Interactive Visualization

Sweden's vast Bird Fauna

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Contents

Chapter 1

Performance

When working with interactive visualizations, performance plays a crucial role in ensuring a smooth user experience, especially as datasets grow larger and more complex. With increasing data points and variables, the demand for both computational power and efficient rendering becomes essential. Interactive visualizations can encounter performance bottlenecks due to factors such as data size, rendering techniques, bandwidth, and hardware limitations. As data size increases, performance issues can manifest in the form of delayed rendering, increased memory usage, and ultimately, a sluggish or unresponsive interface. These challenges make it essential to understand and implement performance-enhancing solutions such as tiling, level of detail (LOD) management, GPU acceleration, and hierarchical data organization.

In this context, two experiments were conducted to benchmark and understand the performance implications of interactive visualizations, both in terms of data size and choice of visualization libraries. The following sections analyze these experiments, where Figure 1.1 and Figure 1.2 showcase the performance metrics obtained.

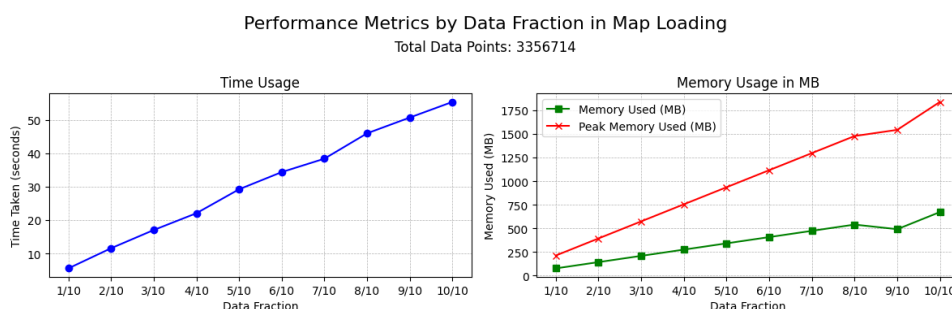## 1.1   Experiment 1: Impact of Data Size

Figure 1.1: Performance metrics for incremental data loading in a map visualization.

Figure 1.1 illustrates the performance metrics captured when incrementally loading fractions of a dataset into a map visualization. In this experiment, each data point represented a bird observation in Sweden, and fractions of the dataset were loaded from 1/10th up to the entire dataset (10/10ths, or 3'356'714 observations). Two metrics were recorded: Time Usage (in seconds) and Memory Usage (in MB).

1.1.1   Time Usage Analysis

The left subplot of 1.1 shows a linear trend in time consumption as the data fraction increases. The time taken rises from approximately 10 seconds for 1/10th of the data to over 50 seconds for the entire dataset. This trend reflects the computational load associated with managing and rendering larger datasets in real-time.

This increase in time usage can be attributed to the overhead of both loading data into memory and the rendering process itself. With each increment, the visualization needs to plot more points on the map, which places a growing strain on both the CPU and GPU, depending on the level of interactivity and graphical requirements.

1.1.2   Memory Usage Analysis

The right panel of Figure 1 captures memory usage with two lines: one for Memory Used and another for Peak Memory Used. Memory Used remains relatively lower, while Peak Memory steadily climbs with

each data increment.

The growing gap between regular and peak memory usage can be attributed to the temporary memory required to process the data before rendering. As the data size increases, the visualization needs to allocate more temporary memory for computation, even if the plotted memory stabilizes.

This memory trend suggests that managing data efficiently, such as by tiling or downsampling, could reduce the memory load, making the visualization more responsive without compromising on detail.

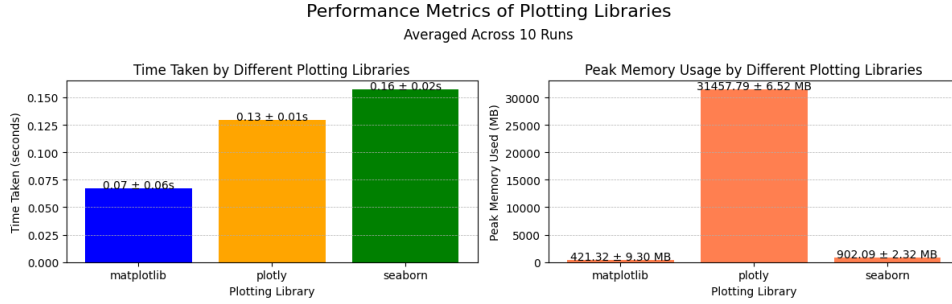## 1.2 Experiment 2: Impact of Plotting Library on Performance

Figure 1.2: Performance metrics for different plotting libraries.

In Figure 1.2, the performance of three plotting libraries—Matplotlib, Plotly, and Seaborn—was measured by plotting the frequency of the 10 most common bird species in Sweden. To ensure accuracy and confidence in the results, each test was run 10 times, and the Time Taken and Peak Memory Usage metrics were averaged across these runs, with standard deviations included to quantify variability.

1.2.1 Time Taken Analysis

The left panel of Figure 1.2 shows that Matplotlib remains the fastest library, with an average time of 0.07 seconds ± 0.06 seconds. Plotly and Seaborn, however, took considerably longer, with average times of 0.14 seconds ± 0.02 seconds for Plotly and 0.15 seconds ± 0.01 seconds for Seaborn.

The high standard deviation for Matplotlib indicates some variability in its runtime, possibly due to fluctuations in processing lower-level operations. In contrast, Plotly and Seaborn show relatively stable performance with smaller standard deviations, reflecting their structured approach to rendering but at the cost of increased processing time.

Matplotlib's efficiency is likely due to its streamlined focus on static plotting, while Plotly's interactivity and Seaborn's additional styling complexity add to their time overhead. These findings emphasize that while Matplotlib is optimal for static visualizations, Plotly and Seaborn introduce extra time due to their functionality and aesthetic layers, respectively.

1.2.2 Memory Usage Analysis

The right panel of Figure 1.2 reveals a stark contrast in peak memory usage among the libraries. Plotly uses significantly more memory, averaging 31,471.73 MB ± 40.09 MB, highlighting the high cost of interactivity. Seaborn requires considerably less memory, averaging 903.09 MB ± 2.13 MB, and Matplotlib remains the most memory-efficient, with an average of 422.25 MB ± 9.62 MB.

The consistent but high memory usage for Plotly suggests that its interactive features, such as hover and zoom functionality, impose a substantial memory footprint. These features, while enhancing user engagement, demand extensive resources for rendering and data management, particularly when handling large datasets or complex visualizations.

Seaborn, despite being built on top of Matplotlib, requires additional memory to manage stylistic elements. Matplotlib's low memory usage reaffirms its suitability for static visualizations where memory constraints are critical. This suggests that when designing interactive visualizations with large datasets,

it is essential to account for Plotly's memory requirements, while Matplotlib and Seaborn serve as better choices for simpler plots.

Chapter 2

Design Principles

2.1   Introduction to Shneiderman's Mantra

In the realm of information visualization, effective data exploration is really important. Ben Shneiderman, a prominent figure in human-computer interaction, proposed a foundational guideline known as Shneiderman's Mantra to improve user interaction with complex datasets. The mantra states: *"Overview first, zoom and filter, then details-on-demand"* [1]. This principle stands as a blueprint for designing intuitive interfaces that hold efficient data analysis.

Shneiderman's Mantra emphasizes a hierarchical approach to data exploration:

1. **Overview First**: Present the entire dataset in a high-level view to provide context and scope.

2. **Zoom and Filter**: Allow users to focus on subsets of the data that interest them.

3. **Details on Demand**: Enable access to detailed information about specific data points when required.

This sequence allows interfaces to cater to both regular users and experts and provide scalable means to interact with data of varying complexity.

2.2   Implementation in the Birds of Sweden Dashboard

I developed the Birds of Sweden Dashboard in this course to enable users to navigate and explore Sweden's bird fauna interactively. Implementing Shneiderman's Mantra within this dashboard makes sure that users can effectively analyze bird observation data across the country.

2.2.1   Overview First

Upon launching the dashboard, users are presented with a comprehensive map displaying all bird observations across Sweden (Figure 2.1). This initial view provides an immediate sense of the spatial distribution and density of bird sightings which fulfills the "Overview First" principle.
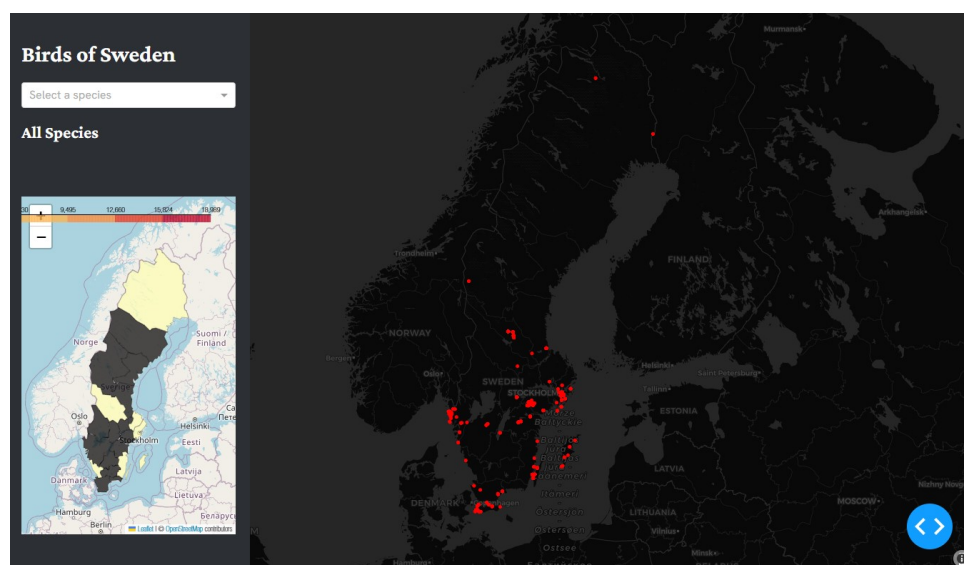

Figure 2.1: Initial overview of all bird observations in Sweden.

The map utilizes a scatter plot where each point represents an observation, allowing users to perceive patterns such as hotspots of biodiversity or migratory pathways. Additionally, the sidebar includes a state observations map that consistently displays the entire country's outline, highlighting the number of observations per state. This reinforces the comprehensive nature of the overview.

2.2.2 Zoom and Filter

To facilitate more focused exploration, the dashboard incorporates interactive filtering mechanisms. A dropdown menu enables users to select a specific bird species from an extensive list derived from the dataset (Figure 2.2). Upon selection, the main map updates to display only the observations pertaining to the chosen species.
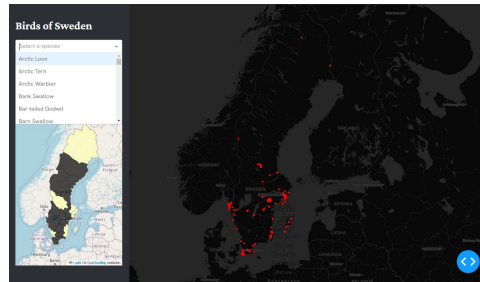
Figure 2.2: Species selection dropdown for filtering observations.

This filtering capability exemplifies the "Zoom and Filter" principle, allowing users to narrow down the dataset to areas or species of interest. The state observations map in the sidebar also updates accordingly, highlighting only the states where the selected species has been observed, thus providing a filtered geographical context (Figure 2.3).
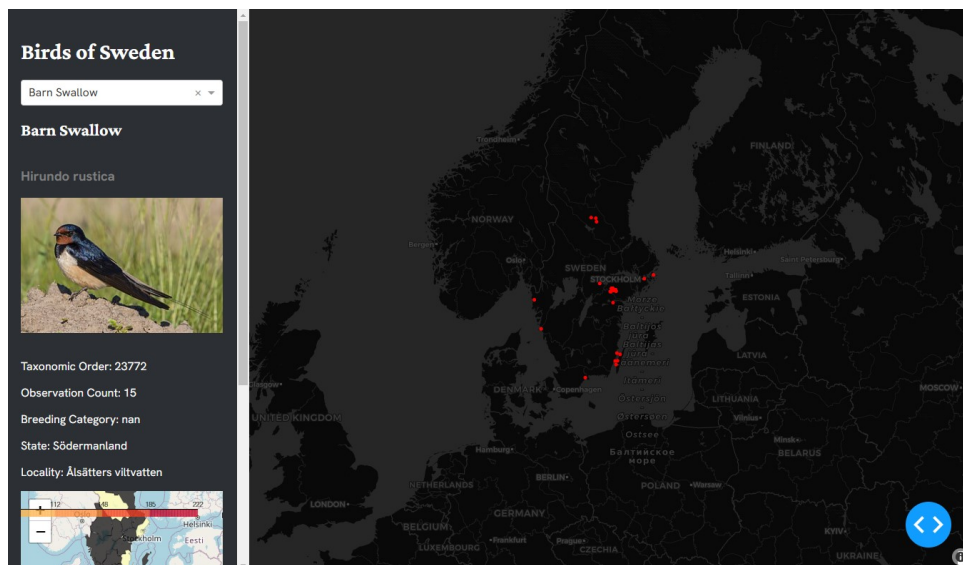
Figure 2.3: Map displaying observations of a selected species after filtering.

2.2.3 Details on Demand

To offer in-depth information, the dashboard provides detailed data about specific observations and species. When a species is selected, the sidebar displays:

- **Species Name and Scientific Name**: Clarifies the common and scientific nomenclature.

- **Species Image**: Retrieves an image from Wikipedia for visual identification.

- **Additional Information**: Presents taxonomic order, observation count, breeding category, state, and locality.

This implementation of "Details on Demand" ensures that users can access specific information without overwhelming the initial view. Moreover, clicking on an observation point on the map sets the species in the dropdown, updating the sidebar with relevant details (Figure 2.4).

Figure 2.4: Detailed information displayed upon species selection.

2.2.4 Technical Implementation

The dashboard leverages the Dash framework for Python, enabling the creation of interactive web applications. Key implementation aspects include:

- **Data Loading**: The full dataset is loaded without slicing to ensure all observations and species are available.

- **Data Cleaning**: Missing values in critical columns such as `LATITUDE`, `LONGITUDE`, and `COMMON NAME` are handled to prevent empty maps or dropdowns.
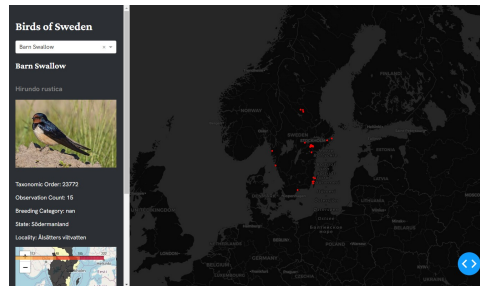
- **Callbacks**: Dash callbacks are used to update the map and sidebar components dynamically based on user interactions.

- **Geographical Consistency**: The state observations map uses the `fitbounds="geojson"` parameter to always display the entire country's outline, regardless of the data filtered.

By addressing initial issues such as empty maps on startup and mismatches in state naming conventions, the dashboard now aligns with the intended functionality and provides a seamless user experience.

2.3 Goals and Hopes for the Dashboard

The primary objective of implementing Shneiderman's Mantra in the Birds of Sweden Dashboard is to enhance user interaction and facilitate the exploration of bird fauna data. The specific goals include:

2.3.1 Improving User Interaction and Experience

By providing an intuitive interface that adheres to established principles of information visualization, users can navigate the dataset effectively, regardless of their familiarity with the data. The hierarchical approach reduces cognitive load and allows for a more engaging experience.

2.3.2 Facilitating Exploration of Sweden's Bird Fauna

The dashboard serves as an educational tool, enabling users to discover patterns and insights within the bird observation data. For instance, users can identify regions with high biodiversity, track migration patterns, or explore species distribution.

2.3.3 Enabling Users to Gain Insights

Through interactive filtering and detailed information access, users can perform analyses that may lead to new findings or support research efforts. Conservationists, ornithologists, and bird enthusiasts alike can leverage the dashboard to inform their work or interests.

2.4 Conclusion

Implementing Shneiderman's Mantra in the Birds of Sweden Dashboard has resulted in a powerful tool for data exploration. By providing an initial overview, enabling focused filtering, and offering detailed information on demand, the dashboard aligns with best practices in information visualization. The hope is that this approach not only enhances user engagement but also contributes to a deeper understanding of Sweden's rich bird fauna.

Chapter 3

HCI Basics

3.1 Introduction

Human-Computer Interaction focuses on creating interfaces that are not only functional but also intuitive and accessible to users. In the context of the *Birds of Sweden Dashboard*, HCI principles guide the design decisions to ensure users can effectively explore and analyze bird observation data across Sweden.

This chapter goes through how Interaction Design principles are applied.

3.2 Interaction Design and the Five Dimensions

3.2.1 What is Interaction Design?

Interaction Design (IxD) is the discipline of designing interactive products and services with a focus on how users will interact with them. It goes beyond the mere functionality of an item, considering users' needs, limitations, and contexts to tailor the experience accordingly [2]. This user-centered approach ensures that the design meets precise demands, facilitating seamless interaction between the user and the product.

3.2.2 Application of Weber's Law and Fitts's Law

Perceptual laws like Weber's Law and Fitts's Law play a significant role in interface design, influencing how users perceive and interact with elements.

Weber's Law Weber's Law states that the just-noticeable difference between two stimuli is proportional to the magnitude of the stimuli [3]. In interface design, this means that subtle differences in element sizes or colors may go unnoticed.

Fitts's Law Fitts's Law predicts that the time required to move to a target area is a function of the distance to the target and the size of the target [3]. Smaller targets that are farther away are harder and slower to click.

Application to the Dashboard

- **Hoverability of Data Points**: Initially, small scatter points on the map made it difficult for users to hover over and click them, violating Fitts's Law.

- **Improvement Implemented**: By adding `hovermode='closest'` to the scatter mapbox, the interactive area around each data point (cursor bubble) was increased.

- **Benefits**:
  - **Easier Interaction**: Users do not need to precisely hover over tiny points, reducing the effort and time required.
  - **Enhanced Accessibility**: Larger interactive areas assist users with motor impairments or those using touch devices.

3.2.3 The Five Dimensions of Interaction Design

Gillian Crampton Smith and Kevin Silver defined five dimensions that interaction designers consider when designing interactions [2]:
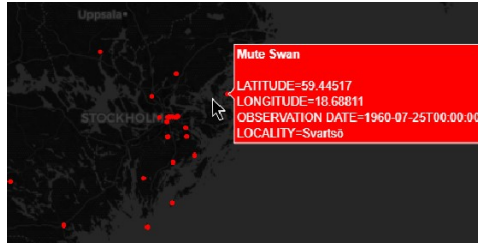
Figure 3.1: Tooltip displayed if cursor is near a data point.

1. **Words (1D)**: Text elements like button labels that provide necessary information to users.

2. **Visual Representations (2D)**: Graphical elements such as images, typography, and icons that aid user interaction.

3. **Physical Objects/Space (3D)**: The medium through which users interact with the product, like a mouse, keyboard, or touch screen.

4. **Time (4D)**: Media that change over time, including animations, videos, and sounds.

5. **Behavior (5D)**: How the previous dimensions define the interactions a product affords, including user actions and system reactions.

Interaction designers utilize these dimensions to consider interactions holistically, envisioning real-world user demands for designs not yet introduced.

3.2.4 Application to the Birds of Sweden Dashboard

The *Birds of Sweden Dashboard* incorporates the five dimensions of interaction design to enhance user experience:

Words (1D) The dashboard uses clear and concise text to guide users:

- **Button Labels and Dropdown Options**: The species selection dropdown is labeled "Select a species," providing a straightforward instruction.

- **Informational Text**: The sidebar displays species names, scientific names, and additional details, ensuring users understand the information presented.

Visual Representations (2D) Graphical elements are employed to facilitate understanding:

- **Maps**: The main map and the state observations map visually represent bird observations geographically.

- **Images**: Species images retrieved from Wikipedia help users visually identify birds.

- **Icons and Typography**: Consistent use of fonts and styling enhances readability and aesthetic appeal.

Physical Objects/Space (3D) Users interact with the dashboard through various physical mediums:

- **Mouse**: Primary interaction for clicking, hovering, and navigating the map.

- **Keyboard**: Supports navigation through the dropdown and accessibility features.

- **Touch Devices**: Basic touch interactions are possible, though optimization is needed.

Time (4D) Temporal elements enhance the interactive experience:

- **Interactive Map Updates**: The map dynamically updates when a species is selected, providing immediate feedback.

- **Hover Effects**: Tooltips appear when hovering over data points, offering additional information.

Behavior (5D)   The dashboard's behavior defines user interactions:

- **User Actions**: Selecting species, zooming the map, and clicking on data points are intuitive actions supported.

- **System Reactions**: The dashboard responds to user inputs by updating visuals and information displayed, reinforcing progress toward user goals.

3.3   Cognitive Walkthrough

A cognitive walkthrough was performed using Rick Spencer's *Streamlined Cognitive Walkthrough Method* [4] to evaluate the dashboard's usability. The walkthrough focuses on typical tasks users might perform, assessing whether the interface supports these tasks effectively.

3.3.1   Users and Tasks

User Profile   The primary users are:

- **Bird Enthusiasts**: Individuals interested in birdwatching and bird data exploration.

- **Ornithologists and Researchers**: Professionals studying bird patterns and behaviors.

- **Conservationists**: Individuals involved in wildlife conservation efforts.

Selected Tasks   Four key tasks were identified:

1. Explore the overall distribution of bird observations.

2. Find information about a specific bird species.

3. Identify regions where a selected species is commonly observed.

4. View detailed information about a specific observation.

3.3.2   Action Sequences and Walkthrough Analysis

The action sequences are presented on the left, with the corresponding walkthrough on the right.

Task 1: Explore Overall Distribution of Bird Observations

Action Sequence	Walkthrough Analysis
1. Open the dashboard. 2. Observe the initial map displaying all observations.	• **Will the user know what to do?** Yes; the map is immediately visible upon opening the dashboard. • **Will the user know they are making progress?** Yes; the dense distribution of data points indicates active observations.

Table 3.1: Cognitive Walkthrough for Task 1

Task 2: Find Information About a Specific Bird Species

Action Sequence	Walkthrough Analysis
1. Locate the species dropdown in the sidebar. 2. Click on the dropdown to view options. 3. Type or scroll to find the desired species. 4. Select the species from the list.	• **Step 1**: The dropdown is labeled and prominently placed, so users will know what to do. • **Step 2**: Clicking the dropdown is a common interaction. • **Step 3**: Users can type to search or scroll through the list. • **Step 4**: Upon selection, the map and sidebar update, so users know they are making progress.

Table 3.2: Cognitive Walkthrough for Task 2

Task 3: Identify Regions Where the Selected Species is Commonly Observed

Action Sequence	Walkthrough Analysis
1. Observe the main map after species selection. 2. Note the distribution of observation points. 3. Look at the state observations map in the sidebar.	• **Step 1**: The map is the focal point, so users know what to do. • **Step 2**: Clusters indicate regions with frequent observations, helping users track progress. • **Step 3**: The sidebar map provides a choropleth view. Color intensities reflect observation counts, so users understand their progress.

Table 3.3: Cognitive Walkthrough for Task 3

Task 4: View Detailed Information About a Specific Observation

Action Sequence	Walkthrough Analysis
1. Hover over a data point on the main map. 2. Click on the data point. 3. Observe any additional information displayed.	• **Step 1**: Users may naturally hover, but tooltips might not be expected if points are small. • **Step 2**: Clicking is not immediately obvious; a prompt could help. • **Step 3**: The sidebar updates, but additional visual feedback (e.g., animation) would improve the experience.

Table 3.4: Cognitive Walkthrough for Task 4

Chapter 4

Evaluation

4.1 Introduction

Evaluating the usability and user experience of an interactive visualization is crucial to ensure it meets the needs of its intended audience. This chapter presents an evaluation of the *Birds of Sweden Dashboard* through a qualitative user study involving five participants from diverse backgrounds. The goal is to gain insights into how different users perceive and interact with the dashboard, identifying strengths and areas for improvement.

4.2 Methodology

4.2.1 Selection of Evaluation Method

A qualitative interview approach was chosen for this evaluation due to its effectiveness in exploring users' thoughts, feelings, and experiences in depth. Unlike quantitative methods, qualitative interviews allow for open-ended responses, providing rich insights into user behavior and preferences. This method is appropriate for measuring user experience in the context of the dashboard, as it enables the identification of usability issues and the collection of detailed feedback that can inform future design enhancements.

4.2.2 Participants

Five users with varying backgrounds, expertise, and interests related to bird observation and data visualization were involved in a qualitative interview:

1. **Anna** – A 31-year-old bird enthusiast and amateur photographer who enjoys birdwatching during her travels across Sweden.

2. **Lasse** – A 50-year-old conservationist and hobby ornotihologist.

3. **Noah** – A 23-year-old web developer studying Data Science.

4. **Boran** – A 24-year-old carpenter, now studying Data Science.

5. **Agnetha** – A 65-year-old retiree who recently started birdwatching as a hobby and is not very tech-savvy.

4.3 Interview Questions

Five open-ended questions were designed to explore key aspects of the user experience:

1. **How intuitive did you find the navigation and interaction with the dashboard?**

   Purpose: To assess the overall usability and whether users can navigate the interface without confusion.

2. **What features did you find most useful or engaging, and why?**

   Purpose: To identify which elements of the dashboard are most valued by users, informing future enhancements.

3. **Were there any difficulties or frustrations you encountered while using the dashboard?**

   Purpose: To uncover usability issues or pain points that need to be addressed.

4. **How well does the dashboard cater to your specific needs or interests related to bird observation?**

   Purpose: To evaluate the dashboard's effectiveness in meeting the diverse needs of different user groups.

5. **What improvements or additional features would you suggest for the dashboard?**

   Purpose: To gather user-driven ideas for enhancements that could improve satisfaction and usability.

4.4 Results

The participants' responses are summarized below. Tables are used to present the key points from each interview for clarity.

Participant	Responses
Question 1: Navigation and Interaction Intuitiveness	
Anna	Found the dashboard mostly intuitive, appreciated the straightforward species selection, but initially unsure about clicking on map points for details.
Lasse	Navigated easily due to familiarity with similar tools; found the interface clean and professional.
Noah	As a developer, found the interface user-friendly and appreciated the responsive design.
Boran	Experienced slight confusion with the sidebar updates; suggested clearer visual cues when data changes.
Agnetha	Felt overwhelmed at first but became comfortable after a brief exploration; found the dropdown helpful once located.
Question 2: Most Useful or Engaging Features	
Anna	Loved the species images and details; enjoyed seeing where her favorite birds are commonly found.
Lasse	Valued the data visualization of observation distributions; useful for his research on migration patterns.
Noah	Impressed by the interactive maps; appreciated the hover effects and dynamic updates.
Boran	Found the state observations map valuable for identifying regions needing conservation efforts.
Agnetha	Enjoyed the ability to select different species and see where they are located; found it engaging and educational.

Table 4.1: Participant Responses to Questions 1 and 2

Participant	Responses
Question 3: Difficulties or Frustrations	
Anna	Had trouble hovering over small data points; suggested larger clickable areas or zoom functionality.
Lasse	Noted a lack of advanced filtering options, such as filtering by date or observation count.
Noah	Pointed out that the dashboard is not fully optimized for mobile devices; experienced issues on her tablet.
Boran	Found it challenging to use the dashboard with assistive technology; suggested improvements for accessibility.
Agnetha	Initially confused about how to select a species; the dropdown was not immediately apparent to her.
Question 4: Catering to Specific Needs or Interests	
Anna	Felt the dashboard catered well to her interest in discovering new birdwatching spots.
Lasse	Appreciated the geographical data but desired more detailed analytics for academic purposes.
Noah	Found it inspiring for design ideas; appreciated the integration of interaction design principles.
Boran	Saw potential for using the dashboard in conservation planning but needed more data layers.
Agnetha	Enjoyed learning about different species; helped her as a beginner in birdwatching.
Question 5: Suggestions for Improvements	
Anna	Recommended adding bird call sounds to enhance the experience; suggested a tutorial for new users.
Lasse	Suggested incorporating time-series data to observe changes over seasons or years.
Noah	Proposed making the dashboard more responsive for mobile use; adding gesture controls.
Boran	Emphasized the need for accessibility features like screen reader support and high-contrast modes.
Agnetha	Wanted larger text and icons; suggested simplifying the interface for ease of use.

Table 4.2: Participant Responses to Questions 3, 4, and 5

4.5 Analysis

The qualitative interviews revealed several key themes and insights:

4.5.1 Usability and Navigation

Most participants found the dashboard intuitive, particularly those with technical backgrounds. However, less tech-savvy users like Sara experienced initial confusion, indicating a need for improved onboarding or tutorials. The visibility of interactive elements like the species dropdown could be enhanced to aid navigation.

4.5.2 Engaging Features

Interactive maps and species information were consistently highlighted as valuable features. Visual representations and the inclusion of images contributed positively to user engagement, aligning with the importance of visual elements in interaction design.

4.5.3 Usability Issues and Frustrations

Common difficulties included:

- **Hovering over Data Points**: Small interactive areas made it challenging to access tooltips, supporting the need to apply Fitts's Law considerations.

- **Accessibility**: Users like Olle emphasized the lack of support for assistive technologies, echoing the findings from the literature on accessible visualization.

- **Mobile Optimization**: Issues on tablets and mobile devices suggest the dashboard is not fully responsive, limiting usability across devices.

4.5.4   Meeting User Needs

Participants with specific interests, such as conservation and research, found the dashboard partially met their needs but desired more advanced features like filtering options and additional data layers. This indicates opportunities to expand functionality to cater to specialized user groups.

4.5.5   Suggestions for Improvement

Key recommendations included:

- **Enhancing Accessibility**: Implementing features like screen reader support and high-contrast modes.

- **Mobile Responsiveness**: Optimizing the dashboard for use on tablets and smartphones.

- **Interactive Enhancements**: Adding bird sounds, gesture controls, and tutorials to improve engagement and usability.

- **Advanced Features**: Incorporating time-series data and advanced filtering to support research and conservation efforts.

4.6   Conclusion

The evaluation provided valuable insights into the user experience of the *Birds of Sweden Dashboard.* While the dashboard effectively engages users and offers useful features, there are areas for improvement, particularly in accessibility, mobile optimization, and user guidance. Addressing these issues will enhance usability for a broader audience, ensuring the dashboard meets the needs of diverse users ranging from casual bird enthusiasts to professional researchers.

Future development should focus on:

- **Improving Accessibility**: Integrate support for assistive technologies and design for inclusivity.

- **Optimizing for Mobile Devices**: Ensure responsive design principles are applied for seamless use across all devices.

- **Enhancing Interactivity**: Implement user suggestions like auditory feedback and gesture controls to enrich the interactive experience.

- **Expanding Functionality**: Add advanced features like time-series data and detailed filtering to cater to specialized user needs.

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