Fostering Comparisons: Designing an Interactive Exhibit that Visualizes Marine Animal Behaviors

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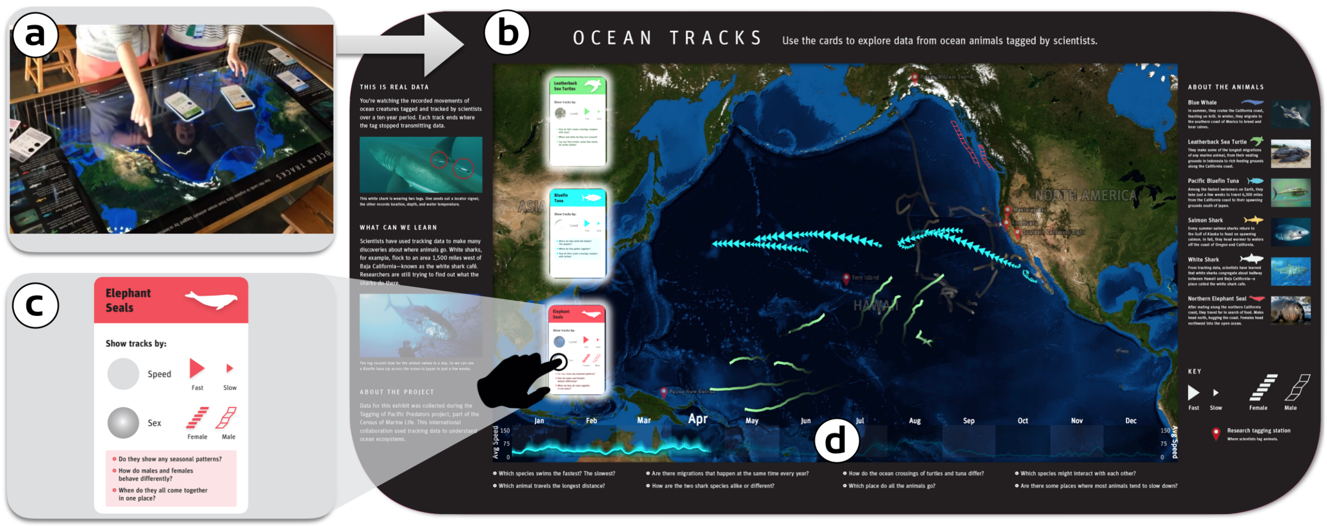

Figure 1: A system overview of our exhibit prototype which allows museum visitors to explore migratory marine animal trajectories over time. (a) Visitors place the cards on the table to observe animal migration patterns. This picture was taken when we conducted the formative evaluation in the museum. (b) The label around the table provides background knowledge of the data set and a legend of visualizations. (c) Placing the physical card on the table will highlight the corresponding species. Visitors can tap the buttons through holes to toggle different visual encodings. (d) The timeline shows the speed profile of selected species visualized with the speed encoding.

Abstract

We share our challenges and lessons learned in designing our exhibit prototype that encourages museum visitors to learn about marine animal behaviors through interactive visualization and data exploration. Our intent is to have visitors draw comparisons between animal behaviors, similarly to how scientists would, to make insights and discoveries. In our efforts, we have designed a set of visual encodings around the Tagging of Pelagic Predator (TOPP) data set to create the appropriate abstractions of this rich and complex field data. We have incorporated Multiple External Representations (MERs) and tangible user interfaces (TUIs) to provide a complementary representation of the data and promote self-learning. Through the formative evaluation, we can identify a few strengths and weaknesses of our prototype design. Our evaluation results suggest that we are progressing in the right direction—we observed the public making some comparisons and inferences—but still require further design iterations to improve our visualization exhibit.

1 Introduction

Designing an interactive visualization exhibit for a museum setting poses unique challenges. Visualizations intended for the public differ greatly from those designed for professional domain users. To bridge this gap between the professional and the public, we focused on developing an exhibit experience for visitors to engage their inner data scientist and learn through inquiry, which we hoped would lead to insights and discoveries of the data. We focused our design to foster comparisons, as it is a salient characteristic of inquiry-based learning. In an ongoing effort to create an effective visualization in this regard, we prototyped a set of visual representations to be explored using TUIs and MERs with a multi-touch, object-tracking table.

We visualized the data from the TOPP program, an international, multidisciplinary collaboration that collects and studies data about highly-active migratory species in the Pacific Ocean. The data can be used to characterize a multitude of marine animals behaviors in response to factors such as environmental (e.g. temperature, chlorophyll, and ocean current) and biological variables (prey availability and primary production) [2, 10]. Increasing understanding of their movements enables scientists to study animals' habits and address the impacts of global climate change and other human-induced environment changes. In our exhibit, we curated the data and visualized the migratory patterns of six species: White Sharks, Salmon Sharks, Bluefin Tuna, Leatherback Sea Turtles, Blue Whales, and Northern Elephant Seals. We chose to highlight speed and sex patterns such that visitors can make meaningful comparisons of these data attributes.

In this paper, we introduce our exhibit design, which highlights our use of TUIs and MERs, and discuss the results of our prototype's formative evaluation. The formative evaluation was conducted by the Visitor Research and Evaluation (VRE) Department at San Francisco's Exploratorium, a museum of science, art, and human perception. This formative evaluation helped identify issues which are to be addressed in future design iterations, but also highlights the potential in our visualization for supporting inquiry-based learning. We have a follow-up paper in development, focusing on a more rigorous assessment of this prototype.

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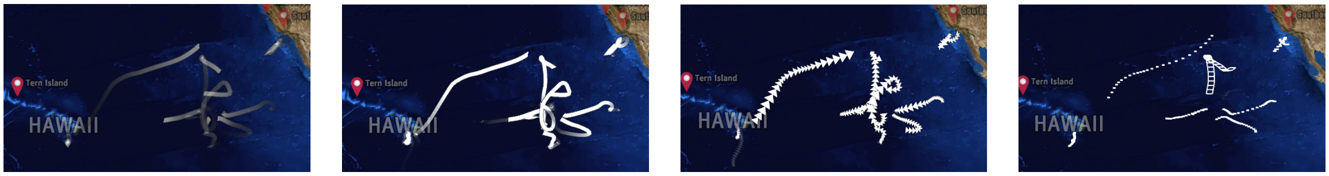

(a) Inactive (b) Active (c) Speed (d) Sex

Figure 2: Four trajectory visual encodings used in the prototype. (a) Inactive is designed to minimize distractions, but still entice viewers. (b) Active is bright to identify selected species and follow their movement. (c) Speed uses triangles to quantify speed: Faster speeds are drawn to be larger, whereas slower speeds are smaller. (d) Sex uses patterns to isolate behaviors indicative of males or females of the selected species.

2 Related Work

Most visualizations are designed around professional domain users, let alone to the public who likely are unfamiliar with data. Although interpreting visualizations is considered an acquired skill [22], several findings suggested that there is only a relatively small difference in ability level across disciplines [19]. In order to ease the accessibility of science visualizations to the public, there are several works [3, 12, 18, 24, 26] that are dedicated to the data interpretation and user interaction design. The challenges of building accessible visualizations for the public mostly are related to bridging prior knowledges to the visual mapping, which is comprised of data attributes and facilitates data exploration [7, 9, 16].

To address these challenges, we built our visualization upon prior research in education and cognitive thinking. As such, we incorporated MERs [1] and TUIs [14] in hopes of creating an effective visualization and learning experience [5, 17, 20]. MERs are designed to be complementary while constricting interpretation, as a means to aid comprehension. TUIs introduce the interdependent use of physical and virtual representations with the intent of having a positive impact on learning. Both concepts have been extensively researched and when applied, have been shown to positively impact the learning of various subjects, such as mathematics, engineering, and the sciences [18, 23, 25]. However, most studies are typically conducted in a classroom setting and do not mirror a museum experience, which includes crowd dynamics and the emphasis to learn through self-exploration of field data. Our goals are to promote inquiry-based learning, in contrast to informative learning, as it can encourage self-thinking and reasoning when one asks the right questions [4, 11].

3 Exhibit Design

We present the details of our visualization to provide context to the effectiveness of our exhibit in relation to fostering comparisons, which is discussed in Section 4. With our collaborators at the Exploratorium, we underwent many intensive critiques of previous prototype designs and believe this design best supported our objectives.

Our interactive prototype was a web-based system implemented in JavaScript for the ease of portability and maintainability. The exhibit was deployed on a MultiTaction multi-touch and object-tracking table, which is a 55-inch touch screen with 1920 x 1080 pixels resolution. Our exhibit consisted of three major elements:

1. **Animated trajectories:** visualizing the animals' trajectories on the map with different visual encodings.
2. **Physical interfaces:** involving the table and tangible cards to filter data attributes and select species of interest to explore.
3. **Timeline and MERs:** showing the progression of time along with an additional summary of the average, minimum, and maximum speed of currently selected species.

A supplemental video can be found online that demonstrates the use of our exhibit prototype at https://youtu.be/psGvUuYxEbM

3.1 Visual Encoding of Tracks

Animal trajectories, or "tracks," are the main visualization encoding in our system. We group each species using color, which is an effective channel for categorical attributes [21]. When visitors filter the data to focus on a particular behavior attribute, the rendering of the animal tracks change for that species as shown in Figure 2. Tracks are superimposed onto the map with four different states:

- **Inactive state:** Initially, all tracks are inactive. The opacity lowers to minimize distractions, but only to the extent that the viewer is enticed by the trajectories' movements. It serves as an entry point for data exploration.
- **Active state:** Tracks are depicted with fade out tails. The tracks are rendered at full opacity so that they are distinguishable from inactive tracks. In particular, we rendered the tracks to highlight their intersections. These intersections hint at the tortuous movement of some species, suggesting high traffic areas or instinctive behaviors such as foraging or mating.
- **Speed encoding:** At each data point, triangles represent the animals' speed. The size of the triangle quantifies the animals' speed: Larger triangles indicate faster speeds and smaller triangles depict slower speeds. We normalized a triangle's size based on the slowest and fastest speed traveled in our data set. By doing so, visitors can make inter- and intra-species comparisons across the data. Triangles are oriented to a track's direction and we found that it complements the animation well. The fade out effect is omitted to reduce the impression of changes in depth and instead triangles are rendered at full opacity.
- **Sex encoding:** We used patterns to encode the unique migratory patterns observed in different sexes. We used outlines of stacked rectangles to depict males and squared dots to depict females. We found these patterns to be distinct from the other encodings as well as from each other. Only tracks with sex data are visualized; individual animals without collected sex data are omitted when this state is used.

Since each animal's data was recorded using different sensing technologies, each track might have been collected either once or multiple times per day. To have a consistent notion of time, we preprocessed the data to represent one day's worth of travel.

We use a sliding time window to show at most two months of data at any given time, with intent to minimize visual clutter and capture the global and local patterns of the trajectories.

3.2 Physical Interfaces

Multi-touch table. The multi-touch, object-tracking table enables our design and implementation of MERs and TUIs. This technology detects finger touches and tracks objects based on their fiducial. Labels around the table frame (Figure 1b) provide context to our visualization: another point of reference on how to use our exhibit and background information in the TOPP data set. In

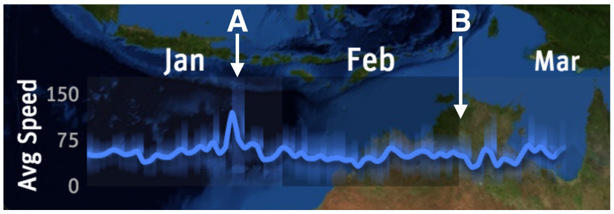

Figure 3: Speed timeline shows the average speed profile of each selected species, in this case, the Blue Whale. The faded banding represents the minimum and maximum within the species. Points A and B are used in an example described in Section 3.3.

particular, the background information explains that the data being displayed is authentic pre-collected field data, rather than being simulated or real-time data.

Physical cards. We have designed a set of physical cards as our TUIs, which serve as a "data explorer" tool and give visitors a subset of controls to filter the data and see the immediate feedback from our visualization. As shown in Figure 1c, the card is labeled with the species name, associated color, a legend of the available species encodings, and questions for visitors to answer. A fiducial marker is attached to the back of the card which allows the card to be linked to its respective species. Each species card has one to two holes, functioning as buttons, which constrain visitors to visualizing the data attributes of speed and sex. The cards are intended to structure visitors' observations, allowing them to make insightful comparisons, by highlighting unique behaviors associated with that species.

3.3 Timeline with integrated MER

The timeline (Figure 1d) serves two purposes: presenting time to the user and displaying a line graph of average speed and speed ranges. All of which are designed to complement the visualization of speed-encoded tracks.

Time. The timeline at the bottom of our application represents the progression of time. When there are no species depicted with the speed encoding, the timeline only has month names, along with a thin progress line for viewers to follow time. The changing font size along with a progress line situates the users in time, as months progress and loop.

Line Graph as our MER. When there are one or more species shown with the speed encoding, the timeline expands and reveals the line graph that plots the species' average speed profile. The colors of the lines match the associated species colors. The faded banding represents the range of minimum and maximum speed for a given species. The lighter portions of the banding represent when the species' speed was more variable. The more solid portions of the banding indicate more consistency among species' speed. The line graph collapses when no data is filtered for speed.

Each line represents the average speed over time for one species in miles per day (MPD). When more than one species are plotted in the graph, visitors can compare the variance of average speed over time across species. The speed timeline is intended to be a statistical overview of data and enables comparisons of speed trends amongst species. For example, in Figure 3, point A shows that Blue Whales' average speed on January 30th was about 95 MPD, while minimum and maximum speed were about 10 and 150, respectively. At point B, the average, minimum, and maximum speed on February were 50, 80, and 20 MPD, respectively.

4 Discussion

The Exploratorium's VRE Department conducted a formative evaluation using this prototype with voluntary visitors recruited from

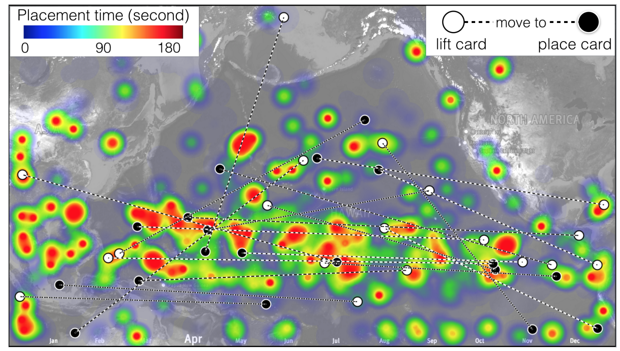

Figure 4: Analysis of card placement on table in relation to our visualization. The respective legends are found at the corners. The heat map shows the aggregated time of cards placed on the table at a particular x, y location. The paths show where visitors lifted and placed the card at its new location.

Exploratorium's Life Sciences section. Using a think aloud protocol, the evaluators collected data on usability and basic understandability of the visualization. A short post interview followed the think aloud. In total, the think aloud and interview for each dyad lasted less than 20 minutes. The evaluators recruited 12 dyads, nine male adult + female child, two female adult + female adult, and one male adult + male adult. With minimal guidance from the evaluators, each dyad interacted with the prototype. In addition, we logged the visitors' actions programatically to record user interactions with our exhibit prototype.

From the formative evaluation, we can better ascertain the strengths and weaknesses of our prototype. We discuss the possibilities of why our design was not effective, namely with the TUIs and MERs, and relate our speculations back to prior research work in the education and cognitive fields. From the results, we generalize our prototype's shortcomings to the following:

- **Interactivity issues:** The TUI design was unintuitive in relation to the data set and the input sensitivy led to unintended actions.
- **Unfamiliar data representations:** Introducing a new form of data representation is tricky and can be overshadowed by traditional representations.
- **Difficulty in using both TUIs and MERs:** The implementation of these can be highly interdependent and can cause confusion and undesired tasks performed by the user.

We only use these evaluation results to improve our future design and cannot make any claims with the small sample, which is typical of usability studies.

4.1 TUI Effectiveness

Visitors suggested that the physical cards were ineffective. Dyad6 stated "We put all cards down and had no idea what was happening." A common theme across dyads seems to be that it was unintuitive to link the physical cards to the animal trajectories.

One factor that likely contributed to this was the buttons' sensitivity and the immediate visual feedback; this created a jarring effect as the visitor had no intent on filtering for that data attribute. This scenario was exacerbated when both visitors triggered encodings simultaneously–the results being a visual overload of the data. From these findings, we concluded that our event-driven interaction was error-prone.

We also suspect that the cards are too abstract: They do not have a direct relationship with the tracks. As featured in previous work, most TUIs had a metaphorical, virtual counterpart. Marshall's work [20] surveyed the applications and learning domains using TUIs finding that TUIs seem to be most effective when conveying spatial information. One of Marshall's examples [13] explains how programmers use graphical and spatial representations to create an effective debugging environment. In contrast, our design experiments with TUIs as tools to filter information and do not seem to yield the same benefits, making the interaction between cards and tracks unintuitive.

To back up our speculations, we visualized the x, y placement of cards and the trajectories of how cards were relocated on the table. We originally expected that visitors would place the cards on land to avoid obstructing the visualization that takes place in the ocean. However, as depicted in Figure 4, it appears that visitors did the opposite. Since we designed the holes to act as buttons, visitors seemed to interpret it as "viewers" into the ocean. Dyad3 expected "More interaction. Moving card gives a feeling of doing something or unveiling. Swipe card to reveal something." This comment suggests that the use of holes as buttons was ineffective. Since cards were moved onto animal trajectories in the ocean, visitors commented that the "cards are too big." This caused clutter and occlusion problems, especially when visitors seemed to move the cards to the central focal point of the visualization: the ocean.

4.2 Line Graph Effectiveness

As our MER, the line graph appeared to be the more successful component in our prototype; visitors showed signs of comparisons using speed. However, despite our expectations, it appears that the speed banding was overlooked by visitors. One visitor acknowledged the banding, but explained that it makes the line graph "blurry."

We believe the average speed line plot is effective because of visitors' prior exposure and knowledge of this data representation. Many people have seen line graphs–single or stacked–when exposed to mathematics, statistics, or infographics. As a result, visitors seemed to effortlessly follow the seasonal trends of animals' speed. When asked about this during the post-exhibit interview, all of the visitors correctly interpreted the line graph. Also, visitors suggested including the speed units to have better scaffolding for their comparisons. The speed timeline seemed to convey clear relations between temporal patterns and speed, which is likely attributed to the juxtaposition of the timeline on top of the line graph and "progress-bar" effect on the speed graph. Dyad7 explains "I noticed average speed [points to the text on the screen], so their increased behavior throughout the year when the curve gets higher." However, it is unclear if visitors made active comparisons across different species and if they consciously utilized the MER to link the speed profile with the trajectories. This reveals that we may not have designed proper constraints on the interpretation when comparing multiple species, as up to six can be shown on the graph at one time. This may be too much for a visitor to process, making it hard to isolate trends found in particular species.

Although the speed graph alone seems to communicate speed adequately and can be complementary to the visualization, it seems that visitors did not know when or how the line graph would appear. We designed the event of toggling for speed encodings to expand the timeline, such that visitors can establish a connection between MERs and the data filtering of speed. However, due to the sensitivity of the current prototype's buttons, this event-driven behavior appeared to be unsuccessful. This observation alludes to the difficulty of connecting TUIs and MERs while also attempting to prompt visitors to perform the expected cognitive tasks that should better structure their comparisons.

To our surprise, we did not find any mention of the minimum-maximum banding on the average speed line. Although this effect is somewhat similar to previous work in uncertainty visualization [8, 15], we did not intend for it to suggest uncertainty in the data since the speed range is already known from the field data. However, upon further consideration, it seems that visitors do not have prior experiences with variances displayed in this manner, let alone superimposed onto another data representation. We speculate that the closest representation of these bar-bandings is a "candlestick" plot. We originally stylized the graphical representation in this manner to not detract from the average line plot, but instead supplement the species' speed profile with intraspecies' speed variance. As previously mentioned, this individual component of our MERs seemed to be interpreted as a styling effect to the line graph–evidence that this uncommon representation was overshadowed by a more readily known representation.

4.3 Future Design

TUI Redesign. Since our TUIs are an abstract representation of personal "data explorers," we plan to provide more instructions on how to use the cards in the form of a digital wrap-around. This wrap-around will include textual information that we believe will better connect the cards with the tracks and their encodings. By moving more information to the digital space, we can reduce the cards' size to maximize the available physical real-estate of the table, thereby alleviating occlusion problems caused by the cards. By better articulating the TUIs' intent, we expect that this will discourage visitors from using it for "...[use the circles for] tracking and so you had to move the card where the line was moving." - Dyad12. Also, we may want to consider incorporating the spatial relations of the tracks to the cards, as TUIs have shown to be effective tools in this respect [20].

MER improvements. Since the banding feature of our MER implementation is not commonly found, we will provide more information as to what it represents. Also, the results reveal opportunities to add more interpretation constraints. We can improve our design such that visitors can compare at most two species at once, since it is more natural to compare in pairs [6]. This may reduce the extent to which visitors are overwhelmed with information and make better comparisons across intra- and inter- species.

5 Conclusion

We have presented our design and implementation of an interactive exhibit intended to foster comparisons amongst marine animals of the TOPP data set. We have experimented with the use of TUIs and MERs to equip visitors with the proper tools for data exploration. However, the formative evaluation identified design issues, and we have discussed the reasons as to why, relating back to previous work and frameworks used in education and cognitive fields. Enveloping technology into education has shown signs of promise, whether in the forms of TUIs or MERs, but can be difficult to exercise in a museum setting. We believe with future iterations of our design, we can better encourage data exploration through fostering comparisons. Our experiences and lessons learned can provide insight and guidance for developing visualizations intended for a public environment, especially when the combination of TUIs and MERs are utilized.

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