Cognitive Biases and Data Visualization

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INTRODUCTION

In 1974, the term *cognitive bias* was coined by Tversky & Kahneman (1974). Since then, there has been an abundance of research in multiple disciplines such as economics, healthcare, social sciences, and psychology that has been impacted by this term (Featherston et al., 2020). Cognitive biases are errors in judgment or decisions that are made by humans when they attempt to process too much information at a time or when they do not have sufficient information to make correct decisions. Cognitive biases can be found in disciplines from accounting to healthcare. Biases such as overconfidence, anchoring, framing, and confirmation can affect an auditor's judgement and decision-making abilities (Chang & Luo, 2021). Gopal et al. (2021) developed a checklist to assist medical providers to guard against bias such as mental shortcuts that can lead to errors in diagnosing and treating patients.

Researchers have identified several cognitive biases and there is no doubt that these cognitive biases have led to poor decisions in a multitude of disciplines. Cognitive biases are pervasive across many disciplines. For example, 75% of clinical errors in internal medicine clinical settings are thought to be rooted in cognitive biases (D O'Sullivan & Schofield, 2018). Another study found that it is impossible for cancer patients to make informed choices owing to the treatment provider's cognitive biases and this is likely to lead to overtreatment (Ozdemir & Finkelstein, 2018). Companies that wish to enter international markets can encounter cognitive biases that, if not overcome, can lead to failure of new product launch (Paul & Mas, 2020).

Data visualization can assist in reducing cognitive biases. Data visualization plays a key role in decision-making process. Visualization allows for data to be consumable, that is, interpretable easily. If data is not consumable, there is a tendency to ignore the facts and rely more on biases. Data visualizations should guard against cognitive biases. However, researchers have found that cognitive biases do exist within data visualizations and can affect decision-making abilities (Padilla et al., 2018). Most recently, there has been interest in designing empirical studies that determine whether cognitive biases can be alleviated (Cho et al., 2017; Dimara et al., 2018; Valdez, Ziefle, & Sedlmair, 2017; Xiong, Van Weelden, & Franconeri, 2019). Some of these studies have provided mitigation strategies to guard against cognitive biases in data visualizations. For example, viewing the data from different positions such as simply reordering the values in a visualization and allowing multiple individuals to critique and provide feedback related to the visualizations (Xiong et al., 2019).

With the advent of big data, practitioners and researchers have become more reliant on data visualizations as a decision-making tool. Telecommunication companies are able to amass large amounts of detailed user data to better understand their customers. Utilities use smart meter data to reduce outages,

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assign crews, measure energy consumption and meter quality. Governments are able to use data from sensors to monitor road conditions and change the duration of red and green signals of traffic lights according to real-time traffic patterns. With large and complex data, associations, insights, patterns, and errors can be more easily understood with graphical representations than using tables and numbers. The human brain can make sense of pictures more rapidly than tables of numbers. To maximize the impact of big data, it is necessary to incorporate visual analysis at all levels of an organization.

Classical graphing tools do not scale well to big data. However, advances in visual analytics have led to a much broader use of classic visualizations than are normally encountered in small data set environments. Visual analytics goes beyond the traditional dashboard with a few scatterplots and bar charts. They provide more interesting information than classic visualizations. For example, an analytic visualization such as a scatterplot might show an association between women and a certain type of golf club in a particular state. Another analytic visualization could predict the future revenue of golf clubs in a particular geographical area and help determine growth. Sharing reports and dashboards based on analytics conveys more information about future possibilities and promotes collaboration, which leads to more strategic decision making. Visualization technologies that support more complex data and the ability to utilize more cognitive tasks are areas of growth (Borland, Wang, & Gotz, 2018).

When cognitive biases crop up in data visualizations and influence decision-making, the impact can have consequences for the individuals that are affected. College admissions is one such example. The decision to accept or admit a college applicant involves both expertise and heuristics. These heuristics have multiple cognitive biases attached to them (Sukumar & Metoyer, 2018). For example, confirmation bias refers to "the tendency to seek and overweight confirming information in the information gathering and evaluation steps, and to favor conclusions that are consistent with initial beliefs or preferences" (Chang & Luo, 2019, p. 6). The confirmation bias can manifest itself when an admissions reviewer makes up their mind about the accept or rejection status of an applicant before the applicant review process is complete. The reviewer will look for data to support their hypothesis. For example, a reviewer might have decided, based on initial or incomplete data and before the interview process occurs, that an applicant should be rejected. Then, in the interview process, the reviewer will ask questions and look for ways to support the reviewer's early opinion that the applicant should be rejected. The biases can have direct consequences to the applicants themselves but also a larger societal impact. Sukumar & Metoyer (2018) developed visualizations to mitigate biases that occur often in the college admission decision.

Another example of biases influencing decisions that are made using visualizations are climate change implications. Maps are used extensively when displaying data and information related to climate change. Maps are used to display geographical areas of floods, extreme heat, drought, vulnerable animal populations, and sea rise (De Sherbinin et al., 2019). However, maps are an example of how a visual can display and hide information at the same time (McInerny et al., 2014). McInerny et al. (2014) provides an example of how different types of maps can alter the audience's perception of and ability to question data related to jaguar populations in Africa. Luo & Zhao (2021) discuss the importance of visualizations mitigating perceptual biases related to climate change. The authors use the example of greenhouse gases. Many times, people's perception of the effects of greenhouse gases and the reality of these gases are not aligned. To bridge this gap between perception and reality, it is important that visualizations are created with solid design techniques implemented (Luo & Zhao, 2021; Harold et al., 2016).

This chapter provides a background for cognitive biases that are related to data visualizations, with a particular interest toward visual analytics in big data environments. Cognitive biases that crop up in visualizations will be discussed. A review of recent studies related to designing experiments to mitigate cognitive biases in data visualizations will be presented. Recommendations, using applied frameworks

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