Staged Analysis: From Evocative to Comparative Visualizations of Urban Mobility

Till Nagel*
Urban Complexity Lab, FH Potsdam
Hochschule Mannheim

Christopher Pietsch†
Urban Complexity Lab, FH Potsdam

Marian Dörk‡
Urban Complexity Lab, FH Potsdam

Abstract

In this paper we examine the concept of *staged analysis* through a case study on visualizing urban mobility exhibited in a public gallery space. Recently, many cities introduced bike-sharing in order to promote cycling among locals and visitors. We explore how citizens can be guided from evocative impressions of bicycling flows to comparative analysis of three bike-sharing systems. The main aim for visualizations in exhibition contexts is to encourage a shift from temporary interest to deeper insight into a complex phenomenon. To pursue this ambition we introduce *cf. city flows*, a comparative visualization environment of urban bike mobility designed to help citizens casually analyze three bike-sharing systems in the context of a public exhibition space. Multiple large screens show the space of flows in bike-sharing for three selected world cities: Berlin, London, and New York. Bike journeys are represented in three geospatial visualizations designed to be progressively more analytical, from animated trails to small-multiple glyphs. In this paper, we describe our design concept and process, the exhibition setup, and discuss some of the insights visitors gained while interacting with the visualizations.

Keywords: Flow maps, comparative visualization, urban mobility, bike-sharing, geovisualization, storytelling, public displays.

1 Introduction

New technologies are stimulating changes in our urban mobility. The digital transformation of our cities enables new services, ranging from car sharing and pooling, to multi-modal transportation and personalized travel routes. With the rise of these alternative transport options the way we move in our cities is being diversified resulting in changing transport patterns. Cycling is increasingly recognized as a critical component of our future urban mobility mix. Riding a bike is largely independent of other traffic, it remains unaffected by road congestion, and has health and environmental benefits. Paralleling the renaissance of bicycling, many cities around the world have installed bike-sharing systems in order to promote the use of bicycles among locals and visitors. The recent proliferation of bike-sharing systems poses an interesting opportunity for visualization research to investigate new ways to help citizens make sense of a complex urban phenomenon that is relevant to their everyday experience of the city.

In this paper, we introduce *cf. city flows*, an interactive multi-display exhibit visualizing bike-sharing mobility in three cities. By showing the flow of multiple cities side by side, exhibition visitors can compare their extent and dynamics. The visualizations are designed to support different levels of insight, from piquing visitors' interest to encouraging analysis. We explore this shift from surface to in-depth observations as *staged analysis*, to refer to a progressive increase of analytical capability from one view to the next.

In the remainder of the paper, we first discuss prior research, then develop the concept of staged analysis, and describe our design of cf. city flows. We finish with observations from a deployment during an exhibition and close with a discussion of open questions and promising directions.

*e-mail: mail@tillnagel.com
†e-mail: cpietsch@gmail.com
‡e-mail: doerk@fh-potsdam.de

2 Related Work

Our work relates the most to prior research on visualizing spatial movement patterns and targeting non-expert audiences in public settings such as exhibitions.

Various techniques have been developed for the visual analysis of movement data [2]. These have been used to visualize urban mobility, ranging from traffic data [7] to urban movements based on mobile phone data [11]. Flow maps are an established visualization technique for depicting movement between multiple geographical locations, typically showing lines connecting the flow origins with the destinations, often with the flow magnitudes mapped to line thickness. Recently, various techniques were proposed to improve flow maps for large networks such as through edge bundling [15, 21]. Others developed new techniques to lessen occlusion problems, such as OD maps [26], separating origins and destinations [5], or by clustering trajectories [1]. In the field of bike-sharing, urban planners have investigated public bicycle systems to analyze spatial networks and communities [3], or to study how weather affects its use [10].

Besides targeting the 'initiated' such as urban scholars, planners, or activists, visualizations of urban data can help city inhabitants to become more aware of their immediate environment, and provide the opportunity to communicate around current issues [24] and personal behaviour changes [23]. In order to reach non-expert audiences, visualizations of urban mobility have already been displayed in exhibitions, ranging from animated visualizations of bike-sharing [25] to interactive tabletops showing public transit [18]. However, visualizations in public settings tend to offer fairly reduced representations with limited analytic capability. Most systems provide interactive views only for a single city, and only static graphs for multiple cities. Current research is exploring how to support interactive comparisons across multiple locations. Spatial scale differences as well as data complexity pose technical as well as perceptual challenges. Existing work already allows the visualization of urban activities in multiple cities [4, 11], but only in sequence and not in juxtaposition for comparative analysis. It is not possible to conduct detailed comparisons of flows for far apart areas. However, visualizing mobility patterns between multiple cities could enable citizens to put their own city into a larger perspective. In addition it is also the comparison between different locales within a city that is lacking in most public visualizations, even though it could help viewers to relate the data to their own everyday life.

3 Towards Staged Analysis

Traditionally aimed at experts, data visualizations are gaining currency in the wider public, especially with their expanding use in news and social media. However, when designing visualizations for

Figure 1: Visitors observing bike-sharing in New York, Berlin, and London each shown in the citywide view.

a broad audience, it can be difficult to reach the right balance of aesthetic quality, data complexity, and analytic capability. Related to the aim of supporting short-term and long-term explorations [14], the challenge for visualizations in exhibition spaces is to support a gradient from vague interest and curiosity to open-ended exploration, specific insights, and casual conversations. It is still likely that visitors encounter a given visualization technique for the first time. Being unfamiliar with the visual encodings and interaction techniques might make the represented phenomena considerably more opaque than expected.

The first necessary step is to actually gain the attention of visitors and then, if successful, gently guide them through a visualization exhibit. Ideally a visitor would reach instant rapport with the visualization and be continuously stimulated until their curiosity is satisfied and they have made an interesting observation. However, often visualization exhibits fall behind the technical status quo in order to not overwhelm visitors with varying backgrounds. The question is, how can we encourage citizens to engage with these relatively new representations and help them to make sense of complex datasets such as urban mobility patterns?

To explore the challenge of gradually moving from interest to insight we propose the term *staged analysis*. Invoking temporal and theatrical notions, we define 'staged analysis' as a carefully choreographed process of breaking up a complex whole into its component parts and purposefully preparing the manner of their appearance. In the context of visualization, the concept of staging typically refers to animated transitions broken up to be more easily observed [13]. We build on top of this notion of staging and extend it to a guided analysis process.

Staged analysis starts with a high-level perspective on the phenomenon and then gradually shifts into specific views supporting structured comparisons. At the beginning a visualization designed with staged analysis in mind should first provide the opportunity for an aesthetic experience, which forms the basis for the later stages that encourage an analytical engagement with the represented data. In short, our aim is to devise ways for piquing a visitor's interest in a visualization of a complex phenomenon, growing their capacity to make sense of the visualized data, and encouraging them to engage in discussions about the topic with other people.

3.1 Design goals

To transfer the theoretical concept of staged analysis into practical manifestation of a case study, we propose three design goals for visualizations in exhibitions that operate at three levels: the aesthetic, functional, and social.

Provide evocative aesthetics (EA). The overall experience of the visualization exhibit should be designed in such ways as to attract visitors and pique their curiosity. While it is certainly challenging to measure, it has been shown that aesthetically pleasing visualizations can increase a viewer's interest and lead to lower abandonment rates [6]. The default views of the visualization should already be compelling in order to attract and engage visitors passing by [20]. To encourage people to explore the data for longer, the system should also provide fluid interactions including high responsiveness and smooth view transitions [9].

Support comparative analysis (CA). Visualizations designed for staged analysis should encourage visitors to compare multiple aspects of complex datasets, for example, in the case of urban mobility various spatial and temporal comparisons are feasible. Comparative views on urban mobility may help visitors to better understand their specific city in the context of others and their own mobility pattern across the day. Making mobility patterns visible to citizens, can be seen as an invitation to think globally and relationally, possibly even with regard to their own mobility. In this way, we hope people can start to place their own urban experience in relation to other cities and consider themselves as informed global citizens. Different comparisons should be connected in an order that aligns with increases in the analytic capacity of the viewer.

Open a discursive space (DS). Besides the individual engagement with a visualization, public exhibitions offer the unique opportunity to have visitors interact with each other around the visualizations. Furthermore, people should be able to decide whether to interact with the system or to observe the visualizations. The setup of the exhibition should enable both individuals and groups of people to engage with the visualizations. The visualizations should support varying levels of insights to provide an inviting space for people with different backgrounds. Visual presentations and simple interaction mechanisms should be provided in such ways to be accessible to diverse groups of visitors. The social space around visualization exhibits should encourage casual reflection and discourse about the represented phenomenon and maybe even the visitors' own role in urban mobility [19].

To encourage staged analysis as a shift from cursory to profound experiences with data visualizations, the visualization, interface, and overall exhibit need to be designed towards above three goals operating at three distinct, yet interdependent levels: the aesthetic, functional, and social. The design goals stand in an ordered dependency with each other, in which evocative aesthetics (EA) forms the necessary basis for comparative analysis (CA), which in turn allows for a discursive space (DS) to open around the subject matter.

3.2 Approach

Our goal is not to quantitatively measure the varying levels of interest and insight of visualization users, which would be considerably challenging to do in an exhibition space. Instead we seek to develop and refine the conceptual ideas and design goals of staged analysis through a case study of a comparative visualization environment of urban bike mobility designed to help citizens casually analyze bike-sharing systems in the context of a public exhibition space. Besides exploring the viability of staged analysis, the aim of the case study is to enable insights into complex urban spatiotemporal data, support understanding of a city's mobility patterns, and encourage casual discourse among citizens. We believe that geo visualizations can empower citizens to make sense of the invisible layers in their environment and help people to better participate in the creation of the smart city. The city was always much more than its built form; by visualizing urban data we are now exploring novel methods to reveal these ephemeral and latent aspects of the city. We developed the project in an iterative design process, including various visualization experiments, discussions with public transit experts and potential users, and incorporating results therefrom into the system. Especially in a data visualization project, we deem an explorative design process useful in order to identify the relevant facets of the data and inherent stories first ourselves. More importantly, we wanted to investigate which techniques stimulate interest, and which are more analytical, and how to integrate them into a unified system. In this process we were oscillating between data analysis and rapid development of visual probes.

4 CF. CITY FLOWS

cf. city flows[1] is an interactive installation visualizing bike-sharing systems in three cities (see Fig. 1). Each system is visualized through a set of three interconnected views with gradually increasing analytic prowess, going from high-level views to small multiples. The installation was designed as an interactive triptych to be displayed in an exhibition setup suitable for a group of people, with one person controlling the visualization, and multiple persons able to watch and converse.

In the following, we introduce the underlying mobility data and describe the visual encodings, interaction techniques, and exhibition setup, while explaining the reasoning behind our design decisions along the way.

4.1 Bike-sharing data

As transport authorities and companies have begun to understand the value of open data, more and more bike-sharing providers are starting to share some of their system's data. This ranges from basics such as number and locations of stations, to available bikes and journeys between stations. While static data about the stations is abundant, only few providers share dynamic trip data, i.e., origin-destination information. It is particularly the dynamic aspects of bike-sharing activity that promises to be appropriate for our case study, first because it is data that is likely to be of interest to city inhabitants and second, because the bike movements between the stations lend themselves well to conceive inviting visuals. We selected the station-based bike-sharing systems of London[2] and New York City[3], for which origin-destination data is available. We also added Berlin[4], for which trip data has not been published so far. We scraped the data from a real-time map showing availability containing IDs for each bike. Thus, we could derive trip data on the assumption a trip started once a bike has been removed from the map and ended once it re-appeared later (potentially including non-trip bike movements, e.g., for re-balancing purposes). The chosen systems do not provide route information as the bike systems typically do not record GPS tracked movements (for cost and privacy reasons). We used the locations of the journey's start and end stations to calculate optimal paths via the HERE routing service[5] (with the pedestrian option).

While we collected months of bike-sharing data, for the exhibit we selected a Wednesday to tell the story of ebb and flow for a single working day. We chose 3 June 2015, which had similarly good cycling weather in all three cities, i.e., no rain and roughly 20°C, to minimize the influence of detrimental weather conditions.

4.2 Visualization design

Following the core idea behind staged analysis as a shift from interest to insight we devised a visualization environment with gradually increasing depth and detail. *cf. city flows* features three viewing modes, all visualizing trips of rented bikes, but focusing on different levels of spatial and temporal granularity of cycling mobility:

- The **citywide view** aggregates all trajectories of bike-sharing trips for a given day in the respective city and animates the trails for trips at a given time.
- In the **station view** only the bike trips to and from a selected station are shown, allowing for the distinction between incoming and outgoing journeys.
- A **small-multiple view** shows spatiotemporal patterns for three stations each in an exploded view separating incoming from outgoing and morning from afternoon/evening trips.

Visitors can switch between these viewing modes resulting in smooth transitioning into the next scene. To encourage the comparison between the cities (CA), the viewing modes are synchronized between the three displays. Each view shows an animation moving through the day, and highlighting bike trips of the current time with a fading trail for better visibility. The views of all three screens are temporally and spatially coordinated as they show the same time of day and have the same map scale. Each screen prominently displays the name of its city (top left) and the current time (bottom left). Additionally, the right bottom corner shows an arrow pointing north to indicate the current orientation of the background map.

We aimed to design our system in a highly aesthetic style in order to attract visitors in the exhibition space of an art and design gallery (EA). The background map's main purpose is to give visitors a quick overview of the city and provide the backdrop for the bike-sharing visualizations. The design of the basemap is inspired by the historic Nolli map, containing a figure/ground distinction between black and white shapes to denote private and public areas in Rome. In our map, the aim is to show where bicycles can go and where not. Building data is in the highest available resolution from the respective land survey authority. The map's color scheme is set in such a way to complement the bright bike trip trajectories as the main protagonist of the view. We selected and styled the geographic features for the base map to be unobtrusive, while still giving orientation and spatial context.

4.2.1 Citywide view

In the first viewing mode, the trajectories of all bike trips at a given time window are animated on top of the background map (see Fig. 2), one of the most common types to visualize movement of discrete entities [2]. This animation runs through the day, and highlights bike trips of the current time with a fading trail for better visibility. Underneath, all bike trips of the day are displayed as thinner,

[1] Besides for city flows, *cf.* also stands for *confer* (latin) resulting in a meaning of: compare the flows of different cities.

[2] https://www.tfl.gov.uk/info-for/open-data-users

[3] http://www.citibikenyc.com/system-data

[4] https://www.callabike-interaktiv.de

[5] https://developer.here.com/

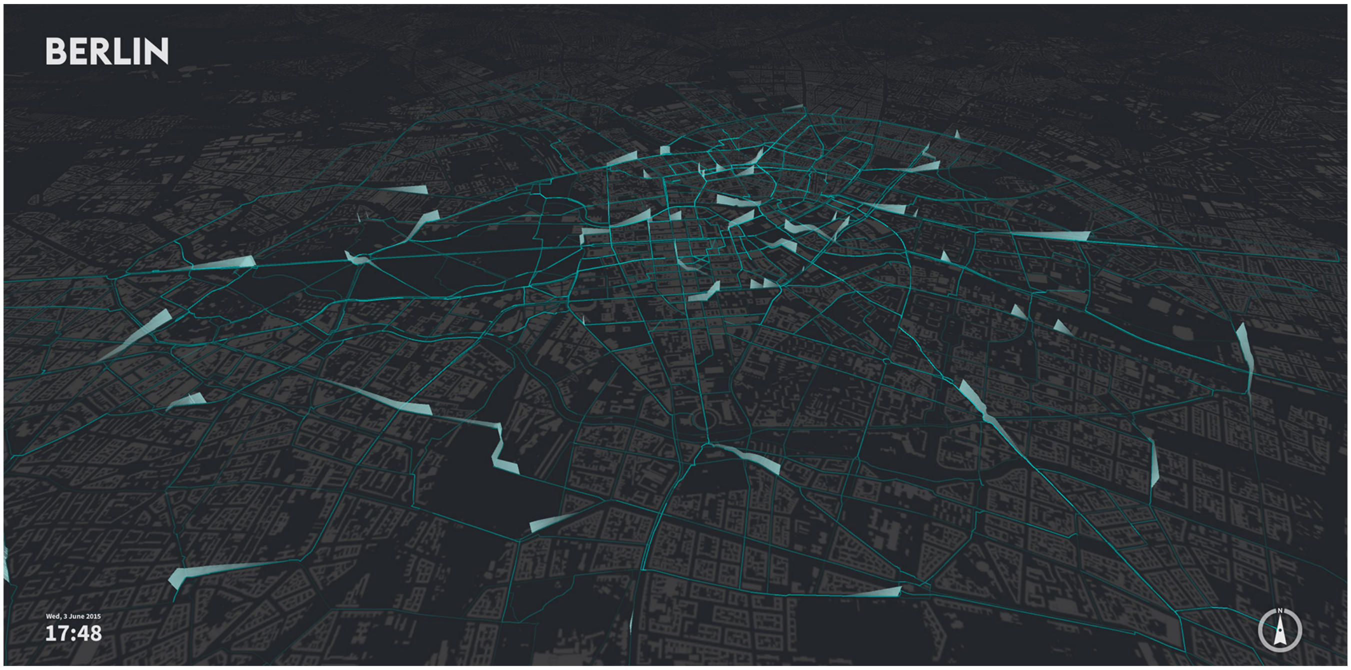

Figure 2: Citywide view showing bike journeys on a summer afternoon in central Berlin as animated trajectories, with all bike routes visible in the background.

lighter paths in order to give a subtle impression of the whole space of flows, and to allow comparing the current activity with the overall bike-sharing network.

Lacking actual GPS tracks, the trip trajectories are rendered as smooth paths of the calculated optimal bike routes (not only the locations necessary for navigation, such as street corners). We chose geographic routes instead of pure origin-destination paths for two reasons: First, straight paths across the city disregarding the physical infrastructure would be aesthetically uninspiring and most likely very dense (EA). Second, by aligning the bike movements with actual urban structures different trajectories would still share some segments of the street network, making it possible to compare the accumulated use of urban infrastructure (CA).

Trails are used to visualize the bike trips underway at the currently selected time. The trails are rendered in what we call a *firefly style* with the current position brightest and the previous ones fading, resembling how a moving light source appears in a long-exposure photo. However, the trails are not simply a stylistic choice; the length of the trail depict the covered distance within a time range of two minutes, thus visualizing the current speed of the bike. The longer the trail the higher the average speed of a given bicycle. This results in giving an indication of the relative speeds of different riders.

Lastly, the citywide view is displayed in a 2.5D perspective. The planar base map is tilted, with the trails displayed as 3D triangle strips. The whole city map rotates slowly around its center, with a focal length set so the outer skirts become blurry. The rationale behind this animated rotation is to entice visitors to engage with the installation (EA). Even when no interaction is underway the time animation and rotation continuously change the perspective.

4.2.2 Station view

The second mode is the station view showing trips to and from a pre-selected station. For each city, a station with high activity all day is highlighted and its name displayed. By selecting a single station we can distinguish the directionality of bike trips via color coding and closely observe changing ratios between incoming and outgoing trips. This distinction is introduced here to later allow for a more detailed comparison of multiple stations along this ratio.

While tapered lines for representing edge directionality has been shown to be more efficient [15], we decided on using colored lines and a diverging binary color schema with turquoise for incoming and orange for outgoing bike trips. As the trails are moving there is no need to have an additional encoding for direction. We also do not show a legend explaining the color mapping, as the ever-running animation directly depicts directionality. The rationale behind this color schema was to integrate with the other viewing modes, and not to interfere with the background map. The encoding was intended to be either self-explanatory or at least easily explained during conversations in the gallery (DS).

In a similar manner as the citywide view, the station view continuously animates over the day and highlights the trajectories of the trips at the current time window. Parallel to the decreasing heights of the trajectory trails, their colors are faded out in this view. Thanks to the color mapping and the fewer shown trips this view reveals more specific spatiotemporal patterns. For instance, in New York more trips start in the morning at the selected bike station than ending there, which hints to the commuters arriving by public transit at the train station and cycling to their workplaces.

4.2.3 Small-multiple view

The third view features an arrangement of small multiples presenting a detailed perspective on the activity of three bike stations per city. The bike trips for a selected bike station are separated into four map glyphs by directionality and temporality and set in a two-by-two grid. In the upper row all trips to, and in the lower all trips from that station are displayed. In the left column all trips in the morning, and on the right all trips in the evening are aggregated. Compared to the other two viewing modes, the small multiples is intended to support the highest level of comparative analysis (CA). Following its Greek antecedent, we pursue the notion of 'analysis' as an investigative unravelling. Analyzing a spatial structure along its temporal and directional dimensions results in what may be called *urban fingerprints*, characteristic small multiples of four

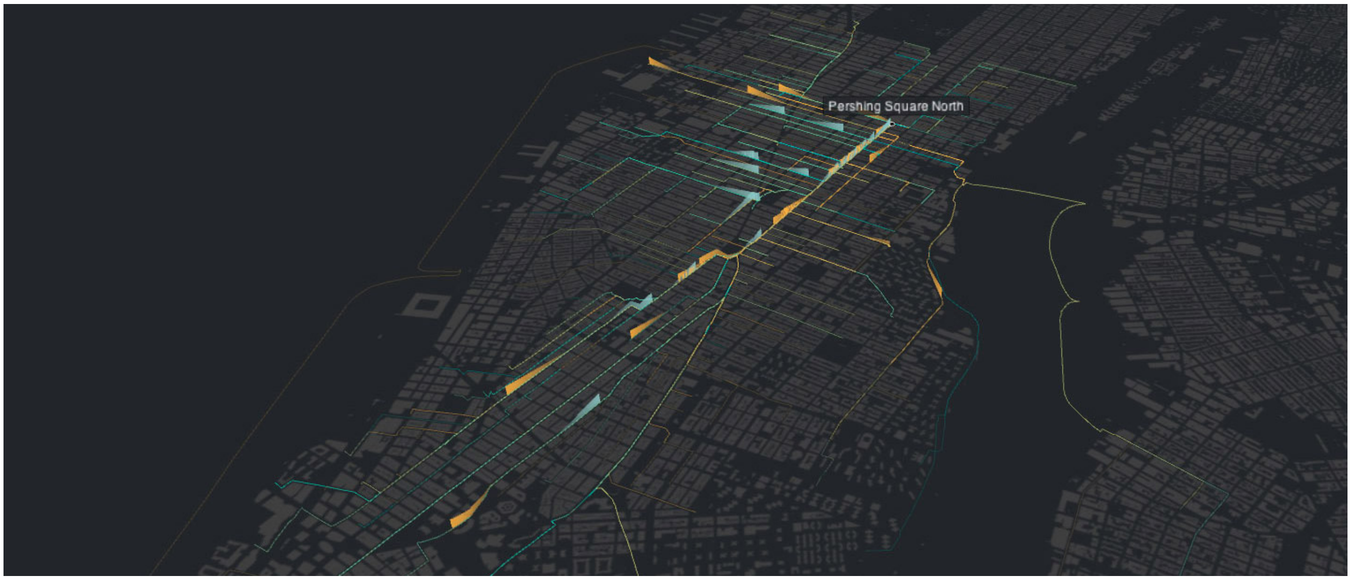

Figure 3: Station view showing bike trips to and from a selected station are shown as colored trajectories, with all the station's trips visible in the background. Here shown is the activity of a bike station in front of a major transit hub in New York.

graphs visualizing cycling activity.

For each city, this view shows urban fingerprints for three stations with different bike-sharing properties. They can reveal tempo-spatial mobility patterns, such as commuters arriving to an office district in the morning, and leaving the area in the evening (see Fig. 4 left). Compare that with the small multiples on the right, where more trips beginning in the morning and ending in the evening might indicate a residential or leisure area. There are numerous other distinctive groups of stations, from which we chose a transit hub with incoming and outgoing activity all day long and and a residential area with more departures in the morning and more arrivals in the evening (Fig. 4, middle and right).

Consisting of 2×2 (glyphs) $\times 3$ (stations) $\times 3$ (cities) in total, this view becomes visually quite complex. However, the visual mappings and distinctions are in part used in the previous viewing modes in order to iteratively expand the depth of the visualization. Due to the high-resolution screens people can decide to watch the visualization from different viewpoints. Up-close, visitors can study details of a single station, and investigate its catchment area. Looking from a medium distance, they can compare stations with different urban fingerprints. Through the two-by-two grid of glyphs a mnemonic shape emerges, enabling to understand its spatiotemporal properties at a glance. A major axis from top/left to bottom/right signifies places of work, while a mirrored axis signifies places of living. From further away, visitors can compare stations between cities, for instance to investigate how bike-sharing activity in residential areas differs among multiple cities.

In summary, the third view allows for detailed intra- and intercity comparisons (CA). While cities all have their own character, many have comparable functional units of urban mobility. The small-multiple visualizations are designed to let viewers recognize similarities and differences between stations of one city, and between stations of different cities.

4.3 Interactive dashboard

The interaction with the visualization is provided via a tablet embedded in a stilt at about one meter distance to the display wall. A dashboard on the tablet shows further details about the bike-sharing systems such as the total number of stations, bikes, and trips as well as morning and evening trips per city (see Fig. 5). The temporal fluctuation of trips over the day is displayed as a horizon chart [12], in order to keep the y-axis comparable for the three cities while still being able to show the widely different rented bike numbers.

Below the city details, users can switch between the views by tapping on one of the circular buttons. The buttons only allow for discrete steps in order to follow the deliberate sequence between the three views. We designed these in such a way to provide access only to the views currently available, as one has to go via the intermediate view in order to understand the more complex third view. At the bottom of the dashboard is an interactive time slider that shows the current time, and allows visitors to select any time of day directly. Each temporal selection is reflected in all screens instantaneously.

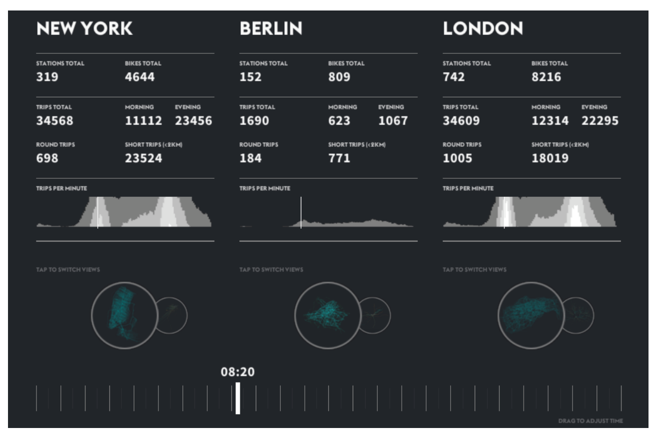

Figure 5: Dashboard with statistics for each city (top), buttons to switch the view, and an interactive timeline to set the current time window (bottom).

4.4 Staging transitions

When a visitor switches to another view the systems fluidly animates between the old and the new view through staged transitions [13]. Besides supporting the perception of changes between different data graphics, we use the animations to introduce the vi-

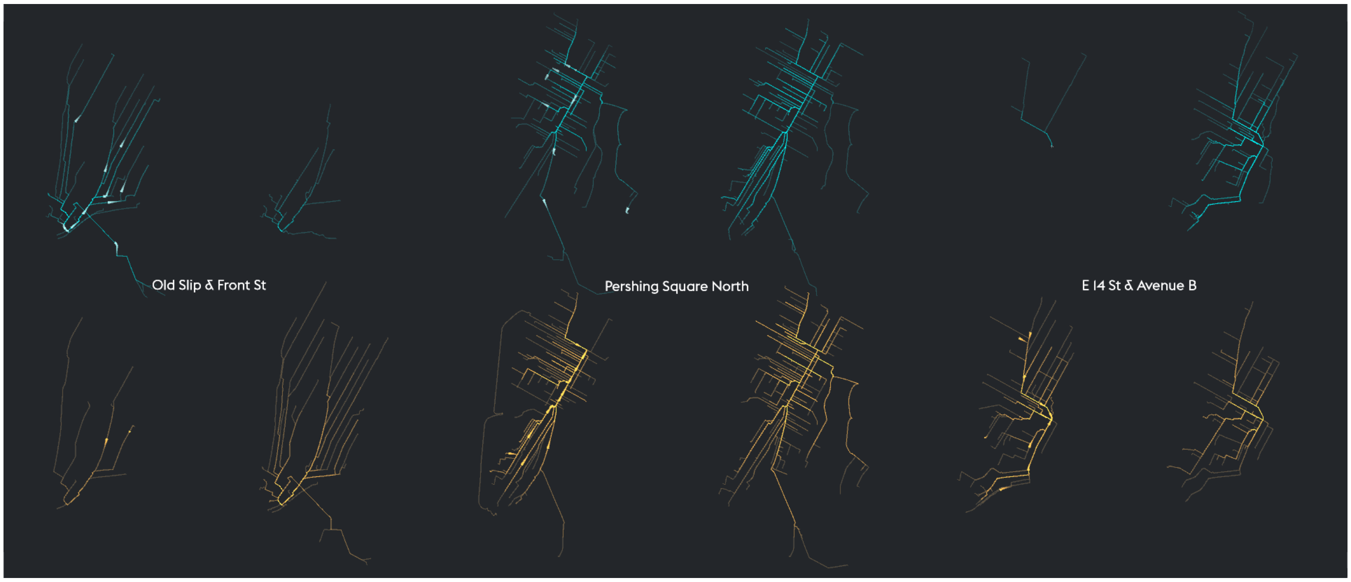

Figure 4: Small-multiple view showing trips to (top) and from (bottom) selected stations in different areas of New York with varying characteristics: the financial district (left), nearby central station (middle), and in a residential area (right).

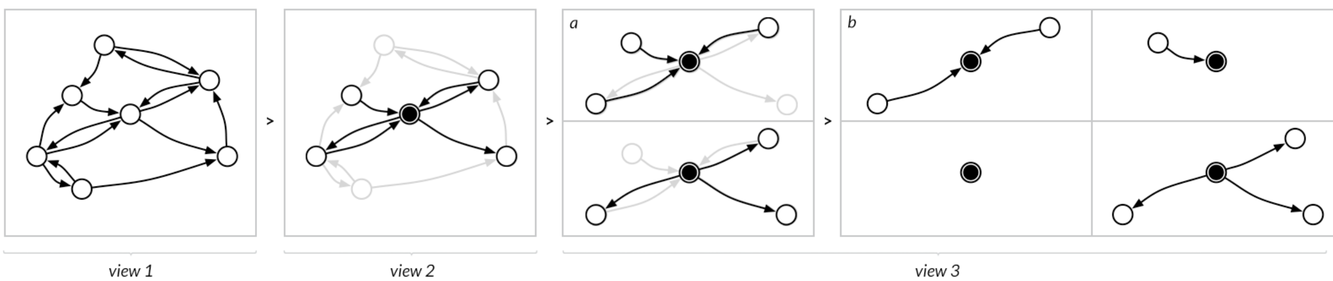

Figure 6: Staged analysis reducing visual complexity while increasing the depth of potential insights. From trips between all stations (view 1), to trips of a selected station (view 2), to a dual view distinguishing directionality (view 3 a), to four-part view also separating morning and afternoon/evening trips (view 3 b).

sual encodings of the next view. For the individual transitions we use slow-in/slow-out easing functions [8]. However, each change of the viewing mode consists of a number of staged detail transitions.

Switching from citywide view to station view, the trajectories of all non-station trips are faded out and their 3D trail sinks into the map, while simultaneously the incoming and outgoing trips of the station become colored (see Fig. 6, view 2). The name of the selected station is blended in, and a circular visual highlight temporarily shown around its location to catch the viewer's eye. Switching from station view to small-multiple view, the map first rotates back to north via the shortest path, and tilts back to a 2D map, as the trajectories in the small multiples are planar and oriented north. After the basemap has faded away, the trajectories for three stations animate into the grid of the small multiples. Each glyph represents all the bike trips made to (top) and from (bottom) per station over a day (Fig. 6, view 3a). After the vertical split along the period of the day, the view horizontally explodes into morning (left) and afternoon/evening (right), resulting in the small multiple of four glyphs for each station (Fig. 6 view 3b).

The transitions are a core component of our staged analysis concept, as they allow us to visually explain the steps from the high-level animation in the citywide view to the more fine-grained perspectives of the station and small-multiple views. While we could have designed the same views with discrete cuts between, the orchestrated transition process gently walks the viewers through without the need of potentially disruptive explanation texts. For example, the color coding in the station view to denote directionality becomes an important stepping stone into the possibly more demanding, helping to visually explain the four graphs per station. In addition, the trail animation are intentionally included to increase the visual appeal of the final view (EA).

4.5 Exhibition design

For the exhibit of *cf. city flows*, we used three high-resolution screens (2560×1440 px at $27''$ resulting in 109 ppi, with an overall resolution of 7680×1440 px), and put them side by side in a custom made frame so that the screens were at eye level (see Fig. 7). We opted for displays with higher resolution and against projectors with a larger display space in order to provide crisp images even for visitors watching the visualizations up-close (CA / DS). The touch-capable tablet featuring the dashboard has a resolution of 2048×1536 px at $9.7''$ in order to show the detailed information about the bike-sharing systems. This tablet is set in a stand-alone column, placed in the center front of the three screens in such a way that a person can interact with the controller device, and observe and compare all visualizations from that same position.

The look and feel of the furniture is part of the overall exhibition design concept. The exhibition furnitures were dark and minimal, while the room was a classic white space in order to put attention to the visualization pieces on display. The material used was black

Figure 7: The exhibition setup with three screens, and the controller column in center front.

colored medium dense fibreboard. The surface was deliberately left unsealed preserving the visitors individual traces on the surfaces of the pieces. The angles and edges of the object were inspired by the ground-plan of the exhibition room, while still following the function of providing different spots for visitors (DS).

5 Deployment during exhibition

The prototype was on display for one week in Berlin as part of an exhibition themed around urban visualizations. On the opening night over 150 visitors came to the gallery space, and 30-50 persons were visiting the exhibition per day for the subsequent week. In the following, we describe our main observations during this deployment and share some of the ad-hoc feedback we received from visitors.

5.1 Comparisons as conversation starters

One of the first observations many people made were the vastly different numbers of journeys in Berlin compared to London and New York City, and contrasted this fact with their individual knowledge about the many bikes on Berlin's streets. Some visitors were objecting the validity of the visualization, while others made the connection to the shown data and understood that the three displays solely visualized bike-sharing use in the three cities. While cycling indeed is more common in Berlin than in London [17], Berlin's bike-sharing scheme is mostly used for tourist and leisure activities [22]. Arguably these observations are not particularly sophisticated, but we see this as a good example for encouraging a discussion among visitors on the basis on fairly simple observations.

More advanced were the findings on spatiotemporal patterns in individual cities. People pointed out significant spatial patterns, such as the barrier between Middle Manhattan and Central Park, or the inner city area in Berlin. These are assumed barriers, as all stations are within those areas; yet the data does provide evidence whether people actually left those areas or not. All three bike-sharing systems cover only parts of their respective cities.

Especially for conversations among strangers straightforward observations can form a safe basis for a casual conversation. For example, visitors also recognized expected temporal patterns such as that there are fewer people cycling at night. Similarly, several visitors noted the apparent differences between New York's grid street plan in contrast to the idiosyncratic street layouts of historically grown cities Berlin and London. While these observations might be trivial, they can help visitors to build rapport with the visualization as well as with other visitors of the exhibition. To better understand the nature and varying levels of insights that exhibition visitors have using a data visualization we still need to devise unintrusive research methods.

5.2 Challenging complexity

We noticed that several visitors had difficulties understanding the urban fingerprints in the small-multiple view. This was especially the case when they approached the exhibit with the small multiples being active (and not the citywide or station view). While many visitors expressed how they liked the staged transitions of the urban fingerprints from single to two and then to four separated journey network glyphs, few fully understood the distinction between morning and evening. It is likely that the jump in analytic depth from the second to the third viewing mode was too challenging for some exhibition visitors. There is room to further investigate more gradual steps towards sophisticated analysis. While all views including the small multiples equally piqued visitors' curiosity and allured them to get closer, there is a need to further encourage a cycling between the different viewing modes especially for those visitors that approach the visualization in the most advanced viewing mode.

Many of the visitors were familiar with at least one of the shown cities. Most were able to relate and compare known stations and areas with similar ones from other cities. As the exhibition was held in Berlin, many visitors were already familiar with the city's overall layout. Of the few visitors who knew any of the other two cities, several knew some of the neighborhoods where the selected stations are. Ideally, visitors are inhabitants in one of the cities, and can interactively explore their neighborhood, or other areas relevant to their life. However, the exhibited visualizations did not allow for interactive selection of stations, as we opted for pre-selecting stations which exemplify different characteristics (as described in Section 4.2.3).

Few visitors actually used the interaction device on their own, i.e., without one of our exhibition guides encouraging to do so, or watching other visitors first. When they started tapping on the dashboard, most used the timeline. But fewer still used the dashboard to switch between the views. Some tried to tap or drag over the statistic or bar charts, the parts of the dashboard that were actually not interactive. While these issues can be resolved in further iterations of the interface design, there is clearly an opportunity here to further investigate how to encourage the use of interactive capabilities as it has been explored in the context of web-based visualizations [**?**].

5.3 Perspectives and constellations

Several visitors explicitly stated how they loved the style of the visualization, and how fascinating the seemingly endless stream of trails were to watch. In addition, also the design of the exhibition furniture was commented on positively by many visitors.

We observed three typical places that visitors took to observe and interact with the system: side, center, and close-up. Several visitors stood first to one side of the column, and thus closer to one of the side screens (left or right). Visitors often started in this position, interested in the visualization, but not sure yet whether or how to interact with the installation. Typically, visitors moved from the side to the center position, just in front of the controller column, where visitors had about the same distance to all three screens and were able to interact with the tablet. A third position was often a close-up look at the display, in order to able to take a more detailed look at the visualization. Moving close to the display meant that the person would potentially stand between the visualization and other people. Being aware of that, the close-up views were typically taken at one of the side screens, also in order to more quickly step away again. These three interactivity levels match user roles described in [27].

In addition to above positions, visitors also stood further away in the gallery space and observed the installation from afar. In the case of groups, it was often one particular person, who would conduct temporal selections in the dashboard, while the others watch the animation update from the side. We have also seen whole groups standing very close in front of the display discussing specific patterns someone found, typically pointing directly onto the screen.

6 Conclusion

In this paper we pursued the question of how an integrated approach to designing visualizations for exhibition spaces can bring together aesthetic, functional, and social considerations. We presented the design of *cf. city flows*, an installation comprising multiple visualizations of bike-sharing journeys in three cities combining established mapping and visualization techniques within a highly aestheticized form in order to attract visitors to engage with urban mobility. Following the particular challenge in designing visualizations for diverse visitors of exhibition spaces, we described the aim of shifting from interest to insight as *staged analysis*. To examine the viability of this concept, we formulated three specific design goals at the aesthetic, functional, and social level. Our first observations are promising, in that most visitors did find the installation compelling (EA), were able to make different kinds of comparisons (CA), and often ended up in conversations (DS). While the role of sequence is especially recognized in the context of visualization for journalistic purposes [16, 20], the exhibition context poses additional challenges. More research is needed especially on the specific variations of insight among exhibition visitors as well as encouraging more interaction with the visualization.

In summary, we have made two main contributions: first, we have proposed the notion of *staged analysis* as a choreographed process of breaking up a complex whole into its component parts in order to ease the understanding of a visualization in an exhibition space, second, we presented *cf. city flows*, an interactive installation that visualizes the flows of bike-sharing movements and their relations within and between urban districts. The resulting visualization exhibit is neither a visual analysis tool for urban planners to optimize a bike-sharing system, nor a service for users of the system to improve their personal travel. Instead it is a visualization for citizens to engage with the spatiotemporal complexity of urban mobility and compare it with others.

The visualizations support comparing one city with others, which can help citizens to become better informed and demand a greater system. In this sense, depicting the current state can help reflecting on how a future system should be. We believe that geovisualizations can empower citizens to make sense of the invisible layers in their environment, and help people to better participate in the creation of a smart and sustainable city.

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