Extending Tam to Information Visualization: A Framework for Evaluation

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Abstract: Studies on the evaluation of information visualization techniques are flourishing, and related methodologies have been discussed in a growing number of recent studies. Yet, these evaluations concentrate mostly on usability measures and cognitive evaluations. In contrast, this contribution focuses on the various factors that drive the adoption of information visualization techniques. The Technology Acceptance Model and the Diffusion of Innovations theory are deployed to develop a framework for evaluating information visualization adoption. These seminal theories are extended and adapted to Information Visualization, resulting into a framework with three main dimensions: perceived ease of use, perceived usefulness, and perceived authority. The application of this theoretically-based evaluation framework is illustrated through positive and negative examples. As many visualization solutions have not achieved a wide use, the question of which factors foster their adoption seems to be a particularly relevant yet under-researched topic.

Keywords: Information Visualization, Technology Acceptance Model, Diffusion of Innovations, evaluation, adoption

1 Introduction

Information visualization is increasingly used in organizations (Tegarten, 1999) and a considerable body of literature analyzes the efficacy of visual representations of data, mainly in terms of time spent completing a task, number of errors, or pattern recognition. Yet, few researchers have examined the reasons for the adoption of certain information visualization solutions, while disregarding others. This article aims to extend Information Systems theories to explore the evaluation and adoption of information visualization. The aim is to provide a set of factors which should be taken into consideration when developing, assessing or improving information visualization solutions, in order to ensure a wide-spread adoption of such visuals. The theoretical bases of the proposed dimensions are to be found in Davis' Technology Acceptance Model (Davis, 1989), and Rogers' Diffusion of Innovations theory (Rogers, 2003), which was later adapted to the Information Systems field by Moore and Benbasat (1991; 1996). These well-known and widely applied theories can contribute to the advancement of understanding of information visualization by including adoption criteria into the evaluation. It is argued that not only the "usefulness" of visualizations applications is relevant: the fact that the cognitive aspects are only one of a number of factors affecting usage and adoption of visualizations is explored.

Several suboptimal visualization formats or systems have become widespread, not because of their superior performances in terms of time to completion and reduced errors, but because of social factors. A prominent example is PowerPoint, which is often re-appropriated and used for a variety of tasks such as facilitating meetings, or pie charts which are used to represent large quantities of data (often not even totaling 100 percent). The evaluation of information visualization techniques should thus also include *social* factors, such as the endorsers, promotional effort, and networking effect. In the next Section a review of the literature is provided, covering the evaluation of information visualization, the Technology Acceptance Model and of the Diffusion of Innovations theory. In Section 3 an evaluation framework of the adoption of information visualization is proposed, with 3 dimensions composed of 18 factors. Section 4 continues with illustrative examples of both successful and suboptimal information visualizations, explained through the proposed criteria. In Section 5 the implications for theory and practice are outlined, followed by limitations and conclusions.

2 Literature Review

2.1 Evaluation of Information Visualization

"The term information visualization refers to computer-generated interactive graphical representations of information." (Chen, 2010: 387). Several researchers have shown that visual representations can provide

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considerable advantages by effectively supporting reasoning processes better than textual or verbal information (Larkin and Simon, 1987) and for reducing diverse communication problems (Tversky, 2005): business applications include for instance the modeling of risk in IT projects (Al-Shehab, Hughes and Winstanley, 2005) or crime analysis through geographical predictive models (Ferreira, João and Martins, 2012). The field of Information Visualization has enjoyed a rapid growth in the last decades. In the early days of information visualization evaluation, the assessments mainly focused on time to task completion and number of errors. Starting in 2000 with a special issue on the empirical evaluation of information visualization (Chen and Czerwinski, 2000) the discourse on evaluation has become more structured and the measures more refined. Shortly after Plaisant (2004) put forward a broad discussion on the challenges of information visualization evaluation, with a call to action to investigate adoption and to study visualizations in real settings. In particular, she suggested a number of innovative measures, which included, for instance, satisfaction, learnability, and usage recording. A considerable force for the advancement of information visualization evaluation methods was given by the BELIV workshop series (Beyond Time and Errors - Novel Evaluation Methods for Visualization) (Shneiderman and Plaisant, 2006; Bertini, Plaisant and Santucci, 2007; Bertini, Perer, Plaisant and Santucci, 2008; Andrews, 2008), which was started in 2006, and subsequently held biannually. It stimulated a significant increase in attention on visualization evaluation. Beyond time and error, researchers proposed innovative measures and methods, such as multi-dimensional, in-depth, long-term case studies (Shneiderman and Plaisant, 2006) or the consideration of social and emotional factors surrounding the context of use (i.e., engagement, social interaction and playfulness of visualizations (Herr, 2006).

In 2008, two insightful reviews of evaluation methods were published: Andrews (2008) provided a schematic aggregation of nine common methods specifically used in information visualization, and Carpendale (2008) offered a comprehensive discussion of qualitative and quantitative evaluation methods. Subsequently, the specific topic of information visualization evaluation in large companies was addressed (Sedlmair, Isenberg, Baur and Butz, 2011); the authors used a wide-ranging set of methodologies, differentiated by phase (pre-design studies, design phase, post-design). They described a set of challenges and recommendations for conducting field work. An innovative methodological article was published in 2011 (North, Saraiya and Duca, 2011) which rigorously compares two information visualization evaluation methods: the benchmark tasks method and the insight method, through a 2x3 experiment (with the 2 methods and 3 graph visualization alternatives). Finally, in 2012 the results of a massive and systematic review of over 800 papers on information visualization evaluation have been reported (Lam, Bertini, Isenberg, Plaisant and Carpendale, 2012). The authors categorized each of the reviewed studies into the seven most commonly used scenarios, and provided details – including typical methodologies – for each scenario. The authors state that most articles written on the subject of evaluation provide only a list of methods. In contrast, the contribution of this article aims to provide a synthetic and theoretically-based structure for the comprehensive evaluation of information visualization, which is based on widely-used and often cited theories. In the following section a review of these theories is offered.

2.2 The Technology Acceptance Model and the Diffusion of Innovations Theory

In the field of Information Systems, Davis' Technology Acceptance Model (TAM) has been widely applied, validated and cited (Rogers 2003, Taylor and Todd, 1995; Venkatesh, 2000; Venkatesh and Davis, 2000; Venkatesh, Morris, Davis and Davis, 2003; Lee and Wan, 2010). It is reported that "TAM studies occupy 10% of total (leading IS journals) publications." (Lee, Kozar, and Larsen, 2003: 764).

Similarly, Roger's Diffusion of Innovations Theory has received great attention and replication (Moore and Benbasat, 1991; Moore and Benbasat, 1996). These two theoretical perspectives can also be beneficial when applied to the evaluation of information visualization. These theories can support researchers and practitioners in understanding the adoption of visual formats. Nevertheless, to our knowledge, these two useful and seminal theories have seldom been applied to the study of visualization.

2.2.1 The Technology Acceptance Model

Starting from the observation that "scales for predicting user acceptance of computers are in short supply", Davis (Davis,1989) analyzed the factors influencing technology acceptance, and identified two main drivers: "perceived usefulness" and "perceived ease of use". He developed scales for these factors and tested his model, subsequently proving that perceived usefulness and perceived ease of use have a positive impact on users' acceptance of information technology.

In particular, the "Perceived Usefulness" scale is measured using the following criteria: (1) work more quickly, (2) improve job performance, (3) increase productivity, (4) enhance effectiveness, (5) makes it easier to do my job, and (6) useful. The "Perceived Ease of Use" scale is composed of: (1) easy to learn, (2) controllable, (3) interaction is clear and understandable, (4) flexible to interact with, (5) easy to become skillful, and (6) easy to use. The results of his study, published on MIS Quarterly, enjoyed a large coverage in diverse fields, and, at present, has nearly 15.000 citations.

2.2.2 The Diffusion of Innovations theory

A second related theoretical perspective which can contribute to the assessment of information visualization is Rogers' Diffusion of Innovations theory (2003). Rogers' book "Diffusion of Innovations" has received over 45.000 citations to date. His theory aims to explain how new ideas/technologies spread. He observed that an innovation should be widely adopted in order to be sustainable: it should reach a so-called *critical mass*. Based on this thought, he categorized users of a particular innovative idea/technology, as "innovators, early adopters, early majority, late majority, and laggards" (Rogers, 2003). Rogers also classified "attributes of innovation", namely: rate of adoption, relative advantage, compatibility, complexity, trialability and observability.

Rogers's valuable contribution was to identify and take into account the social component in the adoption of technologies and ideas, in addition to the cognitive aspects of that adoption. The large majority of theories related to technology and usability focus on the tool, the interface or the cognitive aspects of the interaction. Rogers has also considered an aspect which we could call the "networking effect". An application of the theory to the Information System domain has been proposed by Moore and Benbasat, (Moore and Benbasat, 1991) who developed "an instrument to measure the perceptions of adopting an information technology innovation".

2.2.3 TAM, Diffusion of Innovations Theory and Information Visualization

Davis' Technology Acceptance Model and Rogers' Diffusion of Innovations theory can both be seen as valuable and complementary theoretical perspectives in explaining the adoption of different information visualization formats. The complementary nature of the two theories has already been noted: Venkatesh and colleagues have aggregated and discussed prominent models of user acceptance, and have proposed a unified model, called the "Unified Theory of Acceptance and Use of Technology" (Venkatesh et al., 2003). Their study found that the unified model outperformed the individual models, thus offering a more comprehensive perspective. Their resulting model is comprised of: (1) "performance expectancy" (related to Davis' "Perceived Usefulness") (Davis,1989) (2) "effort expectancy" (related to Davis' "Perceived Ease of Use" (Davis,1989) and Moore and Benbasat's "Ease of Use" (Moore and Benbasat,1991)) which was in turn based on Rogers' "Complexity" (Rogers, 2003) and (3) "social influence" (based on Moore and Benbasat's "Image" (1991) Venkatesh and Davis (TAM 2) "Subjective norms" (2000) and Thompson et al. "Social factors" (Thompson, Higgins and Howell,1991)). As these theoretical perspectives have not yet been applied in the information visualization field, the next Section offers an adaptation of the aforementioned theories with regards to the specific field of information visualization.

3 Key factors fostering information visualization adoption

By using the theoretical foundation of the aforementioned seminal theories, we can articulate a combined framework adapted to the field of information visualization.

The factors that have emerged from the literature can be classified into three main dimensions: (1) Perceived Ease of Use, (2) Perceived Usefulness and (3) Perceived Authority. The first two categories correspond to Davis' Technology Acceptance Model (Thompson, Higgins and Howell,1989). His model stipulates that perceived usefulness and perceived ease of use are the fundamental determinants of user acceptance. His strong and consistent findings in technology acceptance can be applied to the specific area of information visualization. However, based on the insights of Roger's theory of Innovation Diffusion (with its emphasis on communication), and on the subsequent work of Moore and Benbasat (1991), and of Venkatesh and colleagues (Venkatesh, Morris, Davis and Davis, 2003), it is important to incorporate a third category, namely, Perceived Authority. Perceived Authority represents the degree to which a person is confident that using a particular information visualization technique is a good choice. This dimension takes into account the social elements involved in human decision making when adopting a particular visualization type. It includes the following soft factors: “Image” (Venkatesh et al., 2003; Moore and Benbasat,1991), “Network Effect” (Venkatesh et al., 2003; Thompson et al.,1991), “Subjective Norms” (Venkatesh et al., 2003; Lee and Wan, 2010), “Branding” (i.e., the self-explanatory value of the name and the associated promotional activities) (Kapferer, 2004), “Observability” (Rogers, 2003) and “Aesthetics” (Herr, 2006).

The three dimensions of Perceived Ease of Use, Perceived Usefulness and Perceived Authority play a complementary role in the adoption process of visualizations and all must coexist to allow for the widespread adoption of a specific format. This implies that even if an information visualization technique is deemed useful, but its usability is low and it is not supported by any promotion or branding effort, then it is unlikely that it will achieve a substantial diffusion. An example is 3D virtual worlds, a type of visualization which has been hyped for a long time, but has not achieved mass adoption, perhaps due to the intrinsic difficulties in manipulating and understanding 3D space (Shneiderman, Dunne, Sharma and Wang, 2011) or to the lack of usefulness.

Finally, innovation principles apply to visualizations as well: an information visualization format could be useful and usable, but if there is no proper communication of its benefits or no authoritative endorsers (in terms of people, brands or software packages) (Plaisant, 2004), it is very unlikely that the technique can achieve widespread use. A positive example of this networking effect can be seen in the adoption of mind mapping. Mind maps were first made popular by the bestselling books of Tony Buzan which had great mass appeal (Buzan, 1996). Buzan thus became a public authority on creativity and note taking which in turn facilitated the adoption of mind mapping in organizations. A negative example is the common use (and perhaps overuse) of pie charts. Although a suboptimal visualization method for most dataset types (Reynolds, 2011), they became widespread because they are intuitive and have been a default or prominent option (listed at the top of the menu) in most software packages (i.e., M.S. Excel), and are often displayed in magazines and popular press.

The debate on usability and utility is not completely new to the information visualization community (Grinstein, Kobsa, Plaisant, Shneiderman and Stasko, 2003). Shneiderman and colleagues have addressed the topic of information visualizations innovation – including social and networking elements such as trade press articles, patents and academic papers (Shneiderman et al., 2011). Yet, a holistic framework considering usability, utility, and social aspects of information visualizations is missing. The discernments gained from the major theories reviewed above are integrated with evaluation measures specific to the information visualization domain. In order to be usable for evaluation studies, the three dimensions are broken down into measurable key factors specific to information visualization.

The resulting classification is provided in Table 1. The factors emerged from the literature reviewed above are reported in bold characters. Below each factor a definition specific to information visualization is proposed with references. The concepts of Perceived Ease of Use and Perceived Usefulness (Thompson et al., 1989) are retained as in the original work by Davis, and adapted to information visualization applications. In particular, the aspect of “insight” is integrated into the dimension of Perceived Usefulness as the main purpose of information visualization is to provide insight and new understanding (Chen and Czerwinski, 2000; Cawthon and Vande, 2007; Plaisant, Fekete and Grinstein, 2008; Carpendale, 2008; North et al., 2011).

The third dimension of Perceived Authority integrates social and emotional elements derived from Roger’s theory and the follow up extensions or adaptations of his theory by Venkatesh and colleagues (Venkatesh, Morris, Davis and Davis, 2003), and by Moore and Benbasat (1996). More in detail, the factor of “subjective norms” is derived from TAM2, an extended version of the original Technology Acceptance Model (TAM) (Venkatesh and Davis, 2000; Lee and Wan, 2010) and is defined as: “Important people think that the information visualization should be used.”

Recent developments in social media make it necessary to consider the viral effect of social networks to spread information and drive the adoption of new ideas, including information visualizations. This factor – named “Network Effect”- is an extension of the concept of “Social Factors” identified in the Unified Model (Venkatesh et al., 2003; Thompson et al., 1991). The factor of “Image” is derived from the work of Venkatesh and colleagues (Venkatesh, 2000; Morris, Davis and Davis, 2003), which was based on Moore and Benbasat (Lee and Wan, 2010) and is defined as: “The use of the information visualization is perceived to enhance one’s image or status”. “Observability” is a factor directly derived from Roger’s theory and is defined as: “The information visualization is visible to others” (Rogers, 2003). Furthermore, theoretical perspectives on innovation and adoption have rarely considered the aesthetic and emotional value of specific innovations, with few exceptions including Venkatesh's consideration of emotion, playfulness and enjoinment (Venkatesh, 2000; Lee et al., 2003). The information visualization field, due to its visual nature, has a greater need to consider aesthetics (van Vijk, 2006; Tufte, 2006; Cawthon and Vande Moere, 2007) compared to other technological realms.

Several studies show the so-called "halo effect": an aesthetically pleasant or more emotionally appealing object or interface is considered as more valuable and usable (Norman, 2002). Therefore, a factor named "Aesthetics" is introduced, and defined as: "The visualization is fun and a pleasure to the eye". A notable example is Apple's design of products and interfaces. Apple, considered a master in innovation, is also putting a strong emphasis on branding, an aspect seldom considered in information visualization or in the innovation literature, and yet is crucial for the communication and recognition of any new product or technology (Kapferer, 2004). Shneiderman and colleagues (Shneiderman et al., 2011) have proposed an approach which "offers the information visualization community a history of how certain ideas evolved, influenced others and were adopted for widespread use". This includes tracking academic publications, patents and trade press articles. These communication activities are relevant to inform and convince the academic and practitioners' world about the novelty of information visualization. As communication and promotion are fundamental for reaching users and opinion leaders, the factor of "Branding" is included. For the context of information visualization innovations, we define branding as: "The visualization has a distinctive name and is actively promoted with academic papers, press, conferences presentation, and through prominent endorsers, or it is embedded into existing software packages" (Plaisant, 2004; Kapferer, 2004).

The three dimensions and relative factors can be used for the assessment of information visualizations. Each factor is a question to be evaluated. Designers and researchers can use the framework as a checklist to assist in performing heuristic evaluations. Action guidelines can be derived from the framework to make the adoption of a visualization more likely and to identify which factors and dimensions of a visualization still need to be improved.

4 Illustrative Examples

In order to show how the framework can be used, four examples are provided: two positive cases contrast two suboptimal ones. The examples are not offered with the aim to prove the validity of the dimensions, but rather to illustrate their potential application for the evaluation of information visualizations' adoption factors. The assessments provided in the examples below are based on the current body of literature and on the authors' expertise in the visualization field (see Table 2 for a synthetic overview).

4.1 Treemap

A Treemap (Figure 1) is an information visualization technique which displays hierarchical data as a set of nested rectangles. It displays tree-structured data by representing each branch of the tree with a rectangle. Each rectangle is composed of smaller rectangles representing sub-branches (or sub-categories of the hierarchy). Their area is proportional to a dimension of the data, and color can be used to display an additional dimension, such as a category. The technique makes very efficient use of space, compared to traditional hierarchical data visualizations, completely filling-in the page without any empty space. Thus it can display thousands of data points simultaneously in a single screen or page, offering a meaningful overview. Through the use of position, size, and color to display different dimensions, it makes it easy to spot patterns and correlations which might be difficult to detect with other hierarchical data information visualization formats. This technique was developed by Professor Ben Shneiderman in 1992. Shortly after Van Wijk created an algorithm which makes rectangles closer to squares, as opposed to columns, as in the original version. This version of Treemap has been popularized by SmartMoney, depicting a "Map of the Market" by using a Treemap to visualize the entire U.S. stock market (see an example in Figure 1). In 2004 the Newsmap was created by Marcos Weskamp, which uses a Treemap structure to display news headlines and thus brought Treemaps to a non-specialized audience. Since then, the Treemap technique has been used by a variety of companies, including Microsoft Research, IBM (, Spotfire (TIBCO), it is often used by the New York Times for its renowned graphs, and it is now embedded into Google Chart Tools and Google Docs, among others. For an extended review of the history of Treemaps and comparison to similar visual techniques, see (Shneiderman, 2009).

Table 1: Key factors influencing information visualization adoption

1. Perceived Ease of Use (adapted from TAM)	**2. Perceived Usefulness (adapted from TAM)**	**3. Perceived Authority**
1.1 Easy to learn It is easy to start interacting effectively with the visualization format (Davis,1989; Rogers, 2003; van Vijk, 2006)	**2.1 Work more quickly** The visualization helps to focus on relevant aspects and speeds up the analysis process (Davis, 1989; Rogers; van Vijk, 2006)	**3.1 Subjective norms** Important people think that the information visualization should be used (Venkatesh and Davis, 2000; Venkatesh et al., 2003; Lee and Wan, 2010)
1.2 Controllable The visualization can be interacted with and parameters can be easily changed (Davis, 1989)	**2.2 Job performance** The visualization helps augment reasoning and coordination processes (Davis, 1989; Rogers, 2003)	**3.2 Network effects** The peer use of the system increases its positive perception regarding reliability and usefulness. Innovators start to use the system, setting the trend and creating useful macros/ guidelines for the community (Rogers, 2003; Plaisant, 2004; Herr, 2006; Venkatesh et al., 2003; Thompson et al., 1991; Wattenberg, 2005)
1.3 Clear and understandable Previous knowledge is not required for using the visualization (Davis,1989; Plaisant, 2004)	**2.3 Increased productivity** The visualization allows working better and faster (Davis, 1989)	**3.3 Image** The use of the information visualization is perceived to enhance one's image, status or self-esteem (Venkatesh et al., 2003; Moore and Benbasat,1991; Gomez and Pather, 2012)
1.4 Flexible The visualization is easy to manipulate and to adapt to specific purposes (Davis, 1989; Norman, 2002)	**2.4 Effectiveness** With the information visualization tasks can be achieved promptly (Davis, 1989; van Vijk, 2006)	**3.4 Observability** The information visualization is visible to others (Rogers, 2003)
1.5 Easy to become skillful The information visualization can be used at its full potential swiftly (Davis, 1989)	**2.5 Makes job easier** The visualization simplifies achieving the main tasks (Davis, 1989; Rogers, 2003)	**3.5 Branding** The visualization has a distinctive name and is actively promoted through articles, conferences presentation, and through prominent endorsers, or it is embedded into existing software packages (Plaisant, 2004; Kapferer, 2004)
1.6 Easy to use /understand The visualization can be used with limited cognitive effort (Davis, 1989)	**2.6 Useful** The predefined form of the information visualization format type leads to the emergence of new insights (Chen and Czerwinski, 2000; van Vijk, 2006; Carpendale, 2008; Plaisant, et al., 2008; North et al., 2011; Reynolds, 2011)	**3.6 Aesthetics** The visualization is fun and a pleasure to the eye (Herr, 2006; Cawthon and Vande Moere, 2007; Tufte, 2006; Norman, 2002)

4.2 Tag clouds

"Tag clouds are visual presentations of a set of words, typically a set of 'tags' selected by some rationale, in which attributes of the text such as size, weight, or color are used to represent features of the associated terms" (Rivadeneira, Gruen, Muller and Millen, 2007). Tag clouds were brought to popularity by the photo sharing website Flickr (Figure 2) in 2002. The website embedded tag clouds in its pages to show the popularity of photo tags through font size. Soon after, del.icio.us and Technorati followed the trend, displaying tag clouds in their websites (Viégas and Wattenberg, 2008). The concept of the tag cloud was conceived long before by Stanley Milgram, a social psychologist who created a mental map of Paris in 1976. Font size was used to display how often a certain word was mentioned by people. In 2001 Fortune used an innovative sort of tag cloud static graph to display the relative importance of companies in each country, by varying font size (Wadley, Gibbs and Ducheneaut, 2009). With the Web 2.0 revolution tag clouds became ubiquitous, and tools for the creation of this visualization type abound. They are used not only to display tags, but also for the examination of text documents such as political speeches, technical reports, and books. Beyond these analytical tasks, tag clouds are increasingly used for marketing purposes, to offer at the same time an overview of the products and clues on their popularity. The website Wordle (www.wordle.net) had a prominent role in diffusing this visual technique. Created by Jonathan Feinberg in 2008, it gained popularity very quickly reaching 600,000 word clouds generated in the first nine months. It was also featured in the magazine WIRED (Viegas, Wattenberg and Feinberg, 2009). Wordle creates aesthetically pleasant layouts of words, unlike classic tag clouds which juxtapose different font sizes leaving irregular white spaces between lines. Additionally, this technique provides a number of visual parameters that can be changed, such as color, font type and size. Viégas, Wattenberg and Feinberg (2009) have investigated the sources of Wordle popularity and found that "emotional impact" was a key reason for choosing Wordle. Tag clouds are a relevant example to analyze because they are considered a sort of mystery in information visualization and design. They were developed outside academia, have questionable usability and the principles behind the visualization are often not understood by the users (Viegas et al., 2009). And yet, they have been widely adopted by the general public (Hearst and Rosner, 2008). This observation seems to point toward the consideration that usability or usefulness are indeed not the only drivers of adoption, and that other "social" factors should be taken into account, such as peers' opinion, endorsement by popular website or magazines, aesthetics (Seifert, Kump, Kienreich, Granitzer and Granitzer, 2008), and the free available tools online to create and share these visualizations.

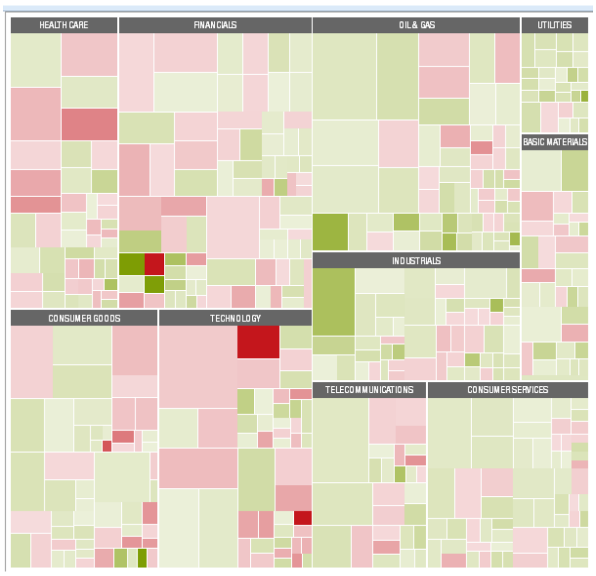

Figure 1. Positive example: Treemap used in Smartmoney to represent the U.S. stock market

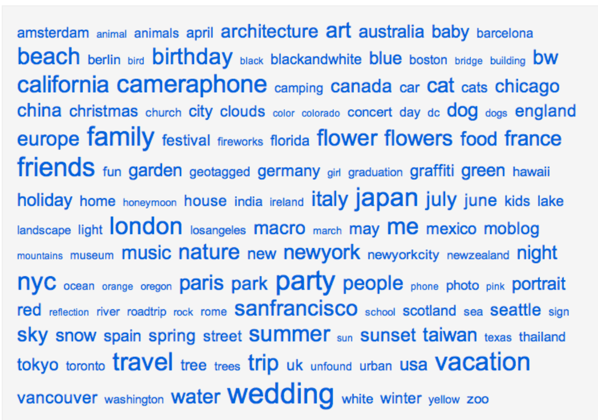

Figure 2. Positive example: a tag cloud used on the photo sharing website Flickr.

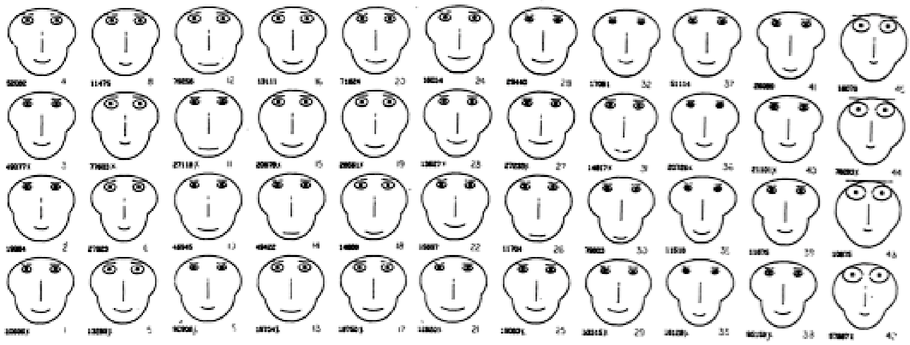

Figure 3. Suboptimal example: Chernoff faces used to represent points in k-dimensional space (Chernoff, 1973)

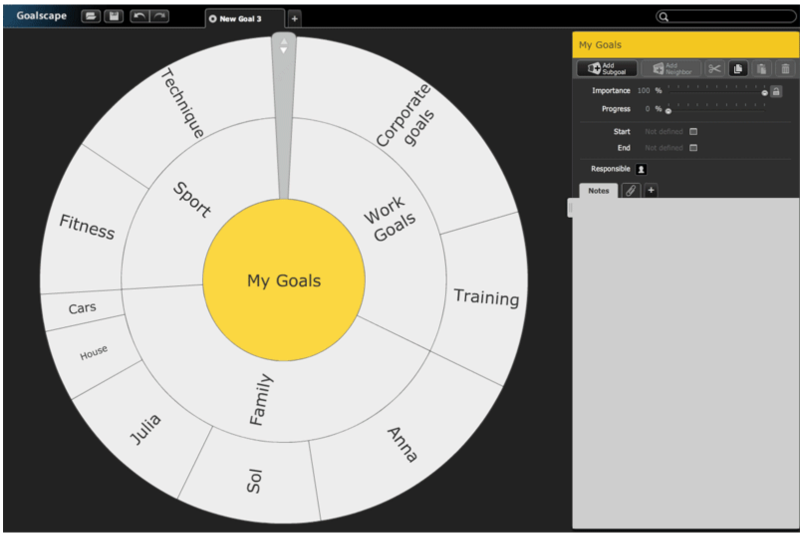

Figure 4. Suboptimal example: a SunBurst graphs in GoalScape (http://www.goalscape.com)

4.3 Chernoff faces

The third example aims at illustrating a negative case: an information visualization technique which did not reach extended adoption. The so called 'Chernoff faces graph' (Figure 3) was developed in 1972 to represent points in k-dimensional space by the mathematician and statistician Herman Chernoff, now Professor Emeritus of Applied Mathematics at MIT and Professor of Statistics at Harvard University. Variables are visualized through 18 facial features such as eyes, lips, nose, eyebrows, etc. Each part of a face represents a variable, and its value is expressed by changing the shape, size and position. This visual format is a type of glyph: "A glyph is composed of several visual attributes, each of which encodes the value of a particular variable that measures some aspect of an item" (Few, 2009). This technique is based on the assumption that the human brain can easily recognize faces and detect even small differences in facial expressions, thus faces could be used as a metaphor to represent multivariate data. In 1973 Chernoff illustrated his technique in an article titled "Using faces to represent points in k-dimensional space" (Chernoff, 1973). Since then, Chernoff's idea has received attention by academics, and a number of studies have been conducted (Morris, Ebert and Rheingans, 1999). Faces are fun to create and bloggers have re-appropriated the method in diverse ways. Yet, the technique has received several criticisms. First, the link between a variable and a specific facial feature is arbitrary, thus it requires cognitive effort to remember the association. Secondly, certain features of faces are perceived more prominently then others, for example eye size and eyebrow (Morris et al., 1999; Kosara, 2007). This implies that the mapping of variables on facial characteristics should not be random, but rather carefully chosen. Thirdly, the assumption that humans can recognize separate facial features does not seem based on evidence:

rather, faces seem to be interpreted in a more holistic way (Kosara, 2007). In particular, Ware points out that there are strong interactions between the different features, and that the variables' values are not perceived as linear (Ware, 2004). Finally, faces are just one of the many metaphors which can be used, and glyphs should be adapted to the meaning of the data, and not to arbitrary shapes and associations (Kosara, 2007).

4.4 SunBurst graphs in GoalScape

The forth example focuses on a visualization type which seems easy to use and useful, but has not (to the present day) reached wide scale adoption. GoalScape is an interactive "Visual goal management" software (available at: http://www.goalscape.com/). The inventors (and company founders) are a group comprised of Olympic level competitors, coaches and designers who aimed at developing "the world's only holistic goal management software" (see Figure 4 for an example). The interactive visualization – a specific use of the SunBurst visualization (Stasko and Zhang, 2000) – allows users to set their own goals, change the relative importance of each goal (by modifying the size), define sub-goals and track their progress. The interface works with a simple drag and drop mechanism. A 14-day trial of the software can be downloaded for free, after which a subscription (either for cloud or desktop use) is required. The tool aims at keeping the user focused on his/her own goals, and on monitoring their progress. It can be considered a valuable tool for project management when used to break down each goal into specific sub-goals, and to track the progresses for each respective sub-goal. Yet, this visualization does not enjoy the network effect allowed by social media, as the produced visualizations cannot easily be shared with the online community. Examples and case studies are provided by the company on their official blog, but there are no possibilities to comment or share information. GoalScape is officially present on major social networks, but promotional activities are limited, both in the academic and in the practitioners' world. It costs 120US$ and there are no academic papers discussing, presenting or evaluating the visualization.

4.5 Comparison between the four illustrative examples

The framework proposed for the evaluation of information visualizations can be used to assess the aforementioned visualizations. In the following table (Table 2) the information visualization techniques are schematically compared, according to the 18 previously defined factors. As these are illustrative examples, only an indication of the level reached is given, with the symbols "+", "0" and "–" indicating a high, low, or negative value, respectively.

Table 2. Schematic comparison of four visualization techniques according to the key adoption factors

	Treemap	**Tag cloud**	**Chernoff faces**	**GoalScape**
1. Perceived Ease of Use				
1.1 Easy to learn	0	+	-	+
Controllable	+	0	0	+
1.3 Clear and understandable	+	0	0	0
Flexible	+	0	+	0
1.5 Easy to become skillful	+	+	-	+
1.6 Easy to use /understand	+	+	-	+
2. Perceived Usefulness				
2.1 Work more quickly	+	0	-	+
2.2 Job performance	+	+	+	+
2.3 Increased productivity	+	0	0	0
2.4 Effectiveness	+	0	-	0
2.5 Makes job easier	+	+	0	+
2.6 Useful (insights)	+	+	0	+
3. Perceived Authority				
3.1 Subjective norms	+	+	-	0
3.2 Network effects	+	+	0	-
3.3 Image	+	+	0	0
3.4 Observability	+	+	-	0
3.5 Branding	+	0	0	0
3.6 Aesthetics	+	0	0	0

From these examples, we can see that the first two visualization techniques are strong in most of the three factors of Perceived Ease of Use, Perceived Usefulness and Perceived Authority. The third example, the Chernoff faces graph, is rather weak in all three. The fourth example is particularly weak in the Perceived Authority dimension.

Chernoff glyphs score low on Perceived Ease of Use because the association between variables and facial features is arbitrary, non-natural, and thus requires extensive cognitive effort. Concerning the Chernoff glyphs' Perceived Usefulness, they allow the visualization of up to 18 variables and compare them in a limited space. However, extensive time is needed for decoding and processing this large amount of information. Perceived Authority is rather low, since domain experts often criticize this technique.

The Treemap is perceived as easy to use, as the metaphor is rather natural and it utilizes visualization principles (proximity, distribution, colors) appropriately. It is also perceived as useful as it synthesizes relevant information in a space-efficient manner. Finally, Perceived Authority is very high, given that Treemaps are endorsed by several professors, and market leaders in different industries from IT specialists to daily newspapers.

GoalScape provides an example of the relevance of social aspects of visualizations. However, with lack of branding effort and network effect, the visualization technique has not yet enjoyed a widespread adoption, in spite of its relative perceived usefulness and ease of use.

Tag clouds offer a relevant case for explaining the relevance of the framework. Academic evaluations seem to show that users have worse performances when using tag clouds for searching, compared to classic alphabetical lists (Viégas and Wattenberg, 2008). Secondly, font size is difficult to compare. While researchers are thus perplexed by the rapid and pervasive diffusion of tag clouds, the proposed framework can support the understanding of the phenomenon. First, the measures of Perceived Usefulness depend on the task. Researchers typically measure time spent to find a specific tag (in general, time to task completion) or recognition. However other studies recognized that people like tag clouds for very different reasons, which include the fact that a website with tag clouds is perceived as social and fun, or because tag clouds signal that the website has tagged content and thus helps to quickly form a general impression (Hearst and Rosner, 2008). This implies that a general list of measure for the evaluation of information visualization techniques cannot be provided; it has to be task specific. Secondly, effectiveness is just one of the several aspects which drive the adoption of innovative information visualization. The principle of tag clouds is simple to grasp, and the visualization is easy to create, thus providing high ease of use and a clear perceived benefit to users. In addition, the fact that word clouds have been used on trendy social media websites has created a positive 'networking effect'; having a tag cloud signals that the website is up to the latest trends, evokes feelings of social interaction, fun and interactivity. Thus, using a tag cloud enhances the image of those who deploy it.

5 Implications

The framework makes a contribution to theory by applying and adapting seminal IS theories to information visualization, which can provide a theoretically sound and practically relevant guide for a comprehensive evaluation of information visualization techniques. Davis' categories of Perceived Ease of Use and Perceived Usefulness have been extended to information visualization evaluation. In addition, the category of Perceived Authority has been adapted from Rogers to include a social and market perspective, which is relevant in supporting information visualization adoption.

The relevance of this contribution for practitioners is to be found in providing factors to be considered during the development and evaluation of new visualization applications. The framework offers a 360-degree view on the perception of visualizations by potential users. It invites developers and designers to consider collaborating with marketing and communication experts to bringing novel visuals to the market. The communicative and social aspects of visualization should not be considered an "add-on" option to be eventually included at the end of the innovation process, but rather as fundamental elements shaping the success and adoption of new information visualizations. This means that it is not enough to advertise an innovation on social networks (as in the fourth illustrative case of GoalScape); the social and emotional components should be integrated into the design of the information visualization technology to exploit the viral effect of online and offline communities.

The three factors of Perceived Usefulness, Perceived Ease of Use and Perceived Authority should be considered when developing, improving, or assessing information visualizations. In particular, each dimension is comprised of six visualization-specific factors that can be used for the heuristic evaluation of information visualization, or for discussing the visualization's advantages and problems.

Academics and practitioners can evaluate and compare information visualization by rating them according to the eighteen defined factors. The resulting assessment will provide indications of areas that can be improved to increase the adoption rate of the information visualization technique considered. A further learning point for engineers is that visualizations should not be judged only for their usefulness and usability, but that their *viral* potential should be examined by analyzing at the Perceived Authority as well.

6 Concluding remarks

This contribution aimed at extending TAM to information visualization for providing a comprehensive framework for the evaluation of factors that drive the adoption of information visualization techniques. The limitations of this research include the lack of empirical validation and the scope of the examples. The proposed dimensions are inherently broad and abstract (as in the original work of Rogers and Davis). Readers should be made aware that different tasks will require different specifications: the factors should be adapted to particular tasks, for instance designing for the general public (i.e., online) as opposed to domain experts, depending on the complexity of the tasks. For the sake of clarity, simple and popular visualizations have been selected as illustrative examples, yet the framework can also be used for assessing more complex tasks such as financial analysis or healthcare applications.

Future research could focus on translating the identified adoption factors into task-specific measures and guidelines for evaluators and developers of information visualization. In fact, information visualization techniques cannot be evaluated with a one-size-fits-all-approach. Diverse tasks require different measures (Lam et al., 2012). For instance, information visualization for e-commerce should measure sales or perceived service quality rather than time efficiency (Pather, Erwin and Remenyi, 2003; Plaisant, 2004) and applications in the context of development should consider also empowerment and social cohesion (Gomez and Pather, 2012).
In order to gain a complete assessment of a visualization technique, both objective and subjective measures should be employed, because users often do not recognize the true effect of visualizations. Another future research challenge is to validate the identified adoption factors. Possible methods to conduct such studies include experiments (e.g., testing for isolated effects, such as Perceived Authority on propensity to use), case studies, or longitudinal adoption studies in real organizational settings (Shneiderman and Plaisant, 2006).

Information visualization is a rapidly growing field with great potential, as demonstrated by numerous innovations over the last twenty years. However, in order to realize this potential and to bring it to the users, it is not sufficient to only conduct usability evaluations for new applications. Information System theories can contribute to the advancement of this emerging field by providing guidance for the systematic evaluation of visual solutions to move the discipline of visualization forward and enable it to make a relevant and recognized contribution to solving today's challenges.

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