Chapter 3

Dashboard Poetry

3.1 Abstract

This proposal considers an entire dashboard to be a well-orchestrated collection of charts in data visualization.

A chart is similar to a sentence in that it presents a straightforward piece of information and visually represents data to facilitate comprehension.

For example, a chart could be a bar graph depicting sales over a year, a pie chart illustrating the percentage distribution of a budget, or a scatter plot illustrating the correlation between two variables.

A chart conveys a single data narrative, like a sentence expressing a complete thought. A dashboard is a visual display of the essential information needed to achieve one or more objectives, consolidated and arranged on a single screen so the data can be monitored at a glance (Few, 2006a).

A dashboard is analogous to a paragraph.

It is a collection of charts (similar to sentences) that present a more comprehensive view of the data landscape.

Each chart on the dashboard contributes to the overall comprehension of the situation, similar to how each sentence in a paragraph contributes to the larger

concept.

A dashboard may combine multiple graphs, tables, and metrics to provide an all-encompassing view of a company's performance, a project's development, or market trends. However, a counterexample to this analogy could be a poorly designed dashboard presenting overwhelming information without clear organization or hierarchy. In such a case, the charts may compete for attention and confuse the reader, similar to how a paragraph with too many disjointed sentences can lead to confusion and a lack of coherence. This counterexample highlights the importance of thoughtful design and effective communication in creating an informative and comprehensible dashboard. The research objective of this study is to investigate how changes in real-time data displayed on a dashboard affect ensemble perception and the user's ability to make accurate and rapid decisions based on summary statistics in a dynamic environment.

3.2 Introduction

Research Question: How do individual charts function as syntactic and semantic sentences within the paragraph of a dashboard, and how can multidimensional ensemble theory be applied to optimize the coherence and interpretability of dashboards in a multi-stakeholder environment?

The research objective of this study is to investigate how changes in real-time data displayed on a dashboard affect ensemble perception and the user's ability to make accurate and rapid decisions based on summary statistics in a dynamic environment. The multidimensional ensemble theory framework could examine how various dimensions— data types, user roles, and organizational goals, interact to create a coherent and effective dashboard. It considers how ensemble perception operates when data is static and adapts to fundamental changes, particularly on a dashboard where such fluctuations are common. The research aims to improve the design of dashboards by focusing on the user's decision-making capabilities.

The grammar of graphics is a framework that helps design and understand data visualizations (Wilkinson, 2012).

By decomposing graphics into components such as data, aesthetics, and geometry, the grammar of graphics provides a structured method for conceiving and creating visualizations.

It permits a high degree of customization and flexibility in creating visualizations. Static visualization is commonly used in the communication phase of data science workflows, and data scientists sometimes use it as part of the analysis.

John Tukey's Exploratory Data Analysis (EDA) methods are well-known and well-vetted.

However, Satyanarayan et al. addressed this by introducing a high-level grammar of graphics called "Vega-Lite," which presents a set of standardized linguistic rules for producing interactive information visualizations using a concise JSON format for data to be represented by the grammar (Satyanarayan et al., 2016).

Vega-Lite has been directly implemented in R via the `ggvis` package using the same, albeit at a slightly lower level. The principles of the grammar of graphics can be applied to dashboard design to create more effective and informative dashboards.

"Graphical Tests for Power Comparison of Competing Designs" by Hofmann et al. presents a graphical method for comparing the power of two or more

competing designs in an experimental study (Hofmann et al., 2012). The article demonstrates that the graphical method helps compare the effectiveness of various experimental designs.
It enables researchers to intuitively and straightforwardly visualize and compare the effectiveness of different designs. Understanding cognitive load is crucial for designing compelling data visualizations, as it influences how users perceive, process, and remember the data presented in the visualization. When designing visuals, it is essential to consider the cognitive load they may place on the viewer. Cognitive load is the mental effort required to process information, and minimizing it can enhance a graphic's effectiveness.

In addition, displaying as much raw data as possible while minimizing cognitive load can improve the graphic's clarity and precision. Here are some general guidelines for making better graphics with works from Few (**few2012?**), Tufte (**tufte1983?**), and Cairo (Cairo, 2016):

1. Keep it simple - Avoid overwhelming the viewer with too much information at once by employing a clear and concise design with minimal distractions.

2. Use visual hierarchy - Utilize size, color, contrast, and placement to highlight important information and direct the viewer's focus.

3. Choose appropriate charts - Choose the chart type that best illustrates the data and facilitates comprehension.

4. Label clearly - Use labels that are clear and concise for axes, legends, and other essential information to avoid confusion.

5. Use data-to-ink ratio - Focus on the data by minimizing the amount of non-data ink, such as decorative elements or excessive grid lines.

6. Avoid distortion - Use appropriate scaling and avoid distortions to ensure that the graphics accurately represent the data.

7. Provide context - Add context to assist the viewer in comprehending the significance of the data and its relevance to the topic.

3.3 Literature Review

To understand the current landscape of dashboard design and gather insights from existing research, the following section will review relevant studies and frameworks that provide valuable perspectives and actionable insights. The literature review will explore various frameworks and studies related to dashboard design. It will cover evaluation criteria in healthcare, learning dashboards in educational settings, design patterns and trade-offs, academic literature reviews, and practical tips for implementation. The literature review has provided a comprehensive overview of various frameworks and studies related to dashboard design. Evaluation criteria in healthcare, learning dashboards in educational settings, design patterns and trade-offs, academic literature reviews, and practical tips for implementation have been explored. These frameworks and studies offer valuable insights and guidance for creating functional and impactful dashboards. However, it is essential to note that the success of dashboards relies heavily on the quality and accuracy of the presented data and customization to meet specific user needs.

3.3.1 Ensemble Perception

Ensemble perception is the cognitive ability to quickly derive summary statistics from sets of similar items (Chong & Treisman, 2003). This component of visual cognition enables the visual system to summarize and describe collections of comparable objects or features effectively. This capability is often activated at a glance and is crucial for making sense of complex visual scenes.

David Whitney's fundamental review outlines the core principles of ensemble perception, emphasizing the extraction of summary statistical information from groups of similar objects (Whitney, Haberman, & Sweeny, 2014) and (Dakin & Watt, 1997).
(J. Haberman, Brady, & Alvarez, 2015) further discussed that individual differences exist in ensemble perception capabilities, indicating the presence of multiple, independent levels of ensemble representation.
Recent studies have expanded on these principles.
Khayat et al.'s work explores how ensemble perception can create a unified perception from groups of similar objects and also delves into the implicit perception and memory of set statistics (Khayat, Ahissar, & Hochstein, 2023) and (Khayat, Fusi, & Hochstein, 2021).
The study "Perceptual History Biases in Serial Ensemble Representation" by Khayat et al. focuses on ensemble perception, explicitly examining how past visual experiences influence the perception of current visual ensembles.
The study investigates the serial dependence of ensemble perception when each ensemble set is presented simultaneously but spatially distributed over the screen.

This suggests that the objects and our prior experiences with similar ensembles impact how we perceive groups of similar objects (Khayat et al., 2023). This adds a layer of complexity to the understanding of ensemble perception, which is generally considered the visual system's ability to summarize groups of similar objects into a unified perception efficiently.

The study "Perceiving ensemble statistics of novel image sets" by Khayat et al. focuses on how the human visual system perceives summary statistics of sets of stimulus elements.

The study is particularly interested in how we perceive novel image sets and hypothesizes that our capacity to summarize statistical data from these sets affects how well we can comprehend and interpret new visual information (Khayat et al., 2021). This research contributes to the broader field of ensemble perception, which explores how the visual system can efficiently represent groups of similar objects as a unified perception.

The study implies that not only can the visual system quickly grasp the "gist" or essence of familiar visual ensembles, but it can also do so for novel sets of images.

This ability to quickly summarize statistical information from new visual stimuli could be a fundamental feature of human perception (Khayat & Hochstein, 2018).

Other research has investigated the role of ensemble perception in both high- and low-level visual information, such as emotion and brightness, and how it can even operate when scene information is incomplete (Chakrabarty & Wada, 2020) and (J. M. Haberman & Ulrich, 2019).

Furthermore, ensemble perception is not just a specialized function but a pervasive aspect of visual perception.

It has been discussed holistically to engage a general audience and has been shown to condense redundant information into summary statistical representations (Corbett, Utochkin, & Hochstein, 2023) and (Whitney & Manassi, 2022).

Lastly, stable ensemble representations have been found to facilitate visual search, even when they are not predictive of a target location (Utochkin, Choi, & Chong, 2023). The study focuses on a coding model that emphasizes the crucial role of the "pooling layer" in ensemble perception.

Ensemble perception refers to the ability of the visual system to summarize information from a group of similar objects. The "pooling layer" in the model likely serves as a computational mechanism for aggregating or summarizing this information, potentially providing insights into how the brain processes complex visual scenes. The study aims to provide a more structured understanding of ensemble perception by introducing a model highlighting the importance of a specific computational layer, known as the "pooling layer," in summarizing visual information.

3.3.2 Multidimensional Ensembles

Initial research on ensemble perception primarily focused on one-dimensional ensembles, where summary statistics are extracted from a single feature or dimension (J. Haberman et al., 2015). For example, in a study on facial expression perception, participants were presented with an ensemble of faces displaying different emotions. In this case, the pooling layer would analyze the overall emotional expression of the ensemble, summarizing the various individual facial expressions into one general emotion perception.

This model allows researchers to understand how humans perceive and interpret complex emotional expressions more systematically. However, as (Maule & Franklin, 2015) notes, real-world scenes often consist of complex, multidimensional attributes, and research has gradually shifted towards understanding how the human visual system processes these more intricate ensembles. Research on multidimensional ensembles has explored how people simultaneously perceive summary statistics across multiple attributes, such as size and color.

(Dakin & Watt, 1997) were among the first to explore how orientation statistics are computed from visual textures, extending the concept of ensemble perception into a multidimensional setting. (J. Haberman et al., 2015) expanded this research by showing that individual differences exist in ensemble perception capabilities, suggesting multiple, independent levels of ensemble representation exist. The existing literature on multidimensional ensembles in visual information covers various topics, from neuroscience to data visualization.

For instance, studies have explored the role of neuronal ensembles in controlling visually guided behavior and their influence on visual working memory (Carrillo-Reid, Han, Yang, Akrouh, & Yuste, 2019). Research has also delved into the use of aggregated plots for multidimensional visual analysis, although these don't explicitly mention ensembles (Fofonov & Linsen, 2018).

Fast ensemble representations have been investigated to understand high-level perceptual impressions based on visual information (Leib, Kosovicheva, & Whitney, 2016).

Additionally, the aesthetic complexity of visual information has been quantified using information theory, offering a potential framework for ensemble-based representations (Karjus, Solà, Ohm, Ahnert, & Schich, 2023). But a detailed example of why you shouldn't use aggregated plots for multidimensional visual analysis is when the individual data points in the ensemble show significant differences. Data aggregation may obscure important patterns in such scenarios and lead to misleading interpretations. Further, ensembles may fail to capture the fine-grained details and nuances present in the individual plots, compromising the overall accuracy and precision of the analysis. The long-term stability of neuronal ensembles in the visual cortex has been studied, shedding light on their potential role in visual perception (Pérez-Ortega, Alejandre-García, & Yuste, 2021). Ensemble visualization techniques, particularly in computer simulations, have also been reviewed (Afzal et al., 2019). Lastly, the structure of neural networks has been shown to affect working memory, which could have implications for visual ensembles (Leavitt, Pieper, Sachs, & Martinez-Trujillo, 2017).

3.3.3 Dashboard Design

A dashboard is a visual display of the essential information needed to achieve one or more objectives, consolidated and arranged on a single screen so the data can be monitored at a glance (Few, 2006a). Dashboard design creates visually informative and interactive interfaces that present data and key performance indicators (KPIs) in a consolidated and simple-to-understand format.

The objective is to provide users with insights and enable them to make intelligent decisions based on the presented data.

As organizations increasingly rely on data-driven decision-making, well-designed dashboards become pivotal.

The literature on dashboard design provides a comprehensive roadmap for understanding and implementing effective dashboards, focusing on critical frameworks such as evaluation criteria in healthcare, learning dashboards in educational settings, design patterns and trade-offs, academic literature reviews, and practical tips for implementation.

Each of these frameworks offers unique perspectives and actionable insights. These frameworks serve as pillars for the subsequent discussion on creating functional and impactful dashboards.

However, it is essential to note that even with a comprehensive roadmap, the success of dashboards heavily relies on the quality and accuracy of the presented data. If the data used in the design and implementation of dashboards is flawed or incomplete, it can lead to misleading insights and ineffective decision-making. Additionally, different user groups' specific needs and preferences may not always align with the frameworks provided, requiring customization and adaptation that may not be adequately addressed in the comprehensive roadmap.

The Karami 2017 study focuses on creating evaluation criteria for effective dashboards in healthcare organizations (Karami, Langarizadeh, & Fatehi, 2017).

The study employs the Delphi method to offer a set of criteria that can be universally applied to assess the effectiveness of dashboards in healthcare settings. Utilizing the Delphi method, the study aims to establish a robust set of criteria for evaluating the effectiveness of dashboards within healthcare organizations.

The research provides a structured framework for healthcare professionals to assess their dashboards' utility, functionality, and impact.
By doing so, the study improves patient care and operational efficiency.
This work serves as a valuable guide for healthcare organizations looking to implement or refine their dashboard systems, offering a set of universally applicable criteria for effectiveness.

A systematic literature review by (Schwendimann et al., 2016) discusses the state-of-the-art in learning dashboards. The paper identifies critical design features, dividing them into functional and visual features.
This study is particularly useful for educational institutions implementing learning analytics dashboards. Conducted as a systematic literature review, the study categorizes critical design features into functional and visual aspects, providing a comprehensive understanding of what makes a learning dashboard effective.
The research is especially relevant for educational institutions implementing or optimizing learning analytics dashboards.
By identifying key design elements and their impact on student performance, the paper is a foundational resource for educators and administrators looking to leverage dashboards to enhance educational outcomes.

A 2022 paper by (Bach et al., 2022) discusses design patterns and trade-offs in dashboard design.
The paper also discusses possible design frameworks, providing a comprehensive view of the design aspects of creating a dashboard. The study not only reviews existing design frameworks but also introduces a collection of new patterns that can guide designers in creating more effective dashboards.

The paper provides a balanced view that helps designers make informed decisions by discussing the trade-offs involved in choosing specific design elements. This work is particularly valuable for those designing and developing dashboards, offering a comprehensive set of guidelines and frameworks that can be applied across various sectors and use cases.

(Scheuer, Jache, Sumfleth, Wellmann, & Haase, 2021)'s paper discusses the integration of interactive dashboards into academic literature reviews.
The study argues that such integration can make academic research more accessible, interactive, and impactful. Researchers can better synthesize and present complex data by leveraging dashboard tools, broadening academic literature's reach and utility.
This paper is a pioneering resource for academics and researchers, suggesting a novel approach to literature review synthesis that can enhance the process and the dissemination of scholarly work.

Microsoft provides practical tips for designing an effective Power BI dashboard, focusing on making the most important information stand out. Focusing on making critical information stand out, the guide provides actionable tips that practitioners can immediately apply.
While not a peer-reviewed article, this resource is invaluable for professionals in various sectors looking to design or optimize their Power BI dashboards.
It emphasizes user-centric design and data visualization techniques to ensure that the dashboard is a functional tool for data-driven decision-making. It is a go-to resource for best practices in Power BI dashboard design. Although not a peer-reviewed article, it offers valuable insights for practitioners (Staff, 2023).

3.3.4 Ensemble Visualization

Ensemble visualization refers to the graphical representation of ensemble data, which typically consists of multiple related datasets. It aims to provide a comprehensive view that allows for rapidly extracting visual statistics and insights about distributed information.

The goal is to provide a comprehensive view that allows for rapidly extracting visual statistics and insights about distributed information. Ensemble visualization is an emerging field that focuses on the graphical representation of ensemble data. By providing a comprehensive view and allowing for the rapid extraction of visual statistics and insights, ensemble visualization techniques can aid in identifying areas of interest and facilitate data interpretation. Ensemble visualization techniques can vary, including Ensemble Surface Slicing (ESS) to visualize regions of similarity and difference among surfaces and statistical visualization techniques to identify areas of interest quickly (Alabi et al., 2012) and (Potter et al., 2009).

Ensemble visualization is an emerging field focusing on the graphical representation of ensemble data, which typically consists of multiple related datasets. The aim is to provide a comprehensive view that allows for the rapid extraction of visual statistics and insights about distributed information.

By combining various statistical visualization techniques, (Potter et al., 2009) presents the Ensemble-Vis framework in his paper as a way for scientists to identify areas of interest quickly. The paper's thorough methodology, which combines various statistical visualization techniques to build a more helpful ensemble visualization framework, makes it noteworthy. This framework has been referenced by many other studies, leading to the development of new visualization methods.

This paper by LM Padilla investigates how ensemble displays, which plot multiple data points on the same Cartesian coordinate plane, affect the viewer's understanding and interpretation of the data. The paper contributes to the theory by examining the cognitive aspects of ensemble visualization. By exploring the effects of ensemble and summary displays on data interpretation, Padilla's research adds valuable insights to the field (Padilla, Ruginski, & Creem-Regehr, 2017). However, a counterexample to the effectiveness of ensemble displays can be observed when the data points are highly overlapping and densely packed, leading to visual clutter and difficulty distinguishing individual data points. In such cases, ensemble displays may hinder the viewer's understanding and interpretation of the data rather than enhance it. This highlights the importance of considering the specific characteristics of the presented data when deciding whether to use ensemble displays. Additionally, summary displays, which provide an overview of the data, can be a helpful alternative in situations where ensemble displays may be less effective. Summary displays condense the data into crucial statistics or visual representations, allowing for more straightforward interpretation and analysis, especially when dealing with complex or dense datasets. Further research is needed to explore the optimal conditions for ensemble and summary displays to maximize their effectiveness in data interpretation.

3.3.5 Grammar of Graphics

The central concept of the grammar of graphics is the representation of visualizations as a combination of essential components, including data, aesthetics, geometries, scales, and statistics.
These components can be combined in numerous ways to generate various visual representations.
For instance, data is the foundational element; aesthetics map data variables to visual properties; geometries determine the representation of data points; scales map data values to visual values; and statistics transform the data before visualization.

While the grammar of graphics provides a robust theoretical framework for data visualization, there may be research gaps in its application to dashboard design and functionality.
Despite significant developments in data visualization and human-computer interaction, there are still glaring research gaps in interactivity, data synchronization, and user-centered design.
Users' capacity to interact interactively with visual data hasn't been adequately investigated in terms of its effects on cognition and best design practices.
Another area that needs more in-depth research is data synchronization, particularly in multi-user and multi-device scenarios; seamlessly integrating real-time data changes across many platforms is essential for creating increasingly powerful collaboration tools.
In research, user-centered design, which puts the requirements and behaviors of the end-users first, also frequently takes a backseat, resulting in products

that may be technically remarkable but lack intuitive usability. These gaps highlight the need for more targeted research projects to comprehend the technology potential and human elements contributing to the efficacy of interactive systems and data visualization. These gaps highlight the necessity for more targeted research projects to comprehend the technology potential and the human elements that contribute to the efficacy of interactive systems and data visualization.

Graphics grammar primarily emphasizes static visualizations.
However, dashboards are inherently interactive, allowing users to explore and interact with the data. There is a need for research to determine how to effectively incorporate the principles of the grammar of graphics into interactive dashboards while maintaining a positive user experience and avoiding user overload.
Dashboards often present data from multiple sources or datasets.
Ensuring data synchronization across different visualizations and components is critical to maintaining accuracy and consistency.
Research is needed to investigate methods for handling data updates, refresh rates, and synchronization challenges in dashboard design.
The grammar of graphics focuses on data-driven principles, but effective dashboard design also requires a deep understanding of user needs, tasks, and goals. Further research should investigate how to integrate user-centered design practices into applying the grammar of graphics in dashboard development.

3.3.6 Interplay between Grammar of Graphics & Dashboard Design:

In the evolving discourse on data visualization and dashboard design, the proposed theory positing the "grammar of graphics" as the foundational framework offers a compelling analogy: if a graph is akin to a sentence, then a dashboard can be considered a paragraph.

Just as sentences are constructed using grammatical rules to convey complex ideas clearly, graphs employ principles such as scales, coordinates, and marks to represent data comprehensibly.

Extending this analogy, a dashboard serves as a cohesive "paragraph," where multiple graphs or "sentences" are organized in a meaningful sequence to provide a more nuanced understanding or narrative.

This framework suggests that the same rigorous thought applied to individual data visualizations should also be extended to the design of dashboards, where the interplay of multiple graphs must be syntactically and semantically harmonized to communicate the overarching message or insight effectively.

Here is how published theory relates graphic grammar to dashboard design:

Data Layer: is the foundation of visualizations in the grammar of graphics. This means that data should drive the dashboard design process. Dashboards should be constructed using accurate, pertinent, and well-organized data that aligns with the dashboard's objectives.

Aesthetics Layer: refer to the mapping of data variables to visual properties such as color, size, shape, and position. Aesthetics play a crucial role in dashboard design for accurately and effectively representing data. Choosing appropriate colors, scales, and shapes for visual elements expedites users' ability to comprehend and interpret data.

Geometries: determine how data points, such as bars, lines, points, or areas, are represented in the visualization. The selection of appropriate geometries is crucial in dashboard design for communicating the intended message. Various types of charts and graphs may be used to represent various types of data or to illustrate particular relationships.

Composition and Layers: Graphics grammar permits combining multiple layers of data and geometries to generate more complex visualizations. This translates to structuring information hierarchically in dashboard design, utilizing multiple charts, graphs, or elements to present a comprehensive view of the data without overwhelming the user.

Faceting: is the process of dividing data into subsets and displaying them as multiple smaller visualizations. Faceting can be used in dashboard design to display multiple aspects of the data simultaneously, making it easier for users to compare and contrast various parts of the data.

Annotations: as mentioned in the previous response, annotations are a crucial component of statistical graphics and also apply to dashboard design. Annotations strategically placed can aid users in comprehending key insights, provide context, and guide them through the dashboard's narrative.

Using the principles of the grammar of graphics, designers can create visually appealing, informative, and user-friendly dashboards that effectively convey data-driven insights to their audience.

3.4 Multidimensional Ensembles in Dashboards

The integration of multidimensional ensembles in dashboard design can facilitate quicker and more accurate data interpretation (Szafir, Haroz, Gleicher, & Franconeri, 2016). For instance, using color-coding along with shape variations can convey a richer set of information within a single graph or chart, making it easier for users to derive meaningful insights (**Szafir2018?**).

3.5 Gaps in Research

The literature notably lacks specific studies on how multidimensional ensembles are processed in the context of dashboard design. Understanding this could pave the way for creating dashboards that leverage human ensemble perception abilities for more effective data comprehension and decision-making.

3.6 Methods:

Ensemble perception involves the rapid and often unconscious extraction of summary statistics from similar items (Chong & Treisman, 2003) and (Whitney et al., 2014).

In the context of multidimensional ensembles, this would refer to the simultaneous extraction of features such as mean, variance, and other statistical attributes across multiple dimensions (Maule & Franklin, 2015) and (J. Haberman et al., 2015). Understanding this concept will provide a unique way to interpret dashboards that contain data from multiple dimensions. Traditionally, Bland-Altman plots present the difference between two sets of measurements against their mean, providing a graphical representation of agreement or bias.

However, this one-dimensional representation might not capture the full complexity of real-world data, where measurements can often be multidimensional (Dakin & Watt, 1997).

Ensemble perception involves the rapid and often unconscious extraction of summary statistics from a set of similar items (Chong & Treisman, 2003), (Whitney et al., 2014). In the context of multidimensional ensembles, this would refer to the simultaneous extraction of various features such as mean, variance, and other statistical attributes across multiple dimensions (Maule & Franklin, 2015), (J. Haberman et al., 2015). Testing the effectiveness of a dashboard involves evaluating its usability, user experience, and the effectiveness of conveying information to the target audience. Here are some key steps and methods to test the effectiveness of a dashboard:

Usability Testing: Conduct usability testing with real users to observe how they interact with the dashboard. Use think-aloud protocols, where users vocalize their thoughts while using the dashboard. Observe if users can easily navigate, interpret data, and find relevant information using the collection of charts.

Eye-Tracking: Use eye-tracking technology to understand where users focus their attention on the dashboard. This will reveal if users are drawn to the critical information presented through the collection of charts.

User Interviews and Observations: Conduct interviews with users to gain deeper insights into their experiences and preferences regarding the collection of charts. Observe how users interact with the dashboard in their natural environment.