’s feelings, whereas the social category includes disadvantages caused by the collaborative use of visualizations.

The categorization presented has implications for practice, as it can support visualization users and producers to prevent, reduce, or eliminate visualization threats. In this sense, it can be used as a negative checklist. Designers as well as researchers are supported by having a comprehensive view of the most common cognitive problems as well as the often overlooked social and emotional issues that may exist when using graphic representations of information. Visualization users can utilize the table as an instrument to control or reflect on their own potential biases as well as a designer’s quality of work.

We do not claim that all the elements identified in the table are always problematic. There may be instances where one or several of the listed issues are productively used on purpose. Visual ambiguity, for example, may lead to the creative re-interpretation of a graphic representation and thus lead to new insights (Eppler et al., 2008). Another example of a visualization risk that may provide a benefit is the shocking or disturbing effect of a graphic or an emotionally exaggerated visualization that, as a benefit, would be remembered for a long time (e.g., Figure 3). Furthermore, a high level of complexity should not be considered negative in absolute sense; rather, it depends on the familiarity and training of the target audience. Table 2 provides a brief description of each of the visualization pitfalls, based on the literature.

In the next section, we provide examples of the application of the classification for the evaluation of visualizations.

Examples

The aforementioned classification can be used as a reference point for evaluating and improving visualizations. To simplify this task for practitioners, the classified list of pitfalls is provided also in the pragmatic format of “Questions to Ask” in the appendix, which can be used as a checklist by visualization producers and users.

It is worth noticing that we do not expect to find issues with all the characteristics listed in the classification when looking at specific examples, but rather only with a few of them for each analyzed image. We will provide two examples of visual representations that present problems, and we will analyze the first from the point of view of the designer (an encoding problem), and the second from the point of view of the user (a decoding problem), following the cause-related criteria proposed in the classification.

We start by analyzing Figure 1, reported and discussed by Wainer (1984) and representing U.S. imports and exports, taking the point of view of a designer who receives the task of reviewing and improving the visual. We conduct an analytical evaluation of visualization problems based on the classification (with each identified disadvantage reported within quotes), and we use the evaluation as a guideline to describe the solutions to counteract the negative effects.

For this task, we need to consider the “encoding” section of the classification, as we want to identify issues induced by the designer (the left column of Table 1). The classification can simply be used by considering the list of pitfalls, one by one, against the visual representation to be analyzed. In the proposed example (Figure 1), we find issues with “breaking conventions” (which is the second listed issue in the classification, as we want to identify issues induced by the designer) and the second from the point of view of the user (a decoding problem), following the cause-related criteria proposed in the classification.

Continuing with comparing the list of negatives with the image, we see that there is “inconsistency” (Cawthon & Vande Moere, 2007; Tufte, 1986): In fact, the colors indicating the imports and exports are inconsistent between the right-hand side and left-hand side graph. In particular, in the graph about China trades, the imports are depicted in black and the exports in white, whereas in the graph on Taiwan trades (on the right-hand side), the meaning of the color is reversed. Next, we find a problem with “misleading/distorting” information (Tufte, 1986; van Vijk, 2006; Wainer, 1984).
because the colors used to represent trade to and from the United States are inverted within the same graph without any reason, thus misleading the reader. Proceeding with the list, we can identify a “redundancy” (Few, 2006; Tufte, 1986) in the visual representation, as the data refer to the same quantities (time and millions of dollars): Higher efficiency could be achieved by depicting all the data on one single graph (to optimize the so-called “data-ink ratio” proposed by Tufte, 1986). In this specific image, we do not identify issues related to emotional or social effects.

Given the specific disadvantages of this visualization identified through the schema, we can propose solutions to improve it. As a first step, the axes should follow the convention of having the same scale on both graphs. Similarly, the import and exports should be depicted with consistent colors across the graphs. To facilitate the comparison of the information provided, we can avoid the redundancy of having two graphs and draw all the data on one single chart. An improved representation, based on the identified problems, is shown in Figure 2. We now have a completely different insight regarding the meaning of the data. First, we swiftly notice that there is greater trade exchange occurring with Taiwan than with China. Second, the dotted lines depict exports, whereas the continuous lines represent imports; we can see that the U.S. level of exports to China is greater than the imports. The reverse is true for Taiwan, from which the United States imports more than it exports. These visual insights were not available with the original version of the image. The classification has thus helped in systematically identifying issues with the visual representation, which can then be addressed and solved.

We now take the point of view of the user to explain the “decoding” section of the classification: We act as a common reader of a visual representation found in a magazine or on the Internet. We show how to read a visualization critically using the proposed classification to be aware of pitfalls induced by our reading of the image. As exemplary illustration, we consider Figure 3, which represents civilian war casualties of the 20th century by country (Understandingusa, 2007).

Although there might be issues with the visualization induced by the designer, in this paragraph, we focus on differences in interpretation caused by the viewer. To do so, we utilize the right-hand side column of the classification (Table 1), which refers to decoding issues, and consider the visualization pitfalls one by one. We do not identify issues with change blindness or channel thinking, whereas we do recognize that interpretation of this visual is based on “perceptual skills” (Nisbett, 2003; Tufte, 1986; van Vijk, 2006) and “prior knowledge and experience” (Avgerinou & Pettersson, 2011; Chen, 2005): Some participants interpret the concentric circles as an indication of the quantity of civilian casualties by country, assuming that the larger the circle is, the higher the number of deaths. However, if we read the image carefully, we can see that the opposite is the case: In the innermost circle (which is the smallest) are positioned countries that had more than 1,000,000 casualties, whereas in the outermost circle, we find countries that witnessed less than 5,000 deaths. This is the case because the visual is developed on the metaphor of the shooting target; thus, more points are scored when hitting the center. However, users not familiar with shooting sports might find it difficult to detect and understand the intended metaphor.

Second, we find an issue also with the emotional user-induced effect of “personal likes and dislikes” (Tversky, 2005). In fact, different people may react differently to this type of graphic representation depending on their gender and sensitivity: The target superimposed on the image of a family is a very strong choice.

Finally, the social user-induced issue of “cultural and cross-cultural differences” (Avgerinou & Pettersson, 2011; Bresciani, 2014; Ewenstein & Whyte, 2007; Forsythe, 2011; Henderson, 1995; Nisbett, 2005; Segall et al., 1966; Ware, 2004) plays a role in the interpretation of this visualization, as some cultures are less inclined to crude representations, whereas others regularly use shocking visualizations to attract the attention of readers (Chan et al., 2007).

Through the above examples, we aimed to show how the classification of visual representations pitfalls can be used to systematically analyze visual representations with regard to their potential drawbacks.

Discussion/Theoretical Implications

Motivated by van Vijk’s (2006) call to action to develop articles on the limitations and pitfalls of visualization for the advancement of the field, and by the acknowledgment by the academic community of the unprecedented rise in the use of visuals (Meyer et al., 2013), we have provided a classification of visualizations pitfalls. This contribution adds to theory by aggregating the currently scattered knowledge on the pitfalls of visual representation of information and can be valuable for researchers in a number of domains from visual literacy and graphic design to information visualization and management. In particular, this work connects the different domain of visualization around the central topic of visualization negative effects.
The errors made while creating or perceiving visualizations are not only aggregated and listed but also classified into cognitive, emotional, and social negative effects: This classification can thus act as a basis for the further systematic investigation of visualizations’ effects by providing a structure to guide work in visualization quality assessment.

It is also relevant to differentiate theoretically between mistakes induced by the designer and the reader: It seems particularly interesting to consider the mistakes in reading or decoding visuals made by users to understand the boundaries of visual representations’ effectiveness.

The classification can be useful also for scholars in a variety of related disciplines including marketing, advertising, film studies, photography, multimodal communication, and journalism, among others.

**Conclusion and Outlook**

In this article, we have aimed to provide a first classification of visualization pitfalls. We believe that an analytic and comprehensive compilation of visualization pitfalls is crucial, especially in the modern day context of the rising use of visualization by non-experts, and because of the emergent use of visualization in social media, the availability of new graphic technologies, and new ways of generating and sharing pictures. We have introduced a new classification of visualization problems that can be used by visualization producers (e.g., designers, analysts, software companies, statisticians, consultancy companies, researchers, etc.) and in education for increasing students’ visual literacy, for both the production and the critical interpretation of visualizations (Eppler, 2006).

The limitations of our work include the lack of scientific testing for its comprehensiveness and usability. The next step in this research is the testing of the schema, for instance, through field experiments, comparing the performances of designers and users in two conditions: participants who use and participants who do not use the classification. We foresee that the current form of the classification can be subject to ongoing revisions and additions. Furthermore, it would be

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**Figure 3.** Twentieth-century civilian war casualties by country. *Source:* © Understandingusa (2007).
theoretically and pragmatically relevant to rank the pitfalls according to how common or how severe they are. Scholars could survey a sample of images to determine the occurrence and severity of the pitfalls here identified. Many challenges remain regarding the appropriate level of granularity of the disadvantages, as well as how this can be taken into consideration without excessively increasing the complexity of the classification. Nevertheless, we believe that our categorization is a first step toward a comprehensive formalization of visualization risks, and that such work is needed to support the information design, information visualization, and visual communication community in developing valuable visualizations, and for the analytic assessment and measurement of visualization quality. As Edward Tufte (1986, 1990, 1997) has shown in his books, the world is filled with misleading, unattractive, and confusing visualizations of information. Strategies to avoid these pitfalls have not yet been comprehensively defined, and we hope that our first and provisional classification is an initial step toward a more complete and instructive analysis of the pitfalls of visualization.

Appendix

A Pragmatic Guide of Questions to Ask Regarding Visual Representation Pitfalls

| Encoding (Designer-induced) | Decoding (User-induced) |
|-----------------------------|-------------------------|
| Cognitive                   |                         |
| **Ambiguity:** Can the visual be mistakenly interpreted in different manners? Does it contain unlabeled arbitrary symbols? |
| **Breaking conventions:** Does the visual break established visual conventions (e.g., is time shown left to right)? |
| **Confusion:** Is the overall logic clear? |
| **Cost to make explicit:** Is it difficult/time-consuming for users to make explicit the meaning of the visual? |
| **Cryptic encoding:** Is the format used to represent information/knowledge universally understandable? |
| **Defocused:** Does the visual distract from the main message? |
| **Hiding/obscuring:** Does the visual format hide actual data (e.g., by changing a graph starting point)? |
| **Inconsistency:** Are symbols used consistently? For example, Arrows should indicate either time or causality, not both in the same graph. |
| **Low accuracy:** Does the visual present information in a less accurate manner compared with tables or numbers? |
| **Misleading/Distorting:** Does the visual format lead to wrong interpretations or conclusions? |
| **Not respected gestalt principles:** Are the Gestalt principles respected (see Koffka, 1922)? For example, is it clear which part of the visual is the background and which is the foreground? |
| **Over-determinism:** Does the visual specify more information than it should? For example, if the intending meaning is “a person,” is the visual unnecessarily specifying the gender or ethnicity? |
| **Over/under-reliability appearance:** Is the visual sketchy enough or polished enough for the intended purpose? For example, if the aim is to discuss an idea, is the visual appearing provisional enough to encourage feedback? |
| **Over-complexity:** Is the visual depicting elements in a more complex manner than necessary? |
| **Over-simplification:** does the visual leave out essential information (maybe to simplify the message)? |
| **Redundancy:** is the same information presented more than once in the same graph? For example, in a matrix are the X and Y axes displaying the same criterion? |
| **The viewer may not get the meaning of the image** |
| **Change blindness:** Look again at the picture paying attention to the details: Do you notice any important change in the pictures that you missed earlier? |
| **Channel thinking:** Does the visual channel or direct your thinking in an inappropriate direction? |
| **Depending on perceptual skills:** Are you seeing a picture differently from the average population due to your physical or cultural background? For example, if you are East Asians did you look primarily at the background? If you are a Westerner, did you look only at the central object? |
| **Difficult to understand:** Do you find the image to be hard to understand given your experience? |
| **Focus on low relevance items:** Are you focusing on the most relevant items of the image? |
| **High requirement on training and resources:** Do you have enough training or expertise to understand the image? |
| **Knowledge of visual conventions:** Are you familiar with visual conventions (e.g., how to read maps, or which is the expected reading pattern)? |
| **Misuse:** are you interpreting and utilizing the image for a task for which it was not intended? |
| **Overload:** based on your experience do you feel that the image has too many elements to be processed? |
| **Reification:** are you mistakenly attributing properties of a material object to a concept (e.g., when a visual metaphor or diagram is used)? Are you treating an abstraction as if it were a real thing because it is visualized? |
| **Wrong salience:** Are you concentrating on the message or are you being distracted by the tool or the visual appearance? |

(continued)
### Appendix (continued)

| Encoding (Designer-induced) | Decoding (User-induced) |
|-----------------------------|-------------------------|
| **Task-visualization fit**: is the visual appropriate for supporting the specific task? | **The viewer may suffer because of the image** |
| **Technology/template driven**: is the pre-defined template or schema suitable for the task or message? | **Visual stress**: Does the visual cause illness when viewing it because of its patterns? |
| **Time-consuming to produce**: Is it worth spending time visualizing the information? | **Personal likes and dislikes**: Is the visual in line with your preferences (in terms of colors, format, or design)? |
| **Unclear**: does the visual leave too much room for user’s interpretation of the message? | **Prior knowledge and experience**: Does your previous positive or experience with a visual influence the willingness to use it? |
| **Unevenness**: Does the visual format constrain thought more than necessary? For example, if a visual metaphor is utilized, does it shape people thinking in a certain (unwanted) manner? | **Wrong use of color**: Are colors used in adequate combinations (see Duarte, 2008, chap. 7)? For example, are red and green not used in the same image to differentiate information (because they cannot be distinguished by people with color deficiencies)? Is the image color combination restricted enough not to create a childish rainbow effect? |

| Emotional | Social |
|-----------|--------|
| **The visualization may cause inappropriate feelings in the viewer** |
| **Disturbing**: Can the visual cause emotional harm to the viewer because of its shocking content? | **Affordance conflict**: Does the visual signal the wrong kind of expected action to the viewer? |
| **Boring**: Is the visual banal and thus not able to attract the attention of the viewer? | **Hierarchy, exercise of power**: Is the visualization used politically to disincentive certain people from contributing to the discussion (e.g., by making it too polished to invite contributions)? |
| **Ugly**: Does the lack of aesthetics of the image reduce the viewer’s motivation to explore it? | **Inhibit conversation**: When the visual is used, are participants less outspoken (e.g., because their contribution will be visualized publicly)? |
| **Wrong use of color**: Are colors used in adequate combinations (see Duarte, 2008, chap. 7)? For example, are red and green not used in the same image to differentiate information (because they cannot be distinguished by people with color deficiencies)? Is the image color combination restricted enough not to create a childish rainbow effect? | **Rhythm of freezing and unfreezing**: Does the format or appearance of the visualization make it appear too fixed (or too provisional) for the specific task at hand? |
| **Turn taking alteration**: When a visual is used to guide a group conversation, does the visual affect the natural turn taking group behavior? | **Unequal participation**: When using a visual in a group, are you focusing too much of your attention on the visual at the expenses of participants’ body language and gestures? |
| **Unequal participation**: When using a visual to facilitate a conversation, do certain participants participate more in the conversation (e.g., because they are more skilled in modifying the visual)? | **Different perspectives**: Are all people looking at the picture in the same manner (e.g., focusing on the same aspects, based on their organizational level or job)? |
| **Recency effect**: Is your interpretation of the visual biased by your recent experience? | **Hiding differences of opinion**: When a visual is developed in a group context, are differences of opinion hidden for the need to find a common representation of the discussed topics? |
| **Time-consuming to agree**: When a visual is used in collaborative settings, is it taking more time to agree on the content, compared with a purely verbal discussion? | **Altered behavior**: Is the group interaction affected by the use of the visual to facilitate the conversation? |

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