Deep Impact: Explore Meteorite Impacts on Earth

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ABSTRACT
We introduce *Deep Impact*, a visual tool to explore the known meteorite impacts on Earth with basis on the data provided by The Meteoritical Society. We explain the development process of the tool, describing the tasks and questions posed at the beginning of the project, the dataset that provides the answers and the implementation that allows users to explore this data. *Deep Impact* was built on Javascript and D3.js and makes use of different visualization techniques to fulfill the relevant tasks, prominently a world map used as base for a choroplet and modified dot map visualization to convey combined geographical and quantitative information on meteorites. Bar charts, parallel coordinates, star charts and a timeline complete the available idioms in *Deep Impact*. We guide the interested user through the use of the visualization. Finally, we discuss the present implementation's pitfalls and how it could be improved.

Author Keywords
Meteorites; geoprojection; information visualization; .

INTRODUCTION
Here we present *Deep Impact*, a visual tool to explore the existing records of meteorite impacts on Earth.

Upon exploring the datasets made available by NASA (https://data.nasa.gov/Space-Science/Meteorite-Landings/gh4g-9sfh), we identified the need for a tool to go beyond the simple sorting of meteorites by the available attributes. *Deep Impact* allows comparing meteorites easily across geographies, for chemical composition, monetary value and elevation through time.

The development of *Deep Impact* was centered on the display of impacts on a *Mapa Mundi*. The other implemented views were carefully positioned and sized around the map to convey their corresponding information while keeping the map in evidence. We are not aware of the existence of a tool providing such a functionality for this kind of data. While tools for visualizing data overlaid on maps are ubiquitous, no tool exists, to our knowledge, that allows a user to explore meteorite impacts this way.

Specifically, we wanted to address the following tasks; for each task, we indicate its type, we describe what was proposed at the project's inception and, briefly, how it was actually implemented in the delivered visualization. Additionally, we indicate the initial questions we wanted to answer and how these were addressed.

1. Discovering the variation in number and kind of impacts over time
   a. Type: *Analyze > Consume > Discover*
   b. Proposed work: Grouping impact data by year of impact, our visualization will allow the user to, at a glance, identify the impact trends over time - if any exist. The grouping can be refined to include only certain types of meteorites or certain locations.
   c. Actual implementation: We implemented a timeline showing the amount of meteorites fallen over the years. This timeline allows brushing to select a certain time window for meteorites to be visualized.
   d. Questions:
      i. *What are the geographical areas with highest historical density of impacts?* Answered by direct visualization of the map. For easier interpretation of data in areas of high density, hexagonal binning is used coupled with a color scale where darker blue means more impacts and lighter blue means less impacts. If the user wants to get information only for a certain time window, they can select that window by brushing over the timeline; then only the meteorites that fell during the selected period are displayed.
      ii. *How did the frequency of meteorite impacts vary over time?* Visible by direct inspection of the timeline.
      iii. *What is the most common type of meteorite?* We were unable to answer this question, as we do not provide a ranking of the different types of meteorites.
2. Identifying objects with specific properties
   a. Type: *Query > Identify*
   b. Description: Display rankings of most heavily hit cities or countries, meteorite value, meteorite mass...
   c. Actual implementation: We did not exactly implement the ranking but we present a coordinate plot where the coordinates are mass, elevation and chemical components. It allows the selection of meteorites by brushing the axes for a range of each of these coordinates.
   d. Questions:
      i. *Which country was hit by more meteorites?* While this question wasn't directly answered,

the user is able to compare the number of meteorites fallen in different countries by inspecting a choropleth or a hexagonal binning chart.

   ii. *What's the most valuable meteorite?* We did not answer this question, as we do not provide a ranking of the most valuable meteorites. However it is possible to know the value of each meteorite individually.

3. Browsing for impacts near a user-defined location
   a. Type: *Search > Browse*
   b. Description: Using impact coordinates and Google's geolocation services, our visualization allows a user to see a distribution of impacts within a given radius of their location.
   c. Actual Implementation: The tool allows point-and-clicking on a country, displaying only the meteorites fallen on that country.
   d. Questions:
      i. *How many meteorites have fallen within 100 Km of my house?* The user is able to use a search box to find a city or a specific coordinate and upon selection of the location, it is centered in the map with concentric isolines showing distance to the city. By zooming in or out on the map overlayed with hexbins, the user is able to see where meteorites fell around the city and how many fell in each spot represented by a hexbin.
      ii. *How many meteorites impacted near a certain city?* The user is able to use a search box to find a city and, upon selection of the intended city, it is centered in the map with concentric isolines showing distance to the city. By zooming in or out on the map overlayed with hexbins, the user is able to see where meteorites fell around the city and how many fell in each spot represented by a hexbin.
4. Looking up information about a specific meteorite
   a. Type: *Search > Lookup*
   b. Description: Select a meteorite and display information about it.
   c. Actual implementation: On mouse-hovering over a meteorite, information about that meteorite is displayed in a tooltip.
   d. Questions:
      i. *What's the estimated monetary value of a meteorite?* This information is provided by a tooltip when mouse-hovering on the intended meteorite.
      ii. *What's the chemical composition of a meteorite?* Displayed in the same tooltip.
      iii. *What's the mass of a meteorite?* Displayed in the same tooltip.
5. Comparing places with respect to meteorite hits
   a. Type: *Query > Compare*
   b. Description: Compare places (different elevations, countries, cities...) with respect to meteorite value, number of hits, meteorite mass...
   c. Actual implementation: number of meteorites and density can be inspected directly on the map, with the choropleth and hexbin layers, respectively. Distributions of measures can be visualized in bar charts and a parallel coordinate plot.
   d. Questions:
      i. *Do places at higher altitudes get more hits?* Impact altitude distribution can be visualized in a parallel coordinates plot and in a bar chart.

RELATED WORK

We are not aware of another means to visualize meteorite impact data along time and geographical coordinates.

DATA

Our work was based on a dataset freely available at NASA's website (https://data.nasa.gov/Space-Science/Meteorite-Landings/gh4g-9sfh) and also, actually with more detail (more attributes), at the website of The Meteoritical Society (http://www.lpi.usra.edu/meteor/index.php). While the data could be downloaded as a comma separated file (.csv) from the NASA website, the data from The Meteoritical Society was (easily) manually copied from an html document to a .csv file. Unfortunately, there was no way of getting the whole dataset from a single page from The Meteoritical Society.

Additionally, we wanted to retrieve the country where each meteorite fell. For this purpose, we used the geographical coordinates from the NASA .csv file and queried the Google Maps Geocoding API with a simple Python script. However there is a problem with the collection of information and many meteorites do not have the correct information regarding the country where they fell.

The data regarding the geographic coordinates of the cities were retrieve from Geonames.com.

Finally, we wanted to estimate an approximate monetary value for the meteorites. We found values for three of the most abundant components of the meteorites (Fayalite, Ferrosite and Whollastonite) at alibaba.com. We compute the monetary value for each meteorite as the sum

Our data contains information about the meteorites (name, location, year of discovery, type, chemical composition and value). We cleaned it by removing the entries that are missing critical values such as coordinates or mass and correcting non-crucial values, either by filling missing values using approximations of neighboring values or sentinel values (0) for the elevation, or correcting them (i.e. year 2105 as change to 2015).

VISUALIZATION

Overall Description – “Overview first, details on demand.”

At the center of the *Deep Impact* visualization you’ll find a **world map** projection. Several world map projections are available for the user to choose from (Mercator, stereoscopic, equirectangular, among others). The default projection the user first sees is equirectangular.

In the standard view, the user will see hexagons representing bins of meteorites that fell in the area defined by each hexagon. The darker the hexagon, the more meteorites fell in the corresponding area. The user can intuitively zoom in and out on the map. The zoom is semantic, as the detail on the data increases as the user zooms into smaller areas of the map – the **hexagonal bins** are recalculated for the level of zoom chosen by the user. Additionally, when the number of meteorites in a bin becomes one the hexagon becomes a circle, informing the user that they reached the single-meteorite level of detail. The user may choose to visualize only the meteorites fallen in a certain country by clicking on that country; this action highlights the country with a different color and adjusts the zoom to frame the country in the available visible space.

Below the map, the user finds a **timeline**, displaying the number of meteorites fallen over the years and a **parallel coordinate plot**. In the parallel coordinate plot, each line corresponds to a single meteorite and each coordinate to an attribute. This approach allows the user to explore trends in the relationships between the attributes for the collection of meteorites. The user is further empowered with **brushing** along the coordinates, allowing him to select a group of meteorites within a certain range of values along one or even several coordinates. Brushing is also enabled on the timeline, allowing the user to choose to visualize information for a certain time window. When brushing is activated, only the corresponding meteorites are displayed in the map. The several brushing implementations and the country selection in the map are linked: the **filtering** applied in one component is propagated to all others.

The composition of the meteorites is represented in a **star plot**. On mouse-hovering on a meteorite on the map, the star plot shown in the tooltip the tooltip shown with a line representing the chemical composition of the meteorite.

Finally, the user can use a search box to type the name of a city or geographical coordinates of interest to the user.

Rationale

Using a **map** projection to visualize the geographical distribution of meteorite impacts was the obvious choice. This way, the user has has a panoramic overview of which areas of the planet have more or less recorded impacts. Then they are able to zoom in to areas of interest and explore the individual meteorites fallen in a region. It is also possible to filter the meteorites fallen in a country by directly clicking on that country; the information in other available idioms is updated accordingly.

The **timeline** idiom was chosen to give the user information about the variation of the number of impacts that occurred through the years. It is also an idiom that lends itself well to brushing and zooming, allowing the user to explore the meteorites that fell within a user-defined time window.

At the inception of the project, the distribution of measures associated to the meteorites (mass, value, etc.) was to be visualized using a **jitter plot** with buttons to toggle different measures. However, we decided to replace the jitter plot with a **parallel coordinate chart**. The parallel coordinate chart not allows to visualize the distributions of these measures by representing them on separate parallel axes while avoiding the use of the uninformative “jitter” axis. In addition, on a parallel coordinate chart correlations between the measures come to evidence; finally, it lends itself naturally to brushing linked to the other views, allowing the user to continue exploring a different area of the visualization for a partition of the data defined in the parallel coordinates.

Star plots were chosen to inform about the composition of the meteorites. In the initial design, a space was reserved for a permanent start plot that would display information for selected meteorites. This would allow the user to visualize and compare the composition for a group of selected meteorites. By hovering on a meteorite in the map or on a line in the start plot, it would be highlighted in the start plot in a different color. In the final design, we decided to switch the star plot to the tooltip, hence it appears for a single meteorite on hovering over on it. This decision comes at a loss of the ability to compare several meteorites in the plot, however it reduces clutter in the overall design. It also makes the exploration using the tooltip a more pleasurable experience for the user The comparison between the chemical composition of diferent meteorites is now possible with the **parallel coordinate chart**.

The **choropleth** idiom was chosen to inform the user about the total number of meteorite impacts in each country. While this technique suffers from the inherent problem that countries have different areas, which may interfere with the perception of the user, it is mitigated by the careful choice of an appropriate color scale. It also has the advantage of being familiar to mot users and hence easily interpreted. For an uncluttered exploration of the choroplet, the user can switch off the hexbins by clicking on a toggle widget at the upper right corner.

To allow users to locate a specific city, we included a **search box** in the upper left corner. This search box responsively shows possible locations as the user types the intended city. Upon selection of a city, the corresponding country is highlighted and the map automatically zooms to focus on the country.

Demonstration

When the user first opens the application, they are presented with the choroplet view of the map, the parallel coordinate plot in the bottom and the timeline separating the map area from the parallel coordinates area. At the upper left corner, the user can see a minimap. At the lower left corner, the user finds the city search box and widgets to toggle between the choroplet and the hexbin views of the map and between the parallel coordinates and the bar charts (figure 1).

Figure 1 *Deep Impact* as first seen by the user when the app starts up.

When the user toggles on the hexbin view in the lower left corner widget, the map view switches accordingly, and the user gets a visualization similar to that of figure 2.

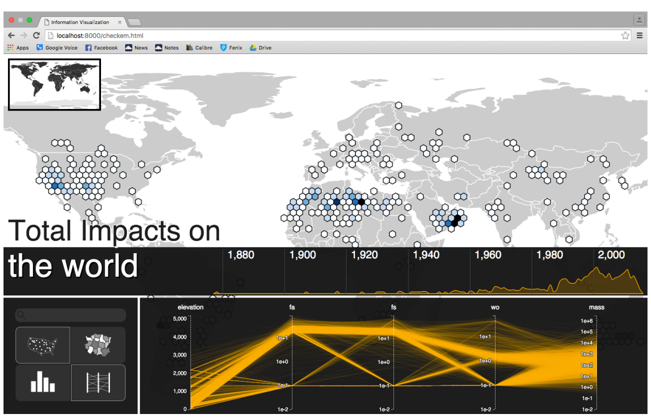

Figure 2 Deep Impact overview with the hexbin map selected.

The user may pan and zoom the map to find meteorites in regions of interest.

In the lower left-side panel, it is possible to choose among a view showing bar charts (figure 3) and a view showing the parallel coordinate plot.

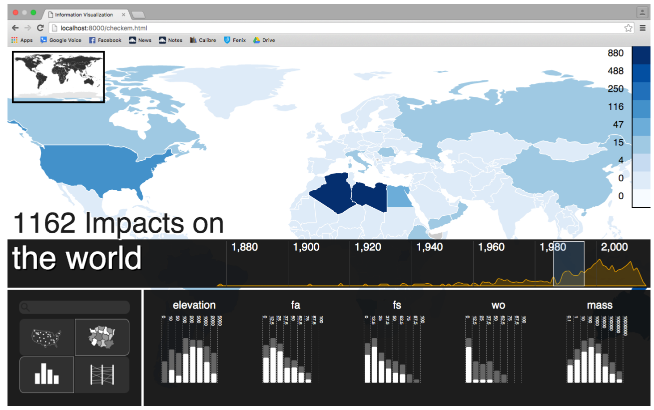

Figure 3 Bar charts at the bottom of the visualization convey information about a selected group of meteorites. The currently selected meteorites are represented by white bars in the foreground, but the whole dataset is kept in darker-shaded bars in the background for easy comparison and proportion assessment.

The user may also hover on hexagons to get information about the meteorites in a tooltip (figure 4). The tooltips present star charts for the hovered meteorite as well as year of discovery, mass, altitude and monetary value information. The tooltips were carefully crafted to smoothly appear on “mouse in” and smoothly disappear on “mouse out”. In case the hovered hexbin represents a group of meteorites instead of a single one, the tooltip presents information about the group, i.e. it presents a star chart with lines for all meteorites in the bin and ranges of values for the other aforementioned measures. The tooltip is also shown when the user hovers on the bars of the bar charts in the bottom panel.

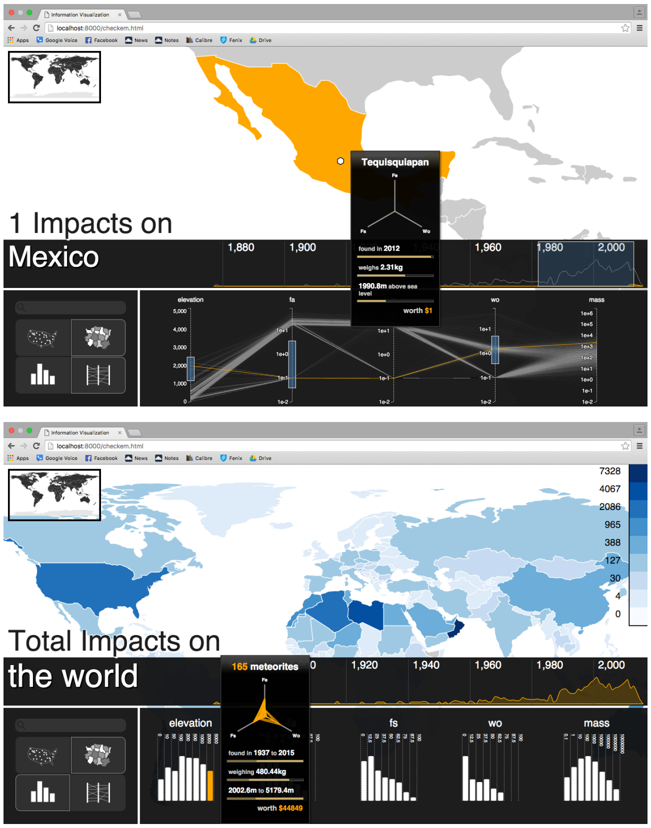

Figure 4 Tooltips are shown when the user hovers on the hexbins (upper panel) or the bars in the bar charts (lower panel).

Countries can be clicked on; when the user clicks on a country, it's area expands to fill the visible area and gets centered in the map view. When a country is selected this way, only information about its meteorites are shown in the other views (figure 5). The user can return from a country-specific examination to the main view by clicking on a water area in the map.

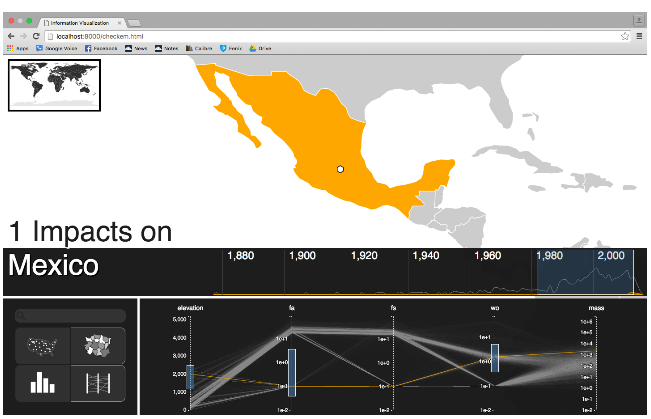

Figure 5 Highlight and focus on a country up clicking on its area.

The user also has the ability to filter data for closer examination through extensive brushing, present in the axes of the parallel coordinates and the time line (figure 6). All filtering through brushing and country-clicking is linked, hence the user is delivered coherent information about a set of meteorites throughout the entire app at a certain instant of the exploration.

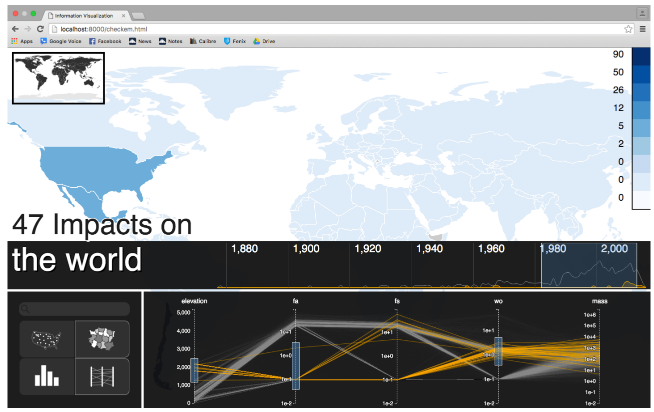

Figure 6 Brushing is possible along the axes in the parallel coordinates and the timeline (upper panel).

Implementation Details

Deep Impact was built on D3.js, a data visualization library for the Javascript language.

The implementation strategy followed a modular pattern: in the beginning, the different idioms were coded separately, though in a coordinated fashion. As the quality of the idiom implementations approached the intended quality standard, they were integrated into the visualization.

A possibly interesting aspect of *Deep Impact*'s implementation is that, instead of relying completely on D3.js functions to handle the data linked to the visualization, we often found more convenient to rely on Javascript itself, especially in data filtering operations. We often relied on D3's *each* method, which allows calling a function to perform operations on selected elements of the

Pitfalls

We are aware of some issues with our visualization that would be improved before release of a future version.

Specifically, when the window of the browser is resized, the different components of the visualization do not resize accordingly; pint-and-clicking a country occasionally breaks the zoom functionality. It also is shown to work well only with the Google Chrome web browser; for example, in Firefox parts of the app are not fully rendered.

It would also improve the application to add more interactivity features, such as filtering upon clicking on bar chart bars

Regarding the functionality of the app, we would like to include more statistical information about the data, namely mean, standard deviation and perhaps quartiles. For this information, whisker plots would be appropriate.

It would also be nice to implement a fisheye lens to allow for local magnification where there is a high density of impacts.

There are two countries which are not identified on the map, these are

Some of the countries associated with meteorites are wrong which means that when you select a country some of the meteorites are drawn in other locations. For this reason, the default visualization includes only a subset of the whole dataset. Still, for interested user, we include the file with the larger dataset.

CONCLUSION AND FUTURE WORK

Our visualization clearly shows that some areas have many more registered meteorites than others. For example, the south of the Arabic Peninsula, the United States and North Africa have clearly been hotspots for meteorite hunters.

Regarding future work, an obvious direction is to fix the dataset that is currently not being displayed correctly, as explained in the pitfalls section. There were also questions that were part of the initial project proposal that were not addressed in the presented version. Specifically, we can include more bar charts showing information about meteorite monetary value and type, but, most importantly, a view should be included for the user to be able to sort meteorites according to different attributes and answer more objectively to the questions posed in the first and second tasks described in the introductory section.