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Trust in Information Visualization

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Abstract

Trust is an important factor that mediates whether a user will rely and build on the information displayed in a visualization. Research in other fields shows that there are different mechanisms of trust building: Users might elaborate the information deeply and gain a good understanding of the uncertainties in the data and quality of the information. But they might also use superficial cues as indicators for trust. Which processes are activated depends on the trustworthiness on the side of the visualization and on the trust perception by the users. We lay out challenges for future research to further improve our understanding of trust in information visualization.

CCS Concepts

• ***Human-centered computing*** → *Information visualization,Visualization design and evaluation methods;* • ***General and reference*** → *Surveys and overviews;*

1. Introduction

In 2009, Thomas and Kielman [TK09, p. 312f.] identified trust as one of the top-10 challenges for visual analytics, referring to the need that "the provenance and validity of the data must be known, and the security of the sources and privacy of individuals guaranteed". *But what actually is trust in the context of Visual Analytics (VA) and information visualization (InfoVis)*? Trust is used and defined differently in many different contexts [CDHP11], but it mainly originates from the evaluation of a social relationship: How likely is it, that relying on another person will not turn out to be harmful for me? In the context of technical systems, the trustee takes a non-human form [SCH13], an information system for example. Transferring this understanding of trust to InfoVis, **trust** is the user's *implicit or explicit tendency to rely on a visualization and to build on the information displayed*. Thereby, trust is an important factor that will mediate whether the represented information is actually used [KFW08].

To develop a better understanding of trust in InfoVis, we review selected literature on trust and (visual) information in information science, HCI, and visual analytics and complement it with classical studies on trust and information processing in psychology. We aim to gain a better understanding of the underlying processes (section 2), of relevant factors for trust on the user side and on the visualization side (section 3), and we identify open research challenges to improve our understanding of the role of trust in InfoVis (section 4).

2. How is trust established in information visualizations?

Arguably, trust is not a relevant factor for every interaction with InfoVis, but it becomes relevant when there is some kind of *risk* associated with the use of the information [MD03, p.471]. What constitutes this risk in InfoVis? According to Kelton et al. [KFW08, p.365] trust is required to reduce the *uncertainty* associated with digital information, especially if the trustor is *vulnerable* to suffer some kind of loss if he or she relies on it (e.g. taking a wrong decision, humiliation by others), but also *depends* on the information.

Therefore, in VA, trust was conceptualized in relation to the visualization of uncertainty. MacEachren et al. [MRO*12, p. 2498] define trustworthiness as "source dependability or the confidence the user has in the information", which encompasses multiple aspects of uncertainty like completeness, consistency, lineage, currency, credibility, subjectivity, and interrelatedness. Similarly, in the model of trust in VA by Sacha et al. [SSK*16] trust is built when an analyst makes sense of the data and becomes aware of the uncertainties in the data and in his own understanding.

But in some cases it is not possible (e.g. due to time pressure or too much information) or necessary (e.g. in casual InfoVis [PSM07]) to gain full awareness of all uncertainties in the visualization. Therefore, the trustor will not always (be able to) engage in a detailed analysis of all information available. Still, he might put trust in the information. Building on the "Elaboration Likelihood Model", it is assumed that users elaborate information more or less deeply to decide whether it is trustworthy based on different situative factors [KLK19]. In some cases - e.g. given sufficient time

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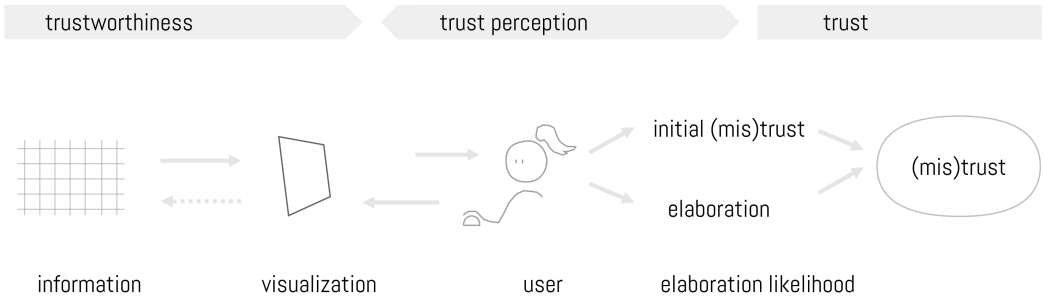

Figure 1: *A model for trust in InfoVis, integrating visualization trustworthiness of the visualization and information, trust perception by the user, and processes of elaboration.*

and a risky decision - the information will be processed deeply until full awareness of all relevant aspects of uncertainty is achieved (like in the model by [SSK*16]). But in other cases, situational cues, like references to the information source, are used to establish trust [CDHP11, KFW08].

Kelton et al. [KFW08] describe different processes for establishing trust in information—building on a more or less thorough elaboration and evaluation of the information: (1) A user relies on an already known source, which proved to be trustworthy in the past. (2) The information stems from a source with the reputation of being trustworthy (good reviews, authority of the source, or certifications). (3) A user identifies with a source, because it conforms to his own goals, knowledge, or values and therefore decides to put trust into it. (4) The use establishes an emotional connection due to the aesthetics and graphic design. (5) The user carefully checks the reliability of the information, e.g. by using and comparing multiple sources.

Many different processes can lead a user to put trust in an information (visualization). Which one is chosen depends on the interaction with the InfoVis: Trust is a situative construct [MD05]; it is established online and—depending on the information, visualization, user, goals and planned action—it changes and evolves during the interaction with the InfoVis. Factors on the side of the user and on the side of the InfoVis will determine which processes are activated. Figure 1 draws together the basic contributions from the visualization and the user side - and integrates the essential role that processes of elaboration play for trust.

3. Two Sides of Trust in Information Visualization

As trust is a two-sided (i.e. a referential) construct, we have to understand both sides: the side of the trustor—the user—and the side of the trustee—in our context the information visualization (see figure 1). *Trustworthiness*, on the one side, refers to the properties of the visualization (and the underlying data) that lead users to trust it. *Trust perception*, on the other side, is the user's subjective evaluation of the quality and reliability of the visualized information.

3.1. The Visualization Side: Trustworthiness

There are two aspects, which have to be considered on the side of the visualization: the trustworthiness of the information and of the visualization design.

Factors that influence the *trustworthiness of information* are its accuracy (free from error), currency (up-to-dateness), coverage (completeness), objectivity (unbiasedness and availability of multiple perspectives), as well as its validity and predictability [KFW08]. A good visualization thus should contain all information the user needs to evaluate these aspects of the quality of the underlying data or information.

Therefore, *trustworthiness of the visualization* depends firstly on the inclusion of all relevant information. In their paper on "Critical InfoVis", Doerk et al. [DFCC13] emphasize that disclosure of the underlying data and the designers' decisions about data, representation, and interaction can increase trustworthiness. Transparency of this information will help to establish a (kind of "social") relationship between the user and the designer and is likely to increase trust.

An important trustworthiness factor for expert users is the appropriate representation of uncertainty. Sacha et al. [SSK*16] present a trust model in which the visualization acts as mediator between uncertainty propagation and trust building. They examine uncertainty from both the human and the computer side while discussing sources of uncertainty from each step of the knowledge chain. The authors state that trust is increased when the users are informed about the presence of uncertainty in the data. To make uncertainties transparent, MacEachren et al. [MRO*12] suggest several techniques to visualize uncertainty in spatial and temporal data. However, to our knowledge until now this assumed link between the visualization of uncertainty and trust was not studied empirically. One might argue, that in some cases (e.g. users with low prior knowledge on statistics) the visualization of uncertainty might increase distrust and a sparser visualization design would be more trustworthy. A recent study [BPHE17] showed that even data analysts cope differently with uncertainty—from ignorance to minimizing, understanding and exploitation.

Until now, hardly any studies were conducted on the trustwor-

thiness of visualizations. Kong et al. [KLK19] observed in a recent study that the more the underlying data have been processed, the less they were perceived as credible: The actual data were most credible, followed by the visualization and the title (as the most condensed, but sometimes biased summary of the information), which was considered the least credible.

Also design factors like usability and user experience (such as a positive look and feel) can increase trust [CDHP11]. High user experience can activate positive feelings towards an interface, which can also co-activate trust. But if the interaction with a visualization is interrupted (e.g. by bugs or inconsistencies in the design), the user will either end the interaction and decide not to trust the information or he will elaborate the information more deeply to understand these inconsistencies.

Overall, the importance of each of these factors on the visualization side also depends on the context of use and on user specific factors like prior knowledge [CDHP11].

3.2. The User Side: Trust Perception

As already stated, inconsistencies within a visualization can lead the user to question the visualization and the underlying information. The result of this questioning can go both ways: While poorly designed visualizations can make users wary of a representation, they can also trigger a deeper processing of the information and activate reflections of critical thinking. Exemplarily, the lack of clarity can merely irritate a user, but it can also raise doubts about the accurateness and certainty of the information displayed. Hullman et al. [HAS11] speak of "visual difficulties" in this context, which are assumed to activate critical thinking and lead users to scrutinize a visualization (see also [RN15]).

Coherence within the visualization [SWSM16], but also between the visualization and its title plays a crucial role in understanding a visualization. A recent study by Kong et al. [KLK19] hints that misalignment of visualization and text affects understanding and thus credibility of the information depicted.

Prior knowledge is an important, but yet not fully understood factor for the formation of trust [CDHP11]. The acceptance of novel information depends also on the representations already stored in a receiver's memory. Information is accepted—and trusted—more easily if it can be linked to the user's prior knowledge with little effort and if it is in accordance with the user's attitudes on the topic. For example, Dasgupta et al. [DBHR17] observed that familiarity with a visualization system inspired trust, whereas novel visualizations acted as barrier. If there is no prior attitude, experience or knowledge about the object, other trust processes will be activated, e.g. whether the source or the visualization provider is already known.

Arguably, specific dispositions to trust information and visualizations exist for each individual user [CDHP11]. Based on prior positive experiences when trust was granted under uncertainty, users are more or less likely to grant trust in novel information [KFW08]. Also personality traits can determine perceived trust. Petty and Cacioppo [PC82] postulate an individual "need for cognition", the extent to which individuals voluntarily and habitually think thoroughly. They found that people with a high need for cognition are more influenced by the quality of arguments than people with a low need for cognition, who focus more on emotional aspects of information.

Another important factor on the user side are the user's intentions and perceived risk: Sprague and Tory [ST12] found that trust perception influences the usage of casual InfoVis, when the information is personally very relevant or a decision based on incorrect information would be high in costs. In a study by Roghanizad et al. [RN15] user were predominantly inclined to trust a website a priori, but re-evaluated their trust when they had to take a decision entailing a personal risk. Therefore, we assume that the user's task and the associated risk are an important factor for trust in InfoVis as well: When users (be it expert or casual ones) have to make a critical, risky decision, they will elaborate the trustworthiness of the InfoVis more deeply, but rely on superficial trust cues in less relevant or less risky tasks.

4. Research Challenges

Overall, our review of literature showed—though there is a huge body of research on trust in other fields—that little is known about the factors that influence trust in InfoVis until now. To further advance our understanding in this area, there are many open research challenges, which should be addressed by the InfoVis community in the future.

4.1. Measuring Trust and Understanding Trustworthiness of Information Visualizations

To conduct studies on trust in InfoVis, we have to establish meaningful ways and methods to measure trust. In the study by [KLK19], trust was measured via the credibility of the information - Do you trust the visualization to show real data? But in our review of literature it became clear, that many different indicators of information quality [KFW08] and visualization design [DFCC13,CDHP11,HAS11] determine the trustworthiness of InfoVis and the users' trust perception. We thus contend that the assessment of trust should measure up to the complexity of the concept by measuring different aspects of trust perception.

Next to outcome measures like credibility [KLK19] or the self-calibrated degree of confidence in taken decision [DLW*17], also methodologies studying the process of trust building would be interesting to better understand when users are likely to elaborate the information more or less thoroughly. Such studies could help to identify visualization design cues that support or hinder trust.

These results are also relevant for the measurement of trustworthiness. If relevant trust design cues are known, heuristic analyses could be an efficient way to evaluate the trustworthiness of a visualization.

An important aspect of measuring trust is that our measures have to be in line with the definition of trust: Trust results not from the user's perception only, and it is not the trustworthiness of the InfoVis alone. Trust results from the user's (often implicit) assessment and evaluation of a visualization and it translates most explicitly into his or her actions, which build on this information. Therefore,

an assessment of trust should at least measure a user's behavioral intentions (Would you rely on the facts in this InfoVis? Would you use the information for a decision?), if not his actual behavior.

4.2. Temporal (In)Stability and Variation of Trust

Whether a user trusts an information—or not—might also change over time. In 1951, Hovland has pioneered research into the long-term effects of the persuasive effect of information [HW51]. In this study, trustworthiness of information varied according to the expertise that was attributed to the information sources, while the content of the information was the same. As expected, the more trustworthy the information source was, the more the message was trusted. However, also an interesting long-term effect was observed: The extent to which an information was accepted decreased over time for very credible sources, while acceptance increased for neutral or negative sources. In psychology, this so-called "sleeper effect" received high interest [KA04]. One possible explanation for the sleeper effect is that passing time since the perception of an information dissembles cognitive relations between the content of the perception and the information source, i.e. that trustors forget from which source the information originated. Especially for persuasive InfoVis [PMN*14], a better understanding of such long-term effects on trust are needed (e.g. on opinion formation or attitude change).

4.3. Certifying, Visualizing, and Standardizing Trustworthiness

An important indicator to trust an information is the reputation of the source [KFW08,CDHP11]. For example, third-party certificates help users to judge a source as trustworthy. It could be a logical next step to develop such certificates for the trustworthiness of InfoVis groups or organizations.

In other contexts, visualizations have been developed to show the trustworthiness of online information sources like Wikipedia [CHF10]. They visualize indicators like the number of contributors and the interlinkedness of information. Similar visualizations could assist users to better assess the trustworthiness of InfoVis - this would be especially helpful for novices or casual users. A starting point for the development of such visual trust indicators could again be heuristic analysis checklists for the trustworthiness of InfoVis (see section 4.1). In the long-run, implementing such checklists could also help to establish standards for more trustworthy visualizations.

4.4. The Negative Sides of Trust

When we want to develop a better understanding of trust in InfoVis, we also have to look at the negatives sides of trust. Marsh [MD05] defines *mistrust* to be the placement of trust into an information, where it turns out to be not justified, e.g. because the information is outdated, represented in a misleading way, or because the designer actually wants to actively disinform or mislead the users. Such experiences of misplaced trust can lead to untrust or even distrust in InfoVis; whereas *untrust* refers to a resentment to put trust into a visualization a priori and the search for indicators of trustworthiness, *distrust* refers to the user's expectation that the InfoVis *aims* to disinform or harm him.

In a time of increasing social and political polarization, we see also a need to reflect on the essential social foundations of trust. Arguably, what Kelton et al. [KFW08] call "reputation" of a source often results from the perception of other perceptions—such as a peer group's reviews and opinions. While this is an obviously problematic foundation for trust, it arguably is a widely operating one, also because it saves time and efforts. Lewis and Weigert [LW85] call this phenomenon "trust in trust" - and against a horizon of polarized mediaspheres, parties and public it is obvious, how socially influenced trust can do harm to the idea of unbiased perception and open communication. As an extreme consequence, the debate of a "post-truth society" has to explore novel conditions for science communication [IM18]. A striking example are the "partisan climate maps", which document how social trust can also become erratic and counter-productive and impede or subvert the trust into established scientific facts [MMHL17].

5. Conclusion

In 2009, trust was identified as an important challenge for VA and InfoVis design [TK09]. Ten years later, we gained a useful model [SSK*16] and some empirical research [SS19, IXW18] on the role of uncertainty and trust in knowledge building by expert users. However, until now our knowledge is limited, when it comes to the question what might lead a user to trust in a visualization without deep elaboration of the information.

In this paper, we synthesized additional mechanisms which lead a user to trust in information and their visual representation. We identified several factors on the the user and on the visualization side that can influence trust. Yet we also see several research challenges, which point out the need of future investigations - to gain a better understanding when users put trust in a visualization - and whether this is based on trust cues in the design, on their own initial perception, or a deep elaboration of the information.

We are aware that this paper is only a first step towards a better understanding of trust in InfoVis. And—to be transparent—we do not trust all the findings of our literature review to be accurate and relevant for the transfer into our field. Our understanding of trust still contains many vacancies and uncertainties. Even though some findings on trust from other fields seem to be plausible also for the visualization field—and therefore trustworthy on first sight—they should be applied and evaluated in studies in an InfoVis context in the future. As such, we expect to develop a better foundation of trust in InfoVis and—as an aim of even more importance—to enrich and elaborate our practical guidelines and standards for trustworthy representation design.

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