언론정보학 석사학위논문

Discovering a Design Space for the Transition of News Articles with Data Visualization from Large to Small Screen Devices

큰 화면에서 작은 화면으로의 데이터 시각화 기사 전환을 위한 디자인 스페이스 모색 연구

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Abstract

[Background] Small screen devices (e.g., smartphones) are one of the prominent news channels these days. Similarly, the mobile market is also an active place for news articles with data visualization. However, presenting those articles on small screen devices is often challenged due to physical and environmental differences. In the field of web development, developers tend to start with desktop versions to provide web documents for multiple types of devices. Considering that visual articles are mostly presented in a web environment, a design toolkit is needed to transition news articles with data visualization from large to small screen devices.

[Research Goal] A design space that organizes various design patterns can be a solution to this problem for two reasons. First, it contains design patterns which refer to repeatedly used design methods, so authors can effectively apply previous design methods to their works. Second, a well-structured design space can function as a framework for design process by categorizing the design patterns. Therefore, we conducted a design space analysis in order to derive a reusable design space for the transition of news articles with data visualization from large to small screen devices. The design space can be more useful when there are guides to use it, so we also conducted two paper-prototyping workshop sessions in order to derive design implications.

[Study 1] For the design space analysis, we reviewed 104 news articles with data visualization from the *New York Times* and the *Wall Street Journal* through a mixed method of content analysis and open-coding. The resultant design space consists of three dimensions: targets, actions, and strategies. Targets refer to what to change, actions indicate how to change, and strategies guide the likely impact of a change.

[Study 2] To make the design space more useful, two paper-prototyping workshops (n=20) were operated with a task of transitioning the desktop versions of news articles with data visualization to mobile versions. The participants were also given prototyping toolkits. From the workshops, I could derive four design implications: narrowing down for quick insights, making shorter for length and visibility, interactively compensating for information reduction, and making readers curious of next.

[Implication] Finally, the proposed design space has both theoretical and practical implications. Theoretically, it enriches the discussions on design spaces of visualization by adding a device factor and connecting it to previously emphasized concepts. Practically, this offers a design-thinking convention for data visualization on multiple device platforms.

Keyword: Data Visualization, Small Screen Devices, Design Space

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Chapter 1. Introduction

These days, the mobile market is undoubtedly one of the prominent places for online news. As shown in Figure 1, in 2017, American adults (19-49) are more likely to consume online news through mobile devices ($\geq 79\%$), such as smartphones and tablets (Lu, 2017). This trend implies that the key players in the field of digital journalism need to put their efforts in the mobile market. Indeed, they have already initiated their mobile platforms.

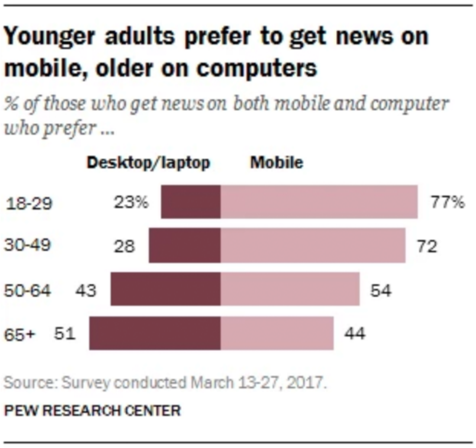

Figure 1. The trends in online news consumption (copyright by Pew Research Center)

As part of digital journalism, news articles with data visualization are also needed to be seamlessly presented on both large and small screen devices. Data visualization has effectively digitalized one of the traditional news formats, static visualizations. Through news articles with data visualization (or visual articles), readers can interactively explore data and personalize them to a degree. Due to the upsurge of mobile news consumption and the significance of data visualization in digital journalism, the fluent transition of visual articles between various devices is demanded.

However, the seamless transition of visual articles between desktop and mobile devices is often impeded due to physical (Chittaro, 2006b) and contextual (Oulasvirta, Rattenbury, Ma, & Raita, 2012) differences between them. As Chittaro (2006a) denoted, various techniques for data visualization on desktops might not often be applied to mobile devices. For example, an overview section might not be readable due to its extremely small size on mobile devices. Also, the text messages with a data visualization might be too lengthy in height when the screen has portrait dimensions.

Limited resources in time and human often amplifies the difficulty in presenting visual articles concurrently on desktop and smartphones. One probable reason can be that data visualization requires the combined work of data scientists, designers, programmers, and journalists. In that case, desktop versions have often been a starting point (Marcotte, 2011), after which mobile versions are developed. This is probably because web pages and web applications have been implemented in the desktop environment, where developers can easily mock up and debug their works. This is why this research focuses on the transition from large to small screen devices (the large-to-small transition).

Previously, there has been a large volume of discussion in the fields of web development and visualization to address the large-to-small transition issue. However, those previous cases have both pros and cons. For example, Responsive Web offered technology for coping with layout issues. Owing to Responsive technology, many front-end developers became able to create seamless web applications on various devices. Nevertheless, it did not help interaction factors nor provided design guidelines. Besides, many approaches to the interaction and representation have been attempted in the field of visualization. Although they could support particular types of visual tasks, they also cause other problems, mainly longer scroll or complex physical sequence for interaction.

This paradoxical situation implies that we need to find balanced ways of using such pros and cons of those techniques for mobile visualization. In the field of visualization, approaches based on visual storytelling have dealt with this issue. Considering the development of visualizations as visual creation of data-driven stories, the perspective of visual storytelling stresses the utilization of visualization techniques for compelling storytelling. For example, the arrangement of visualizations in an article can be randomly ordered or strictly prescribed. In this case, an author may allow readers to visit the visualizations in a random order if the specific order of reading is less likely to influence the main point of the article. However, it might not be feasible with an article that features a time-serial development of a historical event.

Consequently, finding effective methods for the large-to-small transition bifurcates to two particular questions of deciding what and when to apply those techniques in accordance with the purpose of a visual article. To answer 'what,' a set of applicable design techniques has to be provided for transitioning news articles with data visualization from large to small screen devices. Concerning 'when,' probable situations of those techniques need to be guided. Therefore, this research focuses on developing a design space for the large-to-small transition of news articles with data visualization and then tries to derive design implications based on it.

A design space is a useful tool to patternize and generalize design techniques from previous cases, a . According to Schulz, Nocke, Heitzler, and Schumann (2013), a design space can be understood as a "conceptual hood," or a framework, of design patterns with several dimensions. Design patterns refer to recurrent or reusable design techniques from previous design cases. In a design space, design patterns are organized in a table format, in which each pattern can be easily located. The research process to derive a design space is called design space analysis.

Accordingly, we conducted design space analysis and a paper-prototyping workshop. The design space analysis is based on a mixed approach of content analysis and the open-coding of grounded approach. These methods were helpful by enabling us to review the samples in the opposite directions. Then, we conducted two paper-prototyping workshop sessions in order to improve the design space to be more usable by providing design implications.

This research has three prominent contributions both theoretically and practically. The significant contribution of this research is that it organizes the recurrent design techniques for transitioning data visualization articles from large to small screens. Next, this research will also enrich the stream of discussions on data visualization regarding device factors. Finally and practically, the findings from the workshop provide design implications that suggest ways to realize design intentions. They are expected to help visualization authors to disseminate their works through multiple types of devices.

In what follows, we first examine the challenges to the large-to-small transition of news articles with data visualization, previous attempts, and the perspectives of storytelling and design space (Chapter 2). Then, the design space analysis is presented in Chapter 3, and the paper-prototyping workshop is detailed in Chapter 4. At last, we will brief the limitations and implications of this research in Chapter 5.

Chapter 2. Literature Review

2.1 Differences between Small and Large Screen Devices

In this section, we will discuss the physical and contextual differences between small and large screen devices. These differences often complicate the large-to-small transition of news articles with data visualization. They require a partial or complete redesign of information and interaction of visual articles to be successfully delivered to readers.

Before proceeding, the term ‘small screen devices’ generally refer to devices with smaller screens, such as smartphones, cell phones, or PDAs, than that of desktops or laptops (i.e., large screen devices) in the related studies (Chittaro, 2006b; S. Jones, Jones, Marsden, Patel, & Cockburn, 2005; Roto, Popescu, Koivisto, & Vartiainen, 2006; Ziefle, 2010). Such devices have also been termed ‘mobile devices,’ ‘hand-held devices,’ or ‘touchscreen devices.’ Among those terms, this research will use ‘small screen devices’ because the below-presented differences are mostly derived from the size matter.

2.1.1 Physical Differences

According to Chittaro (2006b)’s summary, the small screen devices are mainly distinguished from large screen devices for several physical factors. Among them, we will discuss three factors: (1) screen size and dimensions, (2) input modality, and (3) computing power. We focus on these factors because the other differences, such as connectivity, software tools, and display color support, are considerably resolved these days.

First, small screen devices have a heterogeneous screen type from that of large screen devices. Smaller screen also means the reduction in the amount of concurrently available information on a screen. One of the most vivid examples is a poor overview. As Shneiderman (1996) stated in the Visual Information Seeking Mantra, "Overview first, zoom and filter, then details-on-demand'', an overview has an important role in visualization. An overview can provide conclusive, comprehensive, or exhaustive ideas of a visualization. However, when it becomes smaller, the contained information might become less identifiable.

In addition, the portrait screen dimensions of small screen devices necessitate alternative ways to organize information elements. When converting a document for a small screen device, the contents tend to be vertically serialized. The order of the new arrangement is often determined as written in the markup file (Roto et al., 2006) unless it is specified. One problem with this serial reorganization is the increased scroll length of the document. To avoid this, developers often need to make a decision which part of the information to omit.

Second, small screen devices employ touch-based input modality, whereas large screen devices receive user inputs through pointing and typing devices (mice, trackpads, and keyboards). Screentouch interaction has enhanced the usability of direct manipulation[1]. However, the augmented directness has brought several challenges to successful user interaction. Without a precise pointing device, e.g., the pair of a mouse and a cursor, it is hard to make accurate manipulation because human fingers are bigger than several pixels, which is called 'fat-finger' problem (B. Lee, Isenberg, Riche, & Carpendale, 2012). Besides, different manners of user interaction need to be designed for small screen devices. A touchscreen allows native 'multi-touch manipu-

[1]For further information about direct manipulation, see Shneiderman (1983)

lation' (e.g., pinching, swiping, and Force-Touch), yet it disables hovering, which is a frequently used interaction technique on large screen devices.

Another problem is that input tools for relatively complex interaction are not 'ready-to-hand' for small screen devices. Instead, they are often hidden and on-demand. For example, when typing text, a hidden keypad of a smartphone pops up after activating an input form, while people can use a present-at-hand physical keyboard with a laptop or a desktop. Ready-to-use devices make it less interrupting to switch from viewing mode to input mode (Hornbæk & Oulasvirta, 2017; Svanaes, 2014). In addition, such hidden input instruments are less likely to provide 'real' affordance. Thus an interface on touchscreen needs to educate its users to give 'perceived' affordance (Norman, 1999).

Third, the computing power of small screen devices is generally less powerful than that of large screen devices. Small screen devices are mostly designed under the assumption that a single application is operated at a time. For example, Apple's latest smartphone model, iPhoneXS, employs an all-in-one processor chip that combines CPU, ROM, and RAM, but its laptop model, MacBook, has separate chips for those functions. In addition, Samsung's recent smartphone, Galaxy Note 9, has 6 GB of RAM memory, whereas its regular laptop model, Notebook Series 7, has 16 GB[2].

The weaker computing power of small screen devices is likely to impede complex interaction features and highly dynamic representation (Chen, 2005). For example, when a visualization contains a representation with more than 1,000 particles, a severe delay in loading the particles is highly likely to happen on small screen devices. In this case, those particles are often replaced by a static image. This means that the

[2]For reference, see iPhoneXS (https://www.apple.com/iphone-xs/specs/),
MacBook (https://www.apple.com/lae/macbook/specs/),
Galaxy Note 9 (https://www. samsung.com/us/mobile/galaxy-note9/specs/), and
Notebook Series 7 (https:// www.samsung.com/us/computing/windows-laptops/notebook-series-7 /notebook-7-spin-15-6—16gb-ram–np740u5m-x02us/).

interactions for those particles are disabled on small screen devices. Consequently, the number of visual insights are often reduced on small screens.

In sum, there are physical differences between large and small screen devices concerning screen factor, interactivity, and computing power. As we reviewed, those differences often limit visualization on small screen devices although they can provide alternative ways to create visualizations. In other words, the large-to-small transition of visual articles is likely to diminish possible visual representations and interactions, and the resultant insights on small screens. The question is, then, how to alter visual articles for small screen devices.

2.1.2 Contextual Differences

Before explicating the question of how to change visual articles for small screen devices, contextual differences between large and small screen devices also need to be reviewed. The way people interact with a particular device type depends on its context of use in part. For instance, even though smartphones are near us most of the time, people rarely use smartphones for work on a regular basis. Similarly, people are often reluctant to access e-mails via smartphones (Smith, 2010), but they are slightly more likely to access business e-mails on mobile devices than personal e-mails (Capra, Khanova, & Ramdeen, 2013).

Specifically, small screen devices are used in contextually different ways regarding the condition and the purpose of use. First, when people use small screen devices, they are likely to be surrounded by external distractions, such as walking and talking (Oulasvirta et al., 2012; Pascoe, Ryan, & Morse, 2000). Also, they are prone to be directly interrupted by other people. For example, one might look at a map application while walking to a destination, or one might send an e-mail while sitting in a vehicle. In addition, according to Google (2016)'s extensive log-based investigation, people often use smartphones with another device, such as a TV, a laptop, or a tablet.

As a consequence, the greater amount of cognitive attention is required, making it hard to perform an accurate manipulation. In an interruptive environment, even simple daily tasks need a higher degree of 'visual attention' than in a stable setting (Kristoffersen & Ljungberg, 1999) where desktops and laptops are preferred. Moreover, the error rate of performances increases, as the mobility of a condition increases, whereas the target selection time showed no significant difference (Lin, Goldman, Price, Sears, & Jacko, 2007; Schedelbauer & Heines, 2007). Taken together, the external interruptions affect both sensory and motor attention.

Second, the purpose of using small screen devices are different from large screen devices, which also pertains to the temporal length of use. Field surveys (Google, 2016; Kang, Seo, & Hong, 2011; Smith, 2015) have found that people used their small screen devices for relatively simple intentions, such as communication (e.g., instant messaging, e-mail, video/voice calls, and social media), entertainment (e.g., watching videos, listening to music, and shopping), and simple search (e.g., fact-checking from Wikipedia and getting directions). Those activities tend to be passive rather than in-depth (Cui & Roto, 2008). The reason for this can be analogized to research on spreadsheet applications on small screen devices. They were often evaluated unsatisfactory (Flood, Harrison, Iacob, & Duce, 2012) or auxiliary (Gorlenko & Merrick, 2003) on small screen devices.

Furthermore, Oulasvirta et al. (2012) found that people tend to do SIRB activities with smartphones about two times more than with laptops. The SIRB activities refer to *s*hort, *i*solated (not followed by another activity), and *r*eward-*b*ased activities. For example, social media use is a typical example of the SIRB activities. Social media applications are likely to be used in a short period, often independent, and rewarded by social networking.

Habitual and repeated use of small screen devices for simple purposes seem to develop 'device affordances' (Verplanken & Wood, 2006; Verplanken, 2006) that small screen devices are for simple or auxiliary purposes. In other words, as people repeatedly use small screen devices for simple purposes and their pursuits are fulfilled, the perception that they are used for simple purposes is reinforced. Therefore, the usage pattern of small screen devices matters when considering another way of designing information and interaction on small screen devices.

In turn, the perception that small screen devices are designed for simple works may estrange readers from in-depth visual articles. Because news articles with data visualization usually encompass a large volume of data, those articles resemble investigative news articles of which the length and depth tend to be profound. When readers are expected to prefer to use small screen devices for simple purposes, visual articles might not be attractive to them.

In this section, we mentioned how the physical and contextual differences between large and small screen devices make. Those differences are summarized in Table 1. In the next section, we will review how the previous approaches coped with these differences.

Category	**Large**	**Small**	**Problems**
Physical differences			
Screen Size	Large	Small	Less amount of information
Screen dimensions	Landscape	Portrait	
Input modality	Pointing + Typing	Screen touch	Redesign of interactivity
Computing power	High	Low	Limited complexity
Contextual differences			
Condition	Stable	Distracting	Increased attention
Purpose	In-depth	Simple	Device affordance
Length	Long	Short	

Table 1. Differences between large and small screen devices

2.2 Previous Attempts for the Large-to-Small Transition

The large-to-small transition of data visualization is not a recent issue, but various related fields have handled this issue. Approaches in Web development and information visualization can be referred for visual articles. However, those attempts mostly have not only strength and but also weakness. Considering that the primary purpose of visual articles is to deliver a story, the balanced way of using the methods from those previous cases is critical to tell a visual story effectively. First, in this section, we will review previous attempts for the large-to-small transition regarding Web development and information visualization.

2.2.1 Web: Responsive Technology

In the Web environment, developers have widely adopted Responsive technology to overcome the differences between various screens (B. Kim, 2013). Before Responsive technology, Web engineers developed algorithms for rendering mobile web pages (Roto & Kaikkonen, 2003; Wobbrock, Forlizzi, Hudson, & Myers, 2002; Büring, Gerken, & Reiterer, 2006), and detail browsing interactions techniques for mobile devices (Milic-Frayling, Sommerer, Rodden, & Blackwell, 2003; S. Jones et al., 2005; Baudisch, Xie, Wang, & Ma, 2004). Responsive technology and its ancestors aim to prevent web developers from creating additional HTML documents for multiple screen types. Instead, this allows web developers to render a single HTML document for various screen types.

According to Marcotte (2011), the Responsive presentation of a Web document for multiple devices is possible through a grid system, flexible media, and media queries. These elements of Responsive technology generally address layout tactics.

Grid system refers to the division of space into even-width columns. The width of each column is flexibly adjusted in accordance with the current screen width. Next, flexible media means that the size of a media element (e.g., image, video) is adjusted proportionately to its container. This can be achieved by defining their size in a relative unit (i.e., %). Finally, it is media queries that enable all the different views by devices. A media query is a CSS query language that defines the medium to provide a document (e.g., screen, paper) and its specification (e.g., width, height). For example, one can set different CSS settings for screens with more than 1000-pixel width and a screen with less than 1000-pixel width.

For Responsive technology, large screen devices tend to be the media platform to start a design process with (Marcotte, 2011). It is faster and easier to mock up a desktop version and debug it on a desktop environment. When testing an application for small screen devices, developers and designers need to use another device or special tools to check the rendered outcomes. Thus, we decided to focus on the transition from large to small screen devices.

However, Responsive technology does not adequately address the problem of the large-to-small transition of news articles with data visualization for three reasons. First, Responsive technology helps developers to handle the layout of a web page. Setting aside its scope (i.e., Web), data visualization does not have only visual part but also interaction part (Kirk, 2012). That is, Responsive technology cannot assist the large-to-small transition of interaction features of visual articles. One cannot build non-simple interactions with CSS media queries.

Next, Responsive technology cannot cover all of the issues regarding data visualization although they share several common issues, such as aesthetics and layouts. Visualization authors have to consider complexity, accuracy, visual saliency of their works. For example, if the size of a visualization is proportionately reduced on small screens, it might generate a couple of problems. First, its complexity might increase as the amount of information per (absolute) unit area increases. Next, its accuracy might decrease because some small significant information is compressed together. Also, visualizations can be less visually salient due to the portrait dimensions of small screens. To be specific, when a visualization takes the full area of a large screen, its proportionate reduction might take only about a third of a small screen.

More fundamentally, Responsive technology is a "technology" that enables alternative ways to render a web page. It can be understood as a platform for the large-to-small transition. However, as many platforms do not always offer successful tactics, Responsive technology does not provide specific design techniques to apply. It is still the authors' role to consider how to perform the tasks of the large-to-small transition. Therefore, we focus on more guided design techniques for the large-to-small transition.

2.2.2 Approaches in Information Visualization

The importance of presenting visualization on small screen devices has been acknowledged since the appearance of PDAs. As the fidelity of smartphones escalates, academic collaborations also happened, such as a tutorial in Mobile HCI 2015 (Watson & Setlur, 2015) and a workshop in CHI 2018 (B. Lee et al., 2018). The previous efforts for mobile visualization can be categorized into three groups: simplification, detail-browsing, and highlighting.

First, one of the mainstream approaches was to simplify visualization regarding the quality of graphics or the content of a visualization. On the one hand, authors may diminish the quality of graphics, considering the low level of the computing power of small screen devices. For example, Butson, Tamm, Jain, Fogal, and Krüger (2013) suggested reducing the resolution of the texture of visual objects (e.g., from a delicate illustration to a harsh depiction) and an option to disable lighting for 3D objects. On the other hand, visualization can be simplified in order to reduce readers' cognitive resources, which was termed as "generalization" by Zipf and Richter (2002). For instance, Pattath et al. (2006) proposed "clustering" of data points, and Chittaro (2006a) suggested removing detail information.

However, reducing cannot be a cure-all solution. As S. Y. Kim, Jang, Mellema, Ebert, and Collinss (2007) noted, a visualization requires a particular type of information which may differ by its specific domain. In the case of evacuation situations, detailed information of the exits of a building is highly required regardless of the screen size (S. Y. Kim et al., 2007). Even though the screen size is small, a building's exit number, their location, and their status cannot be omitted or aggregated. Otherwise, it would seriously impede people or firefighters' appropriate decision.

Inevitably, the reduction of content calls for interaction techniques for detail-browsing. For example, Andrews (2018) applied a fisheye interaction (context+zoom) with pinching, which is a common finger interaction for a touchscreen. This fisheye zoom helps people can see a small graph more in detail on small screen devices when the details are less readable due to the graph's small size. Similarly, Pattath et al. (2006) suggested detail-on-demand interaction for aggregated visualization for small screen devices.

When adding an interaction feature, the level of complexity does matter. Highly complex interaction often causes 'interaction cost' which occurs due to a complex or lengthy sequence of operation (Lam, 2008). Interaction cost tends to interrupt users' tasks (M. Jones, Marsden, Mohd-Nasir, Boone, & Buchanan, 1999). These imply that extra interaction features might have a negative influence on users' experience of visualization in some cases.

Third, highlighting techniques are preferable options to utilize small screens.

Generally, key data points or significant ranges of data are marked saliently. Considering that users' interests are important information, it is recommendable to assign highlights to users' particular points of interest (Reichenbacher, 2004; Chalmers, Sloman, & Dulay, 2001). Additionally, interactable highlights can induce people to discover more information. For instance, (Paolino, Romano, Tortora, & Vitiello, 2013) highlighted a direction to which users can find more relevant information when they panned a map.

Although highlighting can make it easier to explore a visualization, highlights cannot be added as much as needed for two reasons. First, highlights are meaningful when they are more salient than the other visual objects in the same visualization. Second, too many highlights might not be comprehensible due to readers' limited mental capacity (Lam, 2008; Haroz & Whitney, 2012). Thus, an adequate level of highlighting needs to be sought.

As a summary, in the field of information visualization, simplification, detail-browsing interaction, and highlighting have been attempted for more successful visualization on small screen devices. As we reviewed in the previous subsection, Responsive technology also involves this problem in that those tactics have both pros and cons. The question is, then, how to use various design techniques in a balanced way. Therefore, in the next section, we will introduce relevant perspectives, visual storytelling and design space.

2.3 Solution through a Design Space

Previously, we discussed the differences between large and small screen devices and the previous techniques to handle the issue of the large-to-small transition. As a result, we learned that the balanced way of utilizing the strength and weakness of each technique is important. In this case, the purpose of visualization is one of the most substantial factors as well as the physical and contextual conditions of small screen devices. To address this issue, there has been a discussion on visual storytelling in the field of visualization. Moreover, a design space has played a significant role in giving solutions for this complicated problem. Therefore, in this section, we will brief the perspective of visual storytelling and the role of a design space.

2.3.1 From the Perspective of Visual Storytelling

The perspective of visual storytelling is closely related to the purpose of data visualization. According to definitions of data visualization and information visualization, they are created to "amplify cognition" through representation and interaction (Kirk, 2012; Card, Mackinlay, & Shneiderman, 1999). Making visual information into a story plays a crucial role in "amplifying cognition." A set of information is easier to remember and understand when they are incorporated into a story than when they are merely listed (Bower, 1976; Negrete & Lartigue, 2010). Likewise, a data visualization without a particular narrative frame is harder to understand because its readers cannot tell essential elements from peripheral ones (Gershon & Page, 2001).

Segel and Heer (2010) mapped the representation and interaction of data visualization to the guidance of authors and the participation of readers, respectively. Their viewpoint is consistent with that a piece of visualization consists of representation and interaction. They viewed the visual storytelling approach as how to attune the balance of authors and readers. They termed this attuning process as 'a spectrum of author-driven and reader-driven approaches': the degree of author's intention and reader's intervention. As they expressed it as a 'spectrum,' data visualization is not always clearly classified into either author-driven or reader-driven, yet they have criteria: ordering, interactivity, and messaging.

First, when a data visualization is comprised of multiple sub-visualization, their ordering is more strictly linear in an author-driven visualization than a reader-driven counterpart. Second, a highly author-driven data visualization tends not to allow user interactions, so user tasks can only be achieved passively, depending on the given representation. Conversely, users can make more changes in a highly reader-driven data visualization, such as hovering to identify, clicking and dragging to filter. Third, as data visualization becomes more author-driven, it is likely to provide explicit verbal stories for introduction, conclusion, and interpretation. Those language elements can be voice-based or text-based. More reader-driven data visualizations are reluctant to give such guiding narratives; instead, it tries to let users explore with its interactive features so that they can discover their insights.

In 2015, for example, the *Wall Street Journal* revealed the record of Medicare to report how the biggest ever nation-wide social security system is well operated[3], which won Pulitzer prize in the investigative report section (Figure 2, left). This example of reader-driven data visualization greatly emphasized personalization feature with a search tool. One can search by the name of a doctor or the region, and check how much amount of medical expenditure the Medicare compensated for each doctor. A little amount of text message was provided: only the title, the introductory sentence, and the automated summary sentence.

In contrast, the *New York Times* publicized a 3-minute-long video article based on the records of male 100-meter race in the Olympics[4]. As in the right side of Figure 2, the scenes were selectively included by the editor, and each scene was auditorily explained from the beginning to the end. Since it was a video, readers can play or stop, but changing the order of presentation is quite limited. The first scene in the

[3] See http://graphics.wsj.com/medicare-billing/ .

[4] See http://www.nytimes.com/interactive/2012/08/05/sports/olympics/the-100-meter- dash-one-race-every-medalist-ever.html .

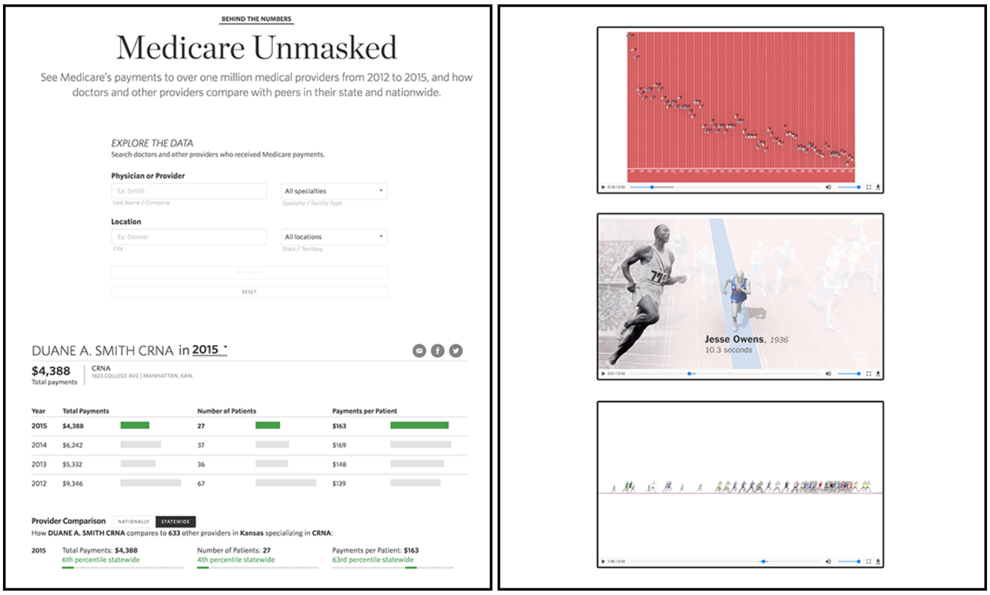

Figure 2. Examples of visual storytelling. (Left) A reader-driven visual article, "Medicare Unmasked" (Right) An author-driven visual article, "Once Race,EveryMedalistEver"

figure made it possible to read a trend. Each player is arranged at the position where he would have been running when Usain Bolt had finished his race if Bolt had been in the same race. The second scene describes a player who has a significant record. The last scene compares the Olympic players with the American youth runners.

The effects of visual storytelling methods have steadily become a major discussion topic in data visualization research. First, the ordering of a visualization does not seem to lead readers to follow it, when the order is not coerced (Boy, Detienne, & Fekete, 2015). Eye-tracking evidence about Web page reading behavior also proved that information overload might promote skim reading (Duggan & Payne, 2011; Pan et al., 2004). Next, messaging can function as a guide to the understanding of a visualization by setting an explicit narrative frame (Hullman & Diakopoulos, 2011; Segel & Heer, 2010). However, some empirical studies did not show the significant effects of messaging (Boy et al., 2015; E.-J. Lee & Kim, 2016). Finally, various controversial arguments have been made over the effects of interactivity. In terms of the trade-offs of the cognitive resources, overly high interactivity might overwhelm readers by providing too many options to choose (Lam, 2008; Schwartz, 2004), resulting in reduced usability (Bucy, 2004). In contrast, complex representation with overly low interactivity might also cause a similar problem (Haroz & Whitney, 2012; Huang, Eades, & Hong, 2009) because appropriate interaction features can support readers to explore complex visualizations with a large dataset (Amar & Stasko, 2004; Hullman & Diakopoulos, 2011; Saraiya, North, & Duca, 2005; Tominski, 2015).

Somewhat paradoxically, this controversial debate amplifies the necessity of storytelling for the large-to-small transition. Telling a story through visualization implies that we set a purpose and try to pursue it when creating a visualization. This is entirely different from a sought for a cure-all solution. Rather, visualization authors need to set the purpose of their works on small screen devices, with the consideration of the physical and contextual characteristics. Then, they need to seek the methods to accomplish the purpose. Naturally, preliminary questions of 'what' and 'when' can be raised regarding design techniques for the large-to-small transition of visual articles.

2.3.2 To the Problem-Solving through a Design Space

A design space is useful when answering the 'what' question. Though it may have several meanings, the term, "design space," has a more algebraic sense in this research. Schulz et al. (2013) conceptualized a design space as a 'conceptual hood' of design patterns with several dimensions. Here, a design pattern refers to 'a solution to a recurring design problem' (Borchers, 2000). In the field of visualization, there has been a research stream concerning taxonomies of visualization tasks (see Appendix B). In terms of the format in which they are presented, design spaces resemble taxonomies to a degree.

Design space is distinguished from design guidelines in that a design space provides a set of ready-to-use design techniques (or design cases), not a set of directions for a design problem. Considering that the problem of the large-to-small transition requires the effective utilization of various design patterns, the approach with a design space seems more plausible with this research. Nevertheless, a design space becomes more useful when the component design patterns are guided.

Design spaces have helped the field of visualization to formalize various concepts, such as visualization technique, the combination of visualizations, visual tasks and interaction techniques, and storytelling. For example, Chi (2000) suggested a taxonomy of visualization techniques based on the data abstraction process. He classified previous visualization techniques by graph styles, such as geographical visualizations, multi-dimensional visualizations, and trees. In regards to the layout of visualization, Javed and Elmqvist (2012) introduced a design space for combining two visualizations. They classified those combinations regarding spatial relation and data relation.

Furthermore, the discussion on visual tasks and interaction techniques has been popular. Both of them pertain to what people do with visualization, but visual tasks are more relevant to a mental process (Amar, Eagan, & Stasko, 2005) while interaction techniques are more related to a physical process. Shneiderman (1996); Brehmer and Munzner (2013); Amar and Stasko (2004) tried to classify visual tasks in various approaches. On the other hand, Yi, Kang, Stasko, and Jacko (2007) extensively analyzed previous interaction design cases and research of data visualization, and then proposed the seven categories of interaction techniques of data visualization.

As we discussed in the previous subsection, Segel and Heer (2010) reviewed data visualization cases and proposed a design space for the storytelling of data visualization. Their design space consisted of the genre, visual narrative, and narrative structure. Genre refers to the construction or format of a data visualization, and visual narrative involves the techniques that visually assist the storytelling of a visualization. The narrative structure is what we discussed in the previous subsection: the spectrum from author-driven to reader-driven.

The research process to derive a design space is called design space analysis. The main purpose of design space analysis is to provide a 'design rationale' (MacLean, Young, Bellotti, & Moran, 1991). Previous studies (Bach, Wang, Farinella, Murray-Rust, & Riche, 2018; Segel & Heer, 2010; Yi et al., 2007; Chi, 2000; Javed & Elmqvist, 2012) took two steps to build a design space. First, they derived design patterns by formalizing recurrent or reusable design techniques from former design cases. Then, they iteratively discussed to organize those design patterns within proper dimensions. In this way, a design space provides a reusable design rationale for another design problem that shares the same dimensions.

A well-structured design space brings both theoretical and practical implications. Theoretically, its dimensions offer a more comprehensive understanding of design problems. On the one hand, Segel and Heer (2010)'s design space for visual storytelling helped make a related theoretical discussion. For example, Bach et al. (2018) scrutinized the data comics, which is one of the seven genres by Segel and Heer (2010), and suggested design space with the dimensions of layout and content relation. Also, Boy et al. (2015) tested the idea of visual storytelling and explained the effects of storytelling on the understanding of a visualization. In the practical side, they directly help design practitioners with guidelines. Particularly, this merit helps visualization authors from various backgrounds, e.g., visual design, statistics, computer science, and journalism.

Therefore, this research proposes the following research question:

RQ1: What is a design space for transitioning news articles with data visualization from large to small screen devices?

To solve this research question, we conducted a mixed-method of design space analysis. This method involves content analysis as a top-down approach and grounded approach open-coding as a bottom-up approach. Then, we synchronized the results of the two approaches in order to arrive at a confluent design space.

On the other hand, a design space can be more powerful when its usages are guided. For example, Javed and Elmqvist (2012) clarified the merits and limitations of their design patterns for combining multiple visualizations. Similarly, Müller, Alt, Michelis, and Schmidt (2010) derived specific guidelines for particular design problems for public display. This way of extending a design space helps prevent the design space from being metaphysical. Instead, it made the design space beneficial when applying those patterns. This is because users can make a conclusive decision based on the background information, not just following a panacea.

Thus, deriving design implications will help the large-to-small transition of visual articles by assisting the balanced use of the related design techniques. This approach is consistent with the purpose of visualization, the effective delivery of a visual story. Especially, those design implications will be derived by matching them to design intentions. Therefore, we also propose the second research question as follows:

RQ2: How can users' design goals be linked to the design space for the transition of news articles with data visualization from large to small screen devices?

To answer this research question, we organized two paper-prototyping workshop sessions (n=20). The task of the workshop was to create a small screen version paper-prototype for a visual article when given its desktop version. In order to induce more productive findings, we encouraged the participants to discuss their prototypes with each other. By analyzing the data through the axial coding of the grounded approach, four prominent design goals were derived, and they were matched to design patterns in the design space.

Chapter 3. Study 1: Design Space Analysis

To answer *RQ1*, we conducted a study to derive a design space for the large-to-small transition of visual articles. The design space analysis of this research utilized a mixed-method of top-down (content analysis) and bottom-up (grounded approach open-coding) approaches. The result of this study is a design space for the large-to-small transition of visual news articles. Before directly introducing it, we will review notable cases of the large-to-small transition at first for background understanding.

3.1 Method

To overview, both of the large and small screen versions of the samples were coded by two coding procedure: content-analysis and the open coding of grounded approach. For content-analysis (top-down approach), each sample article's large and small screen versions were coded with the same coding scheme. Then, the differences of the two versions were analyzed through the open coding of grounded approach (bottom-up approach). Finally, the results of both coding were synchronized. The process of our design space analysis is illustrated in Figure 3.

Figure 3. Overview of the methods of design space analysis

The design space analysis through this mixed method had two significant benefits. First, the top-down coding enabled us to systematically observe the design cases and visibly compare them on large and small screen devices. Second, the open-coding of grounded approach extended the observation by encompassing what might have been ignored in the content analysis. As a result, this mixed method allowed to build a structured and exhaustive design space.

3.1.1 Samples

To fully describe the design space for the large-to-small transition of news articles with data visualization, we collected 104 visual news articles from the 2016 and 2017 collections of the *New York Times* and the *Wall Street Journal*. These media outlets were chosen because they seem to have developed a set of conventions for the large-to-small transition of visual articles in terms of circulation and tradition. They are known to have had more than 1 million paid subscribers at the end of 2016 (World Association of Newspapers and News Publishers, 2017; Richter, 2017). They have also provided visual articles for 7 years since 2012.

In the collections, articles with scalable data sets and statistical or geospatial representations were selected according to previous definitions of data visualization (Friendly, 2008; Kirk, 2012; Michailidis, 2008; Tominski, 2015). Specifically, they were:

- Statistical graphs: line graphs, bar graphs, pie/graphs, histograms, scatter plots, bubble plots, and heat maps.
- Geospatial visualizations: choropleth maps, dasymetric maps, maps with proportional symbols, dot distribution maps, and cartograms.

Visual representations without any possible statistical inferences (e.g., arrays of

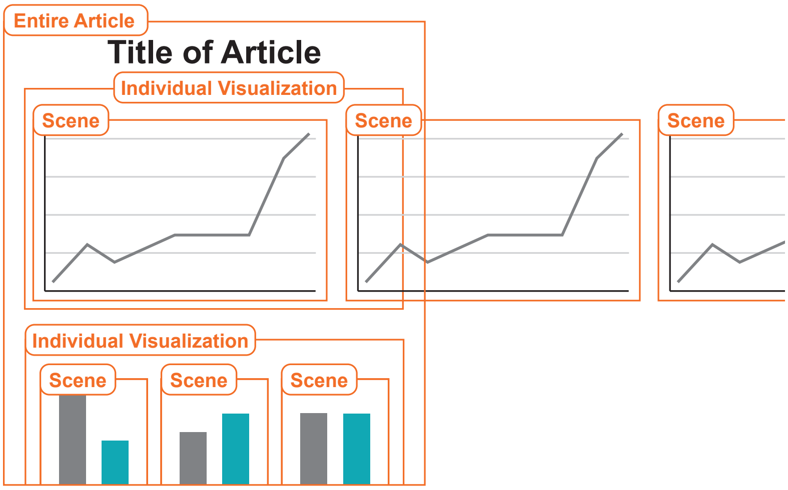

Figure 4. Illustration of the unit of observation

icons, visual helpers) and geographical representation of a series of events (e.g., war progress) were excluded.

Although the unit of analysis was each sample article, we specified the three levels of units of observation for the sake of effective operationalization. They are entire article, individual visualizations, and scenes (see Figure 4). An **entire article** is a data visualization article in the sample set. An **individual visualization** refers to a complete visualization in an article that is distinguished from adjacent elements or visualization in the same article by the layout components (e.g., borders, background shades) or the used dataset. Finally, an individual visualization is divided into **scenes**, which means a single representation at a time, based on Bach et al. (2018)'s definition of a "panel". Panels in a visualization are more related to the division of area whereas scenes involve representations that are changed dynamically as well as static panels.

3.1.2 Top-Down: Content Analysis

For the top-down approach, we performed a content analysis. Two raters coded each sample article twice, once on a large screen (a laptop without a touchscreen) and once on a small screen (iPhone 7), based on the same coding scheme. The coding scheme had categories, and each category was comprised of several coding items. Then, each coding item was coded as one of two or more levels.

The coding categories were developed primarily based on the "narrative structure" suggested by Segel and Heer (2010). There were 2 article-level categories (ordering and messaging) and 4 visualization-level categories (ordering, messaging, interactivity, and general). The specific coding items were developed based on the related works. Then they were revised after the pilot coding of more than 50 visual articles that were not included in the sample set.

Particularly, the ordering category was about the prescriptiveness and strictness of scenes' order. Next, the messaging category involved the length of particular types of messages. Third, the interactivity category pertained to the degree of freedom of each interaction features. To build a systematic scheme for interaction features, I carefully reviewed previous works on interaction and visualization tasks (Amar et al., 2005; Brehmer & Munzner, 2013; Heer & Shneiderman, 2012; Shneiderman, 1996; Yi et al., 2007; Zhou & Feiner, 1998), and concluded into 9 types. A more detailed review is available in Appendix B. Finally, the items of the general category were related to simplicity and construction (or genre).

In order to effectively compare the samples on large and small screens, the levels of each coding item were defined in a linearly scalable way (from author-driven to reader-driven). For example, the length of the introduction (messaging) was coded as long ($\geq$ 100 words), short, or none. Each interaction category was coded as free, mid, mixed, not free, or none, regarding the user's agency in using it.

The reliability was checked with Cohen's κ (average .65) and agreement (average .89). After we resolved disagreements, the coding results on large and small screen were combined into a direction as author-driven, reader-driven, or no change. For example, if 'identify' interaction was 'free' on a large screen and 'not free' on a small screen, it was coded as 'author-driven.' Detailed coding items, levels, and their reliability are shown in Table 2.

Category	**Item**	**Levels (Author- → Reader-driven)**	**κ**	**Agr.**
Entire Article				
Ordering	Multiplicity	Single / Multiple	.91	.96
	Orderedness	Ordered / Unordered	.58	.73
	Skippability	Disallowed / Allowed	.87	.95
Messaging	Dependency	Visual-centered / Mixed / Text-centered	.60	.81
	Overall Summary	Long / Short / None	.81	.87
Individual Visualization				
Ordering	Orderedness	Ordered / Unordered	.68	.84
	Stoppability	Disallowed / Allowed / Controllable	.79	.90
	Skippability	Disallowed / Allowed /	.78	.90
	Transition Methods	Auto, Playback, Scroll, Previous/Next, Toggle, Ordered tabs, Themed tabs, Slider, Search, Free exploration	.64	.91
	Highlights	Exists / None	.39	.75
Messaging	Introduction	Long / Short / None	.82	.92
	Summary (entire)	Long / Short / None	.84	.90
	Summary (scenes)	Long / Short / None	.74	.88
	Annotation (length)	Long / Short / None	.43	.79
	Annotation (distribution)	Long / Short / None	.41	.79
Interactivity	No. of Features	0 / 1-2 / 3-4 / 5+	.83	.92
	Identify	None / Not Free / Mixed / Mid / Free	.89	.96
	Abstract/Elaborate		.47	.96
	Summarize		.59	.94
	Search		.53	.89
	Explore		.81	.99
	Filter		.47	.94
	Compare		.37	.96
	Connect		.47	.97
	Reconfigure		.66	.98
General	Simplicity	Simple / Mid / Complex	.31	.84
	Construction	Static / Movie / Dynamic / Interface	.85	.92
Average			.65	.89

Table 2. Reliability check of the final coding scheme for the content analysis

3.1.3 Bottom-up: Grounded Approach Open-Coding

As the bottom-up approach, the open-coding of grounded approach (Corbin & Strauss, 1990) was performed with two raters. There was no particular framework to guide this process. First, the raters described any difference between the large and small screen versions of each sample article. Then, the two raters' descriptions were combined, and they open-coded this combined description. Finally, they iteratively discussed how to classify the differences ($\geq$ 8 hours)

3.1.4 Synchronization

The synchronization process played a key role in our design space analysis because we attempted to suggest a single design space through the two methods. At first, after each of the two coding processes, the raters identified and labeled design patterns. In the case of content analysis, the coded directions were design patterns. In the open coding, the raters directly labeled design patterns. Then, we matched the discovered design patterns as much as possible. In this process, neither approach was less effective than the other; structured patterns could be obtained from the top-down analysis, and the bottom-up approach offered details.

Finally, we operated iterative discussion sessions with raters in order to propose an initial design space ($\geq$ 8 hours). During this discussion, several versions of classification schemes were compared in terms of comprehensiveness and exhaustiveness. Then we revised the design space after the paper-prototyping workshop.

3.2 Large-to-Small Transition Cases

Before moving on the design space, we will review three notable cases of the large-to-small transition in order to introduce prominent design patterns discovered (marked as **boldface**). The numbers are matched in the screenshots and the corresponding descriptions. The selected cases may not be representative of all samples, yet they are sufficient to understand the key concepts and terms of the design space.

3.2.1 US Cabinet

US Cabinet[1] (Figure 5) is about how the gender ratio of the American presidential cabinet has been changed over time. The data visualizations in this article are presented in the format of a block graph. Each block represents a member of a cabinet. In this article, following transition techniques are applied ([L]arge screen version → [S]mall screen version).

1. **Simplify marks**: [L] Face photo blocks → [S] Gray squares in the small screen version.
2. **Serialize label-mark**: [L] Labels and visual marks (blocks) are horizontally next to each other → [S] They are vertically arranged.
3. **Remove tooltips**: [L] A tooltip appears when hovered → [S] No tooltip is available.
4. **Transpose axes**: [L] X-axis (number/period) and Y-axis (cabinet) → [S] X-axis (cabinet) and Y-axis (number/period)
5. **Fix tooltip position**: [L] A tooltip appears at triggered position → [S] A tooltip is appears at the bottom of the screen.

In the first visualization ([L]: upper part, [S]: left part), (1) simplifying marks considerably reduces given information. Nevertheless, the small screen version itself

[1] https://nyti.ms/ejSp3WT

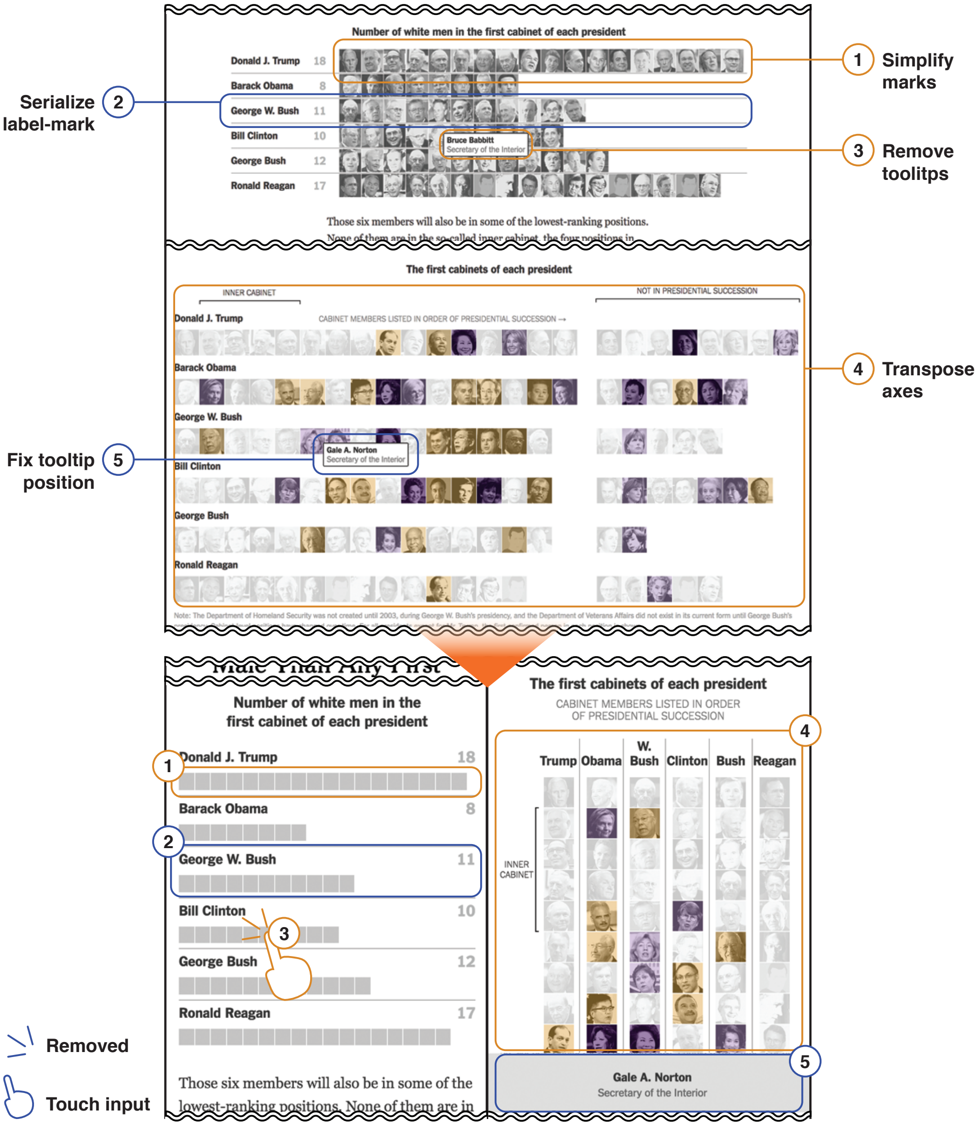

Figure 5. Screenshots of the large-to-small transition of US Cabinet.

seems to be a complete visualization as a bar graph. Next, (2) serializing labels and marks might be intended for efficient use of reduced width of small screen devices. However it can increase the scroll length when there are too many bars, or it may modify the visual distribution of data points when it comes to a histogram. In addition, (3) a tooltip shows the name of a photo block in the large screen version, but it is removed in the small screen version. There are three more visualizations like this one in the article.

Sharing similar characteristics does not imply the same way of transition. In the second visualization ([L]: lower part, [S]: right part), the photo blocks remain on the small screen version. However, the other parts are changed. Most impressively, (4) transposing axes is an available option to fit a wide visualization to the portrait dimensions of small screens. In addition, compared with the previous visualizations, transposing preserves the relative space that the visualization takes on a small screen. Next, (2) fixing tooltip position is an efficient way of using space since a large tooltip might mask the overview of the visualization on small screens when it appears at the triggered position. This fixation might not be problematic; readers might have less difficulty with finding a tooltip that is away from the focused position. This is because the space of a small screen device is more likely to be within readers' eyesight than that of a large screen device.

3.2.2 Megabank

Megabank[2] (Figure 6) illustrates the rise and fall of Citigroup, one of the largest bank in the US. In the large screen version, readers can explore another scene by clicking a tab with a particular theme, or clicking previous/next arrows in the text box at the upper left side. Scenes are changed in the same frame with transitioning animation. In this news article, the following parts are changed from large to small screen devices.

1. **Split into scenes**: [L] A single frame in which scenes are dynamically transi-

[2] http://graphics.wsj.com/citi-revenue/

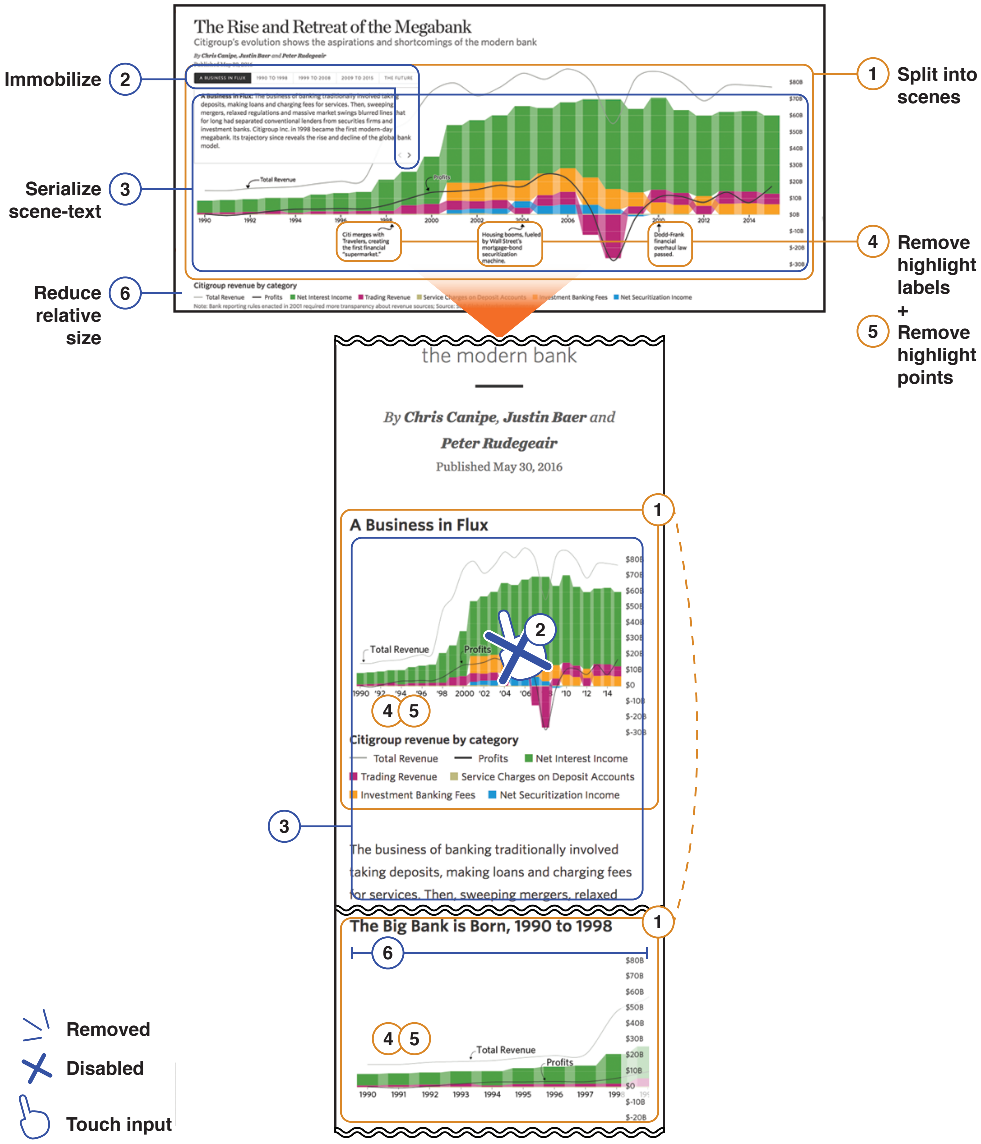

Figure 6. Screenshots of the large-to-small transition of Megabank.

tioned. → [S] The key scenes are all separated and placed in different positions.

2. **Immobilize**: [L] Interactions are available. → [S] No interaction is available.

3. **Serialize scene-text**: [L] Scenes and text messages are placed horizontally next to each other. → [S] They are arranged in a vertical order.

4. **Remove highlight labels**: [L] Particular data points are shortly annotated for enhanced saliency. $\rightarrow$ [S] The short annotations are removed.

5. **Remove highlight points**: [L] Particular data points are marked by arrows for enhanced saliency. $\rightarrow$ [S] The arrows are removed.

6. **Reduce width**: During [L] $\rightarrow$ [S], the relative width is reduced.

7. **Reduce relative size**: [L] Visualization takes nearly full space of the screen. $\rightarrow$ [S] It takes only half of the screen.

The most conspicuous change is the removal of dynamic scene transition. (1) Spatially splitting scenes is useful when the large screen version of a visualization is explored horizontally, or when its free exploration seems to burden the computing power of a small screen device. At the same time, (2) all interaction features are removed in the small screen version, i.e., the visualization is immobilized. In this article, immobilizing is a natural consequence of scene-splitting. However, they can be used independently when manipulation is difficult due to the fat-finger problem or the weaker computing power of small screen devices.

For the text part, (3) scenes and text messages are serialized because of the portrait screen dimensions and the narrower absolute width of small screen devices. This manner can be extended to the situation where two or more scenes are arranged horizontally next to each other.

On the other hand, (4) highlight labels (short annotations for specific data points) and (5) highlight points (enhanced saliency of specific data points) are removed. Removing the highlight elements can be used when they are considered to take too much space on a small screen. When using this pattern, authors need to be careful because it may result in unguided reading. Removing highlight labels does not always imply removing highlight points. Instead, they can be independent to a degree. In this case, it is also possible to replace the highlight points with dots or to provide the highlight message below the visualization.

Finally, the size of the visualization is changed. (6) Reducing width might result in an increased slope of lines. In the sense that the slope of a line can influence the perception of visual information (Cleveland & McGill, 1985), this pattern might need to be applied carefully. Although it is intended to preserve the width/height ratio to a degree, (7) reducing relative size may reduce visual impact, or saliency, of a visualization.

3.2.3 Startup Stocks

In Startup Stocks[3] (Figure 7), readers can browse the fluctuations of the stock value of startup companies. In the large screen version, readers can check the overview of the entire data, where each line represents a company. This overview is interactive, so when hovering or clicking a line, the details are available. Readers can also scroll down to see the details. Above the overview, interaction features are arranged in a certain layout. From the left side, the first feature is a filter option by industrial sectors. The second one is an input box with auto-complete by which readers can search for a particular company. The right-most one is the pair of up and down buttons by which companies are focused in a certain order. Below them, there is a slider by which readers can set the time range of the data. Below the overview, the list of startup companies is provided. By clicking a row, the corresponding company's detail visualization appears. This second visualization is also interactive; by hovering a line, the names and values of data points are provided in a tooltip. The table of the raw data is presented below. This large screen version is converted to the small screen version by following techniques.

[3]https://www.wsj.com/graphics/tech-startup-stocks-to-watch

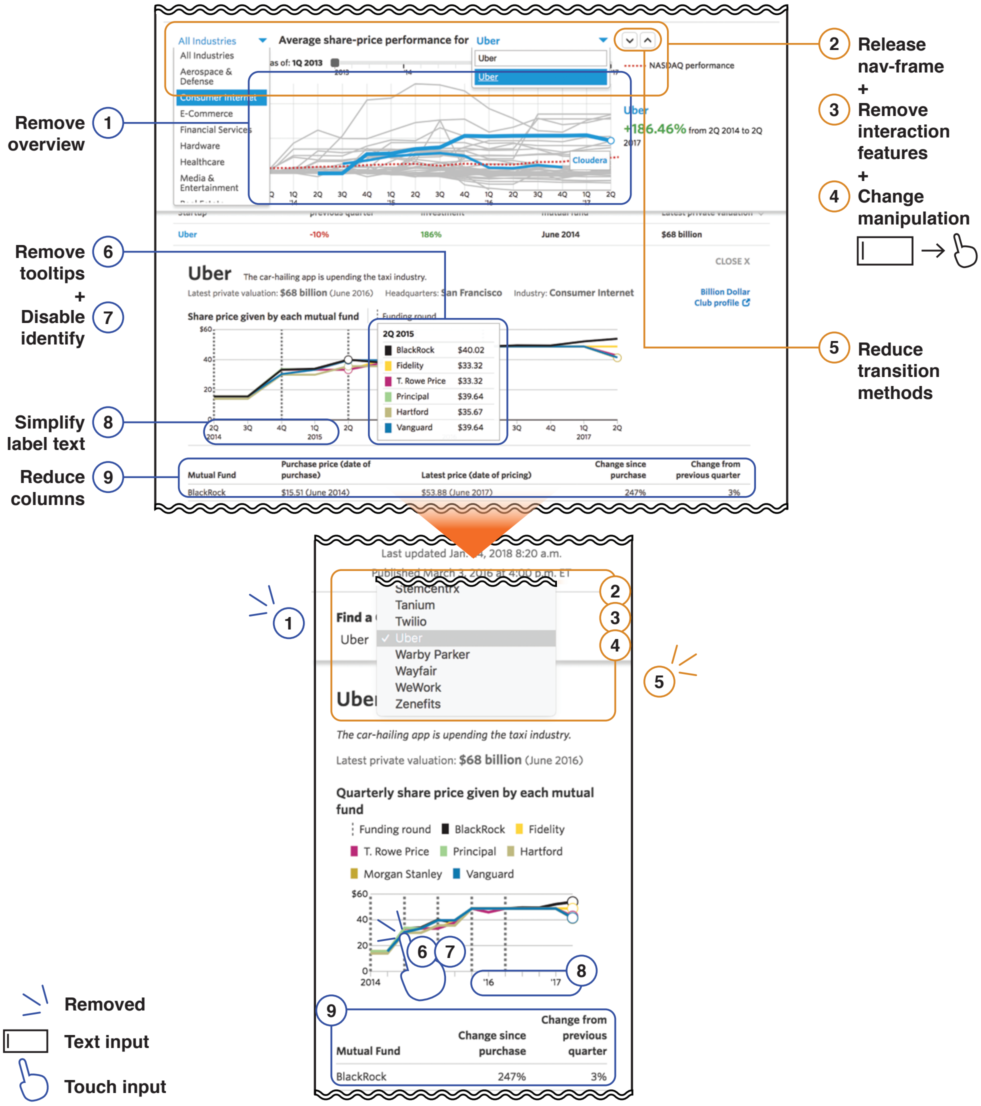

Figure 7. Screenshots of the large-to-small transition of Startup Stocks.

1. **Remove overview**: [L] The overview of entire data is presented. → [S] No overview is presented.

2. **Release nav-frame**: [L] The interaction features are organized in a table-like layout. → [S] This part is presented as general elements.

3. **Remove interaction features**: [L] The filter box, the time slider, and the up and down buttons are provided. → [S] They are removed.

4. **Change manipulation**: [L] The search interaction is available by a text input box. → [S] This is available by an option box.

5. **Reduce transition methods**: [L] Moving to a different company is possible by clicking a line in the overview, by searching, and by clicking the up and down buttons. (This is abstractly a sort of scene transition.) → [S] This can be done only by selecting a company in the option box.

6. **Remove tooltips**: [L] Detail information is provided in a tooltip. → [S] No tooltip is provided.

7. **Disable identify**: [L] Via tooltip, the name and value of a data point is identifiable. → [S] Identify interaction is not possible with an explicit manner.

8. **Simplify label text**: [L] In the X-axis tick, a label consists of the pair of a 4-digit year and a quarter. → [S] Except for 2014, 2-digit year is only provided.

9. **Reduce columns**: [L] The detail table is comprised of 5 columns. → [S] It is comprised of 3 columns.

(1) Removing an overview can be used when the overview becomes visually too complicated after being reduced, or when the overview takes a too long time to load. (2-5) The changes regarding interaction features and navigation frame might be a result of removing the overview, but it can also be used to coerce a reading order. In this case, (3-4) removing tooltips disabled the identify task. If an author wants to avoid disabling the identify task, she or he might provide clear labels for the data points entirely or selectively. Finally, (8) simplifying the label texts and (9) reducing

the columns of the table can prevent overly high complexity and allow efficient space use.

3.3 Design Space for the Transition of News Articles with Data Visualization from Large to Small Screen Devices

The design space of this research consists of three dimensions: target, action, and strategy. The target dimension pertains to particular elements to change (what), the action dimension specifies the manner of change (how), and the strategy dimension concerns the reader-side impact of a change at an abstract level (after). The components of the design space–the design patterns–lie on each of the three dimensions. The entire design space is presented in Figure 8, and the illustrations of the prominent patterns that are not mentioned in the case reviews are available in Figure 9.

3.3.1 Dimension 1: Target - What to Change

In the design process of the large-to-small transition, the target dimension deals with the beginning part, deciding what to change. The target dimension is comprised of physical elements in a visual article. With this dimension, authors can systematically identify which object is problematic and relate it to further steps. The initial classification and the naming of the target dimension was proposed with reference to the conventional specification of visualization components (Stephen, 2009; Kirk, 2012). After the workshop, however, this classification needed to be revised. For example, the participants had a difficulty with identifying highlight elements when there was no category for highlights. They also told that interaction features and the layout of those features should be separated. That is, when the arrangement of interaction

Targets → Actions ↓	Label / Text	Visual Marks	Highlight (HL)	Interaction Features / Navigation Frame	Representation	Visualization
Reduce	[M] Simplify Label Text [M] Reduce Labels [M] Reduce Text	[C] Simplify Marks [C] Reduce Marks [C] [Aggregate]	[O] **Reduce HL Points**	[I] Reduce Outcomes [I] Reduce Transition Methods [I] [Preset Options]	[C] Reduce Ticks [C] Reduce Representation Types [C] Reduce Rows [C] Reduce Columns	[L] **Reduce Width** [C] Reduce Area [C] Reduce Exploration Area [L] Reduce Relative Size
Remove	[M] Remove Labels		[M] **Remove Annotations** [O] Remove HL Points [MO] Remove HL Labels	[I] **Disable Identify** [I] **Immobilize** [I] **Remove Interaction Features** [I] Remove Tooltips [L] Release Nav-Frame		[O] Remove Scenes [O] Remove Visualizations [O] Remove Overview
Toggle		[IC] [Accordion]	[IM] [Toggle HL Massages]	[I] Toggle Interaction Features		[OI] [Hide & Open-Up] [OI] [Interactive Slideshow]
Increase						[L] Enlarge Relative Size
Add			[O] [Add HL Points]	[I] Add Passive Interaction Features [I] Add Active Interaction Features		[O] [Add Visualization]
Shift	[L] Incorporate Labels	[O] Move Marks	[O] Externalize Annotations [O] Number Annotations	[I] Change Manipulation	[O] Fluid Small Multiples [C] [Change Representation Types]	[O] [Visualization then Text]
Fix				[L] Fix Tooltip Position [IM] Unhide Labels [O] [Freeze Nav-Frame]		[OI] Prevent Skipping [O] [Overview as Default]
Transpose				[L] Transpose Nav-Frame	[L] Transpose Axes	
Serialize	[O] Serialize Labels-Marks [O] **Serialize Scenes-Text** [O] Overlay Text			[L] Serialize Nav-Frame [L] Serialize Scenes-Interactions	[O] Serialize Small Multiples	[O] **Serialize Scenes** [OI] Split into Scenes

Figure 8. The design space for the transition of news articles with data visualization from large to small screen devices. [Bracketed patterns] are those discovered from the paper-prototyping workshop. Strategies are denoted by superscript (O: Ordering, M: Messaging, I: Interactivity, C: Complexity, and L: Layout). Popular patterns are denoted by boldface ($\geq$ 10) and underline ($\geq$ 5).

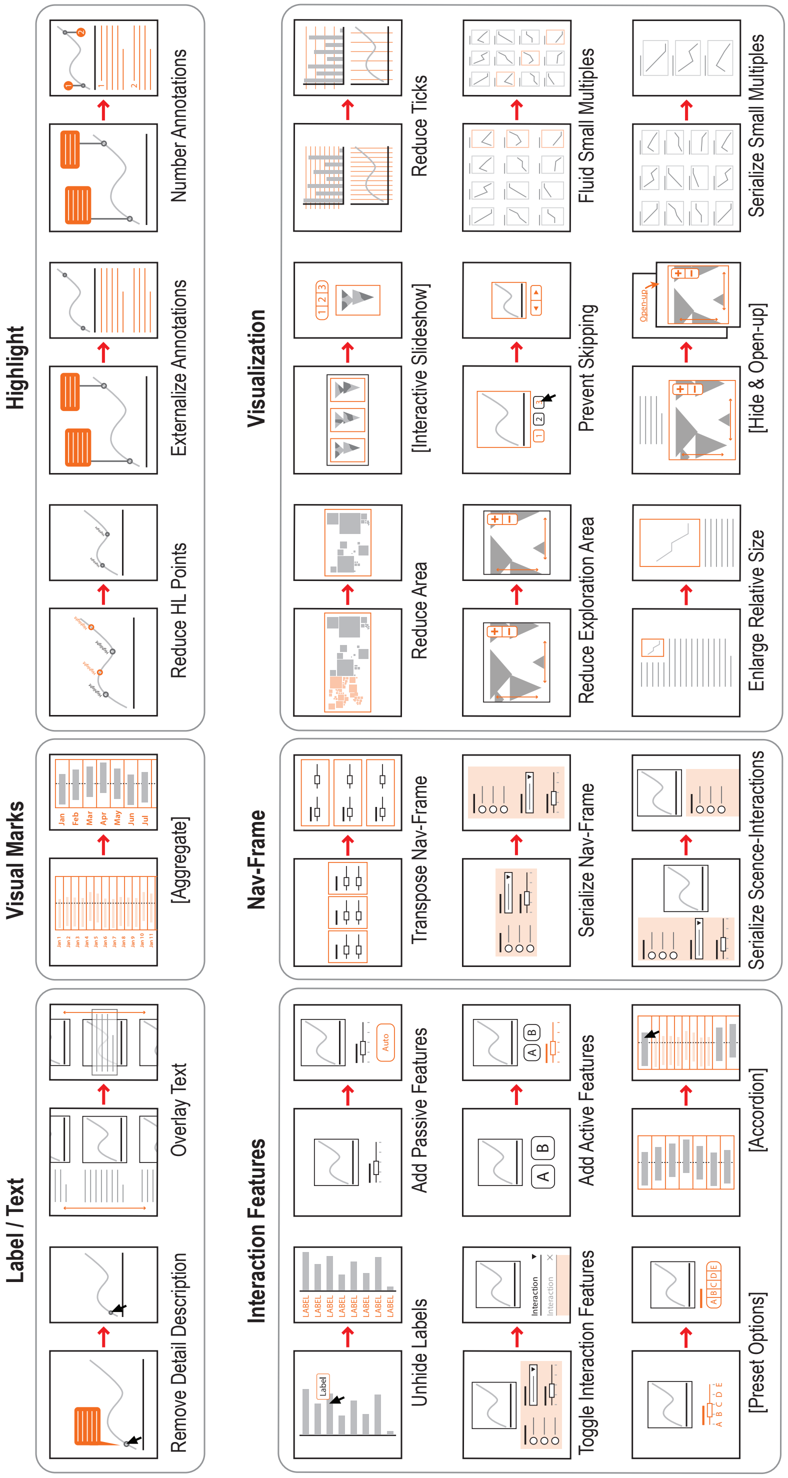

Figure 9. Examples of some design patterns (large→small). Orange-colored parts are what are changed in each pattern.

buttons was changed, some participants did not think that it was the change of the interaction features. In the final version, the target dimension consists of label, text, visual marks, highlight, interaction feature, navigation frame, representation, and visualization. Their definitions are presented below, and they are illustrated in Figure 10.

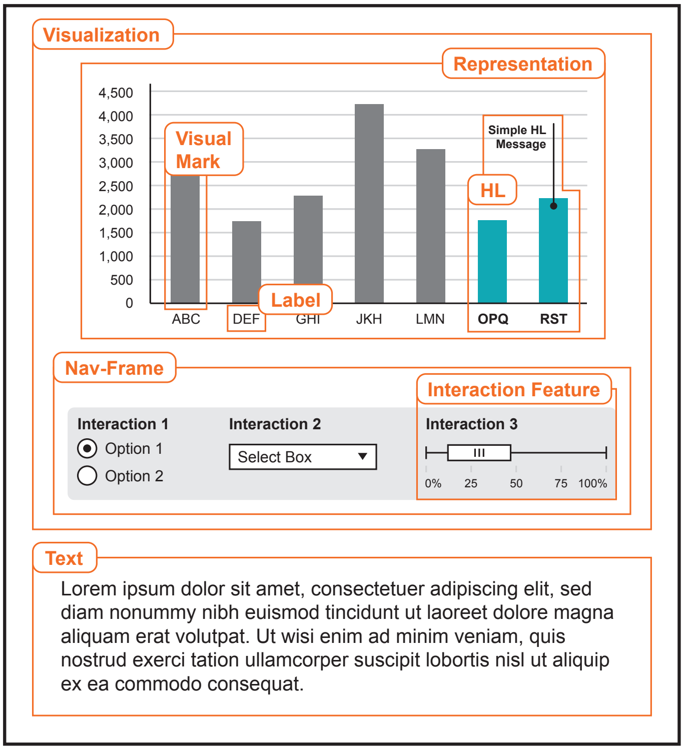

Figure 10. The illustration for the target dimension

- **Label**: a word- or phrase-level text element for the name or the value of a visual mark.
- **Text**: a sentence- or paragraph-level text element for an introduction, a summary, or additional information.
- **Visual mark**: a physical form of (a) visual variables to which each data point

is mapped (e.g., a bar in a bar graph, a line in a line graph, or a colored region in a map).

- **Highlight**: a modification or addition of text/visual/layout elements for enhanced saliency (e.g., a selective annotation, a shade denoting a range of period, or a mark for an important data point).

- **Interaction feature**: a feature that receives particular user input and returns one or more results (e.g., a slider, a tab, scrolling, or a tooltip).

- **Navigation frame (Nav-Frame)**: an organized layout within which a set of interaction features are placed. (e.g., a table of filters, or an app-like interface).

- **Representation**: a overarching visual format into which a dataset is encoded (e.g., a bar graph, a pie graph, a map, or a network).

- **Visualization**: the target data visualization as a whole, of which properties are hard to be divided into components (e.g., the size of a visualization, or the arrangement of scenes).

In the design space, targets are arranged in the order from elemental levels to aggregate levels. For example, labels, visual marks, and highlights belong to a representation which also comprises a visualization. A higher level target is proposed to address more aggregate-level concerns that are not explainable by the sum of its components. For instance, 'reduce width' is more appropriate for a visualization, rather than visual marks.

3.3.2 Dimension 2: Action - How to Change

The next step after deciding what to change is to consider how to change it. To articulate this, the action dimension specifies methods by which the large-to-small transition of a target is actually operated. With this dimension, the direction of a change can be guided. This dimension consists of reduce, remove, toggle, increase, add, shift, fix, transpose, and serialize. This way of classification was inspired by the insights from the various attempts for Web page optimization on small screen devices (Milic-Frayling et al., 2003; Roto et al., 2006), and the usage of Responsive Web (B. Kim, 2013).

- **Reduce**: to decrease the quantity, size, or complexity of a target on a small screen. For example, when multiple representation types are used together (e.g., a scatter plot + a trend line), it is possible to disable one of them (**reduce representation types**).

- **Remove**: to make a target not exist on small screen. While the reduce action keeps a certain feature of the visualization article, the remove action eliminates the feature at all. For example, a visualization can be deleted at all. (**remove visualizations**).

- **Toggle**: to hide a target and allow it to be revealed. This is a useful manner in that it reduces the space of a target while preserving the amount of discoverable information. For instance, authors can conceal a free-explorable visualization and provide a link to it (**hide & open-up**).

- **Increase**: to increase the quantity or size of a target. This is the opposite of the reduce action. A visualization's **relative size is increased** when it floats in the corner of a paragraph in the large screen version but takes a full paragraph width in the small screen version.

- **Add**: to create a target on a small screen that does not exist on a large screen. A **passive interaction feature** can be added, such as GPS-based location search or autofill, to assist complex user interaction.

- **Shift**: to change the position of a static target. Specifically, static to dynamic and static to static changes come under this action. For example, when annotations are placed in their corresponding focus area in the large screen version, they can be moved out of the visualization (**externalize annotations**).

- **Fix**: to alter the position or the state of a target to be strictly fixed. Dynamic to static changes come under this action. For example, authors can reveal all the labels next to the related marks on a small screen when they are interactively toggled in the large screen version (**unhide labels**).

- **Transpose**: to interchange the horizontal and vertical axes of a target. When interaction features are arranged in two particular axes, they can be transposed (**transpose nav-frame**).

- **Serialize**: to place horizontally arranged targets in vertically serial order. For example, small multiples can be serialized in the small screen version rather than arraigned in a matrix format as in the large screen version (**serialize small multiples**)

3.3.3 Dimension 3: Strategy - After Changing

The strategy dimension is composed of categories for the expected reader-side impact of a transition at an abstract level. This dimension is essential in that authors need to consider how readers will perceive the transitioned visual article for small screen devices. After deciding what and how to change, authors can check the probable impact of target + action with this dimension and then they can finally decide whether to use it or not. The name of this dimension is ‘strategy’ because it offers benefits when planning large-to-small transition by giving hints of the subsequent impact of a change.

The strategy dimension is divided into two groups: storytelling and non-storytelling. Storytelling strategies (ordering, messaging, and interactivity) are those from the visual narrative structure (Segel & Heer, 2010). The non-storytelling strategies (complexity and layout) are those less relevant to the visual storytelling structure. Specifically, they are:

- **Ordering**: the order of scenes, visualizations, and text messages in which readers explore, browse or read a visualization. For example, this can be adjusted by removing marks, adding highlights, or removing scenes.
- **Messaging**: the amount of language-based introduction or explanation of a visualization. For example, this strategy can be altered by simplifying label text, reducing text, or toggling highlight messages.
- **Interactivity**: the degree of freedom to which readers can manipulate the representation of a visualization. For instance, this can be changed by reducing outcomes, preset options, unhiding labels, removing tooltips, or hide & open-up.
- **Complexity**: the amount of visual information presented at a time (e.g., the complexity of a representation). This can be decreased by reducing marks, representation types, or (exploration) area.
- **Layout**: the arrangement or the size of a target that does not directly affect the ordering of the visualization. For instance, reducing/enlarging relative size, transposing, or changes within a nav-frame belong to this strategy.

The strategy of a pattern can be multiple. For example, the prevent skipping pattern affects interactivity as well as ordering in that it blocks transition interaction and coerces a reading order. Moreover, the interaction feature and the navigation frame targets do not always belong to the interactivity strategy. For example, the fix tooltip position pattern does not affect interactivity. Also, a change of the navigation frame might not adjust interactivity.

3.4 Discussion

In this chapter, we proposed a design space for the transition of data visualization article from large to small screen devices. The design space analysis was conducted through a mixed method of content analysis and the open-coding of the grounded approach. In this section, we will discuss additional observation: the direction of changes and the condition of the large-to-small transition.

3.4.1 Direction of Changes

From the content analysis, we could observe the overall direction of the large-to-small transition utilized by the journalism industry. In this subsection, we will describe the prominent trends that we discovered in terms of storytelling approaches. This comparison was conducted by counting the number of articles that involve either author-driven or reader-driven changes in each storytelling structure (ordering, messaging, interactivity, and construction). If an article includes changes for both directions, it was counted respectively. Then, the proportions of both directions were compared by T-test. The comparison data is available in the Table 3

First of all, the directions of change in ordering, interactivity, and construction were more likely to be author-driven than reader-driven. In the Table 3, 14 articles

Category	Direction of change			
	Author-driven		Reader-driven	
Ordering	14	**13.46% (p<0.01)**	3	2.88%
Messaging	0	**0% (p=NA)**	18	17.31%
Interactivity	20	**19.23% (p<0.01)**	1	0.96%
Construction	15	**13.46% (p=NA)**	0	0.00%

Table 3. The directions of change. The number of entire samples was 104.

out of 104 (13.46%) adopted author-driven changes in ordering, while 3 (2.88%) applied reader-driven changes in ordering. Similarly, the interactivity of articles was likely to be adjusted in an author-driven way rather than a reader-driven way. At last, construction (i.e., format or genre of a visualization, see Appendix A) tended to be changed to more author-driven one (e.g., dynamic to static, interface to dynamic), rather than reader-driven one (e.g., interface). This implies that providing visual articles on small screen devices has been affected by the assumption that highly interactive or less ordered visualization might confuse their readers. However, the message part has changed toward a more reader-driven way (18 out of 104, 17.31%). Particularly, short text messages were likely to be reduced or removed rather than added or created. It can be speculated that the authors of visual news articles have been cautious not to overwhelm their mobile readers with lengthy text descriptions.

The effects of storytelling approaches are not always straightforward, but controversial. This contradiction becomes more complicated when device factors are taken into account together. Therefore, the empirical studies on the effects of various storytelling approaches, e.g., Boy et al. (2015), are more and more required to test if these conventions of the large-to-small transition are appropriate for the comprehension of news articles with data visualization.

3.4.2 When to Transition

When considering the large-to-small transition, it might be curious whether the transition is needed or not. In our observation, certain types of visualizations do not need to be transitioned for small screen devices. In fact, 7 articles (6.7%) did not transition at all, and 15 articles (14.4%) applied design patterns only in the layout strategy only. Those cases are likely to be under one of the three conditions. The first is when a visualization does not take too much space on a screen. The second is when the complexity of a visualization is not too high, so the reduced absolute size does not harm the visual accuracy or overview. The third condition is when the physical movement of the interaction features can be more fluent or native on small screen devices, such as dragging, pinching, and swiping. For example, *Draw It*[4] is not significantly changed from large to small because its quiz-like format and drag interaction to answer can be more native on small screen devices (see Figure 11).

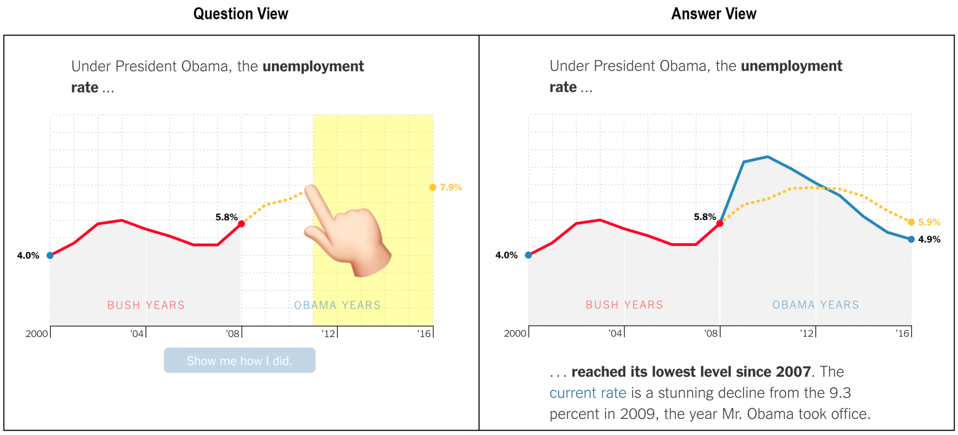

Figure 11. The screenshot of *Draw It*

Furthermore, in the design space analysis, we observed that text messages were

[4]https://nyti.ms/ejS9b4b

not likely to be reduced or removed even when they were relatively long. In contrast, short messages in tooltips or highlight labels were often removed. This might be due to two possible reasons. First, since the samples we observed were all news articles, the authors might not have tried to reduce or remove messages because they did not want to leave their readers less guided with a large dataset. This seems quite contradictory with the previous mention about short text messages. Hence, an empirical study needs to be followed regarding the guidance and overwhelming effects of text messages. Second, since text tends to convey clearer and more explicit messages, changes in them might generate a misunderstanding problem. In the workshop (see chapter 4), P9 in Day 2 (a Ph.D. candidate in political journalism) pointed out that this matters more when the article is about political, economic or diplomatic issues.

Chapter 4. Study 2: Paper-prototyping Workshop

In the previous study, we generalized design techniques by which the large screen versions of visual news articles are transitioned to their small screen versions. Then, we also organized them in a design space for a more parsimonious description and enhanced usability. Considering that visualization authors have various backgrounds, not every author is used to design conventions, and some of them are likely to need more guided descriptions. For example, a visualization author with statistical backgrounds might need more time to become familiar with a design space. However, the proposed design space does not offer such guidance. Therefore, if our design space is linked with design implications, it will help those with various levels of literacy in design.

To achieve this goal, I conducted two sessions of a paper-prototyping workshop. These two sessions were not dependent on each other, but they were repetitions of the same workshop program. Through this study, I could obtain design intentions and match them to their realizations. The tools, tasks, and procedure of this workshop were inspired and motivated by VizItCards (He & Adar, 2017) and Bach et al. (2018). This workshop was approved by the IRB of SNU (IRB No. 1808/002-011).

4.1 Method

4.1.1 Participants

A total of 20 people (13 females and 7 males, mean age = 29.5) participated in the two workshop sessions. 10 participants were present at each session. They were recruited from online forums for data visualization and HCI research as well as a graduate student group of communication and journalism majors. Their literacy in data visualization and paper-prototyping varied. 5 participants had not studied data visualization nor done paper prototyping (low), 9 of them had experiences in interface design or data analytics (mid), and the other 6 participants had several years of academic or field experiences in data visualization (high). The more detailed information of the participants is available in Table 4. The participants were rewarded KRW 20,000.

Day	Group	No	Gender	Age	Literacy	Background
Day 1	G1	P1	Female	31	Mid	Interface design
		P2	Female	31	Mid	Data analytics
	G2	P3	Female	36	Mid	Took a related course
		P4	Male	19	Low	Statistics
	G3	P5	Female	41	Low	Industrial design
		P6	Female	26	High	HCI Ph.D. student
	G4	P7	Female	30	Mid	Application director
		P8	Male	19	Low	Statistics
	G5	P9	Male	23	High	Took several related courses
		P10	Female	28	Low	Humanities
Day 2	G1	P1	Male	27	High	Visualization Ph.D. student
		P2	Female	25	Low	Master in journalism
	G2	P3	Female	28	High	Visualization director
		P4	Male	28	High	HCI Ph.D. student
	G3	P5	Female	43	Mid	Data analytics
		P6	Female	24	Mid	Visual design
	G4	P7	Male	27	Mid	Industrial design
		P8	Male	29	Low	NGO officer
	G5	P9	Female	31	Mid	Journalism Ph.D. student
		P10	Female	44	Mid	Big data researcher

Table 4. The Detail Information of the Participants

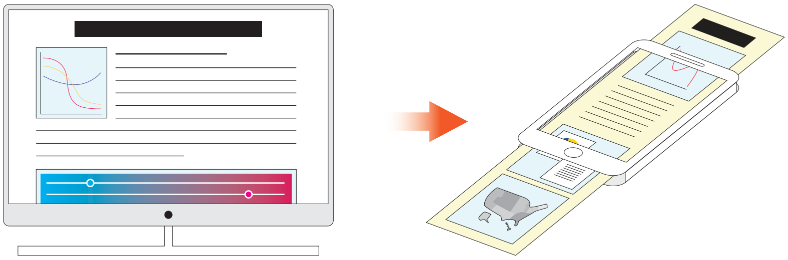

Figure 12. The task of the paper-prototyping workshop

4.1.2 Tasks and tools

The workshop's task was to make a paper-prototype for the small screen version of a news article with data visualization which was given as its large screen version. The task is illustrated in Figure 12. The task was assigned to a group of 2 participants (5 groups per session). The participants were grouped based on their degree of literacy and their interests. Each group was provided prototyping tools: a pasteboard prototyping frame with 6.8 cm $\times$ 12.2 cm screen size, a 2 m-long rolled paper, colored pens, sticky notes, the initial version of the design space, and the design pattern cards. The participants drew their prototype design on the rolled paper, and then they put it in the prototyping frame to simulate their prototype on a small screen device, The usage of these tools is shown in Figure 13.

The design pattern chart and the design pattern cards were given to facilitate and assist the prototyping process. The chart was similar to the final version (Figure 8), but it had the color and shape indices by which participants can quickly find the corresponding design pattern card. The design pattern cards were double-sided; their name and color & shape indices were on the front sides, and their illustration (as in the Figure 9) and a brief description were on the back sides. The distributed version of design space chart is in Figure 14, and the example of a design pattern card is available in Figure 15.

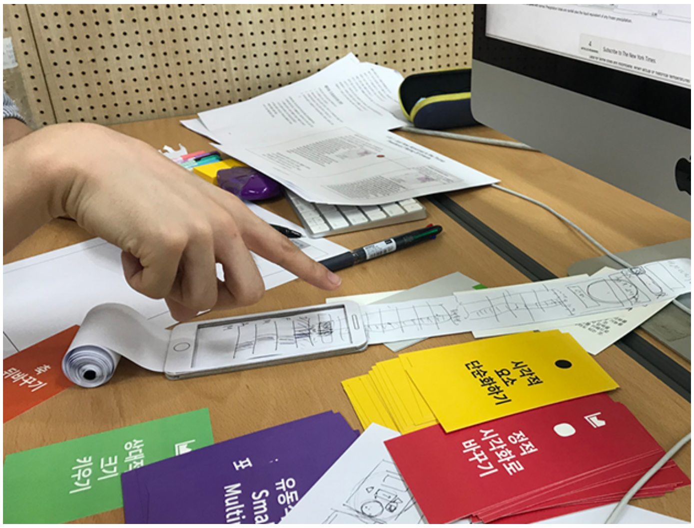

Figure 13. The usage of the prototyping tools

구분	라벨	시각적 요소	텍스트	시각적 재현	상호작용 기능	장면/시각화
줄이기	[M] 라벨 문구 단순화 [M] 라벨 줄이기	[C] 시각적 요소 단순화하기 [C] 시각적 요소 줄이기 [O] 하이라이트 포인트 줄이기	[M] 텍스트 줄이기	[C] 시각적 재현 방식 줄이기 [C] 눈금 줄이기 [C] 행 줄이기 [C] 열 줄이기	[I] 상호작용 기능 토글하기 [I] 결과 개수 줄이기 [I] 전환 방법 줄이기	[C] 면적 줄이기 [C] 탐색 면적 줄이기 [L] 가로폭 줄이기 [L] 상대적인 크기 줄이기
없애기	[M] 라벨 삭제 [I] 툴팁 제거	[O] 하이라이트 삭제	[M] 상세 설명 삭제 [M] 하이라이트 메시지 삭제		[I] 상호작용 기능 제거 [I] 식별 기능 제한 [I] 정적 시각화로 바꾸기 [L] 상호작용 기능의 레이아웃 해제	[O] 시각화 삭제 [O] 오버뷰 삭제 [O] 장면 삭제
늘이기						[L] 상대적인 크기 키우기
만들기					[I] 수동적인 기능 추가 [I] 능동적인 기능 추가	
바꾸기	[L] 라벨을 포함시키기 [M] 참고 메시지 밖으로 옮기기 [M] 참고 메시지에 번호 달기	[O] 시각적 요소 옮기기 [O] 하이라이트 중요도 바꾸기		[O] 유동적인 Small Multiples [L] 유동적인 레이아웃	[I] 조작 방법 변경	
고정시키기	[I] 라벨 드러내기 [I] 툴팁 위치 고정하					[O] 건너뛰기 방지하기
축전환하기				[L] 축 뒤바꾸기	[I] 상호작용 기능의 레이아웃 뒤바꾸기	
직렬화하기	[O] 라벨과 시각적 요소 직렬화		[O] 텍스트 오버레이 [O] 장면과 텍스트 직렬화	[O] Small Multiples 직렬화	[I] 상호작용 기능을 직렬 배치하기	[O] 장면 직렬화 [L] 장면과 상호작용 기능을 직렬 배치 하기 [O] 장면으로 분할 [O] 시각화 직렬화

Figure 14. The initial design space chart (in Korean)

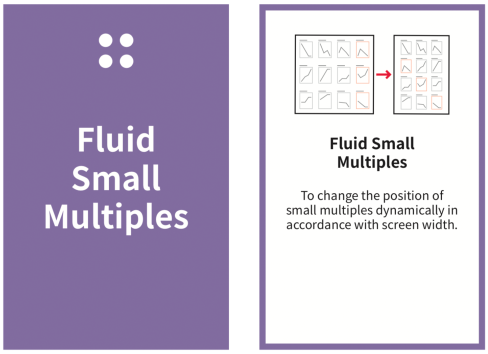

Figure 15. The initial design space chart

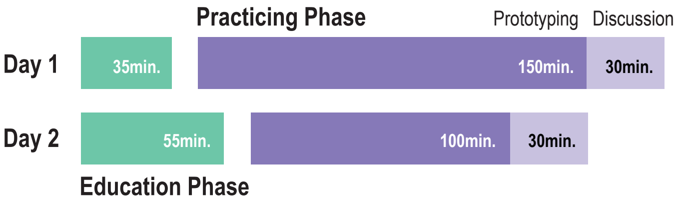

Figure 16. The workshop process and the time consumed

4.1.3 Procedure

Each session of the workshop was composed of two phases: an education phase and a practicing phase. As indicated in Figure 16, the education phase took approximately 35 minutes on Day 1 and 55 minutes on Day 2. The practicing phase took about 150 minutes on Day 1 and 100 minutes on Day 2 (excluding approximately 30 minutes of discussion).

In the education phase, the participants introduced themselves and then learned the overall purpose of the workshop, the design space (as its initial version), specific examples of frequently used design patterns, and how to use the prototyping tools. They were instructed to mention their background experience related to data visualization and their daily interests. There was a difference in this phase on Day 1 versus on Day 2. On Day 2, the participants were instructed to actually match some design patterns to the corresponding cards using the color and shape indices. On the other hand, on Day 1 they were instructed to look up the introduced design patterns in the chart.

The practicing phase consisted of grouping, ideation, prototyping, and discussion. The participants were grouped based on their literacy and interests mentioned in the self-introduction. I tried to balance the groups' degree of literacy. Also, I tried to assign workshop materials that are matched to the participants' interests as best as possible. During the ideation process, each group was strongly recommended to write down (1) the main points of the given visual article, (2) the expected problems without the large-to-small transition, and (3) applicable design patterns to fix those problems, as clearly as possible. Then, they moved on to the above-described task. Finally, each group presented its prototype to the other participants, and then they discussed it together. When presenting, they were instructed to mention the intention of their use of design patterns.

4.1.4 Materials

5 visual news articles (in Figure 17) were chosen for the workshop material and assigned to each group (G1 G5). The materials were the same in both sessions. These articles were selected based on their representativeness, accessibility (unpaid use), and expected difficulty. As well, I tried not to include articles with data visualizations that require a high degree of background knowledge to comprehend. Specifically, they are:

- *How Much Warmer (G1)*[1]: an interactive visualization with several UI components by which users can search for a city and get its climate information.

[1] https://nyti.ms/ek16cZP

- *Manhattan Reconstruction (G2)*[2]: a full-screen map visualization with simple interaction features (zoom, pan, tooltips, and filter).
- *French Election (G3)*[3]: a magazine-style article with static visualizations of various degrees of complexity.
- *LeBron (G4)*[4]: an interactive slideshow with a parallax scene transition and a table of small multiples.
- *British Election (G5)*[5]: a magazine-style article containing dynamic visualizations with simple interaction features (tooltips and tabs).

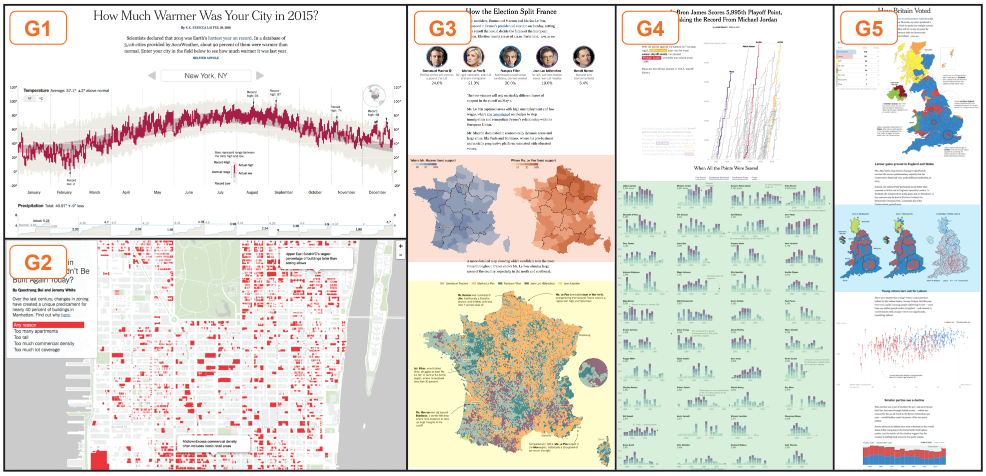

Figure 17. The materials for the workshop

[2]https://www.nytimes.com/interactive/2016/05/18/upshot/which-buildings-in-manhattan-couldnt-be-built-again-today.html
[3]https://nyti.ms/2pbI1uD
[4]https://nyti.ms/2s1yRz2
[5]https://nyti.ms/2s1bI36

4.1.5 Analysis

The written ideation process, the paper-prototypes, and the transcripts of the discussion were analyzed through the open and axial coding of the grounded approach (Corbin & Strauss, 1990). This process focused on connecting the participants' intentions and their use of design patterns to realize the intentions. During the open-coding process, we attempted to capture their intentions and use of design pattern. Then, through the axial coding process, we tried to connect the categorized intentions and design pattern usage.

4.2 Evaluation

Aside from deriving design implications, the effectiveness of the design space was also evaluated during the workshop. Before proceeding to the design implications, I will describe the evaluation. After finishing the workshop, the participants responded to an evaluation questionnaire about the usability, functionality, difficulty, simplicity, effectiveness of the proposed design space. Each close-ended question was measured by 7 point scale of semantic differential according to (Bucy, 2004; E.-J. Lee & Kim, 2016)'s usability measure. The scales were unusable - usable, non-functional - functional, hard to use - easy to use, complex to use - simple to use, and ineffective - effective. The closed-ended questions and their results are presented in Figure 18. They also answered an open-ended question about the design space and the design pattern cards.

In general, the design space was positively evaluated. The specific scores were usability (6.06), functionality (5.56), easiness-to-use (5.06), simplicity (5.44), and effectiveness (5.67). From the open-ended question, participants mentioned the way of informing how to use design space and the design pattern cards. In Day 1, the

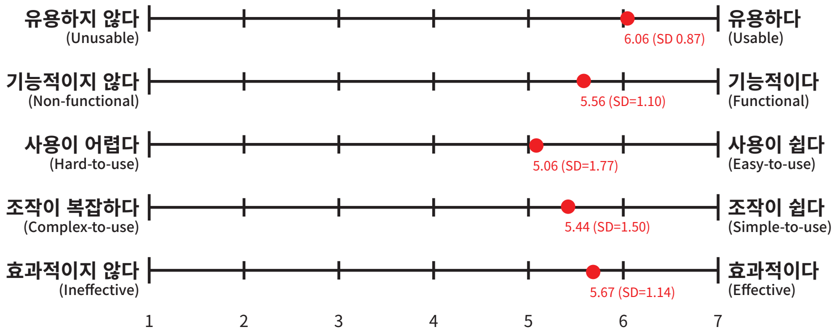

Figure 18. The evaluation result of the design space

tools were taught in a relatively drier way, and some of the participants mentioned it was slightly hard to use them due to the relatively terse introduction. Reflecting those comments, I revised the process by giving more chances to practice how to use them in Day 2. As a result, the participants of Day 2 evaluated the use of the design space and the design pattern cards more positively in the open-ended question. They also mentioned the visual illustration of a design pattern was intuitive.

4.3 Design Implications for a More Guided Use of the Design Space

In this section, I will discuss four design implications (DIs) that are derived from the paper-prototyping workshop. Sample prototypes are available in Figure 19. Those design implications will support visual journalists to design small screen versions of news articles with data visualization by making our design space more ready-to-use. I will present the design implications by describing how they can fulfill specific design intentions for the large-to-small transition. This way of description is more problem solving-oriented.

As depicted in Figure 20, the four design intentions were (1) giving quick in-

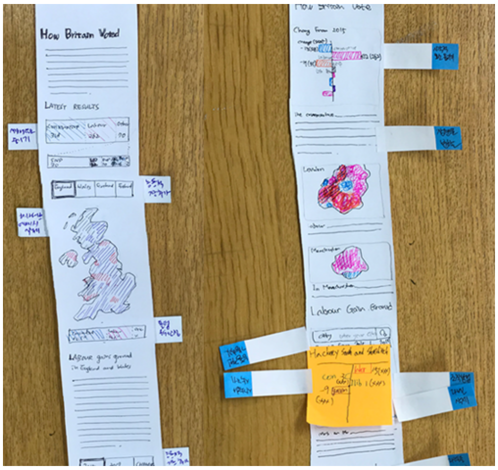

Figure 19. Sample Prototypes of the Workshop

sights, (2) managing scroll length and visibility, (3) compensation for reduced information, and (4) keeping readers interested. In the workshop, the participants made use of design patterns to fulfill these intentions. Those methods are grouped by (1) narrowing down, (2) making shorter than a single scroll height, (3) adding an interaction for details, and (4) making readers curious of what comes next.

4.3.1 DI1: Narrow Down to Give Quick Insights

The design intention to give quick insights was often mentioned in the workshop due to the contextual factors of small screen devices. People might have difficulty in paying full attention to a news article on smartphones. To solve this problem, some of the participants (G1, G2, and G5 in Day 1 and 2) suggested to narrow down the focuses of news articles with data visualization. As specific design techniques for narrowing down, they suggested to (1) avoid random and (2) fitting representations types.

First, an article can be more relevant to readers by avoiding random. When an article is relatively less related to their backgrounds and interests, they might perceive

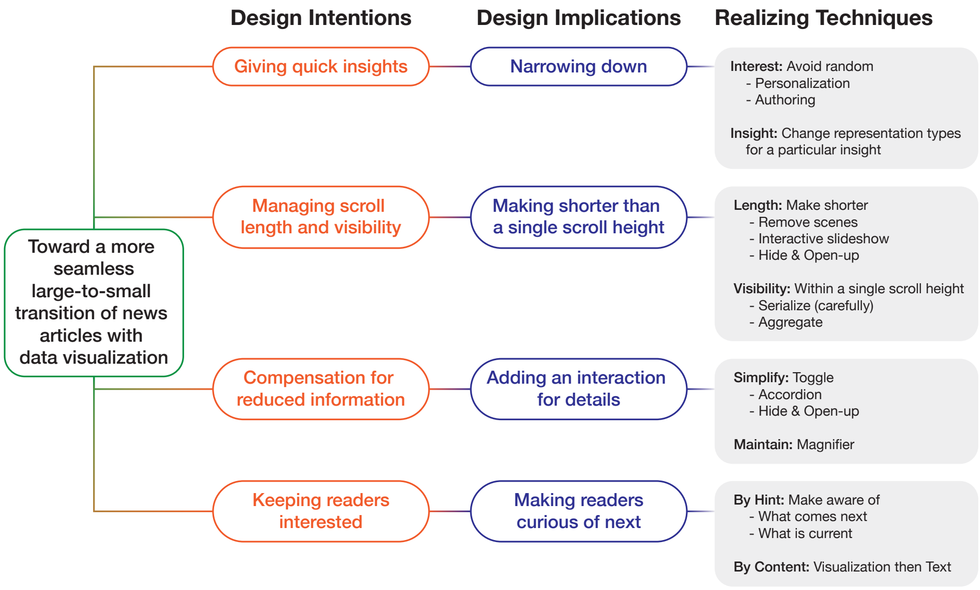

Figure 20. The Summary of Design Implications

that it is arbitrary. In this case, New York City and Manhattan are less relevant to those who do not work or live there. In other words, when an news article is perceived less arbitrary, readers' cognitive resources to relate the article's focus toward their interest might be lessened. Specifically, participants suggested both reader-driven (personalization) and author-driven (authoring) methods.

For example, G1 in Day 1 and 2 suggested personalization by adopting a GPS-based location feature (**add passive interaction features**). *How Much Warmer* (G1) sets New York City as the default among major cities in the world. With a GPS feature, readers can easily manipulate the article to their area on small screen devices. In previous cases, Lodha et al. (2003) utilized a GPS-based location system to mobile map applications for the enhanced usability. Similarly, interactively editing a visualization to one's favor on mobile devices has been stressed in other previous works (Burigat & Chittaro, 2005; Chalmers et al., 2001; Reichenbacher, 2004).

On the other hand, G2 in Day 1 and 2 authored the article in a way that delivers more general information. *Manhattan Reconstruction* (G2) sets the central part of Manhattan (from the 37th to 63rd Streets) as default. Various methods of data abstraction (or generalization) have been applied to ease readers' cognitive attention (Zipf & Richter, 2002). G2 in Day 1 decided to provide an overview as default, and G2 in Day 2 decided to display several important scenes statically (split into scenes). By showing aggregate-level information or selective points, the article might be more interesting to those without significant relevance in the region.

Second, G5 in Day 1 and 2 tried to provide quick insights by **changing a representation type** toward particular types of insights. The first visualization of *British Election* (G5) contains a bar graph about the election results. In the large screen version, this graph has a general format of a bar graph. Interestingly, it was changed in two different ways depending on each group's intention. G5 in Day 1 stressed the difference in the share of seats between two latest elections. Thus, they changed the uni-directional bar graph (the number of seats) into a bidirectional bar graph with plus and minus quantities. On the other hand, G5 in Day 2 prioritized the share of seats of the major parties. So, they changed the bar graph to a single-line stacked graph. Although it blurred the minor parties, this change reduced the space on a screen while summarizing overall political dynamics. This way of removing details seems applicable to deliver insights more quickly according to Chittaro (2006a). This also helped reduce its space on a small screen.

In their prototypes, illustrated in Figure 21, the type of the representation was changed from on for general insights to ones for more specialized insights. The original bar graph on the left side of the figure provides relatively more general insights by visualizing raw quantities and displaying the increments. In this visualization, readers have more options for interpretation, such as distribution, increments, and paired differences. In contrast, the prototypes on the right side of the figure offer more pro-

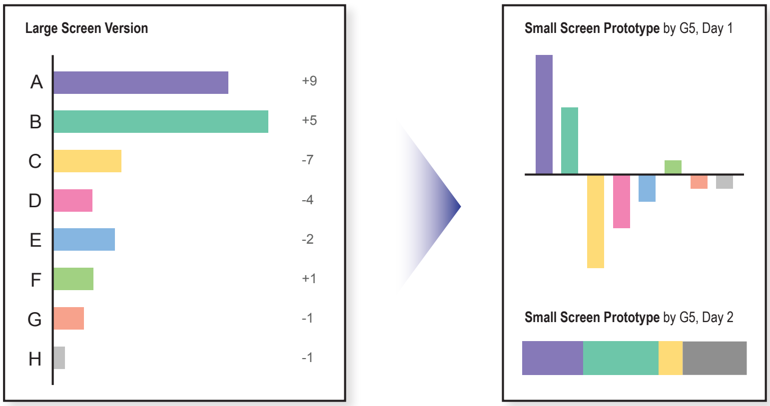

Figure 21. The illustration of workshop prototypes for changing representation types

cessed data (i.e., increments and proportion). As a result, the raw data and their accurate distribution are hardly available, but they deliver insights more explicitly and expeditiously.

4.3.2 DI 2: Make Shorter for Length and Visibility

Another primary concern of the participants was the arrangement of elements in a news article because of the reduced absolute screen size and the portrait dimension of small screen devices. This design intention can be specified in two parts: length and visibility. Serializing targets can be an immediate option, but it might result in excessive lengthiness. Furthermore, a visualization longer than a scroll height might hinder its at-a-glance overview.

Many of the participants (Day 1: G3, G4, G5; Day 2: G1, G3, G5) suggested various methods to overcome this problem. Specifically, those who cared the lengthiness of an article applied design patterns to (1) shorten it. On the other hand, those who were concerned with the visibility of visualizations adopted design patterns to (2) place targets within a single scroll height. During the workshop, the paper-prototyping frame was helpful for this design intention by allowing them to check

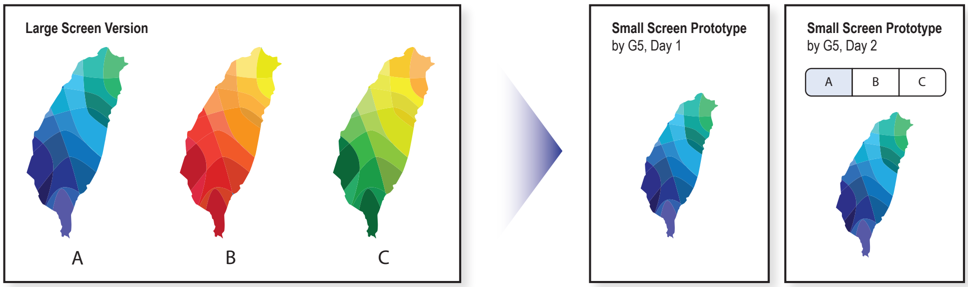

Figure 22. The illustration of workshop prototypes for managing scroll length

the feasibility of participants' idea.

First, removing tactics were often used to reduce the length of a visualization. For example, the three British maps in *British Election* (the blue-shaded part in Figure 17) might be too long when serialized because those maps have a vertically long shape. Thus, G5 in Day 1 removed two less important scenes (see Figure 22). Similarly, G4 in Day 1 (*LeBron*) hid the set of 50 small multiples (the green-shaded part in Figure 17) because they thought that it took too much space on a small screen.

On the other hand, G5 in Day 2 took a different approach with the same article. They hid two scenes and allowed them to be toggled (**interactive slideshow**, see Figure 22). This interactive option seems to be appropriate when the reduction in size might have a negative effect on readability (Chittaro, 2006a). This is also relatively easy to apply by using front-end frameworks, such as Bootstrap and Materialize.

Second, visualizations were carefully placed within a single scroll height to ensure an at-a-glance overview, which is vital for visual analytics tasks. For instance, G3 in Day 1 and Day 2 serialized the two maps of France (the orange-shaded part in Figure 17) to be placed within a single scroll height. When they presented their prototypes, other participants asked if the resulting visualization could be seen together at a time. Then, they answered that they also wanted to allow the immediate comparison of the two maps.

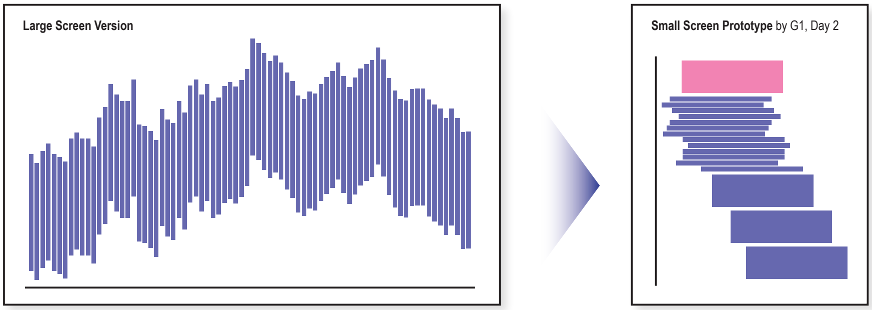

Figure 23. The illustration of a workshop prototype for aggregating

Furthermore, G1 in Day 2 suggested the **aggregate** pattern (i.e., to aggregate the data into a higher level). They aggregated the data from daily level to monthly level by mean values (see Figure 23). This was because when they transposed the axes to fit the portrait dimensions, they worried whether the resulting visualization has an incomplete look on small screen devices. The idea of aggregation is highly related to Zipf and Richter (2002)'s suggestion of 'generalization' for reducing readers' cognitive resources.

4.3.3 DI 3: Interactively Compensate Reduced Information

As described earlier in the design space analysis and the workshop results (DI 1 and 2), the amount of information is often reduced during the large-to-small transition of news articles with data visualizations. The participants also recognized this issue, so they suggested interactive methods to compensate the reduced information (Day 1: G1-4, Day 2: G1-3, 5). They tried to realize their design intentions in two ways: toggling and magnifier.

First, when simplifying or removing targets, participants suggested toggling interactions. For example, when G1 in Day 2 (*How Much Warmer*) aggregated the data, they provided the visualization in the accordion format. As a context+focus technology, it helps the back-and-forth transition between overview and detail. As Munzner, Guimbretière, Tasiran, Zhang, and Zhou (2003) noted, this enhances the detectability of data when the data are aggregated for the sake of visibility. This is especially useful to cope with the reduced information space of small screen devices[6]. In addition, when G2 in Day 2 (Manhattan *Reconstruction*) immobilized the map and split it into scenes, they provided a hyperlink to a free-explorable map (hide & open-up). G4 in Day 1 (*LeBron*) also applied this design pattern as compensation.

Second, as a context+focus interaction, a magnifier is applicable when the accuracy of data needs to be maintained. As S. Y. Kim et al. (2007) mentioned, when some part of the information is necessary for accurate perception, it should be prioritized over abstraction of data. In the workshop, G3 in Day 2 (*French Election*) were aware of this problem, so they added a magnifier (add **active interaction features**) to allow readers to explore the detail of the map (the yellow-shaded part in the Figure 17). This is depicted in Figure 24. They were concerned if the complex color-coding might not be visible when the relative size of the map is reduced on small screen devices. However, they did not want to merely simplify it because the simplification might misrepresent the demographic proportion of regions. Indeed, the discrepancy between urban and rural area is important to understand population geography data. Therefore, they added a magnifier to ensure the accuracy of the visualization.

4.3.4 DI 4: Make Readers Curious of Next

When converting a visual article for its small screen version, it is important to keep readers interested until the end of the article. This is mainly because the increase of the overall length of an article is highly unavoidable during the process of large-to-small transition, which might promote skim reading (Duggan & Payne, 2011; Pan

[6]For further examples, see Slack, Hildebrand, and Munzner (2006) and Pattath et al. (2006).

Figure 24. The illustration of a workshop prototype for a magnifier

et al., 2004). The participants of the workshop (Day 1: G4 and G5; Day 2: G2) also recognized this problem, so they suggested to two ways to make readers curious of what comes next: (1) by giving a hint and (2) by presenting visual first.

First, visualization authors may indicate that there are more parts to read. For example, P7 (G4, LeBron) in Day 1 removed the parallax transition and split the visualization into several static scenes instead. Because it seemed to lengthen the article, they "tried to place the title of the next visualization within a single scroll height." This is also applicable when serializing scenes. Similarly, G2 in Day 2 (Manhattan Reconstruction) split the visualization into several important scenes. In order to manage the resultant lengthiness, they suggested a fixed-position navigation (freeze nave-frame). They tried to make readers aware of where they are reading and that there is something left. As Paolino et al. (2013) suggested, giving a hint of what is not on the screen is another way of using reduced screen space efficiently by inducing readers to discover the hinted information.

Second, presenting visual part prior to text part is another option to keep readers interested. In the workshop, G5 in Day 1 (British Election) changed the order of the visualization and text, so that the visualization can capture the readers' focus. P9

(G5) in Day 1 said, "I thought that people tend to skim (when reading on a small screen device). So, it will be better to provide a visual overview and then let readers read text messages for further details." Considering that visual information is more eye-catching than text information with small letters (Bucher & Schumacher, 2006), this particular way of arrangement seems to encourage readers to stay with a visual article.

4.4 Discussion

In this chapter, I presented how I conducted the paper-prototyping workshop and detailed the findings from the workshop sessions. This process helped to connect the design space to users' intention. In this section, then, I will discuss the key lesson from the workshop and an issue regarding HCI education through a design space.

4.4.1 Not Conforming But Fine-Tuning

One might question whether reducing the size, deleting objects, and rotating to fit small screen devices will be sufficient for the large-to-small transition of news articles with data visualization. The results of the workshop, however, reconfirmed that this process is not the conformation process but the fine-tuning of visualization authors' intention and its realization. I will introduce several fine-tuning cases that are seemingly less intuitive.

First, although some interaction features might provide lower usability on small screen devices, it does not mean that adding a new interaction is always a bad choice. For example, G1 in Day 2 (*How Much Warmer*) intended to promote quick insights by giving a brief overview. They thought that only transposing the axes to fit a small screen will not result in a recognizable overview because of the large volume of the data. Thus, they suggested combining the aggregate and accordion patterns. This allows readers to perceive an overall tendency through simplified representation as well as to discover details when interested. Similarly, G5 in Day 2 (*British Election*) also proposed an interactive slideshow not only for the efficient use of screen space but also to provide a constant frame for a comparison task.

In addition, the simplification of visualization (e.g., simplify elements) is not desirable when the accuracy of the representation is highly essential. Although the third visualization of French Election (the yellow-shaded part in the Figure 17) was expected to be too complicated on a small screen device, neither of two groups simplified it. They all knew that the visualization's precision should be preserved because, otherwise, it might misrepresent the election's outcome due to the difference of the demographic proportion in urban and rural areas.

Finally, adding new visual marks or highlights is not a taboo, too. When a reduced area lacks contextual information, readers might have difficulty in understanding the visualization or in taking away important insights. For instance, G2 in Day 2 (*Manahattan Reconstruction*) added highlight points (famous buildings in Manhattan) to the scenes (sub-maps) they split, so as to make the geographical location of each sub-maps recognizable (**add highlight points**).

4.4.2 Design Space and Design Pattern Cards in HCI Education

A design space also has educative benefits because it can systematically introduce the design problem to beginners. For instance, Aalst, Carey, and McKerlie (1995) applied design space analysis to the design education. That is, they made students to build their own design space, so that the students could use a developmental model for the concerned design problem. In addition, the results of design space analysis also have educational effects. For example, Bach et al. (2018) analyzed data comics into a design space. Then, they fabricated design pattern cards, inspired by VizIt-Cards (He & Adar, 2017). Finally, they applied the cards to the educational workshop of data comics creation. This implies that a well-defined design space has a potential to enhance or assist learners' acquisition process. In the light of its educational implication, the paper-prototyping workshop in this research needs to be reviewed.

In the paper-prototyping workshop, I stimulated the participants' physical engagement in the design space chart and the design pattern cards, and it was found to be crucial for successful learning. As noted in §4.1.3 (the procedure of the workshop), the education phase of the two sessions were different. Based on Day 1's experience, I revised the education phase in Day 2. In Day 2, the participants were instructed to find the corresponding design pattern card whenever the example of a new design pattern was introduced. The education phase was prolonged by approximately 20 minutes, but the prototyping process was shortened by approximately 50 minutes (see Figure 16). This implies that physical engagement in the chart and cards seems to catalyze their use. Of course, this is an exploratory observation. Therefore, more structured research is demanded in the future to examine the effects of various engagement methods for a design space under HCI education settings.

Chapter 5. Conclusion

To sum up, this thesis casts two research questions: (1) a design space for the transition of news articles with data visualization from large to small screen devices and (2) design implications for the better use of the design space. To answer these questions, we conducted the design space analysis and the paper-prototyping workshop. The design space analysis consisted of content analysis and the open-coding of grounded approach. The resultant design space was comprised of three dimensions: target, action, and strategy. They represent what to change, how to convert, and the impact of transition, respectively. Then, the two sessions of the paper-prototyping workshop were operated with 20 participants. From this workshop, four design implications were derived: narrowing down for quick insights, making shorter for length and visibility, interactively compensating information reduction, and making readers curious of next.

The findings from this research seem to have both theoretical and practical contributions. Theoretically, the framework proposed in this research provides a reusable explanation tool for the large-to-small transition of visual articles. This also works for newly discovered patterns, which was confirmed while formalizing the design patterns suggested by the workshop participants. On top of the framework, this design space will broaden the continued discussion on the design space of data visualization by adding a between-device factor. Practically, this design space can help the process of creating news articles with data visualization. The design space chart and the design pattern cards from this research will function as both an educational toolkit and a field appliance. Finally, the results from the workshop extend the design space by connecting the authors' intention and the usage of the design patterns. This can guide visualization authors about when and how to apply the design patterns rather than merely introducing design techniques to them.

On the other hand, this research also has limitations: the scope of observation, and the direction of the transition. First, the scope of our observation in the design space analysis is limited to data visualization news articles from the *New York Times* and the *Wall Street Journals*. As noted in §3.1.1, the two media outlets were chosen because they have offered their visual articles both on large and small screen devices. Due to this limitation, the current design space seems to be less extendable to other types of visualizations. Nevertheless, there is still a room for generalization, in that the changes regarding text part mostly pertained to short text elements, and that the current design space is described at an elemental level.

Second, some might argue that the problem we address can be solved by adopting a mobile-first design process, rather than scrutinizing the idea of transition from desktop versions. This claim seems cogent to a degree. Notwithstanding, the design space seems applicable to a mobile-first design process as well as desktop-first one. By flipping the direction of the transition (e.g., from reduce to enlarge), the current design space can also be applied to the transition from small to large screen devices.

In addition to these contributions and limitations, this research also suggests an idea that the large-to-small transition needs to be perceived not as a reducing or stuffing process but as a fine-tuning process of authors' intention and its realization. Through the design space analysis and the prototyping workshop, it was rediscovered that the change in a visualization may have a potential influence on how the narrative of the visualization is delivered. Of course, further empirical examination needs to be followed regarding its actual effects on reading. However, the role of storytelling cannot be more stressed when transitioning news articles with data visualization from large to small screen devices.

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Appendix A. The coding scheme for the content analysis

Part 1. Terms

(A) Individual Visualization: a complete visualization that is distinguished from other visualizations and elements because of

- the title attached to it,
- layout components (e.g., borders, background shades) that demarcate area, or
- distance with other elements that is enough to distinguish.

However, a group of **small multiples** is considered as a single visualization. Small multiples come under

- the repetition of the same visual format,
- the organization with rows and columns, and
- the physically close arrangement.

Exclude **tables**, but include them when there are visual graphs in them.

(B) Scene: a snapshot of an individual visualization that is based on some part of the entire data. There are multiple scenes when

- there is a major change (addition/modification/deletion) of visual elements with a transition,
- multiple visualizations are closely arranged or within a single borderline, or
- they are component cuts for video-based visualization.

- However, the addition of highlights (or similar level elements) is not a major change.

(C) Visual formats are visual frames that have been named a conventional term, e.g., line graphs, bar graphs, pie graphs, scatter plot, network plot, or map visualization.
(D) the messages of an individual visualization are

- those within the same layout area of related visualization, or
- article text that is for introducing or analyzing the data in the visualization.

Part 2. Entire Articles

Category A. Ordering

(1) Multiplicity: whether the article contains a single visualization or multiple visualizations

- **Single**: There is only one visualization.
  - When there are multiple scenes based on the same data set.
- **Multiple**: There are multiple visualizations.
  - If it seems like a single visualization, but each part of it has entirely different data set, consider it as *multiple*.

(2) Orderedness: Whether the visualization's order is prescribed when there are multiple visualizations

- **NA**: When there is only one individual visualization
- **Ordered**: when the arrangement of multiple visualizations are straightforward and authored.

- Numbered visualizations.
- Previous/Next buttons or numbered tabs that indicate the prescribed order.
- Related to temporal order or has a time slider.
- Overview and detail relationship.
- Arranged in accordance with the narrative of the article.
- Previous visualization is critical to understand the next one.

• **Unordered**: when the visualizations are just arranged in a parallel way, and random visiting does not violate the author's intention.

  - The number is meaningless.
  - Pan or Zoom interaction for map visualization.
  - The article itself is comprised of individual stories without a main story throughout the article.

(3) Skippability: Whether the prescribed order is skippable when there are multiple visualizations

• **NA**: When there is only one individual visualization.

• **Allowed**: It is allowed to skip the given order between visualizations.

  - Ordered or unordered tabs that enable random visits.
  - Parallex transition.
  - Movies with playback slider.

• **Disallowed**: It is not allowed to skip the given order between visualizations.

  - Previous/Next buttons are the only transition methods.
  - Movie that only allows play and pause.

Category B. Messaging

(1) Dependency: The overall dependency on text or visualization

- **Visual-centered**: The entire article is clearly dependent on visualizations.
  - With visual impacts, without text impacts.
- **Mixed**: The entire article is dependent on both visualizations and text.
  - With both visual and text impacts.
- **Text-centered**: The entire article is clearly dependent on text messages.
  - Without visual impacts, but without text impacts.

There is a **visual impact** when

- There is a visualization large enough to cover the screen,
- There is a highly dynamic visualization with more than 2 interaction features, or
- Visualization parts take more than 80 percent of the entire article.

There is a **text impact** when

- the text article without visual parts comprises a complete story, or
- the content of text message is based on the other data that are not used in the visualizations,
- Text parts take more than 80 percent of the entire article.

(2) Overall Summary: Whether there is an overall summary for multiple visualizations. If a text message belongs only to a particular visualization, it is not viewed as the overall summary.

- **NA**: When there is only one individual visualization.
- **Long**: More than 100 words.
- **Short**: Less than 100 words.
- **None**: No overall summary.

Part 3. Individual Visualizations

Category A. Ordering

(1) Orderedness: Whether the scenes' order is prescribed when there are multiple scenes.

- **NA**: When there is only one scene.
- **Ordered**: When the arrangement of multiple scenes are straightforward and authored.
  - Numbered scenes.
  - Previous/Next buttons or numbered tabs that indicate the prescribed order.
  - Related to temporal order or has a time slider.
  - Overview and detail relationship.
  - Previous scene is critical to understand the next one.
- **Unordered**: When the scenes are just arranged in a parallel way, and random visiting does not violate the author's intention.
  - The number is meaningless.
  - Pan or Zoom interaction for map visualization.

(2) Stoppability: Whether the transition of scenes can be stopped by readers when there are multiple scenes.

- **NA**: When there is only one scene.
- **Controllable**: Scene transition is triggered by user interaction.
- **Allowed**: Scene transition is automatic but can be paused.
- **Disallowed**: Scene transition is automatic and cannot be paused.

(3) Skippability: Whether the prescribed order is skippable when there are multiple scenes.

- **NA**: When there is only one scene.
- **Allowed**: It is allowed to skip the given order between scenes.
  - Ordered or unordered tabs that enable random visits
  - Parallex transition
  - Movies with playback slider
- **Disallowed**: It is not allowed to skip the given order between scenes.
  - Previous/Next buttons are the only transition methods
  - Movie that only allows play and pause

(4) Transition Methods: available transition methods between scenes (multiple choices).

- **Free exploration**: Readers can freely explore the visualization with pan or zoom interaction.
- **Scroll**: Scenes are transitioned with scroll interactions.

- **Playback**: Movies that with playback features (play, pause, stop, resume).
- **Auto**: Scene are transitioned without any user interaction.
- **Ordered tabs**: There are tabs marked with numbers or a particular order.
- **Themed tabs**: There are tabs marked with topics or themes.
- **Previous/Next**: There are next and previous buttons.
- **Toggle**: Two scenes are toggled with each other or a scene is toggled through a check box or a button.
- **Search**: There is a search input that results in scene transition.
- **Slider**: There is a slider to change scenes.

(5) Highlights: Whether there are predefined highlights or highly salient features in the visualization.

- **Exists**: Some part of visualization is annotated or visually marked.
- **None**: Every part of visualization is verbally or visually marked (or unmarked).

Category B. Messaging

(1) Introduction: Whether there is a text message that introduces or guides the visualization.

- **Long**: More than 100 words.
- **Short**: Less than 100 words.
- **None**: No overall summary.

(2) Summary (entire): Whether there is a text message that summarizes the message of the visualization

- **Long**: More than 100 words.
- **Short**: Less than 100 words.
- **None**: No overall summary.

(3) Summary (scenes): Whether there is a text message that summarizes the message of each scene

- **NA**: When there is only one scene.
- **Long**: More than 100 words on average.
- **Short**: Less than 100 words on average.
- **None**: No overall summary at all.

(4) Annotation (length): The length of annotations for visual elements.

- **Long**: More than 100 words on average.
- **Short**: Less than 100 words on average.
- **None**: No annotation at all.

(5) Annotation (distribution): The distribution of annotations for visual elements

- **Overall**: More than 50% of visual elements are annotated.
- **Mixed**: There are two or more types of annotations, one of which is applied to less than 50% of visual elements, and the other of which is applied to more than 50% of visual elements.

- **Selective**: Less than 50% of visual elements are annotated.
- **None**: no annotation at all.

Category C. Interactivity

(1) The number of interaction features. They are counted by their input channels.

- **0**
- **1-2**
- **3-4**
- **5+**

Below coding items are related to individual interaction features. The coding levels are the same for each item. They are,

- **Free**: every available target is subject to interaction.
  - Mouse hovering or clicking available for every visual elements
  - Search input that indexes every data points
  - Sufficiently various options for an interaction
- **Mid**: some available targets are subject to interaction.
- **Mixed**: Free/Mid + Not Free.
- **Not Free**: the interaction happens unintendedly.
  - Scrolling that results in identification, summary, or reconfiguration.
- **None**

(2) Identify: an interaction feature that supports checking the name of the value of a visual element

- Toolitps triggered at every data point **[Free]**
- Names appear when a scene is transitioned **[Not Free]**

(3) Abstract / Elaborate: an interaction feature that supports to aggregate or split data points into higher or lower level

- Whenever focused, a data point is divided into lower level elements, vice versa (e.g. state to county) **[Free]**
- When scrolled, some data points are divided **[Not Free]**

(4) Summarize: an interaction feature that supports to summarize visual information into text summary or a simple table.

- Summary text appears as a result of selection or search **[Free]**
- Summary text appears when a scene is transitioned, but it can be predicted because scene change provide some clues such as the titles of all the scenes **[Mid]**
- Summary text appears without any expectation **[Not Free]**

(5) Search: an interaction feature that supports to specify a particular visual element by its name or value.

- There is a search box or indexed list **[Free]**
- Some key data points are listed **[Mid]**

6) Browse: an interaction feature that supports to explore the visualization in detail without an intention to find a particular visual element.

- Pan, zoom, time slider, drag rotation, or comprehensive categories **[Free]**
- Not comprehensive tabs **[Mid]**
- Scene transition with next or previous buttons, quiz format, or no playback for a movie **[Not Free]**

(7) Filter: an interaction feature that supports to select visual elements that satisfy a particular set of criteria.

- Readers can freely set filter condition **[Free]**
- Filter conditions are prescribed by the author **[Mid]**
- Filter happens when a scene is transitioned **[Not Free]**

(8) Compare: an interaction feature that supports to observe the numerical relationship between several data points.

- Every pair of data points can be selected for the comparison (e.g., a direct dialog for comparison) **[Free]**
- Themed tabs gather data points in a way that is easy to compare **[Mid]**
- Two or more data points are gathered when a scene is changed **[Not Free]**

(9) Connect: an interaction feature that supports to relate two or more data points that are highly relevant to each other.

- Every pair of data points can be connected whenever they are relevant to each other **[Free]**
- Whenever selecting a visual element, related elements are marked **[Free]**
- Themed tabs gather data points in a way that is easy to relate **[Mid]**

- Two or more data points are connected by a line or other visual objects when a scene is changed **[Not Free]**

(10) Reconfigure: an interaction feature that supports to change the given visual representation into another format.

- There are three or more reconfiguration options **[Free]**
- There are two reconfiguration options **[Mid]**
- Reconfiguration happens when a scene is transitioned **[Not Free]**

Category D. General

(1) Simplicity: the degree of simplicity of visual representation. When there were multiple scenes, the average level of simplicity was coded.

- **Simple**: The data for the representation consists of two columns.
- **Mid**: The data for the representation consists of three columns.
- **Complex**: The data for the representation consists of four or more columns.
- However, when the visualization has a highly traditional format, e.g., bar/line graphs, donut/pie graphs, code it one level lower.
- For a matrix visualization, when the edges are weighted, there are three columns.
- When the data set is time series one, the column count is added by 1.

(2) Construction: the format of a visualization.

- **Static**: There is no interaction feature at all.
- **Dynamic**: There are one to four simple interaction features.

- **Movie**: Movie clip or GIF.
- **Interface**: There are more than five interaction features or three to four highly complex ones that are arranged in a particular layout.

Appendix B. Discussions on the taxonomy of visualization tasks and interaction

Tasks	Shneiderman (1996)	Zhou & Feiner (1998)	Amar et al. (2005)	Yi et al. (2007)	Heer & Shneiderman (2012)	Brehmer & Munzner (2013; Intent / Execution)
Approach	Data-type	Function-Argument	Level of task	Interaction	-	Level of task
Identify	-	Emphasize, Reveal, Identify, Distinguish	Retrieve	Select	Select, Annotate	Identify / Select
Abstract / Elaborate	Details-on-demand	-	-	Abstract / Elaborate	Derive	Discover / Annotate
Summarize	Overview	Generalize, Sum	Derived value, Range, Distribution	-	-	Summarize / Aggregate
Search	-	Search, Locate	-	-	-	Lookup, Locate / Select
Browse	Zoom	-	-	Explore	Navigate	Browse, Explore / Navigate
Filter	Extract, Filter	Categorize	Filter	Filter	Filter	- / Filter
Compare	-	Compare, Rank	Extremum, Anomalies	-	-	Compare / (combination)
Reconfigure	-	-	Sort	Reconfigure, Encode	Visualize, Sort, Organize	Discover / Arrange, Change
Misc*	History	-	-	-	Share, Guide, Record	Import, Derive, Record

*Miscellaneous: Features for computing system or sharing behaviors.

국문 초록

큰 화면에서 작은 화면으로의 데이터 시각화 기사 전환을 위한 디자인 스페이스 모색 연구

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[연구 배경] 오늘날 스마트폰과 같은 작은 화면 기기는 주요 뉴스 소비 채널 중 하나로 자리 잡았으며, 이러한 모바일 시장은 데이터 시각화 기사 제공에서도 중요한 영역이 되었다. 그러나 작은 화면 기기와 큰 화면 기기 사이의 물리적, 맥락적 차이로 인해 데이터 시각화 기사를 작은 화면 기기상에 제공하는 데에는 종종 어려움이 따른다. 웹 개발 현장에서는 여러 종류의 기기에 웹 문서를 제공하기 위해, 큰 화면 기기를 위한 버전부터 디자인을 시작하는 경향이 있다. 기본적으로 시각화 기사들이 웹 환경에서 제작된다는 것을 고려할 때, 시각화 저자들이 기사를 큰 화면에서 작은 화면으로 옮기는 것을 돕는 툴킷이 요구된다.

[연구 목적] 디자인 스페이스는 이러한 문제 해결에 다음의 두 가지 이유로 기여할 가능성이 있다. 첫째, 디자인 스페이스를 만든다는 것은 곧 디자인 패턴을 수집한다는 것이다. 디자인 패턴은 과거의 디자인 사례를 유형화한 것으로, 이를 통해 저자들은 효과적으로 과거의 디자인 방법을 자신의 작업물에 적용할 수 있다. 둘째, 충분히 구조화된 디자인 스페이스는 디자인 패턴들을 분류하여 디자인 과정의 프레임워크로 기능할 수 있다. 따라서, 우리는 큰 화면에서 작은 화면 기기로의 데이터 시각화 가시의 전환을 위한 디자인 스페이스를 유용하고 재사용 가능한

형태로 도출하고자 한다. 이를 위해, 우리는 디자인 스페이스 분석을 진행하였다. 한편, 디자인 스페이스의 활용성을 재고하기 위해서는 가이드라인이 필요하다. 이를 제공하기 위해, 두 차례의 페이퍼 프로토타이핑 워크숍을 실시하였다.

[연구 1] 디자인 스페이스 분석을 위해 우리는 뉴욕타임스와 월스트리트 저널에서 공개한 104개의 데이터 시각화 기사를 샘플로 선택하여 내용 분석 및 근거 이론적 접근의 개방형 코딩을 활용하여 분석하였다. 결과로서 디자인 스페이스는 목표물, 동작, 전략이라는 세 가지 차원으로 구성되어 있다. 목표물은 무엇을 바꿀 것인지, 동작은 어떻게 바꿀 것인지, 전략은 그 전환의 효과는 무엇인지와 연결된다.

[연구 2] 디자인 스페이스를 더 유용하게 만들기 위해, 두 차례의 페이퍼 프로토타이핑 워크숍(n=20)을 진행하였다. 워크숍 과제는 주어진 데스크톱 버전의 데이터 시각화 기사를 보고, 작은 화면 버전을 위한 페이퍼 프로토타입을 제작하는 것이었다. 참여자들에게는 프로토타이핑 및 디자인 툴킷이 제공되었다. 워크숍을 통해 사람들이 의도 달성을 위해 어떻게 디자인 스페이스를 활용하는지 확인할 수 있었고, 네 가지의 디자인 시사점들을 도출할 수 있었다. 그 의도들은 빠른 통찰을 위한 좁혀나가기, 길이와 가시성을 위한 줄이기, 정보 소실의 보상을 위한 상호작용, 그리고 다음에 올 내용을 궁금하게 만들기 등이었다.

[함의] 본 연구는 이론적 및 실용적 함의가 있다. 이론적으로 이 연구는 데이터 시각화의 디자인 스페이스에 대한 논의를 확장할 것이다. 이는 기기 요인과 기존의 주요 논의를 연결하는 작업이다. 그리고 실용적으로, 이 연구는 다양한 기기 환경을 위한 디자인 사고방식을 제공한다.

주요어: 데이터 시각화, 작은 화면 기기, 디자인 스페이스

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