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ARTICLE

Off the Grid: Visualizing a Numismatic Collection as Dynamic Piles and Streams

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This research explores the merit of alternative arrangements of cultural artifacts to expose the aesthetic abundance of a cultural collection. The conventional display of museum objects in online interfaces tends to neglect the physical gestalt of the collection. For example, coins typically end up in tabular grids of thumbnail pages in online collections mimicking their rigid placement in storage drawers of a depot and glass cabinets in exhibitions. The overall aim behind this research was to devise visualizations that do justice to the material and semantic richness of an entire collection, while providing a casual mode of access that is inviting to people with no background in numismatics. To do this, we undertook an iterative design process, which involved a close collaboration with numismaticians and playful ideation with actual coins. Carefully negotiating expert knowledge and lay curiosity, the resulting visualization represents the collection's dimensions using thousands of thumbnails as visual data points. The coins can be arranged into various layouts such as piles representing, for example, metal types, or streams visualizing the ebb and flow of coins over the centuries. In the interface, one can play with the coins in a manner that would be unthinkable in a physical exhibition and that has not been tried in a digital display. The article reports on the overall research and design process of this project, the resulting interface concept and prototype, and the feedback received during two evaluations.

Introduction

With over half a million historic coins and medals the Münzkabinett Berlin is one of the most significant numismatic collections in the world. While it is impossible for the Münzkabinett to show all of their coins at once in their physical exhibition, web-based interfaces pose a great opportunity to expand access to such a comprehensive collection. Akin to many collecting institutions, the Münzkabinett has been investing considerable resources into digitization with a strong emphasis on the semantic annotation of the coins. The online catalog currently contains over 30,000 digitized objects, for which the museum provides detailed, high-quality metadata and images. Despite efforts to enrich the collection, the display has to date been relatively conventional. The coins almost always end up in tabular grids, regardless of whether they are in the storage drawers of the depot, the glass cabinets in the exhibition, or thumbnail pages in the online interface. While ubiquitous across collecting institutions, these static and rigid arrangements lack the potential to represent semantic relationships or convey physical patterns among the individual items in this large collection.

Over the past few years, there has been an increased research interest in the visualization of cultural collections (e.g., Hinrichs et al., 2016; Kräutli 2016; Whitelaw, 2009; Windhager et al., 2018). While most collection visualizations keep the abstract and concrete aspects of artifacts separate, there is a promising direction of work that explores new ways to combine the semantic structure with the material texture of collection items (Glinka et al., 2017; Whitelaw, 2015). With this research, we pursue the same ambition and wish to expand the dynamic quality of the layouts. More specifically, we wish to investigate how the arrangements of artifacts could reflect the material abundance that the collection exhibits while providing a playful mode of access that is inviting to a lay audience.

To pursue these aims we have collaborated with numismaticians who are familiar with the Münzkabinett's coin collection and their ongoing digitization efforts. During the design process, we negotiated their specialized expertise about the collection and our ideas for an inviting interface. The resulting visualization concept blurs the boundaries between the concrete quality of the physical coins via their images and the abstract data patterns derived from semantic metadata. This

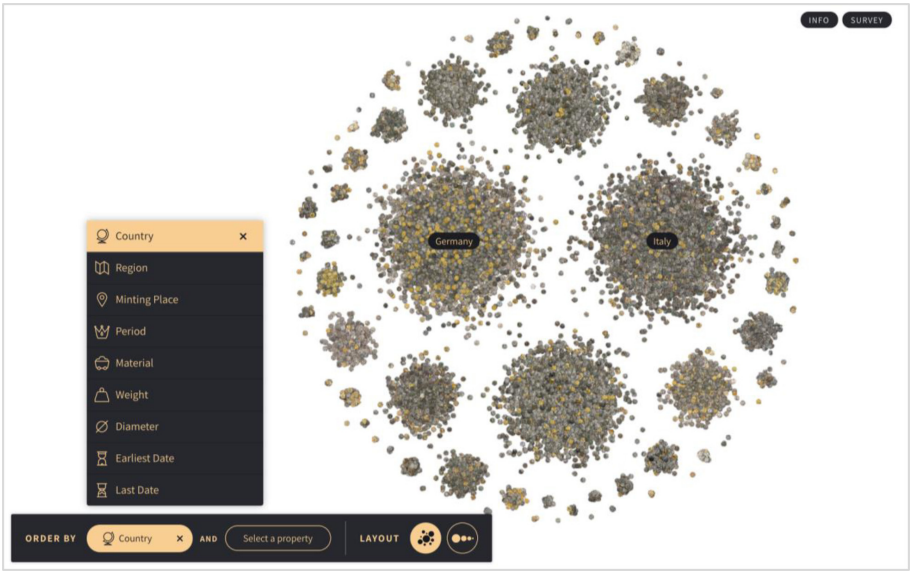

Figure 1: The coin visualization translates categorical metadata fields such as country into discrete piles of different size.

integration is realized with thumbnails of 26,000 coins positioned in a variety of one-dimensional and two-dimensional visualizations realized as organic layouts, such as, piles, clusters, streams, and grids (see **Figure 1**). In this paper, we discuss the prior research related to our work, reflect on the design process, and present initial feedback gathered in a user study.

Related Work

Traditional museum exhibitions tend to be relatively clinical with vitrines and text-heavy signs. In such environments, visitors are rarely allowed to explore the objects with their hands. Dudley (2012) promotes the opportunity for a more sensuous experience, during which visitors touch and smell objects in order to identify with an object and its creator or owner. Furthermore, she suggests that artifacts will 'speak' by themselves through their materials and forms, while detailed information should be accessible on demand. Independently, Rogers et al. (2014) show how an individual artifact can provide an entry point into a collection, in particular in an in-situ display, while remote access can also start with an overview of the entire collection. While an online visualization invites a person to browse through the

collection, 'tell a story about the character of the collection', and may 'lead to serendipitous discoveries' (ibid, 4), visitors walking through a physical exhibition may encounter a special artifact, which can provide a segue into the whole collection. What Rogers et al. term 'remote exploration' is a common approach to representing a collection. Overviews of entire collections providing interactivity for detailed exploration of objects include: Yi et al., 2005; Dörk et al., 2014; Whitelaw, 2015; Glinka et al., 2017.

The persona of the 'information flaneur' aims to shape serendipity-oriented visualization design (Dörk et al., 2011), with the bi-partite interaction framework, consisting of horizontal exploration and vertical immersion, used to distinguish between different modes of access and levels of detail. Along these lines, Whitelaw (2015) argues that the classic entry point via search bars should be re-considered and replaced with rich 'generous interfaces' to the collection contents. To increase the amount of information available on collection interfaces, he recommends the provision of rich subject overviews, information about the whole collection, and high-quality content, as well as a consideration of the relationships between objects. While the persona of the 'information flaneur' and the principle of information generosity are useful for the design of collection interfaces, it is not clear how the semantic and material specifics of a collection can be considered in unison.

To better understand how existing collection interfaces are designed for exploration, Kreiseler et al. (2017) examined the information architecture of eight websites of museum collections. While all museum websites in the study featured explorative elements, overall there was limited interactive capability in the arrangement of the artifacts and the navigation topology was not ideal for exploration. Similarly, the online catalog of the Münzkabinett contains rich content about all displayed coins, however, the relationships among coins are hardly utilized for open exploration. More generally, cultural institutions seldom present entire collections with their abundant facets and relationships online. If a special object is selected, the relationship to the rest of the collection is rarely given. So far, the idea

of monadic exploration (Dörk et al., 2014) has not been implemented for cultural collections. However, this approach could address the challenge of providing the viewer with a rich overview about a part of the collection from the perspective of an individual artifact without reducing the complexity of its culturally situated significance or resorting to a search box.

A particular predecessor to our work is the 'Past Visions' project (Glinka et al., 2017), a filterable visualization of historic sketches, which integrates temporal summaries with highly detailed views in a zoomable environment. In contrast to the static nature of image plots (e.g., Hochman & Manovich, 2013), the interface allows for the dynamic filtering of the images using an adjacent tag visualization. In the area of physics-based visualizations, 'Dust and Magnet' (Yi et al., 2005) is a good example as it uses a magnet metaphor with an almost physically correct layout. Attributes serve as magnets and data as dust particles, which build piles that can again be filtered. Common to these projects is the availability of multiple layouts, as arguably no collection can be conclusively displayed in a single representation (Dörk et al., 2017). Besides the typical overview in the form of a timeline or a grid, many visualizations also provide alternative layouts like piles or networks. As the 'Bohemian Bookshelf' (Thudt et al., 2012) demonstrates, the availability of multiple layouts not only provides a multiplicity of access points, but can also increase the likelihood of serendipitous discoveries.

In summary, it has been shown how visualizations of cultural collections already provide a range of overviews of entire collections, while giving access to the specific details of individual items. However, most collection interfaces still feature relatively rigid and abstract representations that do not integrate the physical gestalt and manifold semantics of the collection.

Approaching a rich collection of coins

What would it take to translate the unique material qualities of a cultural collection into the design of the visualization used for exploring it? In the following, we briefly introduce the collection used in this project and describe the initial steps of our design process including workshops, paper prototyping, and data explorations. These

steps lead to the specific design goals which form the basis for a unique interface concept and prototype.

From rows and columns to coin collages

The permanent exhibition of the Münzkabinett Berlin contains about 5,000 numismatic objects. Typically, the collection items are presented in tabular grid presentations mostly in vitrines and some in stand-up displays. The objects in the vitrines are labeled with numbers and at the bottom of the display further information is given on signboards. In a small corner between two cabinets the visitors can touch replicas of the coins. Another opportunity for visitors to access the collection is the online catalog, which the Münzkabinett has built up over the last ten years. Currently, about 30,000 of 500,000 objects are digitized and are part of a search-oriented online catalog (Münzkabinett, 2017). When using the search functions, the filtered objects are returned in a grid of thumbnails. The page for each numismatic item contains extensive information including title, current location (storage or exhibition), provenance, year, and origin. Some of these fields are linked to reference databases such as the German National Library, GeoNames, VIAF (Virtual International Authority File), and Wikipedia. The main issue with this type of presentation is the lack of clarification of the relationships among the objects themselves. Akin to Kreiseler et al.'s analysis of museum interfaces, the catalog leaves 'the impression of following a one-way street or even an impasse' (2017, 11).

To initiate the ideation process, we held a co-creation workshop in the rooms of the Münzkabinett building using the method devised by Chen et al. (2014). With this format we gained more insights into the expectations and aspirations that people with varying background in numismatics had for visualizing the collection. Nine participants attended this workshop, five of which were employees of the Münzkabinett and four of which had no prior knowledge about numismatics. During the workshop, each participant created at least one collage to represent aspects of the coin collection which they found significant or interesting.

After the collages were created, participants presented and discussed them one by one in the group. The collages showed mostly maps and networks (see

Figure 2: Collages of the workshop at the Münzkabinett Berlin (2016).

Figure 2). While we did not analyze the collages in detail, they helped to structure the exchanges with and among the workshop participants. Seven participants placed a particular focus on the relationships between persons and coins. The numismaticians especially emphasized historically relevant people and events, as well as the coins' provenance. At least two participants considered circulation and material value of the coins. However, to the surprise of the lay people, the experts were not interested in the exchange value of the coins. In addition to historical use, heritage, and provenance, the research focus does not lie so much with the physical coins, but rather the persons associated with them, such as the minters, rulers, and collectors.

After the workshop, we questioned our original ambition to orient the design towards the numismatic interest, and asked whether a perspective geared towards a lay audience may be more beneficial for the purpose of communicating the richness of the collection. Specifically, we asked ourselves one question: How can we devise a new form of access that is playful, while still providing meaningful insights into the collection? To answer this question, we first considered the numismaticians' emphasis on historic people and events, but later shifted focus towards the material qualities of the coins.

Early explorations with data and artifacts

At the beginning of this project, we followed the cues from the experts and engaged in various visual explorations of a set of 29,000 data items, with regard to person-coin relationships. Grids in eight colors visualized the eight different roles of

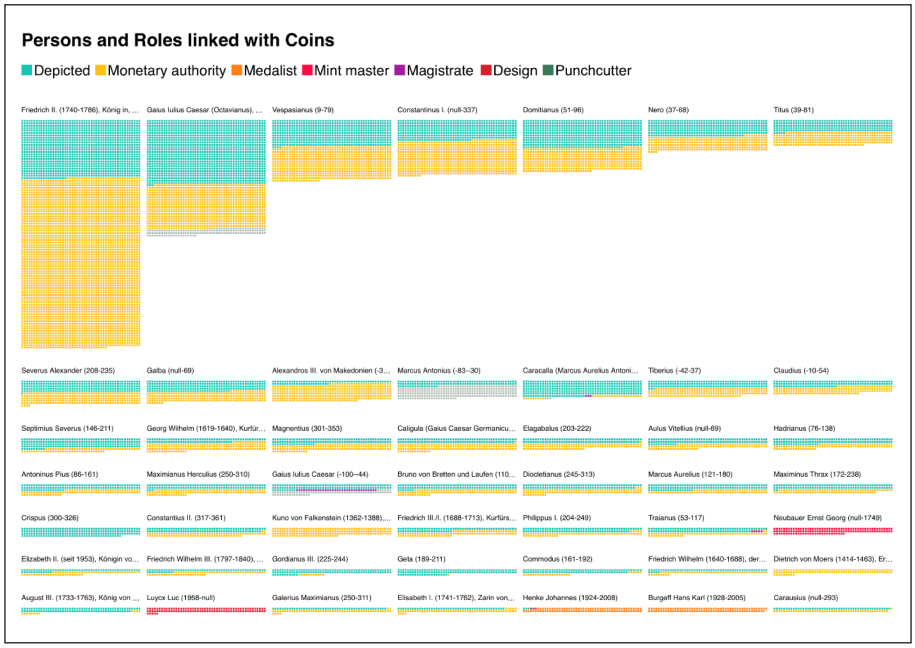

Figure 3: Data exploration of the different roles of historic people within the coin collection.

involved persons (see **Figure 3**). The first exploration shows the 'coins per person' ratio in a grid visualization showing how many numismatic objects are related to one person and the role(s) the person assumes. However, at this point we realized that the opportunities with person-coin relationships were extensive, yet possibly not compatible with the ambition to expose the physical qualities of the collection. Our own preconceived notions of a rich coin collection in the form of a bag or a treasure chest were at odds with the austere aesthetics of the resulting visualizations. However, these data explorations helped us to gain a sense of the structure and semantics of the coin collection and its digitized form.

Despite this, the various other relationships with regard to the material, origin, and time of use of the coins appeared much more clearly in design experiments with real coins (see **Figure 4**). Physical sketching using paper as background and contemporary coins as tokens proved to be particular useful for constructing various arrangements (Huron et al., 2014). Arranging a multitude of coins into various layouts was strangely gratifying and conveyed a sense of abundance resembling spilled gold coins. We were able to quickly examine the viability of different visualization

Figure 4: Prototyping ideas for the coin visualization using actual coins.

techniques, such as networks, piles, streams, timelines, clusters, and monadic layouts (Dörk et al., 2014).

These explorations using both data and artifacts provided us with a better understanding of various semantic and material relationships embedded in the coin collection. We decided to focus on coin-coin relationships, i.e. aspects that can be used to compare and contextualize the individual coins as material objects and historical artifacts. Visualizing these coin-coin relationships suggests the consideration of the collection as a whole, which has a visual gestalt assembled by the various individual coins. Furthermore, the relationships among coins such as origin, material, and time of use promised to be more accessible and attractive for a lay audience.

Design goals

Overall, the aim of this research is to reveal the extent of a digital heritage coin collection, the material quality of its artifacts, and their relations between each other: in short, its rich complexity. Based on our research questions, our insights from the workshop, and data explorations, we arrive at the following specific design goals for the visualization:

1. **Embrace the physicality:** In order to create a connection between the abstract representation of metadata and the concrete display of depicted objects, fluid layouts and high-quality images that do justice to both the material and semantic aspects of the collection should be used.
2. **Provide minimalist interactivity:** The visualization should require minimal effort and knowledge to make one's way through the collection.

As opposed to lengthy dropdown menus, paginations, and search forms, the visualization should support relatively obvious interactions that mimic actions that could be carried out with physical coins too.

3. **Include elements of surprise:** Viewers should be encouraged to make their own serendipitous discoveries without a lead or any predefined selections. The visual interface should allow for a range of selections and arrangements, each of which could generate unique observations and insights into the collection.
4. **Move beyond the grid:** In contrast to the ubiquitous grid of thumbnails, the coins should be arranged in a variety of organic layouts that show relationships among the coins, reveal larger patterns in the collection, and convey a visual gestalt of the collection.

With these goals in mind, we strive to conceive a novel approach to visualizing cultural collections that aims to encourage exploration and discovery by translating data patterns into a range of flexible and organic layouts.

Arranging coins into piles and streams

In the following, we describe the final design of the coin visualization, in particular the logic behind the arrangements and the functions provided for interactive exploration. The interface features a full-screen canvas that acts as a table, on which the coins are spread out. Apart from the canvas there are two distinct areas containing controls to navigate and manipulate the visualization: on the bottom left are the controls for selecting properties and layouts, while selected filters such as a country of origin or an individual coin are displayed in the bottom-right corner (see **Figure 5**). Since the coins are the centerpiece of the tool, the control elements are laid out to take up a minimal amount of space and only appear when necessary.

When opening the website (Gortana et al., 2017), after a short introduction the viewer is presented with all the available coins clustered together into one big pile. While this certainly follows Shneiderman's (1996) practice of starting with an overview and giving detailed information on demand, it also serves an educational purpose. Starting out with a single big pile of coins shows that there is not just one inherent structure to them but a multitude of different ways to sort and slice the

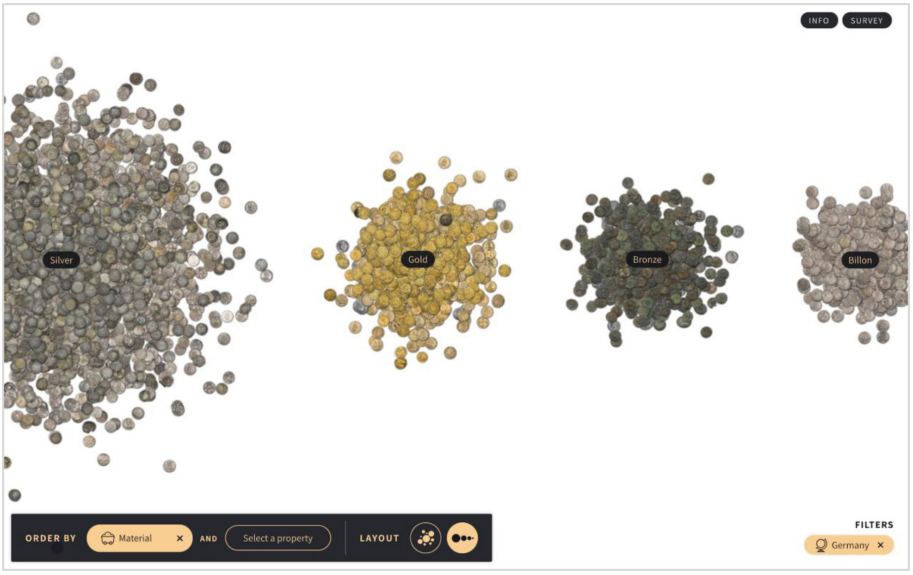

Figure 5: Material is selected as the facet for the ordering in the layout cluster list (bottom left) and Germany is set as a filter (bottom right).

entire collection. In contrast to the physical world, where sorting coins is a tedious task, the powers of an interactive and dynamic display make it possible to try out any number of arrangements, transforming a pile into a sorted grid in the blink of an eye.

Interactivity

The interface offers a variety of interactions, each of which results in a distinct layout for the collection. On the bottom left corner, two control areas can be found: The first one, titled 'Order by', prompts the viewer to select coin properties from a list. In this list a number of categorical properties (Country, Region, Minting Place, Period, Material) as well as numerical ones (Weight, Diameter, Earliest Date, Latest Date) can be selected. Categorical properties are represented in discrete forms such as piles and numerical properties are displayed as continuous representations such as streams. Selecting a property from the list causes the coins to change their spatial arrangement to represent the selected properties across the collection. Depending on the kind and amount of properties selected, a range of layouts becomes available.

The layouts as well as the transitions between them are designed in such a way that the imperfections and constraints of the physical world are respected. This mainly serves three purposes. First, the animated transitions between layout changes

and the object permanence that is in place, even if the collection is filtered, help the viewer to comprehend the changes that were made to the arrangement. Secondly, by having a zoomable canvas with draggable coins and by giving certain layouts an element of apparent randomness, we aim to uphold the common properties of the physical world. This should make it easier for a viewer to create a mental link between the manipulation of a virtual coin and the pushing and dragging of a real object by hand. Thirdly, by staying close to the physical behavior of the real-world objects we introduce an element of serendipity to enable exploration and discoveries in a similar fashion to those that can be made with an actual pile of coins.

Layouts

The layouts are designed to always include the entire collection; coins that are currently not selected are positioned at the periphery. The only variable we make use of in order to reveal relationships and higher order patterns within the collection is spatial arrangement. With each possible combination of selected property types (numerical/categorical) and their respective representations (continuous/discrete) a range of ten layouts is possible (see **Figure 6**).

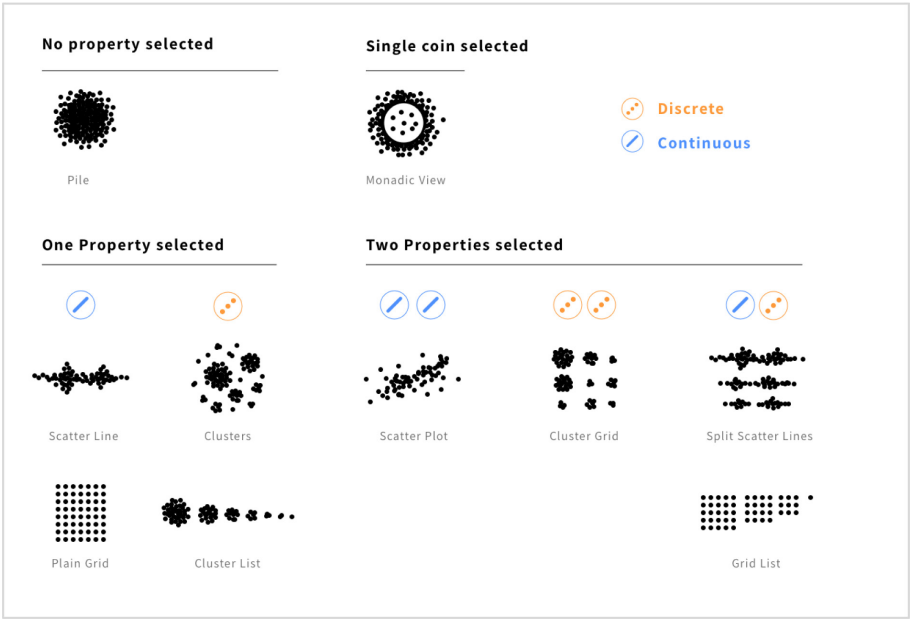

Figure 6: Based on the type and number of properties selected a range of layouts are possible.

The implemented layouts are chosen based on their overall accessibility and their ability to convey a sense of the collection's specific physicality. In many cases the layouts resemble arrangements that would naturally occur if someone were to manually bring order into a physical collection of coins.

Pile — If no properties are selected the coins form one big pile in the center of the screen (e.g., Yi et al., 2005). This is the first layout the viewer sees when opening the interface. Using a random normal distribution, with its maximum at the center of the screen, the collection of coins gives the impression of having been spilled on the floor.

Scatter Line — With one numerical property selected (such as 'date') the coins are positioned along a continuous x-axis according to the value of the selected property. The vertical position is determined by the amount of coins that have a similar value on the horizontal x-axis. The more coins there are with a similar x-value the stronger the scattering along the y-axis becomes. The scattering is again determined by random normal distribution. This causes the vertical amplitude to form visible spikes around the areas with a higher concentration of coins. This way we can make use of the same characteristics that are known from stream graphs (Byron, 2008), while still using only position as a visual variable. The layout is presented with labels that describe the different values. While this layout leaves the viewer with an impression of the distribution based on one specific property, many coins are covered by other coins due to the intentional imperfection of the scattered layout.

Plain Grid — A second layout that is available when one numerical property is selected is a two-dimensional grid in which the coins are sorted by the selected property. Starting from the top left, the positioning occurs row by row leaving the coin with the highest value at the bottom right of the grid. Labels are positioned on the left-hand side of the grid to indicate the values of the current and subsequent rows. The vertical positioning increases when a lot of coins have similar values. This layout forms a considerable contrast to most of the others since it does not attempt to imitate the imperfections of manipulating the coins by hand.

Clusters — Selecting one categorical property such as 'Material' causes the coins to rearrange into discrete clusters, each of which form piles of different sizes. The

position of each cluster is determined by a Circle Packing Algorithm, which efficiently positions any number of circles into one surrounding circle. The space reserved for each cluster is determined by the amount of coins it contains, while their visual size is achieved by using random normal distribution as seen in the Pile layout. The more coins within one category, the more scattering occurs. Each cluster is then labeled with its value. To prevent the labels from overlapping, the labels of smaller clusters only become visible when zoomed to a certain level. The apparent advantage of this layout is the spatial efficiency, by which the entire collection fits on the screen while displaying the categorization over one property.

Cluster List — To overcome the disadvantage of the Cluster, not being able to accurately compare cluster sizes, the Cluster List becomes available for categorical properties. This layout creates discrete clusters of coins in the same way the Clusters layout does, but instead of packing them into a containing circle, it sorts them by cluster size and lines them up on a horizontal axis in a descending order.

Scatter Plot — When selecting two numerical properties, the coins are arranged along two continuous axes into a simple Scatter Plot (e.g., Yi et al., 2005; Chu & Yee, 2015). The first property determines the position on the x-axis, while the vertical position is set by the second property.

Cluster Grid — The selection of two categorical properties causes the collection to arrange into a grid of discrete clusters. Columns are determined by the first property and rows are formed by the second property. Each cluster represents the intersection of a row and a column containing the coins that exhibit both, the row as well as the column value (e.g., Huron et al., 2013).

Scatter Lines — This layout becomes available when one categorical and one numerical property are selected. As the name suggests, this layout is nothing more than small multiples of the Scatter Line layout. The coins are grouped by the categorical property while arranging each group into a Scatter Line. This layout allows for a more nuanced analysis of a numerical property by being able to compare the distribution over the available groups of coins. This might, for example, reveal the time periods in which the usage of certain materials peak (see **Figure 7**).

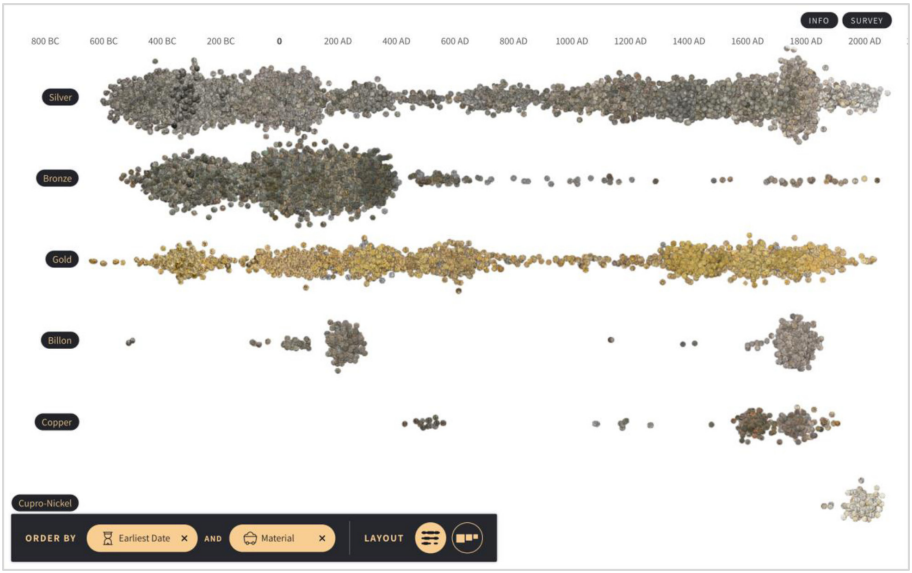

Figure 7: Selection of 'Earliest Date' and 'Material' triggers the Scatter Line layout, which is also changeable into a Grid List.

Grid List — In addition, we implemented an equivalent of the Plain Grid layout applied to multiple groups of coins. The coins get grouped by the categorical property into discrete rectangles and get placed into a grid as described in the Plain Grid layout. Each grid is then placed on a horizontal axis while again being sorted by the number of coins contained by the group.

While these layouts can be used on the entire collection they can also be applied to a subset, which can be created by clicking on a label of a categorical property. When, for instance, the coins are grouped by country, a label such as 'Italy' can be clicked, which causes the layout to rearrange only incorporating the selected coins. Coins not satisfying the selected filter are arranged into a circle outside the viewport, which become visible when zooming out without interfering with the currently selected layout. By repeating this step along multiple dimensions, the viewer can dive deep into the collection, focusing on an increasingly smaller subsection.

Monadic View – As a final way of diving into the collection, the viewer can select a single coin to activate a monadic layout (Dörk et al., 2014), in which all remaining coins are arranged into a radial composition around the selected coin (see **Figure 8**).

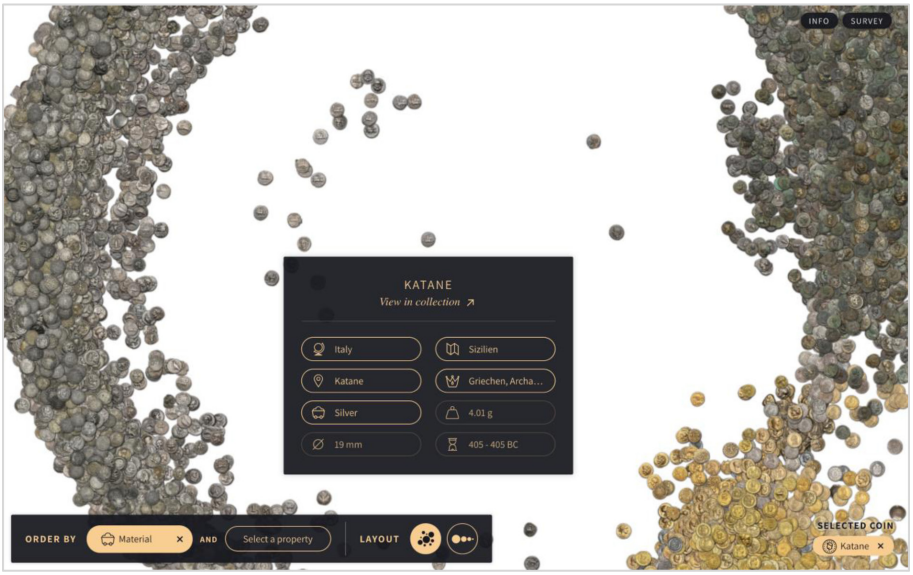

Figure 8: The Monadic View arranges the coin collection around one selected coin based on semantic similarity.

The coins that are related to the selected coin in any way, for example, by sharing the same material, move closer towards the center. The more similarities a coin exhibits with the selected coin, the closer it moves towards it. This makes it possible to move through the collection from one coin to another along various degrees of similarity or difference and to discover new coins accordingly. The Monadic View also visualizes the degree to which a certain coin is an outlier within the collection. While some coins have several hundred similar coins, others have none, i.e., all remaining coins move away. Along with the selected coin appears an information panel listing all the coin's properties, of which the categories are again selectable, making it possible to move to a filtered view based on a property of a single coin. The information panel also contains a link to the relevant entry in the online catalog of the Münzkabinett.

Technical notes

The visualization concept was realized as a web-based prototype using standard web technologies and several JavaScript libraries: D3.js for calculation of positions such as normal distribution and pack layout and for animations, Pixi.js for rendering the coins on the screen using WebGL, and React for rendering DOM elements.[1]

[1] http://d3js.org/, http://www.pixijs.com/, https://reactjs.org/.

A considerable amount of effort also went into the preparation of the data. The preparation of the data included transforming the LIDO formatted XML database export into a stripped-down CSV file only containing the properties necessary for the visualization. In addition, the coin images had to be prepared in a way such that 26,000 of them could be handled by a typical browser and internet connection. This involved creating sprite sheets, which are larger image files each containing smaller images of 1,000 coins resulting in 26 composite images. The position and size of each coin image within a sheet then had to be saved to the CSV for subsequent cropping of the sheet inside the browser. The image preparation also involved making white areas transparent and adding a drop shadow to each coin to provide a more realistic appearance in the visualization.

Evaluation

The final version of the coin visualization is the result of an iterative research and design process during which multiple forms of feedback were solicited. In the following, we briefly report from two approaches to studying the potential of our approach. First, we detail the observations during a user study, then we describe feedback gathered during a web deployment.

User study

The final prototype was tested by ten participants (including both lay people and experts), who were asked to freely explore the collection with the interface and share their thoughts in a talk-aloud protocol. While we were interested to see how they approached the interface, we specifically wanted to better understand whether the layouts and filters were comprehensible and to what degree the visualization would raise questions about and trigger interest in coin collections. Each participant used the tool for about 30 minutes, while sharing what they noticed and why they chose certain properties and layouts.

Five of the participants were given prompts to find special coins. Compared to the other five participants, who were at times unsure about the task to be done, the participants on a quest appeared to have had a greater sense of achievement. All of the participants needed some minutes to grasp the basic functionality of the prototype. We observed that participants often searched for coins that are somehow related to

them, such as those from their own country. One particularly interesting insight from conversations with the non-expert participants was their desire to save coins they found to be interesting in a special 'box of favorite coins' to revisit them later.

While all participants had differing ways of exploring the coin collection, we noticed in the talk-aloud statements two distinct types of approaches, which we coined the 'browsers' and the 'thinkers'. The **browsers** were people who immediately started using the various functions of the tool, without much deliberation. They seemed to decide which coins were of interest intuitively and without fear of doing something wrong. The browsers clicked on different properties, coins, and attributes, and observed what happened next. The particular coins they selected were the ones which attracted them visually or because they stood out due to their position. In contrast, the **thinkers** generally seemed to always have a plan in mind for what they would select and filter. They thought and acted in a more structured fashion and with a clear intention to find the most exciting and promising combination of properties and attributes. To choose a special coin at the end or have a group of coins positioned in a layout helped them to gain more insights, they followed a line of thought before they would select the coin. Interestingly, some of the participants in this group were already knowledgeable about coins. While we draw no final conclusions from these observations, these types suggest that the interface did enable, or at least allow for, these differing ways of making sense of the collection.

Web deployment

Finally, we deployed the visualization as a website to better understand how a broad range of people would use it. User interactions were logged via Google Analytics and a brief survey was linked in the interface. The survey was open for six days in September 2017 with the two questions: 1) What did you learn about coins while using the visualization? 2) What did you like or dislike about the visualization in general?

During the analysis of the survey answers, general trends emerged. The survey had 17 responses (though one person (P12) answered that they did not understand English). Answers from the other 16 were consistently favorable towards the

visualization. For the first question, the various physical and semantic attributes were mentioned most often (six times). These were also mentioned in combination with quantity (P2 and P6), and comparison and similarities (P8). The quantity of coins in the collection was recurring theme ('there are many' P9), which was mentioned by five participants. Furthermore, the occurrence of trends was considered important and mentioned three times, e.g., 'Gold coins were popular around the 1400s' (P16) and the quality of digitization by the Münzkabinett was also mentioned (P7). Furthermore, the variety of coins was mentioned twice by survey participants, along with the opportunity to find comparisons and similarities, and the location of mintage and circulation, as well as the classification of the coins. For the last point, P3 wrote: 'I played with the different views and presentations and I found the order by the properties an [sic] nice way to learn how coins can be classified'.

For the second question the feedback was generally positive, with a several comments containing criticism or suggestions. The viewers mostly appreciated the layout (eight times). P6 had difficulties with the grid layout: 'I don't know if I should drag the grid in every corner. It is exhausting' (translated). Another viewer had lost the overview (P9). A further important theme was the wish to be able to zoom in more (eight times). In addition, two participants shared critical feedback about labels and axes becoming invisible when zoomed out (P2 and P17). P2 also wrote that they wished to compare a smaller cluster with a bigger one through the labels, but it was only possible on another zoom level. Further positive points were the filter and sorting options (three times). Two responses wished for more historical context (P14) and the possibility of flipping coins (P16).

To get some information about the usage of the visualization, the prototype was instrumented with Google Analytics. We chose to track four interaction events triggered by different types of interactions: coin selections, layout changes, and filter operations by selecting attributes or coins. During the online survey there were 397 unique visitors on the website with 487 sessions in total. The average session duration was around three minutes. The sessions contained 5,929 total events in the four event categories. From these total events were 2,853 unique events which means that one event was registered for the first time of one session. Based on the

unique events the most logged actions were coin selections (14.1%) and layout changes (13.5%) followed by attribute selections (9.1%). Less frequent actions were filter selections made via the coin detail display (4.9%) and the deselection of a previously selected coin (4.3%). According to these observations it seems that the focus of the viewers was on individual coins and the overall data patterns provided by the different layouts.

Discussion

The observations during the evaluation indicate the specific potential of collection interfaces to integrate data patterns and physical qualities into visual representations. The coin visualization appealed to the participants of the study and visitors of the website. Their feedback suggests that the interface piqued their interest in the various attributes of the coins, and also the overall size and diversity of the collection. It was possible for viewers to perceive historical trends in the collection, e.g., when certain materials were more commonly used than others. It is this appreciation of the coins as individual elements, the collection as a whole, and general trends in the data that confirms our hypothesis with this research. In the following, we briefly discuss open challenges and questions raised in the course of the evaluation.

The feedback included several suggestions for improvements of the interface. While participants of the user study stated that the interface made them curious about individual coins, they wanted to explore them in more detail and save them for later. For this purpose, they suggested something like a treasure box or a piggy bank could be integrated into the visualization. This function could also address the request for being able to re-find previously discovered coins. With the problem of saving the chosen coins the participants often lost track of the object of their curiosity through zoom operations or other layout changes. Yet, the fact that participants encountered coins that they valued so much to save and revisit them also suggests that the visualization was able to encourage exploration and discovery.

However, an open-ended interface may be challenging for some people to orient themselves in the visualization and find a path through the collection. Following the suggestion by several participants to provide more guidance in the

visualization, we included 'help' overlays describing the main interactive elements and explain how to select coin properties, change layouts, and set filters. To support both the 'browsers' and 'thinkers' we identified during the user study, a collection interface needs to strike a balance between the information that is immediately displayed and that which can be gradually uncovered through exploration. To encourage engagement with the collection, another option could be to pose questions to the viewer when they visit the visualization for the first time. For this visualization, it was our explicit aim to let the viewers explore it on their own, akin to an information flaneur (Dörk et al., 2011) pursuing their own curiosity to discover new things. However, playful tasks could encourage viewers to remain longer within the visualization to gather information. One of the study participants summarized it like this: 'I really liked the way how you tested me with searching specific coins, to get more comfortable with the tool. It felt like a hide and seek game, and I had to search the hidden coin!'

Another question that deems further investigation is to what degree viewers gain insight into the collection. The online users seemed to be curious about the variety and quantity of coins, and the participants of the study noted that they learned general aspects about the collection's temporal and spatial extent. The visualization gave an impression of the whole collection and the participants could compare the different coins with each other, but they did not get particular information about the coin itself like the specific face design from the visualization. Furthermore, participants also wanted know more about the labels and imagery on the coins. Therefore, the zoom operation could also be thought of as a mechanism for providing much more depth than what is provided at the moment, as the zoom level could go beyond high-resolution images and display objects three-dimensionally. This change could also address a limitation of the prototype being geared to a lay audience and not professionals. To think of such an environment as a hybrid tool for people either knowledgeable or curious about coins, more detailed information about the artifacts is necessary, e.g., in the form of relevant academic articles, essays, and biographies (Glinka et al., 2017).

Conclusion

The linear order of grids and lists dominates the display of cultural collections in online interfaces – and to some degree in physical exhibitions as well. With our design-oriented research, we sought an alternative approach to visualizing a collection by acknowledging its material qualities. During an iterative design process in collaboration with numismaticians, we devised a playful visualization of a coin collection that represents material and semantic data patterns across 26,000 items. By running a co-creation workshop, prototyping with coins, and engaging in data explorations, we engaged with the disciplinary expertise of our collaborators, the materiality of the coins, and semantic patterns in the database. The result from this process is a visualization that consists of arrangements such as piles and streams that convey the gestalt of a collection when spread across a table according to specific properties and afford a different kind of exploration. We aimed at creating a unique visualization, with which viewers can contextualize and compare objects, their relationships to one another, and the entire collection. The resulting visualization blurs the boundary between the concrete presentation of coins and the abstract representation of data patterns. Despite deviating from the expert suggestions, we received particularly positive feedback from the numismaticians, who appreciated the visual and playful approach to the collection they hold dear. Furthermore, the results from a mixed-method evaluation emphasize the viability of this approach and raise questions and challenges for future research and design.

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Competing Interests

The authors have no competing interests to declare.

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