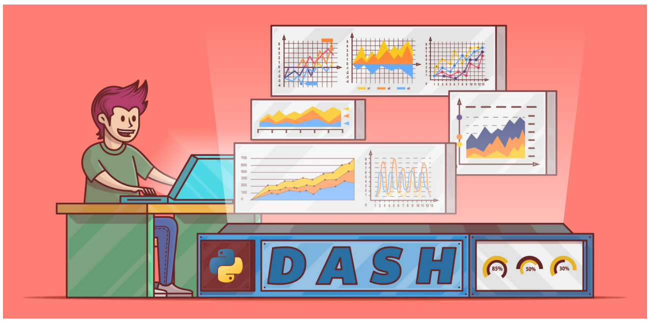


# INTERACTIVE VISUALIZATION

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This paper explores the theoretical underpinnings of interactive dashboards and their effective design, implementation, and evaluation. In the context of increasingly complex datasets, well-designed interactive visualizations play a crucial role in enabling users to extract meaningful insights and support informed decision-making.

The dashboard utilizes the Goodreads dataset, sourced from Kaggle. This dataset, focused on book information and user interactions, was chosen because it effectively aligns with the learning objectives of this assignment. As a large dataset, it inherently enables the exploration of performance considerations (LO1). Its potential for a clear and logical structure allows for the application of Shneiderman's mantra (LO2). Furthermore, the nature of book data lends itself to intuitive interactions such as filters, random suggestions, and detailed views, directly addressing interaction design principles (LO3). Finally, the relatable and enjoyable topic of books, coupled with realistic usage scenarios (e.g., finding new reads, exploring author preferences), makes the resulting dashboard easy to evaluate (LO4) in terms of its usability and user experience. The visually appealing nature of book-related data further enhances its suitability for an effective interactive visualization project.

The original Dataset was too large to be added to git, but can be found here:
Dataset: https://www.kaggle.com/datasets/pooriamst/best-books-ever-dataset

The source code for the dashboard is available on GitHub at:
https://github.com/anniemcpherson/ivi_report

# LO1: Performance

## Theory:

*In the realm of data analysis, interactive visualizations have become indispensable for extracting insights from increasingly large and complex datasets. The ability to dynamically explore data through interaction allows for deeper understanding and the discovery of hidden patterns. However, the very factors that make these visualizations powerful – substantial data volumes and intricate user interactions – can introduce significant performance bottlenecks, ultimately diminishing their utility and user experience. This chapter will delve into the primary causes of performance degradation in interactive visualizations and provide an overview of established and emerging strategies to mitigate these issues.*

As both Brendan Gregg's presentation and the EuroVis STAR Report emphasize, the sheer scale of modern datasets, often surrounding numerous variables, places immense strain on computational resources. Inefficiently designed visualizations can exacerbate these problems by requiring excessive rendering and processing. Gregg's insights highlight the critical role of underlying hardware infrastructure – encompassing CPU processing power, GPU rendering capabilities, memory capacity, and network bandwidth – in ensuring smooth and responsive interactions. Furthermore, the complexity inherent in user-driven interactions, such as intricate filtering, multi-level drilling down, and animated transitions, adds another layer of computational demand that can lead to sluggish performance if not carefully managed.

The provided resources offer a comprehensive overview of techniques aimed at optimizing the performance of interactive visualizations. Brendan Gregg's work advocates for foundational approaches like data reduction and aggregation to decrease the volume of data being processed and rendered. He also underscores the importance of selecting optimized visualization algorithms that are computationally efficient for the specific data and task. The EuroVis STAR Report by Isaacs et al. expands on this with advanced strategies. Tiling addresses the rendering of massive datasets by dividing the visualization into manageable chunks. Level of Detail (LOD) dynamically adjusts the visual complexity based on the user's focus, rendering fewer details when zoomed out and more when zoomed in. GPU acceleration leverages the parallel processing power of graphics cards for faster rendering. Efficient data structures, designed for rapid querying and retrieval, are crucial for supporting interactive exploration. Moreover, the prioritization and hierarchical organization of data ensures that only relevant information is loaded and displayed on demand, minimizing unnecessary processing.

Ultimately, achieving performant interactive visualizations requires a holistic understanding of the interplay between data characteristics, visualization design, and underlying technology. By recognizing the limitations of available resources and strategically implementing the discussed performance-enhancing techniques, developers and analysts can create fluid and responsive experiences that empower users to effectively explore and derive meaningful insights from their data. Continuous evaluation through benchmarking and user feedback is essential for iterative optimization and the creation of truly performant visualization solutions.

## Application:

Addressing Learning Outcome 1, which focuses on performance, the data preparation phase of this interactive book recommendation dashboard has been optimized by filtering the dataset to include only English language books, thereby reducing the overall data volume.
Furthermore, a crucial step involved identifying and correcting invalid publication years. By setting a realistic upper limit based on the current year (2025) and a generous buffer, converting out-of-range years to NAs, subsequent filtering and processing steps are made more efficient. Removing these unrealistic entries ensures that the application focuses on relevant data, preventing potential performance bottlenecks that could arise from processing erroneous or irrelevant information. Targeted data cleaning contributes to a more responsive and efficient user experience when interacting with the dashboard's filtering mechanisms.

## LO2: Dashboard design principles

### Theory:

*Interactive visualization frequently culminates in the creation of dashboards, sophisticated interfaces that integrate a variety of interactive controls and multiple, coordinated visual representations of data. The primary goal of well-designed dashboards is to empower users to efficiently explore complex datasets, identify critical patterns, and ultimately derive actionable insights to support informed decision-making. This chapter will delve into the fundamental design principles that underpin effective interactive dashboards, drawing upon the comprehensive insights provided in the Murray (2017) series. We will explore the crucial concepts of linked views, focus+context displays, the powerful technique of brushing and linking, and the guiding framework of Shneiderman's "Overview first, zoom and filter, details on demand" mantra.*

As likely emphasized throughout Murray's (2017) work, the strategic implementation of linked views forms a cornerstone of effective interactive dashboards. By displaying different attributes or perspectives of the same underlying dataset across multiple synchronized visualizations, users can gain a holistic understanding that would be impossible with isolated charts. The technique of brushing and linking serves as a vital bridge between these linked views. When a user selects or "brushes" a subset of data points in one visualization (e.g., highlighting a group of bars in a bar chart), the corresponding data points are simultaneously highlighted or selected in all other linked visualizations. This immediate visual correlation across different dimensions allows for powerful exploratory analysis, enabling users to uncover relationships, identify outliers, and understand the interconnectedness of various data aspects. The Murray papers illustrate diverse applications of linked views, showcasing how different combinations of chart types (e.g., scatter plots linked with histograms and parallel coordinate plots) can facilitate nuanced data exploration.

Interactive dashboards often need to present both high-level summaries and granular details. Focus+context displays, as likely discussed by Murray (2017), provide elegant solutions to this inherent challenge. These techniques allow users to zoom in on specific areas of interest to examine details without losing sight of the broader data landscape. Various methods exist to achieve this, including distortion techniques like fisheye lenses that magnify the focal area while compressing the periphery, or multi-scale displays that embed high-resolution insets within a lower-resolution overview. By maintaining contextual awareness while exploring specific details, users can better understand the significance of individual data points within the larger narrative presented by the dashboard. The Murray series likely provides examples of how these techniques enhance usability and prevent disorientation during in-depth data exploration.

Ben Shneiderman's influential "Overview first, zoom and filter, details on demand" mantra, likely a key topic in Murray (2017), offers a structured approach to designing effective interactive information interfaces, particularly relevant to dashboards. The "overview first" principal advocates for presenting users with an initial high-level summary of the entire dataset, enabling them to quickly grasp the main distributions, identify potential areas of interest, and formulate initial questions. The "zoom and filter" stage allows users to progressively refine their focus by zooming into specific regions of the data or applying filters to isolate relevant subsets based on specific criteria. Finally, the "details on demand" principle suggests providing access to detailed information about individual data points or groups only when the user explicitly requests it, preventing cognitive overload from an overwhelming amount of initial information. The Murray papers likely provide concrete examples of how interactive dashboards can be designed to seamlessly guide users through these stages of exploration, leading to more efficient and insightful data analysis.

### Application:

The design of the IVI Book Recommendations dashboard strategically incorporates core dashboard principles to facilitate effective data exploration. The deliberate separation of content into "Data Visualizations" and "Book Recommendation and List" directly reflects Shneiderman's "Overview first, zoom and filter, details on demand" mantra. The initial "Data Visualizations" page offers a broad understanding of the dataset, showcasing the popularity of different genres based on ratings and the distribution of publication years. This allows users to quickly identify key trends and potentially formulate initial areas of inquiry.

The "Book Recommendation and List" page then enables users to progressively refine their focus. The consistently accessible sidebar provides filtering controls for genre, publication year, and rating, allowing for targeted data subsetting based on individual preferences. The resulting book list then presents detailed information about the filtered selections, fulfilling the "details on demand" aspect. While fully linked views between the visualizations and the book list are a future development goal, the current consistent filtering mechanism provides an implicit connection, where trends observed in the visualizations can be directly explored in the book data. This phased approach prioritizes providing an initial contextual understanding before allowing users to delve into specific details relevant to their interests.

## LO3: Interaction Design (HCI Basics)

### Theory:

*In interactive visualizations, the design of user interaction is paramount for enabling effective data exploration and analysis. Users must be able to seamlessly navigate the interface and engage with the data through various interaction techniques. This chapter will explore fundamental Human-Computer Interaction (HCI) principles and specific interaction paradigms relevant to interactive visualizations, particularly within the context of linked views on a dashboard, drawing upon the principles outlined in Sharp, Preece, and Rogers' "Interaction Design" and insights from the other linked resources.*

Fundamental interaction techniques such as selection, zoom, and filtering are essential building blocks for user engagement with interactive visualizations. Selection allows users to highlight specific data points or subsets for closer inspection and potential linking across views. Zoom functionalities enable users to navigate different levels of detail within a visualization, providing both overview and granular perspectives. Filtering empowers users to dynamically reduce the displayed data based on specific criteria, allowing them to focus on relevant information and explore specific relationships. The design of these basic interactions should be intuitive and efficient across various input modalities, including mouse, keyboard, and touch interfaces, ensuring accessibility and ease of use regardless of the hardware platform.

Beyond basic interactions, advanced techniques can further enhance the user experience in interactive visualizations. As highlighted in the research paper, these can include sophisticated selection methods, dynamic querying, and the integration of alternative input modalities such as gesture and voice control. The choice of advanced techniques should be driven by the specific analytical tasks and the target user group. For instance, gesture-based interactions might be suitable for touch-based interfaces on tablets or large displays, while voice commands could offer hands-free control in specific scenarios. Responsiveness across different hardware platforms, including desktops, laptops, tablets, smartphones, and even extended reality (XR) environments, is a crucial consideration in designing these interactions.

Effective navigation is critical, especially within dashboards featuring multiple linked views. Animated transitions can provide visual cues that help users understand the relationships between different states or views as they interact with the data. Smooth transitions between zoomed levels or filtered subsets can maintain user orientation and cognitive flow. Breadcrumbs, a common UI pattern, offer a clear navigational history, allowing users to easily retrace their steps and navigate back to previous states within the visualization or dashboard. These seemingly simple strategies contribute significantly to the overall usability and learnability of interactive visualizations.

A user-centered design approach is essential for creating effective and intuitive interactive visualizations. The users' tasks, goals, and cognitive processes should influence all design decisions. The Cognitive Walkthrough, as described in the usability resource, is a usability evaluation method that focuses on assessing the ease of learning and the discoverability of tasks within an interface. By stepping through typical user tasks, designers can identify potential usability issues and areas for improvement in the interaction design of their visualizations and dashboards.

## Application:

The Book Recommendations dashboard prioritizes fundamental Human-Computer Interaction (HCI) principles in its interaction design. The sidebar serves as the primary point of user engagement, utilizing core interaction techniques commonly found in user interfaces. Selection of book genres is enabled through a selectInput component, allowing for single or multiple choices. Filtering of the dataset by publication year and average rating is implemented using sliderInput elements, providing a visual and direct manipulation method for narrowing down results. The action of discovering a random book suggestion is triggered by a clearly labeled actionButton.

These basic interaction elements are intentionally chosen for their intuitiveness and reliance on standard UI patterns, aiming to minimize the learning curve for users with varying levels of technical proficiency. The dashboard is currently designed for optimal interaction using a mouse and keyboard, aligning with typical desktop or laptop usage. However, future development could include ensuring a responsive design that seamlessly adapts to touch-based interaction on tablet devices. Enhancements to the user experience could include providing subtle visual feedback when filters are applied or when a new random recommendation is generated, improving the user's sense of control and understanding of the system's responses. The overall interaction design focuses on empowering users to efficiently find and explore books based on their preferences and discover new titles through a straightforward and accessible interface.

## LO4: Evaluation

### Theory:

*Evaluating the usability and user experience of interactive visualizations and dashboards is a critical step in the design process. It allows designers to understand how effectively users can interact with the interface, extract information, and achieve their analytical goals. This chapter will explore various methods for evaluating interactive visualizations, drawing upon the insights from the IEEE paper on evaluating information visualization interfaces and the task-based evaluation framework proposed by Prof. Dr. Çöltekin et al.*

Reflecting on fundamental concepts from data visualization, the evaluation of interactive systems often centers on usability and user experience (UX). Usability encompasses the effectiveness, efficiency, and satisfaction with which users can achieve specific goals. Key aspects include learnability, efficiency of use, memorability, error prevention, and satisfaction. User experience, on the other hand, is a broader concept encompassing all aspects of the end-user's interaction with the visualization, including their perceptions, emotions, and overall satisfaction. Effective evaluation aims to measure both the practical aspects of task completion (usability) and the subjective aspects of the interaction (UX).

The choice of evaluation method depends on the specific goals of the evaluation and the stage of the design process. As highlighted in the IEEE paper, various techniques can be employed. User studies involve observing users interacting with the visualization to perform specific tasks, collecting both quantitative data (e.g., task completion time, error rates) and qualitative feedback (e.g., user comments, satisfaction ratings). Online questionnaires can gather user opinions and preferences from a larger audience. Qualitative interviews allow for in-depth exploration of user experiences and pain points. Hypothesis testing can be used to statistically compare different design choices. Eye-tracking studies can provide insights into users' visual attention and interaction patterns. Often, a combination of methods provides a more comprehensive understanding of the visualization's effectiveness. The Çöltekin et al. paper emphasizes a task-based evaluation framework, where users are given specific analytical tasks to perform, and their performance and subjective experiences are systematically measured. This approach directly assesses the visualization's ability to support intended user activities.

Selecting the appropriate evaluation method is crucial for obtaining meaningful results. The justification for the chosen method should clearly articulate how it aligns with the research questions or evaluation goals. For example, if the goal is to understand the learnability of a new interaction technique, a user study with novice users and qualitative interviews might be suitable. If the focus is on comparing the efficiency of two different dashboard layouts, a task-based evaluation with quantitative performance metrics would be more appropriate. The chosen method should be sensitive to the aspects of usability and user experience that are most relevant to the specific interactive visualization being evaluated.

Evaluation is not a one-time activity but rather an integral part of an iterative design process. The insights gained from evaluating interactive visualizations should inform design revisions and lead to continuous improvement in usability and user experience. By systematically assessing how users interact with and perceive visualizations, designers can create more effective tools for data exploration and analysis.

## Application:

To evaluate the user-friendliness of the book recommendation dashboard, a user study was conducted with a diverse group including both tech-savvy and non-tech-savvy individuals. - Participants were given a prompt before interacting with the dashboard, such as 'Find a book you would read, and as much information as possible on the genre'. Afterwards, they completed a short questionnaire focusing on ease of use, clarity, intuitiveness, and their ability to achieve the goal in the prompt. Open-ended feedback was also collected.

The prompt gave insight into the functionality on the dashboard and if the intended goal of the project had been fulfilled. As well showing new uses participants found besides the prompt.

The most frequent comment surrounded the need for a way to get more information on books out of the book list. This led to the third tab 'Book Details' where users can search the books they've been recommended and read the description.

Other suggestions were made, such as a 'select all' option for the filter setting on the book recommender, which I wasn't able to execute elegantly, but would be a great enhancement for a later time.

Overall, the feedback was overwhelmingly positive, and I am grateful for my colleges taking the time. For the tests I sat down with the users and let them interact with the dashboard by themselves before discussing the questions.
To evaluate the dashboard more harshly next time I will try leaving the users completely alone with the dashboard and questions, as even though I tried to intervene as little as possible I found more critique may have been given, in a non-face-to-face setting.