Earthquakes and Tectonic Plates Visualization Project

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Overview and Motivation

The purpose of our project was to build an interactive visualization that helps users understand the global relationship between earthquakes and tectonic plate boundaries. Earthquakes occur daily around the world, yet most people remain unaware of how tightly these events follow the edges of Earth's major plates. While textbooks often provide simple maps showing the Ring of Fire or major fault lines, we wanted to create a more dynamic representation that allows users to explore thousands of real earthquake events and visually connect them to plate structures. Our motivation came from the desire to turn raw seismic data into something meaningful and accessible. Instead of looking at a long spreadsheet of earthquake magnitudes and coordinates, users can observe how those numbers translate into real spatial patterns.

Another strong motivation came from seeing how geoscience concepts, especially plate tectonics, can be hard for people to fully grasp without visual support. The theory explains that Earth's crust is divided into multiple plates that interact in different ways colliding, pulling apart, or sliding past each other and these interactions produce earthquakes. By combining real earthquake data with actual plate boundary shapes, our project emphasizes this connection through visual experience. We also wanted to give users control over how they explore the data. An interactive design makes it possible to examine earthquake activity at different scales, filter by magnitude, or focus on specific regions. After experimenting with various tools, we realized how powerful interactive mapping can be for learning and communicating scientific patterns, and that became a major reason we decided to pursue this project.

Related Work

Several existing works influenced both our conceptual direction and our visualization style. One of the most important examples was a Kaggle notebook titled Earthquakes and Tectonic Plates Seismic Analysis, which demonstrated how overlaying real earthquake data on plate boundaries immediately reveals strong spatial relationships. Although we did not replicate that notebook directly, it provided a foundation for thinking about how to structure our own analysis and what kinds of patterns are most meaningful to highlight. In addition to this, map-based visualizations helped us understand how different design decisions impact clarity. That emphasized the importance of selecting appropriate color scales, symbol sizes, and map projections when presenting geographic data, and those principles guided us throughout the design process.

We also drew conceptual insight from the paper Task-Based Effectiveness of Basic Visualizations, published in IEEE Transactions on Visualization and Computer Graphics. This paper argues that simple visual forms, when used carefully, often outperform complex or decorative designs, especially when users are trying to identify patterns or compare values. This helped reinforce our decision to keep our visualizations straightforward and clean, especially because earthquake data can quickly overwhelm the screen if the design becomes too cluttered. Bases on this we shaped a final project that balances simplicity, accuracy, and interactivity.

Questions and How They Evolved

At the beginning of the project, our questions were general and curiosity-driven. We wanted to understand where earthquakes occur most frequently, how closely they follow tectonic plate boundaries, and whether some plates experience more severe seismic activity than others. We were also interested in seeing whether the magnitude or depth of earthquakes revealed any spatial patterns, and whether the map would show clusters or linear trends that match what we know from plate tectonics. As we began exploring the data and developing our first visualizations, these broad questions evolved into more detailed ones.

For example, once we saw how dense the global earthquake dataset is, we started asking how filters could help clarify the patterns. That led us to think about magnitude thresholds, temporal ranges, and depth categories. We also became interested in how different types of plate boundaries convergent, divergent, and transform relate to different types of seismic activity. As we improved the visualization, new questions emerged about how users interact with the map. We wondered whether they would benefit from viewing earthquakes one decade at a time, or whether showing depth in addition to magnitude would be too visually overwhelming. In this way, our research questions gradually expanded from purely scientific ones to design-oriented questions about how best to help others interpret the data.

Data Sources and Preparation

The data for this project came from two openly available Kaggle datasets. The first was the USGS Earthquake Database, which contains detailed records of earthquakes from around the world. Each entry includes latitude, longitude, magnitude, depth, date, and time. Because the dataset spans many years and includes hundreds of thousands of events, it provides an excellent foundation for large-scale spatial analysis. The second dataset was the tectonic plate boundaries dataset created by CW Thompson, which contains shapefiles outlining the boundaries of Earth's major and minor tectonic plates. Each boundary is stored as a geographic polygon or line string, allowing it to be plotted on a map.

Before the data could be used effectively, we had to complete several cleaning and preparation steps. We removed duplicated earthquake entries, standardized date formats, and eliminated events that were missing essential information such as coordinates or magnitude. The plate boundaries required special handling because they are stored as shapefile geometry; we had to convert them into a format that could be read alongside the earthquake dataset. Once both datasets were processed, we merged them into a unified system so that they could be overlaid accurately on a single map. We also filtered out extremely small earthquakes to avoid excessive visual clutter. These steps ensured the final map would be both clean and interpretable.

Exploratory Data Analysis

Our exploration analysis began with simple plots to get a sense of how earthquakes were distributed. When we plotted latitude and longitude on a basic scatterplot, we immediately saw long arcs of dense clusters that matched the outlines of the tectonic plates almost perfectly. This confirmed the fundamental scientific expectation that seismic activity occurs primarily along plate boundaries.

When we explored magnitude patterns, we saw that most earthquakes in the dataset were relatively small, with only a small percentage registering high magnitudes. However, the strongest earthquakes tended to cluster near subduction zones particularly around the western coast of South America and the regions near Japan and Indonesia. Depth patterns were equally informative. Shallow earthquakes dominated the dataset, but deep earthquakes were concentrated only in certain subduction areas, revealing the downward motion of the plates. Temporal trends did not show a simple increase or decrease over time, but there were noticeable spikes corresponding to well-known seismic years. Through this exploratory process, we developed a clearer sense of what patterns were most important to emphasize in the interactive visualization.

Design Evolution

As the project continued to evolve, we recognized that even with filtering, the map alone could not reveal all the relationships we wanted to highlight. This led to several additional enhancements in the final stage of our design. First, we added an interactive year-range selector with both numeric inputs and a slider, allowing users to precisely examine different historical periods rather than viewing all data at once. We also introduced type filters so users could toggle earthquakes, explosions, nuclear tests, and rock bursts independently, which helped separate naturally occurring events from man-made ones.

To further support exploration, we incorporated a small magnitude histogram with quantile-based color encoding. This provided an immediate summary of the magnitude distribution under the current filters, helping users interpret the density of extreme events. Another major improvement was the addition of a “density overlay” derived from a second dataset of plate-related points. Unlike the simple plate boundary lines, this overlay visualizes the underlying structure of tectonic plates as smooth contours, making high-activity zones easier to perceive.

Finally, we added a side panel with two display modes. In line-chart mode, the panel shows yearly event counts and average magnitudes, enabling users to identify long-term temporal trends. In scatterplot mode, the panel switches to magnitude versus horizontal distance and magnitude versus depth, revealing patterns that are not visible on the map alone. Together, these additions transformed our visualization from a static map into a multi-faceted interactive tool that supports a wide range of analytical questions.

As the project progressed, we refined our design to better emphasize visualization-driven exploration rather than relying on interface widgets. Our initial prototype included several external controls such as event type filters and numeric year inputs paired with a range slider. However, after receiving feedback from the instructor, we removed these controls to reduce visual clutter and encourage users to interact directly with the charts and map themselves. This shift allowed the visualization to feel more cohesive and eliminated the need for redundant UI elements.

Another major change occurred in the bottom-right panel. Our original design included line charts showing yearly averages, but we found that these temporal trends did not provide strong analytical value. In response, we replaced the line charts with a bar chart summarizing average magnitudes by event type. This redesign supports clearer comparison tasks and highlights differences between categories more effectively.

We also made a conceptual adjustment by removing the “Rock Blast” event category. Because this category contained only a single data point, it did not meaningfully contribute to the analysis and risked distracting users from the major patterns in the dataset. By removing it, we maintained a cleaner and more interpretable design.

Across the project, these design decisions gradually shifted the visualization from a widget-heavy interface to a more streamlined, visualization-centered experience. The final version relies on the interactions within the charts and map themselves, aligning with the pedagogical goals of exploratory visual analysis.

Implementation

The final visualization incorporates a wide range of interactive features that make the system both exploratory and analytical. Users can freely zoom and pan across the map, enabling detailed inspection of earthquake clusters along tectonic boundaries or in specific regions. A dynamic magnitude legend and color-coded quantile encoding help users quickly distinguish between moderate and high-intensity events. To support temporal exploration, the tool includes both a numeric year input and a linked range slider. This allows users to isolate earthquakes from a particular decade or examine long-term seismic trends from 1965 to 2016. Type filters provide another layer of control, enabling users to separately view natural earthquakes, explosions, nuclear tests, and rock bursts, which helps distinguish natural tectonic activity from human-generated events. A synchronized histogram summarizes the magnitude distribution of the currently selected subset of data. As users adjust filters, the histogram updates in real time, reinforcing the connection between map-level patterns and global statistical trends. Hovering over any point reveals a tooltip with detailed information, including magnitude, depth, coordinates, and exact date. We also introduced an optional tectonic density overlay, which highlights global plate structures using a multi-layer contour map. This overlay can be toggled on or off, allowing users to compare earthquake clusters with the underlying plate boundaries. Finally, the right-side panel offers two complementary modes. In “Line” mode, users can explore long-term trends in both earthquake frequency and average magnitude. In “Scatter” mode, users can analyze relationships between magnitude and horizontal distance or depth. Both modes update automatically based on the active filters and year range. Together, these interactive features transform the visualization from a static map into a rich exploratory environment, enabling users to investigate global seismic behavior from multiple analytical perspectives.

The implementation of the final visualization reflects several important changes made during the refinement process. One of the most significant adjustments was the removal of the external filtering widgets that previously controlled event types and year ranges. Elements such as the type selection row, numeric year inputs, and year slider were removed from the interface. By simplifying the control layout, the visualization relies more on internal interactions, allowing users to explore the data directly through the charts and map instead of manipulating external UI forms.

We updated the side-panel visualization as well. The original bottom-right component included temporal line charts that displayed yearly event averages. These charts were replaced with a bar chart that summarizes average magnitude by event type, providing a more direct and interpretable comparison. This modification aligns the visualization more closely with user tasks and improves readability. Additionally, the "Rock Blast" category was removed across all components, including the map, bar chart, and scatter plots. Since this category contained only a single entry, it did not support meaningful comparison or trend analysis. Removing it reduced noise and improved the clarity of the visual encodings. During final testing, we encountered a layering issue in which hover tooltips appeared behind certain graphical elements, particularly in the bottom-right bar chart. To fix this, we adjusted the z-index in CSS, ensuring that tooltips are always visible during interaction. This small but important improvement enhances usability and ensures smooth exploratory behavior. Together, these implementation updates resulted in a cleaner, more intuitive, and more analytically effective visualization system.

Evaluation and Possible Improvements

After testing the final visualization and sharing it with others, we found that the tool was effective at communicating the strong spatial relationship between earthquakes and tectonic plates. The ability to filter by magnitude or time helped users notice patterns they might not have seen otherwise, such as the concentration of high-magnitude events along subduction zones.

However, the project also revealed several areas for improvement. Because the dataset contains so many points, the map can still feel crowded when all earthquakes are displayed at once. While filtering helps, there may be more effective ways to simplify or cluster the data. Some users also wanted animations showing earthquakes over time, which would help illustrate how seismic activity unfolds. Additionally, incorporating real-time data from the USGS live feed could make the tool more immediately useful for understanding recent seismic events. There is also room to expand the comparison of different plate types or to add labels and annotations that explain particularly important regions.

Overall, our evaluation showed that the project successfully met its goal of making earthquake patterns accessible and engaging. Visualization helps users connect scientific concepts with real-world data in a way that is intuitive and interactive, while also offering a strong foundation for future enhancements.

Evaluating the final visualization revealed several strengths as well as opportunities for further improvement. Users responded positively to the simplified interface after the removal of the external widgets. Instead of relying on dropdowns and input boxes, they interacted directly with the charts and map, which created a more seamless exploratory experience and aligned better with visualization best practices.

The replacement of the temporal line charts with a bar chart also improved clarity. Users found it easier to compare event types directly, and the visualization no longer suggested temporal patterns that were not strongly supported by the data. Similarly, removing the Rock Blast category enhanced readability by ensuring that each category contributed meaningful information.

Fixing the hover-layering issue significantly improved usability during interaction. Tooltips now display properly above all visual elements, making the exploration experience more polished.

However, despite the improvements, some challenges remain. The high density of the earthquake dataset can still cause visual clutter when viewing all events simultaneously. Cluster-based aggregation or sampling strategies could help mitigate this. Additionally, incorporating animated temporal playback or real-time USGS updates could expand the tool's relevance and interactivity. Future versions might also explore more advanced cross-chart interactions, such as brushing or linked highlighting, to further enhance analytical depth.

Overall, the updated visualization successfully communicates the spatial relationship between earthquakes and tectonic plates while providing a cleaner and more intuitive user experience.