Flowstory

The Efficacy of Storytelling Techniques Applied to the Visualisation of Flow and Movement Data

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To all the Flowstories out there.

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and acknowledgements.

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- Johannes

Abstract

Storytelling is an emerging research topic in the field of visualisation. Visual data stories are often said to make visualisations more effective at communicating information in a more memorable, engaging, or persuasive way. However, such expectations the visualisation community has towards storytelling are rarely based on empirical evidence. The growing body of work within different visualisation domains (e.g., cartography, InfoVis, SciVis, business) mainly formalise ideas as models and frameworks. Only little prior research describes the audience's perspective based on empirical evaluations of the effects of narrative visualisations. This research was motivated by the lack of information on how, why, and when storytelling mechanisms may or may not work in visualisation.

A qualitative design space study defines the scope of the research topic: flow and movement visualisation and storytelling. While the research approach may apply to a broader spectrum of visual communication types, flow and movement visualisation was selected because it shares two central characteristics with telling a story: space and time. Descriptive and generative case studies demonstrate the capabilities of the proposed Flowstory design space to develop narrative-visual designs and empirical evaluation approaches. By interweaving visualisation and storytelling, the framework allows others (e.g., data scientists or data journalists) to bring elements from one discipline into the other when making visual-narrative design considerations.

Two empirical between-subjects crowdsourcing studies explore to what extent selected narrative techniques influence visualisation consumers. The first study investigates to what extent varying text-based emplotments of a visualisation affected the ability to memorise and recall gathered information for making predictions. The second study analyses to what extent commonly used storytelling techniques to generate empathy or provide structure influenced people's attitudes towards a topic regarded as contentious or strongly held, like immigration. Contrary to initial expectations, the experiments do not provide much evidence for making strong claims about the benefits of storytelling in visualisation. However, results indicate that storytelling can foster the overall understanding but ap-

pears to not elicit empathy effectively, can force a reader into a line of thought, and hinder creative thinking.

The conducted research contributes new ideas and perspectives to the developing field of storytelling research in visualisation. In conclusion, this thesis provides a valuable descriptive and generative framework that can be used across disciplines but also shows that the research community should not rely on common, but unchallenged assumptions about the benefits of storytelling in visualisation without careful consideration. This conclusions are discussed in the context of methodological implications for future research paths and experiments.

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Chapter 1

Introduction

1.1 Once upon a time . . .

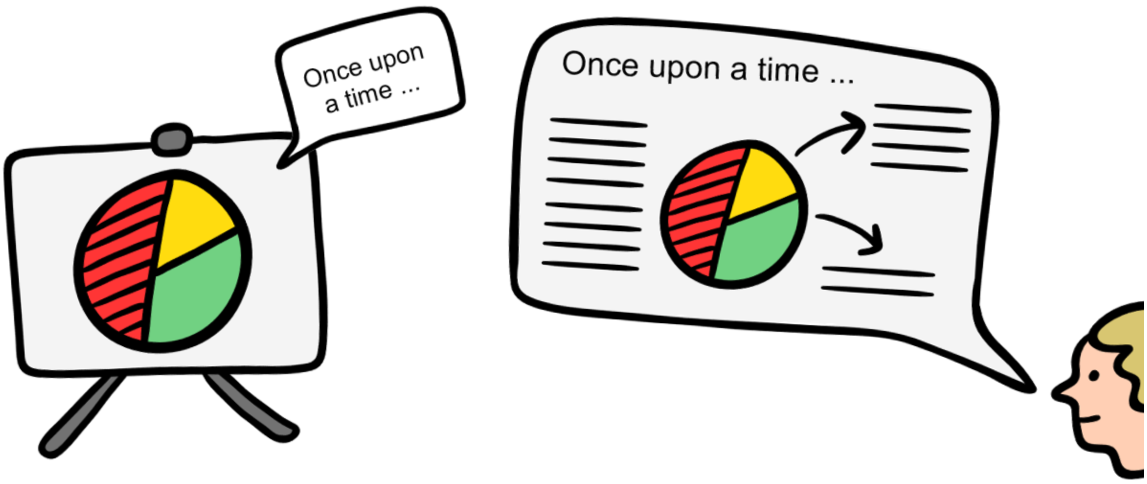


Figure 1.1: Can visualisations tell stories? Can we tell stories with visualisations?

Imagine a pie chart with three sections, as illustrated in the figure above. The title reads *"Why people migrate to the UK?"*. The red section represents people coming for work (50%), the green section are people coming to study in the UK (30%), and the yellow section are people joining someone (20%).

Now imagine a second scenario on the same topic, but you only see an empty circle. Suddenly a name pops up: **Johannes** from Austria was happy to receive a scholarship to come to the UK to study. The name fades out and the circle is now coloured green.

Another name appears: **Roxy** joined Johannes going to the UK, but in the beginning, she was unsure whether she would find a job that would allow her to stay. The name fades out and we see a circle that is half green and half yellow.

Another name pops up: **Cagatay** from Turkey came to work as a Lecturer at City University; a red section appears.

Imagine the visualisation speeding up now, more and more individuals are coming to the UK. The animation ends and we see a pie chart aggregating the entire dataset of 50.000 people, as illustrated in the pie chart above.

There are two views of the presented data. First, the aggregated data showing trends and patterns of tens of thousands of people coming to the UK. Second, the individual, personal experiences of Johannes, Roxy, Cagatay, and others. The research challenge is how to reconcile the two different views by linking data visualisation techniques (abstract graphical representation of data–demonstrated in the first scenario) with storytelling techniques (communicating information in a narrated form–demonstrated in the second scenario). Addressing individuals shows that behind the data are actual human beings. The goal of this approach is to make the abstract data more relatable and to establish an emotional connection between the viewer and the data.

In my research, I used crowdsourcing studies with human participants to test to what extent including arguments, empathy, or narrative structure in data visualisations has an effect on the audience. As with any good story, my research has an unexpected twist . In the conducted studies where we included such techniques in visualisations, we saw different effects than originally expected.

So, can visualisations tell stories or can we tell stories with visualisations? Let's start from the beginning.

1.2 Research Context

Visual data storytelling, or storytelling in visualisation, has become a heavily discussed and applied subject across academic fields and industries (e.g., Denil (2016); Few (2017); Lee et al. (2015); Schwabish (2017); Segel and Heer (2010)). Visual data storytelling now has dedicated conferences (e.g., Tapestry[1]) and conference sessions (at CHI[2], InfoVis[3],

[1] http://www.tapestryconference.com/
[2] https://chi2020.acm.org/
[3] http://ieeevis.org/

OpenVisConf[4]), competitions (e.g., PacificVis Visual Data Storytelling Contest (Brehmer et al., 2017b), Information is Beautiful Awards[5]), specialised departments in newsrooms (e.g., NYT[6], NZZ[7]), and publications targeting the business world (e.g., Duarte (2010); Nussbaumer Knaflic (2015)).

Storytelling techniques are widely used, whether knowingly or not, in visual communication, but such techniques are still underresearched within information visualisation. It is not yet clear how, why, and when mechanisms behind storytelling may or may not work when used in visualisation. Therefore, it is important to further investigate techniques that combine the design spaces of storytelling and visualisation.

In order to limit the scope on the visualisation side, the PhD research concentrated on flow and movement visualisation. One reason why these two areas (storytelling and visualising spatio-temporal data) are suitable to be studied jointly lies in two overlapping properties: space and time.

While research about visualisation techniques and analysis of flows and movements have a long history (e.g., Buonocore (1998); Parks (1987); Robinson (1982); Tufte (1983)) and are still of big interest in different domains (e.g., Andrienko and Andrienko (2013); Brambilla et al. (2012); Jenny et al. (2016c); Rae (2009); van Pelt et al. (2014); Wood et al. (2010); Yang et al. (2017)), research about storytelling in visualisation is an emerging topic.

Effective visualisation and communication of spatio-temporal data is important in a wide range of fields and has a significant impact in interdisciplinary research. Time-varying phenomena are extremely relevant in natural sciences, social sciences, epidemiology, and medical sciences, and are part of complex decision making in market research, law enforcement, and political campaigning. Complex data is, by nature, difficult to simplify and therefore, it is often a challenge to communicate insights about the data. While many different visualisation techniques were developed to minimise or visually reduce complexity, it has not yet been investigated how narrative techniques from traditional narrative forms, like literature or film, might be utilized to effectively support graphical displays of spatio-temporal data.

Examples of complex spatio-temporal data used in the course of this work are migratory flows and the global distribution of pollutants like carbon dioxide (CO_2). When is it beneficial to use narrative techniques to visually communicate patterns, magnitudes, di-

[4]http://www.openvisconf.com/
[5]https://www.informationisbeautifulawards.com/
[6]https://www.nytimes.com
[7] https://www.nzz.ch/visuals/

rections, and individual drivers of such phenomena, which are both the subject of current socio-political (e.g., migration crisis) and ecological (e.g., climate change) discourses?

The PhD research introduces the term *Flowstory* by interweaving the two design spaces of flow and movement visualisation and storytelling. This provides a framework to create and study visual data stories that could lead to insights about the narrative-visual communication process regarding flow and movement visualisations.

By combining these two areas (visualization and storytelling), two main audiences can be identified for this work. One group are people with a computing background (e.g. data scientists or visualization experts), who often have experience in visualization but often lack know-how in storytelling. The other group are people with expertise in telling compelling stories (e.g. data journalists), who often have no technical background but also use visualisation as a means of communication. I see the thesis as a bridge between these two groups. Technically oriented people can learn how to use aspects of storytelling, for example to communicate their scientific arguments in a convincing way. People with expertise in storytelling can learn how to effectively use data visualization to support their message. The work carried out aims to foster collaboration between the groups and to provide a basis for a common language.

1.3 An Underresearched Area

Visual data storytelling, or storytelling in visualisation, is often said to make visualisations more compelling, memorable, understandable, engaging, or persuasive than non-narrative data visualisations (e.g., Figueiras (2014a); Ma et al. (2012); Nussbaumer Knaflic (2015)). While this may be the case, there is little empirical evidence supporting such claims.

Most of the research to date has attempted to formalise aspects of visual data storytelling such as narrative structure, visual elements, and attention cues facilitating storytelling, as well as models of the storytelling process (e.g., Hullman and Diakopoulos (2011); Kosara and Mackinlay (2013); Lee et al. (2015); Ma et al. (2012); Riche et al. (2018); Segel and Heer (2010)). However, from an evaluation perspective, the question of what storytelling in visualisation may contribute is not well researched; only a handful of studies have investigated the question systematically through controlled experiments. Specifically, previous work looked at the effect of using narrative visualisations on memorability (e.g., Borkin et al. (2013, 2016); Hullman et al. (2013)), persuasive visualisation (e.g., Muehlenhaus (2013);

Pandey et al. (2015)), data anthropomorphising (e.g., Boy et al. (2017)), and the relationship between storytelling and level of user-activity (e.g., Boy et al. (2015); Diakopoulos (2010)) or engagement (e.g., McKenna et al. (2017)).

The limited number of empirical evaluations within the research field was one of the major drivers for the presented PhD work and the methodological approaches taken. Storytelling is believed to be beneficial for better memorability and understanding and to be able to influence opinions. These underlying beliefs are largely unchallenged, meriting further investigation and shaping the research aims and objectives of this work. The conducted experimental evaluations investigate to what extent selected narrative techniques have the ability to influence (a) memorability and understanding, and (b) attitudes towards a topic.

1.4 Aims and Objectives

Thesis Statement: The overall aim of this work is to gain greater insight into how storytelling techniques can be included in flow visualisations to create Flowstories. By interweaving these two areas, a framework will be created that allows others to bring elements from one discipline to the other when making visual-narrative design considerations. Furthermore, the research sets out to empirically investigate the extent to which selected storytelling techniques used in information visualisations can influence people.

The following objectives were developed to achieve the overall aim to jointly investigate the visualisation and the storytelling perspective in the context of flow and movement data:

- **O1:** Define and review the design space of (a) flow and movement visualisations and (b) storytelling techniques in respect of the ability to be studied jointly.
- **O2:** Interweave the design spaces of (a) and (b) by building a taxonomy of Flowstories, which reflects to what extent including storytelling techniques in flow and movement visualisations is applicable. Respectively, how elements of such visualisations can foster storytelling.
- **O3:** Investigate to what extent the degree of *narrativity* expressed through *emplotment* influences a visualisation consumer's ability to comprehend, memorise, recall, and apply gathered knowledge.

- **O4:** Investigate to what extent commonly used storytelling techniques that generate empathy or provide structure influence people's attitudes towards a topic regarded as contentious or strongly held, like immigration.
- **O5:** Based on the findings of the above objectives, one goal was to derive a set of guidelines for the creation of Flowstories. However, the results limited the extent to which this could be accomplished in this research, thereby shifting the focus to methodological reflections and recommendations for future evaluation approaches.

More specific expectations of the investigations conducted are formulated in the chapters of the individual research projects.

1.5 Research Projects

Three major research projects were carried out to achieve the objectives above.

The **Flowstory Design Space Study** in Chapter 3, a **qualitative thematic analysis** of more than one hundred examples of visualisations of flow and movement data, addresses **O1** and **O2**. The study interweaves the design spaces of flow and movement visualisation and storytelling using metrics and classifications based on existing work and theory. Several case studies describe various aspects of the design space. The chapter contains a discussion on how the design space can be used in both an analytical and generative way.

The first empirical research project, a **mixed-methods, between-subjects experiment** consisting of two parts (primary and follow-up), addresses **O3**. It investigates to what extent different text-based emplotments of a visualisation affect participants' ability to memorise, understand, and recall gathered information for making predictions. Emplotment is the arrangement of events into a sequence with a certain plot structure (Herman et al., 2010). The **Emplotment Study** compares two emplotments of animated particles with varying degree of narrativity. The first emplotment is a plot with a classical story arc, and the second emplotment is a more technical description of the animation. Based on the narrative form utilising emplotment, it is expected that participants exposed to the first emplotment can better process and understand, memorise, and recall the conveyed information. An animated particle system simulates realistic movements that are easy to understand and can also convey some meaning supporting the message (e.g., accumulating particles portraying a collaborative crowd). Using the crowdworking platform Amazon Mechanical Turk (MTurk or AMT), 300 participants (150 in each group) were recruited and financially compensated.

To answer **O4**, a **between-subject** experiment was conducted. The **quantitative evaluation** in the **Attitudes Study** uses measures from social sciences to assess **attitudes** towards immigration. The survey compares the influence of (a) personal visual narratives designed to generate **empathy**, (b) **structured** visual narratives of aggregates of people, and (c) a fully exploratory visualisation without narrative acting as a control. Thematic, temporal, and spatial structure, as well as empathy, are important areas of visual data storytelling. While structure is generally well investigated, few studies analyse empathy in this context. The expectation is that participants of the storytelling conditions will be more positive towards immigration than participants of the exploratory condition. This expectation is based on two assumptions: (1) designing around empathy helps participants better relate to the personal narratives, and (2) a view dependent on structured narrated information, rather than assumptions about immigration made during data exploration, might lead to more positive views, and that a structured navigation might lead one to understand the information more clearly. The UK-based platform Prolific was used to recruit and pay 600 participants in total. The study consists of two iterations, one with a pre-post and one with a post-only attitude assessment, with three conditions each.

Along with the research projects and their extensive discussion, which addresses **O5**, a review of **related work** provides **background information** and places the research in a larger context.

1.6 Contributions

Before continuing to the background section, the **contributions** of the doctoral research are presented more explicitly. The following applies the recently proposed contribution types by Lee et al. (2019):

Systematic Review: The background section provides a structured review of the available literature of storytelling in visualisation and the visualisation of flow and movement data focusing on geographic visualisation.

Survey: As part of the related work a survey provides a summary of the state of the art of empirical evaluation research of storytelling in visualisation.

Taxonomy and Conceptual Model: The introduced Flowstory design space systematically characterises and interweaves the two research domains. It demonstrates how the design space serves as a mental framework helping to assess and design flow and movement visualisations in a narrative context and derive empirical evaluations.

Evaluation Methodology: Transferring methods from neighbouring sciences by applying well-established scales from social sciences used in the European Social Survey (ESS) since 2002 to measure attitudes and beliefs. While the category described by Lee et al. (2019) as *evaluation methodology* is the most appropriate one, it is rather a *epistemological contribution* in the sense that the understanding of the social sciences of attitudes (what they are and how they are formed) was applied to explain the effect of visualisation.

Presentation: This doctoral research contributes new building blocks, ideas, and insights to the growing knowledge of storytelling in visualisation, which can be used to design further experiments investigating the use of narrative techniques in data stories. The findings help better anticipate the effects of narrative techniques used in visualisation and provide evidence that the research community should not trust common, but unchallenged assumptions about the benefits of storytelling in visualisation without careful consideration.

Lessons from Counter Expectations: Unexpected results, such as those from the conducted studies, that neither confirm our hypotheses nor support common assumptions, are important contributions to the research field as they prevent scientists from relying on plausible, but unchallenged assumptions. Identified methodological implications can guide future research and experiments in the area of storytelling and visualisation.

Chapter 2

Background and Related Work

Having established the motivation and goals of the thesis in Chapter 1, this chapter will discuss the perspective and terminology used regarding *storytelling in the context of visualisation*. The following sections will present relevant contributions from the two main themes of the thesis: *storytelling and narrative in visualisation* and *visualisation of flow and movement data*.

2.1 Towards a Definition of Storytelling in Visualisation

After a brief overview of the current discourse and the various perspectives of storytelling in visualisation, the discussion will turn to concepts of narrative theory, on which the understanding used here is based.

2.1.1 Status Quo

The questions raised in the introduction example, *"Can visualisations tell stories, or can we tell stories with visualisations?"* is not the central question of the PhD, but provokes one to think about the usage of the terms *story* or *storytelling* in connection with visualisation.

Assuming that a goal of visualisation as representation is to visually communicate a topic or a phenomenon in an effective and persuasive manner, there is no prerequisite to *tell a story with the depicted data*. Often this phrase is used when what is really being asked for is communicating an argument effectively through visual means to convince employees, the boss, or stakeholders of *your story*.

Consequently, several experts across data visualisation fields saw the need to clarify the meaning of *story* or *storytelling* (Denil, 2016; Few, 2017; Schwabish, 2017), especially when expressing that *data visualisations tell stories themselves* or the compulsive urge to *narrativise* data visualisations were criticised. In this context, the term narrativisation can be understood as the act of presenting a data visualisation in a narrative form (Herman et al., 2010).

While they all do support the idea of storytelling with visualisation, they demand a more thorough use of the term *story* in connection with data. Stories require a "beginning, a middle and an end" (Few, 2017) and follow the three or five act story arc, including fundamentals like exposition (setting and conflict), rising action, climax, falling action, and resolution (Yorke, 2013). Schwabish (2017) identifies emotion and a meaningful climax as the two essential characteristics of a story. Denil (2016) describes the act of storytelling as something that goes beyond a visualisation's (i.e., map's) ability, which is at most fostering, influencing, or reinforcing a story. Summarised simply by Few (2017), *"Data does not tell stories, people do"*.

Beyond this more traditional perspective, what is the common understanding of *story* and *storytelling* in a data and data visualisation context?

As described by Ma et al. (2012), storytelling using visualisation is a viable approach for communicating complex scientific findings, which may increase comprehensibility, credibility, and involvement, especially when some form of interaction is provided. According to Ma et al., stories are sequences of causally related events that unfold over time creating attention and leave lasting impressions. Following the idea that comparison is one purpose of data visualisation, "information visualisation stories" are stories about comparison or change.

Cruz and Machado (2011) understand *story* as a presentation layer of *data fabulas*, which are a combination of events, agents, actions, and chronology identified in a data set. The process of storytelling is the transformation of such *fabulas* to visual stories using a certain narrative medium (i.e., computer graphics). Cruz and Machado follow Bal and van Boheemen (2009)'s definition of *fabula* being *"a series of logically and chronologically related events that are caused or experienced by actors"*.

Kosara (2014) argues that a *story* consists of facts, casual relations, and a narrative sequence. Consequently, it ties facts together and guides the viewer through their interpretations provided.

Lee et al. (2015) characterise a *visual data story* as *"specific facts backed up by data"* presented in a meaningful order with a high-level of continuity to support the goal of the visualisation (e.g., to educate, entertain, convince, or persuade an audience).

In a recently published book (Riche et al., 2018) that emerged from a Dagstuhl seminar during which 40 international scholars and practitioners explored the vast possibilities of *data-driven storytelling* from many different perspectives, the following terminology is defined: when *narratives* are a sequence of events in a specified order, *stories* are a representation of a set of events of a narrative that may be arranged in a different order, length, or with additional context, supporting memory and recall.

The scholars and practitioners consequently define data-driven stories (DDSs) as *"[. . .] stories that are data-driven in that they start from a narrative that either is based on or contains data and incorporates this data evidence, often portrayed by data graphics, data visualisations, or data dynamics, to confirm or augment a given story. A DDS often incorporates the visual data representations directly into the presentation of the story. A DDS can enhance a narrative with capabilities to walk through visual insights, to clarify and inform, and to provide context to visually salient differences."*

There are many names (narrative visualisations, data-driven stories/storytelling, visual data stories/storytelling, storytelling in visualisation), but at their core share similar ideas revolving mainly around structure, sequence and temporality, reader involvement, emotions, or comprehension and memory. Because of the common, shared concepts, these terms are used interchangeably throughout this work.

All these definitions are implicitly (or more explicitly like Cruz and Machado (2011)) referencing concepts from narrative theory. Using a more modern understanding of *narrative* and *story* allows one to study not just exclusive verbal media, but also visual media such as data visualisations.

2.1.2 Consulting the Experts: What can Narrative Theory provide?

As discussed in the previous section, there are multiple definitions and sometimes different or imprecise uses of the terms *narrative* and *story*. This pluralism is unsurprising since many models and perspectives in narrative theory also exist in parallel. While consistency in terminology is relevant, it is important that the visualisation community accepts the diversity of definitions and approaches. Keeping an open mindset towards different definitions and perspectives can advance and accelerate scientific discourse.

One way to determine whether a visualisation is a story or not is to ask to what extent a visualisation can create stories in a viewer's mind. Cognitive narrative theory provides this slightly different perspective.

2.1.2.1 Story as a cognitive construct

A **common, classical narratological perspective** understands **narrative** as a combination of **story** and **discourse** (Chatman, 1978; Herman et al., 2010), where the story level refers to *what* is told in a narrative and discourse to *how* it is communicated. Story consists of a sequence of events (actions and happenings) and existents (characters and setting). Discourse is concerned with the narrative techniques used to manipulate the events and existents on a representational level (Herman et al., 2010). The definitions used within the visualisation community more or less refer to this concept of narrative.

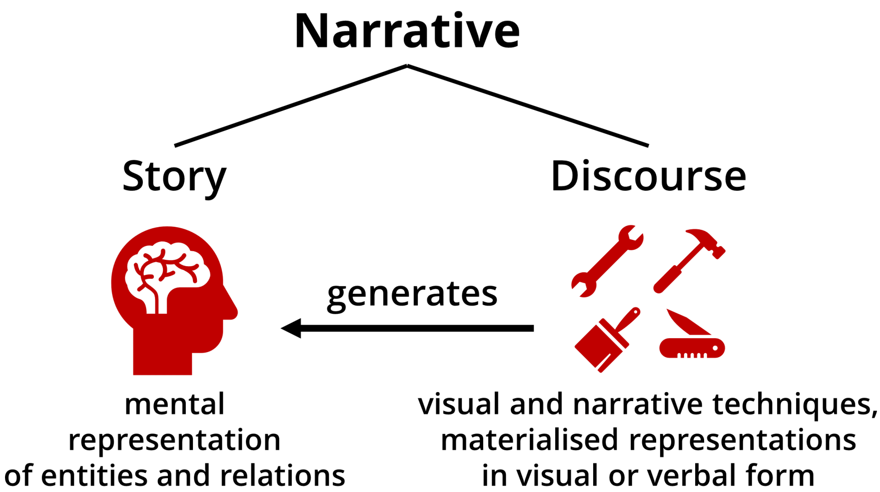


Figure 2.1: Narrative as a combination of story and discourse. Derived from Ryan (2004) and Herman et al. (2010).

In **modern, cognitive narrative theory**, *narrative* is described as a combination of *story* and *discourse*. A *story* is a narrative's mental representation, a cognitive construct in a reader's mind concerned with certain types of entities and relations between them. The *discourse* deals with the ability of materialised representations (e.g., a text or a visualisation) to constitute or evoke story in a viewer's mind (Herman et al., 2010; Ryan, 2004).

Ryan (2004), identifying the major difference between those definitions, states that *"narrative meaning"* does not reside within a text, but is a *"mental image built by the interpreter* *in response to the text"*. It is the ability of discourse to evoke stories in the mind that distinguishes this concept of narrative from others (Herman et al., 2010).

2.1.2.2 "Being a Narrative" vs. "Possessing Narrativity"

In the more classical definition of narrative, the term *narrativity "designates the quality of being narrative, the set of properties characterising narratives and distinguishing them from non-narratives"* (Herman et al., 2010). In this perspective, *narrativity* is often expressed through the act of *"telling somebody that something happened"* (Ryan, 2004).

Based on the proposed partition of narrative into narrative as (1) mental representation (story) and (2) as a materialised representation (discourse), Ryan (2004) introduces the distinction between **being a narrative** and **possessing narrativity**.

Ryan (in Herman et al. (2010)): *"The property of 'being' a narrative can be predicated of any semiotic object, whatever the medium, produced with the intent to create a response involving the construction of a story. More precisely, it is the receiver's recognition of this intent that leads to the judgement that a given semiotic object is a narrative, even though we can never be sure if sender and receiver have the same story in mind. 'Possessing narrativity', on the other hand, means being able to inspire a narrative response, whether or not the text [. . .] was intended to be processed that way, and whether or not an author designs the stimuli."*

Ryan (2004) argues that this distinction allows one to extend the concept of narrative beyond written or spoken text to other forms of media such as images, videos, and digital media including maps and data visualisations. Ryan concludes that such nonverbal forms *"can have narrativity without being narratives in the literal sense"*, and further clarifies that *"it seems clear that of all semiotic codes language is most suited to storytelling"*. Ryan notes that *"this does not mean that media based on sensory channels cannot make unique contributions to the formation of narrative meaning"*.

Transferring this idea to visual data storytelling, it is not important to investigate if a visualisation *tells a story*, but to what extent a visualisation *has narrativity*. Particularly, research in this area should investigate which elements of a visualisation can contribute to evoking a story in a reader's mind.[1]

[1] The terms *reader*, *viewer*, *user*, and *consumer* are used interchangeably throughout the work. It is the person who perceives a narrative and interacts with it.

Using this perspective, one might argue that any visualisation possesses narrativity, even though one may not perceive the visualisation as narrative or the visualisation is not presented in a narrated form. For example, a title may evoke narrative meaning in a visualisation viewer's mind, resulting in only a low narrativity. On the other hand, a more comprehensive news piece, with a mixture of verbal text, audio-narration, and data visualisation, has a high narrativity and therefore, a higher potential to generate a story (a mental image).

Accordingly, *narrativity* reflects the ability of the used visual-narrative techniques, which are expressed through signs (i.e., visualisation elements including verbal and nonverbal elements), to contribute to construct stories in a users' mind.

This concept of narrative (story and discourse) relies heavily on a visualisation consumer's ability to also infer implicitly stated causal relations from the text or visualisation (Ryan, 2004), which often makes it more complicated when studying visualisation and storytelling. This work does share the concerns from visualisation experts about the sometimes inappropriate usage of the term *story* and it is understood here that narrativising data visualisations has a limited field of application. However, adopting the idea of narrativity helps to move beyond the discussion of whether a visualisation is a story or not and allows this work to focus on the various opportunities the field of visual data storytelling has to offer. In the following sections, different research approaches, visual-narrative techniques and elements, and evaluating the effect of storytelling in visualisation on people are introduced and discussed.

2.2 Storytelling and Narrative in Visualisation

Having outlined an understanding of storytelling and narrative in visualisation grounded in narrative theory, this section will look at related work from visualisation research conducted in the previous two decades. The literature will be discussed from three different angles: the *research approaches* taken, the *narrative and visual elements and techniques* investigated, and the *effects on people* evaluated.

2.2.1 Research Approaches

With the growing interest in storytelling in the past two decades, different research approaches have emerged. Five major types of research contributions stand out: **(1)** positional statements and surveys trying to present fairly holistic perspectives of the subject, **(2)** high-level models and conceptual frameworks of the storytelling process or parts of it, **(3)** design spaces and taxonomies characterising various aspects of narrative visualisations, **(4)** empirical evaluations investigating the effect of storytelling techniques on people, and **(5)** authoring tools and recommendation for practice. These five areas are described in more detail in the following sections. An additional way to look at these contribution types in visual data storytelling is proposed in Section 2.2.1.6.

2.2.1.1 Positional Statements and Surveys

Storytelling in visualisation was first picked up at the beginning of the millennium by Gershon and Page (2001) and got a more heavily discussed topic over the last few years. Several positional and theoretical contributions are discussing the current state and future directions of storytelling in information visualisation (Kosara and Mackinlay, 2013; Lee et al., 2015) or scientific visualisation (Ma et al., 2012). To date, the most comprehensive publication on the topic is the book *Data-Driven Storytelling* edited by Riche et al. (2018). These contributions discuss aspects of authoring, presentation, perception, evaluation, and ethics of visual data stories, as well as illustrate just how broad the field is. Within this work, the focus is on presentation and evaluation, rather than the authoring process itself.

Kosara and Mackinlay (2013) identified storytelling as the next logical step in visualisation research. Kosara (2017b) pondered a few years later whether the hype around storytelling was over, or the initial wave of interest had passed and more complex research lay ahead. He believes the latter, much as this research tries to demonstrate.

Tong et al. (2018) recently presented a dedicated survey of storytelling literature in visualisation. They categorise literature by aspects of authoring, user engagement, narrative, transitions, memorability, and interpretation by both the path a reader traverses through the visual data story (linear, user-directed/interactive, parallel) and the research domain (scientific, information, and geospatial visualisation). Tong et al.'s approach illustrates how difficult it is to capture the many possibilities of storytelling in visualisation within a single survey in a comprehensible manner.

Such position statements and surveys are important to show what has been done and to determine the future direction in which the research in visual data storytelling may advance. As discussed next, other approaches formalise facets of visual data storytelling by developing models, frameworks, design spaces, and taxonomies.

2.2.1.2 Models and Conceptual Frameworks of the Storytelling Process

Models about different parts of the storytelling process provide high-level approaches to create and communicate visual data narratives (Chen et al., 2019; Cruz and Machado, 2011; Ho et al., 2013; Lee et al., 2015; Ma et al., 2012; Riche et al., 2018; Satyanarayan and Heer, 2014). The first step of process models may cover data handling such as data exploration, manipulation, and extraction. Models may also include steps about the structuring of gathered data to a narrative plot by providing background about the data and identifying events, characters/agents, and actions/relationships between them in space and time. This includes providing dramatic tension and establishing narrative by comparing data points, depicting interactions between them, changing the pace and rhythm, or showing development over time. Transferring the plot into a visual narrative can also be a part of the models and may involve the consideration of certain mediums and visual representations, interactions and control widgets, animations, graphical and textual annotations, and text or audio narration. The final step of process models may cover the delivery of the narrative to an audience trying to entertain, educate, or leave a lasting impression.

While storytelling is considered as a presentation mode within these models, more recent research does not limit narrative to a means of communication, but facilitates narrative as a reflective method within the visualisation design process (Wood et al., 2019). The literate visualisation paradigm shows how versatile narrative concepts can be used in the field of visualisation.

2.2.1.3 Design Spaces and Taxonomies

The majority of previous research is based on design space studies or definitions of frameworks and taxonomies. Many of the aspects covered by these contributions are discussed in the next section (2.2.2) that looks at narrative and visual elements and techniques.

Previous analysis mainly discuss how visual operations (e.g., zooming, panning, highlighting, linking) and visual elements (e.g., navigation buttons, tooltips, progress bars) provide structure or aid communication within narrative visualisations (e.g., Gershon and Page (2001); Ghidini et al. (2017); McKenna et al. (2017); Segel and Heer (2010); Stolper et al. (2016)). Other experts describe how narrative elements and concepts like voice-over narration (Gershon and Page, 2001), different plot types (Phillips, 2012), patterns for argument structures (Kosara, 2017a), or sequencing patterns (Hullman et al., 2013) can influence the reading experience.

A few contributions characterise visual-narrative aspects of delivery genres or visualisation techniques like video based data clips (Amini et al., 2017, 2015), data comics (Bach et al., 2017), annotations (Ren et al., 2017), timelines (Brehmer et al., 2017a), or game-like approaches (Diakopoulos, 2010; Diakopoulos et al., 2011).

Furthermore, techniques and devices to persuade an audience or influence a visualisation interpretation were also investigated in the form of frameworks and taxonomies (e.g., Hullman and Diakopoulos (2011); Muehlenhaus (2013); Roth (2016)). Narrative patterns as defined by Riche et al. (2018) are low-level devices following a certain intent for creating or analysing data-driven stories. The example at the beginning, using the "humans-behind-the-dots" pattern, has the intent to evoke empathy and make the data more relatable to the audience.

Bach et al. (2018) introduced design patterns for data comics relating panel layout options with thematic connections between panels, which can influence how a data comic is perceived and interpreted.

Design spaces and taxonomies are well suited to identify, isolate, and study selected aspects of the vast spectrum that visual data storytelling has to offer. In Chapter 3, a design space approach will demonstrate how aspects of flow and movement visualisation and narrative can be explored together.

2.2.1.4 Empirical Evaluations

Few studies have taken on the challenge of measuring the effects visual data storytelling can have on people. The details of these studies are discussed in Section 2.2.3. A brief methodological overview is presented here.

Experimental approaches often compare different conditions (e.g., multiple narrative visualisations with each other and to non-narrative, standard data visualisations) using between-subject or within-subject designs and are of quantitative, qualitative, or mixed method nature.

Many possible effects can be measured. Quantitative studies comparing multiple visualisation conditions typically have a narrow focus and attempt to determine the existence and magnitude of a single effect. The majority of quantitative evaluation studies are *controlled* online studies using crowdsourcing platforms like Amazon Mechanical Turk (e.g., Amini et al. (2018); Boy et al. (2017); Diakopoulos et al. (2011); Dimara et al. (2017); Hullman et al. (2013, 2017); McKenna et al. (2017)). Online studies conducted *"in the wild"* (e.g., as part of an online journalism piece) have high ecological validity, but suffer from control issues (e.g., Boy et al. (2015); Diakopoulos (2010)). Approaches often adapt questionnaires form neighbouring sciences and therefore, use a well defined understanding of the phenomenon. Several studies, for example, adopted scales to measure user engagement (Amini et al., 2018; McKenna et al., 2017).

Qualitative studies, including focus groups (Figueiras, 2014a), observations and structured interviews (McKenna et al., 2017), more advanced interview techniques (Nowak et al., 2018), or story reconstruction tasks (Badawood and Wood, 2014) are conducted in controlled lab settings but are less common than quantitative evaluations.

While different experimental designs have been used, many surveys note that identified effects are negligible, small, or contrary to formulated expectations. Therefore, it is essential to conduct further studies to find out more about the efficacy of storytelling in visualisation. In Chapters 4 and 5 two between-subject studies, which were carried out in the course of this work, are presented.

2.2.1.5 Authoring Tools and Recommendation for Practice

Several tools to help author visual data stories or narrative visualisations have been developed in previous research, often as prototypes to demonstrate frameworks or design spaces. Examples of these tools include creating data videos (Amini et al., 2017), data-driven infographics with a technique called data-driven guides (Kim et al., 2017), stories with free form sketching (Lee et al., 2013), automated annotations for narrative visualisations (Bryan et al., 2017), stories within geovisual analytics workflows (Eccles et al., 2008; Ho et al., 2013), and visual timeline stories (Brehmer et al., 2017a; Wang et al., 2016).

Brehmer et al. (2017a)'s Timeline Storyteller[2] was integrated into Microsoft's Power BI. Other commercial software packages like Tableau[3] also offer storytelling capabilities with the so-called *Story Points*, which implement the *interactive slide show* model from Segel and Heer (2010). ESRI's Story Maps[4] enable anybody to enrich online maps with narrative text, images, or videos.

[2]https://timelinestoryteller.com/
[3]http://www.tableau.com
[4]https://storymaps.arcgis.com/

Additional publications advocate visual storytelling in a business context (e.g., Duarte (2010); Nussbaumer Knaflic (2015); Ryan (2018)). Aspects of the practical organisation of the authoring process and possible evaluation methods for authoring tools are described across chapters in Riche et al. (2018).

In the process of compiling material for the empirical experiments (Chapters 4 and 5), visual-narrative stimuli were created following existing examples and techniques. While recommendations for practice are an important research output, detailed aspects of the authoring process and its evaluation extend beyond the scope of this work.

2.2.1.6 Inside-Out vs. Outside-In Approaches

As another way to organise the five major types of research contributions discussed, a distinction between two complementary concepts in visual data storytelling research is proposed here: inside-out and outside-in approaches. **Inside-out** approaches focus on the usage and evaluation of common visualisation elements and techniques (e.g., panning, zooming, superimposition, widgets for interactions) and their practicability for visual data storytelling (e.g., Brehmer et al. (2017a); Gershon and Page (2001); Stolper et al. (2016)). For example, an inside-out approach might evaluate whether a stepper or scroll setup using staggered animations is more engaging to progress and navigate the narration (McKenna et al., 2017). **Outside-in** approaches adopt and evaluate the applicability of theories and techniques from classical narrative disciplines, such as literature or film, for visual data storytelling (e.g., Bach et al. (2017); Figueiras (2014b); Hullman and Diakopoulos (2011)). For example, previous work has applied Cohn (2013)'s theory of visual narrative structure categories (establisher, initial, peak, and release) to creating data videos (Amini et al., 2015) and deriving argument structure for data stories (Kosara, 2017a).

The idea that narratologists ask "How maps can advance storytelling?" and cartographers ask "how narrative can enhance maps?" (Ryan et al., 2016) nicely reflects this proposed distinction. Furthermore, this terminological distinction helps to communicate across disciplinary borders bringing them closer together.

Within the thesis, both approaches are used. In Chapter 3, a design space study is presented that uses an inside-out approach. How elements of flow and movement visualisations aid narrative is explored. In the evaluation contributions in Chapters 4 and 5, an outside-in approach is used to assess concepts and ideas derived from outside visualisation.

Outside-in approaches can reveal more about the mechanisms of storytelling as a whole making it possible to expand the space of visual data storytelling. Inside-out approaches are better suited for evaluating the effects of a specific visualisation element on storytelling. In the next section, the visual and narrative techniques and elements that were investigated in the reviewed literature are discussed.

2.2.2 Narrative and Visual Elements and Techniques Investigated

There are several research approaches used in storytelling and narrative in visualisation that define, utilise, and evaluate *elements*, *techniques*, *devices* and *patterns*. These terms are often used interchangeably or overlap in their meaning in the context of visualisation. Because the boundaries between the definitions are often blurred, the terms *elements* and *techniques* are used for simplicity. Exceptions are made for already established terms such as NAPA cards[5] (i.e., *na*rrative *pa*tterns).

Visualisation and narrative elements and techniques are part of the **discourse level** when defining narrative. They are the "material signs" an author uses to aid the process of creating a mental representation (story) of a narrative within a viewer's mind. *Elements* may refer to easily perceptible parts of a narrative visualisation (e.g., interactive widgets to navigate a narrative). *Techniques* often describe concepts that are not apparent on first sight (e.g., techniques to reveal the individual behind a data point).

2.2.2.1 Editorial Layers as a Structural Aid

To summarise the elements and techniques described within the various research approaches, the concept of *editorial layers*, introduced by Hullman and Diakopoulos (2011), was adopted in a modified form. Editorial layers capture design decisions regarding visualisation and narrative techniques used in the creation of narrative visualisations, which can manifest at different levels. Hullman and Diakopoulos distinguish between multiple layers where editorial judgement can be made concerning data, visual representation, textual annotations, and interactivity. Decisions made on a data level are made during the data wrangling and exploration phase (e.g., data filtering or scaling). This layer is not adopted one-to-one, but instead integrated into the other three layers since appropriate techniques are expressed within those layers (e.g., cluster symbolisation of aggregated data in the visualisation layer, or meta-data in the context layer). Therefore, the

[5] http://napa-cards.net/

three primary layers used here are: (1) the **visual representation layer**, (2) the **contextual representation layer**, and (3) the **interactivity layer**.

The **visual representation layer** includes elements and techniques that are visible on a representational level concerning the visualisation aspects of a data-driven narrative, which includes layout, transitioning between visually distinct states, visual style, visual data encoding, and methods for making the narrative visualisation more tangible.

The **contextual representation layer** is based on Hullman and Diakopoulos's annotation layer, which includes *"textual, graphical, or social"* annotations that are often used to focus attention. Extending to a context layer allows any additional context that goes beyond the visual representation layer to be included. Other than attention guidance, this includes many different verbal narration elements (e.g., title, captions, labels) and linguistic techniques to manipulate them. It further includes elements and techniques involving a reader's experience and perspective, information on how to use or read the narrative visualisation, or any other additional data (e.g. meta-data, additional articles).

The **interactivity layer** includes interactive elements and techniques requiring active user participation. Such techniques allow a certain level of control over the visual narrative, its content, unfolding, or progression (Figueiras, 2014a; Hullman and Diakopoulos, 2011; McKenna et al., 2017), enable readers to explore data, or challenge them through interactive input prompts.

Many techniques can be applied **across the three layers**, including thematic and temporal ordering of states and events, repetition and redundancy, or addressing the reader as an individual.

These three layers are used in the Flowstory design space study in Chapter 3 to structure the analysis of flow and movement visualisations in the context of data-driven storytelling.

2.2.2.2 Categories of Visual-Narrative Elements and Techniques

In their analysis, Hullman and Diakopoulos (2011) investigated the framing effect of visualisation rhetoric techniques, i.e., how an author's design choices and a reader's cultural, individual, and perceptual constraints may influence the interpretation of a data narrative. Framing is just one aspect used in this literature review. In this section, the discussed visualisation and narrative elements and techniques are categorised by their ability to provide **structure and temporality**, influence **messaging and argumentation**, provide **framing and perspective**, evoke **emotions**, or encourage **user involvement**. All five categories are important components in storytelling and narrative theory and are explained in more detail in the following paragraphs.

Structure and Temporality: Visualisation and narrative techniques that order information thematically, temporally, or spatially can provide structure for data narratives influencing the reading path (i.e., the reading order through a narrative). Narrative visualisations consist of a sequence of states (Hullman et al., 2013; Satyanarayan and Heer, 2014), story nodes (Ma et al., 2012; Wohlfart and Hauser, 2007), or story pieces (Lee et al., 2015), connected through a series of transitions. This can be described as the *plot* of a story, which is one aspect of narrative structure. Techniques belonging to this category often operate across the three editorial layers. For example, narrative structure can be provided through a plot following a classical dramatic arc (temporal and thematic ordering on the contextual layer), expressed through a meaningful layout (spatial ordering on the visual layer), and using a navigational aid (e.g., scrolling) to progress the narration (interactivity layer).

Messaging and Argumentation: Many elements and techniques contain and convey the central message of a visual data narrative. The argument, communicated through explanations, observations, and commentary (Segel and Heer, 2010), can be in a factual or narrated form (Bach et al., 2017). The message, or its interpretation, is influenced by the author's experience and identity, similar to the impact a reader's culture, individual experiences, and perception have (Hullman and Diakopoulos, 2011; Roth, 2016). While verbal techniques may be best suited to convey a message, nonverbal elements are also able to convey a message. On a contextual level, the central argument may be directly communicated through the title or a more complex audio narration. On a visual level, small design decisions (e.g., visual style or omission of data) can support the message. Depending on a narrative's intent, these techniques can contribute to informing, educating, or even persuading the audience, which coincides with the concept of framing.

Framing and Perspective: Framing techniques influence how a message is perceived and interpreted; they can reinforce or dampen an argument. They can be used to "set the stage" and the overall tone of a visual narrative display. Framing techniques also consider a reader's perspective by using a different point of view (e.g., a first-person or third-person narration (Herman et al., 2010)), which can integrate readers to different degrees (e.g., integrate them actively or keep them at a distance). In the context of multimedia narratives, Ryan (2004) describes this as internal and external user involvement. Framing techniques also often influence emotional reactions or user involvement.

Emotions: Visual-narrative techniques can evoke or reinforce emotional reactions (e.g., empathetic, cheerful, surprised, unpleasant, uncertain, or angry emotional states). Herman et al. (2010) summarise that *"understanding narrative, just like understanding in general, is never purely cognitive. It is one of the major attractions of narratives [...] that they elicit emotional responses in their audiences."* Emotion-evoking techniques can support narrative understanding and help engage and immerse the audience (Riche et al., 2018). The effectiveness of visual and narrative techniques depends heavily on the individual reader. Based on personal relationships with a topic (e.g., people immigrating to the UK), different readers may experience different emotional reactions ranging anywhere from strong negative or positive emotions, to feeling indifferent about the subjects in the narrative. Emotional reactions can also refer to the discourse level, how readers *"generally enjoy or dislike the formal characteristics of a work"* (Herman et al., 2010).

User Involvement: When discussing how readers can be *involved* in a narrative visualisation, the distinction between *implicit and explicit user involvement* is made. While implicit user involvement techniques passively try to guide, focus, and increase viewers' attention and engagement, explicit user involvement requires some form of reader activity or participation (i.e., interactivity). Riche et al. (2018) describe user engagement as *"the feeling of being part of the story, of being connected to it, and being in control over the interactions with the story's content."* In the context of interactivity in digital media narratives (e.g., games, hypertext), Ryan (2004) uses the term *ontological involvement*, as such interactions might influence the story created in one's mind. *Exploratory involvement*, on the other hand, allows users to explore the data space without altering the plot (Ryan, 2004).

These five groups were inspired by a collection of *narrative patterns* for data-driven storytelling (Riche et al., 2018). These narrative patterns are one example of outside-in research approaches (how narrative techniques and patterns can be used in visualisation). The following passages also include inside-out approaches (how visualisation techniques and visual elements may aid storytelling).

Next, visual-narrative elements and techniques regarding the five storytelling categories are explored. The discussion is structured by the three editorial layers introduced above.

Elements and techniques can be associated with more than one of the three layers and also influence one or more of the five narrative groupings.

2.2.2.3 Elements and Techniques on the Visual Representation Layer

Spatial ordering: The visual structure or spatial ordering, the layout of visual representations and other elements, can influence the narrative structure of a data narrative (Brehmer et al., 2017a; Hullman and Diakopoulos, 2011; McKenna et al., 2017; Segel and Heer, 2010).

The layout can be used to present successive events from left to right to follow a typical reading order (Brehmer et al., 2017a). Other suggestive spatial mappings (e.g., left for past; right for future; up for good, more, or better; down for less or bad) or some meaningful use of space can be utilised to provide structure and framing (Hullman and Diakopoulos, 2011; Riche et al., 2018).

Bach et al. (2018) identify design patterns for data comics based on how different panel layouts can be used to reinforce the content relations between those panels. In the context of story maps, Roth (2016) suggests to visually partition and sequence information into chunks to reduce complexity.

Visual transitions: Transition techniques, like linking elements trough (staggered) animation sequences, zooming, or panning, allow for moving within or between scenes and provide structure, continuity, and context throughout a data story (Amini et al., 2015; Gershon and Page, 2001; Riche et al., 2018; Segel and Heer, 2010; Stolper et al., 2016). This may help to resolve conflict and ambiguity or reveal surprising connections (Gershon and Page, 2001).

Amini et al. (2017) describe different types of data videos by using specific transition animation effects. For example, within parts of narratives about *creation*, fade-in, drawing, or growing effects to initially draw a visualisation are used. *Destruction* is expressed through fade-out, shrink, or wipe effects to destroy parts of a visualisation. Morphing and transition effects can convey evolution and metamorphosis within a narrative.

Visual style, marks, and encoding: Links between distinct narrative visualisation states can also be established through consistent visual encoding (e.g., mapping of colour or shape) (Riche et al., 2018; Stolper et al., 2016). For example, using consistent colour mapping helps with recognising constant objects or data points that provide continuity and structure, giving readers the ability to focus more on the content.

Visual representations, the mapping of data to the visual domain (Hullman and Diakopoulos, 2011), may take on a realistic or abstract form (Bach et al., 2017) and are often the most visually salient elements (Brehmer et al., 2017a). Visual representations can reinforce the conveyed message or the data characteristics. For example, the cyclical nature of a depicted phenomenon can be communicated with a radial representation (Brehmer et al., 2017a).

Other means of manipulating the visualised information (message) include introducing distraction through visual or semantic noise by overloading a display, introducing ambiguity through multi-encoding, clustering of data points to emphasise their importance, or representing the degree of certainty of sources, data, or messages (Hullman and Diakopoulos, 2011). Visual distortion techniques (e.g., truncated or inverted axis, area as quantity) might also lead to (intended) misinterpretation of a message (Pandey et al., 2015).

Withholding information deliberately or not visually encoding selected data points, is a powerful way to frame the conveyed message. Omitted or silent data (Hullman and Diakopoulos, 2011; Riche et al., 2018) provide some form of structure and engage implicit user involvement. This allows the audience to fill in the gaps and put different information into context to better understanding the message (Gershon and Page, 2001; Riche et al., 2018).

Additionally, the visual style or aesthetics of a visualisation can convey a message, evoke emotional reactions, and frame the perception of the message. Using colours or layout in an associative way and playing with the level of abstraction (Bach et al., 2017) can be effective. Roth (2016) claims aesthetic style is able to set the overall mood, a visual tone congruent with the overall message or story, place, and time (Gershon and Page, 2001). Muehlenhaus (2013), for example, investigated the persuasive power of map design to ascertain which map elements can help to persuade the communication of a message.

Making it more tangible: Other techniques try to reduce complexity in order to make information more tangible, often on an emotional level. This allows the audience to make a better connection, fostering implicit user involvement.

Another technique to help build an argumentation chain is identified by Riche et al. (2018) as *concretisation*, the making of abstract concepts concrete by depicting each data point with a distinct object (e.g., the isotype language). They note that concretising, in combination with other methods, can be used to evoke empathy.

The concept of showing the *humans-behind-the-dots* (Riche et al., 2018) is an additional technique to increase empathy. A selected data point (e.g., about a person) or a subset of records are used as representative examples of the entire dataset within a data narrative with the intention to engage the reader on an emotional level.

Concretisation and humans-behind-the-dots often use pictogram symbols to communicate quantitative information visually, but typically express qualitative information by visually resembling the object of interest (i.e., mimetic symbols). Boy et al. (2017)'s anthropographics design space is an example that uses pictograms of humans, with varying realism and expressiveness, to communicate narratives about migration. DataClips (Amini et al., 2017, 2018) provide the ability to incorporate pictographs.

Visual similes, metaphors, metonymy, irony, and satire using, for example, cartooning and hyper-realism are suggested (Gershon and Page, 2001; Hullman and Diakopoulos, 2011; Roth, 2016) to repack, frame, and simplify information to facilitate the understanding of an intended message. Herman et al. (2010) describe metonymy as *"understanding one thing in terms of something else that is closely related to it"*, including explaining the whole through parts of it, which, from a data perspective, translates to using aggregation or variable selection to explain the underlying phenomenon (Hullman and Diakopoulos, 2011).

With additional visual or interactive techniques, more detailed, contextual information about the individual cases presented in humans-behind-the-dots narratives can be used to convey their characteristics and personal stories.

2.2.2.4 Elements and Techniques on the Contextual Representation Layer

Verbal narration elements: Techniques that provide context going beyond the ability of the visual data representation appear mainly in verbal form. Primarily, language-based elements provide contextual information (Figueiras, 2014a; Riche et al., 2018; Segel and Heer, 2010; Stolper et al., 2016) such as titles, captions, annotations, labelling, introductory, summarising or accompanying text, and textual, audio, or video narration. These techniques may influence the implicit user involvement (draw attention), provide structure (reading order), or shape the central message of a narrative visualisation.

Directing attention: Attention cues include visual and auditory effects such as highlighting and accenting, linking (brushing), focusing, call-outs, animation effects such as dynamic zooming, opacity masks, as well as graphical or textual annotations (Amini et al., 2017, 2015; Gershon and Page, 2001; Hullman and Diakopoulos, 2011; Riche et al., 2018; Satyanarayan and Heer, 2014; Segel and Heer, 2010; Stolper et al., 2016). These attention cues help to frame and emphasise important or unusual information regarding the overall message of a data story (Roth, 2016) and provide structure by guiding readers through a narrative visualisation (e.g. arrows connecting components (Stolper et al., 2016)). The techniques for directing attention may be applied within visual representations, but are often not directly data-driven so much as they are contextual. They also influence how readers are immersed or drawn into the narrative (implicit user involvement).

Verbal manipulations providing perspective: Hullman and Diakopoulos (2011) name literary strategies as framing techniques, which can be used when phrasing titles, annotations, and labels in narrative visualisations. Concepts like irony, metaphor, comparison, and similarity can be used to frame the perspective towards a topic verbally.

Although subtle, asking *rhetorical questions* may affect implicit user engagement (Riche et al., 2018) by provoking specific thoughts in the audience. Rhetorical questions directly address the audience and can set the context framing a subsequent exploration phase (after some direct narration).

Verbal manipulations can also help convince an audience to favour one side of an argument over the other. Persuasive messages that lead a reader to a particular way of thinking can be presented in titles, captions, or longer introductory background texts (Kong et al., 2018; Pandey et al., 2014).

Using first-person or third-person narration can also affect a reader's perspective towards a topic or subject (e.g., immigrants). Switching between narration perspectives, like Riche et al. (2018)'s pattern of *breaking the forth wall* (where the narrative is stopped unexpectedly in order to address the audience directly), can provide narrative structure, increase implicit user involvement, and draw the audience further into the narrative.

Implicit user engagement may be maintained by using goals, rules, and high scores to evoke competition (Diakopoulos, 2010). It can provide feedback to show that a reader's input affects the progression or even the content of a narrative (McKenna et al., 2017).

How-to use: Context can be provided through narrative tutorials – information on how to read a visualisation or interact with it – in the form of explicit instructions (Boy et al., 2015; Segel and Heer, 2010), or by using more subtle hints (e.g., point out interactive elements in the interface) (Segel and Heer, 2010). Techniques such as these are believed to increase the willingness to explore the data, increase engagement, but also frame a user's perspective by setting possible usage constraints.

Provenance: Providing meta-data in narrative visualisation context, including the data source, naming the visualisation designer, or being explicit about design decisions, can be used as framing techniques (Hullman and Diakopoulos, 2011). Being open and transparent about such matters allows the reader to explore the issue further and may increase a visualisation's credibility.

2.2.2.5 Elements and Techniques on the Interactivity Layer

Interaction to explore: Segel and Heer (2010) define three delivery models concerning user involvement ranging from very limited to free interactivity. The *martini glass structure* starts with a guided, non-interactive narrative that later opens up to an interactive, free data exploration phase. In an *interactive slide-show*, the narration is defined by the author, but allows user interaction to investigate details of the data in-between. Finally, a *drill-down story* enables users to decide which parts of a story they are most interested in and wish to learn more information; mainly the user defines the structure of the narrative. The different ways of presenting a narrative can influence the narrative structure or how a story is constructed in a reader's mind.

Diakopoulos (2010) provided a similar approach to classifying data stories by defining how users can explore the data space. In guided, non-interactive "landmark narratives", selected data points of interest (i.e., landmarks) are presented in a certain sequence. "Flexible narratives" allow exploring the data points between the highlighted landmarks interactively. Directed, game-like narratives provide structure by asking and answering questions similar to trivia games. Finally, fully undirected narratives provide a free exploration of the data according to a user's preference.

Often narrative visualisations have limited reader interaction influencing the explicit user involvement marginally. Exploratory elements might be embedded or presented separately (Riche et al., 2018; Stolper et al., 2016). Data exploration techniques include filtering, selecting, zooming, searching, or details on demand using tooltips or hover interactions (Figueiras, 2014a; Segel and Heer, 2010; Stolper et al., 2016). Advanced exploration is often provided towards the end of stories (Boy et al., 2015; Riche et al., 2018), implementing Segel and Heer (2010)'s martini-glass model. Advanced exploration allows users to *"constrain the data depiction based on [their] preferences for certain information"* (Hullman and Diakopoulos, 2011) and to take a "personal" perspective on the data (e.g., by selecting the region the user lives). Tooltips often convey more detailed, supporting arguments of the overall message (Riche et al., 2018; Stolper et al., 2016).

Linking elements through interaction (brushing and linking) can support explicit user involvement (active exploration) and also influence implicit user involvement (attention guidance) (Riche et al., 2018; Stolper et al., 2016).

Navigation aids and progression: To enhance the different structures or paths a user might take to move between states, interactive navigational aids such as buttons, menus, scroll input, breadcrumbs, timelines, or geographic overview maps can be used (McKenna et al., 2017; Satyanarayan and Heer, 2014; Stolper et al., 2016). They not only act as visual progress indicators (McKenna et al., 2017; Segel and Heer, 2010) identifying the current position within the narrative, they also help advance the narrative based on interaction or time and trigger transitions, which can add highlighting, annotations, filters, or additional contextual details (Riche et al., 2018; Stolper et al., 2016).

Challenge users through interaction: Other techniques requiring some form of user input (explicit user involvement) are the *make-a-guess* pattern (Riche et al., 2018) or trivia game elements (Diakopoulos, 2010; Diakopoulos et al., 2011), which increase engagement or stimulate curiosity to create an emotional response. Viewers are challenged to provide an estimation or answer a question related to the depicted data either through simple means (e.g., text, slider, selection input) or through more complex interactions within a visualisation (e.g., drawing or dragging elements such as trend lines or threshold indicators).

2.2.2.6 Elements and Techniques Across Layers

Some techniques are difficult to assign to one layer because they can be used across multiple layers. For example, how a narrative is thematically structured is expressed on both the visual representation and context layers.

Thematic ordering: On an abstract level, Phillips (2012) identifies basic plots of stories told in earth sciences, which relate to basic plots identified in literature. He uses the term plot "to refer to the storyline, plan, scheme, or main story". A discussion of the ambiguity of the term plot from the perspective of narrative theory can be found in Herman et al. (2010). These basic plots or structures of events include: (a) narratives describing relationships between processes and their results; (b) narratives communicating genesis, emergence, metamorphosis, or destruction of phenomena; and (c) narratives about merging, divergent, or cyclical developments. Roth (2016) links these plots to the classical three or five act dramatic arc (exposition, conflict, climax, falling action, and resolution (Yorke, 2013)) and identifies its linearity as a way to enforce structured continuity in reading.

Similarly influenced by the idea of dramatic arcs, Amini et al. (2015) take a more analytic approach and follow Cohn (2013)'s theory of visual narrative structure categories including establisher, initial, peak, and release. Possible subsets and combination patterns are used to study data videos. To reinforce an author's intent (e.g., to educate or call-to-action), Amini et al. (2015) suggest different thematic orderings and repetitions of those narrative building blocks.

Picking up Amini et al. (2015)'s research on visual narrative structure, Kosara (2017a) introduces an argument structure for data stories that include a claim (or question), facts (or evidence), explanation, and a conclusion. This approach of thematic ordering influences the framing of the message and introduces structure to the narrative. They are reflected on visual and contextual levels.

Another way to describe thematic structure is through transitions, moving within or between scenes and providing continuity and context throughout a data story (Amini et al., 2015; Gershon and Page, 2001; Segel and Heer, 2010). Hullman et al. (2013) define different transition types for narrative visualisation including: (a) transitions where a question asked in one state is answered by a new visualisation; (b) transitions revealing casual relationships between states; (c) transitions changing the level of detail (going from specific to general or from general to particular); and (d) transitions allowing comparison by adding, changing, or aggregating variables. Such local transitions affect the overall global sequence and the structure of narrative visualisations.

For example, the comparison of two or more data sets, variables, or facts can be used to highlight both differences and similarities (Riche et al., 2018) and help convince a reader of a particular argument. Opposing perspectives can be compared and contrasted through, for example, layout choices like juxtaposition or animation (Brehmer et al., 2017a; Hullman and Diakopoulos, 2011; Riche et al., 2018) or within contextual elements like titles or captions (Hullman and Diakopoulos, 2011). Contrasting arguments can provide narrative structure and influence how a message is perceived.

Temporal ordering: Temporal aspects may also influence the structure. Events or narrative visualisation states can be ordered in different ways. Hullman et al. (2013) make the distinction between simple, reverse, and future chronological ordering. Based on a variable representing time, the narration cannot just move along a linear chronology, but also moves or jumps back or forward in time, known as analepsis (flashback) and prolepsis (flashforward), respectively (Herman et al., 2010).

Gershon and Page (2001) describe a possible pattern where the narrative starts from the current situation, then jumps back in time, animates through the story to enhance the temporality of events, arrives back at present, and then projects to the future. The traces of temporal ordering are evident on both the visual representation and contextual levels.

Manipulating time: Besides ordering time, temporal aspects may be manipulated in different ways. Wang et al. (2016) implemented visual designs for foreshadowing and time remapping for animated timelines. The foreshadowing technique, which uses different superimposed visual cues, informs the audience in advance about upcoming key events appearing in the timeline. The non-linear time mapping emphasises essential parts and compresses less exciting sections.

Brehmer et al. (2017a) propose that scaling the temporal variable of a timeline-based data story can help communicate relations between events, such as order, duration, and synchronicity. To communicate the order of events, sequential scales can be used. For timelines with large extents and a skewed distribution of events, logarithmic scales may be used.

Riche et al. (2018) note that speeding up and slowing down the narration influences its structure, which can elicit an emotional response and influence the message. Changing speed is evident on both the visual representation and contextual levels.

The two approaches, changing the playback speed and scaling the temporal aspect, mimic the distinction between *discourse time* and *story time* used in narrative theory (Herman et al., 2010). Story time is the actual duration of events throughout a plot (e.g., a *year* in the life of earth's CO_2). Discourse time is the time it takes to tell the story (e.g., three minutes).

Gradual revealing (Riche et al., 2018) or dosing (Roth, 2016) information require some manipulation of discourse time. While those techniques are most prominent on the visual representation level, they are also evident on the contextual level and can be expressed through interaction. Sequencing and chunking techniques provide structure throughout a narrative and reduce the complexity of a message. Most notably, a gradual reveal can create tension and evoke emotional responses.

Reading order: Temporal ordering, layout aspects, or thematic relations may affect the possible paths a reader may take through a narrative visualisation, known as the reading or viewing order.

Segel and Heer (2010) define a continuum between author-driven and reader-driven paths through narrative visualisations. The paths range from linear, highly directed, and user-directed (where users select from multiple alternatives) to undirected random access (where no path is suggested allowing free exploration). This continuum has been picked up by many other experts providing theoretical (e.g., Bach et al. (2017); Stolper et al. (2016)) or empirical contributions (e.g., Badawood and Wood (2014); Figueiras (2014a); Nowak et al. (2018)). In Segel and Heer (2010)'s distinction between author-driven and reader-driven, directed approaches are characterised as having a high volume of messaging and low interactivity; undirected narratives have little or no messaging and more interactive elements.

McKenna et al. (2017) provide three ways for how readers progress through a narrative: (1) linear, ordered path between *story points*; (2) jumping between or skipping story points; or (3) a more complex path following a tree or graph structure.

Repetition and redundancy: Both language-based and visual techniques can be used to introduce redundancy, the repetition of important or unusual information (Gershon and Page, 2001; Hullman and Diakopoulos, 2011; Riche et al., 2018; Roth, 2016; Segel and Heer, 2010) to reinforce an argument and help memorability in an effective manner. Redundancy may be accomplished through repetition of single key information (including multi encoding) or through adding perspective (e.g., providing multiple reasons for a phenomenon).

The reader as an individual: The goal of leaving a lasting impression in storytelling (Lee et al., 2015) can be achieved with the idea of *call-to-action* (Riche et al., 2018). Individualisation techniques like this directly address or appeal to the user as an individual (Hullman and Diakopoulos, 2011; Riche et al., 2018) and provoke user engagement that goes beyond the time a story is experienced. For example, Boy et al. (2017) investigated how much someone was willing to donate after being exposed to human rights narratives.

Anchoring techniques, or providing entry points the audience can identify with, is one way to create a familiar setting (familiarisation), direct attention to the key message, convey a first impression, stimulate default views to orient the audience, and "paint the picture" (Gershon and Page, 2001; Hullman and Diakopoulos, 2011; Segel and Heer, 2010). Anchoring applies on the visual representation and contextual levels alike. Presenting new information in connection with something familiar can evoke emotions, frame a reader's perspective, and impact how involved the reader feels in the narrative.

In contrast, a reader's expectation might be challenged by breaking with conventions or de-familiarisation (Riche et al., 2018), which frames the narrative message and influences implicit user involvement. Another technique that breaks with conventions is to *break the fourth wall*, Riche et al. (2018)). Both techniques can evoke emotion and influence user involvement.

2.2.2.7 Narrativisation of Visualisation

Applying visual-narrative techniques, captured in the descriptions above, to data visualisation may be called *narrativisation.* In outside-in approaches, the process of narrativisation was explicitly demonstrated by Figueiras (2014b) by adding context, empathy, and temporal references in existing data visualisations or by Mocnik and Fairbairn (2017) introducing the *story focus technique* for maps by emphasising time, non-spatial context, subjectivity, and increased expressiveness.

In the context of narrativisation, the balance between visual (nonverbal) and language-based (verbal) techniques in a data story (Bach et al., 2017; McKenna et al., 2017) can influence narrativity. Ryan et al. (2016) describe the difference between *"storytelling with maps"* and *"storytelling through maps"* through the text-map ratio. In storytelling with maps, the text "bares the weight of narration". In storytelling through maps, the text-map ratio is more balanced.

Narrativisiation can also be achieved through an actual narrator. Besides the more implicit aspects of storytelling with the aid of data visualisations, examples of explicit storytelling are Hans Rosling's numerous TED talks[6] about the global development or Jo Wood's TEDx talk about journeys within the London bicycle hire scheme (Wood et al., 2014). Such presentations follow a highly author-driven narrative where the presenter guides and emotionally includes the audience through his or her spoken narration, gestures, and body language. These concepts are not commonly used in visualisation and are, therefore, prime examples of outside-in approaches.

The storytelling technique used by Wood et al. (2014) to contrast two states (visually unorganised vs. structured data) is described by Duarte (2010) as the *"contour of communication"*. This presentation form starts by contrasting the familiar state (*what is*) to a possibly more desirable state (*what could be*), building dramatic tension and providing a *call to adventure*. In the middle part, the contrast between the two states continues to capture an audience's attention by using different delivery models or evoking emotions. Finally, "the call to action" involves and addresses the audience, which leads them to their next adventure.

It appears that the authoring of data narratives is as subjective a process as the perception of data narratives. The same data, observations, and facts often allow different interpretations and yield different narratives (Cruz and Machado, 2011; Phillips, 2012) in a reader's mind. From an author's perspective, this variability is entirely acceptable and can be viewed as a strength. However, the vast number of possibilities makes it harder to evaluate aspects of visual data storytelling. Creating complex and realistic enough stimuli is a fine balancing act. In the next section, research that has investigated the effect of visual data storytelling on people will be reviewed.

2.2.3 Evaluating Effects on People

In this section, studies are discussed that used participants to test and compare different approaches and concepts in visual data storytelling or related fields.

Only a few previous studies have assessed the effects of visual data storytelling on people, including the effect on (a) **engagement** in the sense of **activeness** or **performance**; (b) **engagement** in the sense of **immersion** including **preference** and **likeability**; (c) **empathy** and **affection**; (d) **insights**; (e) **memorability**, **comprehension**, and **recall**; and (f) **attitudes** and **beliefs**.

[6] https://www.ted.com/speakers/hans_rosling

Engagement, activeness, and performance: Two studies have investigated the effects of incorporating narrative elements on people's exploration of visualised data. Diakopoulos (2010) added trivia game elements to an exploratory stimulus map published by an online newspaper. Using interaction logs, the authors noticed that asking quiz questions encouraged people to interact more with the visualisation than when the same visualisation did not have the quiz. However, the uncontrolled nature of the study prevents more definite conclusions from being drawn. Boy et al. (2015)'s controlled online experiment hypothesised that adding visual data storytelling before exposing people to an exploratory visualisation can increase their activity levels and immersion. However, their comparison of the two groups using interaction logs as a proxy to measure engagement did not confirm this hypothesis.

Interaction logs are feasible measures for *out-in-the-wild* studies, but they do not allow a sufficient assessment of the effect of storytelling, because they can not reveal further insight into a user's processing of the narrative.

To evaluate the usage of context providing backstory narratives within visualisation evaluation studies, Dimara et al. (2017) used objective performance metrics measuring task accuracy and attention. Contrary to their expectations, the authors found that such narratives may decrease accuracy when compared to non-narrative study set-ups.

Engagement, immersion, preferences, and likeability: In addition to objective performance metrics, Dimara et al. (2017) also used subjective measures in their survey to assess how the participants felt engaged by asking for their confidence in the given answer, their perceived easiness of the task, their enjoyability of it, and their opinion on the usefulness of the stimulus to accomplished the task. Self-reported answers were collected on a 7-point Likert scale.

Amini et al. (2018) investigated the effect of animation and pictographic symbols on viewer engagement in data videos. Using a 7-point Likert scale, they adopt and refine an engagement scale that includes items such as affective involvement, enjoyment, aesthetics, focused attention, and cognitive involvement. They compare stimuli with varying animation status (static vs. animated) and chart type (standard vs. pictograph). They found higher viewer engagement levels for animated data videos and clips with pictograms than compared to the baselines. Participants rated videos with pictographs when animated higher. The authors further evaluated user preference within this study. Stimuli with animated pictograms were preferred over other conditions. However, static standard charts were preferred over static pictograms and animated standard charts.

McKenna et al. (2017) explored the effects of different modes of visual narrative flow on readers' engagement. They found that visualisations (compared to just text) and animated transitions (triggered through stepper buttons and scrolling) improved reader-perceived engagement. In the same study, they did not find any difference in engagement between a *stepper* and a *scroll* narrative. However, participants indicated a stronger preference for these two conditions than compared to the baseline conditions *text-only* and *static visualisation* narrative. McKenna et al. adopted a subjective questionnaire for measuring engagement (5-point Likert scale) including items to asses focused attention, perceived usability, aesthetics, endurability, novelty, and felt involvement.

In a user study with 12 participants, Wang et al. (2016) evaluated the foreshadowing and time compression timeline visualisations regarding engagement experience and workload, both as perceived, self-reported items on a 7-point Likert scale. The engagement experience was assessed with items like awareness, excitement, enjoyment, curiosity, anticipation, attention, persistence, aesthetics, understandability, and memorability. The participants found the narrative designs more engaging than the non-narrative baseline design. The perceived workload was assessed regarding mental load, temporal cost, efforts and frustration level. The authors conclude that all 12 participants believed that narrative designs reduced perception load.

Through a focus group, Figueiras (2014a) had 16 students rate 11 web-based narrative visualisations in terms of comprehension, likeability, and navigability. Figueiras concluded that the narrative elements *"interactivity, drilling-down, additional context, and the ability to create a sense of relatability are important factors for the users to feel engaged."*

Hullman et al. (2017) investigated sequence preferences and perceptions for a set of different visualisation states (they refer to a state as an "informationally-distinct visual representation") with varying geographic space, time, and measure. In two studies, they found that participants produced and preferred hierarchical structures for sequencing based primarily on space and less on time or measure.

Empathy and affection: Boy et al. (2017) investigated whether anthropomorphising data graphics affected readers' empathy for suffering populations of human rights narratives. They ran a series of crowdsourced experiments to test whether people exposed to anthropomorphised data would have more empathetic responses than people exposed to standard charts embedded in a narrative context. Their results did not confirm that emotion-evoking stories affected people's empathy.

Based on the fact that narrative visualisations have effects on multiple levels, are complex, and trigger both cognitive and affective reactions, Nowak et al. (2018) recently advocated for using qualitative evaluation approaches. Nowak et al. adopted a psychological interview and analysis method that can identify implicit aspects of experiences made when engaging with a narrative visualisation. Nowak et al. found that this method can *"capture rich emotional and sensory experiences and reveal sense-making processes, personal reflections, and meaning-making processes that occur when viewing narrative visualisations."*

Insights: Badawood and Wood (2014) investigated the effect of different delivery modes on the reconstruction of a written narrative. They compared an exclusively author-driven (Hans Rosling presenting data at a TED talk) and a highly reader-driven (interactive Gapminder) approach (Segel and Heer, 2010) representing the same data. They observed that the delivery mode had only a small effect on participants' story reconstruction. Their results showed that participants in the reader-driven exploratory visualisation condition tended to inform their story based on insights about visually salient outliers and less on specific patterns of the data.

Dove and Jones (2012) introduced a model for narrative visualisation evaluation using insight as a metric, where insight is "something that is gained" and "something that is experienced". They suggested enhancing the information visualisation studies with methods from neuroscience, such as electroencephalography and functional magnetic resonance imaging, to evaluate narrative visualisation. To date, no such study has been conducted in the context of narrative visualisations.

Memorability, comprehension, and recall: Recent studies by Borkin et al. (2013, 2016) have shown that the use of human-recognisable objects in visualisations, such as pictograms, may enhance memorability, comprehension, and recall. If unique types of visualisation are more memorable than common ones, then visual data storytelling is likely to be more memorable than non-narrative visualisations. Hullman et al. (2013) defined various transition types between visualisation states (e.g., dialogue transition, in which a question is asked in one state and answered in the subsequent state). They found that visualisation sequences that use parallelism (repeating patterns of transition types) as a structural device were beneficial for memorability.

In the Amini et al. (2018) study on animation and pictograms in data videos, the authors also investigated comprehensibility, the degree the message was understood, by asking questions about the content of a clip. Stimuli with animated pictographs resulted in a higher percentage of correct answers compared to clips with animated standard charts or static pictographs. Furthermore, static standard chart conditions had better results compared to static pictographs.

Other studies mentioned previously also assessed comprehension (Figueiras, 2014a), understandability, or memorability (Wang et al., 2016) with the means of self-reported measures (using a Likert scale). While it is interesting when participants think about whether a stimulus was easy to understand or aided memory or not, measuring such factors more indirectly (e.g., asking about the content, or conducting a follow-up study) might reveal more insights (Bateman et al., 2010).

Attitudes and beliefs: Two studies, in persuasive visualisation (Pandey et al., 2015) and cartography (Muehlenhaus, 2012), investigated how different visualisation types (e.g., bar charts, line charts, and tables) or map styles (e.g., propagandist, authoritative, and sensational) influenced the persuasiveness of the visually conveyed message.

Using persuasion theory models (O'Keefe, 2016; Pandey et al., 2015), attitude and attitude change are used as proxies to measure persuasiveness. While the results showed differences between conditions, further research is necessary to investigate the reasons behind these differences. A recent study (Kong et al., 2018) showed that persuasively worded titles of visualisations on controversial topics can influence the perceived main message but do not have a meaningful effect on attitude change. Pandey et al. (2015) investigated the deceptive effect of visualisations, how distortion techniques (e.g., truncated axis, area as quantity) can shape belief about the conveyed message. They found that message exaggeration/understatement and message reversal techniques do lead to significant misinterpretations.

In the study presented in Chapter 5, the effect visual data storytelling can have on attitudes towards a sensitive topic (i.e., immigration) is explored. In the context of the experiment, it is explained why a concept of immigration attitudes that is linked to human values coming from social sciences was adopted.

2.2.3.1 The challenge of assessing effects on people

Overall, assessing the effects of visual data storytelling rarely leads to conclusive results and when that is the case, the observed effects are relatively small or contrary to formulated expectations. Such ambiguous results align with findings from fields investigating narrative persuasion that are facing similar challenges (e.g., psychology, advertisement, and health) (Dillard and Shen, 2012; O'Keefe, 2016).

This is unsurprising because in contrast to perceptual studies, investigating the effects of narrative techniques involves complex mechanisms, interactions, and cognitive processes that are impossible to fully control. As a result, isolating and measuring a particular effect is challenging, and that measured effect is likely to be small and/or weak. Based on the results of the studies conducted during this PhD research, the implications for future evaluations in visual data storytelling are discussed in Chapter 6.

To scope the research presented in the subsequent chapters, the focus will shift to relevant aspects of the visualisation of flow and movement data. Alongside storytelling, the visualisation of flow and movement data is the second major topic of this thesis and completes the background section.

2.3 Visualisation of Flow and Movement Data

As mentioned in the beginning (see Chapter 1) and outlined in more detail in Chapter 3, telling a story and visualising flow and movement data share two properties: space and time. This connection makes it easier to study both areas together, which aided the decision of selecting this visualisation subset. For an overview of this topic, discussion will revolve around different types of flow and movement visualisations, approaches to avoid visual clutter, how visual marks and channels are used, and how spatial context is integrated.

In the context of this thesis, the term *flow and movement visualisation* includes all kind of visualisations depicting flow and movement data across disciplines on different levels of abstraction and scale. This includes, but is not limited to, various types of cartographic flow maps (e.g., distributive flow maps), flow and network diagrams used in information visualisation (e.g., chord or Sankey diagrams), and flow visualisations as known from scientific visualisation (e.g., pathlines or streamlines).

The boundaries between the different domains using flow and movement visualisation are not well defined. Therefore, a differentiation based on the flow and movement data itself seems reasonable: **Origin-destination (OD)** data describes the magnitude of flow between sources (origins) and targets (destinations) (e.g., migration flows between countries). Based on the underlying data (e.g., geographic location) or the layout, the flow

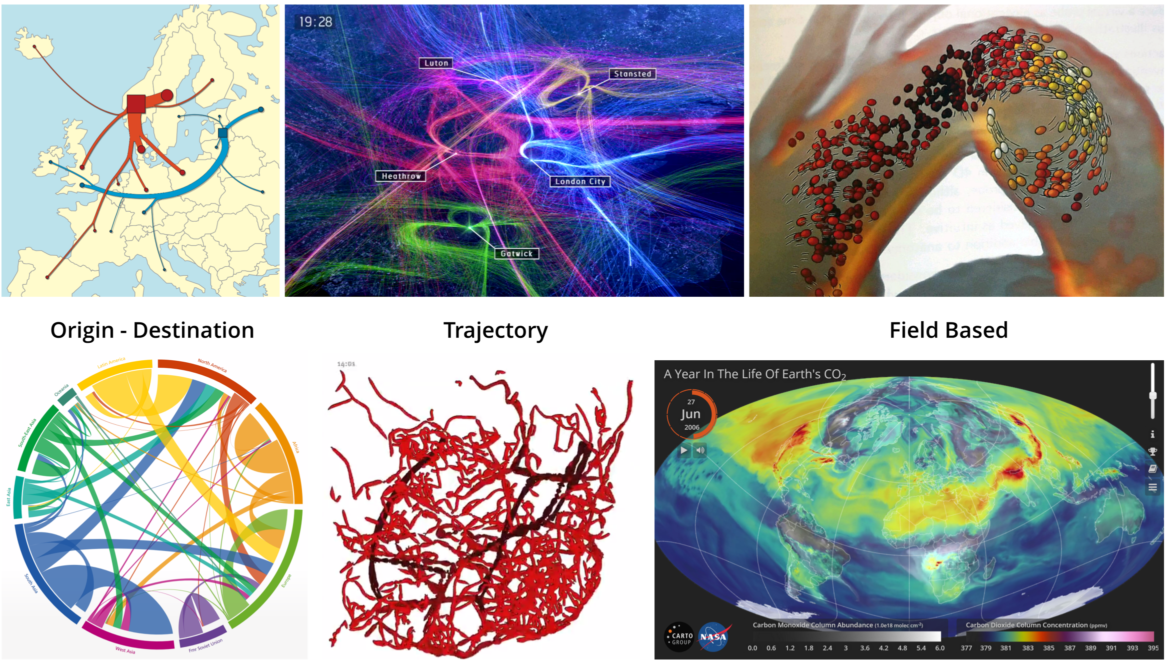


Figure 2.2: Examples of visualisations of different types of flow and movement data. **Origin-destination data (left):** *Migration from Norway and Latvia in 2009* depicted with branching flow lines (top, *FS_051*), *The global flow of people* displayed with an interactive chord diagram (bottom, *FS_002*); **Trajectory data (centre):** *London air traffic over 24 hours* shown in an animation (top, *FS_094*), *Lisbon's traffic over one day* visualised using a blood vessel metaphor (bottom, *FS_007*); **Field based data (right):** *Illustrative blood flow visualisation* using comic-style particles (top, *FS_080*), *A year in the life of earth's* CO_2 as an interactive video map (bottom, *FS_010*). More examples are presented in Section 3.2.1. References can be found using the IDs (*FS_**) in Appendix A.

marks can describe a network (many-to-many) or have a distributive structure (one-to-many), which may have a radial pattern (Dent et al., 2008; Parks, 1987). **Trajectory** data captures the movement of discrete objects along a path (e.g., GPS tracks of vehicles). **Field-based** data describe continuous phenomena being subject to movement (e.g., wind, pollutants, water, blood, etc.).

This review focuses on two domains that may both be employed in a narrative setting. First, flow and movement visualisations with a **geographic context** (e.g., communicating research findings on climate change or migratory patterns) and second, to a lesser extent, the visualisation of **blood flow** (e.g., informing patients about alternative treatment plans).

Although visualisations of flow and movement data are used across different domains, they often have similar goals. The most important aim is to better communicate significant amounts of complex information in an understandable and simplified way by decluttering displays and avoiding occlusion or crossing flow marks (straight, curved, or otherwise shaped lines or paths). This goal seems manageable with a moderate number of flows demonstrated compellingly by hand-drawn visualisations (Kraak, 2014; Rendgen, 2018) or design principles for many-to-many static OD flow maps (Jenny et al., 2016c) implemented a force-directed layout algorithm (Jenny et al., 2017). However, an increasing number of flows require additional methods to provide legible displays. Various strategies were proposed and developed to overcome or at least minimise scalability problems.

2.3.1 Declutter the Clutter

Methods to reduce clutter in visualisations may include elementary filter approaches such as selecting flows with volumes above the average quantity (or any threshold) (Tobler, 1987, 1981), selecting major flow patterns using more advanced algorithms based on spatial criteria (Guo and Zhu, 2014) (e.g., distance), or attributive criteria (Born et al., 2013a) (e.g., flow as part of a vortex).

More advanced computational approaches, which tend to scale better, include bundling, clustering (Ferstl et al., 2016; Zhu and Guo, 2014), or smoothing (with kernel models) (Guo and Zhu, 2014) of flows with similar origins and destinations.

To bundle and arrange multiple one-to-many flows, techniques employing hierarchical clustering and edge routing using splines (Phan et al., 2005) or a tree structure with logarithmic spirals (Buchin et al., 2015; Verbeek et al., 2011) were developed to minimise or avoid line crossings. For network-based (many-to-many) flows, clustering or bundling of straight or curved lines was used (Boyandin et al., 2010). Such approaches emerged from work conducted in graph visualisation, where various methods for edge bundling were developed (Holten, 2006; Holten and Van Wijk, 2009) and refined (Ersoy et al., 2011; Hurter et al., 2014; Selassie et al., 2011) to improve legibility. Smoothing algorithms and different rendering styles (e.g., shading, translucency) enhance this effort as well.

Other approaches also aggregate based on attributes and flow properties (Born et al., 2013a,b). Instead of just aggregating flows, other approaches first partition the underlying space to either provide more meaningful and natural OD locations (Guo, 2009), a summarised view of vast amounts of trajectories (Andrienko and Andrienko, 2010, 2011), or a flow field (van Pelt et al., 2012). Flows are then visualised using conventional methods (e.g., lines, arrows). Based on spatio-temporal clustering, spatial flow situations can be depicted with radial flow diagrams (i.e., roses, spider web, bars) to analyse OD mass mobility data visually (Andrienko et al., 2016). Such glyphs, showing either outgoing or ingoing values, are placed in the respective location on a map.

A technique that removes any occlusion and the saliency bias of conventional flow maps (long flow marks are more salient, but do not have to be more important than smaller ones) is the origin-destination (OD) map (Wood et al., 2010), which is based on the OD matrix approach. Because the topology in an OD matrix may get lost, the OD map design attempts to preserve the underlying geography as much as possible. In the MapTrix approach (Yang et al., 2017), origin and destination geographies remain undistorted. Every region (e.g., state) of an origin and destination map is connected with a non-crossing line to the corresponding row or column of a rotated OD matrix. In every approach, the flow volume is encoded using a quantitative colour mapping of the matrix cells. This allows users to acquire details on demand and is suitable for standard flow maps, which show general overviews.

Flow-density maps (density raster, heat map) are based on the density of straight OD flow lines avoiding visual clutter (Rae, 2009). A similar approach was developed for visualising aggregated trajectories using kernel density estimation to produce density maps, which generalise trajectory patterns and allow anomaly detection, risk analysis, and identify similarities or differences (Scheepens et al., 2011). Such density maps were later overlaid with particle flows to encodes direction and provide more detailed movement patterns (Scheepens et al., 2016).

Various methods and techniques are often combined to reveal major global trends. Interaction methods like spatial, temporal, or attributive filtering and selection allow investigating local patterns on demand (Scheepens et al., 2011). While most approaches try to provide overview and detail together in a single view, others are scale-aware and change when zooming (Guo and Zhu, 2014; van Pelt et al., 2014). Comparison is frequently an important aspect when performing anomaly detection and risk analysis. It is necessary for viewing simulation results and may reveal certain patterns within flow and movement data. This can be realised with juxtaposition (Andrienko et al., 2016; Boyandin et al., 2010; van Pelt et al., 2014), within a single view (de Hoon et al., 2014; Ferstl et al., 2016; Gasteiger et al., 2012; Guo and Zhu, 2014; van Pelt et al., 2014), or with advanced interaction tools (Scheepens et al., 2011).

2.3.2 Visual Encoding: Marks and Channels

When visualising origin-destination or trajectory data, whether they are aggregated or not, straight, curved, or otherwise shaped line marks are most commonly connecting two or more locations. Field based approaches either use (arrow) glyphs (Lawonn et al., 2016;

Turk and Banks, 1996; van Pelt et al., 2010, 2011), line primitives (streamlines or pathlines) (Born et al., 2013a; Lawonn et al., 2014; van Pelt et al., 2010), or surfaces (Gasteiger et al., 2012; van Pelt et al., 2010, 2011) to represent velocity (speed and direction) or other flow characteristics. Furthermore, different visual channels, effects, and symbolisations are used to encode various flow and movement characteristics.

Flow magnitude is generally encoded using the size channel (line width, point size). Sometimes transparency or colour saturation are utilised to encode magnitude or quantity and thereby, regulate the saliency of flows or reduce occlusion (Boyandin et al., 2010; Scheepens et al., 2011; Turk and Banks, 1996; Wood et al., 2011). Choosing an appropriate maximum line width (Tobler, 1987, 1981) is important because it influences perception. Other graphical channels (e.g., colour hue) can be used to map different categories (subsets, trends, simulation results, treatment options) or additional attributes (Ferstl et al., 2016; Scheepens et al., 2011). Arrowheads, asymmetric curve shapes (Guo, 2009; Wood et al., 2011) or motion effects (van Pelt et al., 2012, 2010) often indicate the direction of flow. Fade-out effects and safety margins (Gasteiger et al., 2012), contour box plots (Quinan and Meyer, 2016), and confidence areas or volumes (Ferstl et al., 2016) depicting variability and uncertainty of simulated data can be found across disciplines. The illustrative rendering paradigm (Brambilla et al., 2012) is also used in blood flow visualisation (Born et al., 2013a; Lawonn et al., 2016; van Pelt et al., 2012, 2010, 2011), mimicking a hand-drawn style. Also influencing the style, familiar metaphors from comics have been used to depict blood flows with illustrative particles (van Pelt et al., 2011). Similarly, the metaphor of a living organism (a pulsing network of blood vessels) was applied to a traffic visualisation (Cruz et al., 2015).

2.3.3 Context to foster understanding of flow and movement

Since movements and flows, especially of field-based phenomena and trajectories, often interact with the surrounding context (e.g., blood flow with tissue, migratory paths with geography) it is important to provide context in a visual way. For anatomical context, illustrative (de Hoon et al., 2014; van Pelt et al., 2010) or perceptually based (Lawonn et al., 2014) rendering techniques are often used to enhance the blood vessels and provide a legible anatomical context (van Pelt and Vilanova, 2013). Dynamic cutaway surfaces (Lawonn et al., 2016) or ghost view rendering (Gasteiger et al., 2012) maximise the visibility of the embedded visualisation. To emphasise the interaction, the vessel wall is often colour coded by the wall-shear stress (van Pelt et al., 2012) or wall thickness (Lawonn et al., 2016), which may reveal causal relationships. The same applies in geovisualisation where, for example, choropleth maps or topographic maps (ranging from abstract to more pictorial styles) provide context (Guo and Zhu, 2014; Zhu and Guo, 2014).

Having established the relevant aspects of storytelling in visualisation and the visualisation of flow and movement data, the design space of Flowstories, which are visual narratives that combine the concepts discussed in this chapter, are explored.

Chapter 3

Flowstory Design Space

The *Flowstory design space* study explores the visualisation of flow and movement data in conjunction with storytelling. It investigates to what extent techniques used in data-driven storytelling and narrative theory can be employed when representing such data (*outside-in* approach) or how commonly used visualisations of such data can support narrative (*inside-out* approach) (see 2.2.1.6 Inside-Out vs. Outside-In Approaches).

The design space was created using examples across various domains. The developed flow and movement representation categories (compared to the narrative categories) are based on examples of geographic flow and movement data and the human blood flow, a very classical and traditional visualisation domain. A multi-domain approach makes it possible to apply the framework to any other flow and movement visualisation context (e.g., fluid dynamics for buildings). Over 100 story-like and more conventional visualisations with varying abilities to create a story in a reader's mind (narrativity) were categorised regarding the developed taxonomy (see Section 3.2).

The design space provides a structured way of thinking about the investigated subject matter (i.e., the visualisation of flow and movement data in a narrative context). The developed framework, not the coding of examples, is the main contribution of the approach. In addition to its descriptive power (see 3.3 Design Space Case Studies), the design space can be used generatively to either derive narrative visualisations for a specific dataset spinning of a new design space (see Section 3.4.1.2) or to create empirical studies testing various aspects of the design space (see Section 3.4.2).

Most of the research on storytelling in data visualisation discusses visualisation techniques on a very general level. Contributions may analyse maps in narrative settings regardless of the map type (Denil, 2016; Mocnik and Fairbairn, 2017; Muehlenhaus, 2014) or investigate aspects of data stories unrelated to the visualisation techniques themselves (Hullman and Diakopoulos, 2011; McKenna et al., 2017; Stolper et al., 2016). Rarely has previous research explicitly focused on a unique visualisation technique or take its properties into account like Brehmer et al. (2017a) did for timelines, or how this research does for flow and movement visualisations.

One may ask, why it is useful to investigate the design spaces of flow and movement visualisation and narration together? Why focus on flow and movement visualisation and not on other techniques? The answer is because of the importance of space and time in both narration and data visualisation. This is especially true for the visualisation of flow and movement data, where movement in geographic or any other space always possesses a temporal component. From a narrative perspective, time is an integral component that provides structure and moves a story forward. Space also plays an essential role in narration, for example, as a framing device or by capitalising on its metaphorical or emotive potential (Herman et al. (2010)).

The flow and movement axis of the Flowstory design space follows the three layers explained in the previous chapter (2.2.2 Narrative and Visual Elements and Techniques Investigated): (1) the visual representational layer including spatial, temporal, qualitative and quantitative properties of the flow and movement depiction; (2) the contextual representation layer taking graphical, textual and auditory context into consideration; and (3) the interactivity layer investigating possible user interactions. The narrative axis follows the five components outlined in the same section: (1) structure and temporality; (2) messaging and argumentation; (3) framing and perspective; (4) emotions; and (5) user involvement.

After a methodological overview in the next section (3.1 Design Space Development), the categories of the design space are described in more detail in Section 3.2 (A Design Space for Flowstories).

3.1 Design Space Development

The design space project was approached by adopting a concept introduced by Ryan (2004) when discussing the narrative potential of digital media. Ryan proposes two essential qualification criteria for *narrative media*: (1) whether, how, and why a narrative message (a story) is evoked, presented, and experienced; and (2) the use and combination of certain representational features relevant for narrativity, such as the use of multiple sensory tracks (e.g., visual, audio), spatial and/or temporal dimension, and materiality of signs (how the message is expressed). Consequently, both data visualisations and narrative visualisations can be described as digital narrative media.

Ryan (2004) outlines the following aspects to consider when digital media is discussed in the perspective of narrative: (a) define narrative, (b) identify the distinctive properties and elements of digital media and investigate to what extent these affect narrativity, and (c) review the concept of interactivity and user involvement.

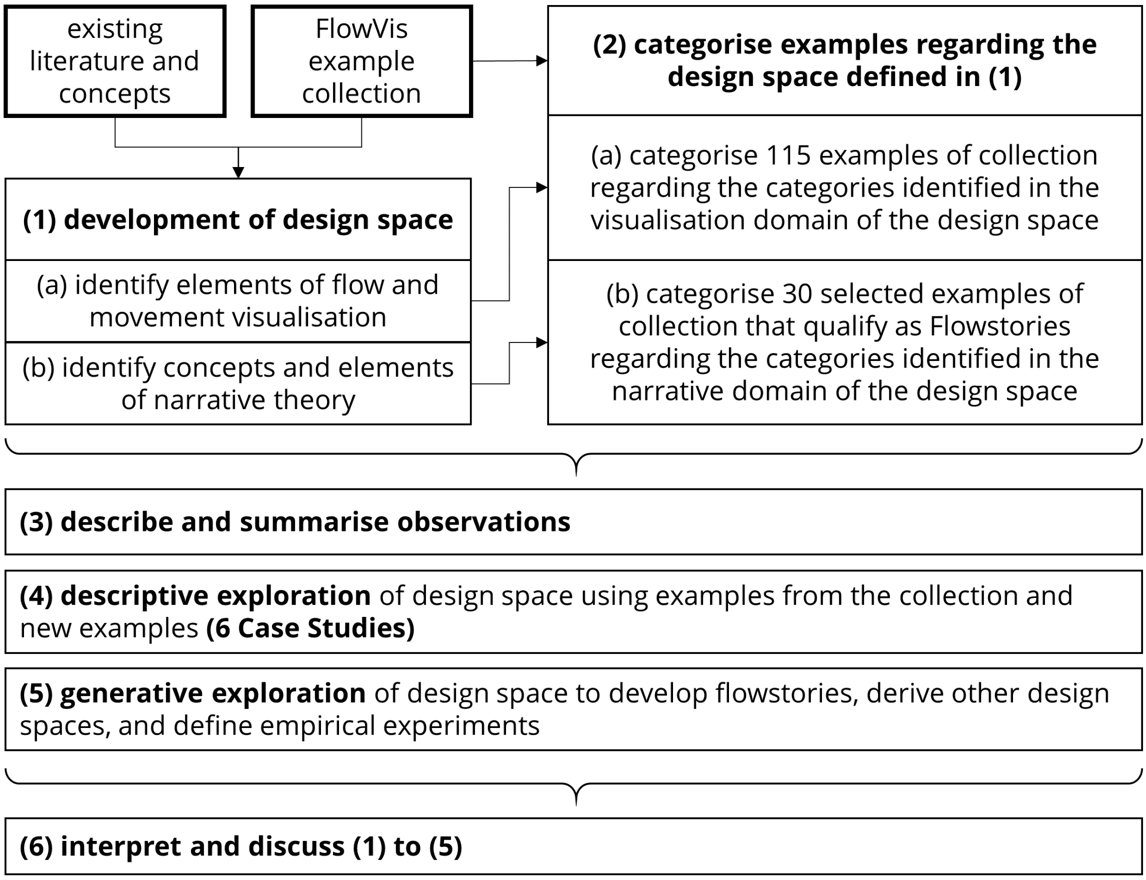


Figure 3.1: Design space study method and procedure overview: Based on existing literature, concepts, and a large set of examples **(1)** categories for the design space are defined, which address flow and movement visualisation on one side and concepts derived from narrative theory on the other side. **(2)** The examples are then categorised regarding (1a) and consequently (1b). In step **(3)**, observations made during the categorisation process are summarised. **(4)** Case studies are used to explore the design space in a descriptive way. **(5)** It is demonstrated how the design space can be used in a generative way. **(6)** A final interpretation and discussion reflect upon the presented design space approach.

Taking these aspects into consideration, the design space survey included multiple stages (Figure 3.1):

0. **Collecting and cataloguing** examples of flow visualisations that meet the criteria of Flowstories to varying degrees and have different degrees of narrativity.
1. **Develop the design space** by (a) identifying the flow and movement visualisation categories based on the properties and elements of the collected examples, literature, and research questions, and (b) defining the narrative categories of the design space based on techniques from narrative theory and data-driven storytelling.
2. **Categorise** the collection regarding both domains. While the categorisation regarding (a) applies to all examples, the categorisation regarding (b) only applies to examples that can be classified as full Flowstories (examples with a high narrativity). The proposed framework enables systematic analysis of existing flow and movement visualisations with varying narrative degrees across domains focusing on design elements and their ability to contribute to story creation.
3. **Describe and summarise** the resulting observations made during the categorisation in (2) in order to identify commonly used elements and techniques, gaps, or infrequently used categories or combinations.
4. **Descriptively explore** the design space through case studies of selected examples. The case studies demonstrate the approach in more detail.
5. **Generatively explore** the design space and explain how to use the framework to *create Flowstories*, *spin-off a new design space*, and *derive experimental designs and protocols*
6. **Interpret and discuss** the strength and limitations of the Flowstory design space approach.

3.1.1 Collection of Examples

The initial step was to build a repository of existing flow and movement visualisations. The current collection consists of 115 examples: **(a)** 63 static graphical displays; **(b)** 19 animated displays and videos; and **(c)** 33 interactive visualisations.

Examples were sampled across various fields including cartography, information visualisation (InfoVis), and scientific visualisation (SciVis). The examples collected include:

(a) 86 geovisualisations (maps) of human (e.g., refugees), animal (e.g., bird migration), or economic (e.g., commodities) movement, as well as earth related flows (e.g., carbon dioxide CO_2 or wind); **(b)** eight non-geographic representations such as Sankey diagrams or network graphs; and **(c)** 21 visualisations of the human blood flow (e.g., in the aorta or within aneurysms).

The examples were collected mostly from online sources including: **(a)** 42 scientific publications; **(b)** 25 blog posts or online news articles; **(c)** 25 web pages dedicated to the example; **(d)** 15 figures from online library collections; and **(e)** eight books and atlases. An overview with detailed sources, images, and videos of the collected items can be found online[1].

Besides the **(a)** 21 blood flow examples, the collection includes visualisations on the following topics: **(b)** 33 examples of the movement of migrants and refugees; **(c)** 23 examples of traffic and travel; **(d)** 14 examples of economy and health; **(e)** ten examples of war or military; **(f)**, nine examples of nature, including animal migration and earth dynamics. **(g)** Five examples have a generic or unspecified theme; this is especially true of examples from scientific publications where the topic is less important than the visualisation technique itself.

The collection also includes *not very story-like* or *conventional* visualisations. These examples provide the possibility to explore narrrativisation, described in this work as the process of converting a not very story-like or conventional visualisation into a Flowstory.

The collection grew throughout the course of the project and is by no means complete. Nevertheless, the large number of collected examples provide a comprehensive overview. The design space's flexibility and the domain-independent categories allow new examples from various fields to be analysed in the future. In the next section, how the categories of the design space were developed using the collection of examples is explained.

3.1.2 Development of Categories and Categorisation Procedure

As discussed in Chapter 2 (Background and Related Work), the dimensions or categories of the design space are based on theory and existing work and were developed using an approach similar to the thematic analysis (TA) introduced by Braun and Clarke (Braun and Clarke, 2006, 2013; Clarke and Braun, 2017). TA is a method to identify, analyse, and interpret patterns within qualitative data, such as the collection of examples introduced

[1] https://flowstory.github.io

in Section 3.1.1. TA's flexibility, as described by Clarke and Braun (2017), is well suited for identifying the relevant categories of the design space. Adopting parts of this approach enables a high degree of robustness and helps minimise errors (e.g., circular arguments).

Developing the categories was an iterative and incremental process. Starting out from a visualisation perspective, but with narrative aspects constantly in mind, the 115 examples were used to investigate and identify the properties and characteristics of flow and movement visualisations across domains. At the time of writing this thesis, the author is not aware of any framework that explores flow and movement visualisation across domains. Most contributions focus on the visualisation of certain data types (e.g., origin-destination data) and provide either visualisation techniques (e.g., OD Maps by Wood et al. (2010)) or design guidance (e.g., for flow maps by Jenny et al. (2016c)). The design space developed here aims to address properties and characteristics of flow and movement visualisations regardless of the specific data types.

One of the first steps was to determine how certain properties of flow and movement were used in the collected examples. The following questions served as guidance during the thematic analysis of the collection:

- How is the flow or movement depicted? Which elements reveal this information?
- How is the direction of the flow or movement communicated?
- How are the origin and destination encoded?
- When did a flow or movement happen? How is time encoded?
- Is the magnitude of the movement or flow indicated? If so, how is it encoded?
- How are speed, duration and/or velocity encoded?
- Which elements show different groups, categories, or types of flow or movement (excluding direction)? How is this information encoded?
- Which elements communicate additional thematic or narrative context?
- How can users participate or interact?

Finding answers to these questions resulted in short observational descriptions. For example, looking at the first question, *flows or movements are depicted* by *animated particles, dots, GPS positions, paths, lines, arcs, streamlines, etc.*. For all answers to this first question, see Figure 3.2. A comprehensive evolution of the entire design space is available online[2]. The categories and their possible values were derived from the observations of each question. For example, observations on *how flows and movements are depicted* yielded the high-level categories of *data*, *spatial abstraction*, *style abstraction*, *motion*, and *dimension of space* with their respective values (Figure 3.2).

Similarly, categories for the direction, origin, and destination of flow and movement, for temporal, quantitative, and qualitative information, as well as for context and interaction, were developed based on the listed questions.

In a second iteration, the categories and values were refined or redefined (see the fields highlighted in blue at the bottom of Figure 3.2). After the categories and values were refined, the example were re-categorised accordingly. Based on this, the categories and values were revised again and a new perspective was taken by introducing a hierarchical structure of layers, topics, and marks or elements. For example, text elements can convey spatial, temporal, qualitative, or quantitative information within the flow and movement representation layer, provide context within the context representation layer, or have interaction capabilities in the interactivity layer. From a user-perspective, clicking on a flow line showing flows between two locations might open a pop-up box with additional text providing detailed temporal and quantitative information and more context, such as the reason(s) for movement.

After re-categorising the first 28 examples, two more iterations of refinement were conducted (see Figure 3.3) to reach the final categorisation and values, which are explained in detail in Section 3.2. The final categories for the flow and movement component of the design space are, in the simplest terms, elements or concepts that an author could consider including or omitting during the design stage of the visualisation.

The five narrative categories were developed by systematically comparing and reviewing existing work. The result is reflected in Section *2.2.2 Narrative and Visual Elements and Techniques Investigated*. The case studies in Section 3.3 illustrate the categorisation process with examples.

After finalising the categories and values, all 115 examples were categorised. Based on their initial subjective narrativity rating (see Section 3.2.3), 30 of the original 115 examples were selected for further evaluation regarding the narrative component of the design space. The marks and elements of the 30 examples were rated on a three-tiered scale (low, moderate, or strong) based on their contribution to one or more narrative categories. For example, the aforementioned text-based element *pop-up box* might have a strong

[2] https://flowstory.github.io/

Initial Question

How is the actual flow or movement depicted? Which elements reveal this information?

Observations

animated particles, dots, GPS positions [exact]
animated particles, dots [not exact]
not animated particle, dots, circle
accumulated particles over time [trajectory based]
icons, arrowhead, arrow, arrow-glyph [field based]
animated icons, dots, line parts along path
path, line, arc, streamline [exact, trajectory based]
animated bands, path line, texture animation
path, line, arc, band, arrow, streamline, stream tape, line bundle, tube [field based, not exact path or no geography]
animated lines or vectors [field based]
contour lines, median line [field based]
(temporal) heat map, heat map (OD matrix), density heat map (line density, kernel density) [derived from lines, trajectories]
surface, planes (2D and 3D) [field based]
pixels, areas [field based]
label, annotation, text, text boxes, alphanumeric, tables [on hover or click, on/in visualisation or aside]
position, layout(left to right, radial), composition
scroll animation
animation over time, animation
illumination [style]
illustrative style
pictorial, figurative symbolisation
custom symbolisation

Categories and Values 1 (Topic: Space)

Data	*Geometry*	*Spatial Abstraction*	*Style Abstraction*	*Motion*	*Dimension of Space*
tabular/od	point	exact	abstract	still	2D
trajectory	line	approximate	geometric	animated (morphing)	2.5D
field based	area		mimetic	moving (tweening)	3D
	field		pictorial		4D
			figurative		
			illustrative		

Categories and Values 2 (Topic: Space)

Data	*Flow Mark*	*Spatial Abstraction*	*Style Abstraction*	*Motion Abstraction*	*Dimension of Symbol*
tabular/od	point	exact	abstract/geometric	abstract	0D
trajectory	line	approximate	mimetic/pictorial	mimetic	1D
field based	area				2D
	field/raster				3D
					4D

Categorisation of 28 examples

Figure 3.2: Category development for one aspect of the design space (part 1): Initial question, observations (answers to the question), category development iteration 1 and 2. (continues in Figure 3.3)

contribution to the *messaging and argumentation* category because of its context (e.g., war as the trigger for movement), has the potential to moderately evoke *emotions,* and it can also provide *explicit user involvement* through interactivity.

Introducing the layer, topic, mark/element structure

Categories and Values 3
Layer: **Flow/Movement Representation**; Topic: **Spatial Information**; Mark/Element: **Flow/Movement Mark**

Geometry	***Spatial Abstraction***	***Style Abstraction***	***Dimension***	***Direction****
point	exact	geometric	0D	colour
line	approximate	intermediate	1D	texture
area		mimetic/pictorial	2D	orientation
raster			3D	shape
			4D	spacing
				motion
				size
				position

Applied to 28 examples

Categories and Values 4
Layer: **Flow/Movement Representation**; Topic: **Spatial Information**; Mark/Element: **Flow/Movement Mark**

Geometry	***Spatial Abstraction***	***Style Abstraction***	***Dimension***	***Direction****
point	exact	geometric	0D	colour
line	approximate	intermediate	1D	texture
area		mimetic/pictorial	2D	orientation
grid			3D	shape
			4D	motion
				size
				position

Applied to 28 examples

Categories and Values 5
Layer: **Flow/Movement Representation**; Topic: **Spatial Information**; Mark/Element: **Flow/Movement Mark**

Geometry	***Levels of Abstraction***	***Direction****
point	geometric	colour
line	intermediate	texture
area/volume	mimetic/pictorial	orientation
grid		shape
		motion
		size
		position/layout

Applied to 115 examples

Figure 3.3: Category development for one aspect of the design space: Iterations 3 to 5. (* The ***Direction*** category was derived from the question, "How is the flow or movement direction communicated?". The ***Dimension*** category was dropped in the last iteration, because that information is conveyed by the type of geometry and visual channels used. See the online material[3] for the entire design space.

Although the development and categorisation process initially progressed from visualisation elements to their ability to evoke story (inside-out), the design space also encourages investigating how concepts from narrative theory might be implemented or supported through the use of elements identified in the flow and movement domain of the design space (outside-in).

If a category value was not used, it was either not a meaningful metric or did not apply to the investigated flow and movement visualisations. These possible “white spaces” in the framework are later evaluated and discussed.

Three important aspects to consider throughout this thesis: First, the categorisation process is not a strict coding. Any quantification process would be of little to no meaning. It is not possible, nor does it make much sense, to determine whether one element offers twice as much narrative structure as another. Instead, the design space provides a framework, a structured way to analyse and think about the problem domain (i.e., the visualisation of flow and movement data in a narrative context). Second, the results reflect expertise built up throughout this PhD research and personal judgements and assessments of the examples in regards to the design space. Due to the qualitative and subjective nature of the research, others may reach different conclusions. Third, the analysis and figures are based on the 115 examples for the flow and movement component and selected 30 examples for the narrative component. Additional examples may lead to additional or different observations.

3.2 A Design Space for Flowstories

Although having emerged over a half century ago, narrative theory does not have a rigorous domain-specific ontology. Visualisation researchers across various domains must accept a certain degree of multiple, differing definitions of narrative and storytelling (the act or process of narration). Therefore, it is essential to clearly define the terms and vocabulary used in the Flowstory design space.

In the context of this work, the term ***flow and movement visualisation*** includes visualisations across domains that depict flow and movement of distinct entities (e.g., humans, animals, cars, or goods) and continua (e.g., blood, air, or pollutants).

Narrative is a combination of *story* and *discourse*; story is a narrative’s mental representation induced by discourse, the representation of a narrative through material and signs. In the background chapter ***narrativity*** was introduced as the degree to which discourse elements can help to evoke story. Narrativity is relevant to the categorising of visualisations for the narrative component of the design space. A ***Flowstory*** is a narrative visualisation that depicts flow and movement data, evoking a story in a reader’s mind.

In subsequent sections, the categories and values for both components of the designs space are discussed using examples from the collection of flow visualisations. These categories help analytically assess flow and movement visualisations in the context of narrative.

3.2.1 Flow and Movement Visualisation Categories of the Design Space

The definition of the visualisation side of design space is driven by the representation of flow or movement, the provided context, and the integrated interaction. As introduced in the background chapter and mentioned in the preceding section, the notion of *editorial layers* is used to provide a top-level structure: a flow and movement representation layer,a context representation layer, and an interactivity layer.

The design space groups possible design elements into five distinct visual marks or elements: **(1)** **flow and movement marks** (; e.g., animated dots or lines showing flow or movement), **(2)** **location** or **origin-destination marks** (; e.g., illustrative symbols conveying origin and/or destination), **(3)** additional **visualisations** and **media elements** (; short: vis-media; e.g., charts, timelines, visual annotations, videos, pictures), **(4)** **text representations** (; e.g., text-based labels and annotations including numeral information), and **(5)** **audio elements** (; e.g., voice-over narration or sound effects). Each of the five marks or elements can convey information within one or more of the three layers. Additionally, **(6)** **interactions** (; e.g., scrolling, detail on demand through click or mouse-over) are taken into account within the design space.

Aspects of flow marks and location marks are integrated into the design space mainly through the **mark properties geometry** and **abstraction** as well as **visual channels** (visual variables) **encoding** various flow and movement characteristics (e.g., direction, magnitude). The following visual variables are used across the design space: ***texture*** (), ***shape*** (), ***colour*** () including hue, saturation, value and transparency, ***size*** (), ***position*** (), ***orientation*** (), ***motion*** (), and ***density*** (). Visual channels are fundamental across visualisation domains. They are, therefore, an essential part of the design space, which aims to bring visualisation aspects together with narrative.

Vis-media, text, and audio elements, as well as interactions, are differentiated by their **mode of integration** relative to the main display of flow and movement. These elements and interactions can be **(a)** coupled or uncoupled and **(b)** superimposed or juxtaposed.

A coupled element is thematically or interactively linked to the main flow or movement depiction. An uncoupled element, on the other hand, provides additional non-flow-describing aspects or does not affect the main display.

The terms superimposed and juxtaposed are not used in the entirely same way as introduced by Gleicher et al. (2011) for strategies for visual comparison. In this case, they are used from a layout or structural perspective. When an element is integrated through superposition, it means that it is contained within the same layout space as the central flow visualisation itself. Following Gleicher et al. (2011), the essential criterion *"is a sense of 'the same space'"*. Such elements might describe or provide further detail about the depicted data space of the flow or movement information (e.g., through tool-tips or pop-ups) or might be integrated into the data space directly (e.g., a background map). Juxtaposed elements, on the other hand, do not share the layout space regarding the main flow or movement visualisation.

By combining these two concepts, there are four **modes of integration** possible. An element can be ***coupled superimposed*** (), ***uncoupled superimposed*** (), ***coupled juxtaposed*** (), or ***uncoupled juxtaposed*** ().

Both concepts, superimposed vs. juxtaposed and coupled vs. uncoupled, are connected by their **proximity** to the central information (flow and movement data). The first concept concerns the layout, and the second concerns the content. Overall, this distinction combines the two central aspects of the design space, visualisation and narration. The goal is to see how different modes of integration are used to foster narrative. Further, this distinction can provide a way for authors to decide how closely selected information should be placed (visually and thematically) to the central display or topic.

Figure 3.4 provides a top-level summary of the frequencies of identified marks, elements, and interactions. For example, 149 flow marks were identified within all of the 115 examples. This means that all of the examples have at least one flow mark and that several examples have two or more flow marks (i.e., about a quarter of the examples). Multiple flow marks in a single example could either convey the same flow (e.g., a line symbol connecting two locations and a point symbol animated along the line) or different movements visible either at the same time or sequentially. 140 location marks were found in 108 of the 115 examples. Again, about a quarter of the examples have more than one location mark, but seven examples have no location marks at all. Almost all of the examples have at least one vis-media element, but over 80% have two or more. More than 95% of the examples have two or more text-based elements. In only 14 of the 115 examples, 22 audio elements were identified (i.e., voice-over narration, background music). Sixty-two examples have some form of interactivity (i.e., 166 interactions were identified, including video playback).

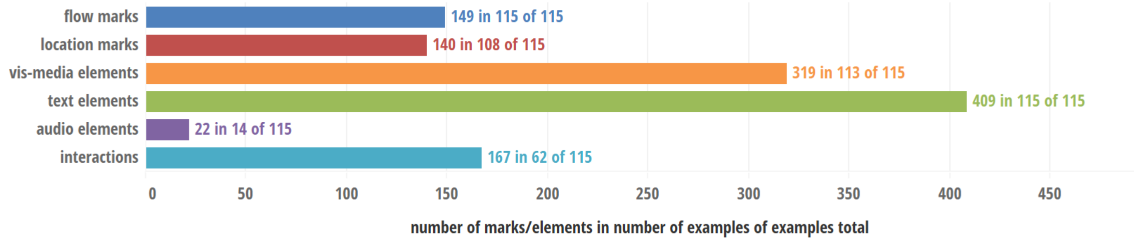


Figure 3.4: Number of marks, elements, and interactions identified in number of examples of 115 examples in total.

The following three sections, applying the three-folded layer differentiation, explain the low-level categories and their possible values with examples and summarise their frequency of use within the whole corpus of examples.

3.2.1.1 Flow and Movement Representation Layer

Most flow or movement visualisations convey the answer to the question: ***When*** and ***how much*** (or fast) did ***what*** (or who) move (flow, pass) from ***where*** to where (or through where)? Thus, visualisation elements represent **(1) spatial** (location and direction), **(2) temporal**, **(3) qualitative**, and **(4) quantitative** aspects and characteristics of flows and movements. All five marks and elements can convey these four aspects of information.

(1) Spatial information — The depiction of location and direction of flow and movement aligns with the idea of *story space*, the space where events take place (e.g. migration between *European countries*). The layout space of a visualisation, on the other hand, can in this context be understood as the *discourse space*. It is the canvas authors fill with a visual narrative using different elements and techniques.

While flow marks and location marks express location through geometry and levels of abstraction and direction through visual encoding, elements that convey location and direction (vis-media, text, and audio) are categorised by their mode of integration. The different possibilities are explained in the following sections.

Flow mark **geometry**:
Regarding spatial information, flow marks are categorised based on their geometry, level of abstraction, and how flow or movement direction is encoded. A flow mark can have a ***point*** ( ), ***line*** ( ), ***area or volume*** ( ), or ***grid*** ( ) based **geometry**.

The examples in Figure 3.5 show a selection of the four possible geometries across domains (Find the citations and references of all examples online[4] or in Appendix A by using their unique identifier *FS_****).

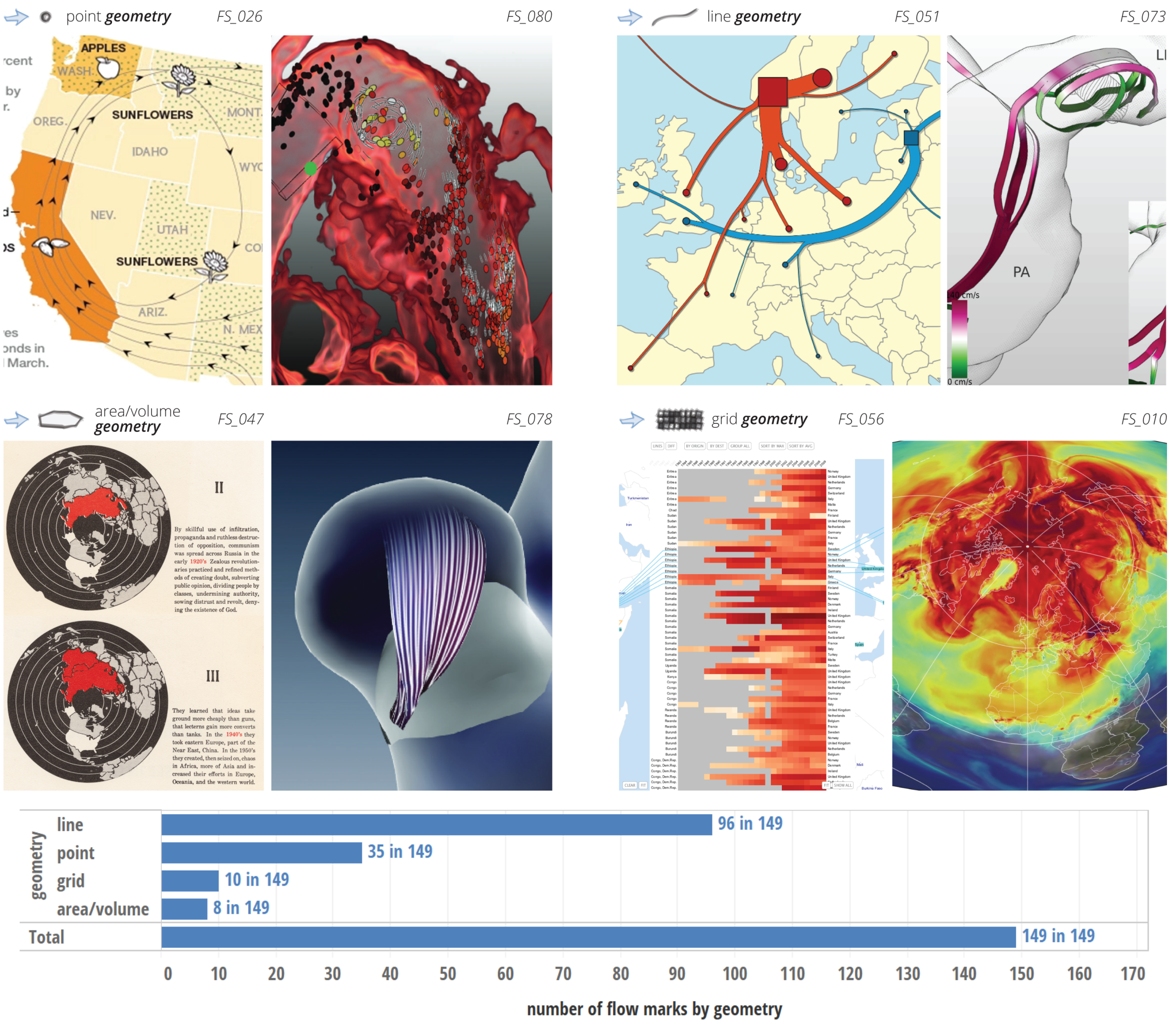


Figure 3.5: ***Top:*** Possible ***geometries*** of flow marks. ***Bottom:*** Frequencies of the four flow mark geometries. In total, 149 flow marks were identified within the 115 visualisations in the collection. An example can have multiple flow marks. For instance, 35 of the 149 flow marks have a point geometry and were found in 34 visualisations. Thus, one visualisation has two point flow marks. Note, the number of visualisations across geometries, the last number, does not add up to 115. This is because a visualisation can have multiple flow marks with different geometries.

FS_026 uses ***animated point symbols*** to indicate the seasonal migratory patterns of beehives (bee farmers) in the United States (US). ***Comic style, deformed circles*** are used in *FS_080* to illustrate blood flow. Alternatively, line geometries can be used to connect origin

[4] https://flowstory.github.io/

and destination (e.g., with a simple arc) or to depict a path (e.g., gps-track, or blood flow path) directly. Example *FS_051* shows the migration of people to Norway and Latvia from European countries using ***flow trees***. An ***illustrative stream tape***, also a line geometry, depicts a pathological blood flow in the left pulmonary artery in *FS_073*. Furthermore, an expanding area or volume geometry can display movement patterns. In visualisation *FS_047*, a US propaganda piece, small multiples depict the propagation of the "Socialist/Communist Conspiracy" across the globe with a ***red area geometry***. In *FS_078*, a ***3D surface geometry*** is used to depict the inflow jet into an aneurysm using surface stripes to convey shape. Grid-based geometries use (raster) cells to depict flows. In *FS_056*, a grid is used to depict migration flows between countries over time using a ***heatmap***. The annual, global dispersion of CO_2 in the earth's atmosphere is the topic of *FS_010* depicting a ***raster-based simulation***.

Location, inherent to flow marks, is in the collection of examples largely encoded through *line* geometries (i.e., 96 of all 149 flow marks found within 92 visualisations). Less than a quarter of all flow marks have a *point* geometry. Only a few examples have an *area or volume* or *grid* geometry (compare Figure 3.5 bottom).

Location mark geometry:
Location marks are also categorised by their **geometry** (see Figure 3.6). A ***point symbol*** may represent a city or region (*FS_055*), and a ***vertical line geometry*** is used for origin-destination marks, for example, in Sankey diagrams (*FS_003*). ***Areas*** depicting location marks may be migratory birds' winter or summer habitats, or as in *FS_003* ***emitter planes*** of blood flow simulations. *FS_003* also uses a ***volumetric anatomical context*** as a location mark. Finally, a ***regular grid*** might be used to segment or tessellate the underlying space (*FS_022*). Location marks indicate from where to where or through where a flow or movement happens or happened.

Within the corpus of examples, more than half of the location marks have *area or volume* geometries and more than a third have *point* geometries. Only a tenth of all location marks have a *line* or *grid* geometry (see Figure 3.6 bottom).

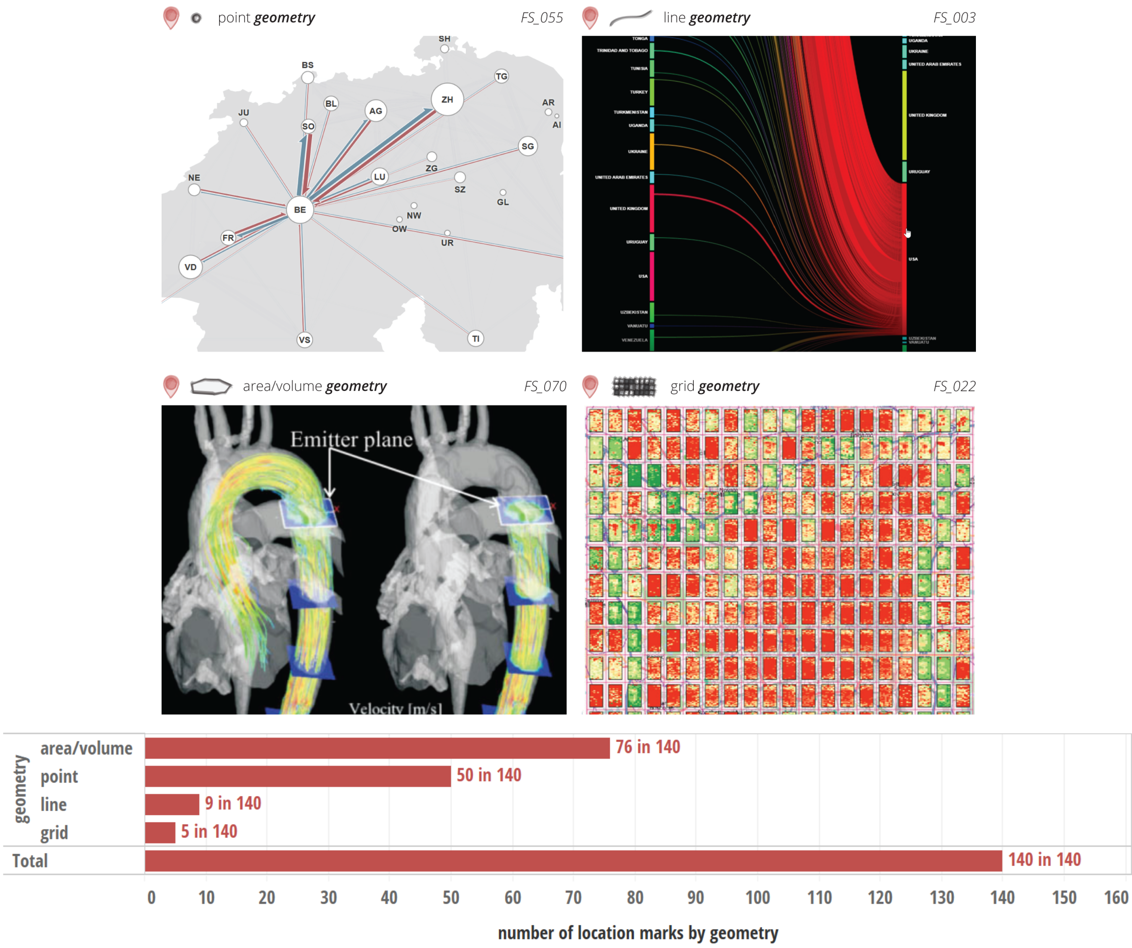


Figure 3.6: ***Top:*** Possible ***geometries*** of location marks. ***Bottom:*** Frequencies of the four location mark geometries. In total, 140 location marks were identified within 108 of the 115 visualisations. Thus, examples can have multiple location marks with different geometries, or none at all. For instance, five out of the 140 location marks have a grid geometry, which were found in five different visualisations.

Both flow marks and location marks can have different **levels of abstraction** as shown in Figure 3.7 and Figure 3.8.

Flow mark level of abstraction:

The visual style can be either ***geometric*** ( ) with a high level of abstraction or ***mimetic, pictorial or realistic*** ( ) with a low level of visual abstraction. For example, a soldier could be displayed with a circle or with an icon depicting a human body holding a rifle. Since this is not strictly binary, ***intermediate*** ( ) was added as a third value, which for example includes sketchy, highly illustrative render styles. Even if the style is more on the abstract side, it may convey some meaning (e.g., a soldier represented through a simple dot where a shaking motion indicates fighting action).

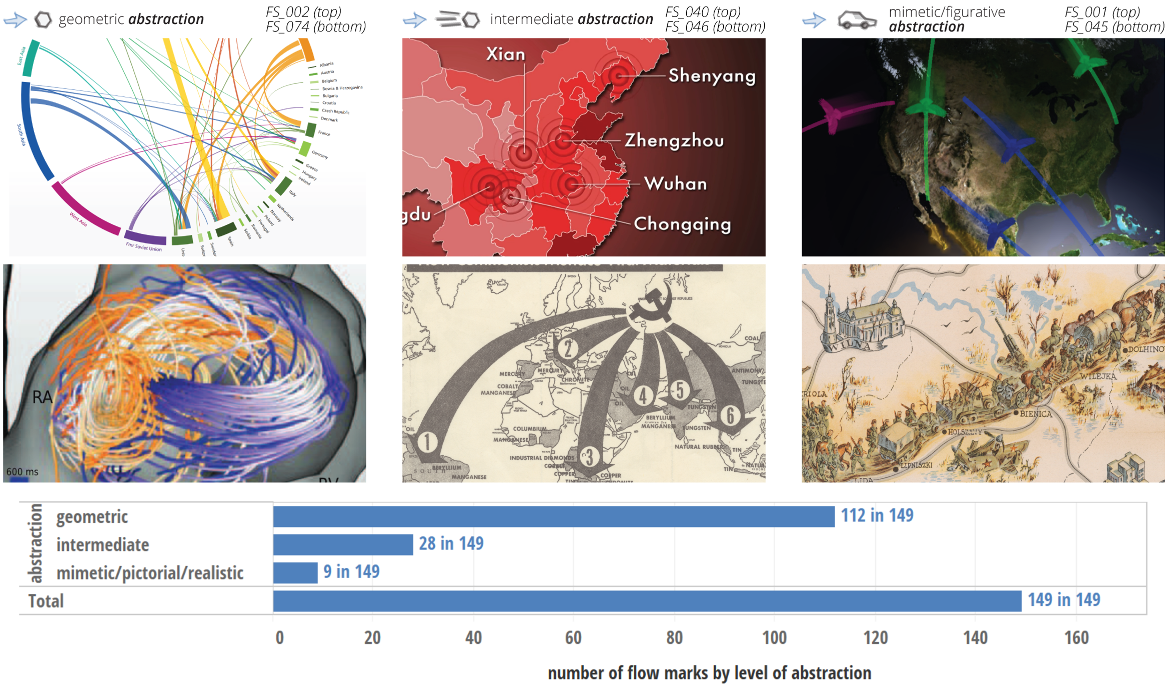


Figure 3.7: ***Top:*** Examples for ***levels of abstraction*** for flow marks. ***Bottom:*** Frequencies of the different levels of abstraction used by the 149 flow marks identified within the 115 examples. For instance, nine of the 149 flow marks have a low level of abstraction (i.e., mimetic/pictorial/realistic), which were found in nine different visualisations.

The ***flow lines*** in *FS_002* and *FS_074* in Figure 3.7 have a geometric style with a high level of abstraction. In the first example, human beings migrating between countries are represented through simple lines in aggregated form. In the second example, blood flow through the human body is represented with streamlines. The migrating birds depicted with ***animated bird icons*** in *FS_001* have a low level of abstraction. Also, the ***figurative soldiers and machinery*** in the map *FS_045* are an example of a mimetic or pictorial level of abstraction.

The cases with an intermediate level of abstraction use, for example, a geometric symbology combined with motion or visual metaphors and therefore convey some meaning. The ***pulsing glyphs*** in *FS_040* reflect the waves of migration towards urban areas in China. In the US propaganda map *FS_046*, the style and the placement of the flow marks indicate that communism spans across the entire globe - much like a ***big claw*** trying to take possession of the whole world.

Three-quarters of the 149 flow marks have a *geometric* level of abstraction and are in over 80% of the visualisations in the collection. Less than a fifth of the flow marks have an *intermediate* level. Very few flow marks have a *mimetic, pictorial or realistic* level of abstraction (compare Figure 3.7 bottom).

Location mark level of abstraction:
In the example *FS_001*, Figure 3.8, the ***blue destination and origin areas*** have a geometric level of abstraction and represent the winter and summer habitats of migrating European honey buzzards. Additional meaning is gained only when combined with the background imagery, which provides additional context (see Section 3.2.1.2). The countries with their respective ***flags integrated into their territory*** in *FS_110* have a mimetic level of abstraction. The ***anatomical context*** of the blood flow depictions in the examples *FS_087* and *FS_088* uses an illustrative rendering style and is classified as a location mark with an intermediate level of abstraction.

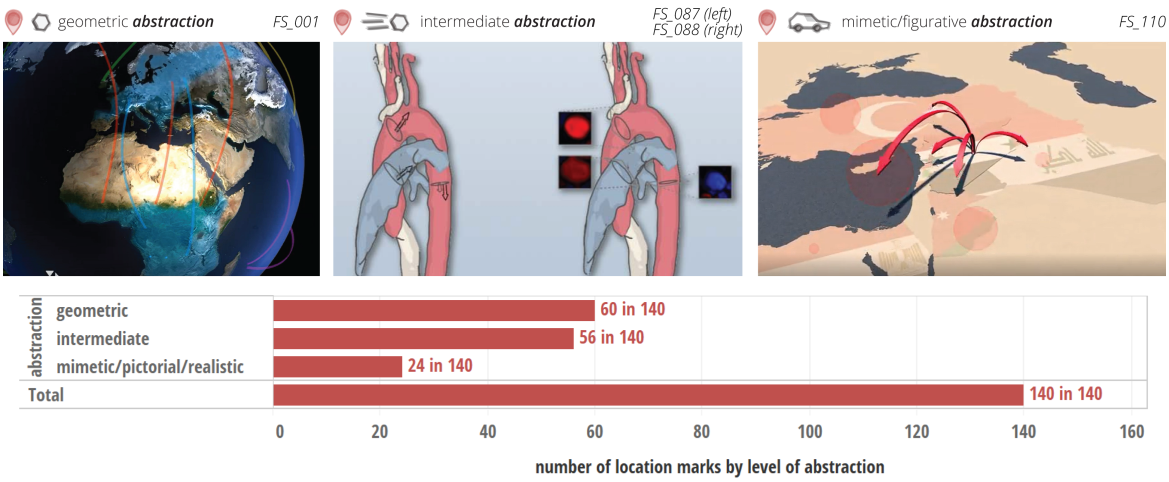


Figure 3.8: ***Top:*** Examples for ***levels of abstraction*** of location marks. ***Top:*** Frequencies of the different levels of abstraction used by the 140 location marks identified within 108 examples in the collection. To illustrate, 60 of the 140 location marks have a high level of abstraction (i.e., geometric). The 60 instances were found in 56 visualisations, demonstrating that several examples contain more than one geometric location mark.

Within the entire corpus of examples, location marks with a *geometric* or *intermediate* level of abstraction are common (i.e., 60 and 56 respectively out of 140). Seventeen percent or all location marks have a *mimetic, pictorial or realistic* level of abstraction (see Figure 3.8 bottom).

Flow marks and location marks can encode **direction** using visual variables as shown in Figure 3.9 and Figure 3.10.

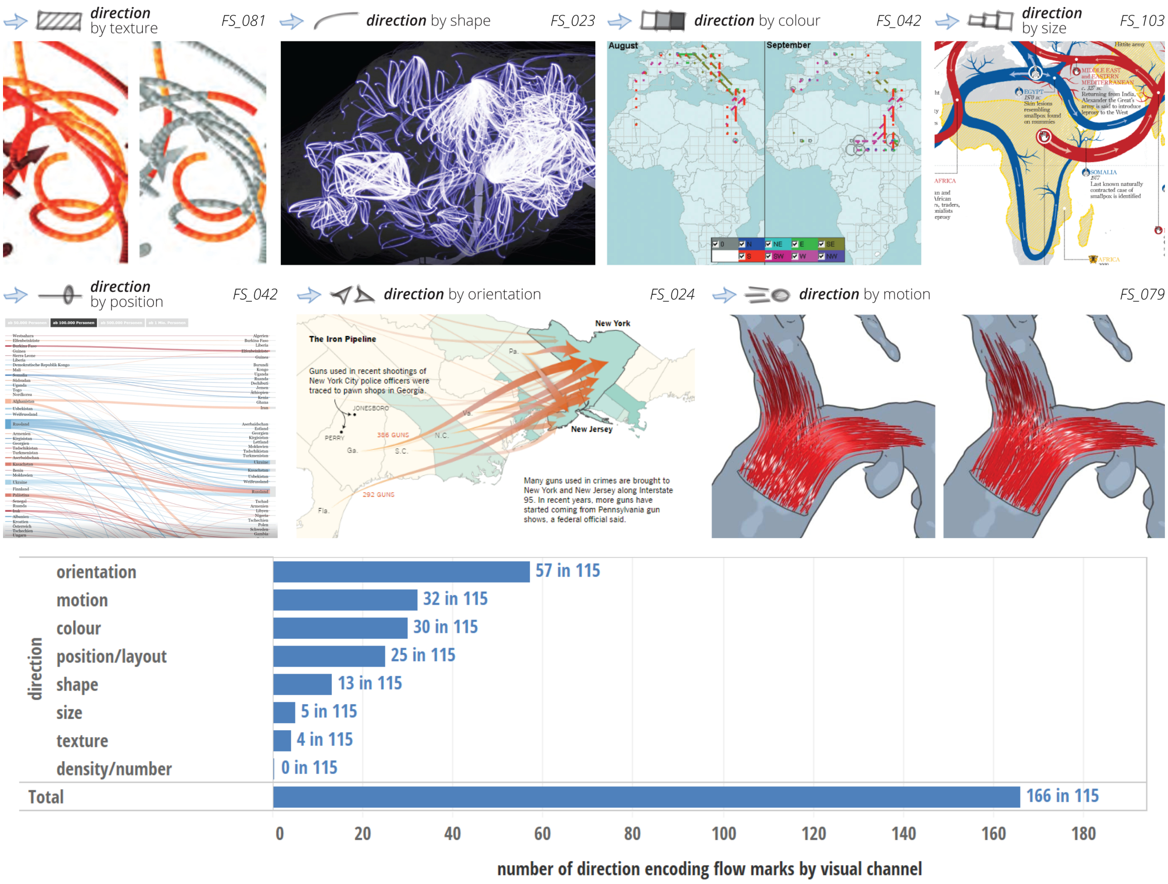


Figure 3.9: ***Top:*** Examples how flow marks can convey ***direction*** of flow or movement. ***Bottom:*** Frequencies of flow marks encoding direction by visual channel. Overall, 115 of the 149 flow marks encode direction. The 115 flow marks encode direction 166 times. Consequently, several flow marks double encode direction, or direction is encoded more than once through different flow marks in one visualisation. To illustrate, 32 of the 115 flow marks convey direction through motion. Those 32 instances are within 30 visualisations. Note, the numbers of visualisations across visual channels, the last number of the label, do not add up to 98 because of multi-encoding of direction in several examples.

Flow mark encoding of direction:

In example *FS_081*, the ***texture***, an arrowhead pattern, of the tuboid flow marks is used to indicate local direction of the depicted blood flow. The ***shape*** of a flow line in *FS_023* expresses in which direction cyclists moved with hire bikes between docking stations. The long end of the asymmetric arc indicates the origin and the short end the destination of a journey. The direction of bird migration is encoded using ***colour*** and ***orientation*** in *FS_042*, where directional bars use different hues to indicate the cardinal directions. It is an example of how a mark can double encode information. In *FS_103*, the ***size***, in this case the width of the flow mark, encodes from where to where the depicted diseases (i.e., leprosy and smallpox) spread out over time (flow from thick to thin). Example *FS_042* encodes direction through ***position*** using layout (flow from left to right). Arrowheads (***orientation***) in *FS_024* indicate from which U.S. states firearms originate and where they are used for crimes in other states. The same example also uses shape (i.e., tapered line from narrow to thick) and colour (i.e., orange gradient from light to dark) to convey direction. Finally, ***motion*** is often used to communicate the direction of movement. In *FS_079*, two stages of animated highlights are shown (i.e., white elements animated along the blood stream lines).

Examining Figure 3.9 (bottom), direction is encoded mainly through the flow marks' *orientation* and *colour* (i.e., hue) in an explicit way. Implicitly, the *motion*, *position or layout*, and *shape* of the flow marks frequently convey direction in the examples. Rarely, the visual channels *size* and *texture* are used to encode direction through flow marks. In the corpus of examples, *density or number* was not used to encode direction with flow marks.

Location mark encoding of direction:
The visual variables shape, colour, position, orientation, and motion are also used by location marks to encode direction (Figure 3.10). In *FS_051*, different ***shapes*** indicate origins (i.e., circles) and destinations (i.e., squares) of migration movements from the top 10 US states to California and New York. ***Colour*** is used in example *FS_015*. Blue location marks are places of birth and red marks are places of death of famous people, which communicates the direction of movement (from blue to red). In *FS_112*, the location mark (i.e., the boundary shape of China as part of the background map) uses ***position/layout*** to convey direction. Exports are on the left side, and imports are on the right. The orientation and colour of the directional bar chart, the location marks of *FS_030*, indicate the direction of the net flow, showing if more people moved to or away from a city. Finally, direction can be encoded through motion. In *FS_115*, the background map is continuously centred according to the motion of the flow mark.

One third of the 108 location marks primarily use the visual channels *colour* and *position/layout* to encode direction. As the chart in Figure 3.10 shows, fewer location marks use the channels *orientation*, *shape*, or *motion*. The other visual variables (i.e., *texture*, *size*, *density/number*) were not applied in the 115 examples to encode direction with location marks.

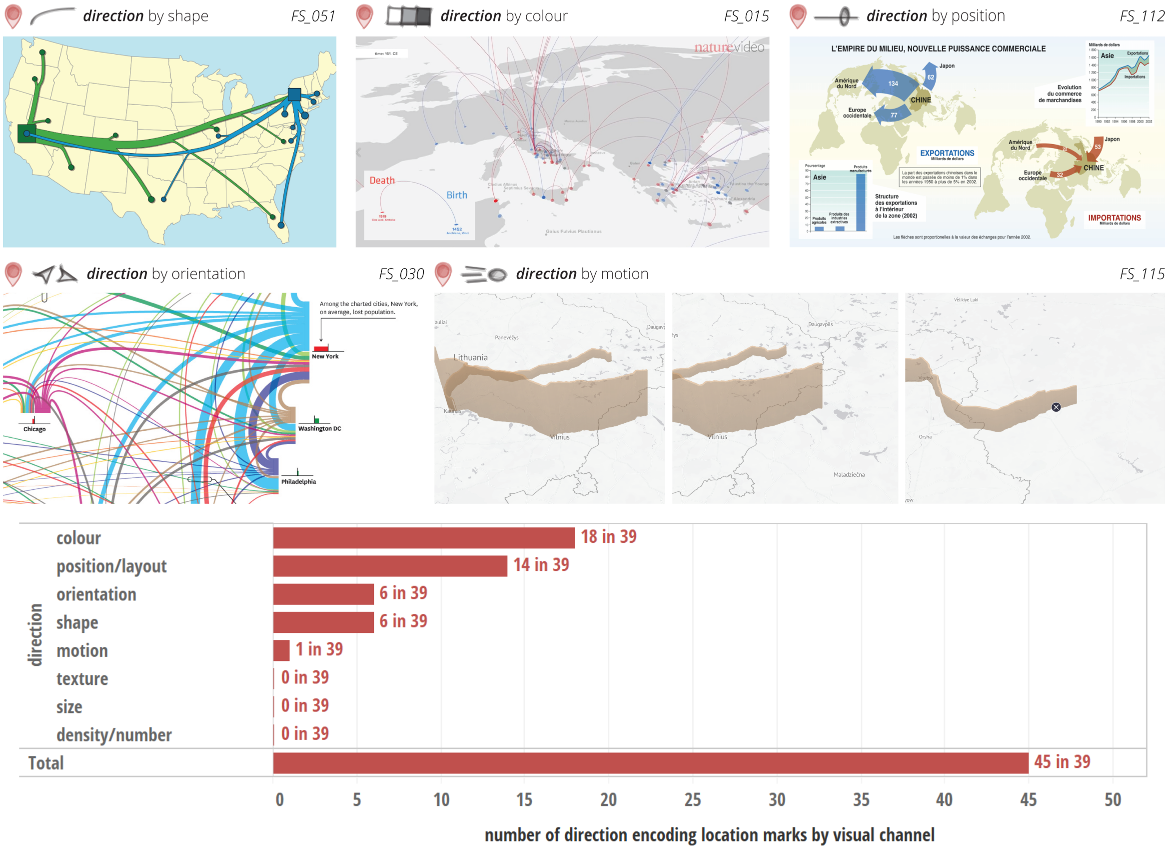


Figure 3.10: ***Top:*** Examples how locations marks can convey ***direction*** of flow or movement. ***Bottom:*** Frequencies of direction encoding location marks by visual channel. Over a third of the 108 location marks encode direction (in 38 examples in the collection). The chart reveals, that (a) no visualisation has an instance using the same visual channel more than once (e.g., the visual channel colour is used *18* times in *18* visualisations), and that (b) several visualisations have location marks that multi-encode direction (i.e., 45 instances of direction encoding flow marks are found in 38 visualisations).

The other three elements (vis-media, text, and audio) can also convey location and direction. These three elements are described by the four **modes of integration** introduced in Section 3.2.1.

Vis-media integration of location and direction:

Coupled superimposed visual annotations can highlight special locations (e.g., the arrow indicating the aneurysm in *FS_051* on the left in Figure 3.11) or direction (e.g., arrows on the right side of example *FS_051*). These elements are coupled because they are directly pointing to or describing the blood flow and its characteristics. They are superimposed because they share the same layout space as the flow depiction.

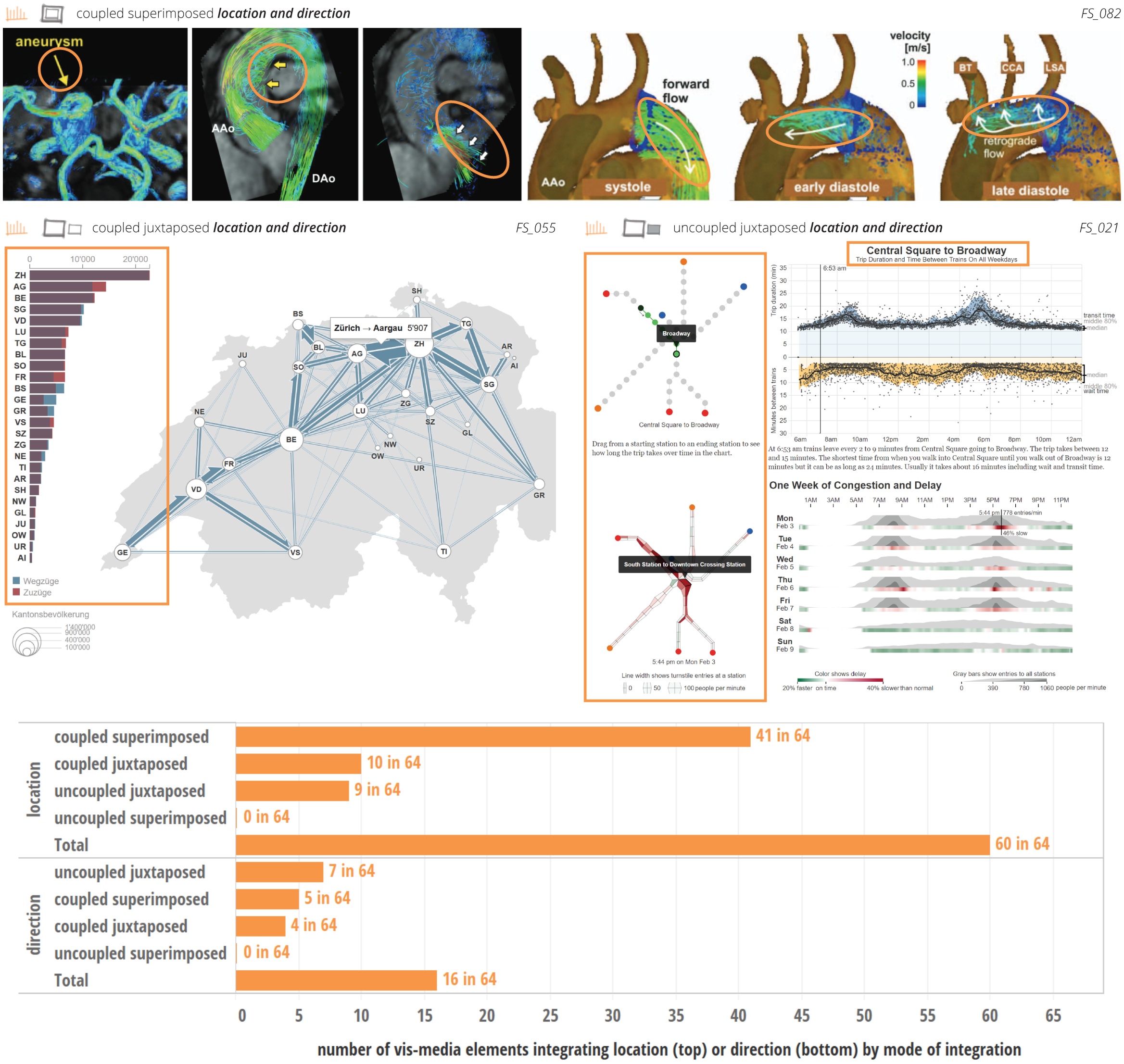


Figure 3.11: ***Top:*** Examples for vis-media elements showing ***location and direction***. ***Bottom:*** Frequencies of vis-media elements conveying spatial information by mode of integration. Only 19% and 5% of the 319 vis-media elements found in the examples, convey location and direction respectively. (How to read the label: instances with integration mode of all vis-media elements containing spatial information in number of visualisations.)

The two other cases in Figure 3.11 show examples of ***juxtaposed*** charts and maps that inform the reader about location and direction. While the axis labels in *FS_055* indicate location, the colours (red and blue) convey the direction of migration between Swiss regions. Since the chart is interactively linked with the flow map, it is categorised as ***coupled***. The vis-media elements in *FS_021* convey location and directions but are ***uncoupled*** from the main visualisation that is placed above. They do not directly address the Boston train movement visualisation of the web-based data story, but provide additional spatial information, context, and functionality (e.g., users can interactively select their own commute in the train network to retrieve filtered data).

Less than a fifth of all 319 identified vis-media elements within the visualisations in the collection integrate location. Most vis-media elements that do integrate location are *coupled superimposed*. *Coupled and uncoupled juxtaposed* integration is used less often. Only a few vis-media elements integrate direction. The integration modes *coupled superimposed* and *coupled and uncoupled juxtaposed* are used almost equally frequently. The *uncoupled superimposed* integration mode is not used by vis-media elements to convey spatial information. That seems reasonable, since uncoupled superimposed information that does not describe the depicted events directly would introduce clutter into the visual display.

Text integration of location and direction:
Text annotations, titles, teaser text, and flowing text (e.g., larger text blocks or articles) can include information about location and direction of flows or movements (Figure 3.12). In *FS_103*, ***coupled superimposed*** text annotations emphasise locations (e.g., Western hemisphere, Italy, or Romania) and convey the direction of the spread of diseases (e.g., *"Spanish conquistadors bring smallpox to the Americas"* or *"Pompey's troops return from Syria with new territory and leprosy"*). Example *FS_017* includes text elements with location and direction information in ***coupled and uncoupled juxtaposed*** form. Text fragments in juxtaposed boxes, which move vertically along the screen through scrolling (i.e., up and down), inform the reader that *"six Japanese war birds moved to attack the Kameohe Naval Air Station"* are coupled. These text fragments are coupled, because they directly describe the spatial context depicted in the map. Even though the box covers the flow map, which would indicate superposition, it is categorised as juxtaposed because the scroll-based box with text and photographs and the map with the movement information are on two different layout spaces. The same example contains uncoupled juxtaposed text conveying spatial information. For example, flowing text at the beginning informs the reader: *"In the 1930s the United States and Japan developed a feud that would eventually lead to war. Tensions arose when Japan began to expand into China and in 1931 they conquered Manchuria, a region of northeast Asia."*

As Figure 3.12 shows, most of the text elements that integrate location are *coupled superimposed*. Approximately less than half are *coupled juxtaposed*. Less than a quarter are *uncoupled juxtaposed*. If text integrates direction, then mostly in a *coupled juxtaposed* and *coupled superimposed* way, and less often with *uncoupled juxtaposed* text elements. As one would expect, coupled elements linked to the displayed content occur more often than uncoupled elements that convey spatial information going beyond what a reader can see. Regarding the unused category *uncoupled superimposed*, the same reasons mentioned for vis-media elements apply to text elements.

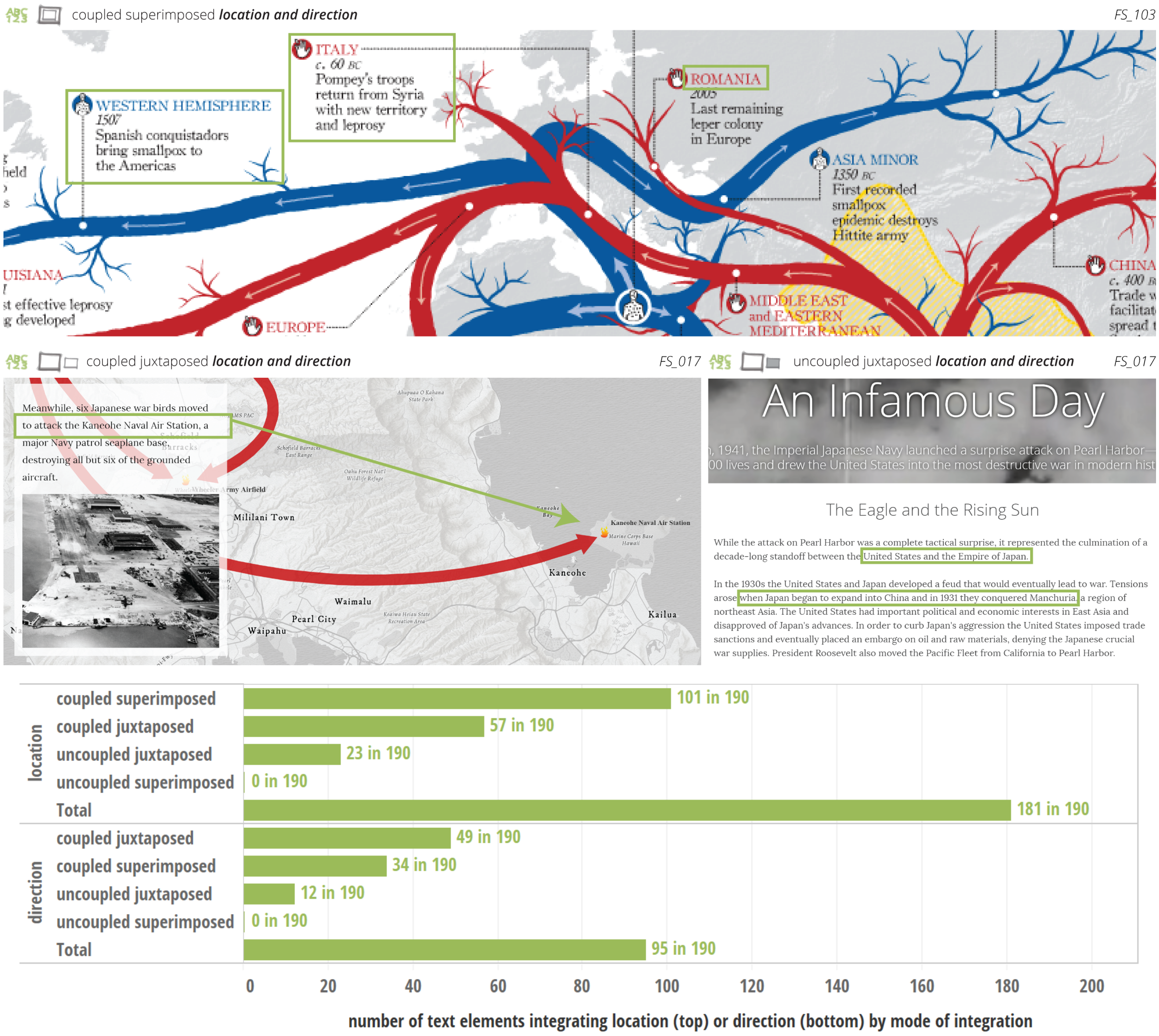


Figure 3.12: ***Top:*** Examples of text elements conveying ***location and direction***. ***Bottom:*** Frequencies of vis-media elements conveying spatial information by mode of integration. Around 44% of the 409 text elements integrate location, 23% integrate directional information. (How to read the label: instances with integration mode of all text elements containing spatial information in number of visualisations.)

Audio integration of location and direction:

Audio elements, most often in the form of voice-over narration, can also contain information about location and directions, as shown in example *FS_027*, a story about the global movement of cargo ships in the year 2012. A narrator explains: *"The red dots are* *the tankers, which send oil from massive terminals in the middle east or from offshore rigs from West Africa or elsewhere, while the blue dots are so called dry bulk ships, which move aggregates, oars, and coal from mines and quarries, many of them found in Australia or Latin America. Many of these raw materials are shipped to manufacturing regions to make finished goods that are themselves then moved back across the ocean in container ships shown here in yellow."* The mode of integration also applies to audio elements. This narration is ***coupled superimposed***. It is coupled because the audio narration describes the spatial activities and relations seen on the map. As the narration moves forward, the interactive map automatically pans and zooms to the area of interest. It is superimposed because the narration is presented simultaneously with the central visualisation.

As shown in Figure 3.13, the ten audio elements integrating spatial information (out of 22 audio elements found in 14 visualisations) are all *coupled superimposed*. They are all voice-over narrations like the example explained above. The other modes of integration are not used to convey spatial information with audio.

Audio elements conveying spatial information using the other modes of integration are possible, however. Other ***superimposed*** examples might be when a user is hovering over a visualisation, and depending on the cursor's location, different audio effects (e.g., the sound of birds in a habitat) or a short voice-over narration about an event or an object including spatial information are activated - depending on the content it might include ***coupled*** or ***uncoupled*** information. ***Juxtaposed*** in connection with audio elements includes for example audio narration that is played back before or after a user interacts with the visualisation of the central flow or movement data, again with ***coupled*** or ***uncoupled*** content.

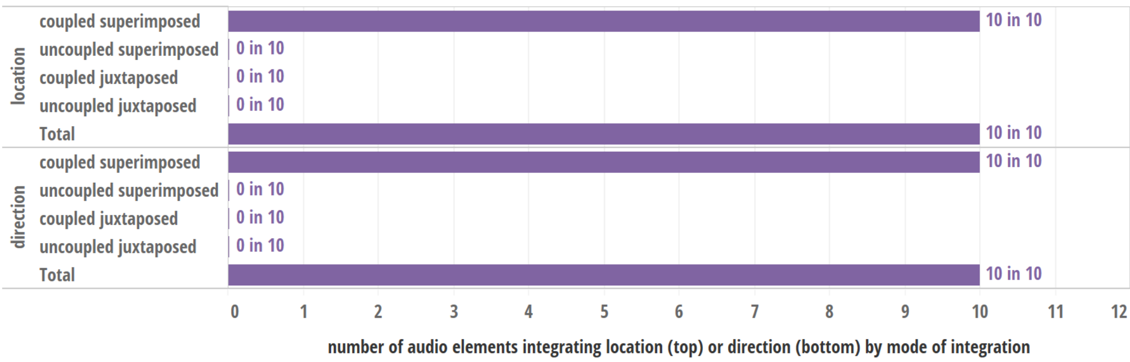


Figure 3.13: Frequencies of identified audio elements conveying spatial information by mode of integration. Fourteen of the 115 visualisations have audio elements. Ten of the 22 total audio elements integrate location and direction.

(2) Temporal information ⧖⧖⧖ — Marks and elements also encode ***when*** a flow or movement happened, the so-called *story time*, which also conveys the chronological sequence of events. In contrast, *discourse time* is the time needed to tell or read a narrative, which also includes the arrangement of time that does not necessarily follow story time (e.g., flashbacks) (Herman et al., 2010).

Temporal aspects can again be encoded using all five marks and elements. While flow and location marks or additional visualisations (e.g., simplistic or advanced time slider) use the visual channels to encode time, vis-media, text, and audio elements are distinguished based on the integration mode explained above.

Sometimes the duration, how long a movement took, is also communicated. Duration is also temporal information, but is discussed in the section on quantitative information. This category focuses on the question when the depicted flow or movement occurred (e.g., in the year 2012, in May).

Flow mark ⇨ and **location mark** **encoding of time**:
In Figure 3.14, example *FS_060*, a visualisation of ship tracks using kernel density, encodes time with ***colour*** and ***size***. While wider lines in yellow tones indicate daytime, thinner, blue flow marks represent vessel tracks during the night. In case *FS_022*, a visualisation of traffic in the city of Milan, the grid-based glyph encodes time by position. The columns correspond to the days of the week, the rows to the hours of a day. The cell ***colour*** encodes the respective traffic volume (see section about quantities). In *FS_071*, colour encoding conveys the blood arrival time (BAT) in a human brain from early to late. In the small multiple view, ***position*** is used to depict the BAT.

Location marks rarely encode time. One example in the collection is *FS_025*. The ***colour*** encoding of the US state boundaries maps to the time of year when commercial beekeepers move to this area (compare with the legend in the example).

In the example collection, few flow marks or location marks convey temporal information (see Figure 3.14 bottom). Whether it makes sense to use these marks to encode time depends on the purpose of the visualisation. While the channel *position* is feasible for encoding time, often other visual channels (e.g., colour and size) are preferred to encode volumes or categorical information.

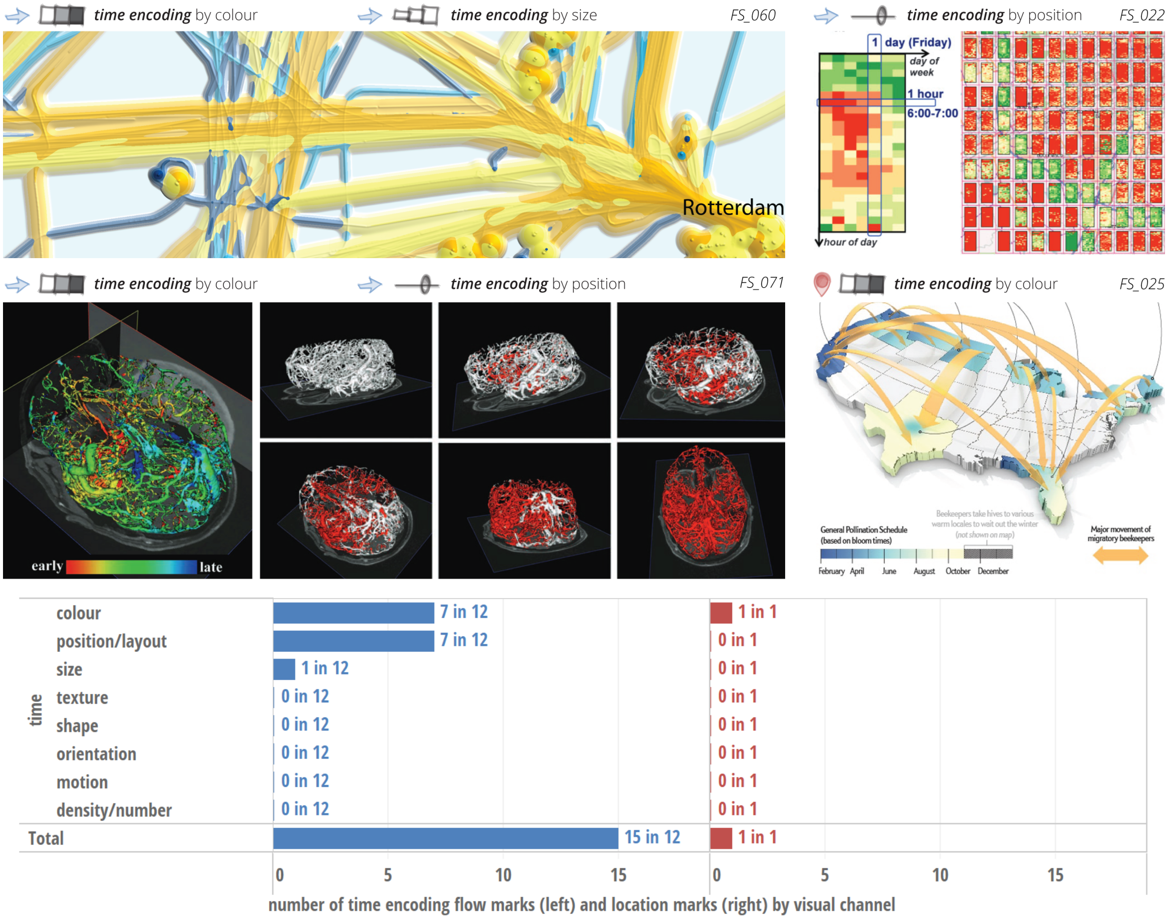


Figure 3.14: ***Top:*** Examples of flow marks and location marks encoding temporal information. ***Bottom:*** Frequencies of flow marks (left) and location marks (right) encoding temporal information by visual channel. Overall, only 12 out of 149 flow marks visually encode temporal information 15 times within 11 visualisations. Just one location mark out of the 140 conveys temporal information.

Vis-media integration and encoding of time:

Very often some kind of vis-media element communicates time. An example for a ***coupled superimposed*** time integration is a line chart of the annual global CO_2 on top of the central flow map showing the CO_2 distribution in the earth's atmosphere (*FS_014*). Together with the axis labels (i.e., month), a yellow dot moving along the line indicates the current time (using the visual variable position). An example for an ***uncoupled superimposed*** vis-media element is the snow layer in the visualisation of global bird migration, *FS_001*. The animated snow layer conveys the time (e.g., winter and summer in Europe). In *FS_027*, two different ***coupled juxtaposed*** vis-media elements encode two different temporal aspects using position. First, the interactive time-line on the bottom of the web page indicates the position in the story time, the time of the data currently displayed.

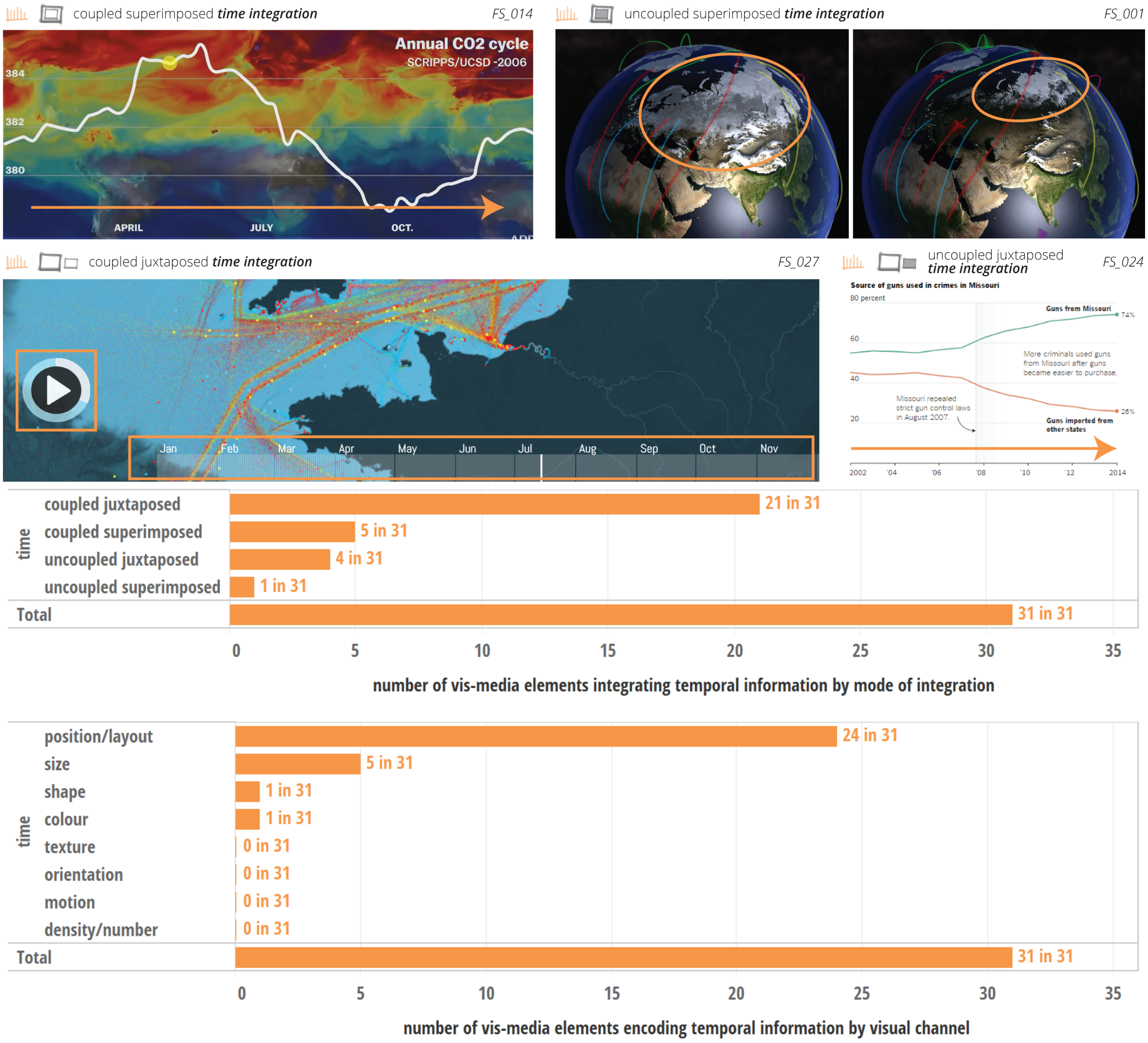


Figure 3.15: ***Top:*** Examples for Vis-media elements showing time. ***Bottom:*** Frequencies of vis-media elements conveying temporal information by mode of integration and visual encoding. Roughly a tenth of the 319 vis-media elements integrate temporal information, primarily using the visual channels position/layout and size.

Second, the time dial on the left side, that also allows to control the play back of the voice-over narration, corresponds to the discourse time, the time it takes the narrator to tell the story. Both are juxtaposed, because they are not directly integrated in the map layout space. Finally, an ***uncoupled juxtaposed*** line chart in *FS_024* conveys time (x-axis by year). The chart revolves around the overall topic of gun trafficking in the US, but focuses on an additional topic. Hence, it is categorised as uncoupled. It is juxtaposed because it is part of the website's flow text below the main flow map, not sharing the same layout space.

The chart in Figure 3.15 (bottom) shows that most vis-media elements that integrate time are *coupled juxtaposed*. A few are *coupled superimposed* or *uncoupled juxtaposed*. Only one is *uncoupled superimposed*. These vis-media elements mainly use the visual channels *position/layout* and *size* (i.e., length) to encode temporal information.

Text integration of time:
In a web-based visualisation of the Swiss train network (*FS_054*), text elements are used to convey time by hour. Clicking on a track section opens a small pop-up annotation (***coupled superimposed***), which includes temporal information (e.g., *"15 trains pass here between 9:00 and 10:00 at avg. speed of 108 km/h"*) amongst other information. Further, in a ***coupled juxtaposed*** form, the same time is displayed next to the interactive time slider that allows the user to change the time over the day. ***Uncoupled superimposed*** text that provides metadata and appears superimposed relative to the main visualisation in *FS_003* conveys temporal information about the depicted data sources (the year 2010). Similarly but ***uncoupled juxtaposed***, a paragraph on the bottom of the visualisation in *FS_053* explaining the methods of the web-based application mentions the time the depicted data covers (the year 2012). Even though both examples describe the temporal aspects of the depicted movements, which would suggest that they are coupled, both text segments are categorised as uncoupled. They are uncoupled because they are buried within text presenting metadata. If the year was part of a superimposed annotation or a juxtaposed title, both easily associated with the central display, they would be coupled.

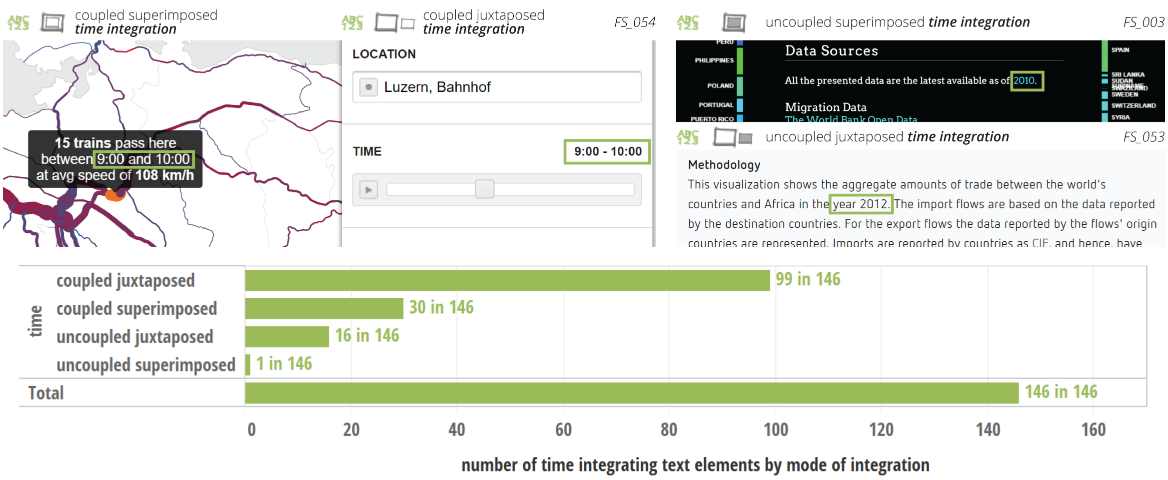


Figure 3.16: ***Top:*** Examples for text elements integrating time. ***Bottom:*** Frequencies of text elements that convey temporal information by mode of integration. Overall, 35% of the 409 text elements integrate temporal information.

Examining Figure 3.16 (bottom), two-thirds of the text elements that convey temporal information are *coupled juxtaposed*. Several integrate time in a *coupled superimposed* or *uncoupled superimposed* way. Within the 115 examples, only one text element conveys time in an *uncoupled superimposed* form.

Audio integration of time:
In example, *FS_028*, the Flowstory has audio elements that convey temporal information, which are ***coupled superimposed***. The male narrator explains how commercial aircraft *"moved across the sky in the last 24 hours"* or states *"as the sun rises on each region, so the take-offs and landings begin"* and finally mentions *"only in the dead of night the sky clears up a little"*.

This example is one of eight that contain a time integrating audio element conveying temporal information in a *coupled superimposed* way. The collection does not include examples using *uncoupled superimposed* or *juxtaposed* audio elements to convey time (see Figure 3.17 bottom). Similarly, as described in the section about spatial information, other modes of integration are possible.

(3) Qualitative information — Categorical information about flow or movement data can also be the subject of a visualisation. All five mentioned marks and elements (, , , ,) may encode location independent qualitative attributes. Why location independent? If flow marks, for example, encode origin information about migrants (e.g. flow marks coloured by country, using different hues) they would be recognised within the spatial information category of the design space. If colour hue, on the other hand, is used to differentiate the gender or goods of the moving entities, which is location independent information, then it would be recognised as qualitative information.

From a narrative point of view, qualitative information in Flowstories often conveys the central message or supports the overall argument. This information communicates the identities of the flow or movement entities depicted.

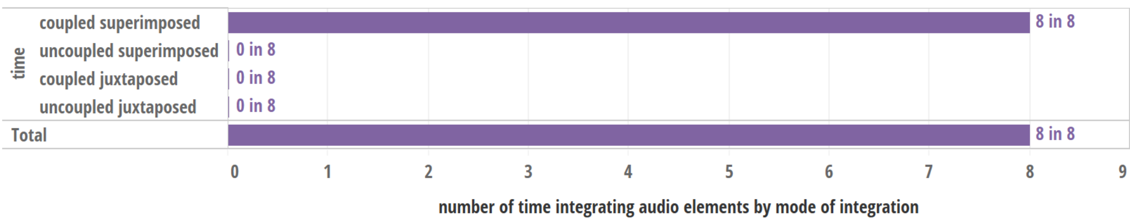


Figure 3.17: Frequencies of identified audio elements conveying temporal information by mode of integration. Eight out of the 22 audio elements convey temporal information in eight visualisations of the collection.

Flow marks and location marks use visual channels to encode qualitative information. Vis-media, text, and audio elements are categorised by the mode of integration.

Flow mark encoding of qualitative information:
Figure 3.18 contains examples of different visual channels encoding qualitative information. *FS_083* compares different treatment options (stent placements) and their effect on the blood flow using ***colour***. In *FS_044*, differently ***shaped*** icons encode categories of transported goods from the American continent towards Europe. A dollar sign ***texture*** of flow marks in *FS_101* indicates monetary flows compared to flows of oil. Finally, ***size***, the width of flow lines, differentiates between ships and airplanes in *FS_017*.

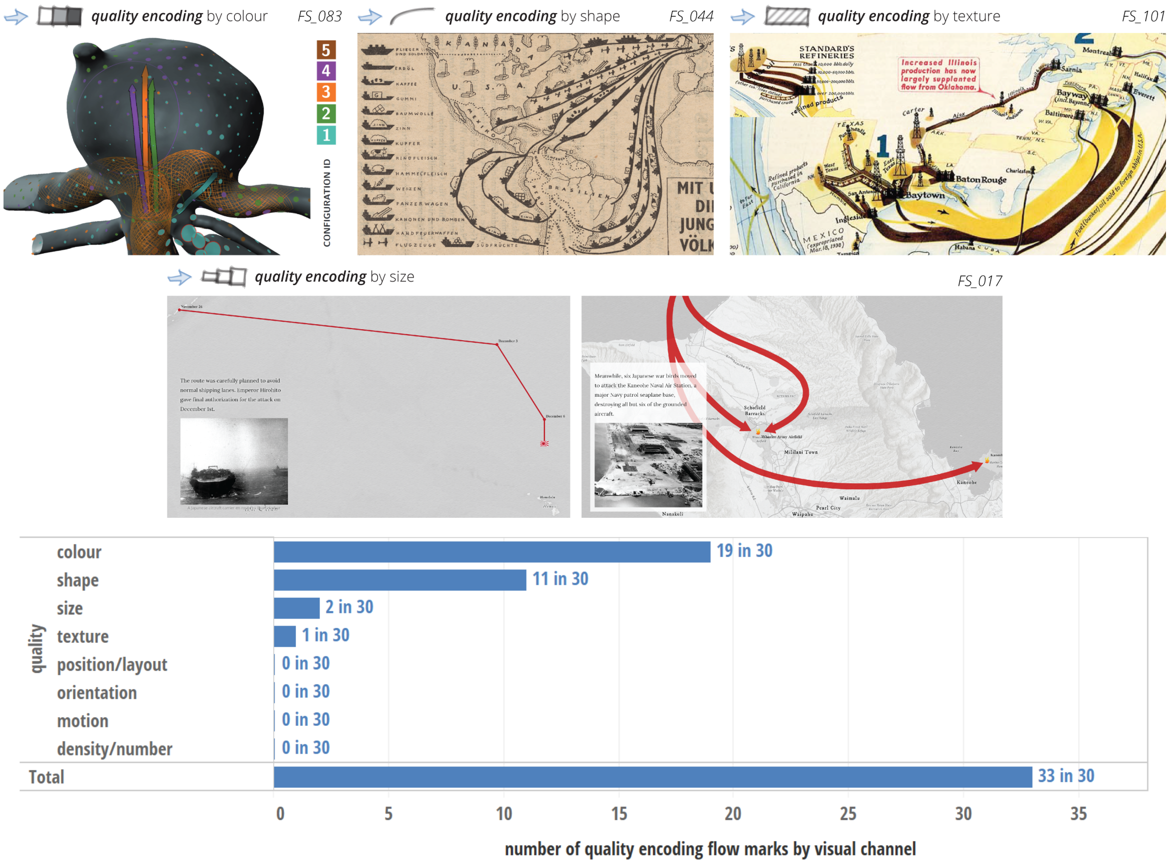


Figure 3.18: ***Top:*** Examples showing how qualitative information can be encoded using flow marks. ***Bottom:*** Frequencies of quality encoding flow marks by visual channels. Overall, about a fifth of the 149 identified flow marks encode categorical information within 25 examples in the collection.

Within the collection of examples, flow marks that convey categorical information largely use the visual variables *colour* or *shape* (Figure 3.18 bottom). Only a few flow marks use *size* and *texture*. None of the flow marks in the 115 examples use the other channels (i.e., *position/layout*, *orientation*, *motion*, and *density/number*) to encode qualitative information. This lack of usage is what one would expect since they tend to be ill-suited for this purpose.

Location mark encoding of qualitative information:
In the conveyor belt flow map in *FS_048*, the flow marks use different ***colour*** hues to discriminate between suppliers of raw material, suppliers of energy, and strategic markets. Differently ***shaped*** figurative icons in *FS_103* indicate different types of diseases and where they originated from. Migration stories in *FS_114* use different ***sized and coloured*** location marks to indicate locations where special events during a migrant's journey towards Italy had occurred. These examples are part of Figure 3.18 (top).

The same Figure (bottom) shows that only seven location marks within six visualisations convey categorical information using the three visual channels discussed above.

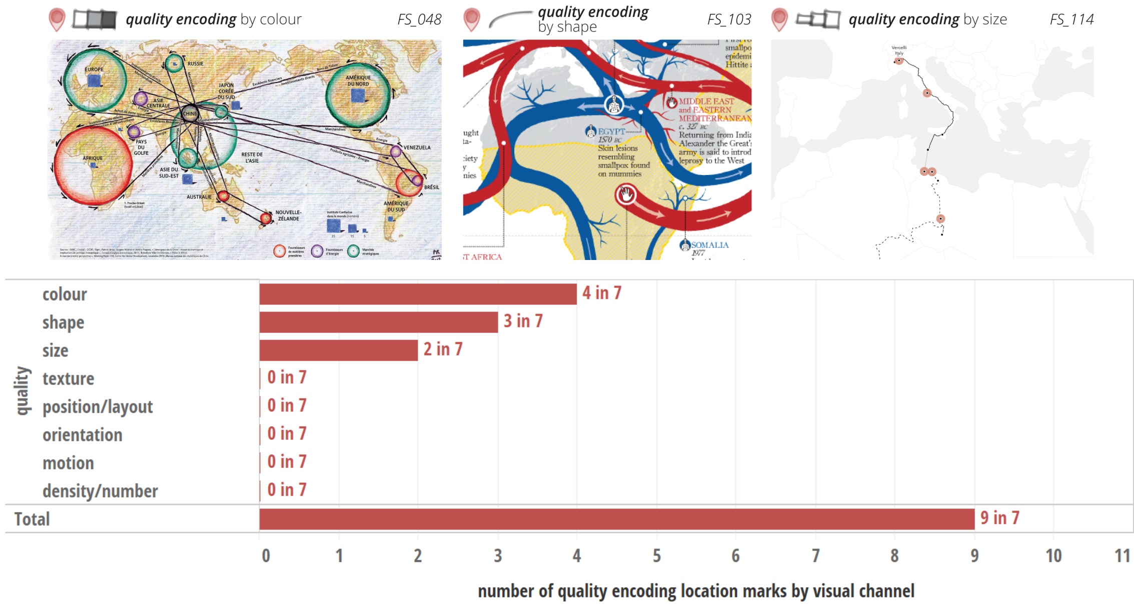


Figure 3.19: ***Top:*** Examples showing how qualitative information can be encoded by location marks. ***Bottom:*** Frequencies of location marks encoding qualitative information by visual channel. Overall, seven of the 140 identified location marks encode categorical information. Two of them double encode the presented categories using different visual channels. One visualisation out of the seven has two quality encoding location marks.

Vis-media integration of qualitative information:
Figure 3.21 presents examples of vis-media elements integrating categorical information. *FS_113* includes examples of ***coupled superimposed*** vis-media elements, integrating qualitative information. They are the little icons resembling the mode of transportation (e.g.,

ship, bus, or car) placed along the path of a single person's journey from Yemen to Austria. The icons are coupled because they directly describe characteristics of the movement (modes of transportation) and are superimposed because they are integrated into the layout space of the main flow map. On the contrary, *FS_001* uses ***coupled juxtaposed*** icons that differentiate migrating bird species using different shapes and colours. While the menu list of different bird species is interactively and thematically coupled with the globe and the visualised movements, it is juxtaposed, because it is not integrated in the globe's layout space. The pictorial chart in *FS_017* is ***juxtaposed*** within regard to the main movement visualisations. While it deals with the same overall topic (Pearl Harbour), it does not deal with the movement, but with additional qualitative information, hence it is ***uncoupled***. It uses colour to differentiate between countries (i.e., Japan and US) and shape to discriminate between destroyed ships, destroyed airplanes, and human casualties on each side.

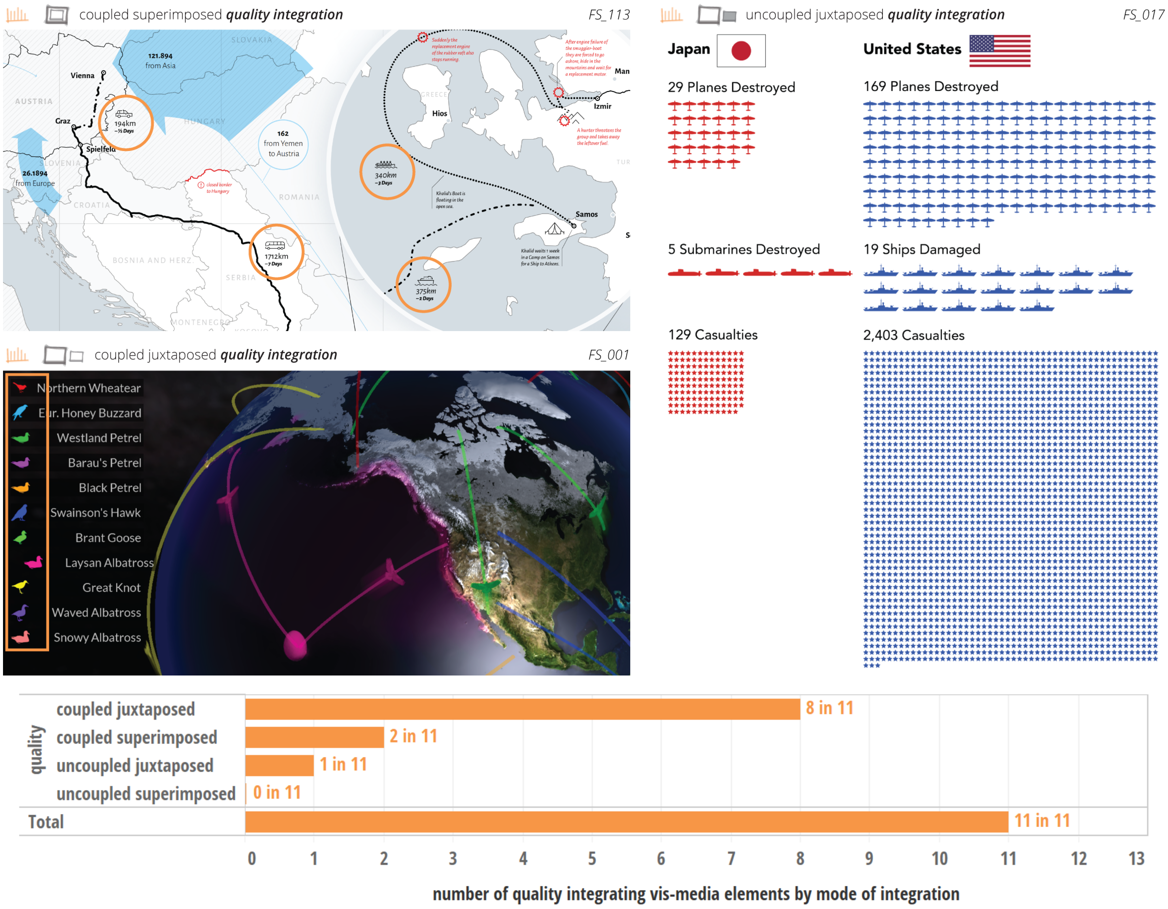


Figure 3.20: ***Top:*** Examples of vis-media elements showing categorical information. ***Bottom:*** Frequencies of quality conveying vis-media elements by mode of integration. Overall, only eleven of the 319 vis-media elements integrate qualities.

Eight visualisations in the collection have vis-media elements conveying categorical information with a *coupled juxtaposed* mode of integration, two with a *coupled superimposed* mode of integration, and one with an *uncoupled juxtaposed* mode of integration. Again, there are no *uncoupled superimposed* vis-media elements conveying qualitative information.

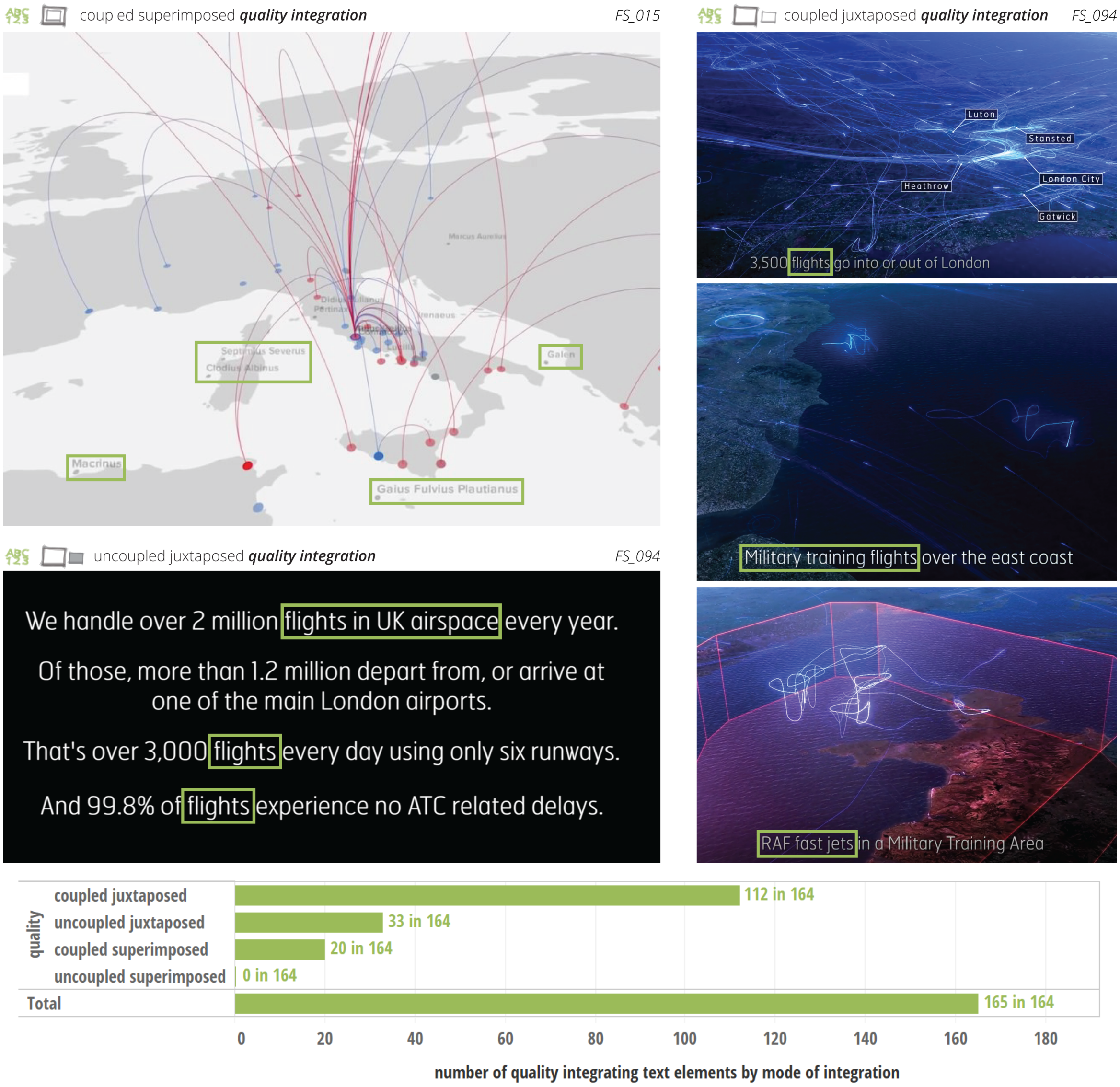


Figure 3.21: ***Top:*** Examples of text elements conveying qualitative information. ***Bottom:*** Frequencies of quality conveying text elements by mode of integration. About 35% of the 409 text elements integrate qualitative information. Note that in several cases, the same text elements integrate categorical information using different modes of integration, or that several visualisations integrate qualities using text more than once.

Text integration of qualitative information:
When text is directly integrated in the layout space of the flow or movement visualisation and it describes aspects of the depicted flow or movement, it is categorised as a ***coupled superimposed*** text element. This applies to the text annotations in *FS_015*. Names of famous people move along the line that connects their place of birth with their place of death.

FS_094, a video about UK air traffic, contains text elements that qualify the depicted flow information (e.g., flights, military training flights, RAF jets, or helicopters). While a general overview text towards the end of the video is ***uncoupled***, text elements visible during the video describing the current animated 3D scene are ***coupled***. Both are ***juxtaposed***, because they are not integrated in the visual space of the visualisation.

Screen shots of these examples are part of Figure 3.21 (top), which also shows the frequencies of quality integrating text elements by mode of integration (bottom) within the collection. Two-thirds of the quality conveying text elements are *coupled juxtaposed*. A fifth integrate categorical information in an *uncoupled juxtaposed* way. About a tenth of the 164 text elements are *coupled superimposed*, integrated in the main visualisation addressing qualitative differences of the depicted flow or movement. As with vis-media elements, there are no *uncoupled superimposed* text elements integrating qualities.

Audio integration of qualitative information:
The ***coupled superimposed*** voice-over narration in the video *FS_013* differentiates between the depicted dynamic processes in our solar system, including cosmic rays, solar winds and storms in the universe, as well as wind and ocean currents on Earth.

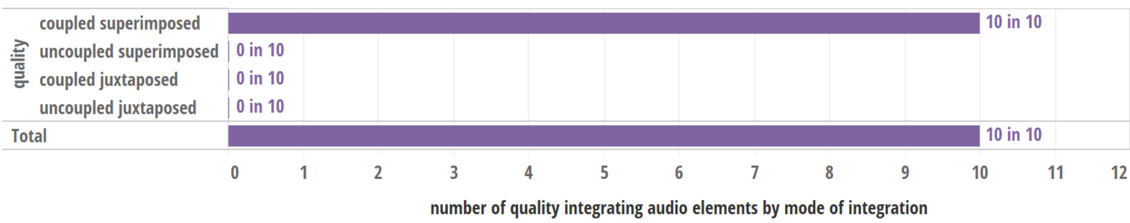


Figure 3.22: Frequencies of audio elements conveying qualitative information by mode of integration. Within the visualisations in the collection, ten of the 14 visualisations with audio elements provide categorical information.

FS_013 is one of the ten examples that have audio elements (i.e., voice-over narration) providing qualitative information (see Figure 3.22). There are no examples where audio elements do this in an *uncoupled superimposed*, *coupled juxtaposed*, or *uncoupled juxtaposed* way. As demonstrated previously, this would, however, be possible.

(4) Quantitative information — How quantitative attributes of the flow of movements are visualised is important. The flow **magnitude/volume** describes how much or how many entities (e.g., humans, animals, goods, money, blood, air) flow or move between or through locations. Information about distance or distribution is also included in this category, since it also conveys magnitude. **Duration** refers to how long, and **speed/velocity** refers to how fast these entities move. These three-quantitative characteristics are captured by this design space category. Depending on the focus, the examples in the collection mostly encode one or two of these properties using the five previously discussed marks and elements.

Again, for flow marks and location marks visual channels are used to communicate quantities. Vis-media, text, and audio elements are described by their mode of integration in relation to the visual display of the flow or movement.

From a narrative point of view, as with qualitative information, quantitative information in Flowstories often conveys parts of the central message or supports the overall argument. This information communicate the magnitudes or other quantitative characteristics of the depicted flows or movements.

Flow mark encoding of quantitative information:
Examples encoding **magnitude** of flow or movement are provided in Figure 3.23. The alluvial chart, example *FS_019*, uses ***size***, the line width of the flow mark, to encode the number of refugees moving between countries. In the MapTrix example (*FS_059*) the grid cells are ***coloured*** relative to the magnitude of New Zealand's domestic migration, where yellows represent low volumes and red represents high volumes. In *FS_028*, the density of flow marks ***density*** on the map reflects a quantity - the number of airplanes moving around the globe. In *FS_066*, the geospatial contour boxplots convey the possible extent of weather features using ***position*** (i.e., outlier contours in relation to a median contour) in a weather forecasting context. While this mainly describes a weather feature's geographic distribution, it also conveys information about its volume.

In the collection of visualisations, magnitude is largely encoded through a flow mark's *size*, followed by its *colour* (i.e., saturation, brightness, transparency) and the *density/number* of marks. Two-thirds of all magnitude encoding flow marks use size. Colour and density/number are each used by about a fifth of the 77 flow marks conveying magnitude. Only one flow mark uses a *position/layout* encoding (see Figure 3.23 bottom).

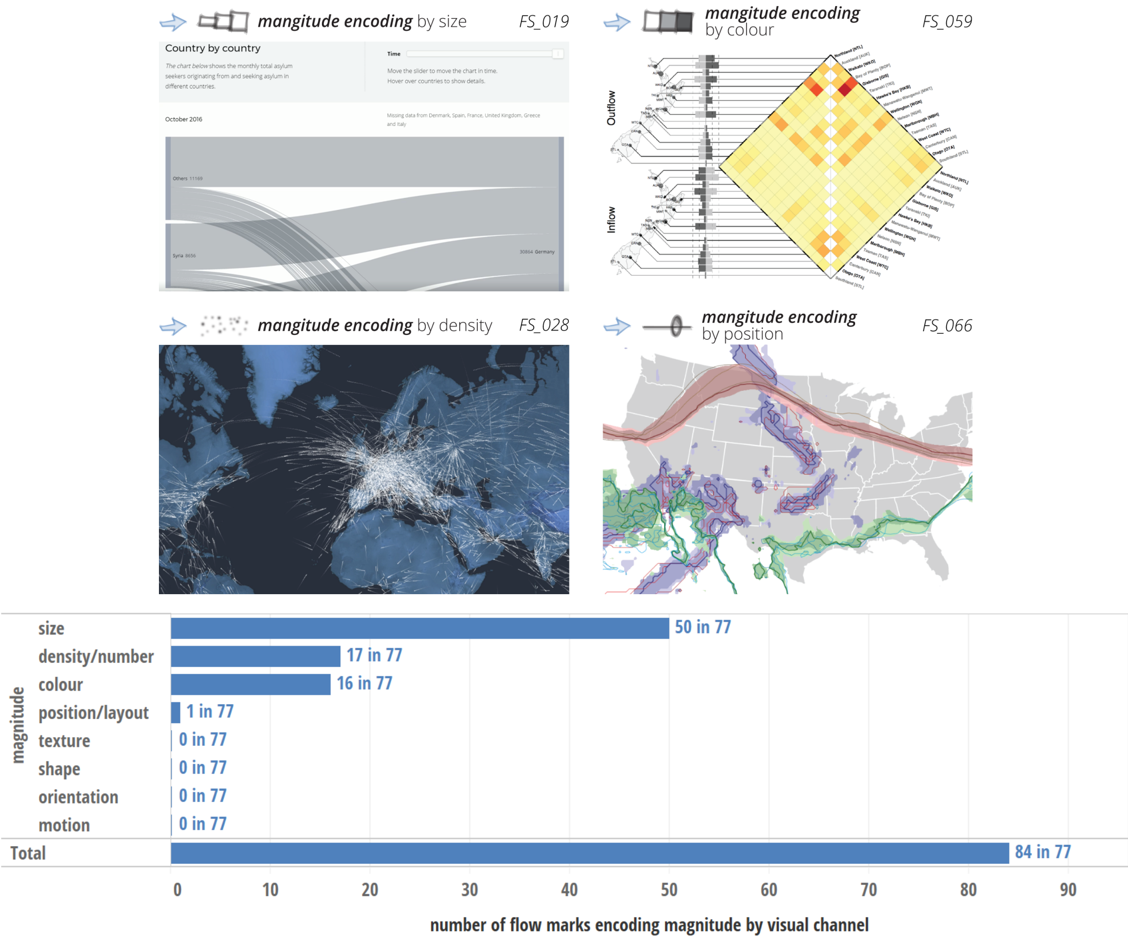


Figure 3.23: ***Top:*** Examples of flow marks encoding flow or movement magnitude. ***Bottom:*** Frequencies of magnitude encoding flow marks by visual channel. Overall, about half of the 149 flow marks identified in the collection encode magnitude. Within these 77 flow marks, colour, for instance, is used 16 times in 16 visualisations to encode magnitude.

Flow marks can also encode **duration** (see Figure 3.24). In *FS_009*, ***colour*** is used to show the duration of distributed denial-of-service attacks, where green represents only a few minutes, yellow represents hours, and red represents weeks. The diagram in *FS_021* visualises the train schedules of three Boston train lines over an entire day. The duration of a ride between the start and end stop is expressed by the ***position*** of the flow mark (lines) in relation to the vertical time axis. A flat line represents less time than a steeper line, which often is the result of delays. ***Density*** is used in *FS_108* to express duration. The number of stacked black lines convey the hours it took to move between stopovers during a road trip from Norway to the UK and back. Originally, the small multiples in *FS_071* are snapshots from an animation, hence ***motion*** encodes the duration of one blood flow cycle through a human brain.

In the visualisation collection, only 8 examples have flow marks conveying duration of flow or movement. These flow marks use the visual channels *colour* and *position/layout*, but also *motion* and *density/number* (i.e., each has one instance). *Texture*, *size*, *shape*, and *orientation* are not used by flow marks identified in the visualisations of the collection to encode duration (compare Figure 3.24 bottom).

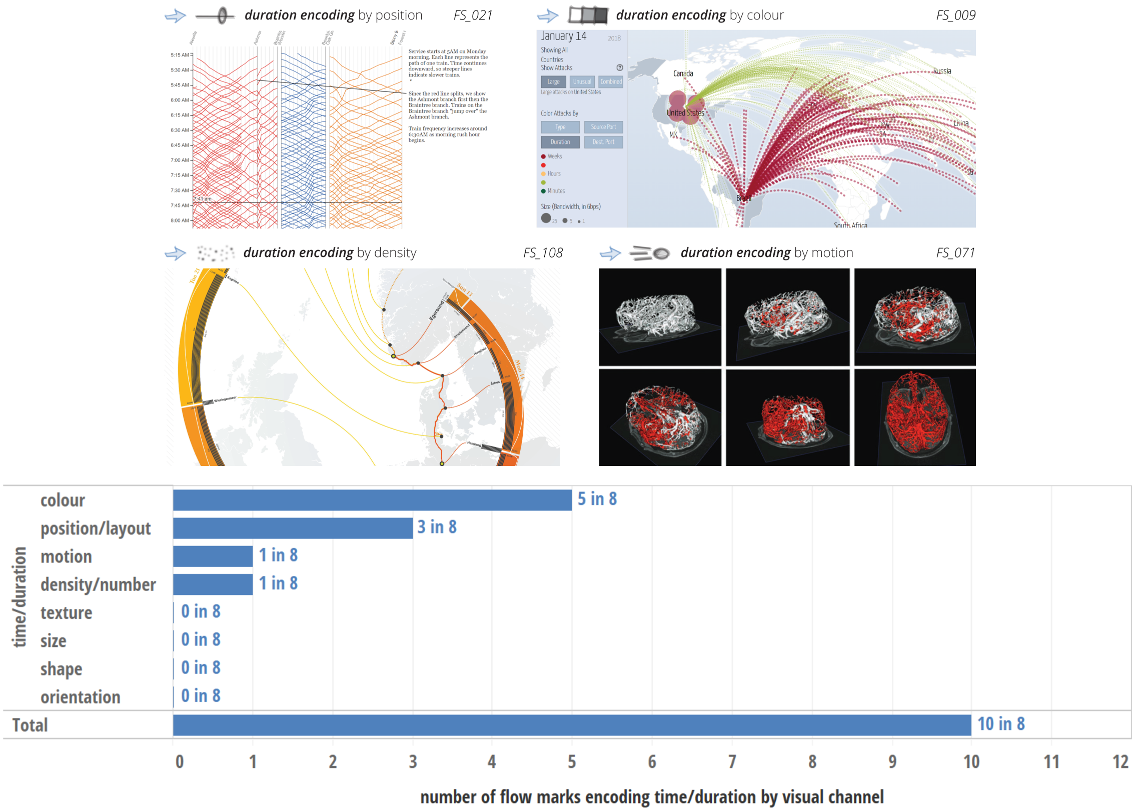


Figure 3.24: ***Top:*** Examples of flow marks encoding flow or movement duration. ***Bottom:*** Frequencies of duration encoding flow marks by visual channel. Overall, only eight of the 149 flow marks convey duration in eight of the 115 visualisations. Two of the eight flow marks double encode duration. Colour, for instance, is used by three flow marks within three visualisations.

Finally, **speed or velocity**, which is defined as speed combined with a given direction, can be expressed through flow marks. In Figure 3.25, the example *FS_080*, is a visualisation of blood flow using small circles with speed lines in a comic-like style, where ***colour***, ***shape***, and ***size*** encode speed. Higher speeds are expressed through deformed circles (elliptical shapes) with the lighter, respective colour of the applied colour map (compare Figure bottom right) and longer speed lines following the point symbols. Lower speeds, on the other hand, are expressed by a circular shape with a darker fill colour and shorter trails. In the video *FS_013*, the velocity of ocean currents is encoded through a combination of

orientation (arrowheads and the orientation of the stream lines) and ***motion*** (animated stream lines convey speed).

Within the 115 visualisations, *speed/velocity* is primarily encoded with *colour* (i.e., 21 out of 29 flow marks). Seven of the speed encoding flow marks use *size*. Shape, orientation, and motion are each used by two flow marks to convey speed or velocity. The other visual variables (i.e., *texture*, *position/layout*, and *density/number*) are not used by flow marks within the visualisations of the collection (see Figure 3.25 bottom).

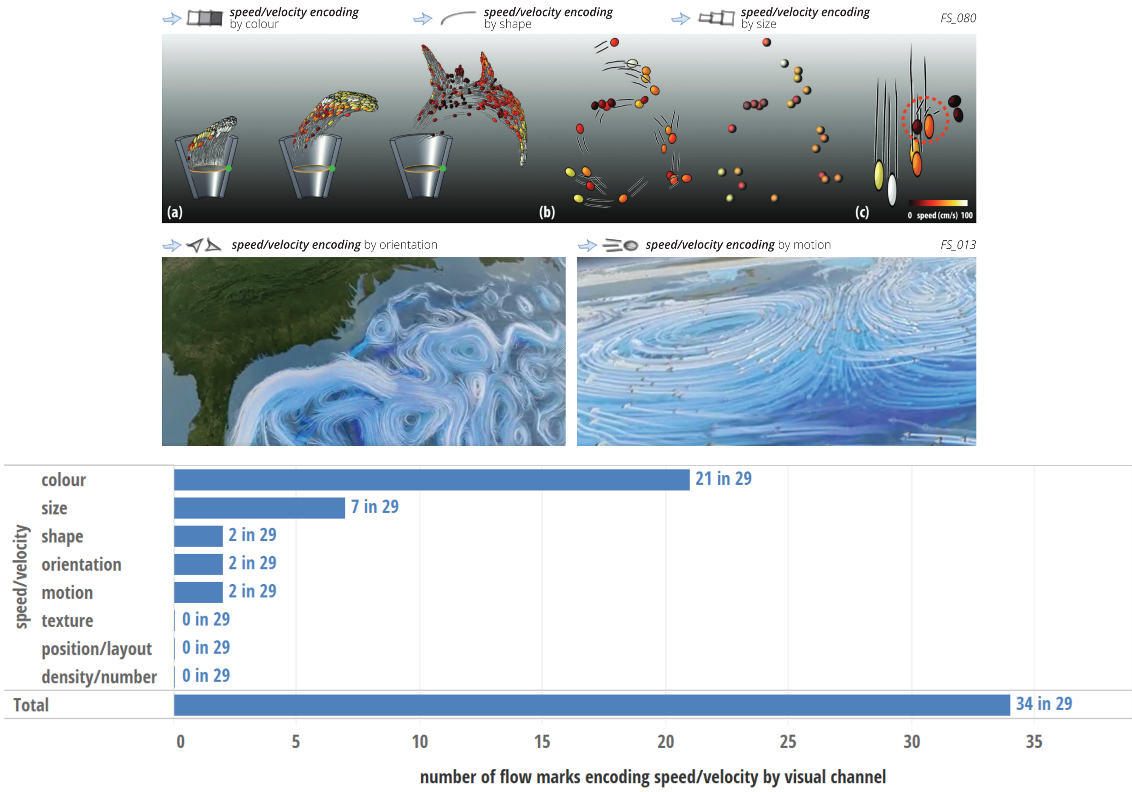


Figure 3.25: ***Top:*** Examples of flow mark encoding flow or movement speed or velocity. ***Bottom:*** Frequencies of speed encoding flow marks by visual channel. Overall, 29 of the 149 flow marks convey duration 34 times in 26 of the 115 visualisations. Five of the 29 flow marks double encode duration. Colour, for instance, is used on 21 flow marks within 19 visualisations to encode speed.

Location mark encoding of quantitative information:

Location marks can also convey quantitative information, as shown in Figure 3.26. The examples in *FS_064* use ***colour*** and ***size*** to compare quantitative information about hire bike journeys in London. The radial charts in the left image compare magnitudes at the given locations showing differences in selected times using red and blue colour values. The display on the right uses the length of the radial bars to aggregate flows of different distant ranges. Distance is part of the magnitude category in the design space. Colour is used as well in the example, where yellow represents short trips and red represents long trips. The pictorial location marks in *FS_101* use ***density***, the number of oil storage tanks to communicate volume. As with the flow marks, ***density*** is also used by the location marks in *FS_108* to express duration. The stacked black lines convey the hours spent in the marked cities during a road trip from Norway to the UK and back. The ***size*** of the little bars in *FS_085* conveys the average driving speed at the given locations and hours in the city of Milan.

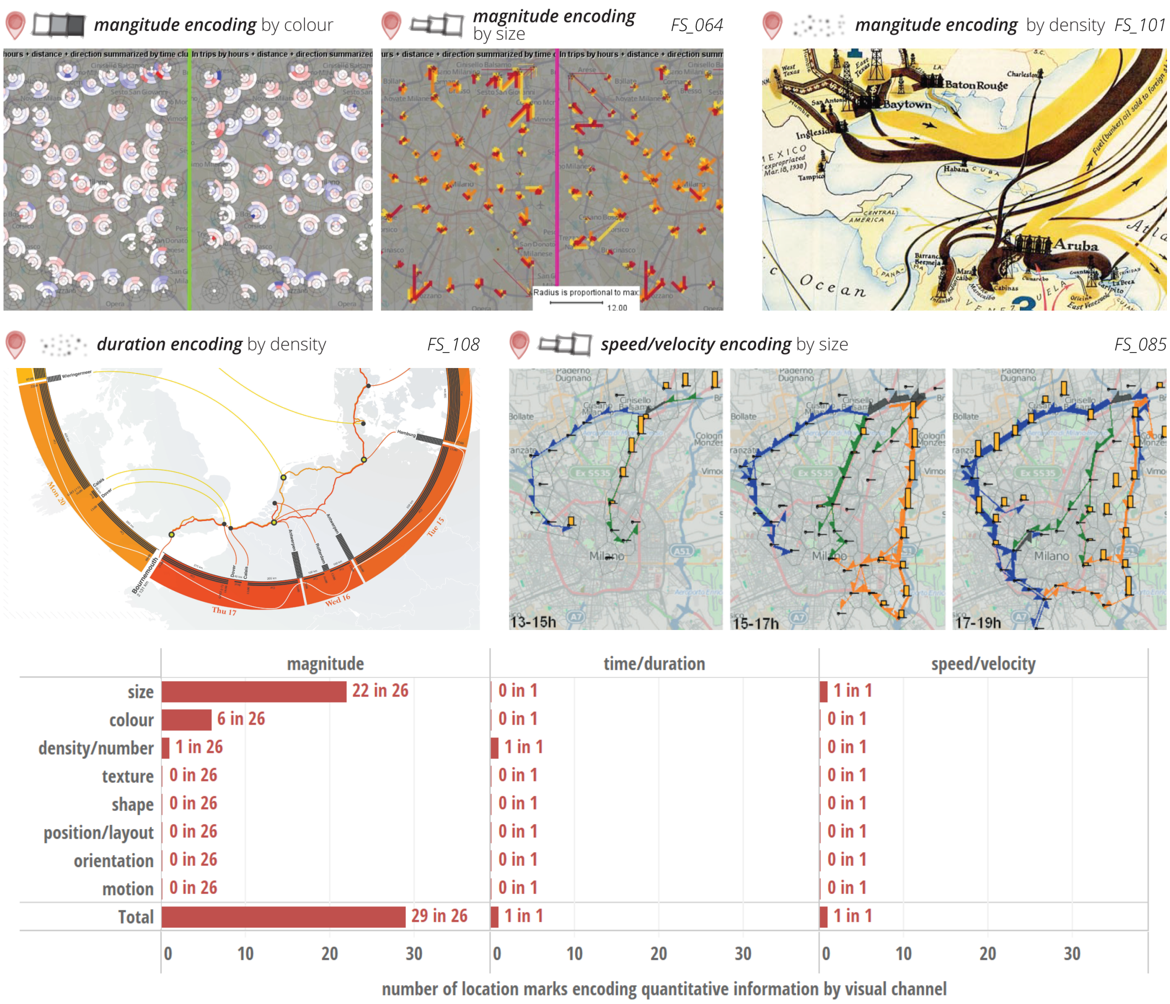


Figure 3.26: ***Top:*** Examples of how location marks can encode quantitative information (magnitude, duration, or speed). ***Bottom:*** Frequencies of quantity encoding location marks by quantity type and visual channel. Overall, 26 of the 140 location marks encode magnitude. Duration and speed are each encoded in only one example of the 115 in the collection.

While duration and speed are each only encoded by one location mark (i.e., the respective examples above), magnitude is encoded by 26 of the 140 location marks. Therefore, the visual channel *size* is used most. *Colour* and *density/number* are also used in a few examples to convey quantitative information. The other channels (i.e., *texture*, *shape*, *position/layout*, *orientation*, and *motion*) are not used by location marks for quantity encoding in the collection.

Vis-media integration of quantitative information:
Vis-media elements can also be used to express quantitative information (see Figure 3.27 top). Bi-directional, ***coupled superimposed*** bar charts in *FS_059* summarise the overall migratory inflow and outflow magnitudes of a region in New Zealand. An interactive, ***coupled juxtaposed*** parallel plot in *FS_057* shows the number of migratory flows between US states refined by the relative distribution of age groups (in comparison the flows on the map show the average age). The plot can also be used to select certain flows (e.g., show only flows that have a high percentage of senior population). The area of the ***uncoupled juxtaposed*** national flags in *FS_101* is proportionally sized to the tonnage of crude oil and refined product transported by a single company's tanker fleet by the respective home port (flags) in the year 1940. In example *FS_114*, duration is expressed through the length of the blue bars along the horizontal axis, which are ***coupled superimposed***. While the dark blue lines are days spent in a city, the length of the light blue bars represent the number of days travelling on a refugee's journey from Africa to Italy. In the right view, the length along the vertical axis is the kilometres travelled. The ***coupled juxtaposed*** bar chart in *FS_108* summarises the hours spent driving and stopping in each country on the road trip from Norway to the UK and back. The chart is coupled, because it aggregates information accessible in the main map. The ***uncoupled juxtaposed*** pie charts in *FS_096* compare the commuting time to workplaces by 15 minute groups between London and rest of the UK. It is uncoupled, because the commuting time is not conveyed by the main visualisation.

FS_072 includes ***coupled juxtaposed*** line charts that convey blood flow speed at given locations over time. They are coupled through the text annotations in the 3D scene and the charts (e.g., AAo, Arch, DAo). Examples of ***uncoupled juxtaposed*** vis-media elements that encode speed or velocity are the additional distribution maps in *FS_060* that show additional flow attributes (compared to location in the main map view). For example, they show velocity over time or velocity by vessel type of the depicted ship trajectories.

Examining Figure 3.27 (bottom), the majority of the vis-media elements that convey quantitative information are integrated in a *coupled juxtaposed* mode. Several magnitude integrating vis-media elements are *coupled superimposed* or *uncoupled juxtaposed*.

These modes are rarely used to integrate duration or speed. No example uses *uncoupled superimposed* quantity conveying vis-media elements.

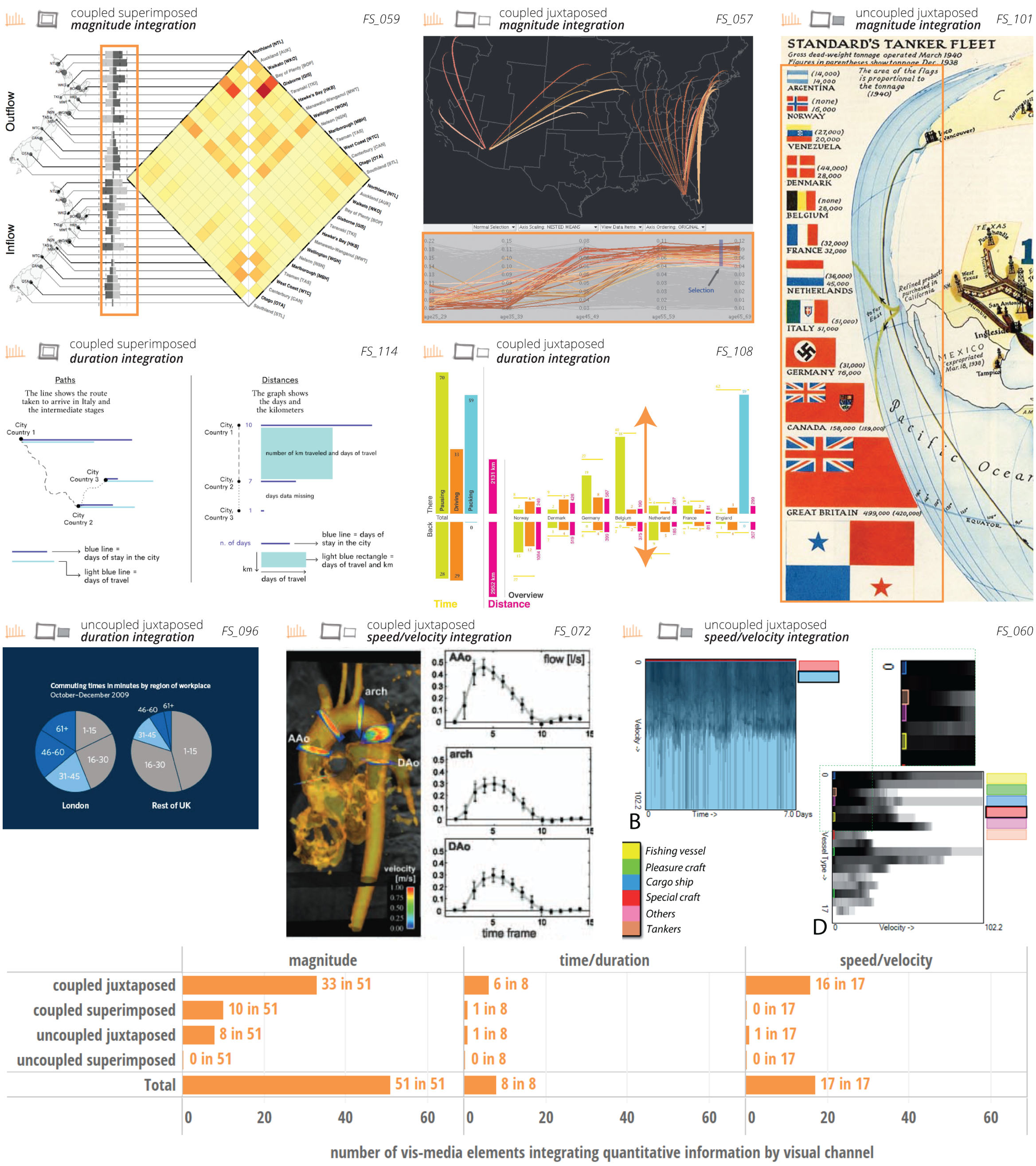


Figure 3.27: ***Top:*** Examples of vis-media elements showing quantitative information. ***Bottom:*** Frequencies of quantity conveying vis-media elements by mode of integration. While magnitude is overall integrated by 51 of the 319 vis-media elements in 39 visualisations, visualisations integrating duration and speed through vis-media elements are far less frequent. For instance, a coupled superimposed integration mode is used by ten (magnitude), one (duration), and none (speed) vis-media elements.

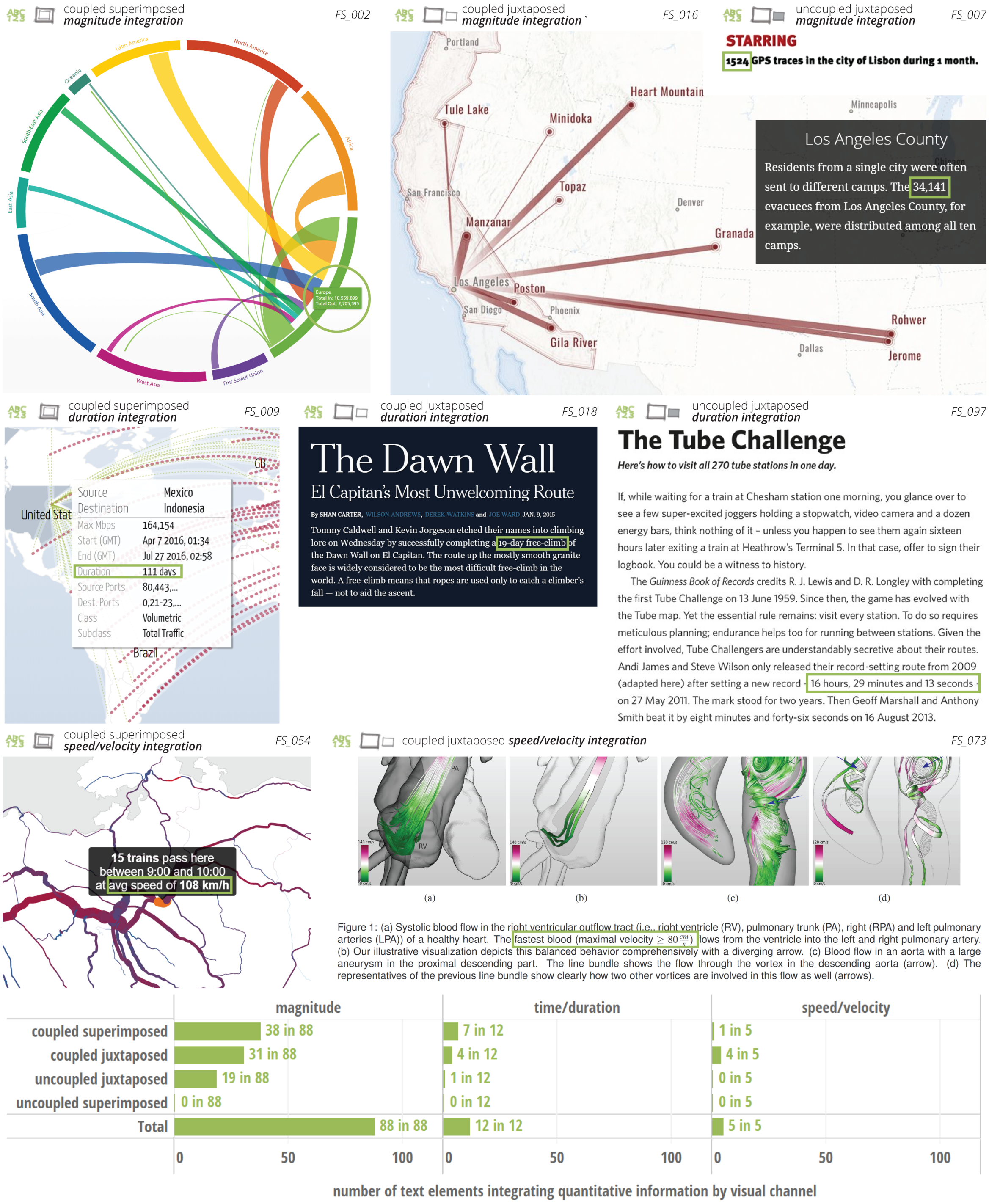


Figure 3.28: ***Top:*** Examples of text elements conveying quantitative information. ***Bottom:*** Frequencies of quantity conveying text elements by mode of integration. Overall 88 of the 409 text elements convey magnitude, 12 duration, and 5 speed. For instance, a coupled superimposed integration mode is used by 38 (magnitude), seven (duration), and one (speed) text elements.

Text integration of quantitative information:
Text-based elements also express quantitative information (Figure 3.28). Magnitude, duration, or speed are most often expressed through absolute or relative numbers (e.g., *“... 34141 evacuees from Los Angeles County ... ”*, *“... completing a 19-day free-climb ... ”*, or *“... at avg. speed of 108 km/h ... ”*), but also through number words such as a half, a quarter, many, few, or several.

Based on the mode of integration, the text-based elements expressing quantities can be ***coupled superimposed*** (e.g., *FS_002, FS_009, FS_054*), where the information is directly integrated in the visualisation's layout space as a label, annotation, or pop-up describing the depicted flow or movement directly. If such quantitative elements do not describe flow characteristics, but provide additional quantitative information, they are uncoupled superimposed. The collection does not include such examples.

Coupled juxtaposed (e.g., *FS_016, FS_018, FS_073*) or ***uncoupled juxtaposed*** (e.g., *FS_097*) text-based elements are integrated through flow text, figure captions, and accompanying journalistic articles, but also in text boxes in scroll-based online stories, which move aside or across the main display. They all are placed on separate layout spaces. A text is coupled if it describes the visualised content directly (e.g., the path of the mentioned *“... 19-day free-climb ... ”* in *FS_018* is visible in the 3D scene next to the text), or is uncoupled if this is not the case (e.g., the duration of the tube challenge mentioned in the text of *FS_097* (e.g., *“... 16 hours, 29 minutes and 13 seconds ... ”*) is the record set in 2011, while the depicted route refers to the record of 2009).

In the body of examples, quantity integrating text elements are mainly *coupled (superimposed and juxtaposed)*. Also *uncoupled juxtaposed* text elements are used to convey quantities, primarily magnitude. Again, no *uncoupled superimposed* text elements convey quantitative information. While only a few text elements encode duration and speed, magnitude is encoded by a fifth of the text elements (see Figure 3.28 bottom).

Audio integration of quantitative information:
As with text, audio elements (mainly voice-over narration) can include quantitative information. In a ***coupled superimposed*** mode of integration, the narrator in *FS_039*, for example, reports on magnitudes of migrants living on other continents, and on how much money they send back home. The narrator in *FS_110* first states *“About half of the Syrian refugees are children.”* (coupled superimposed) and reflects later: *“... In Lebanon, for example, only every fourth school-age refugee child can go to school. For a quarter of a million, there is no education.”* (uncoupled superimposed).

The eight quantity conveying audio elements in the collection only encode magnitude. None of the 14 examples with audio elements contain information about the duration or speed of flow or movement. While all eight superimposed audio narrations provide coupled quantitative information, two also contain uncoupled information about flow or movement magnitude (compare Figure 3.29).

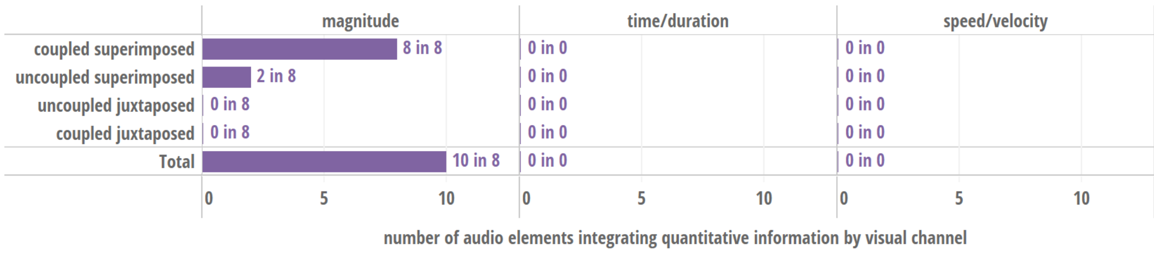


Figure 3.29: Frequencies of quantity conveying audio elements by mode of integration. Overall, eight of the 23 audio elements integrate magnitude ten times within eight visualisations. Two of the eight audio elements provide coupled and uncoupled superimposed content.

3.2.1.2 Context Representation Layer

Context, additional information supporting the main visualisation, may be provided with text-based or audio-based narration, along with additional visualisations or media elements. Because flow and location marks are the subjects described through additional context, they are not included within the context representation layer.

Contextual information, for example, can provide causalities in regard to the depicted flow or movement. Context might convey why a migratory flow was happening (e.g., because of war), why a movement happened along a certain area (e.g., because of topography or anatomy), or how movements and flows affect their environment, or the other way around (e.g., policy changes reducing migration flows, or migration flows inducing policy changes). From a narrative point of view, context is important to support the main message and argument of a visual-narrative and it helps to frame the perspective.

Vis-media integration of context:
Examples of ***coupled superimposed*** context integration often provide some form of spatial reference. Additional anatomical context is provided in *FS_076* by including wall shear stress (forces acting on the vessel wall through blood flow) information represented by colour encoded vessel walls. In *FS_037*, additional context is provided by the pictorial background map with drawings depicting regions or cities.

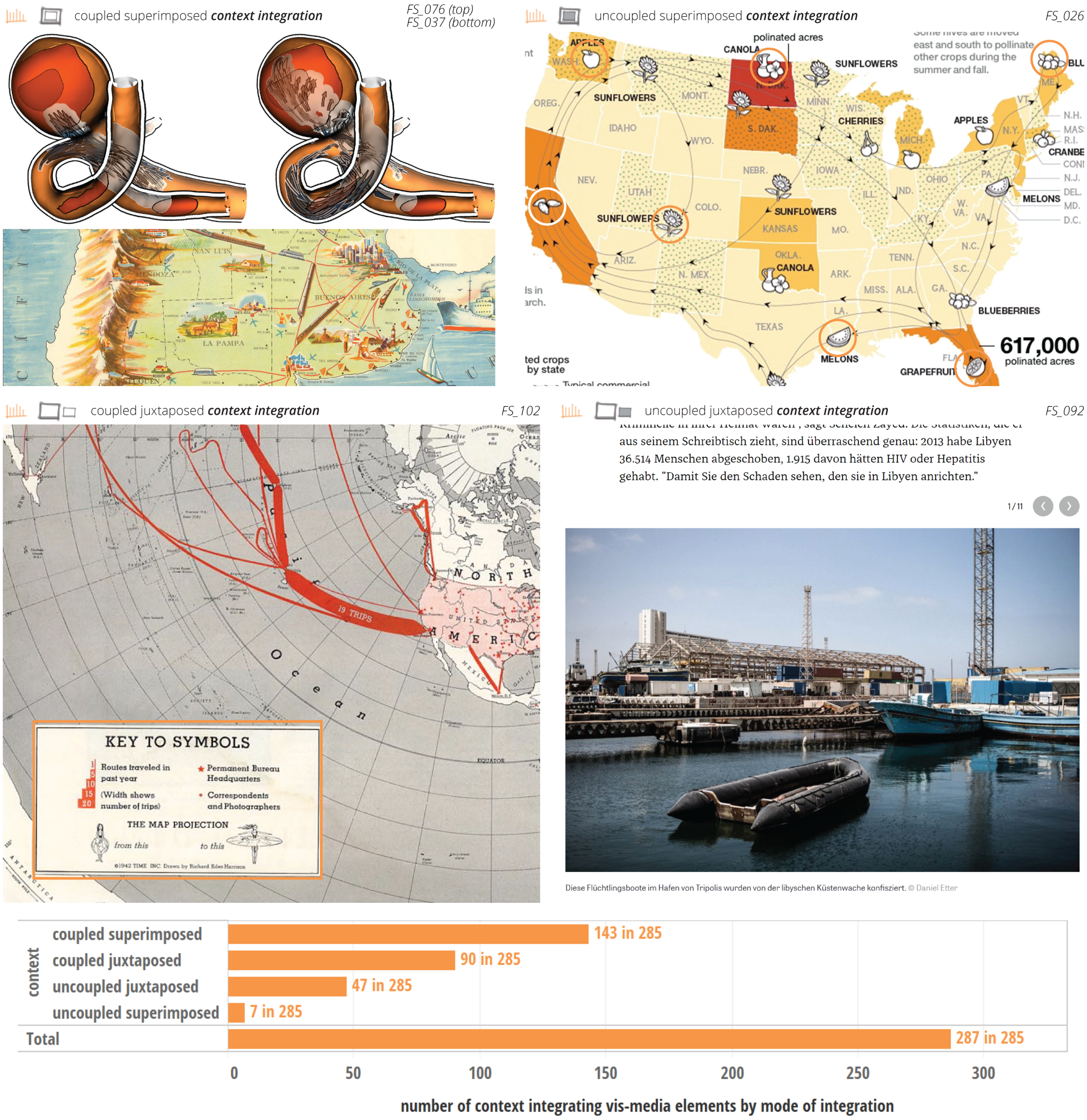


Figure 3.30: ***Top:*** Examples of vis-media elements providing context by mode of integration. ***Bottom:*** Frequencies of identified vis-media elements by mode of integration. Within the collection of visualisations, 285 of the 319 vis-media elements integrate context 287 times in 112 visualisations. Thus, several vis-media elements integrate multiple pieces of contextual information with the same or different modes of integration. Many examples have more than one vis-media element containing context.

Small figurative plant icons (e.g., cherries, apples, and sunflowers) in *FS_026* provide ***uncoupled superimposed*** contextual information. Directly integrated in the map as overlays (superimposed), they add new information about the major crop pollinated by migratory bees (the subject of the story) in the given area.

The legend or key of symbols in *FS_102* provides context in a ***coupled juxtaposed*** mode of integration. While it provides essential information about how to interpret the map symbols, it provides even further context through the little ballerina comic explaining the map projection (coupled). It is juxtaposed, because it is not integrated into the map layout space.

Finally, in *FS_092*, an ***uncoupled juxtaposed*** photograph, that is part of the story's flow text conveys further visual context on the central topic of African refugees crossing the Mediterranean Sea on boats to reach Europe (compare to map in 3.31).

The following Figure 3.30 (bottom) shows that half of the vis-media elements used to convey context are using a *coupled superimposed* mode of integration. One third of these elements provide *coupled superimposed* context. Fewer vis-media elements integrate *uncoupled* context (i.e., 47 juxtaposed, and seven superimposed). Many of the 112 out of 115 visualisations in the collection contain more than one context integrating text element.

Text integration of context:
Text-based elements also provide context (Figure 3.31). *FS_092* has ***coupled superimposed*** text elements with additional context (e.g., the annotation in blue indicating the name of the refugee route across the Mediterranean Sea, or the text box on the lower right giving information about an estimate of "irregular immigrants" being in Libya). *FS_092* also includes ***uncoupled superimposed*** information in the box placed in the top left (*"In addition to Frontex, the Italian coastguard and naval operation Mare Nostrum is deployed in this area."*). The boxes are superimposed in this case, because they are integrated using a speech bubble style that links to the map.

The text annotations in *FS_014* also convey ***superimposed*** context. While ***coupled*** text describes the pollutant's flow pattern, ***uncoupled*** context provides possible causes for regional peaks of atmospheric CO_2 (e.g., *"90% of Americans drive to work"* or *"America's coal plants are mostly in the Midwest and Northeast"*).

Finally, within the frame of a map created by Charles Joseph Minard in 1862, ***juxtaposed*** text provides ***coupled and uncoupled*** context about the *"quantities of cotton imported into Europe in 1858 and 1861"*. The map and the translation of Minard's French handwriting can be found in Rendgen (2018). Minard wrote: *"It was said in England in 1861 that the cotton mills were threatened with near ruin because of lack of raw materials. [...] This* *relief, which my chart underscores, was the considerable increase of cotton imported from India."* While the first part is uncoupled, providing additional causal information, the second sentence refers to the information visible in the flow map. More coupled context: *"Moreover, the chart shows that England, which feared a cotton shortage in 1861, re-exported in that year 133000 tonnes, or twice as much as in 1858, and sold abroad almost a third of what was needed in its mills."* All of this text-based information helps the reader to interpret the visualisation by explaining the reasons for the depicted flows.

As shown in Figure 3.31 (bottom), text elements provide contextual information largely through the *coupled and uncoupled juxtaposed* mode of integration. *Coupled and uncoupled superimposed* text elements are used less frequently to integrate context.

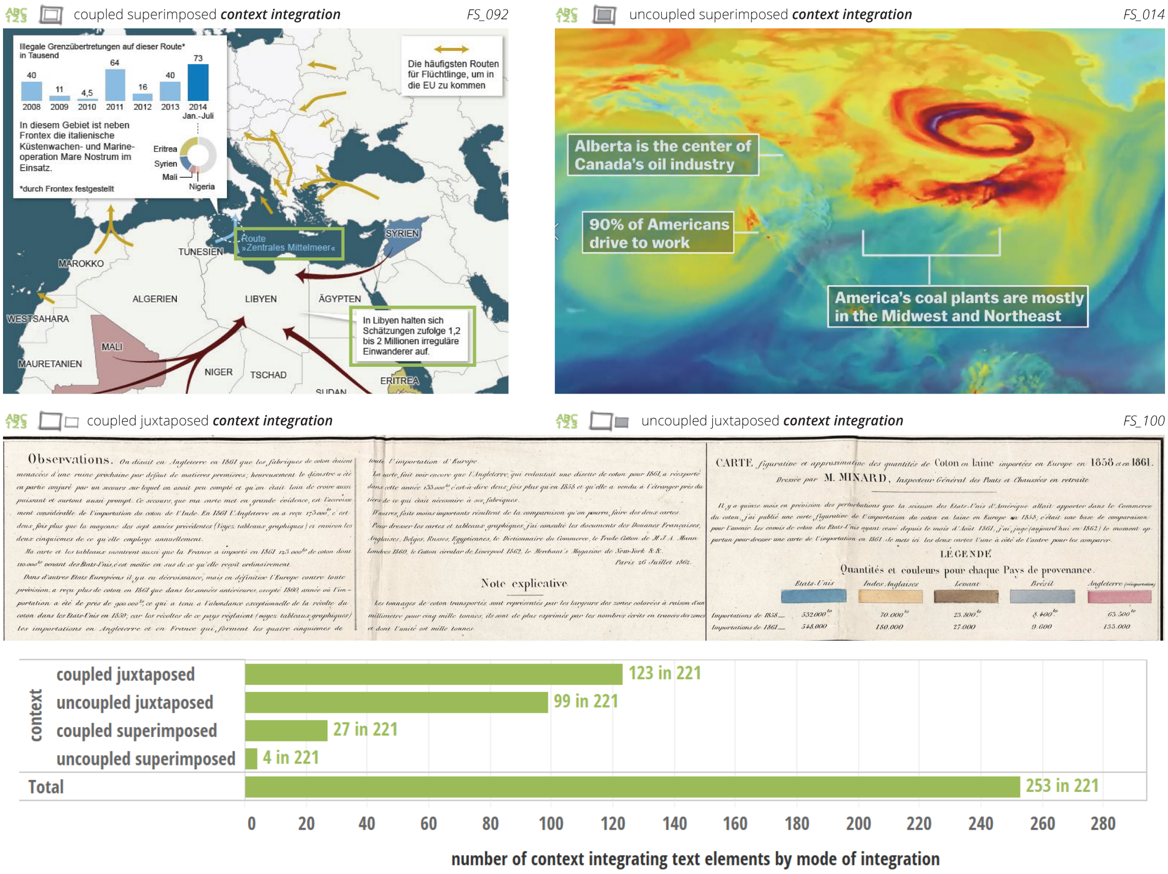


Figure 3.31: ***Top:*** Examples of text elements providing context by mode of integration. ***Bottom:*** Frequencies of context conveying text elements by mode of integration. Overall, over half of the 409 text elements identified within the visualisations in the collection provide contextual information. Many text elements provide context using different modes of integration. Additionally, many visualisations contain multiple instances of text elements that convey context.

Audio integration of context:

Audio-based context can be versatile, and in addition to the very commonly used voice-over narration, it can also include simple sound effects or music in the background. For example, the video *FS_014* starts with an audio collage of news headlines addressing the overall topic of climate change, but it does not reference the atmospheric CO_2 movement visualisation that follows (***uncoupled juxtaposed***).

In *FS_028*, air traffic control radio messages are added in the background to the voice-over narration, providing additional context in a subtle way (***uncoupled superimposed***).

FS_013 also has an additional audio element that provides context. Compared to the other examples (e.g., *FS_027*), which are using uncoupled superimposed background music with the voice-over narration, the dynamic of the music piece in *FS_013* corresponds with the dramatic composition of the video-based visualisation and its voice-over narration. Thus, it is classified as ***coupled superimposed***.

In most of the examples with voice-over narration, both ***coupled and uncoupled superimposed*** context is provided. In *FS_015*, a video mapping the places of birth and death of *"notable people"*, the female voice narrates: *"Let's start in the far east. This is 17th century Japan just opening up to the West. Many of these names are christian missionaries to the country. Some persecuted here for their faith."* (***coupled superimposed***). She also mentions that *"this is the work of a team led by Maximilian Schich based at the University of Texas."* (***uncoupled superimposed***).

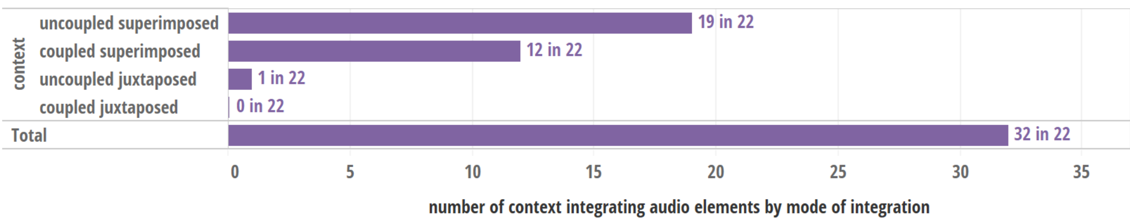


Figure 3.32: Frequencies of audio elements providing context by mode of integration. Overall, 22 audio elements integrate context, with 32 instances in 14 visualisations.

As Figure 3.32 shows, most instances of audio elements conveying context are *superimposed, coupled and uncoupled* alike. Often the same element contains coupled and uncoupled content. Only in one case is an uncoupled juxtaposed mode used. *Coupled juxtaposed* audio elements are not used to provide context. For example, in an audio narration in a teaser sequence where the central flow or movement visualisation is not yet displayed, summarising what a reader is about to see would be categorised as coupled juxtaposed.

3.2.1.3 Interactivity Layer

Interactions, explicit user involvement through an input device like a mouse or a touch screen, can be linked to the five main elements of the design space (e.g., hovering over flow marks or clicking location marks opens a pop-up annotation), but can also exist alongside them (e.g., scrolling or playback of videos).

From a narrative perspective, elements and techniques of the interactivity layer can induce user involvement, increasing active engagement. While it is primarily elements in the other layers that have strong immersion capabilities, interaction can support immersion (immersion is described as *"any state of absorption in some action, condition, or interest"* (Herman et al., 2010)).

The design space also uses the notion of **mode of integration** for interactions. In the corpus of examples, about half of the 115 visualisations provide some form of interaction. They are largely coupled, superimposed, and juxtaposed alike. Uncoupled juxtaposed or superimposed interactions are far less frequent (compare Figure 3.33 bottom).

Examples of ***coupled superimposed*** integration of interaction are browser-based stories that use scrolling to progress the narration and influence the visual display (e.g., *FS_018*). Additionally, navigation interactions like zoom, pan, or rotate, as well as selecting, filtering, highlighting, exploring, or revealing details on demand through hovering and clicking can be coupled superimposed interactions.

An interaction is ***uncoupled superimposed*** if the interaction refers to an superimposed element and does not link back to the main flow visualisation. In *FS_061*, interaction within superimposed pop-up windows provides the ability to analyse and compare areas of interest, either through brushing and linking (left side) or by dragging and dropping the pop-up windows on top of each other (right side).

Interactive time or speed sliders (vis-media elements, e.g., *FS_005*) that influence the flow or movement visualisation, have a ***coupled juxtaposed*** interaction integration. Interactions for filtering, sorting, grouping, video playback, and chapter selection are also often integrated in a coupled juxtaposed way.

Small click-buttons on the side of web-based examples (e.g., *FS_002*), which are ***uncoupled juxtaposed***, open boxes, pop-ups, or linked webpages that provide additional information or how-to use instructions. Those are often used to provide interaction, and they themselves are often subjects of the context layer.

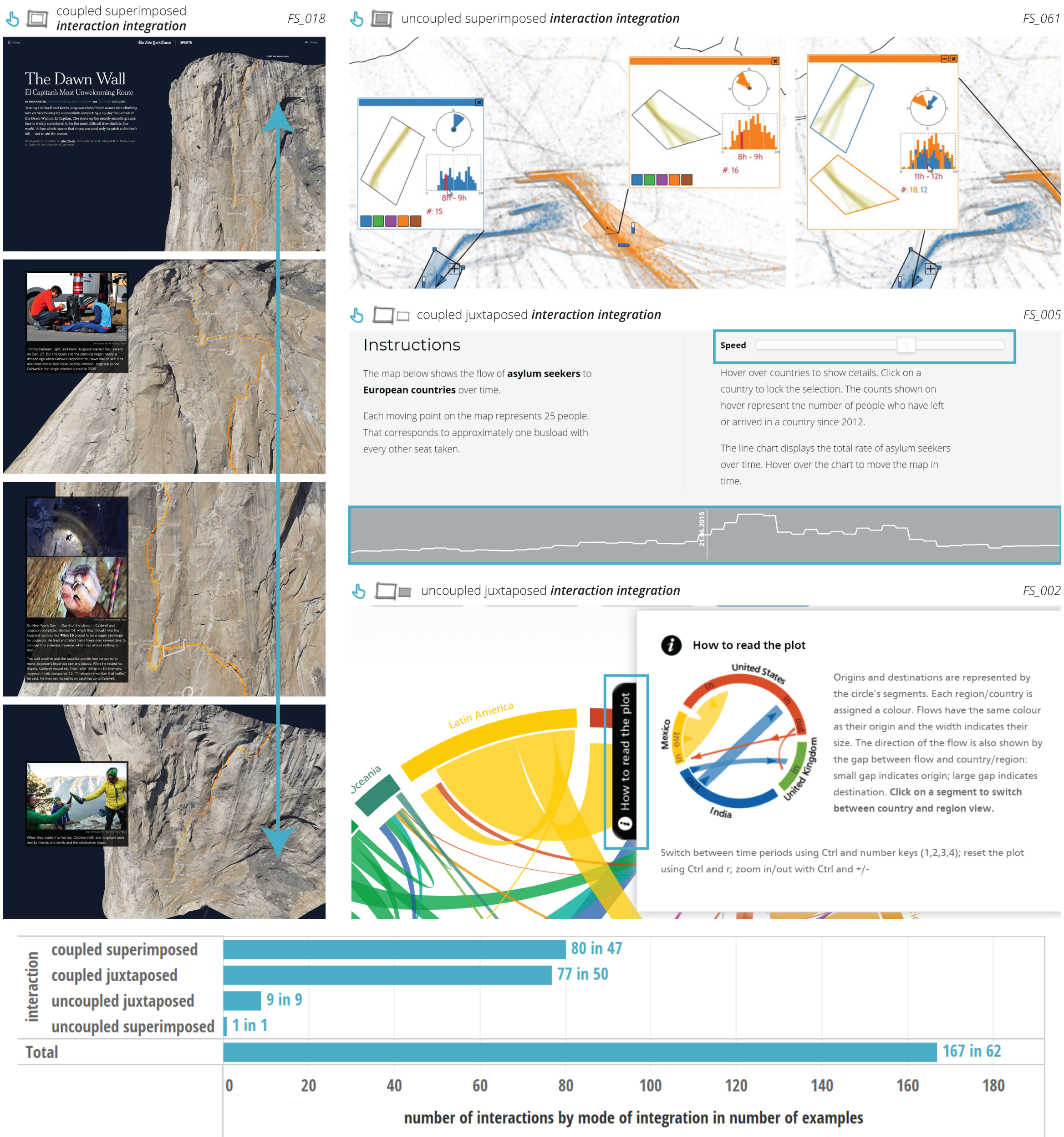


Figure 3.33: ***Top:*** Examples of interactions with different modes of integration. ***Bottom:*** Frequencies of interactions by mode of integration. Overall, half of all visualisations (62 out of 115) provide some form of interaction. A visualisation can have multiple interactions with different integration modes.

3.2.2 Narrative Categories of the Design Space

The previous sections introduced categories of the visualisation aspects of the design space that can be evaluated against its narrative categories, which are explained in the background section in more detail, but are repeated in short here. Examples, and how marks and elements contribute to these categories are given in the next section.

Structure and Temporality: This category includes techniques, that provide spatial, temporal, and thematic sequencing and ordering of a narrative, which define or initiate transitions, progression, and navigation within a narrative.

Messaging and Argumentation: This category includes elements and techniques that contain and convey the (central) message of a visual data narrative. The argument, communicated through explanations, observations, and commentary can be in a more factual form, or in a narrated form. Depending on a narrative's intent, such techniques contribute to informing, educating, or even persuading the audience about an argument made, which overlaps with the concept of framing.

Framing and Perspective: Framing techniques influence how a message is perceived and interpreted; they can reinforce or dampen an argument. They can be used to "set the stage" and the overall tone of a visual narrative display. Framing techniques also often influence emotional reactions or user involvement.

Emotions: Visual-narrative techniques can evoke or reinforce emotional reactions (e.g., empathetic, cheerful, surprised, unpleasant, uncertain, or angry emotional states). Emotion evoking techniques can support narrative understanding and can help to engage and immerse the audience.

User Involvement: When discussing how readers can be *involved* in a narrative visualisation, the distinction between *implicit and explicit user involvement* is made. While implicit user involvement techniques passively try to guide, focus, and increase viewers' attention, engagement, and immersion, explicit user involvement requires some form of reader activity or participation (i.e., interactivity).

The narrative categories listed above help to evaluate how the visual elements and narrative techniques might facilitate the unfolding of a story in a reader's mind. Since the five groups can span across all three editorial layers (visual representation, context, and interaction), the narrative categories are described in a less narrow and detailed format than the visualisation categories. The next section summarise the *rendezvous* between the visualisation and narrative aspects of the design space.

3.2.3 A Rendezvous between Visualisation and Narrative

Now that the categories of the design space have been established, this section illustrates the rendezvous - the interweaving of the two major themes of the design space - between flow and movement visualisation and narrative.

Based on the visualisation collection, examples are given of how marks (i.e., flow and location marks), elements (i.e., vis-media, text, audio), or interactions tend to contribute to which aspects of narrative (i.e., structure and temporality, messaging and argumentation, framing and perspective, emotions, and user involvement). Additionally, charts provide a frequency overview of the identified links between the two domains.

To limit the number of examples to be judged in terms of the narrative side of the design space, two subjective assessments were carried out first: the flow-context-(interaction) balance and the degree of narrativity.

The **flow-context-(interaction) balance** evaluates the saliency of the three editorial layers (i.e., the flow and movement representation layer, context representation layer, and interaction layer). First, the flow-context balance is evaluated, whereby an example can be ***flow-dominant***, ***balanced***, or ***context-dominant***. Additionally, the existence and relevance of interaction possibilities are considered.

For example, the video *FS_094*, an animation concerning the British airspace, is balanced in terms of flow (i.e., accumulated animated flight paths) and context (i.e., text-based elements and a background map). Both layers are equally salient. Interaction, on the other hand, plays hardly any role since it is limited to the possibilities of video playback. More examples of this judgement can be found in each summary of the case studies in Section 3.3.

Figure 3.34 (left) shows that out of the 115 examples, 56 tend to be flow-dominant, 48 are balanced, and only 11 tend to be context-dominant. Within each group, 50% or more have some form of interactivity (Figure 3.34 centre).

This summary of the examples regarding the top-level structure of the visualisation side of the design space (i.e., the editorial layers) is a subjective indicator, and it subsequently supports the first judgement on **narrativity** (the ability of a visualisation to create a story in a reader's mind).

As shown in Figure 3.34 (right), most flow-dominant examples have ***no or little narrativity*** and are therefore not referred to as Flowstories. Balanced and context-dominant examples tend to have a higher degree of narrativity. Half of the balanced examples ***indicate some narrativity***, and respectively have a high potential for narrativisation. Slightly less of the balanced examples have a ***strong to very high degree of narrativity***, and they are called Flowstories. More than half of the context-dominant examples are Flowstories.

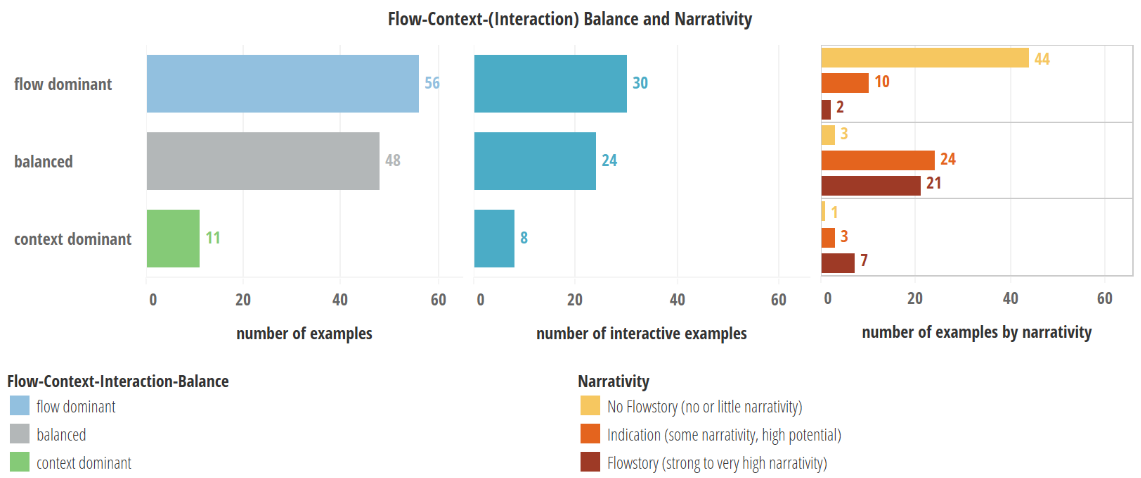


Figure 3.34: Flow-context-(interaction) balance and narrativity. ***Left:*** Number of flow dominant, balanced, and content dominant examples. ***Centre:*** Number of examples in each group that are interactive. ***Right:*** Number of examples in each group judged regarding narrativity.

Figure 3.35 provides an overview of the frequencies of marks and elements used in the **30 selected Flowstories**. Relatively, compared to the 115 examples, the marks and elements have a similar frequency. Only audio elements are relatively more frequent, because almost all of the visualisations containing audio elements were selected to be judged against the narrative aspects of the design space.

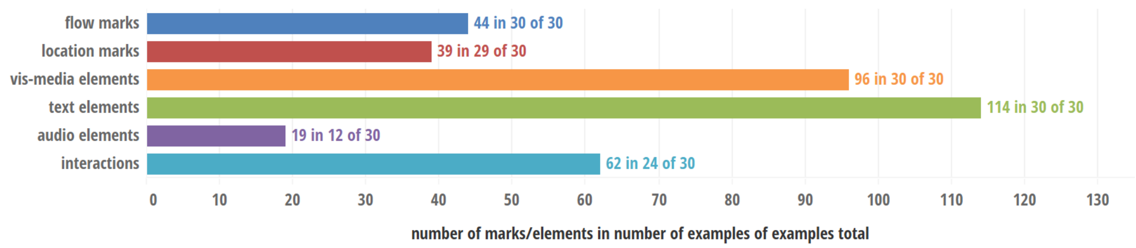


Figure 3.35: Number of marks, elements, and interactions identified in the 30 examples.

The narrative assessment of marks and elements was made on a three-part scale describing the degree of contribution to a narrative category: ***weak***, ***intermediate***, or ***strong***. Of course, ***no contribution*** is also possible. Figure 3.36 provides an overview. Note that the x-axes across marks and elements are not uniform. A comparison between them is not meaningful due to the different frequencies of marks and elements.

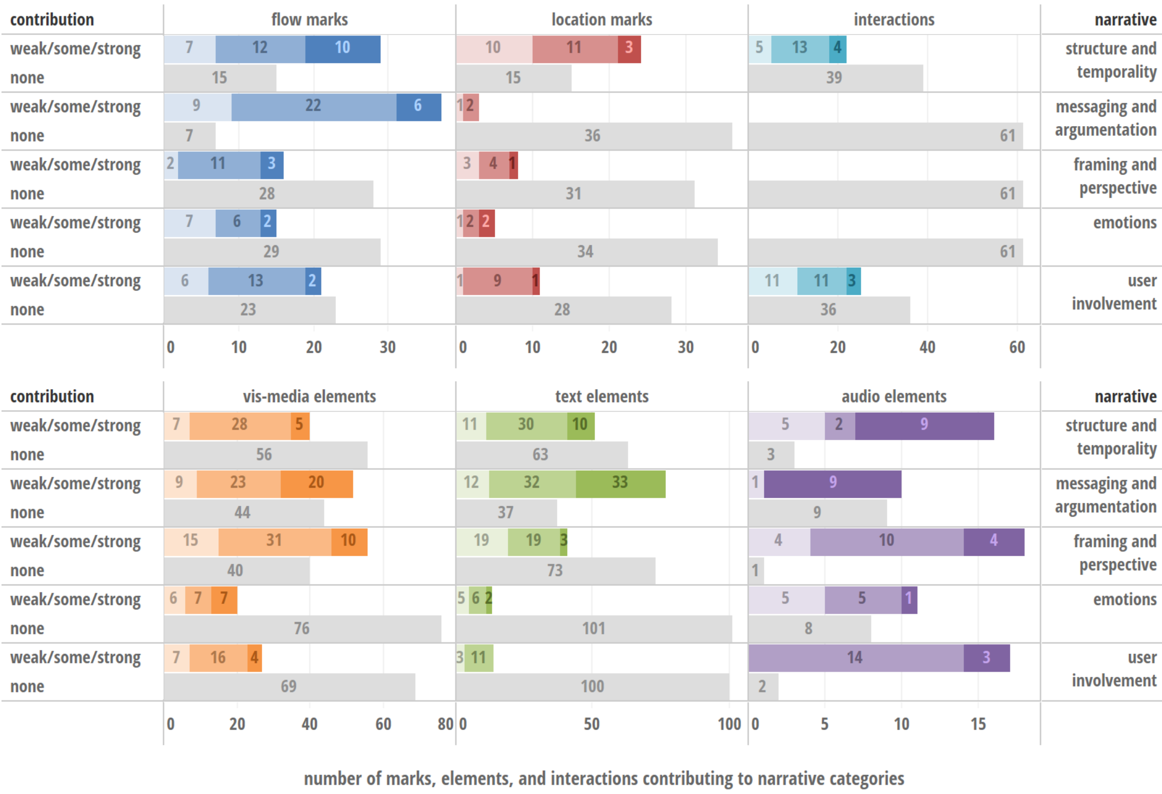


Figure 3.36: Number of marks, elements, and interactions contributing with weak, some, or strong degree to the five narrative aspects of the design space. Note that the x-axes across marks and elements are not uniform.

The following sections provide examples and address the top-level perspective as provided in Figure 3.36 for each type of mark, element, and interactions. Additional charts provide information on more detailed characteristics of the marks and elements that contribute to each narrative component.

3.2.3.1 Flow Marks

Top-level observations: Two-thirds of the **flow marks** provide **structure and temporality** almost evenly distributed across the three contribution levels (see Figure 3.36). Over 80% of the 44 flow marks, most of which have an *intermediate* degree of contribution, support the overall **messaging and argumentation** of a Flowstory. Fewer flow marks induce **framing and perspective** or help to evoke **emotions** (i.e., for each category, about a third of the flow marks do so). About half of the flow marks contribute to the user involvement category. There are several examples in the 30 Flowstories illustrating these links between flow marks and the narrative categories.

Structure and Temporality: Gradually revealing flow marks can provide spatial, temporal, or thematic structure. In the animation of the UK air traffic in *FS_094*, some narrative structure is introduced by focusing first on the commercial traffic across Britain, then on London and other regions. Then individual cases (e.g., military jets and helicopters) are in focus before returning to the overall UK situation. In a second example of the same Flowstory, the 24-hour aggregated departure and landing paths of the five London airports are added to the 3D scene one by one over time until finally, all are visible together, which shows how busy the London airspace is in a 24 hour period.

Messaging and Argumentation: The central message is often supported visually through motion (i.e., animated flow marks). In NASA's Flowstory *"Dynamic Earth"* (*FS_013*), animated arrows resemble the dynamic processes in our universe and on our planet. Other examples, where motion supports the overall theme or message where entities are moving between locations are *FS_015*, *FS_026*, and *FS_038*. The visual appearance of flow marks can convey a message. The slope, straightness, and density of the lines showing train schedules in *FS_021* indicate speed, delays, or rush hours. The number or density of flow marks can amplify arguments where magnitude plays a role. The single route in *FS_018* supports the fact that climbing El-Capitan is a singular performance and it is not achieved every day. On the other hand, the vast number of single dots showing global ship (*FS_027*) and air traffic (*FS_028*), deliberately not using aggregation, supports the argument that both shipping and air transport are matters of enormous proportions.

Framing and Perspective: The selection or omission of flow marks based on country, flow magnitude, or category frames the entire narrative, setting the stage (e.g., *FS_032*, *FS_053*). Using associative colouring offers potential for framing (e.g., the red colour in *FS_047* representing the distribution of communism). In *FS_113*, information is provided from two different perspectives. Aside from the migratory journey of a single person, aggregated global data provide a more general perspective for comparison.

Emotions: The location of flow marks, depending on a reader's relation to the place or the topic, might elicit emotional responses (e.g., London's heavy air traffic in *FS_094*, or gun trafficking in the US in *FS_024*). Mimetic or figurative styles of flow marks (e.g., refugees leaving Syria in *FS_110*, or soldiers engaged in combat related activities in *FS_045*) might evoke emotions. Similarly, associative colouring might have comparable effects (e.g., red signifying danger in *FS_017* and *FS_047*).

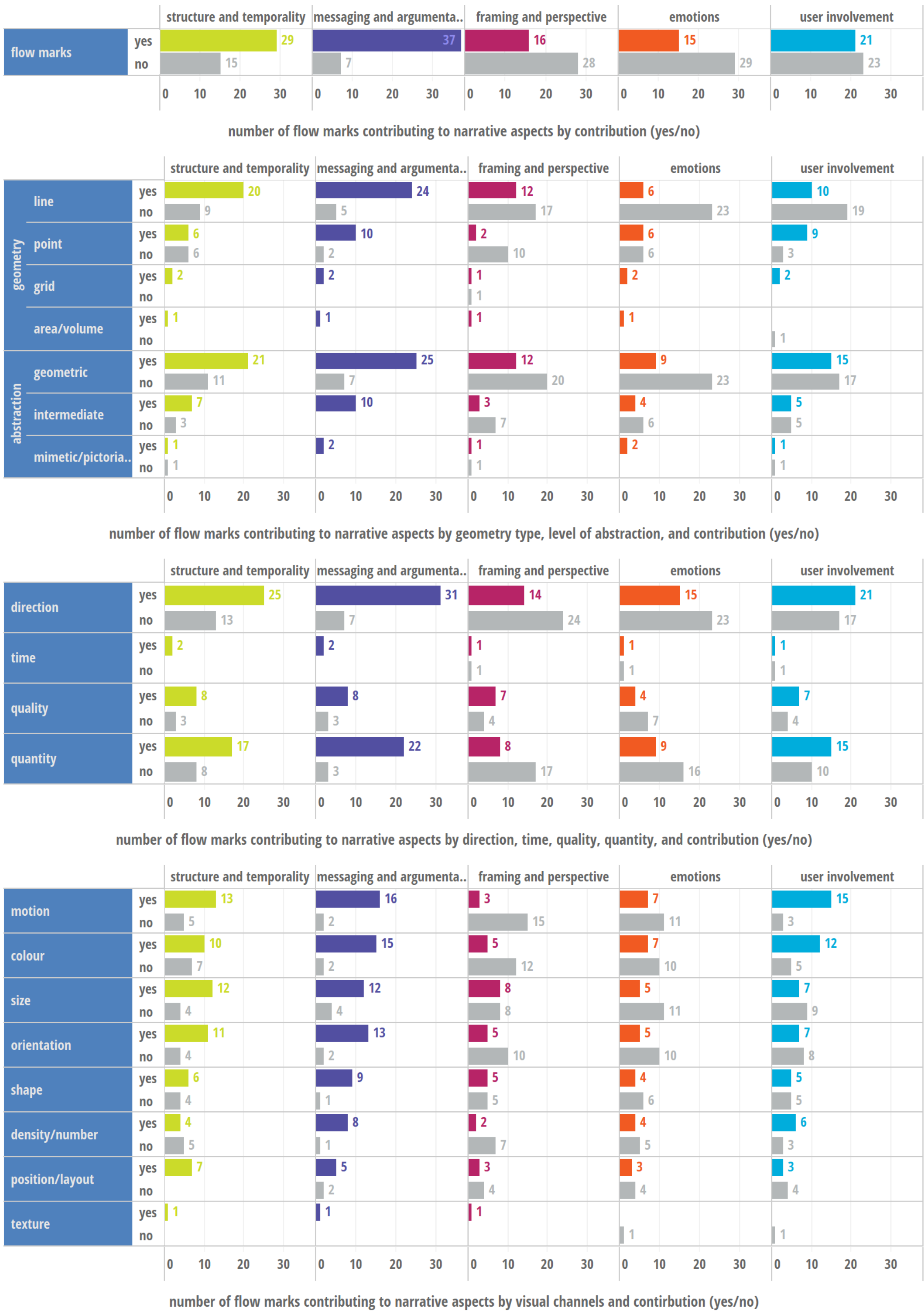


Figure 3.37: **Top:** Top-level perspective of the contribution of flow marks to narrative aspects. **Middle top:** Number of flow marks identified in the 30 Flowstories that contribute to the narrative aspects by geometry type and level of abstraction. **Middle bottom:** Number of flow marks contributing to narrative aspects by type of information. **Bottom:** Number of flow marks encoding information contributing to narrative aspects by visual channel.

User Involvement: Implicit user involvement can be achieved through motion (i.e., animated flow marks). Motion draws attention and has immersion-inducing power, for example, as shown in the Flowstories *FS_013, FS_015, FS_027, and FS_038.*

These examples illustrate the range of possibilities. Based on Figure 3.37, the following paragraphs provide a summary of the various characteristics of flow marks associated with the narrative aspects of the design space.

Characteristics by Geometry (Figure 3.37 middle top): Primarily, flow marks with ***line geometries*** tend to support **structure and temporality**. Line symbols often visually represent the overall narrative structure by linking events in space and occasionally in time. With this supportive strength, to some extent, they emphasise aspects of the main **message** of a Flowstory. This reflects the top-level observations regarding flow marks. It seems that flow marks with line geometries contribute less to the categories **emotions** and **user involvement** compared to the overview perspective. Flow marks with ***point geometries*** tend to support **messaging and argumentation** and **user involvement**. Further, half of the point flow marks support **structure and temporality** and can help to evoke **emotions**. Many of them use animation or an individual visual style to achieve these associations. Compared to the average flow mark, these absolute observations are set into perspective. Relatively more point flow marks contribute to the categories of **emotion** and **user involvement**, and proportionally less of them contribute to **structure and temporality** and framing and perspective. Flow marks with a ***grid*** or ***area/volume geometry*** tend to contribute across the narrative categories. That said, only three flow marks in the 30 examples have such geometries.

Characteristics by Level of Abstraction (Figure 3.37 middle top): In a relative comparison, more flow marks with a ***lower level of abstraction*** (i.e., intermediate and mimetic) tend to contribute to the narrative categories **messaging and argumentation** and **emotions** than flow marks with a ***higher level of abstraction*** (i.e., geometric). For the other categories (i.e., structure and temporality, framing and perspective, and user involvement), there is relatively no large difference between the three levels of abstraction. The chart corresponds to the overview perspective, that flow marks contribute most to structure and temporality, messaging and argumentation and user involvement.

Characteristics by Information Encoded (Figure 3.37 middle bottom): Flow marks that encode directional, temporal, qualitative, and quantitative information are associated with the different narrative categories. Flow marks often encode more than one type of information. Since almost all flow marks encode the ***direction*** of flow or movement, the row direction provides similar information as in the overview chart (Figure 3.36). However, contrary to the top-level observation, it shows that direction encoding flow marks tend to contribute relatively more frequently to **user involvement**. This observation also applies to flow marks that convey ***qualitative*** or ***quantitative*** information. Additionally, seven of the eleven quality encoding flow marks provide **framing or perspective**, which differs from the top-level overview. If flow marks encode ***temporal*** information (there are only two instances in the 30 examples), they tend to support temporality and the main message strongly.

Characteristics by Visual Channels (Figure 3.37 bottom): Flow marks that use ***motion*** and ***colour*** to encode information are important for the categories **structure and temporality**, **messaging and argumentation**, and **user involvement**. While this reflects the overall observations for flow marks for the first two categories, it is different for user involvement. The visual channels colour and motion as well as ***density/number*** are used relatively more often in flow marks that contribute to the user involvement category. Compared to the average flow mark, flow marks using ***size*** or ***shape*** tend to provide **framing and perspective** more often. The channels motion and density/number contribute proportionally less to this category.

Take-aways: **(1)** Geometries visually provide structure and support the message; **(2)** Multiple flow marks (with the same or different geometries) can provide different perspectives; **(3)** Flow marks with a lower level of abstraction better support the overall message and might help to evoke reactions on an emotional level. **(4)** Flow marks encoding qualitative information provide perspective; **(5)** Motion and colour emphasise narrative aspects.

3.2.3.2 Location Marks

Top-level observations: **Location marks** primarily provide support for **structure and temporality** at a *weak* or *intermediate* level of contribution. Location marks tend not to contribute much to the other narrative categories (compare Figure 3.36). Nevertheless, there are examples within the visualisations of the collection.

Structure and Temporality: Background maps as location marks (e.g., *FS_010, FS_024, FS_045*) offer a spatial structure that integrates the represented flows into the local context. Location marks in non-geographic displays (e.g., in diagrams) are often arranged according to layout (e.g., from top to bottom), which is usually aligned to the temporality of events (e.g., *FS_021, FS_114*).

Messaging and Argumentation: Location marks together with flow marks can support arguments concerning the extent of the central phenomenon. For example, the background map in *FS_032* shows that migration is a global phenomenon. The 3D rock in *FS_018* shows that the depicted climb is a single and local event.

Framing and Perspective: The map projection used and the rotation of background maps that act as location marks have framing potential. Depending on the properties of a map projection, depicted data (i.e., flow marks) may appear relatively longer or shorter, or closer or further apart (e.g.,*FS_032*). Rotation and zoom can emphasise phenomena to make them appear larger and more important (e.g., *FS_047*), or set the perspective by focusing on a specific area of interest (e.g. *FS_010, FS_014*). Mimetic location marks such as the country flag fill styles used in *FS_017* and *FS_110* can also provide framing.

Emotions: Location marks, often in connection with flow marks, can evoke emotions. For example, the 3D rock in *FS_018* conveys the danger of the free climb. The huge universe with the planets in *FS_013* might make you feel small and insignificant or awestruck. The flame icons, representing bombardments in *FS_017* might cause you to feel alert or angry.

User Involvement: Along with flow marks, location marks might be animated as well. For example, in *FS_013*, the viewer is taken on a journey from the sun through the universe towards our planet. An author-defined change of focus (i.e., zooming to an area) as in *FS_014* and *FS_015* fosters implicit user involvement. The interactive 3D rock in *FS_018* might draw a spectator into the situation. Similarly, interactive background maps as location marks (e.g., *FS_010*), allow users to explore and investigate familiar regions (e.g., the home country of the user). This is an example of how implicit user involvement can be induced by explicit user involvement.

Characteristics by Geometry and Level of Abstraction (Figure 3.38 middle top): Location marks with an *area/volume geometry* tend to contribute more to **structure and temporality** than *point* location marks. For the same narrative category, ***geometric*** marks are contributing less often than ***intermediate***, less abstract marks are contributing largely. Noticeably, location marks with a geometric level of abstraction provide less support across the narrative categories. A higher level of abstraction contributes proportionally less to the categories of **emotions** and **user involvement** than lower levels.

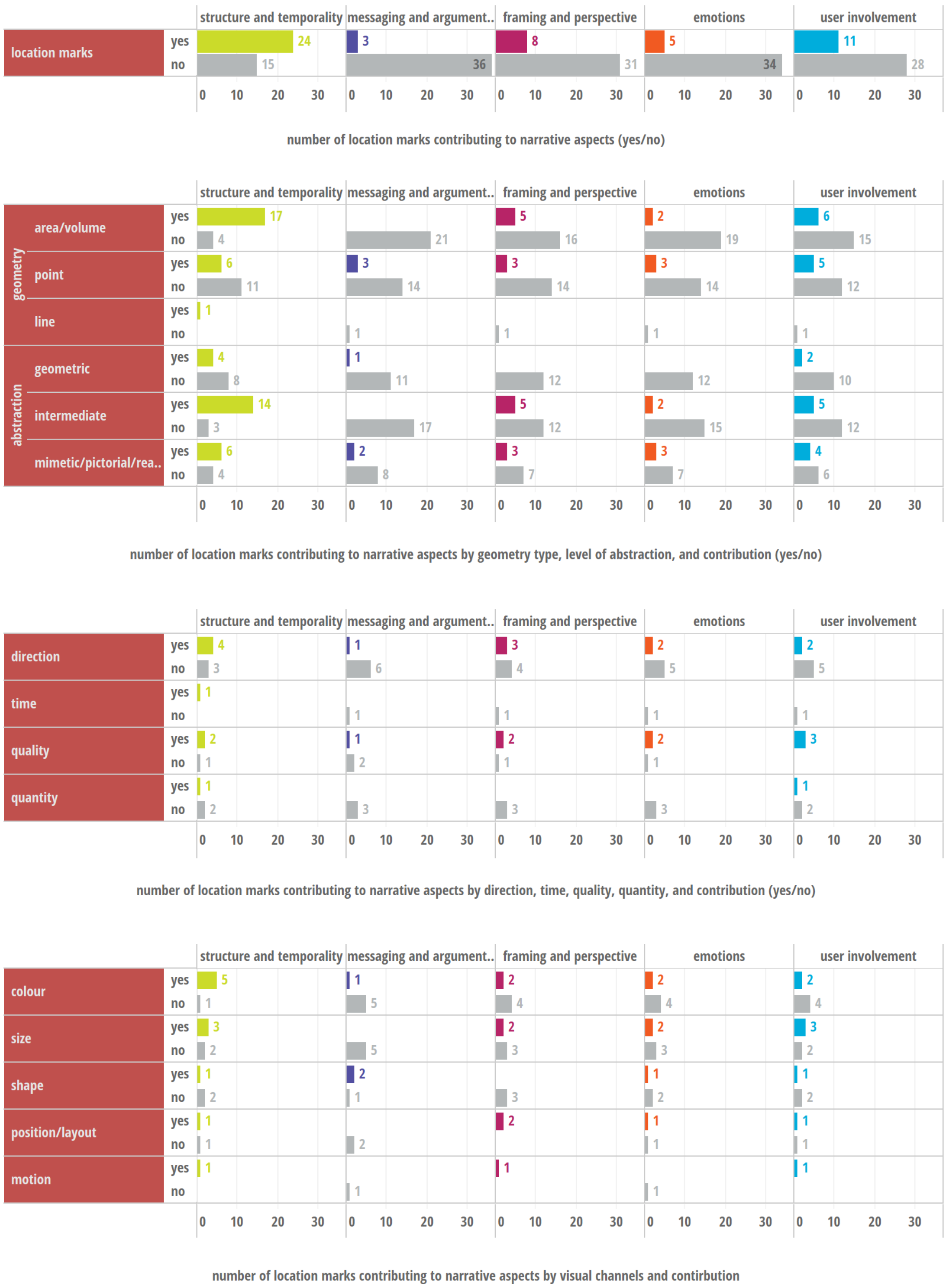


Figure 3.38: **Top:** Top-level perspective of the contribution of location marks to narrative aspects. **Middle top:** Number of location marks identified in the 30 Flowstories that contribute to the narrative aspects by geometry type and level of abstraction. **Middle bottom:** Number of location marks contributing to narrative aspects by type of information. **Bottom:** Number of location marks encoding information contributing to narrative aspects by visual channel.

Characteristics by Information Encoded (Figure 3.38 middle bottom): Few location marks encode information other than location. While ***direction*** encoding marks tend to reflect the top-level observations, ***time*** and ***quantity*** encoding location marks do not provide much support across categories, if they are encoded at all. ***Quality*** encoding location marks tend to, at least to some extent, contribute across the narrative aspects.

Characteristics by Visual Channels (Figure 3.38 bottom): Due to the fact that a small amount of directional, temporal, qualitative, and quantitative information is encoded by location marks, the numbers shown in the chart do not reveal great insight. Colour and size are primarily used to encode such information. Overall, these visual channels reflect the top-level perspective regarding the contribution to the different narrative aspects.

Take-aways: (1) Location marks provide structure; **(2)** With a lower level of abstraction, location marks tend to strongly support user involvement and might help to evoke reactions on an emotional level. **(3)** Location marks often only convey spatial information.

3.2.3.3 Vis-Media Elements

Top-level observations: Vis-media elements largely contribute to the category **framing and perspective** (i.e., 56 of 96 elements) mostly on an *intermediate* level, and to the category **messaging and argumentation** mainly to an *intermediate* and *strong* degree. About 40% of vis-media elements support the Flowstories' **structure and temporality**. They contribute less to the narrative aspects **emotions** (5% of all elements) and **user involvement** (28% of all elements) (see Figure 3.36). The following examples illustrate how vis-media elements can be associated with the narrative aspects.

Structure and Temporality: In *FS_025*, a map overlay, an additional vis-media element, informs readers about the pollination schedule of states in the US, where a colour ramp corresponds to the course of the year. In conjunction with the text annotations, the overlay provides a temporal structure regarding the movements of the migrating beekeepers.

Messaging and Argumentation: Additional vis-media elements can support the main message or help to build up arguments. These include superimposed visualisation layers (e.g., the gun law strictness choropleth map layer in *FS_024*, or a layer showing the global snow and ice cover indicating ice ages in *FS_038*) and additional charts, images, plans, or videos integrated in a juxtaposed way into a narrative visualisation (e.g., *FS_016, FS_017, FS_021, FS_023*). Legends (e.g., *FS_016, FS_024, FS_039*) and embedded scales (e.g., *FS_018, FS_028*) aid in the interpretation of the message provided through the visual marks.

Framing and Perspective: Vis-media elements also have a great potential to frame the interpretation of the narrative. For example, the visual style of background maps (e.g., dark, bright, historic) can set a certain tone (e.g., *FS_006, FS_016*). By providing a sense of place or emphasising specific content (e.g., planes dropping bombs, migrants in camps), pictures and videos can frame the narrative as well (e.g., *FS_016, FS_017, FS_110*). In *FS_015*, an explanatory example at the beginning frames and sets the stage by starting with one famous person, then extending to thousands of people in the next stage. In *FS_040*, a narrative about migration in China, the boundaries of Austria and Switzerland are visually morphed into two Chinese provinces with the same GDP as those European countries in 2010. This comparison gives the facts an additional perspective, making them more familiar for the European audience of the news outlet that created the video.

Emotions: Depending on the content and the individual relation to the topic, additional vis-media elements such as images, charts, maps, or videos can evoke emotions (e.g., destroyed air bases in *FS_017*, people in concentration camps in *FS_016*, refugees facing soldiers in *FS_110*, a chart showing the rapid increase of global CO_2 in *FS_014*).

User Involvement: Vis-media elements (e.g., pictures, charts, or videos) can not only support or frame the message and evoke emotions, but they can also (depending on the content) help to get the audience immersed in the narrative (e.g., *FS_016, FS_017, FS_110*). Examples with legends require users to be mentally invested (e.g., *FS_010, FS_025*). The TEDx speaker in *FS_023* involves the audience by taking them on the bike ride from his workplace to the venue. At the same time, he uses the map showing his commute to introduce how the following flow maps showing thousands of cyclists are to be read, thus mentally preparing the audience. In other examples, highlighted countries in additional map layers help to guide the reader's attention (e.g., *FS_029, FS_047*).

Characteristics by Information Integrated (Figure 3.39 middle): Contrary to the top-level observations, ***location*** and ***time*** conveying vis-media elements strongly provide **structure and temporality**. As with the top-level (but more clearly), ***direction*** integrating vis-media elements contribute to **messaging and argumentation** and **framing and perspective**. The same applies to ***quality*** and ***quantity*** conveying vis-media elements regarding the narrative aspect of **messaging and argumentation**. Almost all vis-media elements provide ***contextual*** information. Hence, the row in Figure 3.39 (middle) reflects the top-level overview in Figure 3.39 (top).

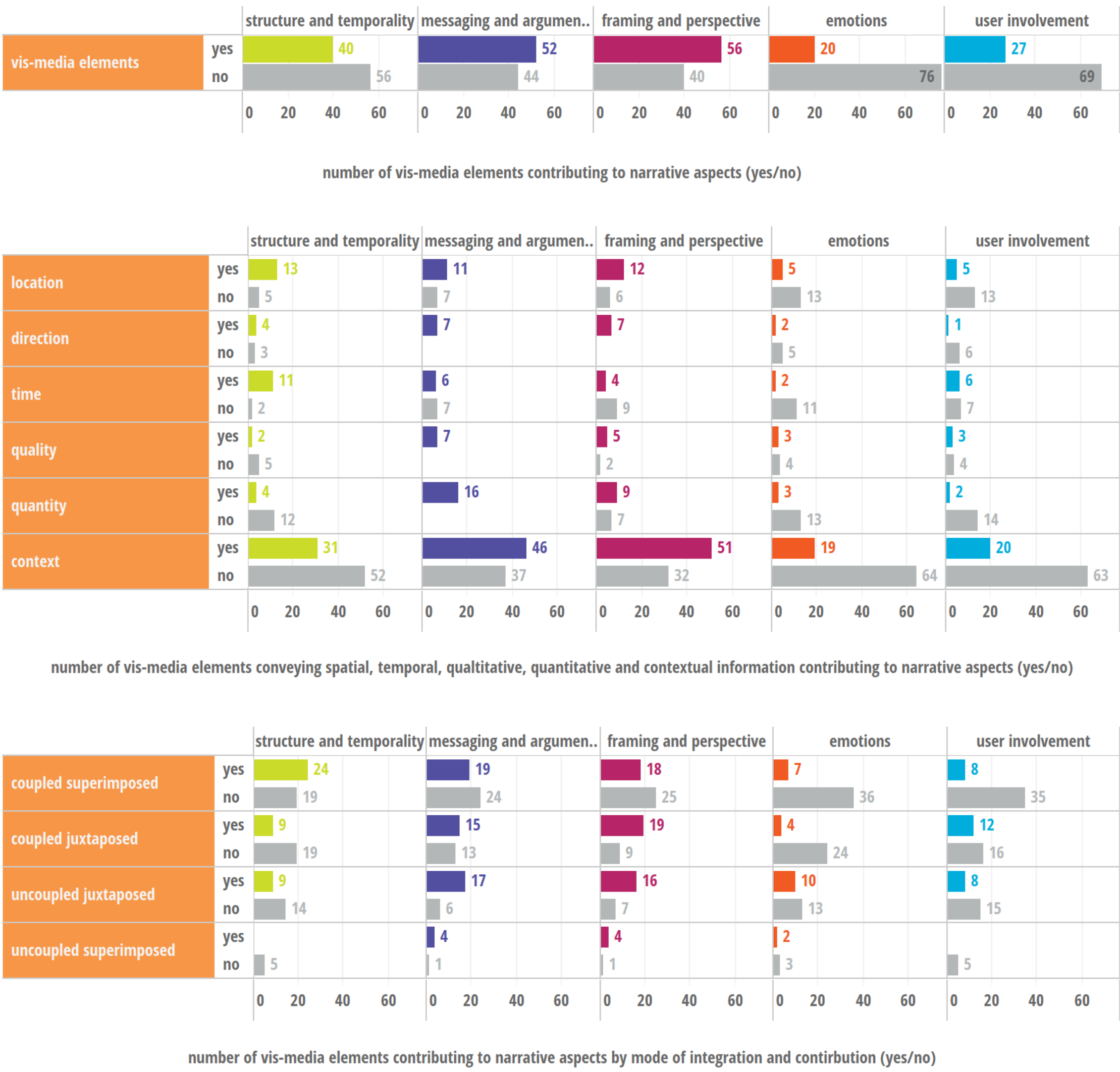


Figure 3.39: **Top:** Top-level perspective of the contribution of vis-media elements to narrative aspects. **Middle:** Number of vis-media elements contributing to narrative aspects by type of information. **Bottom:** Additional perspective showing how the vis-media elements that contribute to the narrative aspects are integrated.

Characteristics by Mode of Integration (Figure 3.39 bottom): Most of the vis-media elements that convey the above type of information are ***coupled superimposed***. Compared to observations at the highest level, they mainly provide **structure and temporality**. ***Coupled juxtaposed*** elements mostly contribute to **framing and perspective**. ***Uncoupled juxtaposed*** elements provide **messaging and argumentation** as well as **framing and perspective**. Relatively, this integration mode also contributes more frequently to the category **emotions**. There are not many ***uncoupled superimposed*** vis-media elements. Overall, they mirror the top-level perspective.

Take-aways: **(1)** Vis-media elements can frame the overall tone, emphasise a certain perspective, and aid the interpretation of the conveyed message; **(2)** Vis-media elements largely provide context contributing across all narrative aspects; **(3)** Different modes of integration tend to aid different narrative aspects. An uncoupled superimposed mode of integration is rarely used.

3.2.3.4 Text Elements

Top-level observations: Two-thirds of the text elements contribute mainly to an *intermediate* and *strong* degree to the category **messaging and argumentation**. About 45% of the text elements also support **structure and temporality**, albeit to a lesser extent (i.e., about 45% mostly at an *intermediate* level). About a third help to **frame and set perspective**, overall with lower degrees of contribution. Text elements do less to contribute to the narrative aspects of **emotions** and **user involvement** (compare Figure 3.36). The following examples provide some further insight.

Structure and Temporality: In *FS_018*, text in boxes retells how two climbers conquered El-Capitan, focusing on major way points in the wall during the 19-day free climb, which reflects the order of events. Since the boxes are coupled with scrolling and appear accordingly, they echo the chronological structure of events.

Messaging and Argumentation: The main message and argumentation is usually communicated in verbal form, using text or audio elements (e.g., flow text, text annotations, voice-over narration). The above-described marks and elements (i.e., flow and location marks, vis-media elements) usually *support* the message rather than *providing* it. Many examples of text elements are part or the case studies that are presented in the following Section 3.3.

Framing and Perspective: *FS_047* provides an example of how a title or text elements can have framing or priming effects. The words used and the overall tone can influence how the message is perceived. The title *"In 42 short years 1917-1959 the Socialist / Communist Conspiracy has conquered 1/3 of the world"* suggests that communism is at least undesirable. As before, the selection and omission of content and examples in text-based elements plays a role in framing (e.g., labels of the selected battles in *FS_045*, or examples of selected countries in *FS_006*).

Emotions: Similar to vis-media elements, the content of text elements can also elicit emotions depending on a user's relation to the topic (e.g., being disgusted or angry reading about the imprisonment of Japanese Americans between 1942 and 1946 in *FS_016*, feeling anxiety or admiration reading about the free climb of El-Capitan in *FS_018*, feeling insecure and small reading about prehistoric human migration in *FS_038*, or being amused learning about the US perspective on the communist conspiracy in *FS_047*).

User Involvement: Linked, text-based journalistic or academic articles allow further engagement with the topic (e.g. *FS_010, FS_018, FS_026*).

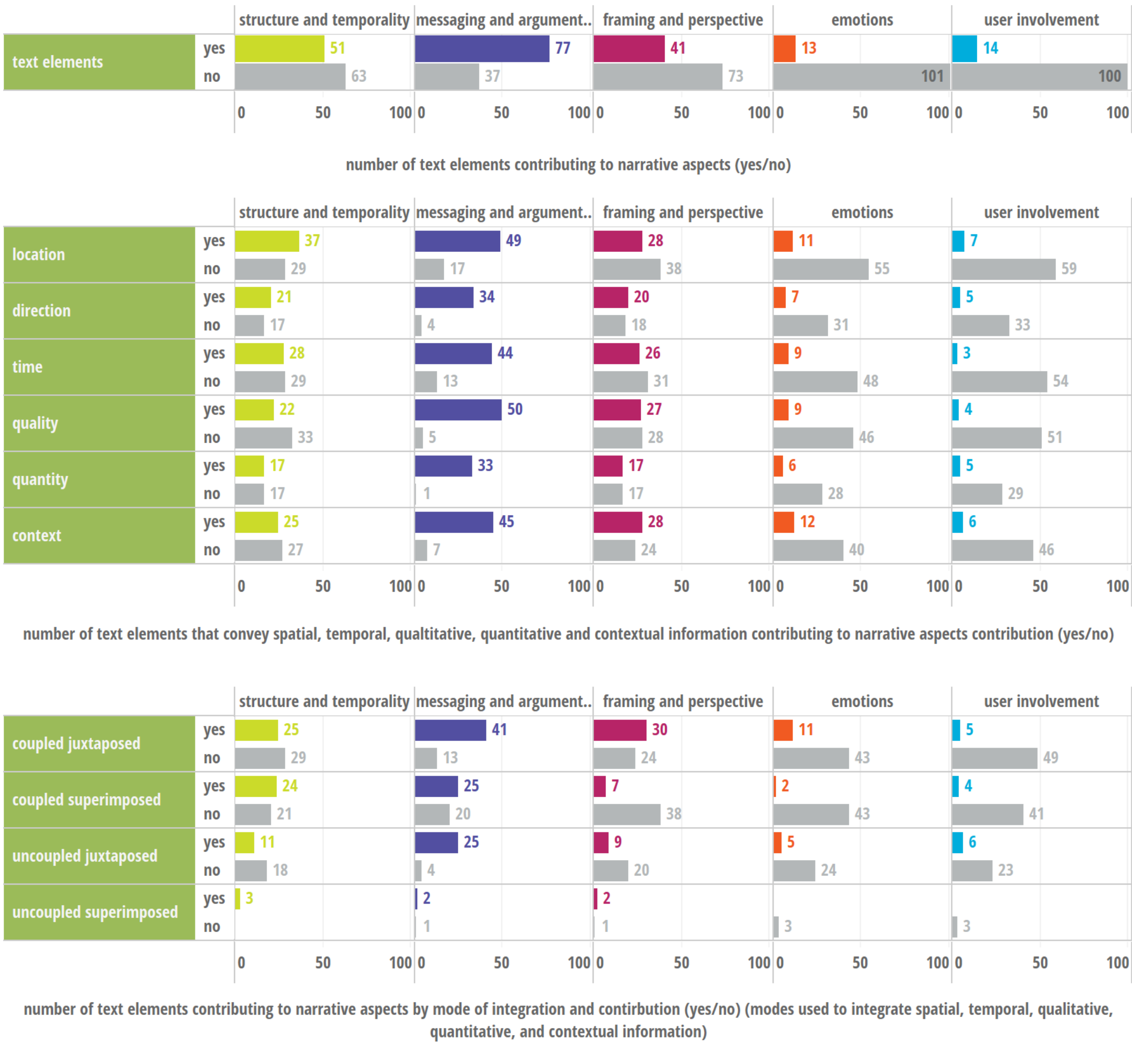


Figure 3.40: **Top:** Top-level perspective of the contribution of text elements to narrative aspects. **Middle:** Number of text elements contributing to narrative aspects by type of information. **Bottom:** Additional perspective showing how the text elements that contribute to the narrative aspects are integrated in relation to the central visualisation.

Characteristics by Information Integrated (Figure 3.40 middle): Across different information types, the contribution of text to the **structure and temporality** category is balanced overall (i.e., approximately half contribute, and the other half does not contribute). Text that integrates ***spatial*** information especially contributes to this aspect. Text elements that integrate ***direction*** and ***context*** communicate aspects of **messaging and argumentation** as well as provide **framing and perspective** with above-average relative frequency. This observation is also correct for ***quality*** and ***quantity*** integrating elements regarding the **messaging and argumentation** component. The chart also reveals that many text elements contain more than one type of information.

Characteristics by Mode of Integration (Figure 3.40 bottom): The figure compares the modes used to integrate spatial, temporal, qualitative, quantitative, and contextual information. Most text elements are coupled (vs uncoupled) and are juxtaposed (vs superimposed). ***Coupled juxtaposed*** text elements, as opposed to coupled superimposed text elements, contribute more frequently to **framing and perspective**. Relatively, ***coupled superimposed*** text elements tend to contribute more frequent to **structure and temporality** as well as to **messaging and argumentation**. ***Uncoupled juxtaposed*** text elements also contribute over-proportionally to the latter category. As with vis-media elements, there are only three instances where text elements integrate information in an ***uncoupled superimposed*** way.

Take-aways: (1) Text elements contain all types of information contributing to many narrative aspects; **(2)** Especially, text often conveys the main message; **(3)** Different integration modes tend to provide support for different narrative categories.

3.2.3.5 Audio Elements

Top-level observations: When Flowstories contain audio elements, they tend to contribute to all five narrative categories to a great extent. For instance, 18 out of 19 elements are used for **framing and perspective**, 17 out of 19 have **user involvement** inducing strength, 16 out of 19 help to support **structure and temporality**, 11 out of 19 elements help to evoke **emotions**, and 10 of 19 contribute to **messaging and argumentation**. In this last, almost equally balanced category, we see the distinction between voice-over narration and other audio elements (e.g., background music).

Structure and Temporality: Voice-over narration reflects how the author arranged the information thematically and temporally. A narrator brings the (often more hidden) structure in visual narratives to the surface (e.g.,*FS_010, FS_015, FS_023*).

Messaging and Argumentation: As with text elements, audio elements are also used to communicate the main message and argumentation in verbal form (i.e., voice-over narration). The case study (*FS_010*) discussed in Section 3.3.1.1 provides excerpts of audio elements conveying the main message.

Framing and Perspective: Audio elements can frame an entire Flowstory. How two different voice-over narrations can frame a visual narrative is demonstrated by two versions of *FS_013*. While one version is narrated by a NASA employee, the other has a narration by Liam Neeson, a famous actor. The different tone and intonation of the two voices alone leads to different perceptions of the identical narrative script. Further, the background music in the same example frames the visualisation (i.e., an expressive composition reflecting the impressive universe).

Emotions: Audio elements also influence emotions. While the intonation (e.g., Liam Neeson narrating in *FS_013*) or the content (e.g., climate change in *FS_010*) of voice-over narration elicit emotions, the purposeful use of music in the background is also a very powerful tool for influencing emotions.

User Involvement: The examples with audio elements show that voice-over narration and background music have a strong ability to induce immersion (e.g., *FS_010,FS_013, FS_027, FS_028*). If the narration is through an actual person (e.g., FS_023), gestures and body language play a role in the presentation, helping to get the audience mentally involved.

Characteristics by Information Integrated (Figure 3.41 middle): All audio elements that convey ***spatial, temporal, qualitative, or quantitative*** information contribute to the narrative categories **structure and temporality**, **messaging and argumentation**, and **framing and perspective**. Almost all contribute to the narrative aspects of **emotions** and **user involvement**. They are all voice-over narrations. ***Context*** is provided not only by voice-overs, but also by sound collages or background music. Overall, context integrating audio elements reflect the top-level observations. One can see that those context elements do not always contribute to the category **messaging and argumentation** (i.e., background music).

Characteristics by Mode of Integration (Figure 3.41 bottom): The chart shows that in many cases, ***superimposed*** audio elements (i.e., voice-over narration) provide ***coupled and uncoupled*** content alike. Other sound elements are primarily ***uncoupled***. An audio element presenting ***uncoupled*** content is placed juxtaposed (i.e., before the central visualisation) only in one instance which acts as a **framing** device setting the perspective.

Figure 3.41: **Top:** Top-level perspective of how audio elements contribute to narrative aspects. **Middle:** Number of audio elements contributing to narrative aspects by type of information. **Bottom:** Number of audio elements that convey spatial, temporal, qualitative, quantitative or contextual information contributing to narrative aspects by mode of integration.

Take-aways: (1) Audio provides an additional perceptual channel to convey information; **(2)** Audio elements contribute to a large extent across the narrative aspects; **(3)** The possibilities offered by different audio integration modes to support narrative aspects are not exhausted in the 30 examples.

3.2.3.6 Interactions

The 61 **interactions** identified in the 30 Flowstories were evaluated in terms of the narrative components. During this process, two different types of interactions emerged: global (30) and local (31) interactions.

Global Interactions (Figure 3.42 top): Global interactions are user interactions that affect the entire Flowstory and are not solely associated with any of the marks or elements. Such interactions only contribute to the narrative aspects of **structure and temporality** as well as **user involvement** (i.e., mainly explicit user involvement). For instance, navigational devices like coupled superimposed scrolling, coupled juxtaposed stepper widgets, or video playback options, used to progress through a narrative, provide structure (e.g.,*FS_018, FS_029, FS_053*). Interactions per se explicitly contribute to the involvement of users, as they require a reader's active engagement.

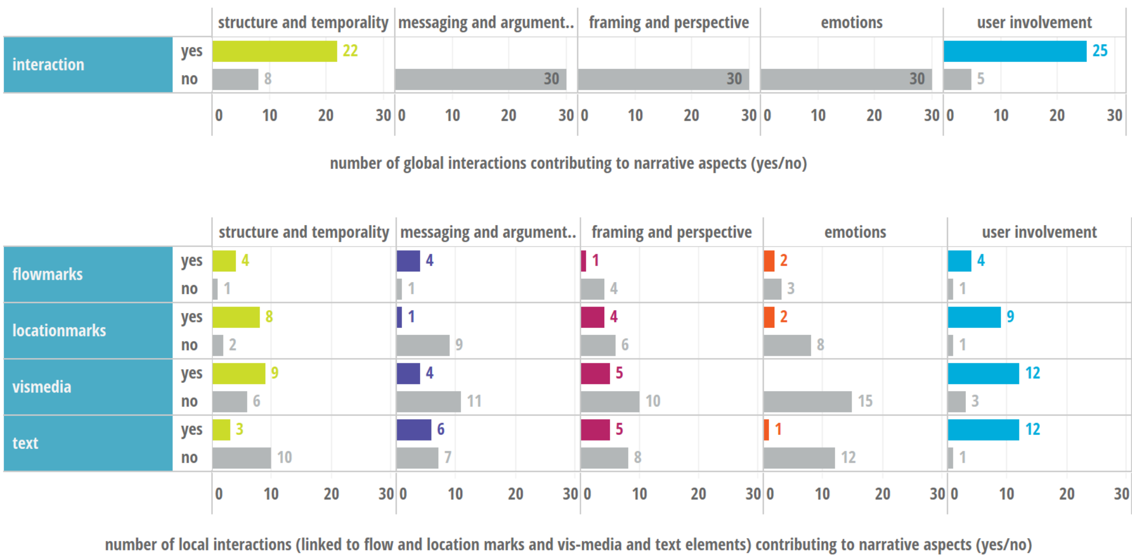


Figure 3.42: **Top:** Number of global interactions contributing to narrative aspects. **Bottom:** Number of local interactions contributing to narrative aspects by associated mark or element.

Local Interactions Linked to Marks and Elements (Figure 3.42 bottom): In comparison, local interactions are associated with the investigated marks and elements. They mainly contribute to the same narrative components as global interactions. Nevertheless, they can also support **messaging and argumentation**, and **framing and perspective**. For instance, the elements supporting or communicating the message often must be activated or revealed through interactions (e.g., pop-up boxes by clicking or hovering over location or flow marks in *FS_115*). Four out of five flow marks that are interactive support messaging and argumentation. Engaging with interactive vis-media or text elements used for filtering or selecting the depicted data can result in different perspectives (e.g., *FS_006*). However, there are not many instances of local interactions supporting these two aspects of narrative.

Take-aways: **(1)** Interactions can help to structure a Flowstory in a certain way; **(2)** Interactions are a simple way to engage users in sense of activeness.

The observations (i.e., take-aways) regarding the potential of the marks and elements to contribute to the narrative aspects of the design space presented in this section open the discussion in Section 3.5. Prior to this discussion, the next section contains six case studies that demonstrate the entire analytical process of assessing flow and movement visualisations regarding the entire design space.

3.3 Design Space Case Studies

In this section, a descriptive exploration of the design space is presented. Now that the visual-narrative possibilities of the design space have been explored, case studies are used to demonstrate how the design space can be used to analytically investigate flow and movement visualisations in the context of the introduced narrative aspects.

The discussion of the selected Flowstories reflects the categorisation of all 115 examples according to the visualisation aspects of the design space and the additional narrative categorisation undergone by the 30 chosen examples. The following six examples are grouped by three topics: CO_2 Maps, War Maps, and Migration. I explain why I selected these current and relevant topics within the sections below.

At this point, it is helpful to recall the distinction between story and discourse - the differences between story and discourse space and time. Story space and time are the places and time-span in which the events occurred (i.e., in the case of Flowstories flows and movements). This concept, following the understanding of narrative introduced in Chapter 2, also includes the unfolding of events in space and time in a reader's mind. Discourse space and time are concerned with *how* story space and time are presented in a narrative in the layout space (i.e., the elements and techniques used by the author to arrange the narrative visually and thematically). Discourse time also includes the time required to read or consume a narrative.

The case studies provide a short synopsis, describe the marks and elements identified, and discuss how they link to the narrative categories of the design space. Further, additional narrativisation opportunities are pointed out. Since the case studies are mainly interactive or dynamic, I recommend opening the Flowstories in the web-browser in parallel with reading this document.

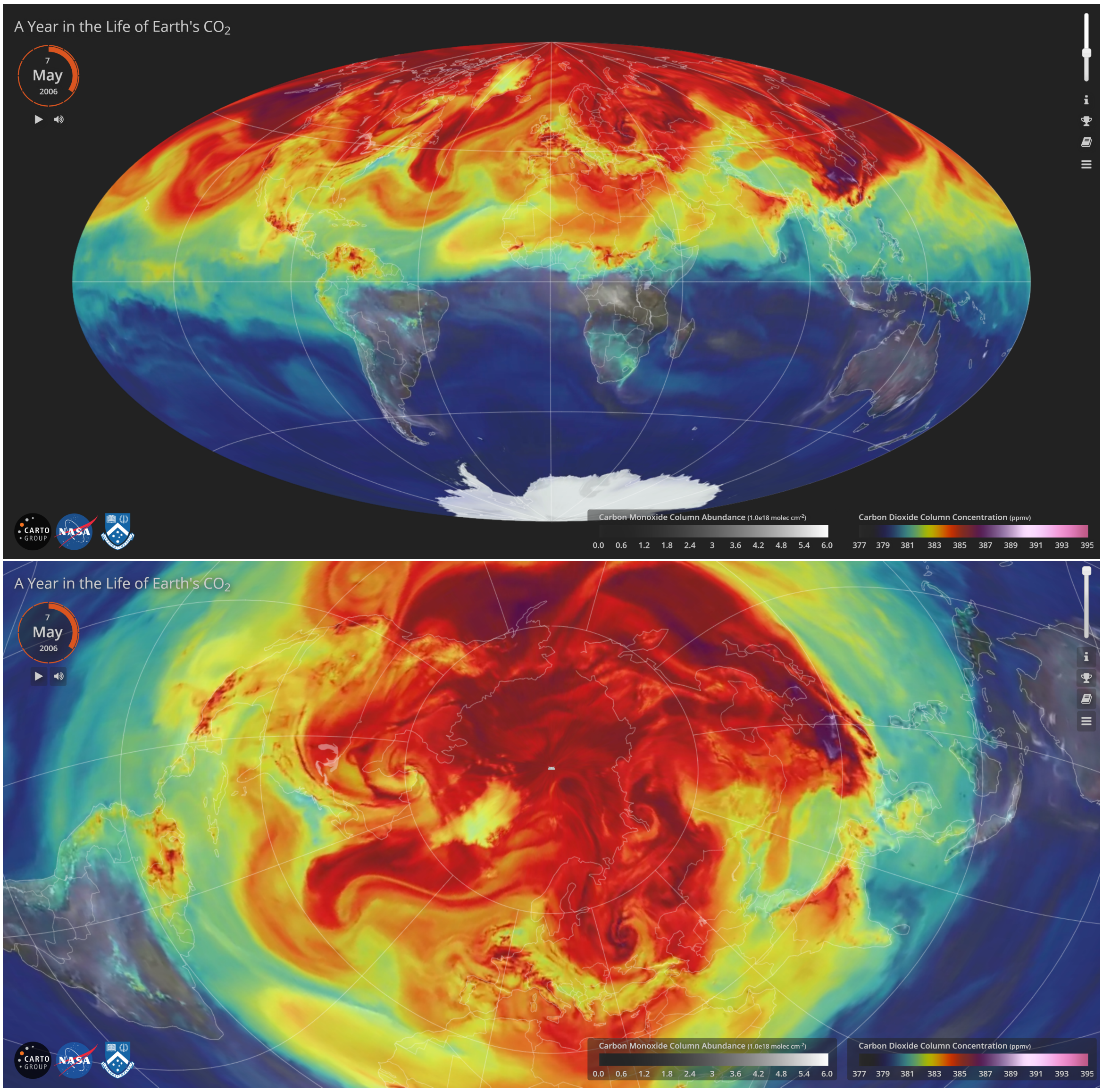


Figure 3.43: A Year in the Life of Earth's CO_2. Top: Interface of interactive video map with an equatorial aspect; Bottom: Changed perspective using zoom and rotation interactions towards the North Pole and Europe.
© Bernhard Jenny, Bojan Šavrič, Johannes Liem, and William M. Putman, 2014.

3.3.1 CO_2 Maps

The following two examples are based on the exact same simulation of the concentration and distribution of atmospheric carbon dioxide (CO_2) in the year 2006 produced by NASA scientists[5]. Both examples demonstrate how using the same data with different techniques can lead to different narrative implementations. I selected the topic CO_2 based on the comparability of the two examples and my personal involvement in the implementation of the first example.

3.3.1.1 A Year in the Life of Earth's CO_2 - *FS_010*

A Year in the Life of Earth's CO_2 is a web-based application that takes NASA's original voice-over narrated video material and converts it to an *interactive video map* (Jenny et al., 2016a). While the purpose of the original video is science communication, the implementation as an interactive video map is a technical demonstration of the real-time re-projection of raster-based maps in the web-browser (Jenny et al., 2016a,b). The example can be accessed via: http://co2.digitalcartography.org/.

Flow mark:

Flow and movement representation layer: The flow mark, which is the animated **CO_2 distribution layer** with a **grid-based geometry**, conveys **spatial information**. The layer has an **intermediate level of abstraction** because the visual style of the inherently geometric mark resembles a pollution cloud covering our globe, which attempts to convey danger. The dispersion of the phenomenon itself provides **spatial structure** and determines the narrative's **temporal and thematic ordering**. **Motion** resulting from the animation indicates the **direction** in which the pollutant is distributed over time. This motion follows the major global wind patterns and might draw a reader's attention (**implicit user involvement**). The flow mark also supports the **argument** that the depicted phenomenon is based on global interrelations and has world-wide effects.

The flow mark layer further provides **qualitative and quantitative information**. It uses two different **colour ramps** to discriminate between two pollutants. A customised rainbow colour scale encodes the carbon dioxide (CO_2) concentration, and a grey colour scale encodes the carbon monoxide (CO) abundance in the earth's atmosphere. High concentrations of CO_2 are emphasised by

[5] https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=11719

the adjusted gradient in the map using bright colours. The strong colours of the visually very salient CO_2 distribution cause the CO abundance to visually fade into the background, which makes it somewhat difficult to perceive. From a narrative perspective, this might have been deliberately implemented to set a **focused perspective, framing** the message. The choice of colour, which attempts to express the phenomenon's danger, may also cause an **emotional reaction** in the reader. Each layer, the CO_2 concentration and the CO abundance, encodes **magnitude** using **colour**. Each raster cell's colour corresponds to the simulation value at the given location and time.

Location mark:

Flow and movement representation layer: The **background map**, with country borders (**area geometry**) on top of satellite imagery, acts as a location mark, providing **spatial information**. The locations the gas moves through are only clear in connection with the map. Therefore, the background map provides **structure** insofar as it helps us to put the CO_2 visualisation into spatial context. The level of **abstraction** is **mimetic/pictorial/realistic**, since the country outlines resemble actual borders and the imagery represents our earth in a photorealistic way. One important aspect of the map is its projection. The original material, a video stream, uses a Plate Carrée projection with area distortions towards the poles, which leads to the problem that the amount of CO_2 closer to the poles appears larger than it actually is. The interactive video map re-projects the video-stream using an oblique Hammer projection, which shows all areas with a correct relative size. Compare Figure 3.43 (top) and Figure 3.44 (column 2, row 5). In this perspective, the type of map projection selected can be used for **framing**, since it influences the appearance of the data and therefore its perception.

Interactivity layer: The map includes **coupled superimposed** **map interaction** capabilities for zooming and rotating the map. The map rotation, changing the point of view, can be used to provide different **perspectives** within a narrative. For example, centring the north pole, a so-called *polar aspect*, reveals how the gas circulates around the northern hemisphere (Figure 3.43 (bottom)). Aside from **explicit user involvement**, the interactivity can lead to **implicit user involvement**, because it allows users to explore and investigate areas and regions with which they are more familiar and can better relate to, such as their home country.

Vis-media elements:

Flow and movement representation layer: The interactive radial date dial encodes **temporal information** using **size**. The length of the orange circle indicates the narrative's progression, but also how far advanced the year 2006 is within the animation. The element provides temporality by conveying both story and discourse time. The radial shape replicates the cyclical nature of a year, which communicates and **frames** the temporal framework of the story.

The legends convey **quantitative information**, the **magnitude ranges** of CO_2 and CO in the atmosphere. The **coupled juxtaposed** colour ramps are required to interpret the depicted values, fostering some **implicit user involvement**, and thus supporting the overall **message and argument**.

Contextual representation layer: The graticule, as part of the background map, provides further context. Especially when the map is rotated, it helps, for example, to identify the poles or the equator more easily. Consequently, the graticule, to some extent, supports the **spatial structure** from a narrative perspective.

The **uncoupled juxtaposed** logos of the authors' affiliation, a famous national authority, and universities in the bottom left corner can act as **framing devices** increasing trust and credibility with respect to the depicted simulation data. Small **uncoupled juxtaposed** pictorial icons on the right-hand side lead to additional text-based context (see next section).

Interactivity layer: The identified vis-media elements also provide some interactivity, allowing users to **explicitly be involved**. While the **coupled juxtaposed** date dial lets users navigate through the story and the discourse time, the **uncoupled juxtaposed** logos and icons are interactive buttons linking additional content and information.

Text elements:

Flow and movement representation layer: The title *"A Year in the Life of Earth's CO_2"* conveys **spatial and qualitative information**. The title is **coupled juxtaposed** because it describes *where* and *what* flows and is detached from the map's layout space, but summarises the **message**, the main content of the narrative visualisation. The legend also contains **qualitative** information as **coupled juxtaposed** text, differentiating CO_2 and CO, the two gases depicted in the map.

The **temporal information** ⌛⌛⌛, the **date string** in the date dial, shows the current day of the year 2006, providing **temporal structure** and indicating the progression of both the story time (the year 2006) and the discourse time.

Context representation layer: **Text-based context**, information going beyond the descriptions as part of the flow representation layer, is provided in text box inserts. The **uncoupled juxtaposed** texts include "how-to-use" information along with links to the original data, the JavaScript code, the scientific publication about the project, and the awards the work received.

How all of this additional context was selected by the authors can provide **some degree of framing** and also **user involvement**, since readers can use it to become invested in the topic. This additional text-based content can only be accessed through the above-mentioned user interactions.

Audio elements:

The audio narration plays a very important role in this example. Excerpts of the entire transcript, which can be found online[6], are used here.

Flow and movement representation layer: The elements of the **narration** that describe movement characteristics while they are visible in the display, have a **coupled superimposed** mode of integration.

The narration conveys **spatial information**, location, and direction. Examples include: *"[...] in the **Earth's atmosphere**."*, *"In the **Northern Hemisphere**, we see the highest concentrations are focused around major emission sources over **North America**, **Europe** and **Asia**. Notice how the gas doesn't stay in one place. The **dispersion** of carbon dioxide is controlled by the **large-scale weather patterns within the global circulation**."*, or *"Notice how these emissions are also **transported by winds to other parts of the world**."*.

Temporal information ⌛⌛⌛ is provided through: *"The visualisation compresses **one year of data** into a **few minutes**."*, which references the story time (one year) as well as the discourse time (a few minutes). Other examples concerning the presentation of the story time on the discourse level are sentences starting with: *"During spring and summer [...]"*, *"During the summer months, [...]"*, or *"As summer transitions to fall, [...]"*. The **temporality** of events over the course of the year also determines the narration's **thematic order** to a large extent.

[6] https://svs.gsfc.nasa.gov/vis/a010000/a011700/a011719/11719.html

Qualitative information is expressed through the mentions of the two pollutants ' *"carbon dioxide"* and *"carbon monoxide"* throughout the narration.

Quantitative information is conveyed mainly through quantifiers, rather than numbers. Examples describing **magnitude** include: *"About **half of** the carbon dioxide emitted from fossil fuel combustion remains in the atmosphere, while the **other half** is absorbed by natural land and ocean reservoirs."*, *"[. . .] **highest** concentrations [. . .]"*, or *"[. . .] a **substantial amount** of carbon dioxide [. . .]"*.

Context representation layer: As in many **voice-over narrations**, this example also contains a large proportion of **coupled** and **uncoupled**, in this case **superimposed**, contextual information. The narration starts with the **uncoupled** text *"Hi, this is Bill Putman. I'm a **climate scientist at NASA**'s Goddard Space Flight Center."*, which may increase trust in the following content, **framing** the rest of the story.

To some extent, **emotional reaction** and **implicit involvement** might be provoked by contextual, mostly **coupled** passages like: *"Carbon dioxide is the most important greenhouse gas affected by human activity."*, *"Meanwhile, in the Southern Hemisphere, we see the release of another pollutant — carbon monoxide. This is a gas that's both harmful to the environment and to humans."*, or *"Although this change is expected, we're seeing higher concentrations of carbon dioxide accumulate in the atmosphere each year. This is contributing to the long-term trend of rising global temperatures."*. They indicate the danger and effects associated with large CO_2 concentrations.

Additional **uncoupled** context is provided by the information included towards the end about the model used for the simulation and NASA's future plans for observations of atmospheric CO_2 in future satellite missions.

Additional acoustic context is created by **background music**, which, for example, connects longer pauses in speech (providing **structure**), but also reflects the dynamic of the gas movement depicted, drawing the **users' attention** towards the visualisation.

Visual-Narrative Summary: Overall, the voice-over narration provides the **overall narrative structure**, conveys the **main message**, and is the driving element which affects the reader's attention, helping to draw them into the topic (**implicit user involvement**).

The story space, the places where the narrative takes place, is our earth and the atmosphere of the earth. The discourse space concerns the authorial arrangement and presentation of story space regarding the layout space of the browser-based visualisation. The main visualisation, the interactive video map, provides the ability to change the perspective onto the story space. Using rotation and zooming, the extent, and thus the focus, on the story space can be influenced. The discourse space also includes the audio narration, which makes references to the story space or subsets of it (e.g., "Northern Hemisphere", "North America, Europe, and Asia").

The story time is the year 2006. On a discourse level, time is presented in a compressed way (the visualisation compresses one year of data into a few minutes), but in a linear, chronological order by day (expressed through the radial time widget). Seasons and months are referenced in the voice-over narration. The example demonstrates that space and time are two tightly coupled concepts that are part of both the visualisation and the narration.

This Flowstory has a high degree of narrativity and, the material presented on the discourse level, allows readers to build a story in their minds. The example has an evenly distributed flow-context-interaction balance. Though the flow is visually most salient, the audio narration provides essential context. Users are free to use the spatial and temporal navigation, provided through map interaction and the dial-widget, at any given moment. The ability to jump within the structure, can further influence how the space and time of the narrative are perceived.

Narrativisation Opportunities: One way of strengthening the link between the content presented by the narrator and the data presented visually would be to explicitly couple the map with the narrative. For example, the map rotation and zoom could be adjusted with respect to the manuscript. For example, when the narrator explains *"During spring and summer in the Northern Hemisphere, plants absorb a substantial amount of carbon dioxide through photosynthesis, thus removing some of the gas from the atmosphere. We see this change in the model as the red and purple colors start to fade. Meanwhile, in the Southern Hemisphere, we see the release of another pollutant — carbon monoxide."*, the map centre could be gradually rotated from the northern hemisphere to the southern hemisphere (compare Figure 3.43). Panning and zooming the map with respect to the narration was implemented in the Flowstory *FS_027*, accessible at https://www.shipmap.org/. Furthermore, focus techniques could be used to highlight regions mentioned in the narration. Based on *"During the summer months, plumes of carbon monoxide stream from fires in Africa, South America and Australia, contributing to high concentrations in the atmosphere."*, these continents or the *"plumes of carbon monoxide"* could be visually highlighted (e.g., by encircled locations or using thicker, differently coloured continent outlines), or the rest could be de-saturated or blurred.

3.3.1.2 A visual tour of the world's CO_2 emissions - *FS_014*

The video *A visual tour of the world's CO_2 emissions* is built upon the same material as the previous example, but uses different means to spin a narrative around it. It only uses parts of the video material and embeds it in a more journalistic piece that presents the scientific message in a more tangible way. The video is available at: https://youtu.be/fJ0o2E4d8Ts. For a better reading experience, the inline icons used in the first case study are not used in this and subsequent case studies.

Flow mark and **Location mark:**

Flow and movement representation layer: Flow and location marks are comparable to the previous example. However, the carbon monoxide layer is visible, but is referenced neither in the legend nor in the text elements. The story focuses on the **CO_2 concentration**, there is no qualitative differentiation. The **background map** (location mark) is simply the satellite imagery used in the original video and no country borders are included. It also uses the original map projection (geographic projection) mentioned previously, distorting relative sizes, so areas towards the pole appear larger.

Vis-media elements:

Flow and movement representation layer: The flow mark shows the global distribution of the CO_2 concentration for a single day. A chart that shows the aggregated global CO_2 over the course of the year 2006 is displayed twice during the story. A yellow, animated dot indicates the current date. The **coupled superimposed line chart** encodes **time** using **position** along the x-axis, and **magnitude** along the y-axis. The title provides **qualitative** information. The chart supports **thematic** and **temporal ordering**.

The **legend** has the same functions described in the previous example.

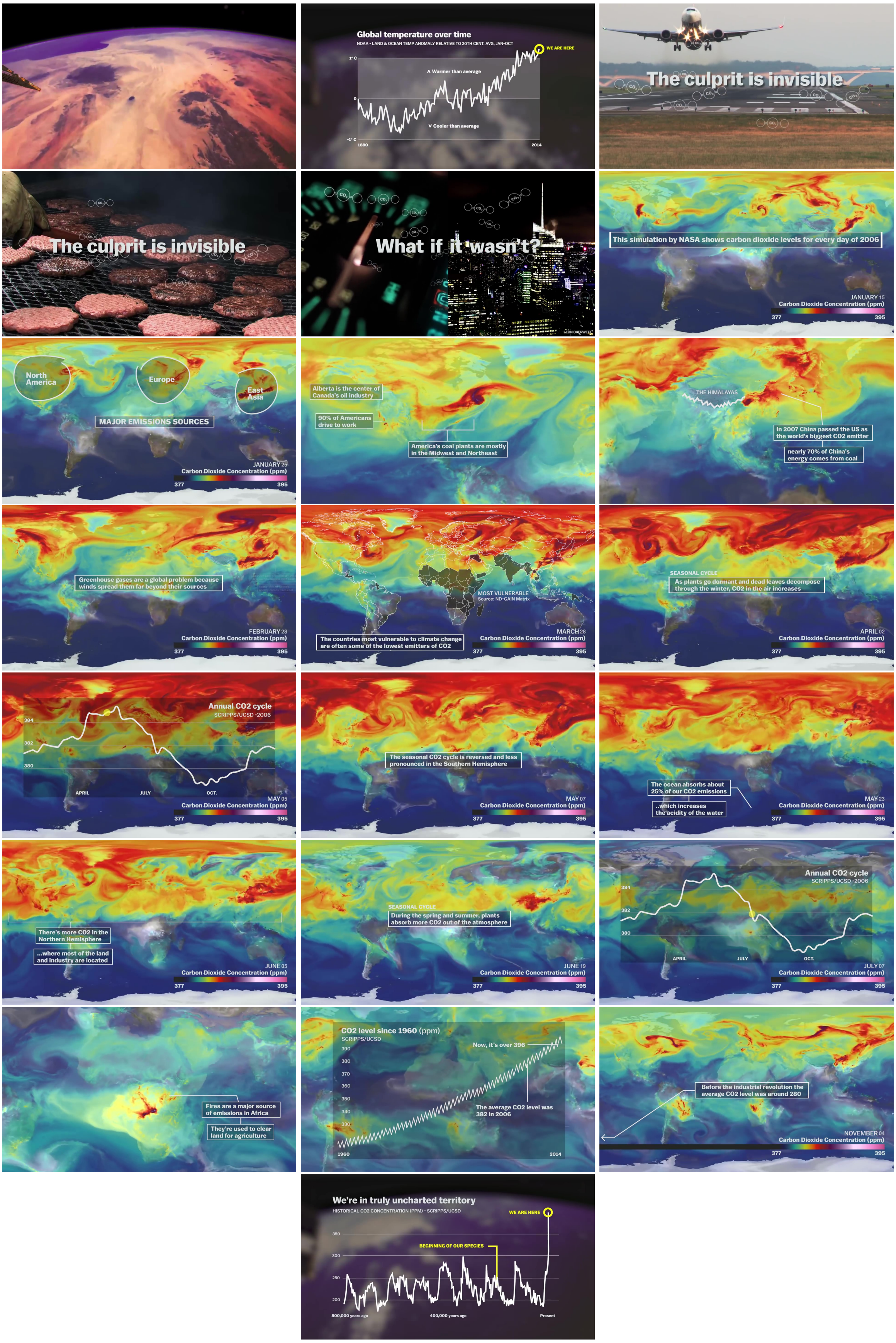


Figure 3.44: A visual tour of the world's CO_2 emissions.
© Vox.com, 2014.

Context representation layer: The video starts by showing the earth from an orbiting satellite's perspective. A **line chart** showing the global temperature anomalies between 1880 and 2014 relative to the 20^{th} century average fades in. A **video sequence** follows, including a departing aeroplane, burger patties on a grill, a car's speedometer, and a large city illuminated at night, which are all symbols associated with climate change and global warming. Together with an audio collage and some text (see below), these **uncoupled superimposed** visualisation and media elements set the stage of the story (**framing**) to support the overall **message**. The **images** are used to connect to a reader on an **emotional** level, raising their attention (**implicit user involvement**).

Additional **coupled superimposed** context is provided through a **map overlay** indicating the countries that are most vulnerable to climate change, supporting the **argument** that they are often some of the lowest emitters of CO_2 (compare to text elements). The layer adds an additional **perspective** on the depicted data, and depending on a reader's personal connection to one of the vulnerable countries, this might elicit an **emotional** response.

The **chart** showing CO_2 over 2006 also provides context, setting the single date depicted into a larger, annual **perspective**. Towards the end the year, 2006 is put into an even larger temporal context, driving this effect forward. An **uncoupled superimposed** chart shows the rise of CO_2 levels since the 1960s. The **legend** is then extended across the video to the left to reflect the comparably low CO_2 values before the industrial revolution. At the very end, a chart showing historic CO_2 concentrations going back 800.000 years is shown, demonstrating that *"We're in truly uncharted territory"*, which provides even more temporal context.

These comparisons convey a thought-provoking **message** implicitly **involving the reader** and possibly producing **emotional** reactions.

Text elements:

Flow and movement representation layer and context representation layer: **Text box annotations** directly on the map convey **spatial**, **temporal**, **qualitative**, and **quantitative** information describing the depicted flow, therefore they have a **coupled superimposed** mode of integration. Many of them contain additional **coupled** and **uncoupled context**, providing causalities for the CO_2 concentrations.

The first annotation stating that *"This simulation by NASA shows carbon dioxide levels for every day of 2006"*, integrates temporal and qualitative information, but also coupled context.

These annotations can contain **locations**. For example, the *"major emissions sources"* are labelled by name (North America, Europe, and Asia) and highlighted with a circle in a sketchy style. Other descriptions like *"Northern Hemisphere or Southern Hemisphere"* also convey location. The narration consequently focuses on two of these regions by zooming into the map and providing local uncoupled context before returning to a global scale. In North America, three annotations state that: *"Alberta is the center of Canada's oil industry."*, *"90% of Americans drive to work."*, and *"America's coal plants are mostly in the Midwest and Northeast."*. Panning to Asia a label informs the reader that *"In 2007 China passed the US as the world's biggest CO_2 emitter - nearly 70% of China's energy comes from coal."* Additionally, the Himalayas are indicated with text and a zig-zag line signature, helping to make sense of the low CO_2 concentration in this region.

The text also provides some information about the **direction** of movement, which is dependent on the global winds: *"Greenhouse gases are a global problem because winds spread them far beyond their sources."*. Additionally, the fact that greenhouse gases are therefore a global problem, provides additional **context**. This is amplified by the following argument, that *"The countries most vulnerable to climate change are often some of the lowest emitters of CO_2"* (shown together with the aforementioned map overlay).

In a middle section of the video, the seasonal CO_2 cycle is the focus of the narration. **Text boxes** and the aforementioned charts explain the development of CO_2 levels in the course of the year 2006 in the following sequence (Figure 3.44 from row 5, column 3 to row 7, column 1): *"As plants go dormant and dead leaves decompose through the winter, CO_2 in the air increases."*, annual CO_2 cycle chart indicating this increase, *"The seasonal CO_2 cycle is reversed and less pronounced in the Southern Hemisphere."*, *"The ocean absorbs about 25% of our CO_2 emissions, which increases the acidity of the water."*, *"There is more CO_2 in the Northern Hemisphere, where most of the land and industry are located."*, *During the spring and summer, plants absorb more CO_2 out of the atmosphere.*, annual CO_2 cycle chart indicating this drop, and *"Fires are a major source of emissions in Africa. They're used to clear land for agriculture."*. These text fragments include **location** (e.g., *"Northern Hemisphere"*, *"Africa"*), **time** (e.g., *"through the winter"*, *"during spring and summer"*), and **quan-**

tities (e.g., *"CO_2 in the air increases"*). But foremost, they provide vital **context** to better understand the reasons for the global CO_2 distribution and concentration within the course of a year. The ordering of the information provided in the text annotations that contain the **main message and arguments**, provide **structure** in the narration to a very large extent. Through the many contextual inserts, the user is being challenged, hence **implicitly involved** to a great degree.

There are also **annotations** that have numeric values indicating **magnitude** at a given time: *"The average CO_2 level was 382 in 2006"*, *"Now, it's over 396."*, and *"Before the industrial revolution the average CO_2 level was around 280."* They are part of the temporal comparison made at the end of the narration.

The legend in the bottom right corner includes text-based, **coupled superimposed** time integration, showing a **Month-Day label**, and **qualitative** information through the **title**.

Context representation layer: As mentioned above, there are short **text fragments** at the beginning along with some video material. The statement *"The culprit is invisible"* (CO_2 as the culprit responsible for global warming) is followed by the rhetorical question *"What if it wasn't?"*. The answer is given promptly with: *"This simulation by NASA shows carbon dioxide levels for every day of 2006."*. The wording alone (*culprit*) contributes to the **framing** of the entire narrative, that is placed at the beginning. The rhetorical question tries to mentally integrate or challenge the user (**implicit user involvement**).

Audio elements:

Context representation layer: A short **audio collage** of news headlines at the beginning (male voice: *"2014 is shaping up to be the warmest year"* - female voice: *"warmest year"* - female voice: *"warmest year ever recorded for planet earth"*) **frames and primes** the entire piece together with the corresponding vis-media and text elements.

Throughout the video, dynamic **background music** adapted to the different sections is played. It supports the **structure** of the narrative and might help to keep a viewer's attention (**implicit user involvement**).

Visual-Narrative Summary: The narrative or story space is the same as in the previous case study (i.e., the earth and its atmosphere). The implementations in relation to the discourse level, the *virtual canvas* used to arrange the story space, is quite different. The introduction sequence presents video snippets presenting places on our earth influencing climate change (e.g., large cities, air traffic). The perspective onto the story space (i.e., the map zoom influencing the map extent) is coupled to the narration. For example, when drivers of climate change in North America are listed, the map extent only shows the corresponding map section.

The story time is different from the previous example. While focused on the year 2006, the data presented in the charts expand the story time. It spans from prehistoric times (i.e., 800,000 years ago) to the present (i.e., 2014). The flow visualisation is in chronological order, but with temporal jumps in between cutting out time, which is called *ellipsis* in narrative theory. Further, additional charts set the present situation into different temporal perspectives. First, a line chart shown twice at different stages compares the current day with the CO_2 volumes of the entire year 2006. Towards the end, similar visual comparisons set the present conditions in context with developments since the 1960s, the time before the industrial revolution, and prehistoric times. In narrative theory, jumping back in time is called *analepsis* or flashbacks.

Since the Flowstory is a video, the only interaction provided is the video playback capability. Depending on the video player, some progression bars might indicate the elapsed discourse time, providing some sense of temporal structure. The coupled juxtaposed interactions play, pause, or jumping in time are very limited with regard to explicit user involvement.

The high degree of narrativity is due to the text-based annotations and the author-defined thematic structuring. The Flowstory starts with a priming video sequence setting the stage, then provides causalities and effects of atmospheric CO_2, and finally puts the present situation into context with the historic development.

The flow-context-interaction balance of this Flowstory is unbalanced. The narrative is *context dominant.* The introduction sequence, the text annotations, and the additional charts provide a lot of context, hence the flow depiction is less salient. Since the Flowstory is a video, interaction is very limited and depends on the video player.

Narrativisation Opportunities: This video is a well-executed Flowstory example, which would not benefit from further narrativisation.

3.3.1.3 Comparison

While the first example builds upon the authorial, scientific voice-over narration to implicitly involve the reader, the second tries to do this by being sensational and selective about the information communicated. The voice-over narration of the interactive video map has a more neutral, informative tone, where the second example uses additional videos, text, and charts to didactically and emotionally influence the viewer, challenging his or her personal involvement with the topic of climate change.

As demonstrated above, even though both visual narratives are based on the same data and topic, differences on the discourse level lead to completely different results. While the first case study is a mix of author and user-driven components, the news video is highly author-driven.

3.3.2 War Maps

The following two examples are also related. While the first example is Minard's famous map of Napoleon's Russian campaign, the second case study, a web-based interactive narrative, is based on Minard's illustrative map and the war that started in 1812 between the French and Russian empires. I selected the topic because Section 3.4.1.2 demonstrates how the design space can be used in a generative way using data from the First World War.

3.3.2.1 Carte figurative des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812–1813 - *FS_099*

Charles-Joseph Minard's *"figurative map"* is a famously discussed example in information visualisation, often in conjunction with storytelling (Denil, 2016; Kraak, 2014; Mocnik and Fairbairn, 2017). Using a very limited number of visual elements, the illustration shows *"the successive losses of the French army during the Russian campaign"* in 1812 and 1813. The example can be found online: https://commons.wikimedia.org/wiki/File:Minard.png.

Flow mark:

Flow and movement representation layer: The most visually prominent element of this map is the flow mark **aggregating French troop** strength over space and time. The **line geometry**, having a **geometric level of abstraction**, encodes **spatial** and **quantitative** information. The **direction** is encoded with **colour**, where the brown

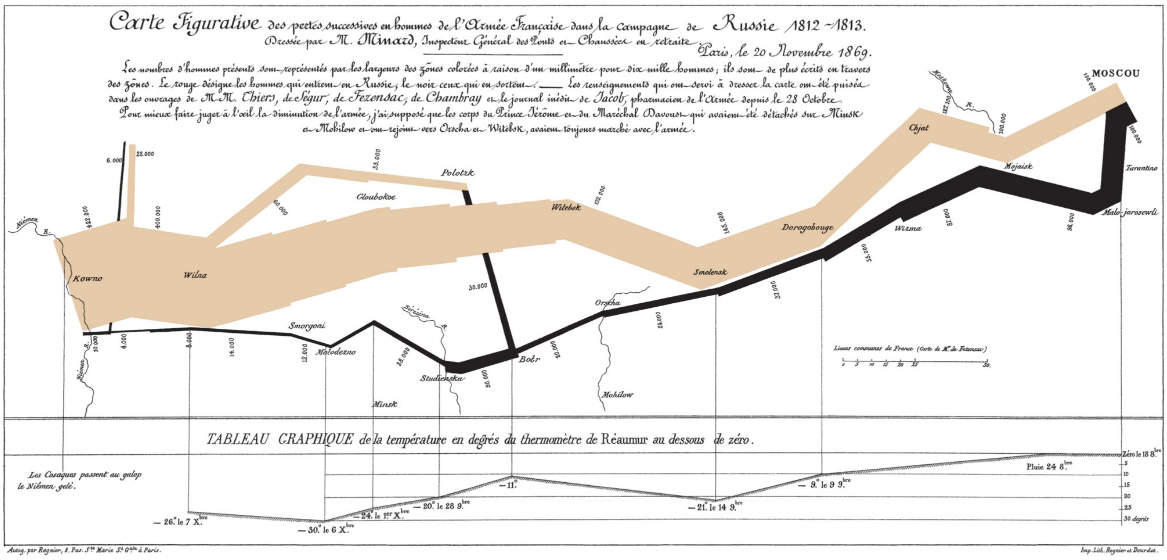


Figure 3.45: Minard's figurative map of the successive losses of the French army during the Russian campaign, 1812-1813.

tone indicates troop movements towards the East and the black tone indicates retreat movements back to the West. Direction is also given implicitly through position/layout and size encoding. The **layout**, the **position** of the flow mark, going from left to right and back, corresponds with a western reading order and provides **visual-narrative structure**. While this is due to fortunate geographical circumstances, Minard rotated the map in other examples to have flows going from left to right, as shown in Rendgen (2018). Based on the fact that the army is shrinking over time, direction is also encoded through the overall shape, which is driven by the flow mark's decreasing **size** (line width). Together with the geography, this causes the story space, and implicitly the story time, to be brought into a **spatial, temporal, and thematic order** on the discourse level by the shape and placement of the flow mark alone. Mainly, the line width (**size**) encodes **magnitude**, the number of French soldiers alive, where a millimetre represents a troop strength of 10.000 men. As pointed out in Kraak (2014) and Rendgen (2018) the illustration is a generalisation of space, time, and the historic events they contain. Although the flow mark does not represent the actual complex movements and combat operations, it conveys the **main message**, the succession of the French army during this military campaign, in a strikingly simple visual way. The colouring of the flow band, which indicates the retreat of the heavily diminished French army, may evoke associations on an

emotional level. To a certain extent, the black colour reflects the cold, dark, and unhappy days that the defeated army suffered.

Location mark and **Vis-media elements:**

Flow and movement representation layer: The reduced, **coupled superimposed background map** just shows rivers with their names and text annotations of cities (see text elements), which both provide **location** information. Even though the very detailed river geometries "[...] do not fit well with the overall message of the map", as pointed out by Kraak (2003), they provide some **visual structure**, embedding the flow mark in the minimal geography provided. Hence, the **background map** also acts as a location mark indicating from where to where, or through where flows are happening. Because this indication is limited and the categorisations regarding the location characteristics (geometry, abstraction, direction) hardly apply, the map is primarily regarded as a vis-media element that also provides some context. This example demonstrates that it is not always straightforward to assign elements to a category.

Context representation layer: The **background map** also provides **coupled superimposed context**. When the troops crossed rivers, the number of soldiers decreased. The smaller line width might indicate that the river crossings were accompanied by casualties. But simply based on the map, without additional historical context, we do not know if this is the case. It could also mean that fighting activities in these places resulted in a smaller number of men.

A **line chart** placed below (**coupled juxtaposed**) shows the cold temperatures below zero degrees along the y-axis during the retreat of the army to the West, providing additional context with an additional **perspective**, helping to interpret the depicted movement. **Time** is encoded along the x-axis from right to left, breaking conventions, to align with the direction of the flow from East to West. Selected dates along the line of the chart are visually coupled with the black flow band using straight lines. The chart provides the **argument** that the decrease of men might be related to the very cold temperatures going down to negative 30 degrees Réaumur (-37.5 °C). Providing such weather information might make it to some extent more tangible for today's readers from a personal, yet distant perspective (**emotion** and **implicit user involvement**).

The **graphical map scale**, which integrates the context in a **coupled juxtaposed** manner, places the distance travelled in a certain **perspective**, making it easier to get a feel for the distance. However, from today's point of view, the historical unit of *common French leagues* (*"Lieues communes de France"*) is rather obscure.

Text elements:

Flow and movement representation layer: The **coupled superimposed** **city names** indicate the **locations** of important battles (Kraak, 2003). This information cannot be taken directly from the map and requires additional historical context. Through providing **spatial** information, the place names together with the other marks and elements provide **visual-narrative structure**.

While the temporal order is implicitly integrated in the flow mark and the line in the temperature chart, the only absolute dates are given by annotations in the temperature chart (coupled juxtaposed in relation to the movement depiction). Such temporal information provides **temporal ordering and structure**.

The **coupled juxtaposed** **title** integrates **qualitative** information, informing the reader what entities are moving in the illustration (i.e., the French army) and also provides a coarse idea of the story time (i.e., 1812-1813). The title conveys to a large extent the **main message** the illustration tries to communicate (i.e., the successive losses during the Russian campaign).

Aside from the line width, **numeric annotations** along the flow mark convey **magnitude**. The **coupled superimposed** absolute values of men alive at the given location and time also support the **overall message**.

The **coupled juxtaposed** **text** above the illustration contains **directional** and **qualitative** information describing the depicted flow (i.e., *"Red designates the men entering Russia, black those exiting."*, translation from Rendgen (2018)).

Context representation layer: The **handwritten text** primarily provides additional **context**. The information on how to interpret the flow mark is **coupled juxtaposed**: *"The numbers of men present are represented by the widths of the coloured zones at a rate of one millimetre for every ten thousand men, and also written across the zones."*.

Minard ends the paragraph with uncoupled juxtaposed information about the data sources (i.e., *"The information used to draw this maps was obtained from the works of Mr. Thiers, Mr. de Ségur, Mr. de Fezensac, Mr. de Chambray, and the unpublished journal of Jacob, pharmacist of the army since October 28th."*) and design decisions he made (i.e., *"To better perceive the reduction of the army at a glance, I assumed that the corps led by Prince Jerome and Marshall Davout, which were detached at Minsk* *and Mogilev and rejoined near Orscha and Witebsk, had always marched with the army."*).

Such contextual information helps to interpret the illustration and its **main message**, fostering **implicit user involvement**.

A **annotation text**, placed at the lower left and linked to a location on the base map with a line, integrates **coupled juxtaposed context**. Rendgen (2018) translates the *"'narrative' label"* to *"The Cossacks gallop over the frozen Neman."* and points out that: *"[. . .] the label can only refer to Russian soldiers chasing the retreating French army in the Winter."*. Rendgen (2018) interprets the label as Minard's *"impulse to complete the narrative contained in the map [. . .] with an anecdote from the retreat"*. Not only the content, but also the placement after the temperature chart in the direction of reading (from right to left) indicates *the end* and provides some **narrative structure**.

Visual-Narrative Summary: The story space and time of this Flowstory is the Western Russian Empire in the years 1812 and 1813. On a discourse level, time is implicitly encoded through the flow mark and more explicitly through the annotations in the line chart. Nevertheless, the temporality of the movement, when the troops moved or stagnated, is not evident. On a discourse level, the most striking thing about the example is its simplicity and visual reduction. Visually, the story space is only indicated through city labels and rivers.

In a discussion on if *maps can tell stories*, Denil (2016) analyses: *"Straight off, we see that great zig-zag of muscular lightning flash across the west Russian plains to strike the capital, and we see the slow, painful trickle of the retreat. This is visceral and emotive. [. . .] We also see the explicit links between the route and the temperature graph [...]. The map leaves things there."*

This summarising statement points towards the lack of causal links, which would explain the reasons for the loss of men expressed in the width of the flow marks. The ability to build up a story in one's mind is highly dependent on a reader's prior knowledge or the additional material available. This reduction limits a meaningful interpretation.

Because of the visual reduction and focus onto the flow mark it is a *flow dominant* example with only a little context provided through the temperature chart and the handwritten text. The low degree of narrativity offers many possibilities for further narrativisation.

Narrativisation Opportunities: The fair amount of knowledge required for a meaningful interpretation of the narrative could be provided through additional means. Aside from the temperature chart, context could be added in a visual or verbal way. Important battles and combat action, rough landscapes, or the lack of food, all plausible factors causing the losses, could be integrated into the illustration. This could be done with additional map symbols or text-based annotations, such as the single annotation mentioned above.

To achieve the simple and reduced display, the map represents an aggregate of many military units. One way to add further perspective, such as soldiers' experiences or historical events that were decisive in the outcome of the war, is to add anecdotal or contextual information (e.g., from personal or military diaries and history books) in an interactive revision of the visualisation. If desired, this might lead to emotional responses and a higher degree of immersion.

Kraak (2003) points out that additional multimedia elements (e.g., images of dramatic paintings) *"give the user an impression of the historical situation"*. He further argues that animation *"allows the dynamic addition of the temporal component of the data"*.

When describing all these possibilities, it is important to note that the example as it is, conveys and communicates *"the successive losses of the French army during the Russian campaign"* very well. However, it does not go beyond this. The next case study is an example that used Minard's map as a starting point for a richer narrative.

3.3.2.2 1812 - When Napoleon ventured East - *FS_115*

"*1812 - When Napoleon ventured East"* is a web-based interactive visual narrative based on Minard's map discussed above. It is an example of the narrativisation of a simpler visualisation, one with a limited degree of narrativity.

The example consists of a map on the left side and a panel with text and vis-media elements organised in chapters on the right. The map and the panel are linked. Scrolling in the panel is used as the main device for progression, and affects the content and extent (i.e., zoom and centre) of the map. The map can be explored freely. When continuing to scroll in the panel, the extent is reset to a predefined setting.

The Flowstory was created by a Russian news agency that added a more Russian perspective by critically examining the perspective reflected in Minard's illustration, and it is available online: https://1812.tass.ru/en.

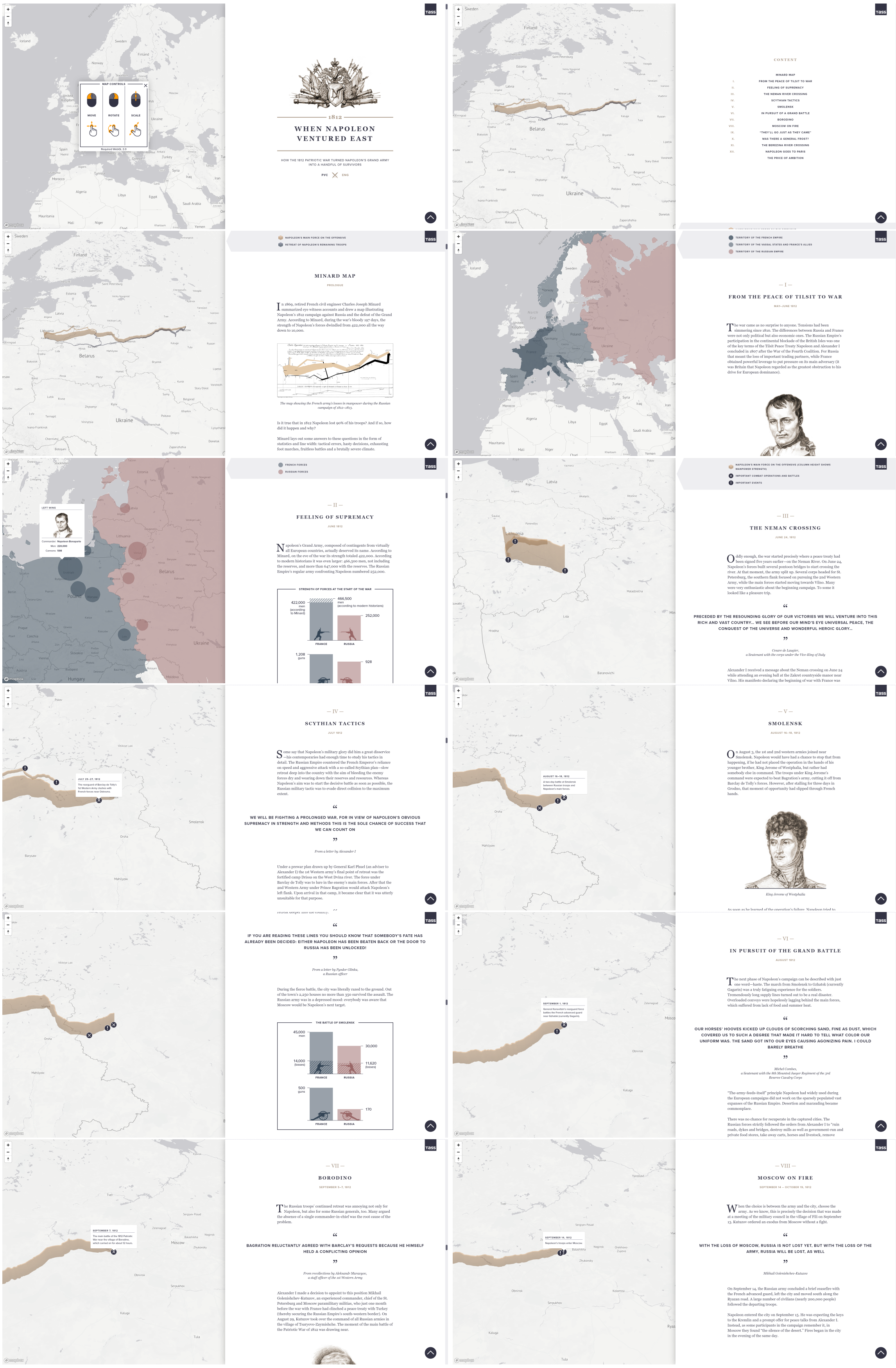


Figure 3.46: 1812 - When Napoleon ventured East (Part 1).
© TASS, 2017.

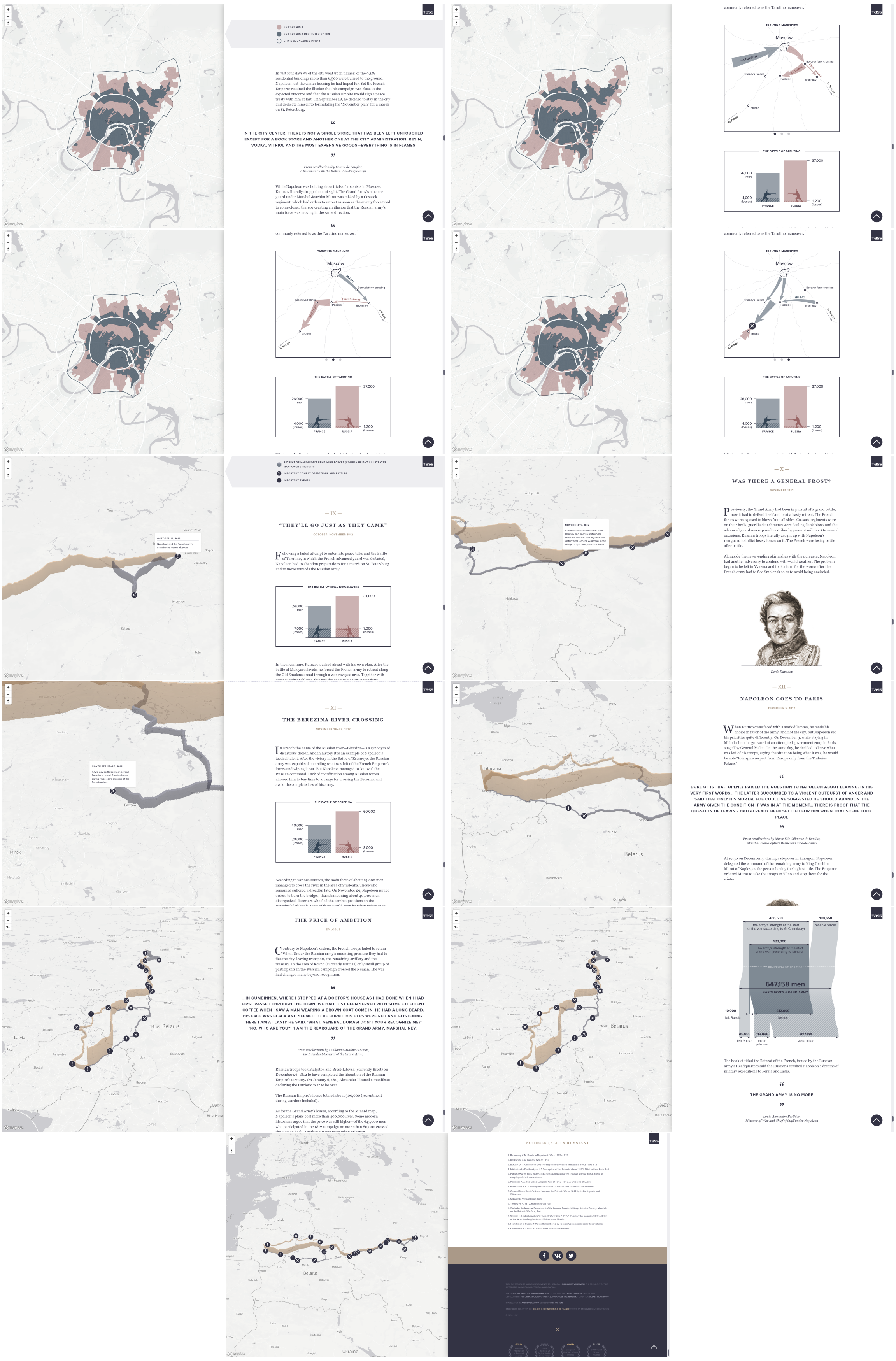


Figure 3.47: 1812 - When Napoleon ventured East (Part 2).
© TASS, 2017.

Flow mark:

Flow and movement representation layer: The **French army's path** (**line geometry**) into Russia and back follows the actual geography and therefore has an **intermediate level of abstraction**. The conveyed **spatial** information does not just include location, but also direction. **Direction** is encoded through a combination of **colour**, **motion**, **size**, and **position/layout**. As in the original, brown indicates the eastward movement towards Moscow, and black indicates the retreat movement towards the west. Depending on the chapter, a staggered animation (**motion**) builds up the flow mark and indicates the direction of movement. Implicitly, based on the flow mark's **size** (height) and overall placement (**position/layout**), inferences about the direction are possible. The **position** of the evolving flow mark and its relative progression also encodes **temporal** information. The **size** (height) mainly encodes **magnitude**, the number of French soldiers alive.

In particular, the gradually animated path (**motion**) provides **visual and temporal structure** linking to the reading order and progression of the narrative. To some extent, the flow mark supports the **overall message**. The resemblance to the original map **frames** the entire piece.

Location mark:

Flow and movement representation layer: Location information is provided through the **background map**, a greyscale modern slippy map that can be interpreted as an **area geometry**. The map elements included (e.g., water bodies, geographic names, or borders) have an **intermediate level of abstraction**. In addition to the animation of the flow mark being coupled to the scrolling, the map extent (i.e., position and zoom) also changes with the course of the narrative. The moving map (**motion**) indicates the **direction** which, together with the geography, provides a **spatial structure**.

Several event locations are expressed with **point symbols** in the interactive web map. Differently **shaped** pictographs encode different types of events (**qualitative** information) and they have a **mimetic level of abstraction**. While exclamation mark symbols indicate the location of important events, two crossed swords show where critical combat operations and battles happened. These locations are referenced in the text elements and thus support the **messages and arguments** given there regarding the overall course of the campaign.

When reaching the end of the narration, the map view zooms and rotates so the entire region is visible, showing all flow and location marks. This summarising **perspective** supports the closing **argument** expressed with the quote *"The grand army is no more"*.

Interactivity layer: Because the map shows today's national boundaries and has **coupled superimposed** **map interactions** (i.e., zoom, pan, rotate), viewers can compare it to a familiar **perspective**. Zooming out allows them to locate the area of the campaign in relation to a more familiar area (e.g., home country) or to larger regions (e.g., Europe), which can have a **framing** effect. **Explicit involvement** leads to **implicit involvement**.

The event locations are connected to a **coupled superimposed** **interaction** fostering **explicit user involvement**. Clicking on the figurative icons provides detail on demand in small pop-ups (see text-based elements).

Vis-media elements:

Flow and movement representation layer: Throughout the narrative, **coupled juxtaposed** **illustrative bar charts** in the right panel contrast the strength (**quantitative** information) of the French and Russian forces (**qualitative** information). The first chart shows the **magnitudes** at the start of the war, and the following five charts provide updates and inform viewers about the strength and losses on both sides due to the major battles of Smolensk, Borodino, Tarutino, Maloyaroslavets, and Bérézina. These charts support the visualisation **message** - the losses of men over space and time.

Three **small maps**, implemented as a carousel widget (i.e., the maps are rotating, and only one map is visible at a time), show strategic movements of both troops in the Greater Moscow Region, namely the Tarutino manoeuvre, leading up to the battle of Tarutino. The maps use arrows conveying **location** and **direction**. This additional map is categorised as **uncoupled juxtaposed** because it is also placed in the right panel next to the main visualisation, and the degree of detail is beyond what can be shown there. One could say that it is ***a Flowstory within a Flowstory***. The authors also paid increased attention to this manoeuvre in a visual form, which **frames** the interpretation of the narrative. From a narrative perspective (i.e., **thematic structure**), it is an interesting point during the campaign, because at the end of the battle, Napoleon's troops start to retreat towards the West.

Towards the end of the narrative, an additional **uncoupled juxtaposed** **visualisation** compares the *volume* of losses of the Grand Army as used by Minard (only 10,000 men of the 422,000 returned) with views of modern historians, which argue that *"the price was still higher — of the 647,000 men who participated in the 1812 campaign no more than 80,000 crossed the Neman back. Another 110,000 were taken prisoner."* Showing this information emphasises the Russian **perspective** of the piece.

Context representation layer: All of the above-mentioned vis-media elements support or describe aspects of the depicted movements, but they mainly provide additional **context**. For example, the visualisations comparing troop strength after the battles indicate the reason for the reduction of the army, which provides additional **perspective** for the main visualisation. Further, several of these charts also include a comparison regarding the number of guns possessed by each force. The *"fabulous"* Tarutino manoeuvre shows how the Russians forced the French out of Moscow in great detail. It provides additional context and reasoning about why the French started to retreat. Comparing Minard's numbers with larger numbers from modern history emphasises the closing **argument** that *"the Russians crushed Napoleon's dreams of military expeditions to Persia and India"*.

The **illustrative portraits** of important people of the campaign, which are part of the panel on the right, but also appear in the pop-ups, are both **uncoupled juxtaposed** and **superimposed**, respectively, and might evoke reactions on an **emotional level** or have an **immersion**-inducing effect.

Minard's original map is the starting point, the prologue of the narrative. The map integrates context in a coupled juxtaposed way. First, the well-known map **sets the stage and frames** the narrative. The authors use the map to question parts of the **message** Minard's illustration has, starting with the events leading up to the war in the first chapter.

During the course of the narrative, three **superimposed** **map layers** are shown. First, a **coupled** layer colours the territories of the French empire, the vassal states and France's allies, and the Russian empire. Second, another **coupled** map layer is added to the first that compares the strength of the French and Russian troops using proportional symbols, which also indicate where the respective troops and allies were located just before the beginning of the campaign. This visual comparison not only supports the **message**, but also **frames** the narrative (it is about West vs. East). As the French troops reach Moscow, an **uncoupled** map layer showing the damaged areas in the city is displayed. It provides visual support for the **message**, that *"in just four days 3/4 of the city went up in flames."*

Interactivity layer: The three **superimposed** map layers mentioned above have **limited interaction capabilities** fostering **explicit user involvements**. Hovering over a feature provides information about it (see Figures 3.46 and 3.47).

Text elements:

Flow and movement representation layer and context representation layer: The **flow text** on the right side takes on a special role, since it contains the majority of the narrative presenting the **message and argumentation** in verbal form. The text in the right panel is divided into a prologue, 14 chapters, and an epilogue, which chronologically present the events during the war. While this reflects the overall **thematic and temporal structure** of the events, the writers' decision to use this sequence influences the overall **message**.

The text is **juxtaposed**, but has **coupled** and **uncoupled** information. In one way or another, the text contains **spatial**, **temporal**, **qualitative**, **quantitative**, and primarily **contextual** information. The text makes reference to the **direction** and **location** of movement. Some examples are: *"As some participants in the campaign recall, on the way from Vilno to Vitebsk each regiment had to search for food on its own."*, *"The march from Smolensk to Gzhatsk (currently Gagarin) was a truly fatiguing experience for the soldiers."*, or *"The surviving remains of what just recently was the Grand Army headed for Vilno towards the border."*.

Temporal information, when troops moved, for example, is provided through: *"Napoleon entered the city on September 15."*, the **subtitles** of each chapter (e.g., *"September 5–7, 1812"*), and year of the campaign is included in the **title**.

Further, *"After the battle of Maloyaroslavets, he forced the French army to retreat along the Old Smolensk road through a war-ravaged area."* or *"On September 14, the Russian army concluded a brief ceasefire with the French advanced guard, left the city and moved south along the Ryazan road."* are examples in the text that convey **who** is moving (besides conveying location, direction, time, and context).

Magnitudes, the strength of the troops, are for example expressed through: *"According to Minard, on the eve of the war its strength totalled 422,000. According to modern historians it was even larger: 466,500 men, not including the reserves, and more than 647,000 with the reserves. The Russian Empire's regular army confronting*

Napoleon numbered 252,000." Further, the **duration** of movements is mentioned in the text: *"Throughout the French army's march from Moscow to Bérézina, in other words, for twenty six days, the bitter frost, though not extraordinary (from –12 °Cto –17 °C), lasted for no more than three [...] or for five days."*.

All of those reference the information depicted in the main visualisation. However, the flow text contains a large amount of **contextual** information. There is **coupled juxtaposed** text that provides context directly concerning the subject (e.g., causal information/reasons why we see the above). Further, the text contains **uncoupled juxtaposed** context: *"During a stop in Polotsk on the same day Alexander I made a decision to create volunteer paramilitary militias. His idea was each nobleman, each cleric and each citizen would take up arms against Napoleon in a joint surge of patriotism. On July 19, Alexander I left the 1st Western Army to start organising gubernatorial militias in Moscow and St. Petersburg."*.

The overall tone of the text **frames** the entire piece and reveals the Russian **perspective**. One example is at the beginning, where the title, more specifically the **subtitle**, demonstrates this fact: *'1812 - When Napoleon ventured east -'How the 1812 patriotic war turned napoleon's grand army into a handful of survivors"*.

Depending on a reader's personal connection with the topic, the narrative might also evoke an **emotional** response. The patriotic tone in particular might elicit affection or dislike.

The information in the **coupled superimposed** **pop-ups**, activated by clicking on the event symbols in the map, contains **location** and **time** (e.g., *"August 16-18, 1812; A two day battle at Smolensk between Russian troops and Napoleon's main forces."*). They also provide additional **context** (e.g., *"August 29, 1812; Prince Mikhail Golenishchev-Kutuzov takes over command of the Russian armies in Tsaryovo-Zaymishche."*), echoing the **message** from the flow text.

Visual-Narrative Summary: The majority of the narrative, and thus also the general message, is contained in the flow text. The visual elements in the map and the flow text echo or support the arguments, events, and facts presented in verbal form. Both, the story and discourse space and time are driven by the scrolling interaction that is responsible for narrative progression. The story space and time of this Flowstory, as for the previous case study, is the Western Russian Empire in the years 1812 and 1813. Within the text, certain dates are referenced and the progression of the flow mark in the map communicates temporality on a discourse level. Also, on the discourse level, the story space is presented visually and verbally on different levels. The names of cities and battlefields in the text or as annotations in the map view provide more detail regarding the story space. Author-defined panning and zooming provide different perspectives onto the story space throughout the narrative (e.g., set the stage by showing the different territories across the Eurasian continent, following the flow mark building up from West to East, or zooming into Moscow as Napoleon's troops arrive).

This high degree of detail regarding space, time, and content, is also expressed through the Tarutino manoeuvre, which, as discussed above, plays a central role in the narrative. The three rotating maps each explain successive troop movements, and form, if you will, a Flowstory within a Flowstory. It also demonstrates that the discourse time is not continuous. Different sections are given different amounts of discourse time.

Judging the flow-context-interaction balance, the example tends to be *context dominant*. Nevertheless, the visualisation of movement is not less salient, and the interactions provided are vital.

Narrativisation Opportunities: The example has a high degree of narrativity. Still, one interesting enhancement comes to mind. The contrast between the French and Russian forces is an essential element in the text, and it is part of the additional visualisations and map layers. However, this is not reflected in the main display visualising the troop movements - only the French army is depicted. Integrating the movements of the Russian troops in the main display would complete the picture. The three maps explaining the Tarutino manoeuvre show the movements of both forces.

3.3.2.3 Comparison

The biggest differences are the differing aims and authorial perspectives. While Minard's original map is from a French perspective, the interactive narrative was created by Russian news outlet, adding a strong Russian perspective. This perspective is produced by the general tone of the text, which glorifies the Russian side on several occasions, and questions Minard's statistics.

While Minard used a simple graphic and a reduced style to convey his message, the web-based narrative provides an extensive narrative in verbal form. All of the context provided there allows the viewer to connect the dots and create a story in their mind. This would be much more difficult using Minard's illustration, which lacks this additional context.

In both cases, the flow marks aggregate and simplify the actual troop movements. This is done in Minard's illustration by not strictly following the geography. On the contrary, in the interactive example, the authors explain that they *"tried to show where exactly the route of the Grand Army lay and to find out what factors resulted in its defeat. The route of Napoleon's army is recreated on a modern geographical map"*.

Overall, the story space is the same, but is presented on different levels of detail on a discourse level. The same applies to the story time. While the event displayed (i.e., the Russian campaign) happened in 1812 and 1813, on a discourse level, the temporal aspects are more detailed in the interactive example.

3.3.3 Migration

The last two case studies share the topic of migration. While they are not connected to each other, both examples use similar narrative techniques. I selected the topic of migration because it is the subject of the stimuli of both empirical experiments presented in Chapters 4 and 5.

3.3.3.1 The Stories Behind a Line - *FS_114*

"The Stories Behind a Line" presents six individual journeys of asylum seekers from West Africa and Pakistan to Italy in a web-based interactive format. Deliberately, the example focuses on individual experiences rather than on presenting any aggregate data. It demonstrates that it is not a spreadsheet, but a human with his or her personal story behind a line.

The webpage provides two different views. While the *map view* uses geographic space to show the journeys, the *distance view* uses simple Cartesian space, where the x-axis is temporal, and the y-axis conveys distance.

Each individual journey has its own section in the beginning, a summary view shows the paths next to each other, which can be used to navigate to each section. The visual narrative can be found at: http://www.storiesbehindaline.com/.

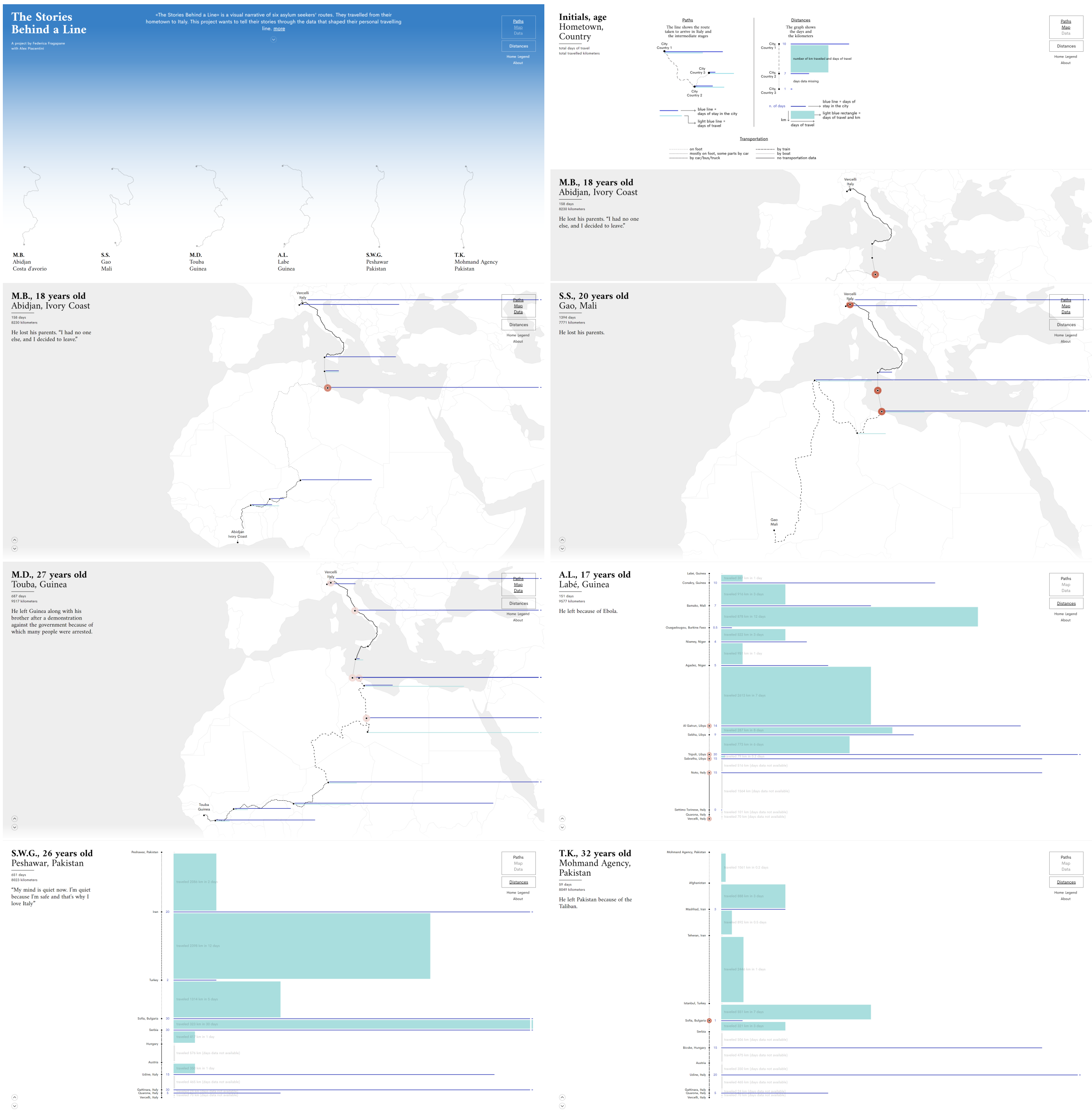


Figure 3.48: The Stories Behind a Line.
© Federica Fragapane and Alex Piacentini, 2016.

Flow mark:

Flow and movement representation layer: In the map view, the flow mark of each story is a **line-based geometry** with an **intermediate level of abstraction** showing the path of the journey according to the geography. In the distance view, the journey is depicted with a **straight line geometry** with a **geometric abstraction level**, conveying **direction** through **position/layout** (i.e., from top to bottom). Both flow marks provide visual structure along the path regarding the sequence of events, and the non-geo-spatial flow mark provides additional structure regarding the reading order (i.e., from top to bottom).

In both views, the mode of transportation is differentiated by stroke type (i.e., **qualitative** information encoded by **shape**). While in the map view, distance is inherent in the geography, the length of each journey segment in the distance view corresponds with the relative distance.

Overall, the flow marks support the main **message** and provide a unique **perspective** on the topic by focusing on individual and personal journeys.

Location mark:

Flow and movement representation layer: The location marks are **stops along the journey** to Italy. In both views, these locations have a **point geometry**. A pulsing red outline on a location mark (**intermediate level of abstraction**) indicates that some text-based narration is available for this location. The **pulsing glyphs** are attention cues (**implicit user involvement**) guiding the user and providing **structure for reading**. While geographic space in the map view helps to structure the order, it is the layout space providing structure in the distance view (i.e., from top to bottom). The selection of the places providing text-based narrative **frames** its interpretation. Is the text-based narrative deliberately omitted because the individuals did not want to talk about their experiences?

In the map view, the **background map** showing national borders (**area geometry** with **intermediate level of abstraction**) provides **spatial structure** for the flow and location marks. It not only shows the local context, but a wider geographic context, allowing the establishment of relations between the continents (e.g., between Africa and Europe).

Interactivity layer: The **pulsing glyphs** integrate **coupled superimposed** **interaction**. When selecting such a location detail on demand, text-based narration appears on the left side (see text elements).

Vis-media elements:

Flow and movement representation layer: **Coupled superimposed** **bars** encode **quantities** in both views. They are placed along the refugee's path and encode **duration** in days by **size** along the horizontal axis. While light blue lines indicate the number of days travelled between two locations, darker blue lines encode the number of days spent in a city. In the distance view, the light blue lines expand to rectangles indicating the kilometres travelled between locations along the vertical axis. The **shape** of the resulting rectangle conveys travel **speed**. A long, narrow rectangle, for example, means that it took only a few days to cover many kilometres, hence a faster travel speed. The bars support the **overall message** and provide **temporality**. Only the bars show that the journeys of refugees towards Europe can sometimes take several years.

Context representation layer: There are two vis-media elements providing essential context. Before the individual stories a **legend** provides information about how to read the visualisations in both views. By using dummy data and labels, the legend mimics the exact visual appearance of both views. The legend provides **perspective** to interpret the message of the visualisation, fostering **implicit user involvement**.

At the top of the web page, a **visual summary** shows all six paths together with their respective initials and place of origin resented next to each other. This view **frames** the entire piece, emphasising the main **message** that the narratives presented are about individual fates.

Interactivity layer: The **visual summary** is also a navigational device, allowing the reader to auto-scroll to the respective narrative, fostering **explicit user involvement** and influencing the **reading order**.

Text elements:

Flow and movement representation layer and context representation layer: The **title and teaser text** at the top of the web page are **coupled juxtaposed** and convey some **spatial** information and **context** about the project, **framing** the visual narrative and supporting the **message** that the lines are actual humans with individual stories.

In the map view, **coupled superimposed** **labels** indicate the origin and destination cities, providing **spatial structure** and mapping out the story space. In the same view, when hovering over location marks, text-based **coupled superimposed** **annotations** appear and reveal **spatial** and sometimes **temporal** information (i.e., the city name and if available, the numbers of days travelled to reach the city). In the distance view, all of this spatio-temporal information is integrated without interaction. Integrating this information aids in the interpretation of the **overall message**.

Each individual narrative has **coupled juxtaposed** **text-based** **spatial**, **temporal**, **quantitative**, and **contextual** information on the left. This includes the asylum seeker's initials, his or her age, the hometown and country of origin, the total days of travel, the and total kilometres travelled. Further, a short statement is given about why they left their home (e.g., *"He left because of Ebola."*, *"He lost his parents. 'I had no one else, and I decided to leave.' "*, or *"He left Pakistan because of the Taliban."*). When clicking on the red pulsing location marks, this statement and the location information are updated and replaced with some further **text-based narrative** providing additional **context**. These statements contain **major messages** and **set the stage**, providing an overall **perspective** on the topic, and they might move readers **emotionally** (e.g., empathy).

As an example, let us take a look at the journey of M.D., a 27-year-old person. His journey from Touba, Guinea to Italy took 687 days and was 9517 kilometres long. *"He left Guinea along with his brother after a demonstration against the government because of which many people were arrested."* They crossed through Mali, Burkina Faso, Niger, and Algeria before arriving in Libya: *"He stayed 1 month in Sebha working in order to earn enough money for the following trip."*. M.D. then made his way to Tripoli, where he stayed for 217 days: *"He arrived in Tripoli in a truck, hidden under some blankets with many other people. "They put us in the trucks as if we were objects. It was too hot and we couldn't move because there were so many people". When they arrived in Tripoli they were stopped by the police and got arrested. They stayed in jail, for 2 months and a week. Then he, his brother and two other people managed to escape. They worked as bricklayers for 5 months. He left Libya with his brother in June, because it was too dangerous. 'In Libya it's too dangerous. I can die every day.' "* Leaving Libya, *"They took a small boat to arrive in Italy. After 8 hours of travel they met a ship whose crew helped them."* The journey continued from Lampedusa to Rome, where they stayed for 240 days. While *"His brother stayed in Rome, he was transferred to Settimo Torinese."* Finally, 687 days after he left his hometown, *"He arrived in Vercelli on August 1, 2016."*

Vercelli, in northern Italy, is the place where all six interviews were conducted. This and other **contextual** information is provided in some **informational text** at the bottom of the web page. The text provides the author's rationale and **perspective** on the project and helps improve the understanding of the data: *"I'm extremely thankful to them, because they shared with me their painful memories. I decided to tell their stories through data and numbers – travelled kilometres, hours spent, transportation – because I think that this information in its simplicity can really depict the exhausting and dangerous experiences lived by persons who are looking for a better life. During our interviews I asked them to help me in filling up these lines* *with data and information and to tell me what they wanted to, without too many questions. This is why in some parts of the lines there are some quotes or notes: these are the moments in which they shared with me a more detailed fragment of their story. There are some missing data and there are two main reasons for that: either they weren't able to recall the information or I was so moved that I simply forgot to ask it. I think that imperfections in this projects are inevitable and I think that's right."*

Interactivity layer: A text-based **menu** in the top right provides **coupled juxtaposed interaction involving the user actively**. The menu allows the reader to switch between the two views and to toggle the visibility of layers in the map view (i.e., the background map and the bars indicating travel duration).

Visual-Narrative Summary: The story space spans between the countries of origin in West Africa and Pakistan and the Italian town of Vercelli, including all the intermediate stops along the presented journeys. The discourse space separates the story space regarding each personal narrative into separate sections of the layout. This design decision emphasises the idea that each asylum seeker has his or her own story to tell. The division of the layout space further provides the overall structure. Progression between these sections happens through scrolling or a small navigational aid (i.e., little up and down arrows placed in the lower left), which influences the discourse time.

While the story space is well defined through the flow marks, the story time is more vague. We know that the *"six asylum seekers [...] arrived in Italy in 2016"*, and we know the duration of each journey in days, which allows us to form conclusions regarding story time. The additional bars that convey the travel time and the time spent stationary in cities provide the temporality of events in the story.

A powerful visual artefact, whether it was introduced intentionally or not, can be seen at the beginning. The six paths of the summary view are facing a blue gradient on top, which is smoothly alternating between a lighter and a darker blue. Resembling ocean currents, this view might communicate that you must cross a potentially dangerous sea to get to Europe, to reach your goal of a better life.

Narrativisation Opportunities: If available and desired, audio excerpts from the interviews could be added to further immerse the audience or move them emotionally. Other ethical or data protection considerations might argue against the use of such primary data.

Superimposed iconographic representations or short text inserts, as was done in the following case study, could present what the migrants lived through more instantly than the juxtaposed text. Adding such visual or verbal annotations might aid the narrative, but on the other hand, would work against the very clear and simplistic design.

3.3.3.2 Khalid's Way - from Yemen to Austria - *FS_113*

This static map presents the journey of a single refugee from Yemen to Austria. Based on interviews and track data, the narrative map depicts the journey Kahlid took to get to Austria over a five year period. Jakob Listabarth, the author, wrote this about his work: *"It shows merely one personal refugee-story out of the countless other ones, which we normally only hear about through statistics, in newspapers, or from television."* While the map focuses on the experience of a single person, the second, statistical perspective is also included in the map.

The above quote and the map are available as part of a blog post:
https://cartography.tuwien.ac.at/another-impressive-student-map-khalids-way/.

Flow mark:

Flow and movement representation layer: The map has two flow marks representing the two perspectives. First, **Kahlid's path**, a **line geometry** with an **intermediate level of abstraction** because it follows the geography, differentiates the mode of transportation by **shape** (i.e., a **qualitative** differentiation between airplane, bus, rubber raft, ship, and taxi). From a narrative perspective, the flow mark provides a **spatio-temporal structure** supporting how a reader consumes the visualisation, supports parts of the **message** (i.e., the modes of travel), and emphasises the single person **perspective**.

The **blue arrow** flow marks provide an additional more statistical, or data-driven **perspective**. They illustrate the number of asylum seekers in Austria between 2011 and 2015 grouped by continents of origin and the number of people leaving Yemen grouped by destination continents. They have a **line geometry** with a **geometric level of abstraction** encoding geometric level of abstraction through **orientation** (i.e., arrow head) and **magnitude** through **size** (i.e., line width). Additionally, the arrow from Yemen to Europe and the arrow to Austria from Asia are connected with a narrow blue line, expressing the volume of asylum seekers in Austria coming from Yemen.

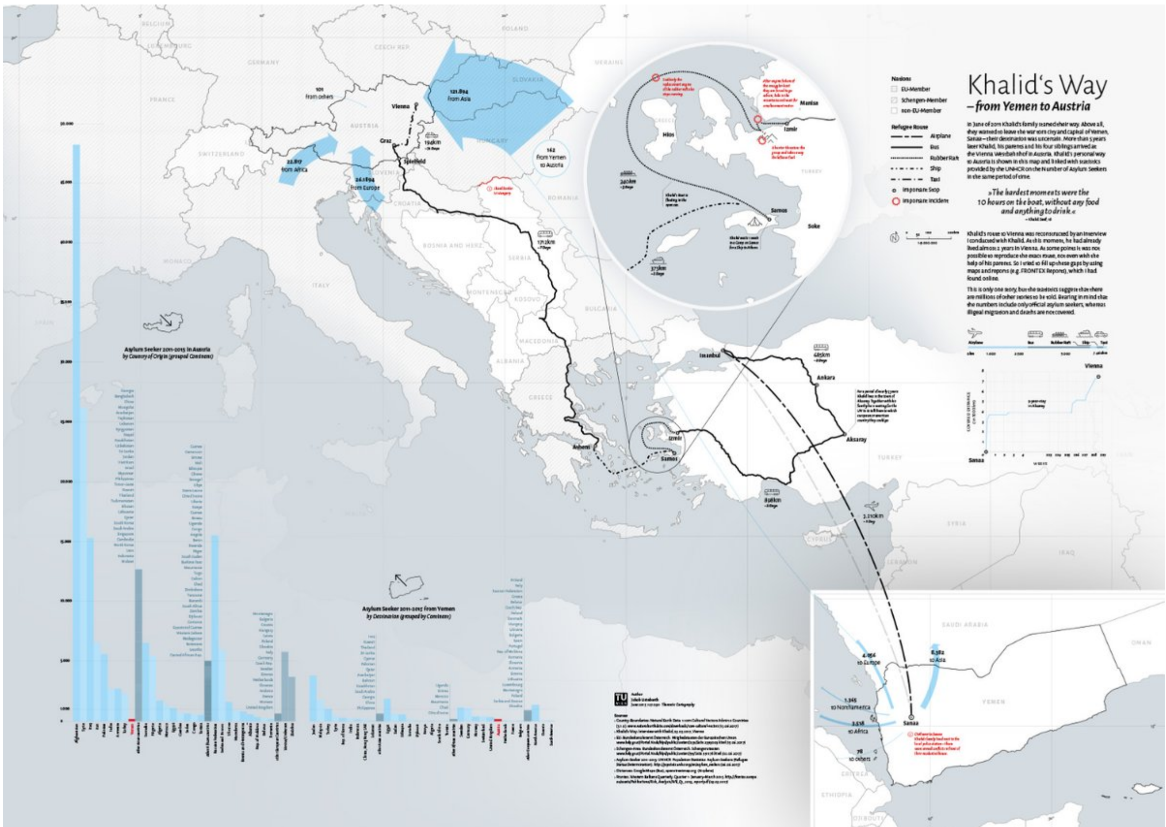


Figure 3.49: Khalid's way - from Yemen to Austria.
© Jakob Listabarth, 2017.

Location mark:

Flow and movement representation layer: Location marks are **important stops in cities** along the way (e.g., Sanaa (origin) in Syria, Aksaray in Turkey, Samos in Greece, or Vienna (destination) in Austria), depicted with a **point geometry** and a **geometric level of abstraction**, and the **background map**. The background map shows national borders (**area geometry** with an **intermediate level of abstraction**) and provides **spatial structure**, allowing Kahlid's journey to be embedded in a wider geographic context.

Vis-media elements:

Flow and movement representation layer: The map contains **coupled juxtaposed chart-like** vis-media elements describing the depicted movement, where one can also differentiate between the two different **perspectives**.

A transport mode **time-line** compares the kilometres travelled by airplane, bus, rubber raft, ship, or taxi, which repeats the **qualitative** differentiation made by the flow mark shape. To a certain extent, this supports the **message** regarding the different means of travel.

In a similar way, a **line chart** supports the **message** and summarises Kahlid's journey by contrasting **elapsed time** (i.e., weeks along the x-axis) and **covered distance** along the y-axis. Together with annotations and axis labels, the chart conveys **location** and **direction**, **time** (i.e., he left Aksaray in week 225), and **duration** (i.e., it took him about 3 weeks to travel from Aksaray to Vienna). From a narrative perspective, this chart shows the **temporality** of his journey and emphasises Kahlid's personal **perspective**. The length and distance of his journey, as conveyed by this chart, might evoke **emotional** reactions.

Two **bar charts** **coupled** to the arrow flow marks show the numbers of asylum seekers between 2011 and 2015 in Austria by country of origin and from Yemen by destination countries. Through labels, text-based and graphic annotations, and layout they convey **location** and **direction**. The bars encode **magnitude** with **size** (i.e., the length of the bars). Aside from supporting the **message** to some extent, the charts provide the statistical **perspective**, showing aggregated data instead of single individuals.

Context representation layer: All of the charts described above integrate **context** by providing additional or more detailed information. The line chart, for example, explains the dashed horizontal line segment with the annotation *"5-year stay in Aksar"*.

From a narrative perspective, the **event map layer** plays an essential role. It consists of vis-media elements and text-based elements (see below). Small, **figurative**, **coupled superimposed** **map symbols** indicate the mode of transportation (e.g., a rubber boat icon), important incidents (i.e., a red circular icon with a zig-zag outline), important notes providing causal information (i.e., a circled, red exclamation mark), or other location-based facts (e.g., a tent symbol representing a camp, or a mountain icon explaining the local topography). These symbols support the **messages** in the related text-elements. Based on the authorial selection of certain events, they help to **frame** the narrative, lead to **emotional** reactions based on the use of colour and meaning to contribute to **implicit user involvement** by drawing attention and guiding the reader.

Another **layer** that provides additional **context**, but is **uncoupled superimposed**, depicts EU membership and indicates the Schengen-Area by nation. This distinction has the ability to **frame** the message.

Text elements:

Flow and movement representation layer and context representation layer: The **coupled juxtaposed** **title** *"Khalid's Way - from Yemen to Austria"* includes **spatial** information and strengthens the **argument** that the narrative focuses on an individual's **perspective**.

The **summarising text** below the title provides **temporal** (i.e., *"In June of 2011 Khalid's family started their way."*) and **spatial** information, providing a summary of the **overall message**. This text, being the first thing read, has the ability to **set the stage** and to **frame** a reader's mindset: *"Above all, they wanted to leave the war torn city and capital of Yemen, Sanaa – their destination was uncertain. More than 5 years later Khalid, his parents and his four siblings arrived at the Vienna Westbahnhof in Austria."*

A **quote** from Kahlid, emphasised through a larger font, might elicit an **emotional** response: *"The hardest moments were the 10 hours on the boat, without any food and anything to drink."*

Additional **context** in this section gives information about the data collection (i.e., interview, reports, and statistics), the authoring process, and the design decisions. Adding such information helps the reader interpret of the visual narrative (**framing effect**).

The **annotations, labels, and text inserts** of the event map layer are **coupled superimposed**, and convey **spatial**, **temporal**, **quantitative**, and **contextual** information. Labels on the arrow flow marks indicate **magnitude** and **direction** (e.g., *"22,817 from Africa"*, or *"162 from Yemen to Austria"*). Annotations that are in conjunction with the mode of transportation icons convey **duration** (e.g., the 1712 kilometres long bus ride from Athens to Graz took *"7 Days"*). Those labels play a supportive role regarding the **overall message** and reinforce Kahlid's **perspective**.

Small **text inserts** provide **context** and annotate certain **places** and **events** during Kahlid's journey. They convey the majority of the **message** conveyed in the map in a verbal form. When starting from Kahlid's home town, a red coloured text provides the reasons why he and his family started this journey: *"Civil war in Sanaa - Khalid's* *family lived next to the local police station – there were armed conflicts in front of their residential house."* After flying to Istanbul, a bus brings them to Aksaray: *"For a period of nearly 5 years Khalid lives in the town of Aksaray. Together with his family he is waiting for the UN to to tell them to which European or American country they could go."* They then travel to Izmir, where they get on a rubber raft. A chain of important incidents followed, with text in red: *"After engine failure of the smuggler-boat they are forced to go ashore, hide in the mountains and wait for a replacement motor"*, where *"A hunter threatens the group and takes away the leftover fuel."* Back at sea: *"Suddenly the replacement engine of the rubber raft also stops running."* Text in black pointing towards the flow mark that circles back to the Southeast states: *"Khalid's Boat is floating in the open sea."*. Associated with a tent symbol, an annotation reveals: *"Khalid waits 1 week in a Camp on Samos for a Ship to Athens."*. After that point, there are no text inserts until the Hungarian border. A red coloured note about the *"closed border to Hungary"* explains routing through Croatia and Slovenia into Austria. The selection of these events for verbal presentation **frames** and influences the overall tone of the piece. The dramatic content and the red colour might move readers **emotionally**.

The geographic names (i.e., cities and countries) on the background map provide additional **location** information and offer **spatial orientation**.

Visual-Narrative Summary: The story space spans between Yemen and Austria, including all the places Kahlid passed through or spent time. Further, the second perspective provided through the bar charts and the arrow flow marks expands the story space to a global one - though less critical for the overall narrative. The story time is a range of more than five years (i.e., 229 weeks), starting during June 2011.

From a discourse point of view, the example uses two interesting techniques for shortening or stretching space and time. First, the map insert on the lower right with an extent containing Yemen and the Gulf region shortens space and time. This technique helps to reduce *white space* and is common in cartography. The flow mark links the region of origin with the main map by crossing the panel frame of the insert in an exceptionally elegant way, indicating the flight from Sanaa to Istanbul. Second, the magnifier view emphasising the events along the Turkish coast stretches out space and time. It does this by providing more discourse space and time integrating the chain of events in a visual and verbal form.

The text inserts and the visual style suggest Kahlid travelled alone from Syria to Austria, despite the fact that it was Kahlid and his family who made this long journey. This authorial decision reflects the aim of presenting the story of a single person.

Narrativisation Opportunities: Being a static map, it is a very well executed example of a balanced Flowstory. As the author points out, the data is about asylum seekers and does not include illegal immigration or death statistics. Such additional data might provide a larger perspective, but would overload the map. Porting the work to an interactive, web based setting, on the other hand, would open it up to further refinement of the narrative. For example, it would be possible to progressively blend between the individual perspective and the aggregated data in a single view.

3.3.3.3 Comparison

The two examples are independent regarding space, time, and content. Nevertheless, sharing a similar topic and aim, both visual narratives have one technique in common. They aim to demonstrate that it is not data, but humans with their personal story, behind each line. I use this technique for an experimental stimulus in Chapter 5 to present personal migration narratives.

3.3.4 Summary

The six case studies provided insight on the analytical application of the design space. A few recommendations were given on how further narrativisation might be possible. In the survey Chapters 4 and 5, the experimental stimuli are examples of how narrative techniques can be added to common flow or movement visualisations.

The design space, though created going from visualisation to narrative (inside-out), does not only allow mono-directional thinking; but also encourages investigation of how concepts from narrative theory (outside-in) might be implemented or supported through the use of the elements identified in the flow and movement domain of the design space (e.g., showing the humans behind the dots by not aggregating information into a single flow mark).

After demonstrating how the design space can be used to analyse visualisations, in the next section of this chapter, I discuss ways how to use the design space genveratively.

3.4 Using the Design Space Generatively

The discussion of the categories and how they interact with each other across the two domains (i.e., visualisation and narration), as well as the case studies, have demonstrated how the design space can be used as an analytical tool. In this section, generative approaches, how to use the framework to create something new, are discussed. These generative possibilities are demonstrated from two perspectives: authoring and evaluation. First, it is shown how the design space can contribute to creating a new Flowstory, and how a new design space can be derived through the authoring process of this new visualisation. Second, how experimental designs for empirical evaluations can be generated from the framework is discussed.

3.4.1 Authoring: Creating Flowstories and Deriving a Design Space

The first two points, creating new Flowstories and deriving a new design space, are the result of a joint project with the National Archives (TNA), U.K. In several workshops, we explored how to visualise aspects of their Operation War Diaries (OWD) data set. These are data extracted from hand-written military diaries from the First World War (WWI), documenting the story of the British Army and its units on the Western Front. This collaboration resulted in web-based prototypes, displayed during the IEEE VIS ArtsProgram 2018[7] (Liem et al., 2018a), joint poster presentations (Liem et al., 2018b, 2019a) and short talks[8] with panel discussions (Butterworth et al., 2019). At the time of the Flowstory exhibition in the VIS ArtsProgram, in autumn 2018, one hundred years ago, in November 1918, the First World War came to an end. Hence, the title of the piece: *WWI00 {World War One Hundred}*.

3.4.1.1 The WWI00 {World War One Hundred} Flowstory

Between 2014 and 2019, TNA have been digitising analogue, hand-written military diaries using a crowd-working approach. The OWD data is not a literal digitisation word-by-word. Citizen historians interactively tagged particular information on top of the scanned diary pages using a predefined category catalogue. Classifying and annotating essential information on more than 1.5 million diary pages, they generated extensive time-series

[7] https://visap.net/2018/
[8] https://fyi-conference.com

data about British military units during WWI. The diaries are not personal, but instead military diaries containing matters such as casualties, unit strength, weather, everyday army life, military activities, soldier names and ranks, location names, and dates. Aside from data cleaning and selecting a subset of unit diaries containing rich information, the pre-processing stage also included the geo-referencing of mentioned place names (i.e., assigning geographical coordinates to place names).

Based on how the data was generated and processed, several uncertainties and ambiguities are associated with the OWD data. Over time, diary pages were lost, or whole sections were no longer legible. The humans involved may have made mistakes or worked at different levels of detail. British soldiers might have made spelling mistakes in French place names. Crowd-workers potentially made typos during the tagging process or carried on existing mistakes. Such errors can further lead to ambiguous information about the soldiers or place names mentioned in the digital data.

Prior to creating the Flowstory, two central aims were formulated. **Aim 1:** Visually communicate the movement of troops over the course of the war. Acknowledge the uncertainties and ambiguities associated with the OWD data and convey them visually. Instead of giving the illusion that the data is complete and clean, we leverage this uncertainty to produce a more *organic* view of a unit's movement over time. **Aim 2:** Visually communicate life *behind the trenches* as described by Grayson (2016). It is not intended to communicate only the battles, victories or defeats of WWI. Instead, the visualisation aims at communicating a sense of the day-to-day life in the war zone. By including fighting and non-fighting activities as documented by the diaries, it aims to shed light on aspects of war that are often not conveyed in history books, but remain buried in documents such as these diaries.

Based on these goals, the interactive prototype in Figure 3.50 was developed. The interface consists of two displays: the map display and the interaction interface. The design process in which the Flowstory design space categories were used is explained below using the three editorial layers.

Flow and Movement Representation Layer
First, the visualisation of a unit's movement over the course of the war was approached. Which type of **flow mark** ⇨ is suitable to meet the defined aims?

We started out by exploring possible geometries to visualise a unit's movement. In the first step, all the locations mentioned within a selected diary were connected chronologically, which results in the alleged movement profile (line geometry) shown in Figure 3.51. Why does it result in such a cluttered, zig-zag map image? The afore mentioned spelling and

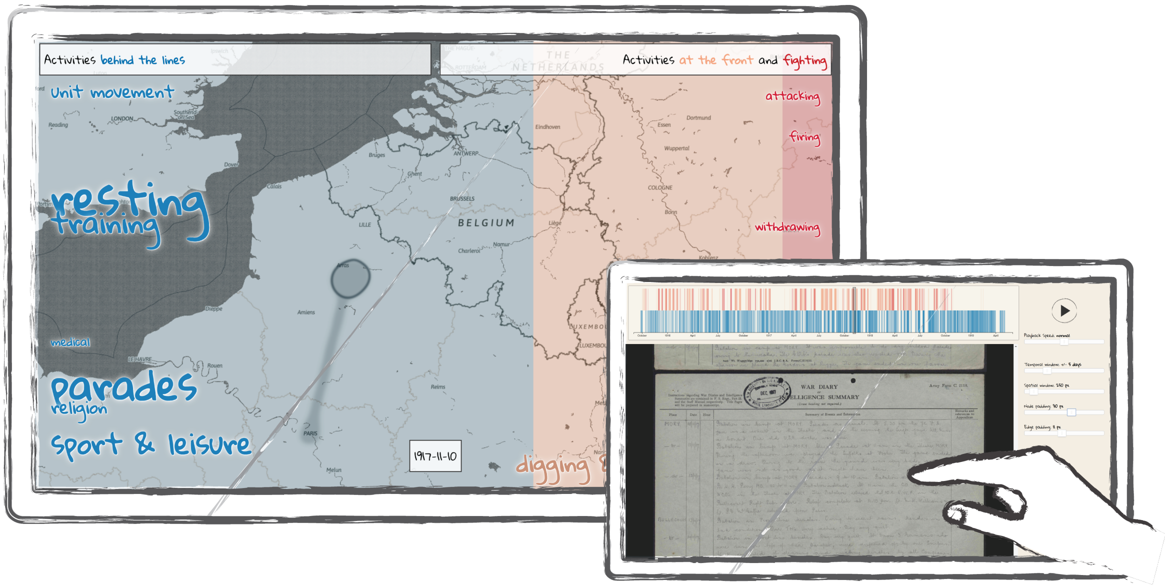


Figure 3.50: The WWI00 Flowstory conveys the movements and activities of the 3rd Division's 8th Battalion, the King's Own Royal Lancaster Regiment from 1914 to 1920. The split screen browser-based prototype uses the mapping framework leaflet (https://leafletjs.com/) with custom D3 SVG overlays (https://github.com/teralytics/Leaflet.D3SvgOverlay) to visualise the OWD data. The geometries for GeoBlobs are calculated using the Bubble Sets algorithm Collins et al. (2009). **Top:** The *map display* contains the background map, the GeoBlob layer, and the activity layer. **Bottom:** The *interaction display* contains an activity-timeline, the diary pages, and a preference panel.

typing mistakes might lead to using incorrect geographic coordinates during the geo-referencing process. Or, if several places were mentioned on the same day, it is not clear in which order the places were visited by the troops. Additionally, the digitised data does not capture in which context a place was mentioned in the diary. Thus, it is not evident whether a place was mentioned as a troop location or for some other reason (e.g., when a soldier was reported to go on furlough to his hometown, the place name was digitally collected, but not the context). The literal spatio-temporal mapping of locations has limitations.

After ruling out designs using points (e.g., animated glyphs), lines (e.g., flow lines with arrowheads Jenny et al. (2016c)), or grid geometries (e.g., OD maps Wood et al. (2010)), animated areas were identified as a suitable geometry for the uncertain and ambiguous characteristics of the OWD data. *GeoBlobs*, a representation of moving entities on a map with uncertain positions, were developed. Instead of showing a unit at a given point in time, GeoBlobs convey an unordered estimation of the possible positions over a specified time period using an enclosed **area geometry**, or blob. GeoBlobs leverage the uncertainty in the data to produce an *organic* view of a moving unit on a map over time, in contrast to the visual certainty that is conveyed by crisp line and dot visualisations.

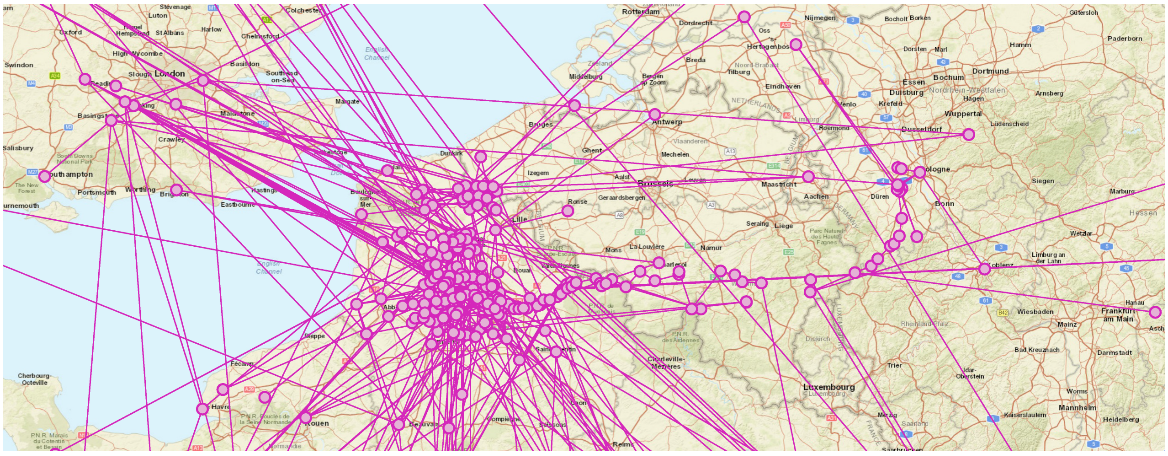


Figure 3.51: Location data (longitude, latitude) after geo-referencing place names for a single military unit connected in chronological order with lines results in a cluttered map display.

When animated, a GeoBlob's **motion** encodes the overall **direction** of the displayed army unit and therefore implicitly encodes temporal information. The temporal and spatial aggregation of possible locations might introduce a certain degree of generalisation (e.g. back and forth movements within a larger temporal window are not obvious), which on the other hand can reflect the uncertainty in the data.

By using multiple stacked layers with different transparencies and by applying sketchy and blurry render styles, GeoBlobs can convey the sense of uncertainty (see Figure 3.57), meeting the first aim. Regarding the Flowstory design space, GeoBlobs have an **intermediate level of abstraction**. While the geometry is geometric, a blob conveys meaning (uncertainty).

If more than one diary is used in the visualisation (compare Figure 3.57), flow marks can have different fill and stroke colours, allowing them to be distinguished visually.

The **location mark** is a custom background map with historical and clean aesthetics. Since locations played an essential role, the familiar geographic space (as opposed to a non-geographic layout), was used to provide geographic context. The location mark has an **intermediate level of abstraction**.

From a narrative perspective, the animation is linked to the progression, and therefore supports the structure and temporality of the events and locations conveyed in the diaries. The historic style of the base map provides spatial structure, embedding GeoBlobs in the geography and framing the message, which sets a certain tone.

The only quantitative information included is the amount of activities mentioned and tagged in the diaries. In the context of the Flowstory design space, this is contextual information.

Context Representation Layer

The graphical display on the main monitor consists of a geographic layer including the background map, the GeoBlobs, and a non-geographic thematic overlay, that communicate the activities within the specified spatio-temporal range (i.e., the activity layer).

Uncoupled superimposed **text** and **vis-media** elements convey this contextual information. They are uncoupled, because they do not directly describe the properties of the movement, but additional information. They are superimposed because by covering the entire map display, they use the same layout space.

The proportions of activities *behind the front* and *at the front* are displayed through the proportional area chart spanning across the screen. Blue is the share of activities behind the lines. Red shades are activities at the front, with light red being non-combat actions and darker red representing fighting activities.

Additionally, the names of the activity categories are displayed using text. The font colour corresponds with the distinction explained above. Activities behind the line in blue are, for instance, resting, training, sport, and leisure. Activities at the front in red include attacking, firing, or withdrawing. The font size relates to the frequency with which the corresponding activity is mentioned in the diary within the defined time range. While the font might be too playful for this serious subject, it mimics the idea of the hand-written diaries. The selected font is a compromise, because many of the old-style hand-written fonts are hard to read.

The layout, the spatial arrangement of the text, and the vis-media element reflects the geography in a certain way. Activities behind the line are on the left, in the West. The activities at the front are on the right, in the East. From a narrative point of view, this reflects the Western Front from a British perspective, supporting the overall message conveyed in the diaries.

The contextual information is also displayed on the interaction screen. The activities mentioned in the diaries are shown on the timeline. Where, again, blue indicates non-combat related activities and red indicates fighting related activities.

Similarly, the layout conveys some meaning. Blue marks (behind the lines) are close to the base line and red marks (at the front) are further away from the base line, reflecting the British perspective.

The diary pages, a combination of vis-media and text elements, are the primary source of the data, and therefore contain all of the displayed information and much more beyond that. If users identify some patterns in the map display or the timeline, they can pause the animation and read the scanned diary pages, which might help to reveal causalities conveyed in the diaries. The immersion-inducing factor of the diary pages together with the animation increase user involvement. The timeline, as well as the diary pages, provides temporal and thematic structure, aligning the reading order with the temporality of events. The diary pages themselves are used to set a specific tone. Providing the diaries as digital facsimiles might let users feel closer to the soldiers fighting during WWI on an emotional level.

Aside from the spatio-temporal movement of Britain's military units, the Flowstory conveys activities and day-to-day life on the Western Front during WWI, which meets the second aim. WWI00 illustrates how soldiers spent their time by contrasting fighting and non-fighting activities. The OWD data show that the balance between time spent in the trenches and time spent behind the trenches are not aligned with our common beliefs about war Grayson (2016), the central argument of the piece. This message is explicitly expressed through the proportional area overlay, where the blue area, the non-fighting activities behind the line, is rarely below 60%. Revealing *life behind the trenches* to the general public might help to convey the more humane aspect of the war and clarify that much of the time was not spent fighting in the trenches. In no case, however, should this mitigate the terrible events of the war.

Interactivity Layer

On the interaction display, users can scroll through the diary or the timeline, which are dynamically linked. When a user scrolls in the diary, the time advances. This change has an effect on the time-window in the timeline and the map display on the main screen. This link is bidirectional. The preference panel on the right allows a user to adjust the temporal range (i.e., how many days should be included in the GeoBlob) and the distance filter (i.e., the distance from a blob's centroid to remove outlier locations forming the GeoBlob) as well as a GeoBlob's style and form parameters. These interactions, which allow influencing the appearance of GeoBlobs, can be used to frame the message and provide a different perspective. For instance, a GeoBlob based on a temporal window of a month conveys a different message than using a shorter window of just a few days. Similarly, a large spatial window conveys a different message than a smaller one.

The aim of visually conveying uncertainty is not covered by the Flowstory design space per se. It might be treated as contextual information in some form. Alternatively, aspects of the Flowstory design space can be selected and extended to meet these aims and requirements. That is how the GeoBlob design space was developed, which is described in the following section.

3.4.1.2 The GeoBlob Design Space

As discussed above, GeoBlobs are an abstract representation of spatio-temporal data dedicated to conveying uncertain location and temporal information of entities that move over time. The design space of GeoBlobs was derived from the Flowstory design space through the process of creating the WWI00 Flowstory. However, the new design space focuses on the topic of uncertainty. Many different parameters can influence the design of GeoBlobs, and the following variations were explored in the context of the OWD data. Only a subset was implemented in the above example.

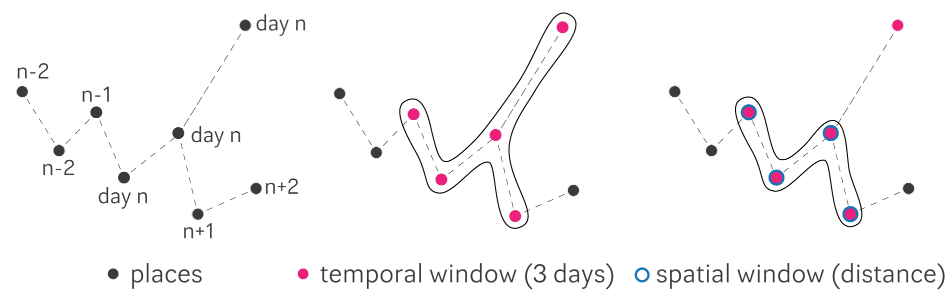


Figure 3.52: Variations of the temporal and spatial window defining the inclusion of locations for GeoBlob construction.

A **temporal window and a spatial window** are used to select data points from the spatio-temporal sequence, which are then used to construct the GeoBlob geometry (see Figure 3.52). While the temporal window is used to select all places mentioned within the specified time range, the spatial window restricts their inclusion by an additional measure (in this case using a simple linear distance measure; other heuristics, weightings, or attributes can also be used). Unlikely locations that have an incorrect geo-location or were not mentioned as a troop location, can be identified by the spatial filter and, if necessary, excluded or treated separately.

The temporal window and the spatial window define the size and shape of the GeoBlob. Keeping both windows constant over time, the size and shape of the geometry convey information about the speed of a unit. While narrow and long shapes imply a greater distance covered, small circular forms indicate local or no movements.

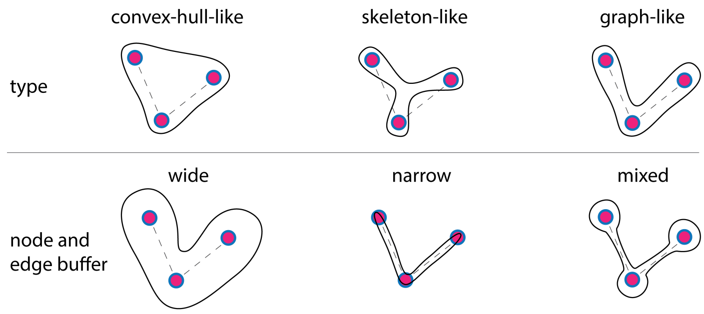


Figure 3.53: Design variations of the shape/form of GeoBlobs.

The design space distinguishes two **shape parameters**. The **shape type** can be convex hull-like, skeleton-like, or graph-like (Figure 3.53 top). While skeleton-like geometries connect locations along the shortest distance, graph-like GeoBlobs consider the temporal order of locations. **Node and edge buffers** can have varying radii (i.e., wide, narrow, mixed) and therefore influence a GeoBlob's appearance (Figure 3.53 bottom).

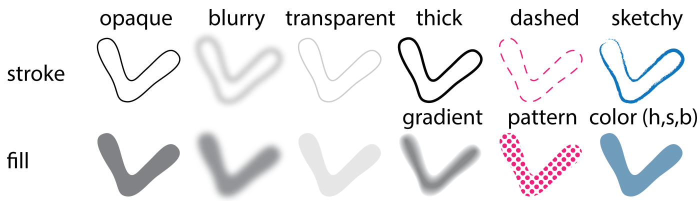


Figure 3.54: Design variations for stroke and fill style of GeoBlobs.

The visual appearance also depends on various **style parameters** for the fill and stroke style of GeoBlobs as shown in Figure 3.54. They are based on visual variables including colour, transparency, focus (blur effect), pattern, or gradient fill. Blurry or sketchy rendering styles (Wood et al., 2012), for example, can convey the sense of uncertainty.

Multiple geometries can be used to display more than one entity (i.e., military units), or they can be stacked to communicate the uncertainties of places. Mapping multiple entities concurrently, as shown in Figure 3.55, allows for comparison of their individual movements (e.g., two units located at the same front, but split after a battle). Generating multiple stacked layers for a single entity, taking the different location probabilities into account, and using transparency accordingly, allows the uncertainty of possible locations to be conveyed (Figure 3.55).

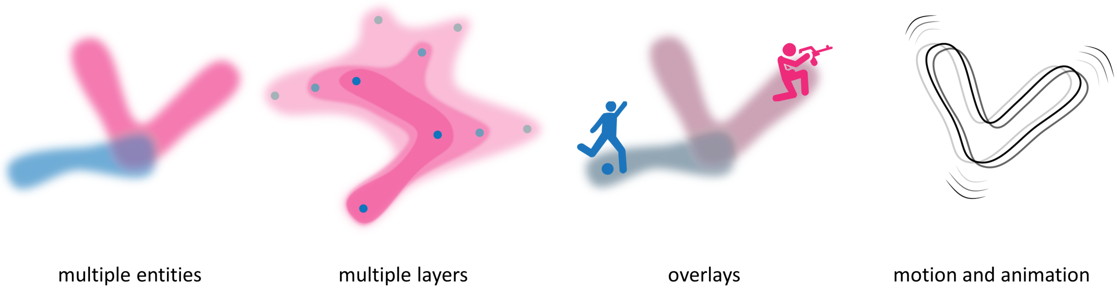


Figure 3.55: Design variations for stroke and fill style of GeoBlobs.

Within the GeoBlob design space, additional **context** can be communicated through isotype-like overlays as well as animation (Figure 3.55). For example, small mimetic overlay icons can visually integrate unit activities like fighting, re-supplying the front, and resting behind the lines. Shaking GeoBlobs can represent combat actions on fighting days. Other methods of **contextualisation** are additional map layers or overlays, such as the activity layer described above.

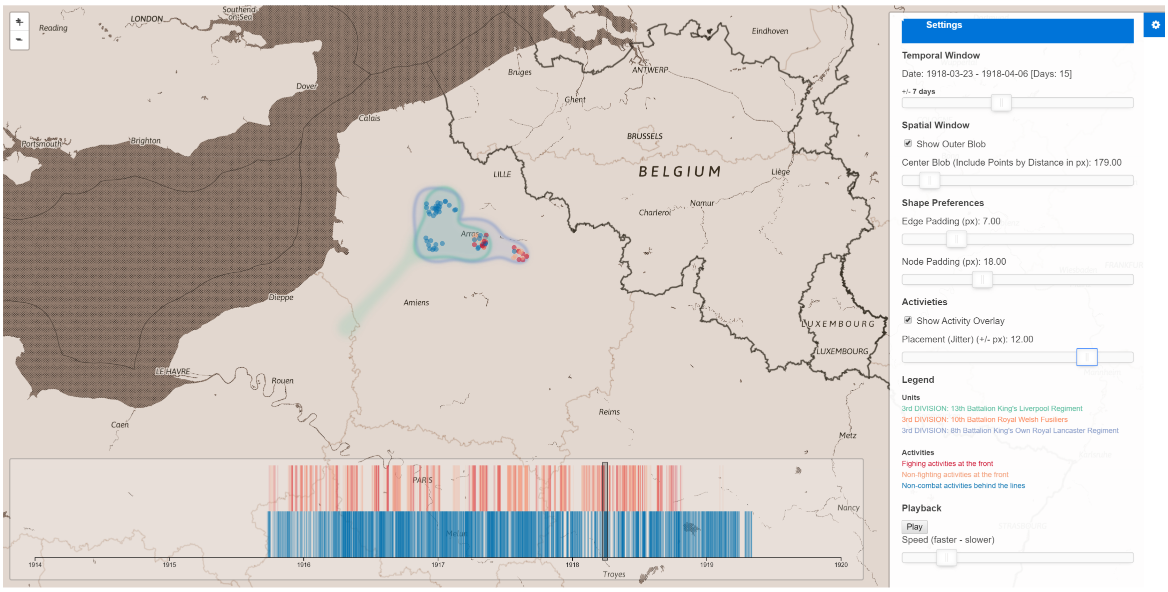


Figure 3.56: Single screen prototype showing GeoBlobs for two units. A jittered dot overlay conveys activities behind the line and at the front.

In earlier prototypes, other means were used to communicate activities. Activities can also be shown as a jittered dot overlay (Figure 3.56). Using the same colours and distinction between *behind the lines* and *at the front*, one can see the front-lines in the East and the camps behind the lines in the West. Isotype-like, mimetic icons can also reflect recorded activities (Figure 3.57 left) and provide context.

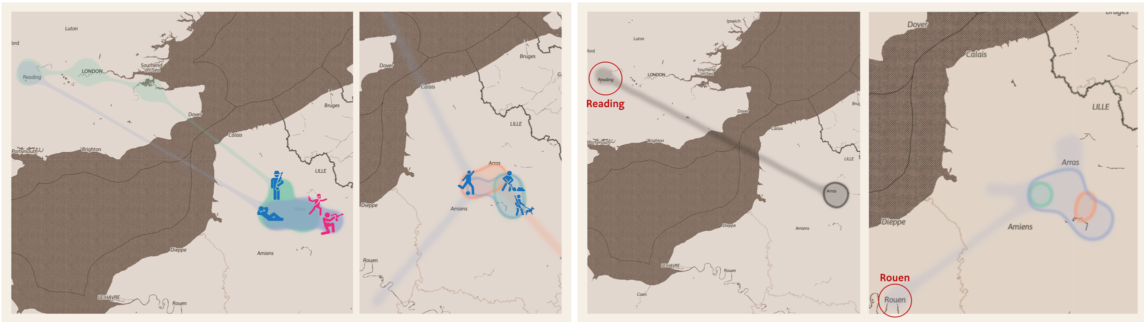


Figure 3.57: Examples of different GeoBlob designs. **Left:** Blobs with different stroke and fill colours, transparencies, and shapes using a figurative overlay. **Right:** Examples of how stacked GeoBlobs using different styles can convey the likeliness a troop was located at a mentioned place.

In Figure 3.57, different visual styles (i.e., transparency, stroke, and blurriness) are used to communicate the likeliness of a unit's position. Each blob geometry is constructed of two stacked shapes, an inner and an outer blob, which each uses these varying styles.

In Figure 3.57 (right), we see one unit (in black) and three units (in orange, green, and purple) located in northern France – indicated by the thick outlines, the inner Blobs. At the given time, it is highly unlikely that the visualised respective units were located in Reading or Rouen. This uncertainty is depicted by the blurry area signature, the outer blob. It is most likely that these places were mentioned in a different context. For instance, *"Sgt. Smith left the unit and returned to Reading"*.

Finally, a short comic-like visualisation (Figure 3.58) depicts how GeoBlobs can be embedded into a short visual narrative by applying aspects of the Flowstory and GeoBlob design spaces.

3.4.1.3 Summary

With the WWI00 Flowstory and the other prototypes, the two aims that were defined at the beginning of the project were met. GeoBlobs represent moving entities on a map over time with uncertain positions. In contrast to the visual certainty conveyed by crisp line or dot visualisations, GeoBlobs leverage the uncertainty in the data to produce an *organic* view of such entities, in this case UK Army units during WWI. GeoBlobs also suffer less

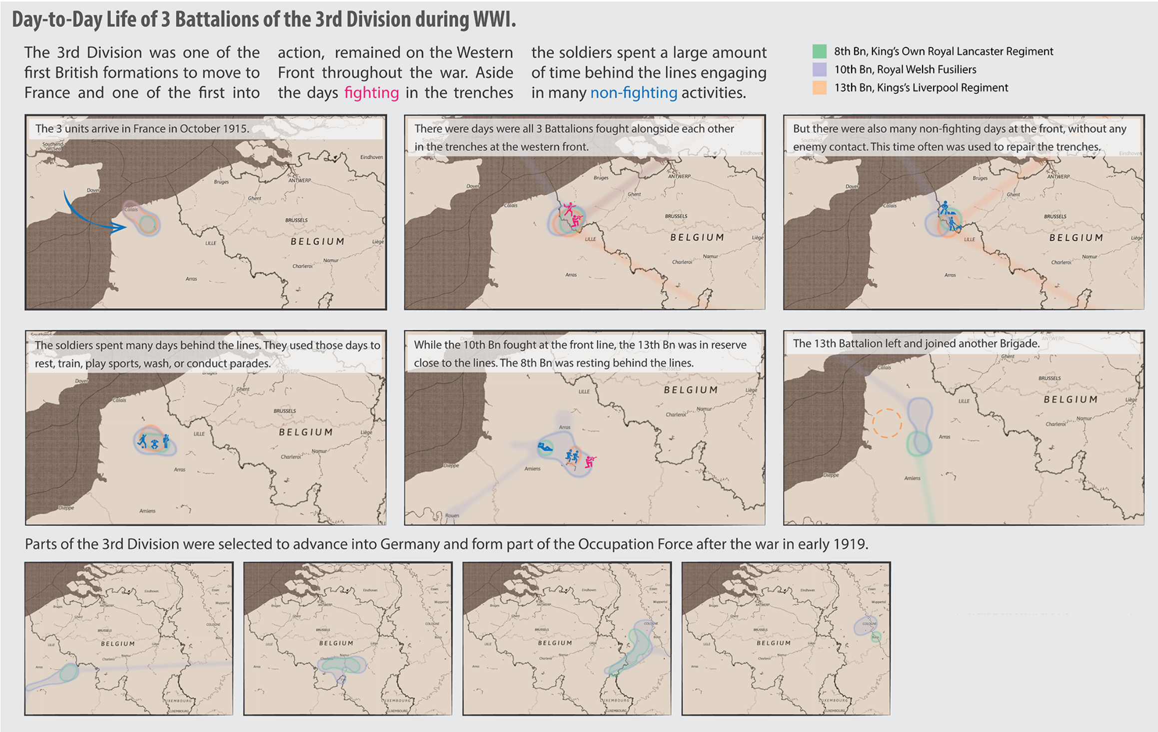


Figure 3.58: The day-to-day life of three battalions of the 3rd Division during WWI.

from scalability issues, while line or dot/glyph visualisations become cluttered when the number of data points is increasing. The derived GeoBlob design space summarises the possible design variations of GeoBlobs. Adding text-based and visual context to the map display and depicting the scanned diary pages helped to support the message about how much time soldiers spent behind the lines.

Nevertheless, **additional narrativisation** in the context of the GeoBlob design space is possible. For instance, additional information from the OWD data or other archival data sources about WWI could be incorporated, which would add more aspects describing *the life behind the trenches*. This could be accomplished with additional map layers (e.g., showing weather information for the given time), and could include vis-media elements (e.g., photographs of activities). Instead of using a historic-looking base map, using an actual historic background map with borders from that time and other war-related information (e.g., trench maps) could help users to put themselves in the situation. Finally, audio was not considered when authoring the WWI00 Flowstory and other prototypes. However, especially in an exhibition context, for example at TNA, voice-over narration or sound collages imitating the soundscape of that time in a camp or at the front, can be powerful tools for narration.

GeoBlobs are well suited to any data set with uncertain locations. An obvious comparison would be with hurricane prediction maps. They too have spatial and temporal uncertainty. One problem they have in common with GeoBlobs with respect to uncertainty is that more uncertain data can lead to much bigger footprints on the map, and users may be confused by the difference between large magnitude events and highly uncertain events. Moreover, the technique can be transferred to domains where the movement data is not uncertain, but has a high density, or the area of coverage is of interest. For example, GeoBlobs are also a promising way of visualising the movement, spatial coverage, the pressure in team sports, as well as visually aggregating the spatio-temporal trajectories of players. All of these are important topics in sports visualisation (Perin et al. (2018)). Due to their configurable visual appearance, we also think GeoBlobs could be used in Data Comics (Bach et al. (2017)).

Another important aspect of research in the context of visual data storytelling aside from authoring and frameworks, is evaluation approaches. The next section provides a discussion on how the design space can be used to derive experimental designs for empirical evaluations.

3.4.2 Evaluation: Deriving Experimental Designs

Measuring the effect of visual data storytelling on people is an essential aspect when researching evaluation approaches. As described in Section 2.2.3, different experimental designs can be used to evaluate the various aspects of visual data storytelling. The design space can also be used to derive experimental designs for investigating the effects of storytelling in the context of flow and movement visualisations.

Using the inside-out and outside-in distinction introduced in Section 2.2.1.6, there are two general approaches to derive different experimental designs regarding the design space. **Inside-out approaches** can be used to investigate the extent to which selected visualisation aspects of the design space can contribute to selected narrative aspects of the design space. For instance, one can investigate whether different flow mark geometries influence messaging and argumentation. Different visual stimuli (i.e., Flowstories) can have varying flow mark geometries (e.g., lines vs. grids), but keep other elements constant. Group differences can be assessed with measures for comprehension and understanding. Studying the effects of the audio elements (e.g., audio-narration, background music, or sound effects) used in Flowstories on implicit user involvement by using scales to assess immersion is another inside-out approach. Or, examining if different ways of displaying flow lines through animation (e.g., flow lines appear all at once or in a staggered way, flow lines fade in as a whole or use tween animation in the direction of movement) affect how participants structure a narrative in terms of time, space, and content when re-telling a story they created in their minds.

Outside-in approaches are more holistic, either starting from the narrative side of the design space or from within the design space and considering aspects across both sides. For instance, a survey can test to what extent a varying narrative structure using different text-based emplotments of a flow or movement visualisation effects memorability and comprehension. For example, using a visualisation of a basic animated particle system, one stimulus follows a classical story arc anthropomorphising the depicted visual symbols. The other stimulus is a technical description of the depicted symbols' behaviour and visual properties. The visual aspects of the stimuli, Flowstories developed within the categories of the design space, are mainly held constant between groups. Questionnaires and repeated tasks asking participants to demonstrate their understanding or to recall what they have seen can be used to assess effects.

Outside-in approaches can further test the effects of different Flowstories that focus on a combination of visual and narrative techniques that are thought to support, enable, or induce narrative structure, messaging, framing, emotions, or user involvement. Such surveys can investigate the effect of such techniques on aspects believed to be influenced by visual data storytelling (e.g., comprehension, engagement, immersion, attitudes; compare Chapter 2.2.3). For instance, a survey design taking this approach can investigate to what extent the use of commonly used visual-narrative techniques that focus on empathy or structure can influence attitudes towards a visualisation topic (i.e., immigration). The survey's stimuli could compare (a) personal visual narratives designed to generate empathy; (b) structured visual narratives of aggregates of people; and (c) an exploratory visualisation without narrative acting as a control condition. Appropriate questionnaires can then assess to what extent the different stimuli influenced attitudes towards the topic.

Both examples have a between-subject design with repeated-measure elements. When assessing understanding in the first study, or attitudes towards a visualisation topic (i.e., immigration) in the second study, a between-subject design is an appropriate approach. Using a within-subject design, where each participant would interact with more than one stimulus (regardless if they are subject to the same or different topics), it would become very hard to isolate possible learning effects (i.e., it is not easy to identify which condition affected a participant's understanding or attitude and to what extent). Furthermore, the suggested measurements to assess memorability and comprehensibility or attitudes, are not based on user perceptions, but rather understanding and opinions about the topic. Participants are explicitly not asked to what degree they feel they were influenced by the visualisation, or any other perception related, self-reporting questions. A within-subject design is beneficial for studies testing more objective measures like the time a task took, how accurately a task was completed, or asking for certain subjective preferences (e.g., Is Flowstory A, B, or C more enjoyable or useful?) or perceptions (e.g., Did a participant felt more engaged or immersed when reading Flowstory A or B?).

It is important to note that the design space does not by itself *recommend* an experimental design. However, its structure of categories helps to select study topics and targets. An appropriate study method and protocol must be selected for each case individually. Creswell and Creswell (2018) provide a good overview of research designs for qualitative, quantitative, and mixed methods approaches.

After the more detailed description of the two studies using the outside-in approach, it is not surprising that I conducted these two experiments as part of this work. While inside-out approaches test how visualisation techniques can be used to foster narrative, outside-in approaches investigate to what extent narrative or visual-narrative techniques applied in visualisation are effective. Both approaches are necessary to advance our field, but I found the latter approach more compelling because I believe it can reveal more about the mechanisms of storytelling as a whole. In Chapter 4, I discuss the *emplotment study*; the *attitudes study* is the subject of Chapter 5. Both chapters present additional examples of Flowstories created based on the design space alongside the experimental stimuli. Before these experiments are discussed, I will summarise the design space project in the concluding discussion of Chapter 3.

3.5 Design Space Discussion

This chapter presented and discussed a design space for Flowstories, visual narratives based on flow and movement information. Embedded in visualisation and narrative theory, the development of the framework showed how these two themes could be brought closer together and examined jointly. Using descriptive, analytical, and generative case studies showed how versatile the framework is. The design space offers a structure within which elements of flow and movement visualisations can be analysed with regard to narrative aspects. Additionally, the design space categories and observations made during the evaluation of the 115 examples can be used to create new Flowstories.

The framework demonstrates the range of possible design variations of Flowstories. Therefore, it is possible that a single data set can lead to different results, or Flowstories can be analysed differently. This flexibility is an advantage of the design space. Two other factors demonstrate the design space's flexibility. On both sides of the design space, the categories can be extended by further factors that go beyond the existing scope (e.g., as demonstrated for uncertainty in the GeoBlob project). Furthermore, the categories were developed in such a way that the framework could be applied across a wide range of disciplines that visualise flow or movement data. While the design space development involved domains with a long tradition in computer science (e.g., scientific visualisation of blood flow) and areas with a comparably recent history (e.g., information visualisation and geovisualisation), the case studies and experiments focused on geographic flow and movement representations in a narrative context. The reasons for this were my interest and expertise in cartography, the need to narrow the scope for evaluation projects, and because maps are a very familiar type of visualisation that are promising to study in a narrative context.

To date, no other framework has brought the two areas of flow and movement visualisation and narrative together. The design space helps to structure thoughts and decisions when working with visualisations that fall within this problem area, be it in an analytical or authoring context. While Flowstories focus on a specific type of information (i.e., flow and movement data), the understanding of narrative (i.e., discourse, story, narrativity), as used in this work, can be transferred to visual data storytelling research in general. Using the concept of narrativity, the degree to which a visualisation is expressed on a discourse level can create a story in a reader's mind. This allows the study of the entire range of flow and movement visualisations whether they *look like a story* or not. Hence, storytelling aspects may not be identified instantly in all visualisations, or may be challenging to integrate during a narrativisation or authoring process, but navigating through the design space step-by-step (i.e., mark-by-mark, element-by-element, and narrative-aspect-by-narrative-aspect) helps to make visual and narrative design decisions. The following observations can be considered when authoring Flowstories.

3.5.1 Observations

The following discussion is based on the observations made during the development of the design space, the categorisation processes of the examples, and the case studies. It will reflect on *the visual*, *the verbal*, and *the interactive*.

3.5.1.1 Reflections on the Visual

Flow and location marks can visually provide structure and temporality. Several geometries, in combination with the use of visual channels, can convey the temporal order of a movement. For instance, this structure is achieved by flow marks with line geometries where a visual channel (e.g., size, colour, motion, orientation) or location marks convey the temporality of events. Point symbols, areas (e.g., GeoBlobs), or grid-based geometries using animation over time are other examples.

Similarly, the layout can be used to provide visual and temporal structure. For example, structure can be provided by panels arranged as small multiples showing different stages or points in time of a movement using non-animated point, line, area/volume, or grid-based geometries. Sankey-like diagrams or other non-geographic layouts where position encodes information (e.g., from left to right, or from top to bottom) provide structure regarding the order and direction of flow and movement.

Aside from these representational aspects, flow and location marks might not be visible all at once, and they might instead be revealed to the audience according to the overall narrative structure and sequence.

This sequence might be chronological, following the events as they happened, but it can also follow a particular thematic order (e.g., showing flows in the order of their magnitude) or another temporal structure. For example, when comparing the current situation of migration with historic migratory events, a narrative jumps back in time. Another scenario one can imagine is GPS tracks showing the entire journey of migratory birds from Africa to Europe, starting the narrative at the end of a movement. Then, in a rewind motion, the geometries quickly move back to the journey's origin to then present the entire journey in more detail, indicating very long stretches and important stops along the way.

Trough this supportive function regarding structure and temporality, flow marks, representing the central subject, also support the overall message of Flowstories.

Multiple flow marks with the same or different geometries displayed simultaneously or consecutively can offer different perspectives on the data and frame a narrative's message. Two different perspectives are, for example, the representation of individual movements or the representation of aggregated data.

In particular, point and line geometries can be used to focus on individual cases. Flowstories that are aiming to communicate personal fates use this technique to demonstrate that there are individuals behind the data.

With an increasing number of data points, there are several possibilities. Depending on the authorial intent, over-plotting individual point and line geometries, and therefore cluttering the display to exaggerate the message, can be a powerful tool for argumentation to convey a message about large volumes or the number of cases. It might be challenging to extract more accurate values from such a display.

Alternatively, the data can be depicted as aggregate, by clustering and bundling multiple flows into a single geometry. Such techniques can convey messages concerning overall trends and high-level patterns. Depending on a Flowstory's narrative intent, the aggregation can be based on space, time, and attributes.

Line geometries, especially when depicted in geographic space, can be misleading. For example, flows with a small magnitude that cover long distances result in lengthy and thin lines. A massive magnitude flow between two close locations results in a short, thick line. Hence, small magnitude movements are visually more salient than larger magnitudes that potentially distort the message. Additionally, a map projection's properties can lead to a skewed representation. Again, depending on the intention of the author, these characteristics can be used deliberately to influence the message.

Grid-based geometries, on the other hand, avoid clutter and do not distort or exaggerate distances. While these geometries are not suitable for showing individual cases, they can show vast numbers of movements in an aggregated form.

Area and volume geometries, depending on the depicted phenomenon, can also show a single entity (e.g., a volcanic ash cloud represented through a volume geometry distributed across the globe) or aggregate the actual movements (e.g., GeoBlobs).

To convey multiple perspectives in one Flowstory, one can either present two geometries at the same time or blend between perspectives using smooth visual transitions. For instance, if individual data points are depicted first, providing a first-person perspective (e.g., a personal migration narrative from Austria to the UK), they can then be morphed into lines representing aggregates that show the overall statistics about people migrating from Austria to the UK (providing a third-person perspective).

Furthermore, spatial and attributive filtering during authoring (or interactively) are techniques that can be used to frame a narrative's message. Information can be deliberately left out to make a particular argument. As discussed in Chapter 6, ethical considerations are important within the context of visual data storytelling.

As discussed previously, different geometries are suitable for different intentions. However, the familiarity of the respective geometries can play a role in the design process. For example, line geometries are much more common than origin-destination matrix or grid-based geometries, which usually require some effort to be understood.

Similarly, familiarity is essential regarding the different levels of abstraction of flow and location marks. Such visual marks with a lower level of abstraction are often more associative and recognisable than highly abstract geometries because they refer thematically to the depicted data. As a result, flow and location marks with a lower level of abstraction better support the overall message, more strongly induce implicit user involvement, and might help to evoke reactions on an emotional level. While mimetic, less abstract marks can convey qualitative information, they rarely encode quantitative information. For example, blending between different levels of abstraction can offer two perspectives, first on qualities, then on quantities. Imagine the following thematic sequence and transition: associatively coloured and shaped icons describe commodities traded between countries, and subsequently those point geometries morph into line geometries communicating the magnitude through line width. Alternatively, pictographic representations (i.e., isotypes) can convey categorical and numerical information simultaneously (Amini et al., 2017). For example, little icons placed along a line connecting origin and destination can be sized, coloured, and oriented with regard to the magnitude, category, and direction of movement.

Location marks often only convey spatial information, which is not surprising since that is precisely their purpose. Nevertheless, point geometries, for example, can utilise isotypes and can also encode qualitative and quantitative information (e.g., the amount of immigration and emigration at a location) supporting the main arguments of a narrative. Similarly, they could encode temporal information, providing temporality and strengthening the message. However, generally, time is more often encoded through vis-media or text elements.

The visual channels encode directional, temporal, qualitative and quantitative information in the Flowstory context. Only by examining the narrative aspects do certain encodings become recognisable. For example, flow marks often implicitly encode relative time. While they do not encode time explicitly, they can implicitly convey the temporality of events. For instance, in *FS_099*, Minard's famous map, the flow mark contains no information about when the troops were at what location, yet the chronological order of the movement is visible.

Flow marks encoding qualitative information can provide different perspectives. For instance, they allow comparison between the migration of two different countries, the spread of two or more diseases, or troops facing each other in combat. Such visual contrasting can support the line of argumentation in the narrative.

Multiple visual channels can also be used to encode information more than once. For instance, the direction of movement can be encoded through a combination of the motion, orientation, and size of a flow mark. Multi-encoding introduces redundancy and repetition, which is beneficial for communicating a central message.

One observation is that motion, or animated flow and location marks, plays an essential role in being able to emphasise many of the narrative aspects. Animation does not just provide visual structure and temporality of events, but also frames the central message regarding the fact that the depicted information is actual movement data. Furthermore, animation tends to draw attention, contributing to Flowstories' immersion-inducing capabilities. Additionally, as shown in the GeoBlob design space, motion can be used to include or repeat context (e.g., shaking blobs to convey combat action).

Colour is also frequently used to encode information. Associative colouring and styles can set the overall tone according to the narrative's content. For instance, base map styles can correspond to the time and geographies of the story time and space.

Vis-media elements are often powerful framing devices, especially images and videos. Additional charts can also influence the overall tone, emphasise a particular perspective, and aid in the interpretation of the conveyed message. Vis-media elements mostly provide context contributing across all narrative aspects. Nevertheless, a majority of the provided context happens through verbal elements in Flowstories.

3.5.1.2 Reflections on the Verbal

Although the visual elements convey and support a narrative's message, in most examples, the central message is explicitly presented in a verbal form, including text elements and voice-over narrations in the context of Flowstories. Text and audio elements contain spatial, temporal, qualitative, quantitative, and contextual information thematically and temporally arranged into a narrative sequence or plot. Longer, continuous text elements often provide the overall narrative structure and message, including contextual information and shorter text elements (e.g., annotations, labels, pop-ups) which tend to convey flow- or movement-specific information (e.g., direction, qualities, or quantities).

While text elements are also perceived visually, audio elements provide an additional perceptual channel to convey information. Moving information to this channel might help to declutter the visual display, allowing emphasis of the critical visual elements with regard to the narration. Furthermore, audio elements, including music, have a strong potential to immerse users in a Flowstory while keeping their attention high. Imagine watching a horror film with muted audio; it would not be particularly scary or thrilling. At the same time, one must consider that voice-over narration is often so salient that it strongly suggests a particular perspective towards a topic. Depending on an author's intent, this may or may not be desirable.

3.5.1.3 Reflections on the Interactive

Interactions linked to flow and location marks are a simple way to engage users and get them actively involved. Often, while flow marks convey overall trends and patterns, interaction (e.g., hovering over a flow mark) can provide further details. In many examples, the overall progression is coupled to global interactions (e.g., scrolling). Though no example provided this, one can imagine a Flowstory where local interactions with flow or location marks dictate the overall progression with respect to how a user navigates through the data and narrative space. This structure could be referred to as a scavenger hunt Flowstory. Coupled with specific tasks, this is an example of how explicit user involvement can lead to implicit user involvement.

3.5.1.4 Modes of Integration

Different modes of integration tend to aid different narrative aspects. Coupled information conveys or emphasises the major arguments describing the properties of the depicted flow or movement. When superimposed, information in vis-media or text elements can be easily perceived together with the primary information regarding the described flow or movement. When juxtaposed, the link between them is not always apparent on first sight.

From a narrative perspective, uncoupled content can be helpful to extend the narrative space and time, and to realise flashbacks or fast-forwards. Uncoupled content is mainly presented in a juxtaposed way. As discussed previously, information integrated in an uncoupled superimposed way is rarely used. Such elements can unnecessarily clutter the main display. In particular, with uncoupled context, contextual information that is overall unrelated to the flow and movement is placed juxtaposed to the central display. Nevertheless, interaction combined with superposition to integrate such information can be beneficial to provide causal arguments.

The possibilities offered by different audio integration modes to support narrative aspects are not exhausted in the 30 categorised examples. While most voice-over narrations are globally superimposed (i.e., they are played back in parallel to the displayed events), providing coupled and uncoupled content, there are no locally integrated audio elements linked to visual elements in the display. For example, one can imagine a short voice-over narration that provides some information when clicking on a flow or location mark (i.e., detail on-demand using audio elements).

3.5.2 Alternatives and Limitations

As demonstrated in Section 3.1, developing the design space categories was an iterative process. Categories were merged, added, or removed until the current version was developed. This was done to keep the design space manageable and because categories sometimes introduced redundant information.

A category that was kept for a long time, but was removed in the final iteration, is a flow mark's *dimension*. This category spans from 0D to 4D. The dimensionality does not refer to the screen space used, but to the flow mark's symbolisation, including space and time. Although matrix approaches have a grid geometry, flows are encoded as zero-dimensional (*0D*) in a single cell. *1D* may be a flow line connecting an origin and a destination or animated point symbols between them. Consequently, a trajectory, like a GPS (Global Positioning System) track visualised as a path line, is *2D*, conveying space over time. Similarly, *3D* and *4D* refer to areas and volumes over time. Although this category links nicely to narrative aspects, it was removed, because the combination of two categories already conveys this information. It is based on the geometry type and whether the direction is encoded by motion.

The strengths of the design space are its flexibility regarding applicability across domains and its extensibility. Nevertheless, there are limitations to the design space. While it is easy to determine which type of geometry is used to depict a movement, it is not always apparent on first sight if, for example, a background map is a location mark or a vis-media element. The categorisation often depends on the base map itself, or on whether additional location marks are provided. Another example that might be tricky is the integration mode of legends. While they are coupled in general, helping to interpret the message, they can turn into uncoupled elements conveying an additional perspective, or contextual information (e.g., the colour ramp in *FS_014* being extended to demonstrate CO_2 levels before the industrial revolution).

Of course, depending on the purpose of a visualisation, a narrative context is not necessarily required. On the contrary, this case is more of a rarity and might apply in a museum or entertainment context. As was shown previously in the *narrativisation opportunities* in the case study of Minard's map, narrative aspects can also be integrated into visualisations that are not perceived as narrative (i.e., visualisations with low narrativity). Overall, trying to consider narrative aspects in a non-narrative context can help the visual communication process, which prompts the question addressed in the discussion in Chapter 6, about whether narrative visualisations are just well-designed data visualisations.

3.5.3 Conclusion

Any design considerations for Flowstories, as presented by the Flowstory design space, must be made with regard to the data, requirements, audience, and authorial intent. Is a Flowstory designed to inform, entertain, or persuade? While considerations regarding flow and location marks are specific to Flowstories, reflections regarding vis-media, text, and audio elements also apply to visual data storytelling in general. The Flowstory design space can be used as an analytical and generative tool. For the creation of new Flowstories or the narrativisation of existing visualisations, the design space provides a framework of design variations on which an author's design considerations can be based.

The considerations made in the design space are based on observations, existing work, theory, and experience. These circumstances, combined with the fact that visual data storytelling is an under-researched area in general, merit empirical evaluations, which motivated the two experiments conducted in the following Chapters 4 and 5.

Both experimental surveys (Chapters 4 and 5) revolve around the narrative aspects of structure and temporality, as well as emotions. The design space analysis showed that many elements of Flowstories support or contribute to structure and temporality. Aspects of this category (e.g., temporal and thematic order, reading order, navigation, and progression) often lead to high narrativity. While different plot structures are used in the first experimental study, the second experiment uses visual-narrative techniques that provide visual, temporal, and thematic structure. On the other hand, the design space analysis showed that there are not many visual marks or elements that contribute to the emotion category in an above average way. This gap in the design space motivated me to explore empathy-inducing techniques in both studies. For example, anthropomorphisation, which might elicit connections on an emotional level, is used in both surveys. In the first survey, anthropomorphisation is implemented through text and the content of the Flowstory. The second study uses visual and verbal means to achieve empathy.

Chapter 4

Emplotment: Evaluating its Effect on Memorability and Comprehensibility

The first empirical research project, a mixed-methods, between-subjects experiment consisting of two parts (primary and follow-up iteration), addresses the third objective formulated at the onset of this work. The experiment investigates to what extent different text-based emplotments of a visualisation affect participants' ability to memorise, understand, and recall gathered information for making predictions. The chapter contains a motivational statement, a description of the different stimulus designs, a discussion of the experimental conditions and procedures, and an analysis and discussion of the results. Preliminary results of this project were presented as a poster at IEEE VIS 2016 (Liem et al., 2016).

4.1 Motivation

Narrative forms and storytelling have long been used to communicate various aspects of people's lives, helping to understand and remember events and the relationships between them (Badawood and Wood, 2014; Figueiras, 2014b; Kosara and Mackinlay, 2013). Understanding and remembering are two closely linked elements in the narrative process of creating a story in one's mind (Herman et al., 2010). Hence, it is believed that storytelling in visualisation can also be beneficial for comprehension and memorability (Kosara and Mackinlay, 2013; Ma et al., 2012). As discussed in Section 2.2.3, few empirical evaluations investigate whether these benefits also apply to visual data storytelling. This gap in research motivated this study.

In the Flowstory design space, the narrative structure is an essential element in the design of narrative visualisations. One option for introducing a narrative structure into a visualisation is through emplotment. Emplotment is the arrangement of events into a plot, a sequence of events reflecting the temporal and causal structure of the narrative (Herman et al., 2010).

In the survey stimuli, text elements are used to create narrativisation through emplotment (see Section 3.2). The emplotment is not achieved with visual elements. Depending on the author's intent and the visual narrative's message, many possible emplotments of the same visualisation are imaginable and may vary widely. For instance, emplotments can be for or against a specific argument, be factual or fictitious, or use a more descriptive narrating style. This results in different degrees of narrativity, which is the degree to which storytelling techniques, implemented on a discourse level, can evoke a story in a reader's mind.

These possibilities raise the question of whether emplotments with different degrees of narrativity can have different effects on people in regards to the expected benefits of storytelling (i.e., being more comprehensive and memorable). Specifically, this study examines to what extent different emplotments with different degrees of narrativity influence a user's ability to comprehend, memorise, and recall acquired understanding at a later time (i.e., predict the outcome of given problems based on the gathered knowledge about depicted movements and their characteristics). This approach helps to evaluate aspects of the Flowstory design space. For example, it can reveal to what extent flow marks with a narrative emplotment vs. flow marks with a technical connotation can influence the communication process.

An online, crowdsourced, between-subject survey with two independent conditions and two iterations (i.e., a primary and a follow-up run) was conducted. The two conditions were based on two different visual-narrative designs (Section 4.2.2). The **plot** and the **non-plot** design use two different text-based emplotments, creating different degrees of narrativity. While the plot design is a fictional, tale-like narrative (high narrativity), the non-plot design is a more technical description (low narrativity) of the depicted particle animation.

Questionnaires and tasks were designed to measure the effect of the two different emplotments on memorability and comprehension (Section 4.3.2). The two iterations were conducted two weeks apart to ensure enough time had passed to evaluate the effect of each condition on participants' long-term memory. By using this survey design, one can assess to what extent visual data storytelling approaches can leave long-lasting impressions, which plays an important role in this context.

Based on the narrative form using emplotment, it was expected that participants exposed to the tale-like emplotment would better process, understand, memorise, and recall the conveyed information. Therefore, they would perform considerably better in the memorability and comprehension tasks they were asked to do, demonstrating how narrative can be beneficial in the visual communication process.

4.2 Experiment Rationale and Materials

For testing whether different emplotments affect understanding and memorability, two different visual-narrative designs (plot and non-plot) using an animated particle visualisation were developed. Additionally, similar visual designs were produced to be used in the testing phase of the experiment.

Next, the selection of the visualisation type is explained, the two visual-narrative designs for the initial stimulus are compared, the testing designs are introduced, and the technical details of the implementation are addressed.

4.2.1 Selection of the Visualisation Type

In both conditions (plot and non-plot), participants were asked to watch a simulated, animated visualisation of a particle system. The two different designs, introduced in the next section, use the same animation and are almost visually identical, but they have different text-based emplotments.

Following Shiffman et al. (2012), a particle system is a *"common and useful technique in computer graphics"* which *"have been used in countless video games, animations, digital art pieces, and installations to model various irregular types of natural phenomena, such as fire, smoke, waterfalls, fog, grass, bubbles, and so on"*. Shiffman et al. defined a particle system as a *"collection of independent objects, often represented by a simple shape or dot"*.

Each particle has a position, velocity, mass, and force. Forces are based on defined attraction, repulsion, or spring interactions between particles. All these factors are used to update all particles' locations in a simulation loop running at a given frame rate. Particles are emitted and added to the system. They have a certain lifespan, after which they are removed from the system.

Systems can be used to model specific particle behaviours and interactions between particles to simulate real world phenomena. For instance, the simulation adopted for the implementation of the stimuli (Section 4.2.4) was initially developed to simulate pedestrian movement patterns. Each iteration of a particle simulation can be visualised, creating a particle animation over time, using visual marks and channels (e.g., colour, shape, size) to illustrate particles' properties.

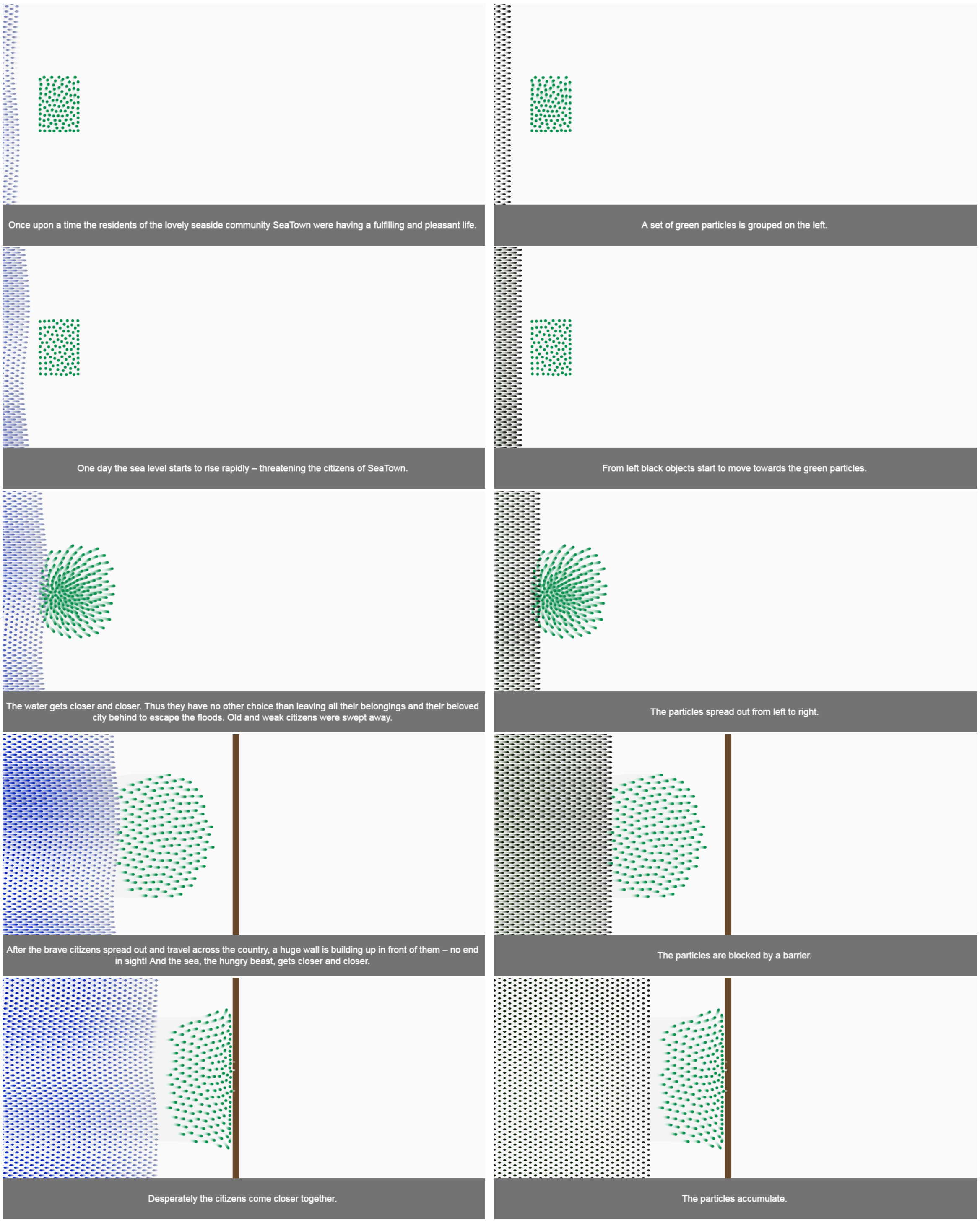
Particles are a compelling way to abstract and simplify complex phenomena and relationships, aiding the visual storytelling process. A simple point geometry together with its visual behaviour can convey spatial, temporal, qualitative, quantitative and contextual information providing visual-narrative structure and perspective as well as supporting a narrative's message and argument. As explained next, these abilities were utilised to create Flowstories to be used as survey stimuli.

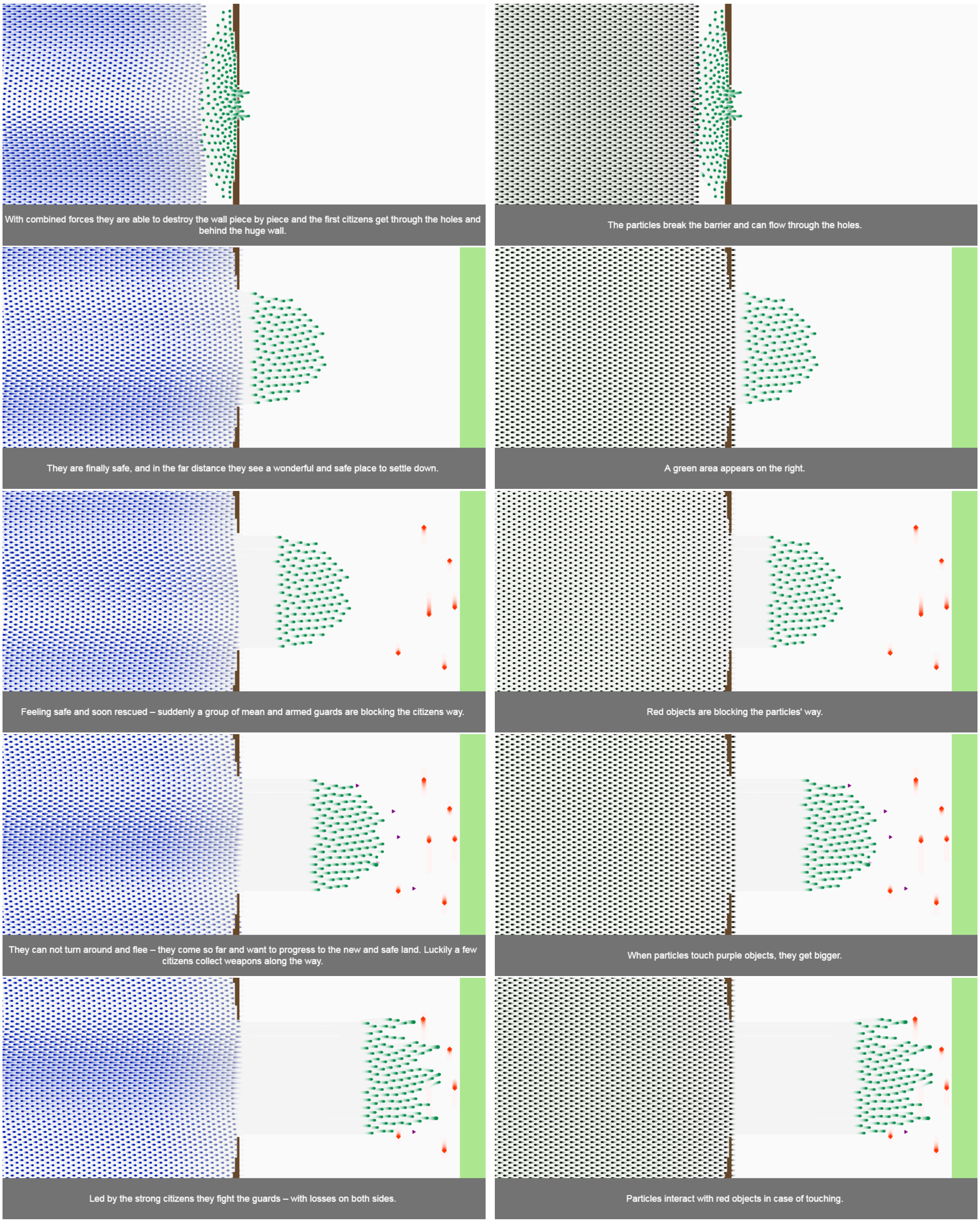
4.2.2 Visual-Narrative Designs: Plot vs Non-Plot

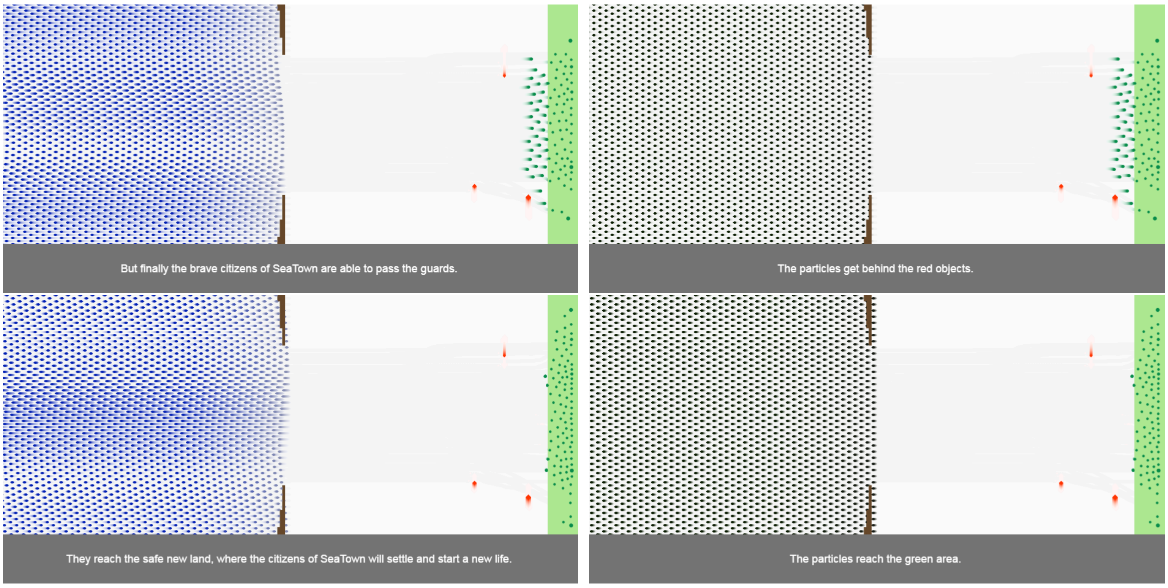
The comparison of the plot and the non-plot design starts with both synopses summarising each text-based emplotment. The storyboards below show several time steps of the animation comparing the plot and the non-plot designs side by side. The text inserts are placed below the animated visualisation and appear sequentially as the animation evolves.

Synopsis Plot:
Citizens of a seaside town have to flee the rising sea. Before their city floods entirely, they leave. A big wall is blocking them on their way, and the sea is coming closer and closer. Working together, citizens can break through the wall. Mean guards are preventing them from reaching a safe new land. Unlucky citizens are killed – only strong citizens, who collected weapons along the way, can fight the guards. Finally, the citizens reach the safe land and can start a new life.

Synopsis Non-Plot:
A set of particles moves from left to right. From the left, a set of regularly distributed dark objects follows. Particles are then blocked by a barrier, which vanishes where particles accumulate. Red objects block the particles' way and can remove particles if they touch them. Only particles that touched purple objects in advance can remove red objects if they touch. The animation ends when the particles arrive at the green area.


Once upon a time the residents of the lovely seaside community SeaTown were having a fulfilling and pleasant life.
A set of green particles is grouped on the left.
One day the sea level starts to rise rapidly – threatening the citizens of SeaTown.
From left black objects start to move towards the green particles.
The water gets closer and closer. Thus they have no other choice than leaving all their belongings and their beloved city behind to escape the floods. Old and weak citizens were swept away.
The particles spread out from left to right.
After the brave citizens spread out and travel across the country, a huge wall is building up in front of them – no end in sight! And the sea, the hungry beast, gets closer and closer.
The particles are blocked by a barrier.
Desperately the citizens come closer together.
The particles accumulate.


With combined forces they are able to destroy the wall piece by piece and the first citizens get through the holes and behind the huge wall.
The particles break the barrier and can flow through the holes.
They are finally safe, and in the far distance they see a wonderful and safe place to settle down.
A green area appears on the right.
Feeling safe and soon rescued – suddenly a group of mean and armed guards are blocking the citizens way.
Red objects are blocking the particles' way.
They can not turn around and flee – they come so far and want to progress to the new and safe land. Luckily a few citizens collect weapons along the way.
When particles touch purple objects, they get bigger.
Led by the strong citizens they fight the guards – with losses on both sides.
Particles interact with red objects in case of touching.



The particles and other visual elements depicted in both visual narratives represent the *actors* and *objects* of the narrative. They are placed on the stage, the discourse space, the rectangular canvas where the narrative visually unfolds. Instead of a complex media piece, a simple particle system together with the coupled juxtaposed text elements (min message) can tell the story of the fates of many people forced to leave their home using a simple visual style and language. While it might be the case, that this oversimplifies such a situation in real life, the Flowstory provides an abstract perspective that is easy to understand.

The actors and objects are characterized differently in the particle simulation system. Depending on the design, the actors and objects have different names (name in plot design [name in non-plot design]). The movement of **citizens [green particles]** are driven by forces determining their direction and velocity. There are normal citizens [normal particles] and strong citizens [big particles]. The **sea [black objects]** move(s) horizontally from a given start to a given end. Along the y-axis, only the sea, not the black objects, form a wave. Along the x-axis, the sea and the black objects have an oscillating movement. The sea [black objects] consists of a grid of particles. **Walls [barriers]** are static, brown, rectangular objects. **Guards [red objects]** are diamond-shaped particles oscillating vertically around a given point by a given amplitude. **Weapons [purple objects]** are static and triangular shaped particles. The **safe land [green area]** is the destination for the citizens [green particles].

All the described actors and objects can interact with each other or show certain behaviours, modelled by attaching forces to or between particles. Citizens [green particles] move, if not blocked, from left to right in an horizontal manner, implemented with a basic directed force. Citizens [green particles] try to flee or escape from the sea [black objects (repulsion). When the sea [black objects] touches/captures citizens [green particles], they drown and die [are removed]. Walls [barriers] block citizens [green particles]. But citizens [green particles] can destroy [remove] a wall [barrier] when working together [accumulating]. When normal citizens [normal particles] touch a weapon [purple object], a normal citizen [normal particle] turns into a strong one. The weapon [purple object] then disappears. Normal citizens [normal particles], with just a moderate repulsion between them, try to stay together. Strong citizens [big particles], having a strong repulsion, try to split up. Normal Citizens [normal particles] tend to follow strong citizens [are attracted by big particles] when close enough. Normal citizens [normal particles] avoid guards [red objects]. Guards [red objects] try to fight and kill [remove] citizens [green particles] when close to each other. This is implemented by adding repulsion and attraction forces. Strong citizens [big particles] fight and kill guards [remove red objects]. Guards [red objects] are not afraid to fight strong citizens [not repulsed by big particles].

All these visual characteristics and behaviours are identical in both designs. The only exception is the sea (plot), or black objects (non-plot), respectively. Their visual designs are slightly differed to visually reinforce the wave movements of the sea in the plot design. Nevertheless, an overall equal visual saliency is maintained between the two design.

While the visual information and complexity are consistent across both designs, the text-based emplotments, as shown with the synopses at the beginning, have a different degree of narrativity. While the plot version has a tale-like emplotment of the visualisation, the text of the non-plot version is a technical sounding description of the animation.

The narration of the plot version follows a traditional narrative arc as originally defined by Gustav Freytag and described, amongst many others, by Yorke (2013). Classical narratives usually have a beginning, middle, and end. Freytag's triangle or pyramid describing this arc consists of five parts: exposition, rising action, climax, falling action, and resolution. The colours correspond with the respective parts paraphrased in the synopsis of the plot version above. Furthermore, the narrative uses an archetypal plot structure defined as *the quest* by Booker (2004). In such narratives, motivated by some form of call or problem (rising sea level), a hero and companions (the citizens) set out on a journey aiming to find a solution (a safe place to live). Along the way, they encounter problems and obstacles (walls and guards), overcome them (fighting the guards with weapons), and finally solve their initial problem (reach the safe land and settle). Because *the quest* is such a recognisable, classical narrative arc, these concepts were applied when creating the plot versions.

Through this tale-like emplotment, the depicted particles are anthropomorphised (i.e., the particles represent humans and their behaviour), fostering connections to the citizens' fate on an emotional level. All these features and design considerations regarding the narrative structure and emotional involvement ensure a high degree of narrativity in the plot version, which helps the audience to immerse into the narration and which is expected to aid narrative understanding and memorability.

The description in the non-plot version avoids any emotional connotations and does not integrate narrative structure deliberately. Nevertheless, the sequence of events in the description, reflecting the order of the depicted events, provides some structure. By avoiding techniques used by the plot version, the non-plot version has a low degree of narrativity.

Both Flowstories are fictitious scenarios and were developed for the study. The animations have an abstract and clean style. The stage was deliberately not overloaded with additional elements that could provide visual context (e.g., geographic context), distract, or influence the participants' thoughts. The abstract space was not further specified. The fictitious nature of the stimuli was crucial in ensuring that none of the participants were familiar with the information presented. The animated particle system simulates movements that are easy to understand and can convey some meaning supporting the message (e.g., accumulating particles portraying a collaborative crowd).

When reflecting on the design space categories, the animated particles are the flow marks using a point geometry. The direction of movement is indicated through motion. Overall, the motion in both Flowstories frames the message and provides strong visual-narrative structure and temporality (moving the story forward). The level of abstraction of the particles is different between the two designs. While it is geometric for the non-plot design, it is intermediate for the plot design because the emplotment adds more profound meaning to the symbols (i.e., anthropomorphisation), aiming to evoke an emotional reaction. Colour and shape are used to encode qualitative information (e.g., citizens [green particles], guards [red objects]). Quantities are encoded through the density or number of citizens [green particles]. The sea and the black objects, respectively, are an additional flow mark. The imaginary emitter area at the beginning (the citizens' land), the walls [barriers], and the safe land [green area] are very abstract area location marks. Again, these elements convey more meaning in the plot version than in the non-plot version. While the coupled juxtaposed text conveys the main message, the visual elements provide visual structure supporting the message (coupled).

The plot and the non-plot designs were used as primary stimuli at the start of the survey in the *observation phase* (see Section 4.3.4).

4.2.3 Visual Test Designs

Compared to the two visual-narrative designs, which were used as initial stimuli, there were five designs used in the testing phase of the experiment. While they use the same visual design and have the same actors and objects, they lack any textual emplotment. When used in the test phase, only the wording of the questions reflect back to the narrative or description conveyed in the introductory designs.

The five designs (Figure 4.1), whose names are derived from the shape or placement of walls or barriers on the stage, are: **tetris design**, **arrows design**, **finish line design**, **harbour design**, and **horse race design.** The names of the designs are only used here, they were not used in the survey. While the first three designs were developed for the main iteration of the experiment, the latter two were designed for the control run. The different designs demonstrate the subjective character of visual data storytelling. While all designs follow a certain rationale (see below) numerous other designs are possible, which shows the creative freedom visualisation authors have.

Each design belongs to one of three levels of complexity. While all designs included the citizens [green particles], the sea [black objects], the safe land [green area], and walls [barriers], the guards [red objects] were added in level-2 designs and weapons [purple objects] were added only in level-3 designs.

A higher level of complexity means there were more elements on the stage, making considerations in the tasks more complex. However, the exact differences of complexity cannot be quantified between the designs since the placement of the wall [barrier], guards [red objects], and weapons [purple objects] were different in each design. The five designs were different in order to test whether the participants could apply what they learned about the actors' and objects' characteristics in new, changing scenarios. The behaviour of the actors and objects is always the same, only the arrangements of the walls, guards, and weapons varied.

The **tetris design** is the only level-1 design (Figure 4.1 top). The citizens [green particles] and the sea [black objects] behaved exactly the same as in the introductory stimuli. However, instead of one large wall [barrier], there were several different walls [barriers] with

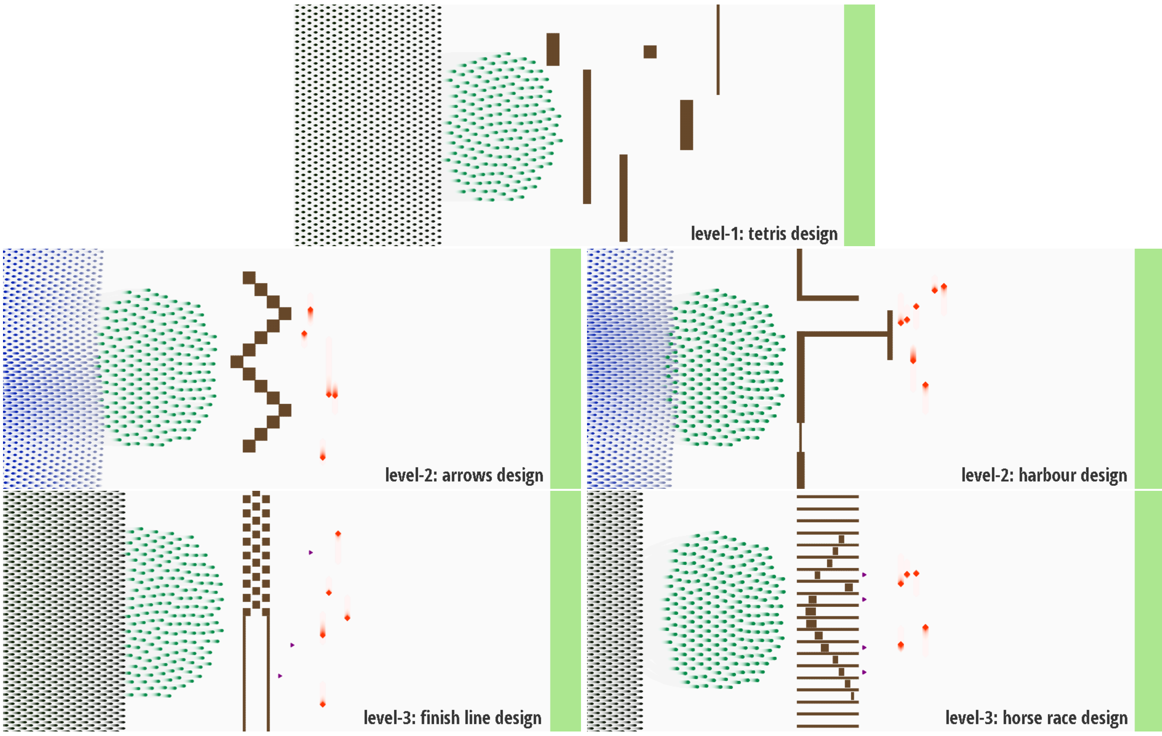


Figure 4.1: Five **visual designs** for the testing phase of the experiment. The examples alternate between the non-plot and plot version, indicated by the black objects or the sea, respectively. ***Top:*** Level-1 design (tetris) with walls [barriers] only. ***Middle:*** Level-2 designs (arrows, harbour) with walls [barriers] and guards [red objects]. ***Bottom:*** Level-3 designs (finish line, horse race) with walls [barriers], guards [red objects], and weapons [purple objects].

varying length and thickness. Citizens [green particles] tended to go around the walls [barriers], but easily broke through thin walls [barriers].

For the level-2 designs, in addition to the walls [barriers], guards [red objects] were added to the scenarios (Figure 4.1 middle). In the **arrows design**, citizens [green particles] advanced quicker when destroying the arrow-shaped wall [barrier] at the thin corner points of the little blocks than taking the detour around the edges on the top or the bottom. This is because citizens quickly accumulated in the funnel shape of the arrows increasing the force on the wall [barrier] elements, which is quicker than moving far up or down. Five guards [red objects] were in the way, however, there was a gap in the lower third and at the very top of the stage. Notice, that some "shadow streak" indicated the section a guard [red object] roughly covered. In the **harbour design**, there was a gap in the wall [barrier] in the upper half. However, seven guards [red objects] were placed behind the gap. The lower half of the wall [barrier] has a very thin section; there were no guards [red objects] placed behind this part. Because of the guards, the majority of the citizens [green particles] could advance on the lower half, the quickest citizen [green particle], though, advanced in the top area (see Section 4.3.4).

In level-3, there were weapons [purple objects] added to the stage (Figure 4.1 bottom). In the **finish line design**, the wall was divided into two parts. In the upper part, three columns of offset, but free-standing, blocks formed the wall [barrier]. The lower part consisted of two, thin-wall [barrier] elements. Five guards [red objects] were placed regularly across the vertical axis. However, there was a gap in the lower half. Three weapons [purple objects] were located in front of the guards [red objects]. The lower two were closer to the gap between the guards [red objects]. The particles advanced equally across the stage. In the **horse race design**, the walls [barriers] formed small tunnels that were blocked with elements of varying thickness. When blocked by those, citizens [green particles] tended to break through the horizontal elements. Four weapons [purple objects], grouped into pairs of two where the weapons in each pair were closer to each other than to the other pair, were located directly after four tunnel exits. The weapons were always placed in front of a cluster of guards [red objects]. The upper cluster consisted of three guards [red objects], the lower cluster only had two guards.

These descriptions reflect what participants have to consider for solving the tasks they are asked to do. How and why these designs are used in the testing phase is explained in the following Section 4.3.

4.2.4 Implementation

The **particle simulation system** was implemented in JavaScript ES 6.0 (JS) and was based on a project implemented in Java, which was initially developed to simulate pedestrian movement patterns (Duckham et al., 2016). The original Java code was written by Prof. Jo Wood (my first PhD supervisor). As explained earlier, the behaviours and interactions between actors and objects were modelled using various forces like attraction, repulsion, or springs.

The **visualisation of the simulation** used p5js[1], the JS version of Processing[2]. Due to a large number of particles, the visualisation of the different simulations did not run with a constant and high enough frame rate. Even on a modern, powerful PC (8GB memory and 2GB graphic memory), the visualisation slowed down considerably as the number of particles on the stage increased. As a solution, image sequences were rendered at a low

[1]http://p5js.org/
[2]https://processing.org/

frame rate in the Opera[3] web browser and exported to the local file system. Subsequently, the image sequences were converted to a browser-compatible video using FFmpeg[4].

Using the stimuli described above in various phases and tasks, the browser-based study (introduced in more detail in the next section) was implemented with the online survey software Qualtric[5].

4.3 Studying the Effects of Emplotment on Memorability and Comprehensibility

In order to study the effect of visualisations with different emplotments on memorability and comprehensibility, a crowdsourced, mixed-methods, between-subject experiment with two conditions consisting of two parts (primary and follow-up iteration) was designed and conducted. Amazon Mechanical Turk (MTurk or AMT) was used to recruit and financially compensate 300 participants in total (150 for each condition).

The developed tasks and questionnaires are both quantitative and qualitative. They attempt to capture a holistic picture of participants' thought processes, including to what extent participants are able to understand, remember, and reuse gathered information.

A between-subject design was used because the experiment compares two different designs regarding two aspects (memorability and comprehension), which are believed to be explicitly influenced by each design differently. If participants were exposed to both designs, as they would be in a within-subject experiment, isolating the extent to which a single design influenced how a participant remembered and understood certain aspects of each visualisation would not be possible. Nevertheless, several successive tasks are used as repeated measures. Additionally, in the follow-up iteration, selected tasks from the first run were repeated. The purpose of the follow-up run was to assess the memorability of the different emplotments over an extended period of time.

Before explaining the different tasks, the two experimental conditions are introduced and compared.

[3] https://www.opera.com/
[4] https://ffmpeg.org/
[5] https://www.qualtrics.com/

4.3.1 Experimental Conditions

The two conditions, based on the plot and non-plot designs presented in Section 4.2, are aptly named **plot condition** and **non-plot condition**.

As mentioned above, the two designs vary only in their text-based emplotment; the timing, order of stimuli, questionnaires, and tasks are identical for each condition. Because of the different emplotments, the terminology is also different between the conditions. However, each conditions' terminology is used consistently throughout all phases of the experiment. For example, if in the plot version a particle represents a *citizen* in the observation phase, it is also called a *citizen* (not a particle) in the subsequent testing phase and vice versa.

This applies to both the primary and follow-up iterations of the experiment. Next, the questions and tasks developed for the testing phase of the experiment are discussed.

4.3.2 Questionnaire and Task Design

The questionnaires and tasks used in the primary run targeted the immediate memorability and comprehensibility of the two visual narratives with varying emplotments. The follow-up iteration, occurring ten days later, tested memorability and recall accuracy over time.

The memorability tasks, where participants demonstrate if they can remember what they have seen in a stimulus, involved short-term memory. The comprehensibility tasks, where participants demonstrate their understanding of what they have been exposed to, involved working memory. As defined within the realm of Psychology, short-term memory is the process of keeping information temporarily, whereas working memory is the process of mentally manipulating this information (Diamond, 2013). Long-term memory was involved when assessing the memorability of the visual narratives in the follow-up iteration.

Before discussing the participants and the detailed procedure, the tasks and questionnaires targeting memorability and comprehensibility are introduced and a spatial reasoning task is explained.

4.3.2.1 Tasks and Questionnaires targeting Memorability

Quantitative task measurements such as time, accuracy, and precision are suitable when testing specific aspects of visualisations and were already used to assess memorability and recall (Borkin et al., 2013, 2016). However, such quantitative measures alone are not enough when testing the effect of storytelling on people, oversimplifying its complexity. Testing how quick and accurate a memorability task was executed is not a meaningful measure in the context of visual data storytelling; it does not reveal a users' narrative comprehension.

Bateman et al. (2010) used a mix of qualitative and quantitative measures to assess the effect of "chart junk" on memorability and comprehension. This survey also used a combination of qualitative and quantitative questions and tasks, where responses demonstrated to what extent participants remembered and understood the communicated information.

The tasks and questionnaires included questions about **(1)** the different particles' shape and colour, **(3)** the number of citizens [particles] that reached certain areas or were killed [removed], and **(4)** the timing of individual events that happened during the simulation. Furthermore, participants had to interactively indicate the maximum vertical extent of the citizens [particles] during the animation **(2)**. Participants were also asked to provide a story summary **(5)**.

(1) Colour and Shape Questions
The first set of questions concerning the colours and shapes of the different actors and objects tested the short-term memory or the visualisations' immediate memorability and how well participants were paying attention.

For the following six questions, participants were asked to select the correct answer from five available options (the correct answer is in parenthesis):

- What shape do citizens [particles] have? (circle)
- What colour do citizens [particles] have? (green)
- What colour do walls [barriers] have? (brown)
- What shape does the sea particle [do dark objects] have? (circle)
- What shape do guards [red objects] have? (diamond)
- What shape do weapons [purple objects] have? (triangle)

(2) Maximum Vertical Extent Task
In this task, participants were asked to indicate the maximal vertical extent of the path the citizens [particles] took in the simulation of the initial stimulus (i.e., the narrative-visual

designs introduced in Section 4.2.2). Participants had to indicate the upper and lower bounds of the particles by using two sliders with handles distributed across the stage. The handles could only be moved vertically and could not cross each other (Figure 4.2).

The purpose of this task was to test whether participants remembered the overall shape or distribution of the particle cloud, especially if they indicated the accumulation in front of the wall [barrier]. This helps to assess to what extent participants can to indicate visually salient flow properties of the depicted movement.

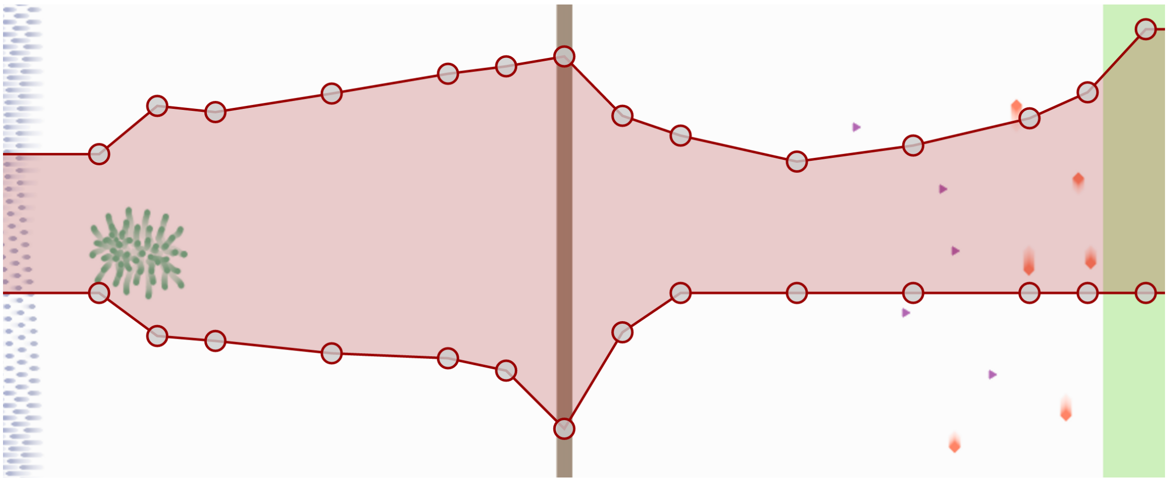


Figure 4.2: Vertical maximum extent task: Indicating the maximum vertical extent of the citizens [particles] by dragging and dropping the handles vertically.

(3) Quantity Estimation Task

In this task, participants were asked to answer the following questions about the number of citizens [particles] that reached a particular area or were killed [removed] during the animation they saw during the observation phase:

- How many (%) of the 200 citizens [particles] reached the safe land [green area]?
- If any, how many (%) of the 200 citizens [particles] were killed [removed] by the sea [black objects]?
- If any, how many (%) of the 200 citizens [particles] were killed [removed] by guards [red objects]?

Participants had to estimate what percent of citizens [particles] survived [were visible] or were killed [removed] during the animation using sliders that ranged from zero to 100%. In order to test whether the conditions affect quantifiability, it was not pointed out that the sum of all three inputs should be 100%.

The purpose of this task was to evaluate participants' ability to remember, recall, and quantify the development of the flow magnitude (the number of citizens encoded by dot density) over time. In flow and movement visualisations, hence also in Flowstories, magnitude is a central aspect. The amount of flow, the number of entities moving, often is the main topic of the (narrative) message (e.g., number of goods, number of people).

(4) Temporality of Events Task

In this task, participants were asked to answer the following questions about the timing of events that happened during the animation:

- When did the citizens [particles] break through the wall?
- When did guards [red objects] appear?
- When did weapons [purple objects] appear?

By using slider that ranged from zero to 100%, participants indicated whether they believed the events happened towards the beginning, the middle, or the end of the simulation. The purpose behind this task was to assess whether participants could remember in which order the events listed above occurred. How accurately participants placed each event in time was less important, nevertheless interesting since the events were deliberately placed in space and time regarding the classical narrative arc. For example, the break through the wall, was not only spatially but also temporally at the half-way point, the climax stage of the narrative arc. The appearance of first the guards and then the weapons both occur during the falling action phase of the narrative. This task can help to reveal to what extent a classical narrative structure vs. a technical description influence the sequencing within a participant's story model (i.e., does the story time within a participant's mental representation align with the discourse time).

(5) Story Summary Task

The story summary task was only used in the follow-up iteration of the experiment. The task investigated the long-term memorability of the two visualisations with varying emplotment and degree of narrativity. This task targeted the participants' ability to recall and reconstruct the story two weeks later.

Participants were asked to summarise the *story* about the *citizens [green particles]* in an open-ended question. No active stimuli (e.g., videos or images) were provided before the participants answered this first question of the follow-up iteration to avoid triggering participants' memories. Only the words *citizens* or *green particles* were used, respectively. The exact wording was: *"About two weeks ago you participated in the first round of our survey. Please summarise in a few sentences what happened during the animations you* *saw - tell the story of the citizens [green particles] in your own words and be as specific as possible (but do not spend more than 2 minutes on this task).”*

The summary participants provided *represented* the *story* constructed and remembered by their minds (*story* understood here as a mental representation). This task and the follow-up iteration were motivated by the belief that (visual) narratives often leave a long-lasting impression. A similar approach was taken by Bateman et al. (2010) to test long-term memorability of a common abstract bar chart and an information graphic of the same data.

4.3.2.2 Tasks and Questionnaires targeting Comprehensibility

Two different techniques were used to assess participants’ understanding of the characteristics of the Flowstory: (1) scenario prediction task, and (2) observed behaviour questionnaire.

In a few visual data storytelling studies, comprehensibility was used as one of many test items. For example, Figueiras (2014a) asked participants in a focus group study to rate eleven narrative visualisations regarding comprehension on a 10-point scale (“Was the information presented in a clear, comprehensible way? Was the purpose easy to understand?”). While this is an explicit and subjective way to assess comprehensibility, the scenario prediction task and the observed behaviour questionnaire in this study used an implicit and indirect way to test whether participants understood the information or not. Amini et al. (2018) used a similar indirect approach asking questions about stimuli’s content to *“investigate whether participants successfully understood the facts presented”*.

(1) Scenario Prediction Task
The previous tasks involved not only the short-term memory, but the working memory as well. Instead of requiring participants to perform the cognitive tasks of just recalling and drawing conclusions, the following tests targeted comprehension and understanding by asking participants to recall, draw conclusions, and predict. By so doing, participants were required to not just remember, but also analyse, combine, and apply information to make predictions based on information gathered so far. In a larger context, these tasks help to reveal the extent to which narrative visualisations are able to aid the participant’s understanding.

In the scenario prediction tasks, participants were presented with the visual test designs introduced in Section 4.2.3. Participants were presented a single frame of the simulation, about one-quarter the way into the animation, just before the citizens [particles] encounter any walls [barriers], guards [red objects], or weapons [purple objects] used in a design. At this point several citizens [particles] were already killed [removed] by the sea [black objects]. Based on this image, participants had to make and justify a **(1a)** path prediction (i.e., where will the quickest citizen [particle] travel) and a **(1b)** quantity prediction (i.e., how many citizens will reach a defined area). In step **(1c)** of the task, the solution videos of the animation were screened.

Thus, the predictions were made based on an already advanced animation with citizens [particles] already killed [removed] by the sea [black objects] but never passed any walls [barriers] at this point. All the actors and objects used in a design were already visible on the stage to allow the participants to perform the estimation tasks.

(1a) Quickest Path Prediction Task
For each design, participants were asked to estimate the path of the citizen [particle] who [which] will most likely be the first to reach a graphically indicated line (i.e., dashed red vertical line).

Considering the behaviours and interactions between actors, objects, and obstacles observed in the initial phase and their new placement on the stage, participants had to indicate the path using the provided slider handles regularly distributed across a part of the stage (from the current position of the citizens [particles] in front of any obstacles to the dashed red vertical line). The linear connected slider handles, only vertically moveable, represent the estimated path (Figure 4.3 top). The tetris test design is used as an example in Figure 4.3.

In an open-ended question, participants were asked to justify their choice in their own words and explain why they think the citizen [particle] that reaches the red dashed line first will take the route they indicated. Both responses combined could demonstrate the participants' understanding of how citizens [particles] would navigate through the obstacles.

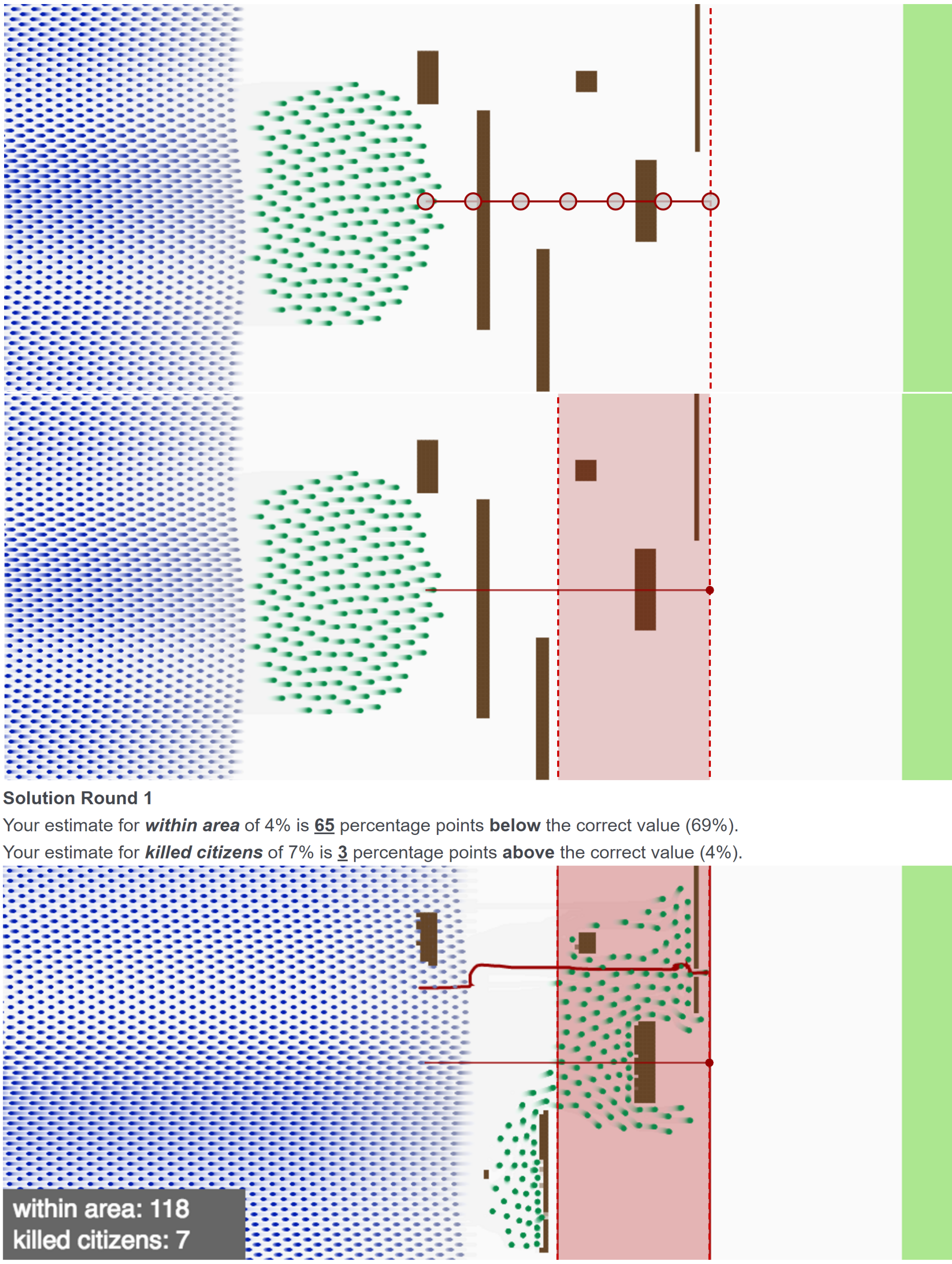


Figure 4.3: ***(1a) Path prediction task (top):*** The tetris design with just walls [barriers] with interactive, draggable handles to indicate the path of the citizen [particle] who [which] will most likely reach the red dashed line first. ***(1b) Quantity prediction task (middle):*** The tetris design with the previously indicated path and the new, added target area. The number of citizens alive [green particles visible] is 171. ***(1c) Solution screening (bottom):*** Last frame of the solution video of the tetris design with the indicated and correct path, target area, number of citizens [particles] in the target area, and number of citizens killed [removed]. Above the stage, participants were shown how close their predictions were compared to the correct values.

(1b) Quantity Prediction Task

The path estimation task was followed by a quantitative prediction. At this point, participants could see the path they indicated, but were not able to change it. A red target area, with the right bound aligning to the participant-chosen path line from the previous task, was added to the stage (Figure 4.3 middle).

Participants were asked to predict how many (%) of the living citizens [visible particles] would be within the indicated target area when the first citizen [particle] reached the right dashed red line. Additionally, participants had to predict how many (%) of the living citizens [visible particles] would have died [been removed] by the time the first citizen [particle] reached the right dashed red line. Input sliders were provided for participants to indicate their answer, demonstrating their understanding.

Similar to the previous task, participants were asked to answer an open-ended question explaining the reasoning behind their decisions. The answers helped interpret the conclusions participants drew.

(1c) Solution Screening

The solution was presented as the last phase of a scenario prediction task to support an active learning process. Within 60 seconds, participants were able to see how the simulation actually evolved. Participants were able to compare their own predictions with the correct values of the simulation (Figure 4.3 bottom). They could graphically compare their path estimate with the actual path and were informed of how much percentage points their estimations (within area and killed [removed]) deviated from the correct values.

(2) Observed Behaviour Questionnaire

In the observed behaviour questionnaire, participants were asked about observations they made while watching the opening animation or the solution videos of the scenario prediction task. The questions related to the behaviours and interactions of actors and objects as described in Section 4.2.2.

By responding to two sets of ten statements , participants indicated whether they were able to comprehend the different properties and interactions of the elements in the Flowstory. Participants were asked to check a box if they thought a statement was correct (see below). The statements in the second set partially repeated or contrasted facts in the first set in order to cross-validate answers. The statements *“I just randomly click answers”* and *“I paid attention during the survey”* were used to discard participants before the analysis (see Section 4.3.3).

Between the two sets of ten statements, participants were asked to argue why they think the sea [black objects] stopped to advance during the animations. This open-ended question was used to collect information on the story participants developed in their minds. At the end of the questionnaire, participants were asked to provide any additional observations they made while watching the simulations, again in an open-ended format. In the overall context, the open-ended format is one way to better understand a participant's story model, even though any answers are only abstractions and representations of the mental image.

Plot:

1. Citizens can kill guards if they collect a weapon.
2. A citizen gets stronger when collecting a weapon.
3. Citizens can destroy a wall when working together.
4. The sea kills citizens.
5. Guards lose their strength when killing citizens.
6. Citizens are not able to destroy walls.
7. There are always more weapons than citizens.
8. Guards just move horizontally.
9. I just randomly click answers.
10. Guards can collect weapons.

NonPlot:

1. Particles can remove red objects if they collect a purple object.
2. A particle gets bigger when collecting a purple object.
3. Particle can break a barrier when accumulating.
4. Black objects remove particles.
5. Red objects get smaller when removing particles.
6. Particles are not able to break barriers.
7. There are always more purple objects than particles.
8. Red objects just move horizontally.
9. I just randomly click answers.
10. Red objects can collect purple objects.

Plot:

1. Strong citizens can kill guards.
2. Citizens can drown in the sea.
3. Normal citizens tend to follow strong citizens.
4. After Guards killed some citizens they die.
5. Weapons help citizens to fight guards.
6. Strong citizens are faster than normal citizens.
7. I paid attention during the survey.
8. The sea kills guards.
9. Guards move in all directions.
10. Weapons just move vertically.

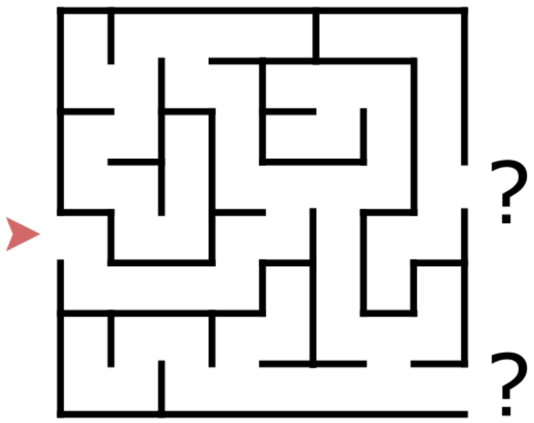
NonPlot:

1. Bigger particles can remove red objects.
2. Particles can be removed by black objects.
3. Normal particles tend to follow bigger particles.
4. After red objects removed some particles, they disappear.
5. Purple objects allow particles to remove red objects.
6. Bigger particles are faster than normal particles.
7. I paid attention during the survey.
8. Black objects remove red objects.
9. Red objects move in all directions.
10. Purple objects just move vertically.

4.3.2.3 Spatial Reasoning Task

A spatial reasoning test was used to assess the participants' general ability to think spatially. Participants were asked to select a sequence of directions allowing a small arrow, placed at the entrance of a maze, to travel to the exit successfully 4.4. On three subsequent pages, participants were presented with three rectangular mazes, each increasing in size and difficulty (easy, intermediate, and difficult). The reason for using mazes with varying levels of difficulty was to achieve a better sense of the participants' ability to think spatially. The more complicated the maze, the more spatial thought was required to solve it. Hence, if participants could complete all difficulty levels, they were better spatial thinkers. Participants had to provide an answer in a given time limit.

Of the many options for spatial thinking ability tests (Lee and Bednarz, 2012), a task targeting shared characteristics with depicted particle movements was developed. While many tests use *shape* and *pattern* as a concept for spatial thinking, the maze example uses *direction* and *orientation*, which also happened to apply to the particle flow visualisations. Therefore, the participants' ability to think spatially could be used as control in the analysis



- right - right - right - left
- right - right - straight - left
- right - left - right - left
- right - straight - left - right
- left - straight - right - left

Figure 4.4: Spatial reasoning task: Intermediate maze with the correct answer **right** - **right** - **right** - **left**

of the collected data. The tasks also acted as a distractor between the observation and testing phase (see Section 4.3.4.4).

4.3.2.4 Demographic Questionnaire

Participants were asked to provide demographic information including age, gender, education, and country of residence. Additionally, participants were asked how familiar they were with information visualisation from a professional point of view using a 5-point scale with answers ranging from *not at all familiar* to *extremely familiar*. If participants were not comfortable sharing any of the information above, they were allowed to select the *prefer not to say* option. The following section explains the recruitment process and the demographics of the participants.

4.3.3 Participants

A crowdsourcing-based approach was chosen to collect responses from an appropriate sample size within a reasonable time. The Amazon Mechanical Turk[6] service was used for the **recruitment and financial compensation** of participants. Since the majority of MTurk workers come from the USA, the amount of financial compensation was based on the US minimum wage and the expected duration of the study (25 minutes for the primary

[6] https://www.mturk.com/

and 10 minutes for the follow-up iteration). About 150 participants were recruited for each experimental condition (a total of 300). Despite budget restrictions, this number of participants seemed to be high enough to derive meaningful statements based on comparisons of between-subject conditions.

The primary run of the survey was open to all MTurk workers (from now on participants) who got approved at least 5000 HITs (human intelligent tasks) and had a HIT approval rate greater than or equal to 98%. The use of such rigorous requirements makes it possible to recruit participants who have submitted HITs at a high-quality level in the past. It is a self-selected sample, as participants are free to choose whether or not to complete the task. As the name implies, HITs are tasks that are explicitly performed by humans, they work from home or any other location and use their equipment (i.e., computer). These include tasks which can be carried out online and remotely like market studies, translation tasks, opinion polls, or such scientific studies.

Before even reaching the information and consent landing page, incompatible devices and browsers were detected and the potential participants were asked to switch to an other device or a modern browser if they wish to participate. Using Qualtrics, the online survey software used to conduct the study, mobile devices or monitors with a low screen resolution, on which the survey would not have been properly displayed were excluded. The browser Safari or older versions of other current browsers were excluded. Only browsers supporting the latest version of JavaScript (JS) and the HTML5 Video tag were allowed.

A problematic phenomenon associated with crowdsourcing-based surveys are so called *random clickers* (Kim et al., 2012). These are participants who answer questions or perform given tasks very quickly and randomly, not paying attention to the actual task, in order to just get rewarded. In the primary run, two statements within the questionnaires asking participants to evaluate true or false statements regarding behaviours and interactions, targeted random clickers: *"I just randomly clicked answers"* and *"I paid attention during the survey"*. Participants, which checked the first or did not check the second statement, were excluded from the analysis, assuming they did not pay much attention.

Table 4.1 summarises the **process of discarding participants** for the primary and the follow-up run. The exclusion process was conducted before any data was further processed or statistically analysed.

Answers that seemed to be (automatically) generated based on the questions or other existing content available online containing words used in the survey were discovered.

Table 4.1: Summary of the process of discarding participants. The values in parenthesis indicate the difference between the steps. Values in brackets in the follow-up run resulted from exclusions in the primary run. All checks were performed only after both iterations.

	Primary Run		**Follow-Up Run**	
	Plot	**NonPlot**	**Plot**	**NonPlot**
Finished survey and submitted code	151	148	66	68
Automated Answer	147 (-4)	143 (-5)	62 [-4]	63 [-5]
Duplicated MTurk Id	147	143	62	61 (-2)
Selected "I just randomly click answers"	146 (-1)	142 (-1)	61 [-1]	61
Not selected "I paid attention during the survey"	141 (-5)	138 (-4)	59[-2]	59[-2]
Valid	**141 (93%)**	**138 (93%)**	**59 (89%)**	**59 (87%)**

Further investigation revealed that all 18 detected responses (in both conditions and both iterations) came from a single Indian IP address. The following answer stood out, and shall not be withheld: *"then two weeks ago for animation was in my first round of my survey and the animations was during the animations saw for the citizens Two of the talents behind Monsters Inc, Toy Story, Inside Out and Finding Nemo inspired the audience - which included many RMIT animation students - with their invaluable insights into character development, animation techniques and storytelling.Directing Animator Andrew Gordon enjoyed sharing his knowledge with the students during the three-day workshop."* [7]

As a consequence, survey responses coming from this IP address were excluded. Other duplicated IP addresses with different MTurk Ids were not discarded since the open-ended answers seemed to be written by humans. In the follow-up run, there was a single instance in the non-plot condition, where a single MTurk worker finished the survey twice, which technically should not have been possible. In order to avoid any irregularities, both answers were excluded from the analysis.

Based on these filters, more than 90% of the participants of each condition submitted valid surveys in the primary run. Slightly below 90% of participants who returned two weeks later gave valid responses in the follow-up run. The rate of return was marginally higher for the non-plot condition (44% and 46%). Applying to both conditions, just above 40% of the participants, who submitted valid responses in the primary run returned to perform also satisfactory in the follow-up run.

[7] online at: http://www.rmit.edu.au/news/all-news/2016/february/bringing-stories-to-life-with-pixar

To check integrity between the primary and the follow-up run the specified gender, which most likely will not change within two weeks, was compared for each participant. There was no case of discrepancy.

There were a few instances where one or more path inputs from the respective tasks were due to technical problems not correctly recorded. In order to exclude as few participants as possible, records with available paths were included in the analysis, which led to slightly changing numbers of participants for the various tests and tasks in the analysis.

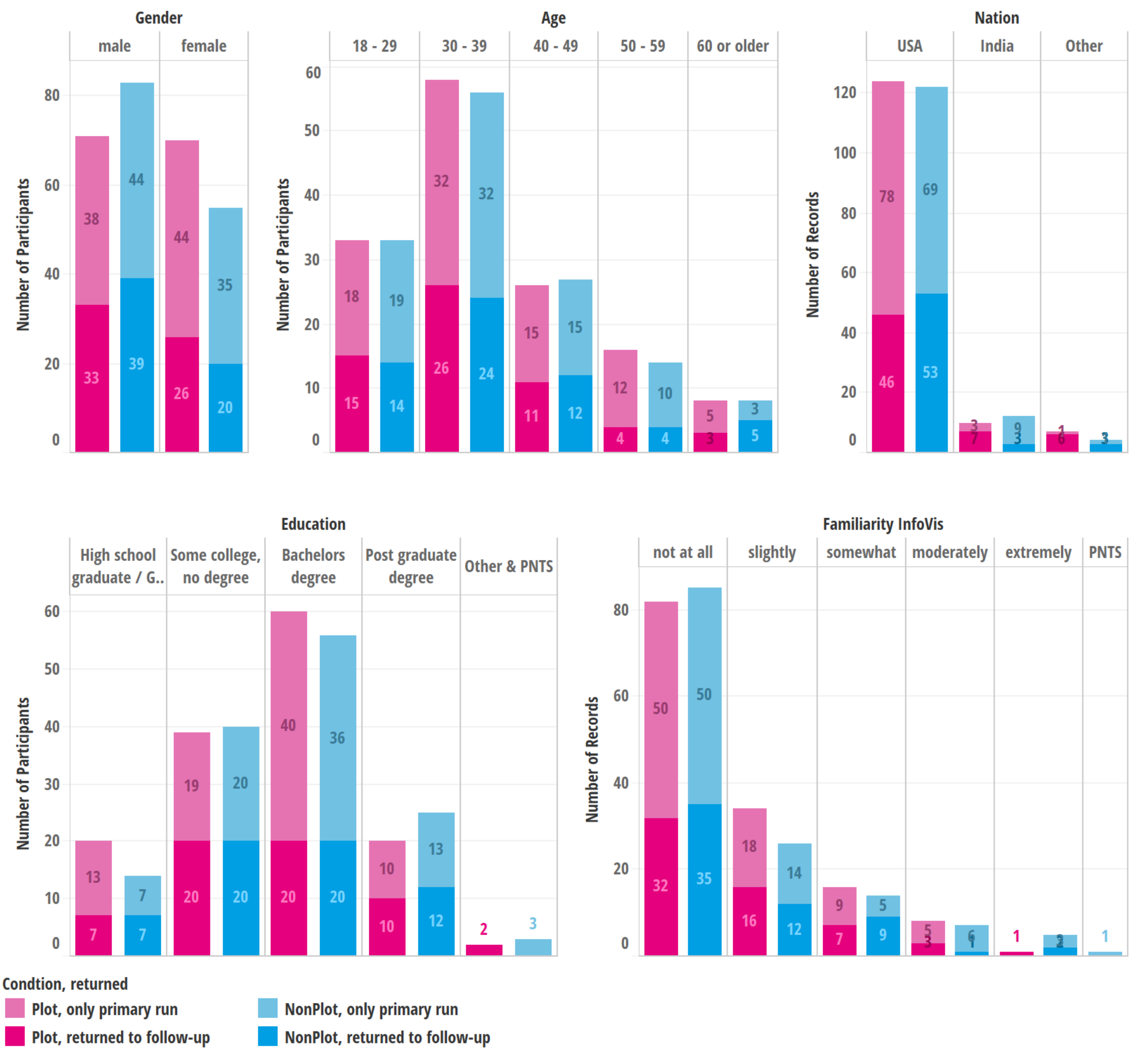


Figure 4.5: Demographics for both conditions and iterations.

Based on the valid responses, the **demographics** between the two conditions are overall very balanced between the two conditions and iterations. Figure 4.5 provides an overview. All participants are 18 years or older, which is a requirement of MTurk and aligns with City's requirements to classify as a low-risk study (amongst other criteria). The **age** structure was balanced across both conditions and both runs. Roughly 25% are younger than 30 years of age. Around 40% are aged between 30 and 39, and 20% are between 40 and 49. 15% are 50 or older. Only in the **gender** structure, there is a noticeable difference between the two conditions. In the primary run of the plot condition male and female participants are equally represented, there are 60% male and 40% female participants in the non-plot condition. For the follow-up run, more male than female participants returned in both conditions. In the primary run, around 88% of participants of each condition selected the United States of America as their **country of residence**. The remaining 12% were mainly from India, and just a few answers came from other nations around the globe. In the follow-up run, 78% (plot) and 90% (non-plot) of the returned participants were from the USA. The distribution of the **educational level** is equal between the two conditions. Most participants have either a Bachelors degree or finished some college (without a degree). Lower and higher levels are less represented. Up to 60% of all participants indicated no **familiarity with visualisation** in a professional context. Between 30% and 40% indicated some familiarity and just a few participants indicated a higher familiarity.

4.3.4 Procedure

After the presentation of the narrative-visual stimuli and the tasks and questionnaires, this section explains the order in which they were presented to the participants.

As shown in Figure 4.6, the two iterations of the online experiment were divided into different phases. Both runs had an introductory phase. The primary run was then continued with the observation phase and a distraction phase. In the follow-up iteration, the next phase after the introduction was the recall phase. Both iterations had a test phase before the final phase. The primary run lasted about 25 minutes and the iteration two weeks later about 10 minutes. These phases are described in more detail in the following sections.

4.3.4.1 Introduction Phase (Primary and Follow-Up)

MTurk workers who decided to participate in the experiment were forwarded to the Qualtrics study. First, the technical checks concerning device and browser compatibility were carried out.

On an initial screen, the aim and procedure of the experiment were outlined to the participants (**informed consent form**). Information on the time required to complete the

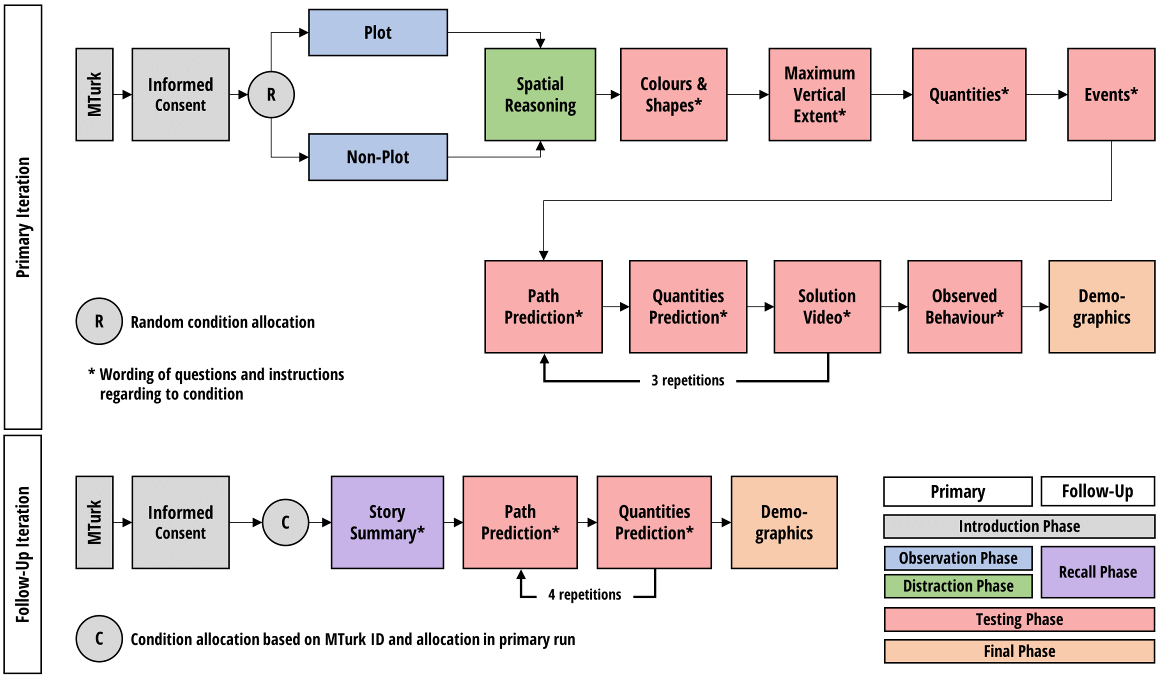


Figure 4.6: Survey procedure for both iterations divided into several phases.

survey, on how the results will be used and the nature of the information collected, was also given. When participants gave their consent and agreed to be part of the experiment, the primary iteration started with the **observation phase**. Participants were randomly but evenly allocated to the two conditions.

Participants who submitted a response in the primary iteration were invited to return for the follow-up run. Similar, they had to go through an informed consent form before they started with the **recall phase**. Depending on their initial allocated condition, participants were forwarded to the corresponding version of the survey.

4.3.4.2 Observation Phase (Primary)

In the observation phase, participants were asked to **watch and follow the animated stimulus** as described in Section 4.2.2. Depending on the condition, participants saw either the plot design or the non-plot design of the Flowstory. Each video lasted two minutes and 40 seconds. There were no other interactions besides watching and reading involved. With the help of several cartographers and information visualisation researchers piloting the study, it was ensured that there was enough time to read the text-inserts on the bottom of the video.

The videos of the simulations were embedded using the HTML5 video tag, which allowed to constrain the interaction possibilities by disabling all controls (e.g., pause, restart, or jump in time). By controlling the online environment as much as possible, similar experiences for all participants could be achieved. In order to avoid interruptions, the video started after it was fully loaded. At the end of the video, the survey auto-advanced to the next phase, the **distraction phase**. To ensure that all participants were exposed to the stimulus the same amount of time, participants were not able to watch the video again.

4.3.4.3 Recall Phase (Follow-Up)

In the follow-up iteration, the information phase was followed by the recall phase, which only consisted of the **story summary task** (see Section 4.3.2.1 (5)).

4.3.4.4 Distraction Phase (Primary)

The **spatial reasoning task** (see Section 4.3.2.3) acted as a distractor between the observation phase and the testing phase in the primary iteration. The follow-up iteration did not include a distractor.

Its primary purpose was to redirect the participants' focus before they were asked to perform the various tasks in the testing phase. A distractor *"is irrelevant to the task or activity being performed. In memory studies, an item or task may be used as a distractor before the participant attempts to recall the study material to be remembered; the distractor minimises the participant's rehearsal of the material and ensures that it is not currently stored in working memory."* [8]

Since this task primarily acted as a distractor, it had to last the same amount of time for each participant to ensure the same conditions for all participants. There was no possibility to advance manually. The survey automatically continued after 30 (first maze), 40 (second maze) and 45 (third maze) seconds, even if no answer was selected. Then the primary run continued with the **testing phase**.

4.3.4.5 Testing Phase (Primary and Follow-Up)

In the **primary iteration** of the experiment, the distractor phase was followed by the testing phase. First, participants were asked to complete the questions and tasks targeting

[8] https://dictionary.apa.org/distractor

memorability in the same order as presented in Section 4.3.2.1 (1-4)). This are the (1) **colour and shape questions**, (2) **maximum vertical extent task**, (3) **quantity estimation task**, and (4) **temporality of events task**. The six questions of (1) and each task (2-4) were displayed on a separate page. Once the pages were submitted, participants were not able to go back and change answers.

Subsequently, participants were asked to complete the tasks targeting comprehensibility. Three iterations of the **scenario prediction task** (Section 4.3.2.2 (1)) were followed by the **observed behaviour questionnaire** (Section 4.3.2.2 (2)). The three iterations of the scenario prediction task were based on three different **visual test designs** with increasing complexity levels (see Section 4.2.3). The tetris design (level-1) was followed by the arrows design (level-2) and the finish line design (level-3). The task consisted of all three steps as described above: (1a) path prediction, (1b) quantity prediction, and (1c) solution screening. In order to avoid influencing the participants' thought processes during the tasks, the observed behaviour questionnaire was asked after all the other tasks were completed.

The recall phase in the **follow-up iteration** was followed by a testing phase only utilising the **scenario prediction task**. Participants were asked to perform four iterations. The scenarios were alternating between visual test designs used in the primary run and new scenarios not displayed before. Two level-2 designs were followed by two level-3 designs: arrow design, harbour design, finish line design, and horse race design. This order ensured that when participants could remember, they did not feel too confident and maintained their attention. In order to minimise any learning effects, which were undesired in the context of testing the long-term effects, the last step of the tasks, the solution screenings were not shown.

4.3.4.6 Final Phase (Primary and Follow-Up)

At the end of the survey, participants were asked to provide **demographic information** including age, gender, educational and professional background and country of residence. In an extra text field, they were able to provide any additional comment about any aspect of the survey. If participants were not comfortable sharing any personal information they were free to do so by choosing "prefer not to say". Finally, participants received a unique **survey code** to request their payment through the MTurk interface. Participants were also reminded that they would be asked to participate in a follow-up survey around ten days later. The exact purpose that they will be asked to recall information from this iteration was not specified.

In the follow-up iteration, participants were asked to provide their age and gender to cross-check their details with the primary run. Like in the primary run, participants were invited to leave an additional comment to any aspect of the experiment and received a unique survey code to request their financial compensation.

Transcripts of the two online surveys (primary and follow-up iterations), including the information and consent pages are presented in Appendix B.1 and Appendix B.2.

4.3.5 Expectations

The expectations towards the survey results can be summarised in the following way: The participants of the plot condition will perform considerably better in all tasks and iterations than the participants of the non-plot condition, as the tale-like emplotment with a certain narrative structure provides the tools to better, memorise, understand, recall, and predict.

4.4 Analysis and Results

The goal of the analysis was to identify any differences between the two conditions (plot and non-plot) regarding the tasks participants were asked to perform to consequently draw conclusions regarding the effect of emplotment and degree of narrativity on memorability and comprehensibility.

4.4.1 Measures and Methods

The results in the figures in this section show, unless otherwise stated, sample means together with 95% BCa confidence intervals (CIs) based on 10,000 bootstrap replicates (Cumming, 2014; Dragicevic, 2015). Krzywinski and Altman (2013) provide information for the interpretation of the statistical significance of the overlap of CI error bars of independent samples. The used point estimates depend on the characteristics of the task and are summarised here.

To analyse the deviation from paths or bounds submitted by participants to the correct paths or bounds, the Fréchet distance (fd) was calculated using the algorithm described by Eiter and Mannila (1994). The Fréchet distance is a similarity measure to compare lines or trajectories. The smaller the fd, the more similar is a participant's input to the correct path. Furthermore, the intersection of a predicted paths with (a) walls [barriers], (b) guards [red objects], and (c) weapons [purple objects] were calculated. The percentage of the intersection was used as a point estimate - the smaller the value, the less a path intersects with an element. For all slider inputs (0-100%), like the count estimates or the temporal placement of events, the error in percentage points (PPS), which shows how far off an answer (i.e., estimate) was from the correct value, was used as a point estimate. For tasks, where participants had to select right answers (e.g., colour and shape or observed behaviours) or had to provide information implicitly (e.g., the correct order of events, indicate the accumulation in front of the wall [barrier]) the percentages of correct answers were used as point estimates. Two open-ended questions of the observed behaviours in the primary run and the story summary responses of the follow-up run were coded and analysed by two independent coders.

4.4.2 Memorability

What were participants able to remember, recall and answer after the distraction task about the initial animation they saw a couple of minutes prior?

(1) Colours and Shapes (short-term memory): At least 80% of all participants (both conditions) were able to pick the correct answer out of five options regarding the colour or shape of the citizens [particles] and walls [barriers]. Looking at the CIs overlap in Figure 4.7, there is no significant difference between the conditions. Much less correct answers (around 40%), but again without a noticeable difference between the conditions, were given when asked about the shapes of the sea [black objects] and guards [red objects]. Only in regard to the weapons' [purple objects'] shape, a highly significant difference can be observed in favour of the plot condition.

Overall, more correct answers were submitted regarding the salient elements such as citizens [particles] and the wall [barrier]. A slightly higher percentage of participants of the non-plot group gave correct answers.

(2) Maximum Vertical Extent (short-term memory, working memory): In order to analyse the maximum vertical extent of the citizens [particles] over time (similar to a convex hull over time), the Fréchet distance (fd) for the upper and the lower input in contrast

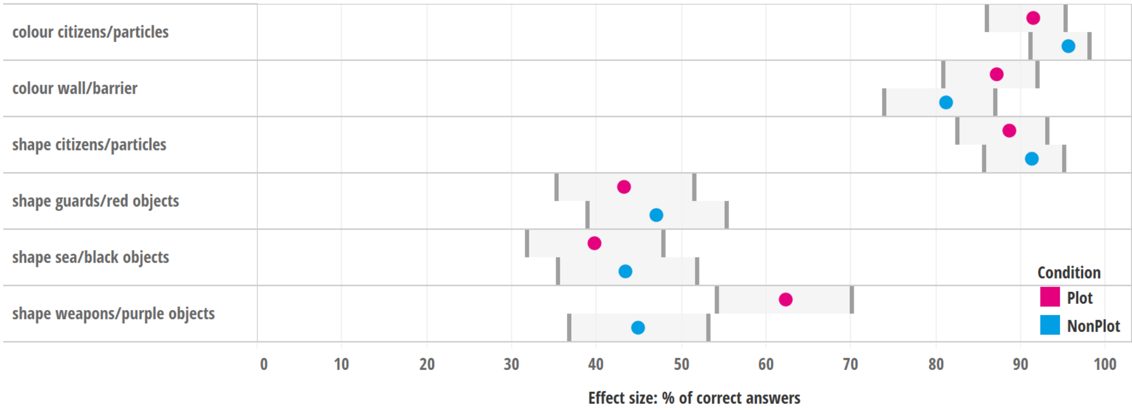


Figure 4.7: Percentages of correct answers to the shape and colour questions for both conditions with bootstrap CIs. While the first three questions were correctly answered by the majority of participants, the latter three were in general submitted correctly by less than the half of participants.

to the correct bounds were calculated. Furthermore, it was investigated to what extent participants indicated the accumulation at the wall [barrier].

Regarding the fd, there is a small but significant difference between the two conditions and the two bounds in favour of the non-plot condition. Overall, the performance for the upper bound was slightly better than for the lower bound. In the path drawings in Figure 4.8, the correct bounds are indicated with a thicker line. Bounds submitted by participants are coloured regarding the fd (i.e., bounds with a fd equal or smaller than 10 are red (plot) or blue(non-plot); bounds with a fd between 10 and 20 are magenta (plot) or cyan (non-plot); bounds with a fd larger than 20 are coloured in light grey).

Looking at the path drawings (Figure 4.8), one can see that many participants did indicate the accumulation in front of the wall [barrier]. For the handle directly in front of the wall [barrier] and the handle precisely on the wall [barrier], the relative position in relation to their previous and following handle was calculated. At least 62% of the participants in both conditions indicated a *peak* at one of the positions for the upper and the lower bound. Around 50% in both conditions indicated a symmetric peak (i.e., a peak for the lower and upper bound at the same position). More participants of the plot condition indicated the peak in front of the wall [barrier], where the citizens [green particles] actually accumulated, and not directly on the wall.

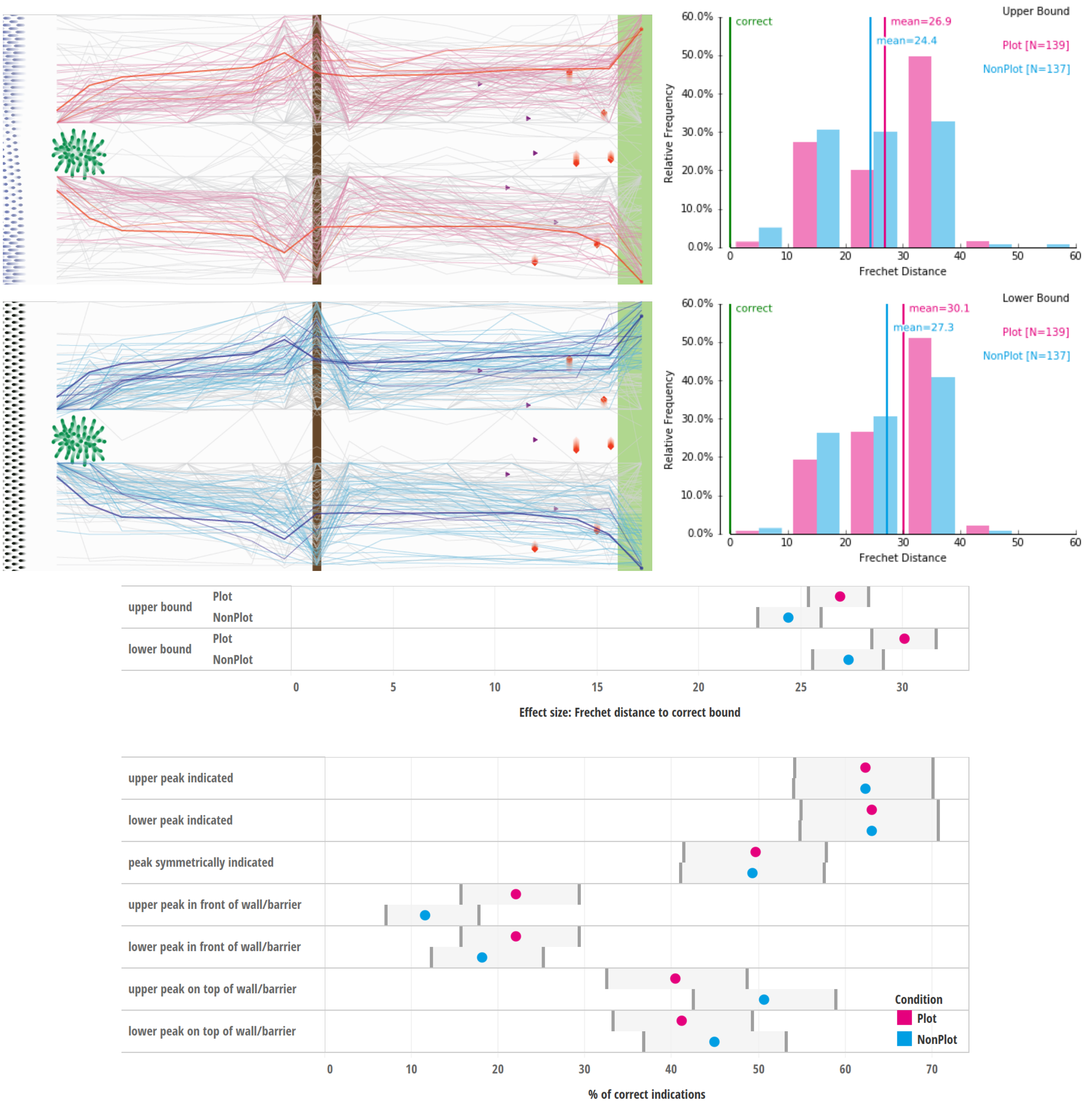


Figure 4.8: ***Path drawings:*** How the participants (red/magenta: plot, blue/cyan: non-plot) remembered the lower and upper maximal extent of citizens [particles] travelling across the stage. The correct bound has a thicker line width. Responses with a Fréchet distance equal or less than 10 have the same colour as the correct bound (plot: red or non-plot: blue). Inputs with a distance between 10 and 20 are coloured in magenta (plot) or cyan (non-plot). Bounds with a fd bigger than 20 are coloured in a light grey. ***Histograms:*** The Fréchet distance for the upper (top) and lower (bottom) bounds compared between the two groups. The closer to zero the higher the similarity to the correct bound. ***Point estimate plots:*** Average Fréchet distance with bootstrap CIs for the upper and lower bounds. Below, percentages of upper and lower peak indications overall and for the two locations (in front of the wall/barrier or on top of the wall/barrier).

(3) Quantities (short-term memory, working memory): In the opening animation, slightly less than half of the citizens [particles] were killed [removed], and the other half survived [were still visible] at the end (i.e., reached the safe land [green area]). The cause of death [removal] was either the sea [the black objects] or the guards [red objects]. The majority (43.5%) got killed [removed] by the sea [black objects]. Guards [red objects] just killed [removed] 9% of the citizens [particles].

While the majority of participants in both groups tended to overestimate the amount of surviving citizens [still visible particles], which reached the safe land [green areas], they tended to underestimate the number of citizens [particles] killed [removed] by the sea [black objects]. Participants of both groups were comparably good at indicating the low amount of citizens [particles] killed [removed] by guards [red objects]. However, participants of the plot group performed significantly better in estimating the amount of surviving citizens [still visible particles]. There is no difference regarding the amount of killed [removed] citizens (compare the CI overlaps in Figure 4.9).

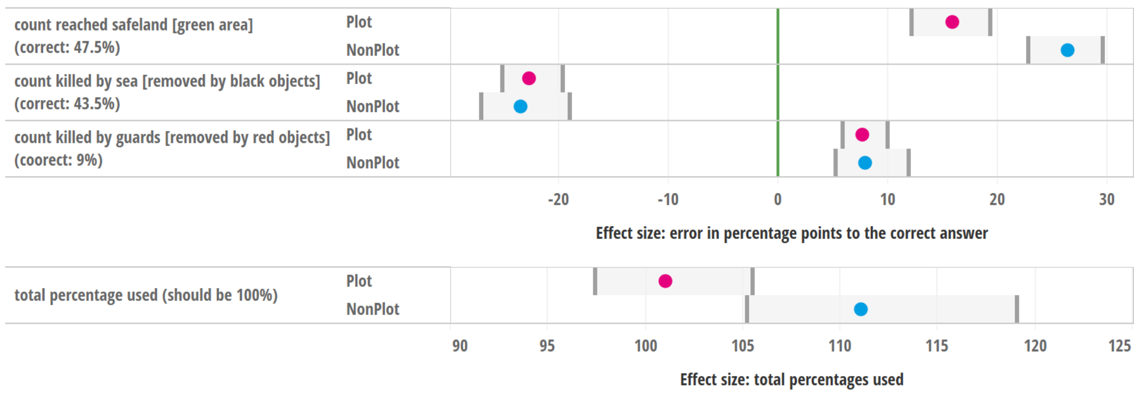


Figure 4.9: The average error of answers to quantity questions in percentage points with bootstrap CIs by condition. The green zero-line indicates the correct answer. The percentage values next to the questions are the correct values. Positive values indicate overestimation, negative values underestimation. Below, the total percentage used in all three estimations (should be 100%) [N: 141 plot, 138 non-plot]

When summing up the percentages participants submitted, all values (i.e., survived [visible] plus killed [removed]) should sum up to 100%. Although it was deliberately not part of the task instruction, it was expected that participants notice this fact and take this into account when adjusting the percentage values with the sliders. However, there is a significant difference between the two conditions regarding the average total of guards. While the average point estimate of the plot group is close to 101%, it is 111% for the non-plot group. The CIs also show that the summed up percentages spread more in the non-plot group.

(4) Temporality of Events (short-term memory, working memory): The vast majority of participants of both groups were very good at temporally placing the breakthrough of the wall [barrier] in the middle of the animation. For the appearance of the guards [red objects] and weapons [purple objects], one can observe a tendency for both groups placing the events later than they genuinely occurred. However, on average, the error was not more than twelve percentage points.

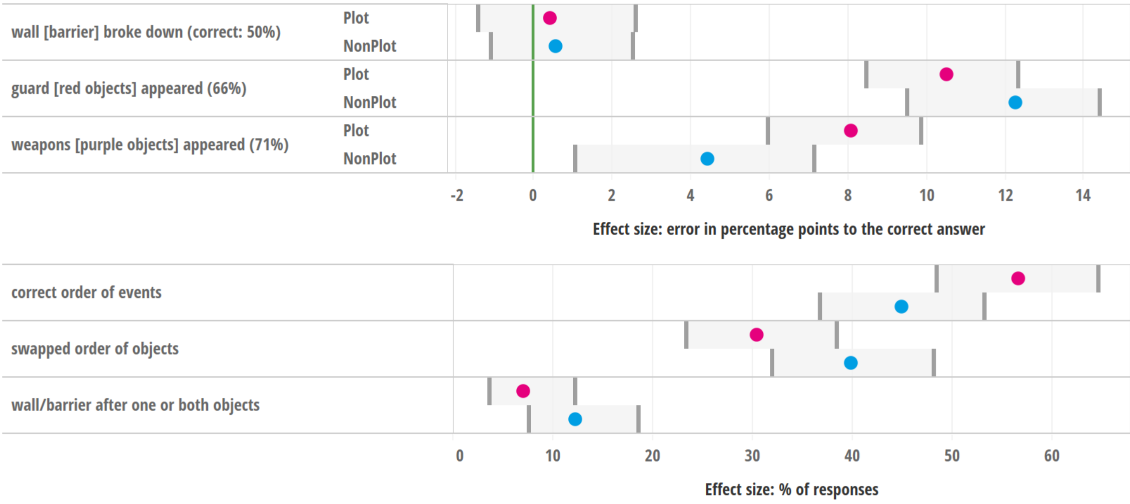


Figure 4.10: The average error of the temporal placement of events in percentage points with bootstrap CIs by condition. The green zero-line indicates the correct answer. The percentage values next to the questions are the correct values. Below, the average percentage of correct responses and responses not conveying the correct order of events. [N: 141 plot, 138 non-plot]

When taking a look at the chronological order of the three events (i.e., breakthrough of wall [barrier], appearance of guards [red objects] appearing, and weapons [purple objects] appearing) one can see a significant difference in the number of correct answers (compare the CI overlap in Figure 4.10). On average, 57% of the participants of the plot condition indicated a correct order. Only 45% of the participants of the non-plot version had the events in a correct sequence. In both conditions, the majority of participants, who did not submit the correct order, just swapped the order of guards and weapons [red objects and purple objects]. Just a few participants placed the breakthrough after one of the other two events.

(5) Story Summary (long-term memory)

All summaries were coded by two coders independently using two primary assessment

Table 4.2: The results of the coding of the answers given in the story summary task in the follow-up iteration by condition.

Category	Numbers of participants Plot (59)	Non-Plot (59)
Participant didn't remember	**9**	1
Participant remembered 1 to 2 group specific words and vaguely events or behaviours	6	**19**
Participant remembered 3 to 4 group specific words and events or behaviours	21	21
Participant remembered 4 to 5 group specific words and events or behaviours	14	13
Participant remembered 5 or more group specific words and events or behaviours	**8**	4
Unrelated answers	1	1

criteria: (1) **condition specific vocabulary** (i.e., Did participants use the exact terms (or synonyms) as used in the primary run?) and (2) **level of detail** (i.e., In which detail and order did participants remember events and behaviours from the narrative?).

A five-part scale ranging from *"not remembered any of the story"* to *"very detailed descriptions of the story"* combining the two criteria was used. The results are presented in Table 4.2.

It is noticeable that more participants of the plot group could not remember anything about the story but at the same time delivered more summaries on the highest level of detail. In contrast, much more participants of the non-plot group were able to remember at least vaguely. More than half of the participants in each group remembered three to five group-specific words and events or behaviours. Just two participants (one of each group) gave answers, which were not related to the question and seemed random, or the participants were mistaking the survey with another HIT.

A few participants provided summaries, which demonstrate their unique and creative mental story, still available a week after they were confronted with the topic. Seven of 59 participants of the plot group and 16 of 59 participants of the non-plot group gave such answers, which occurred across all levels. Such answers were either very detailed or demonstrated thinking beyond what the survey provided and include responses like the following examples.

Plot: *"In the animation, the citizens were threatened by rising waters that forced them to relocate. The citizens had to break through walls in order to escape the rising waters. Once they broke through the walls, the citizens then encountered soldiers who had weapons. Some of the citizens also found their own weapons and some of the citizens and soldiers fought. About 15% of the citizens died in the encounters with the soldiers. The remaining citizens were then able to get through and they found a new and safe location where they were able to rebuild their city and homes."*

Plot: *"If I remember correctly the citizens were running from a flood. They had to get past walls to escape the rising waters. Once they got over the walls they were met by guards from another country that did not want them to enter their land. Some members of the society got to the safety of the opposing shore and others did not."*

Non-Plot: *"The green particles were pushed along by a rushing black fog. Some of the particles were decimated, others were swallowed up by the red beams. Others ate the pink vitamin and grew bigger."*

Non-Plot: *"Green dots flowed on the screen from left to right. They faced assault from black dots at the beginning, had to pass through brown barriers in the middle, and after that a few were able to upgrade with purple cross-signs. Then they had to get through an area infested with red dots that moved vertically, burning them alive."*

Terms like *"swallowed up by the red beams"*, *"rushing black fog"*, *"ate the pink vitamin and grew bigger"*, or *"burning them alive"* demonstrate that participants of the non-plot condition did emplot the technical description with their own narrative, which shows how humans use storytelling for sense making.

Some answers partly or only described the procedures and tasks they were asked to do in the primary run of the experiment a week before (plot: 6/59, non-plot: 8/59). Examples include the following responses.

Plot: *"The animations showed various sequences of flooding scenarios where we had to project when citizens would first reach safety and how many would survive. Different scenarios presented different approaches to achieving safety."*

NonPlot: *"In summary the story was about how green particles flowed. There were different instances and we were to determine if the green particles were able to get through or not."*

After not remembering in the first place, a few participants stated in their comments, that they, as soon as they saw the first test setup, could remember again.

4.4.3 Comprehensibility

The results of the comprehension tests describe how participants performed in making sense of new information and apply it in (1) prediction tasks. Using true or false statements, participants had to demonstrate their understanding of the (2) behaviours and interactions depicted in the stimuli.

(1) Scenario Prediction (working memory): The scenario prediction task included (1a) the prediction of the quickest path and (2a) the prediction of citizen [particle] quantities.

(1a) Quickest Path Prediction: As in the analysis of the upper and lower extent, the Fréchet distance was used as a similarity measure to compare the participant's input path with the correct path. In the path drawings in Figures 4.11 and 4.13 the paths are coloured regarding the fd (red or blue for a $fd \leq 10$, magenta or cyan for a fd between 10 and 20, grey if above 20).

Overall, the differences of the fd between the two conditions for the tested designs (Section 4.2.3) are small and not always significant (compare Figure 4.11). When investigating the path drawings of the tetris design, one can observe, that close to the correct path, only participants of the non-plot group indicated the quickest route (Figure 4.11). However, on average, the fd does not significantly differ between the conditions (Figure 4.12). The situation is different for the arrows and finish line designs. Although the differences are not large, participants of the non-plot group tend to significantly perform better regarding the similarity to the correct quickest path.

A detailed comparison of designs within a condition was not particularly meaningful due to the differences in the designs. Just looking at the path of the quickest particle was sometimes not very meaningful as well, since the second and third quickest could be close behind. Therefore, it was essential to investigate the possible motivation, why participants submitted the given path. Looking at clusters and comparing the intersections of a path with (a) walls [barriers], (b) guards [red objects], and (c) weapons [purple objects] helped to explain the possible motivations (Figure 4.14).

In the **tetris design**, primarily participants of the plot group considered that citizens could flow around walls. However, it appears that participants of the non-plot group considered that citizens could break through thin walls quickly. Similarly, the non-plot

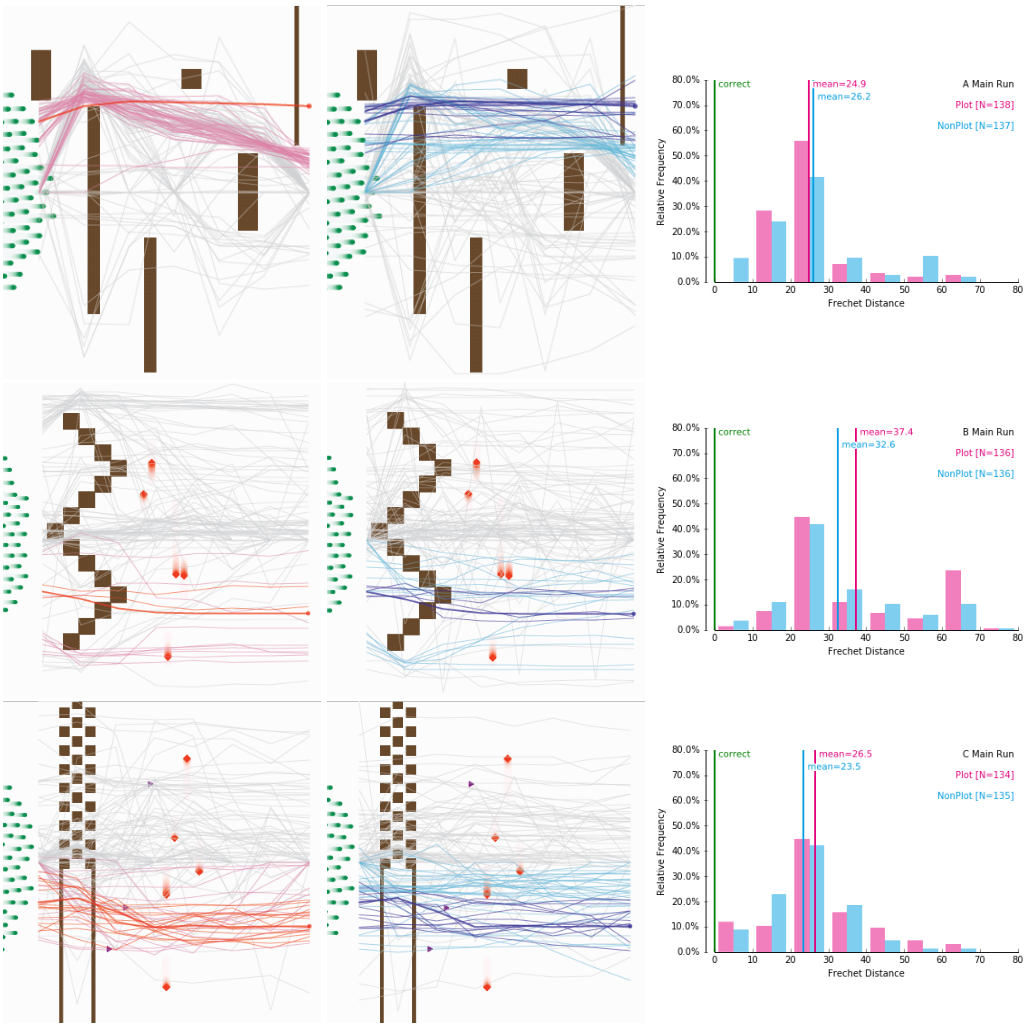


Figure 4.11: The results of the path prediction tasks of the **primary run** as path drawings and histograms for both groups. ***Rows:*** The upper row are the results for the tetris test design. The middle for the arrows and the bottom row for the finish line test design. ***Columns:*** The left column includes the **path drawings** for the plot group (magenta), the middle for the non-plot group (cyan). The correct path is drawn with a thicker line width (red for plot, blue for non-plot). Very close predictions ($fd \leq 10$) are in red (plot) or blue (non-plot). Still close estimates ($10 < fd \leq 20$) are in magenta (plot) or cyan (non-plot). Every path with a $fd > 20$ has a grey line colour. In the right column, **histograms** compare the distribution of the Fréchet distance between both groups. The correct path is indicated by a green vertical line ($fd = 0$).

group participants seemed to be aware at this point, that particles tended to go straight if they are not blocked. This difference is also evident in the plots comparing the percentage of wall [barrier] intersection. There is a highly significant difference between the two conditions. The percentage values of intersection themselves are not very meaningful;

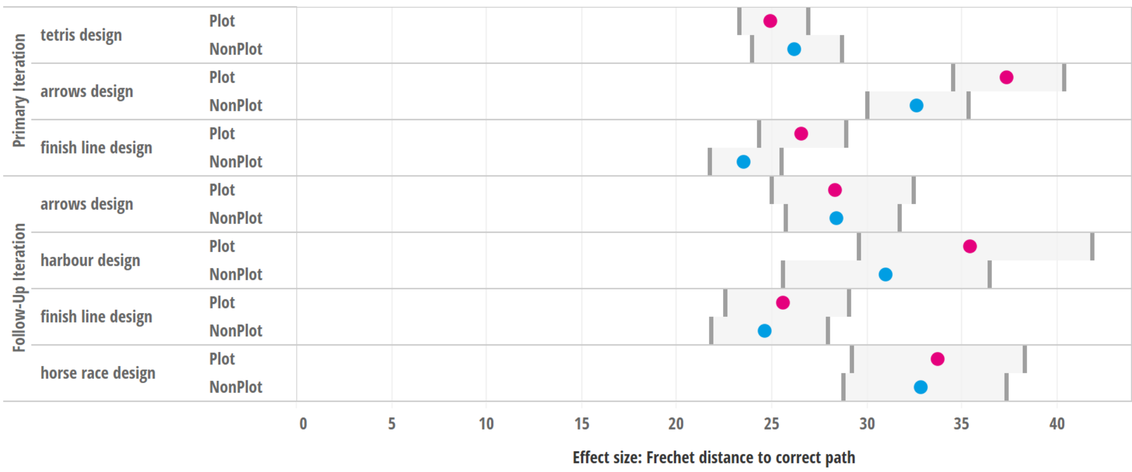


Figure 4.12: Average Fréchet distance of predicted paths for the different test designs with bootstrap CIs for the primary and the follow-up iteration.

it is the relative difference and the CI overlap between both conditions that convey the difference between the conditions.

Similar to the first design, participants of the plot condition tended to avoid the walls also in the **arrows design**. It becomes especially apparent through the cluster on the top of the stage only existing in the plot condition. Also, the chart contrasting wall [barrier] intersections shows this significant difference. Both groups have a strong cluster in the centre. However, the paths are more scattered in the non-plot condition. This central cluster is reasonable because there is a gap to avoid guards [red objects]. Nevertheless, because of the wall's [barriers'] shape citizens [particles] are first moving forward into the arrows' funnel structure, where more non-plot participants drew the path than plot participants. Moreover, regarding the lack of guards [red objects], this is a plausible route. A small cluster can be observed at the very bottom. While this route first avoids the wall [barrier], a guard [red object] is placed after it. Mainly the participants of the non-plot condition routed around this guard [red object]. This stands in contradiction to the overall observation that participants of the plot group tended to avoid guards slightly more often as non-plot participants, although the significance is low.

In the **finish line design**, many participants drew the path in the lower half, where the wall [barrier] consists of two thin elements. While the participants of the plot group tried to avoid the guards by routing around them, many non-plot participants drew the path across the red objects. Additionally, many participants also routed the path through the block structure using the little gaps and then continue straight, which applies to both groups. One significant difference is the path cluster crossing the weapon placed in the top half of the stage, which one can observe only in the plot condition. Looking at the chart showing path intersection with weapons [purple objects], it appears that mainly the participants of the plot group considered the weapons when drawing the path.

In the **follow-up run**, both groups perform more equally regarding the fd. While there are differences for two designs in the primary run, no significant differences could be observed between the two groups in all four designs in the follow-up iteration (Figure 4.12).

However, there were certain tendencies when investigating the clusters and intersections (Figure 4.13). In the **arrows design**, both conditions have a similar cluster in the centre of the stage. While more plot participants routed the path through the funnel of the lower arrow, non-plot participants also used the upper funnel (there is a small cluster). Participants of the plot group have a lower wall [barrier] and guard [red object] intersection, though the differences are not significant regarding the guards [red objects].

In the **harbour design**, many paths are very close to the correct path in both conditions. While the paths in the non-plot group tend to go straight (after “leaving the harbour”) routing through the guarded area [the area with red objects], several paths in the plot group try to avoid the guards [red objects]. Besides this cluster, there is a second cluster in the lower half of the stage, which looks reasonable since the wall [barrier] is thin and there are no guards [red objects] in the way. More participants of the plot condition selected this route.

The most distinct difference between the two groups in the **finish line design**, is the dominating cluster in the centre of the non-plot group. In the plot group, there is a smaller but distinct cluster crossing the top weapon, which is not existing in the non-plot condition. This is also reflected in the Figure 4.14 where one can see a highly significant difference for the weapon intersection.

When comparing the **horse race design**, one can identify a cluster on the top of the stage for both conditions. Those paths are reasonable because there is no blockage in the tunnel, and no guards are following. However, since particles tend to go straight as long they are not blocked, they first go into the blocked tunnels before reaching the unblocked tunnel. The cluster above the middle of the stage is distinct to the non-plot group; the purple object motivates it. Nevertheless, three guards are placed there. In the plot group, a cluster exists at the stage bottom, also motivated by the weapons placed after the tunnel; there are no guards placed there. As a result, there is a significant difference regarding wall [barrier] intersection in favour of the plot group. While there is a small difference in the guard [red object] intersection, there is no difference in the weapon intersection. This is because in this design the weapons are placed at the exits of the tunnels. Barley any participants considered, that citizens [green particles] can break through the horizontal walls when they get get blocked in the tunnel.

The only meaningful comparison within a condition is the comparison of the tasks of the primary iteration that were repeated in the follow-up run. The two repeated designs are the arrows and the finish line designs.

Contrasting the two runs for the **plot condition**, the options to go around the wall (clusters on top and bottom) in the arrows design decreased in the follow-up run. That means that just a few selected paths along the borders of the stage resulted in an overall better mean Fréchet distance for the plot group. The cluster in the middle is relatively denser in the follow-up run instead. There are not many differences regarding the finish line design.

Comparing the answers across both iterations for the **non-plot group**, one can observe only little changes. The centre cluster of the arrow design is more distinct and less scattered in the follow-up run. The changes within the condition for the finish line design are also negligible for this group.

Overall, the observations regarding clusters and intersection are reflected in the **open-ended justifications**, where participants, argued why they drew the path along a certain route. While across iterations and conditions, walls [barriers] are often mentioned in the justifications, guards [red objects] and weapons [purple objects] are mainly used by plot group participants to justify their path (Figure 4.15).

(1b) Quantity Predictions: The quantity prediction task consisted of two different parts. First, participants had to predict how many citizens [particles] end up in a given area at the end of the indicated path. Second, they had to predict how many citizens are going to be killed (removed).

Quantities "In Area": In the primary run, the red target area for predicting quantities of citizens [particles] got smaller with each round (tetris, arrows, and finish line design). Hence, the number decreased for each design (69%, 16%, and 8%). However, the set-up (walls [barriers], guards [red objects], weapons [purple]) got more complex, in the sense that participants had to consider more factors. In the follow-up run, the order of tests was arrows, harbour, finish line, and horse race test design, the *in area rate* was between 8% and 16%. The target areas of the new designs (harbour and horse race) had a similar width as the old designs (arrows and finish line).

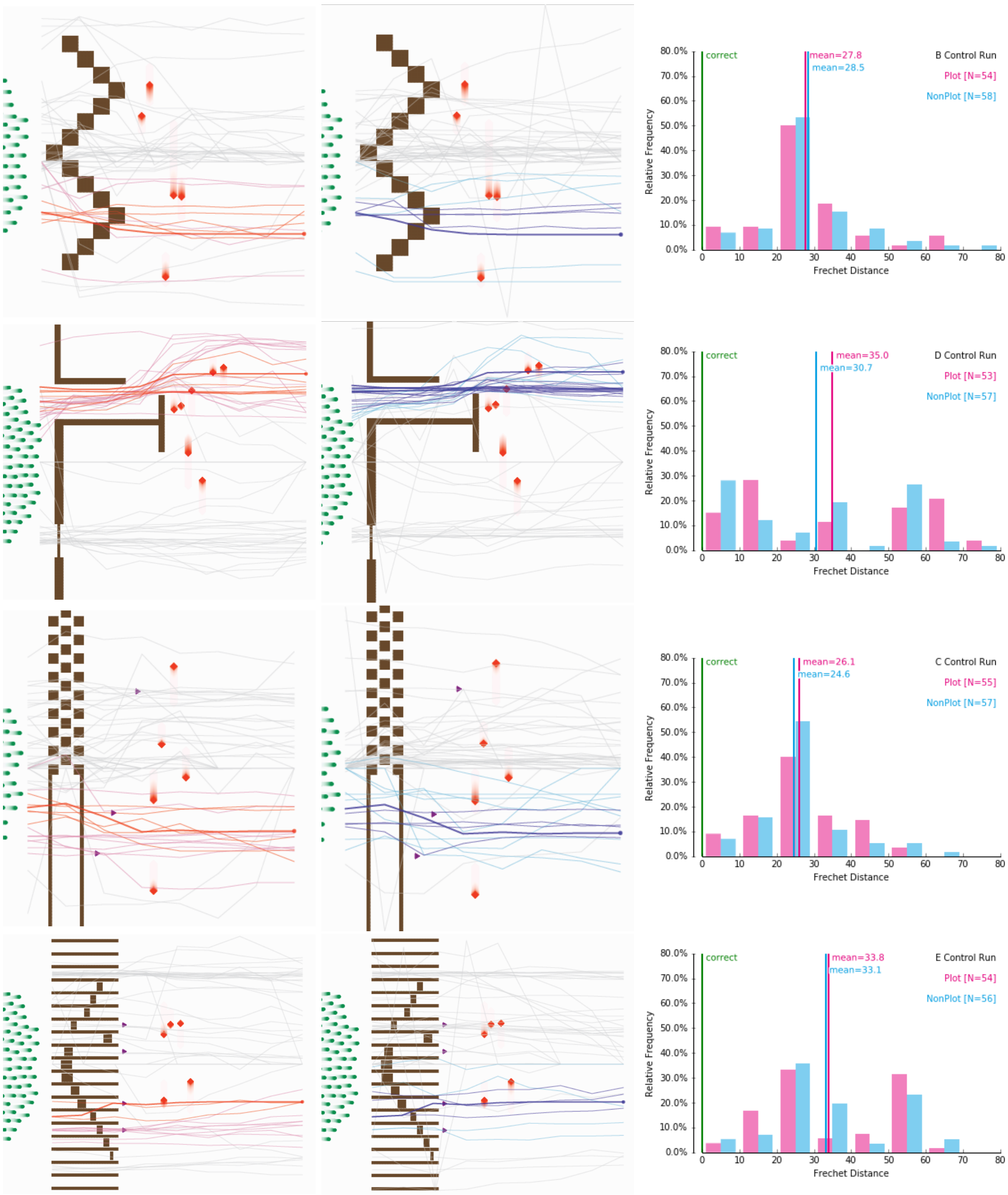


Figure 4.13: The results of the path prediction tasks of the **follow-up run** as path drawings and histograms for both groups. ***Rows:*** From top to bottom are the results for test designs arrows, harbour, finish line and horse race. *Columns:* The left column includes the **path drawings** for the plot group (magenta), the middle for the non-plot group (cyan). The correct path is drawn with a thicker line width. Very close predictions ($fd \leq 10$) are in red (plot) or blue (non-plot). Still acceptable estimates ($10 < fd \leq 20$) are in magenta (plot) or cyan (non-plot). Every path with a $fd > 20$ has a grey line colour. In the right column, **histograms** compare the distribution of the Fréchet distance between both groups. The correct path is indicated by a green vertical line ($fd = 0$).

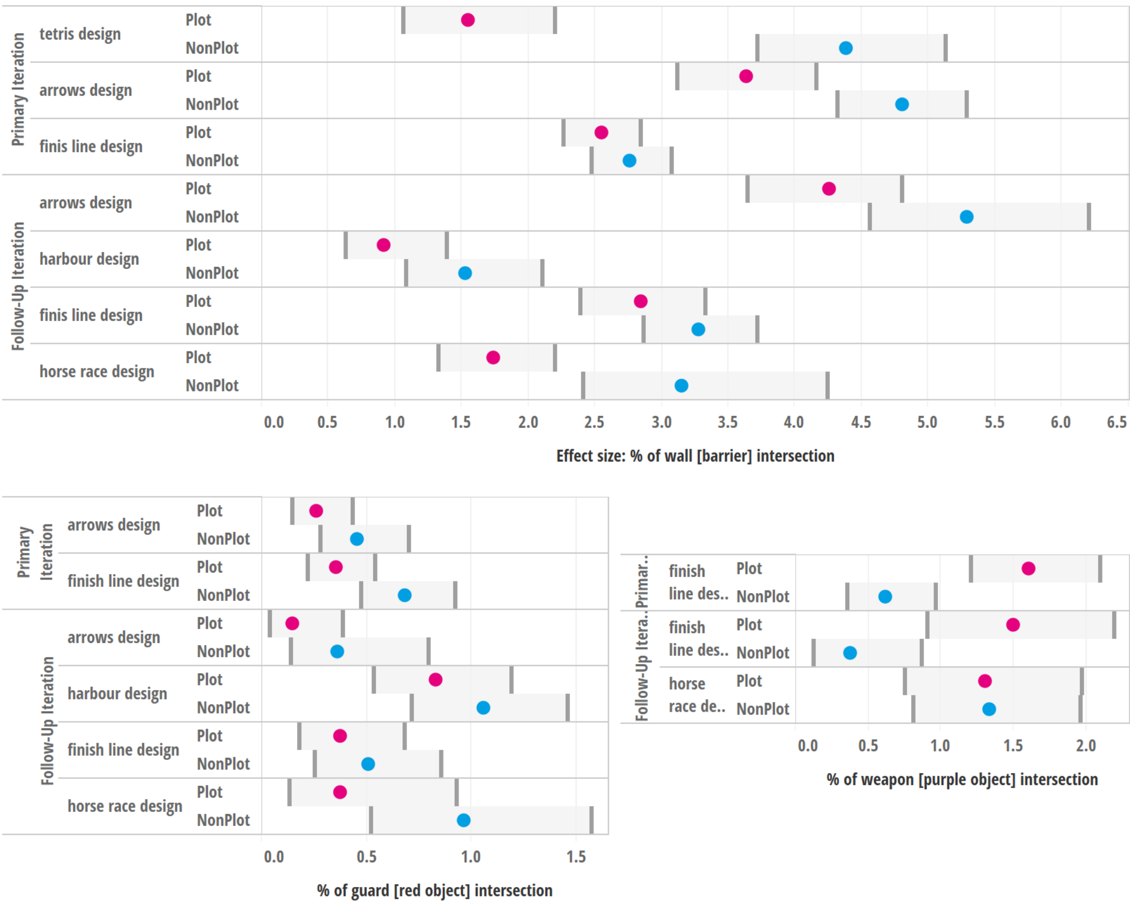


Figure 4.14: Average percentage of paths intersections with walls [barriers], guards [red objects], and weapons [purple objects] and bootstrap CIs for both iterations and conditions.

For the in area prediction in the tetris test design, the plot group performed significantly better overall. Both groups underestimated the correct value. In both other tests of the primary run (arrows and finish line test designs) the non-plot group performed significantly better. Both groups overestimated the correct number (Figure 4.16 top).

One possible explanation of the observed pattern can be the effect of the solution videos (learning effect). Influenced by the result screening of the tetris test design, where many underestimated the correct number, participants tended to overestimate the quantity in the arrows test design. They then performed slightly better in the final finish line test design.

Since there were no solution videos in the control run, one can not observe this pattern there. Overall the non-plot group performed better than the plot group in the control

Primary Iteration

	Path Prediction					
	tetris	arrows	finish line	term1	term2	term3
Plot	74	61	73	*wall*	*barrier*	
NonPlot	84	75	69	*barrier*	*wall*	*brown block*
Plot		63	43	*guard*		
NonPlot		22	10	*red obj*	*red part*	*diam*
Plot			52	*weapon*		
NonPlot			6	*purple obj*	*purple part*	*tria*

Follow-Up Iteration

	Path Prediction Justification						
	arrows	harbour	finish line	horse race	term1	term2	term3
Plot	29	38	30	27	*wall*	*barrier*	
NonPlot	23	30	24	27	*barrier*	*wall*	*brown block*
Plot	24	28	24	23	*guard*		
NonPlot	12	11	6	8	*red obj*	*red part*	*diam*
Plot			20	17	*weapon*		
NonPlot			8	5	*purple obj*	*purple part*	*tria*

Figure 4.15: Terminology used in justification for path prediction tasks for the different test designs for both iterations and conditions.

run. Only in the horse race test design, there is no significant difference between the two conditions.

When comparing the tests, which were part of both runs (arrows and finish line design), one can observe that overall, both groups performed better in the follow-up run in the arrows test design. Especially the non-plot group increased their correct answers. Furthermore, in the finish line test design, both groups performed better in the follow-up iteration, but the increase is small.

Quantities “Killed [Removed]": The *mortality [removal] rates* also varied with the five test designs. In the tetris test design just 4%, in arrows test design 43%, and in the finish line test design 45% died [were removed]. In the follow-up run, it was 50% for the harbour test design and 10% for the horse race design.

The above mentioned learning effect based on the screening of the solution video can be observed again for the quantity predictions of citizens killed [particles removed] (Figure 4.16 bottom). Based on the low value in the tetris test design, the majority also predicted a very low value in the arrows test design, which was not correct. Aware of this mistake after watching the solution of this test, participants performed better in the final finish line test design. This effect is more visible for this task compared to the “in area” prediction.

In general, when looking at all answers of both runs, the differences between the two groups are minimal and looking at the CI overlaps, not significant. When comparing

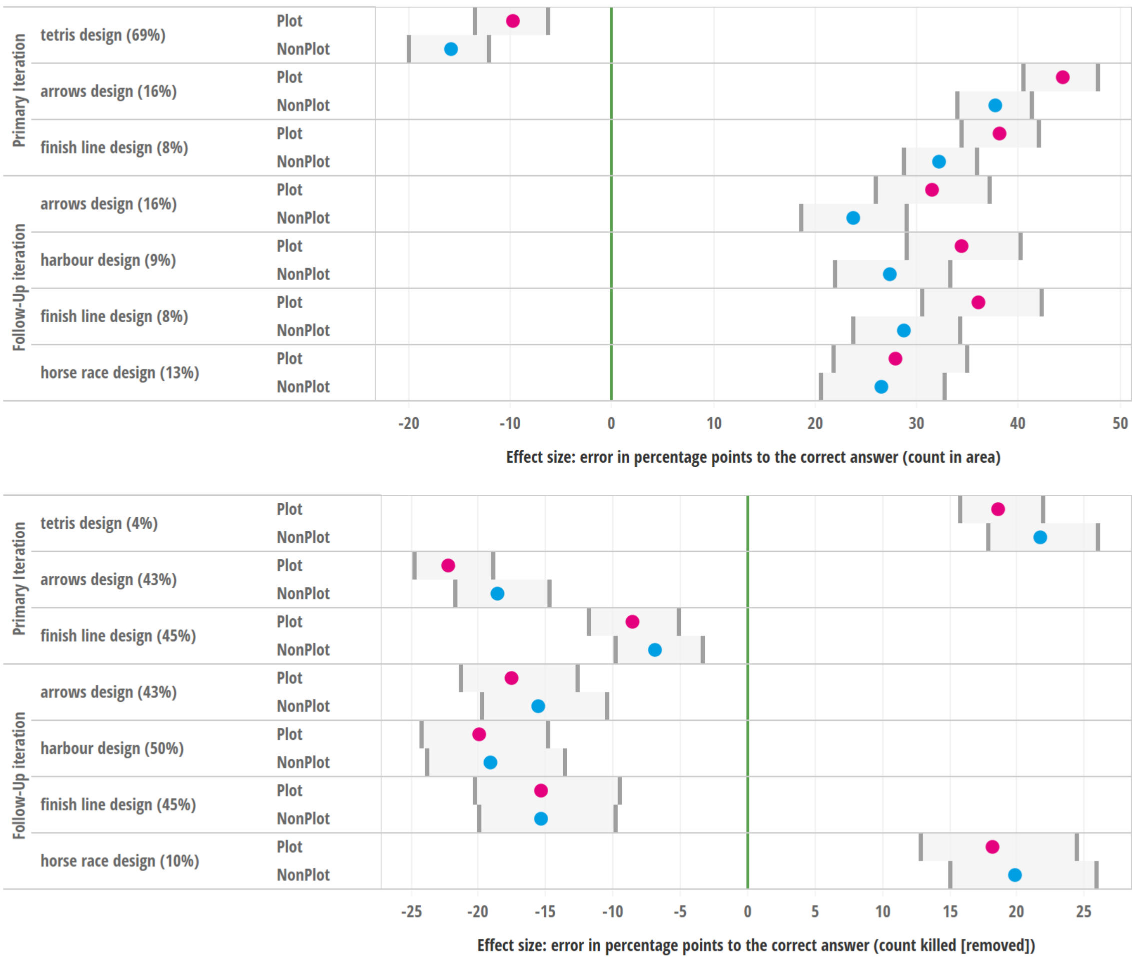


Figure 4.16: Average error in percentage points for the “in area" (top) and “killed [removed]" (bottom) predictions by iteration, test design, and condition. The green lines indicate the correct value, provided in parenthesis after the test design name. Positive values indicate overestimation, negative values underestimation. [N primary run: 141 plot, 138 non-plot; N follow-up iteration: 59 each]

groups across runs for the quantity predictions of killed citizens [removed particles], one can observe, that in the finish line test design, both groups performed better in the primary run. However, for the arrows test design, both groups performed better in the follow-up run. Again, a plausible explanation is the effect of the solution video screenings.

The kind of input mechanism probably influences the tendency of participants to underestimate larger quantities and overestimate smaller values. Participants may tend not to use extreme ends of the slider input but a more centred quantity.

Primary Iteration		In Aera Prediction			Killed Prediction					
		tetris	arrows	finish line	tetris	arrows	finish line	term1	term2	term3
	Plot	35	54	59	45	48	55	*wall*	*barrier*	
	NonPlot	65	66	64	61	57	55	*barrier*	*wall*	*brown block*
	Plot		50	40		60	75	*guard*		
	NonPlot		9	14		27	37	*red obj*	*red par*	*diam*
	Plot			25			22	*weapon*		
	NonPlot			4			6	*purple obj*	*purple par*	*tria*
	Plot	27	18	15	70	52	55	*sea*	*water*	
	NonPlot	7	4	1	25	21	16	*black par*	*black obj*	*black dot*

Follow-Up Iteration		In Area Prediction Justification				Killed Prediction Justification						
		arrows	harbour	finish line	horse race	arrows	harbour	finish line	horse race	term1	term2	term3
	Plot	24	31	29	24	24	27	25	22	*wall*	*barrier*	
	NonPlot	19	25	17	23	15	16	18	16	*barrier*	*wall*	*brown block*
	Plot	14	17	19	17	25	34	33	27	*guard*		
	NonPlot	5	8	5	10	20	16	18	20	*red obj*	*red par*	*diam*
	Plot			13	7			14	12	*weapon*		
	NonPlot			2	3			5	5	*purple obj*	*purple par*	*tria*
	Plot	7	1	4	5	26	20	25	26	*sea*	*water*	
	NonPlot	7	2	2	1	11	9	9	10	*black par*	*black obj*	*black dot*

Figure 4.17: Terminology used in justification for quantity prediction tasks for the different test designs for both iterations and conditions.

The open-ended justification texts regarding the quantity prediction also showed across both iterations that plot group participants used the specific terminology more often than participants of the non-plot condition to explain their decision making (see Figure 4.17).

The open-ended justifications of the prediction task were only evaluated regarding the frequency of terminology used. In general, the justification range from “just guessed" to enhanced explanations on what the indicated path or quantity estimates were based. A more detailed reflection on answers to open-ended questions regarding observed behaviours and interactions are presented in the next section.

(2) Observed behaviours and interaction statements: In a questionnaire with true or false statements and open-ended questions, participants had to demonstrate their understanding of the behaviours and interactions of the different actors and objects.

The two sets of nine true or false statements, each about a behaviour or interaction, were grouped regarding the involved actors and objects, and were tagged with labels targeted by the statements. The labels are: *flocking*, *speed*, *direction*, *count*, *interaction*, and *properties*. It was investigated if participants were able to observe the behaviours stated, thus if they checked the correct and did not check the wrong answers. The differences between the two groups are summarised in Figure 4.18 showing the percentage of correct answers together with the respective bootstrap CIs.

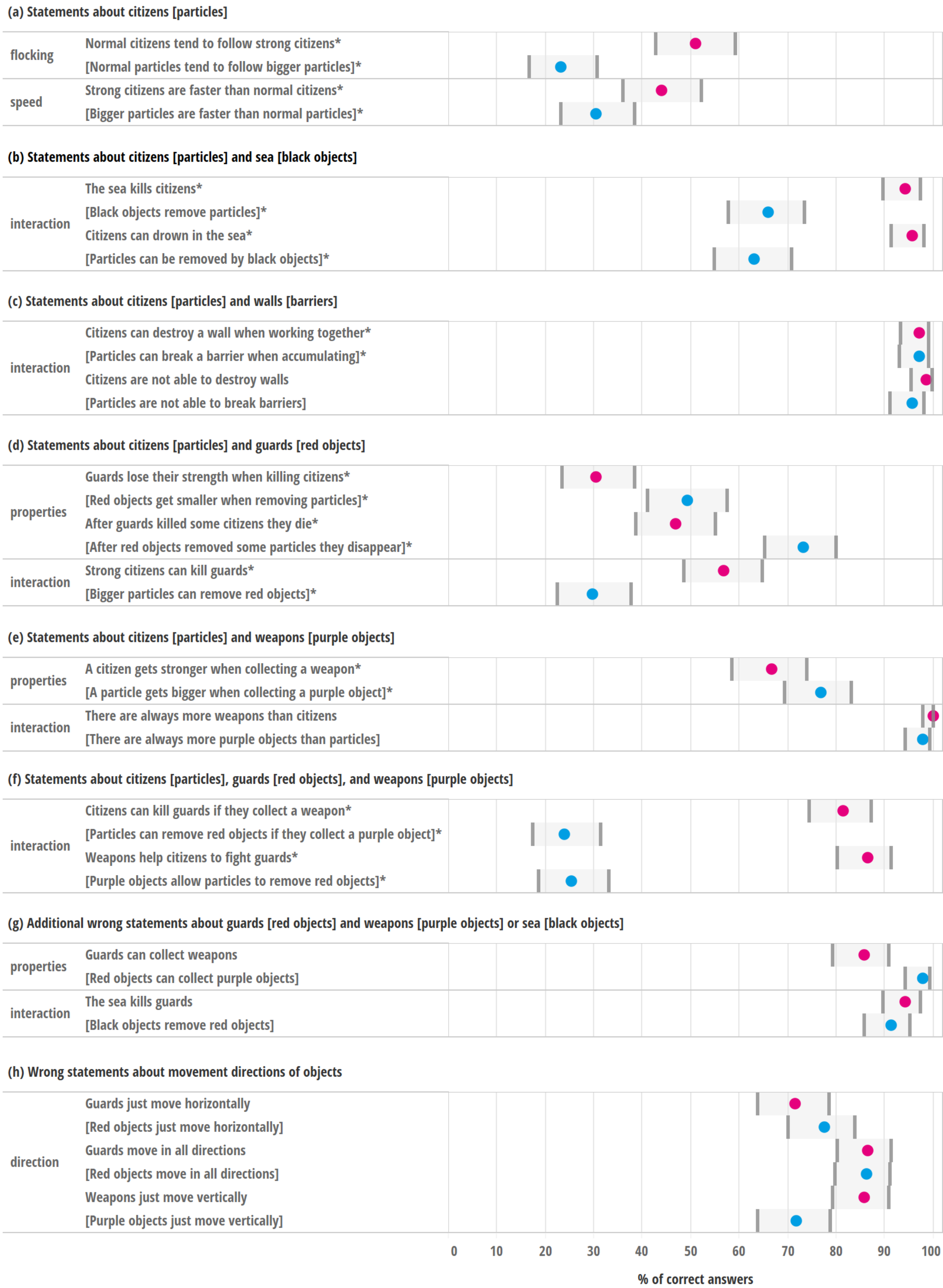


Figure 4.18: Results for the true and false statements regarding behaviours and interactions. Percentage of correct answers by condition with corresponding bootstrap CIs. Correct statements are indicated by an asterisk symbol.

Both statements about the behaviour of the citizens [particles] (i.e., flocking and speed) were correctly indicated by a significantly higher percentage of the participants of the plot condition (Figure 4.18 a). However, only half or fewer participants of each condition provided a correct answer. These two characteristics are visible, but not verbally addressed in the visual-narrative stimuli, and require close attention to be noticed, which might lead to these results.

When testing the interaction between the sea [black objects] and citizens [particles], most participants of the plot condition evaluated the statements correctly (Figure 4.18 b). Significantly fewer participants of the non-plot group provided a correct answer. The two statements, which convey the same information, were part of the two different sets to control consistency. Looking at the values within each group, one can observe very similar percentages of correct answers.

Both groups performed at a very high level and submitted correct answers for the statements about interactions between citizens [particles] and walls [barriers] (Figure 4.18 c). Walls [barriers] play an essential role in all stimuli and are visually very salient. These two statements were also used as a constancy check.

The statements regarding guards [red objects] that they get weaker [get smaller] and eventually die [disappear] when killing [removing] citizens [particles], were correctly indicated by a significantly higher percentage of the participants of the non-plot condition (Figure 4.18 d). It appears that participants of the plot group tend to be less aware that guards can be killed eventually. This might be one plausible explanation of why participants of the plot group tried to avoid guards drawing the paths more than participants of the non-plot group, which seemed to be aware of this fact. In contrast, asking if the interaction between strong citizens [bigger particles] and guards [red objects] was observed the plot group performed better. The fact that strong citizens [bigger particles] can kill [remove] guards [red objects] might have been more apparent through the tale-like emplotment.

The non-plot group performed slightly better when asked about a property of citizens [particles] interacting with weapons [purple objects] (i.e., they get stronger [bigger]). However, the difference is not large (Figure 4.18 e). Both groups did provide correct answers to the wrong statement about the count comparison of citizens and weapons [particles and purple objects].

While participants of both groups understood that collecting [touching] a weapon [purple object] is effecting a citizen [green particle] (i.e., they get stronger [bigger]), significantly more participants of the plot group understood that they could kill guards [remove red objects] with the help of weapons [purple triangles] (Figure 4.18 f). This can explain why non-plot participants did not heavily consider purple objects in the prediction task. Additionally, this is most likely also an effect of the objectification of the purple objects itself. Obviously, a weapon can kill someone, compared to a purple triangle. Both statements are from different sets and target the same observation, although formulated differently. The percentage of correct answers is consistent for both groups.

Finally, there were a few wrong statements, that overall were indicated correctly. For the statements in Figure 4.18 (g), 91% or more participants did not check the answers. Only in the plot group, 14% stated that guards could collect weapons, which they were not able to do.

All three statements in Figure 4.18 (h) were observations participants were not able to make. Still, up to 28% believed they saw guards or weapons move in other directions than they actually did (i.e., participants of the plot group regarding the direction of guards, participants of the non-plot condition regarding the direction of weapons). Possible confusion may have been introduced by using the terms *horizontally* and *vertically*. Maybe using a simpler language (up and down or left and right) would have produced different results.

In summary, an interesting pattern is noticeable. While the plot group tended to perform better or equal in statements dealing with parameters like flocking, speed, interaction, quantities and direction, the non-plot group outperformed the plot group in statements targeting particle properties.

In an open-ended question, between the two sets of statements, participants were asked: **Why did sea [black objects] stopped advancing?** The same two individuals who coded the story summary task coded the answers to this open-ended question. In the course of coding, the following themes or categories emerged.

No Input: The participant did not answer sufficiently for one of the following reasons: no idea, misinterpretation, inconclusive or no answer at all.

Wall/Barrier: The participant reasoned that the sea [black objects] stopped due to physical obstacles such as walls, barriers and blockages.

Force: The participant reasoned that the sea [black objects] stopped due to exogenous or endogenous forces interacting with the system (e.g., tides, weather conditions, climate, or physical properties of objects like inertia).

Topography: The participant reasoned that the water [black objects] stopped due to a change in topography (e.g., hill, steep slope, elevated terrain).

Programme: The participant reasoned that the water [black objects] stopped due to being programmed to do so (e.g., by the programmer, the scientist or a higher power as a god).

A single response could include more than just one theme. This resulted in a total of 164 reason-statements by the plot group (from 96% of the participants) and 118 reason-statements by the non-plot group (from 80% of the participants). More participants of the non-plot group gave answers categorised as *no input*. This appears to be reasonable, since it might be easier to think of a reason having the narrative from the tale-like emplotment in mind. There was more creativity and thinking required from the non-plot participants.

About the half of all statements of the plot group (48%) and 40% of the non-plot group were revolving around the *force* theme. A quarter of the statements of the plot group were categorised with the theme *topography*. While one can expect topography related statements from the plot group, no statement of the non-plot group was somehow connected to change in height or level of the not visible or explained context. Hence, the *walls [barriers]* were a more obvious reason for the non-plot group (35% non-plot and 20% plot). Also the statements in the category *programme* were coming primarily from the non-plot group (25% non-plot and 8% plot). Without the contextualisation, the story-like emplotment, these reasons are maybe more likely to come to one's mind.

Again, a few participants provided answers, which demonstrate their unique and creative story they created in their minds. Five of 141 participants of the plot group and 19 of 138 participants of the non-plot group gave such answers, which occurred across all categories. Such answers demonstrated thinking beyond what the survey provided and include the following examples.

Plot, Force: *"The sea stopped advancing because maybe the sea was rising from melting ice and all of the ice melted and there was no more ice to melt to make the sea rise any further."*

Plot, Force and Typography: *"Several possibilities. If it is a tsunami then it could reach critical point and then recede. If it is just flooding they could have moved to higher elevations."*

Plot, Programme: *"Because God of Sea (most probably Posidon) acknowledged the perils humans went through so he decided to ease back on the flood thing, putting his divine intervention aside and letting humans define their own fate."*

Non-Plot, Wall/Barrier: *"I think they stopped because they encountered the brown barriers. They could not go through the holes made by the green particles because the black objects were more of a solid moving mass and not flowing particles."*

Non-Plot, Force: *"The black objects seem to need some pressure behind them or internal energy to move them as a group, and this pressure or internal energy comes in pulses - it has to accumulate to enough force. And in addition, the black particles do not move if there are a small number of green particles near them - maybe they are preying on the green particles."*

Non-Plot, Programme: *"I saw that and wondered about it because I didn't take that possibility into account when I made my estimates. I looked at this whole exercise as if it was a war game and tried to mentally picture what would happen when the black army advanced on the green one who had their backs to a wall (literally). I thought the red particles were snipers and the purple ones were water/food sources. In that sense, I could see the black army trying to intimidate the greens into giving up or delaying their advancement because they were waiting for the snipers to get into position. If I just look at it as particles, maybe the black particles can't or won't attack a large segment of greens. They only attack stragglers."*

This last response is one example of a few instances, where participants of the non-plot group anthropomorphised the depicted particles in their mind.

About 55% plot group participants and 40% non-plot group participants provided one or more additional observation in the last open-ended question. In total, participants of the plot group provided 76 correct and 17 wrong new observations. The non-plot group submitted 45 correct and 23 wrong additional observations. Only observations, which were not explicitly stated in any previous part of the survey, were counted.

In the final section of this chapter, the results of the experiment, as well as methodological aspects are discussed.

4.5 Discussion

The results could not confirm the initial expectation that the participants of the plot condition would perform much better in the tasks and questionnaires than the participants of the non-plot condition. It was assumed that the tale-like emplotment would foster memorability and comprehensibility. Although several tests found significant differences in condition, the overall impact was small.

However, patterns were identified, suggesting that the tale-like emplotment used in the plot condition might (1) hinder visual processing, but (2) foster the overall understanding. In some tests, the non-plot group performed slightly better (e.g., path and quantity predictions in primary run) in other tasks the plot group did marginally better (e.g., quantities estimate questions, temporality of events, path intersections). The results of the behaviour and interaction statements were in favour of the plot group overall.

4.5.1 Can text-based emplotment hinder visual processing and immediate memorability?

It seemed that non-plot participants were more aware of details that were only conveyed visually (e.g., that thinner walls/barriers can be destroyed quickly, that guards/red objects disappear from the stage). Such details were not explicitly expressed in the emplotments. One plausible explanation is that participants of the plot group were less considering visual details because the narrative processing was more demanding than in the non-plot group.

The argument that the text-based, tale-like emplotment may hinder visual perception and immediate memorability is supported by the results of the colour and shape questions and the results of the average Fréchet distance in the maximum vertical extent task, for which participants of the non-plot group tended to perform better.

Being more aware of critical details, non-plot participants tended to perform better in the scenario prediction tasks of the primary run, especially for the path prediction and "in area" quantity prediction. However, the open-ended justifications showed that they mainly used the term "barriers" and less the terms "black, red, or purple objects" (or similar words) to explain their predictions. Participants in the plot condition, on the other hand, also used the terms "sea", "guards", "weapons" extensively to explain their predictions. This leads to the second observation that participants of the plot group performed better in tests that were relating to information that was conveyed visually and by the text-based emplotments.

4.5.2 Can text-based emplotment foster the overall understanding?

The perspective that the tale-like emplotment led to an overall better understanding is based on the results of several tests in which participants of the plot group performed better. These include the task testing the temporality of the events (wall breaks, guards appear, weapons appear), the peak analysis of the maximum vertical extent task (in front or on top of the wall), the quantitative estimates concerning the surviving citizens in the initial stimulus, as well as the total percentage used for the three quantitative estimations (survived and killed by sea or guards).

While plot group participants did not make better predictions for new scenarios, they tended to consider more alternatives based on the placement of actors and objects when making these predictions, as opposed to participants in the non-plot condition. This was shown by the path intersection analysis and the terminology used for explaining the predictions. The path drawings of the plot group tended to avoid walls and guards more than paths of the non-plot participants avoided barriers and red objects. Intersections with weapons [purple objects] were considerably higher in the plot condition. Moving around walls, avoiding guards, and collecting weapons led to more distinct clusters and less scatter in the path drawings of the plot group (compared to the non-plot condition).

In all these observations above, plot group participants demonstrated a better overall understanding of the visual narrative, which was also the case for most true or false statements regarding behaviours and interactions of particles.

One plausible explanation for these observations is the text-based anthropomorphisation and objectification of the visual elements that provided a more familiar and relatable setting than simple particles. The information that the moving dots were citizens, a group of humans, might have guided participants of the plot group in their decisions. For example, more participants of the plot group than participants of the non-plot condition indicated the accumulation of citizens [particles] in front of the wall [barrier], reflecting the idea, that humans have to gather in front of a wall in order to break the wall down.

Furthermore, on average more participants in the plot group used 100% in total in the quantity estimation task to indicate the proportion of citizens who either survived and reach the safe land or were killed by the sea or guards. This demonstrated the participants' understanding of citizens as a whole, as one unit. Participants in the non-group used on average a total of 111%, indicating they were less aware that the particles form a self-contained unit.

Because the particles were humans, participants of the plot group, might have been more risk averse when predicting the most likely route the quickest citizen would take. They might have avoided guards, because even loosing a single human life is tragic, opposed to removing a single particle out of many. Although, citizens were able to break through thinner walls, participants of the plot group tended to avoid them. The thought might have been that it is a bigger effort to dig through a wall than going around it, saving citizens' energy.

Additionally, the narrative arc and tension of the tale-like emplotment, chaining the events together, might have helped to comprehend and memorise the order of events easier.

Another factor that could contribute to these results are the associative thoughts caused by such concepts as citizens (humans), sea, guards, and weapons opposed to concepts as green particles, black, red, and purple objects. For example, participants had expectations that a guard might be dangerous, or a weapon might be used to kill someone. Red and purple objects do not evoke such expectations. It is one possible reason that cannot be excluded, why participants of the plot group did perform better in the statements about particle behaviour and interaction.

Furthermore, this means that a high degree of narrativity, on the other hand, can provoke certain associations guiding a reader's line of thought into a specific direction, hindering creative thinking. This effect was demonstrated by the answers participants gave to the question of why they thought the sea or the black objects stopped advancing or to the story summary task in the follow-up iteration. Considerably more participants of the non-plot group provided creative answers imposing the notion of causality and agency to particles in some form by either anthropomorphising and objectifying the particles in their minds or providing elaborate explanations of particle interaction. However, it depends on the authorial intent, whether guiding someone's thoughts is a desirable effect or not, or if a visualisation requires a certain degree of creative thinking and problem-solving.

Another finding that was made was the effect of screening the solution videos at the end of each prediction task in the primary run. The previous solutions likely influenced the decisions in the subsequent set-ups. The effect is apparent in the path prediction, the intersection analysis, and the quantity prediction. Nevertheless, the effect could also be based on the differences in the test designs. However, no such effect was observed in the follow-up run, where no solution videos were shown after each round.

4.5.3 Long-term effects

The results of the story summary task where a possible long-term effect was investigated were ambiguous. Following (Herman et al., 2010) that the mental processes forming a story in a reader's mind *"are the products of understanding that are stored in long-term memory"*, one would expect that participants of the plot condition were better equipped to remember what they have seen two weeks prior. While only one participant of the non-plot group did not remember at all, almost a tenth of the plot group participants were not able to recall any facts about the narrative. However, more participants of the plot group provided a very detailed summary of the narrative, which in turn would allow arguing for a long-term effect.

Concerning the long-term effects, it should be noted that the same trends in the scenario prediction tasks were observed in the follow-up as in the primary iteration, especially for the intersection analysis, the "in area" quantity predictions, and the use of terminology in the explanations. This would indicate that the same rationales were used to solve the prediction tasks two weeks later. However, the initial differences regarding the Fréchet distance were not observed in the follow-up iterations, arguing against a long-term effect.

4.5.4 Limitation and Alternatives

The project was done early in the PhD. In hindsight, a few aspects could have been designed differently in order to reduce the complexity of some tasks. While the spatial thinking task worked well as a distraction, it was too complicated for the majority of participants, which were over-challenged and performed very poorly. Thus, the results were not used for the analysis. Although piloting did not suggest this difficulty, three more simple mazes would have been sufficient (instead of increasing the complexity). In several tasks, participants had to input their answer with sliders (e.g., ranging from zero to 100). It appeared that this type of input device influenced responses. Participants were tempted to choose values closer to the centre, than lower or higher values. Hence, participants in both conditions overestimated small values and underestimated larger values. For the interactive path predictions, easier click operations could have replaced the drag and drop handles. Because even if just one handle was not adjusted (e.g., the first or the last one, compare Figure 4.11) the Fréchet distances were more likely to be higher, even if the rest of the path was close to the correct one. As an alternative to the distance analysis, clusters were visually detected and discussed. A computational cluster analysis of the predicted paths in combination with the intersection analysis and the text-based justifications may reveal further insight.

When conducting crowdsourcing-based surveys, there are factors one cannot control easily. There is always the risk that participants are distracted or do other things (or HITs) at the same time. Furthermore, it is not possible to guarantee that an individual performing the survey is, in fact, the person associated with an MTurk account, even if unlikely. On the other hand, surveys (Borgo et al., 2018; Heer and Bostock, 2010) had demonstrated the reliability of crowdsourcing experiments. The most significant benefit is that this approach allows collecting a large sample size in a short amount of time. Nevertheless, if time and resources would have allowed, it would have been interesting to investigate if in a controlled in-house set-up the results would replicate.

During the design phase of the experiment, several alternatives were considered – for example, the use of an audio channel besides the text-based emplotments. As the results suggest, shifting the narration to the audio channel may allow focussing visual processing exclusively on the particle animation. However, because it was a crowdsourcing-based experiment, the audio channel was not used; it would have been hard to control if all participants were able to playback sound. Additional conditions were considered, but ultimately they were not implemented. Two scenarios with a high degree of narrativity, a blood flow and an oil spill scenario were not added since the capabilities of the experiment would not have changed. Text-only or visual-only conditions would influence comparability with the two conditions used (i.e., not all tasks could be used). Therefore, they were not considered.

4.5.5 Conclusion

The results could not confirm the initial assumption that a tale-like emplotment with a dedicated narrative arc is superior to a descriptive emplotment regarding memorability and comprehensibility. The differences found, although sometimes statistically significant, were small. Nevertheless, patterns in the results suggest that text-based anthropomorphisation and objectification can lead to a better overall understanding but can, on the other hand, hinder visual processing and creative thinking.

While these results are difficult to generalise due to their lack of clarity, a few considerations can be made regarding the Flowstory design space. Using text-based elements to convey a narrative with a specific structure can help to communicate the temporality of depicted events. Explicit, verbal anthropomorphisation and objectification of flow marks and other visual elements can support the central message and can reach readers on an emotional level (i.e., feeling more connected to humans than to particles). On the other hand, contextual information presented in a juxtaposed way can distract visual perception of the main flow display (at least for animations). Hence, this is an additional supporting argument for the discussion of the audio channel's potential in visual data storytelling (see Section 3.5).

Finally, the designed stimuli and tests were fictional and very abstract. On the one hand, these designs allowed to isolate the tested effects and minimise confounding factors (e.g., control for any prior knowledge of participants; no one was familiar with the stimuli), on the other hand, they were far from a real-world storytelling scenario people would usually encounter in their daily lives (e.g., in journalistic data storytelling). Additional findings were that the tasks were rather too complicated and lengthy. These considerations were taken into account when designing the second experiment, which is explained and discussed in the next chapter.

Chapter 5

Structure and Empathy: Evaluating their Effect on Attitude

The second empirical research project, consisting of two between-subjects experiments, addresses the forth objective formulated at the onset of this work. This experiment contributes to the emerging body of work by investigating whether selected techniques commonly used in visual data storytelling influence people's attitudes towards the topic of immigration. The chapter contains a motivational statement, a description of the different stimulus designs, a discussion of the experimental conditions and procedures, and an analysis and discussion of the results. This chapter is based on a full paper (Liem et al., 2020), which was virtually presented[1] at EUROVIS 2020[2]. Additional material is available online[3].

5.1 Motivation

Many assumptions about the benefits and efficacy of storytelling in visualisation lack empirical evaluation - as already discussed in previous sections. Only a handful of studies investigated claims that visual data storytelling make visualisations compelling, memorable, understandable, engaging, or persuasive through controlled experiments (see Section 2.2.3). The little empirical evidence merits additional studies investigating new effects and conditions in visual data storytelling. No study has looked at the effect of

[1]https://youtu.be/1r0MtxQoQHc?t=1045
[2]https://conferences.eg.org/egev20/
[3]https://flowstory.github.io/attitudes/

visual-narrative techniques – the tools used in visual data storytelling to create narratives – on people's attitude.

In this study, the question *"Can visual-narrative techniques influence people's attitudes?"* was investigated. In order to address this question, it was explored whether some selected visual-narrative techniques often used in visual data storytelling, influence people's attitudes towards the contentious topic of immigration. To measure attitudes towards immigration, well-established scales from social sciences used by the European Social Survey[4] (ESS) since 2002 (Jowell et al., 2007) were adopted. Two crowdsourcing between-subject experiments with 300 participants each were conducted to compare (a) personal visual narratives designed to generate empathy, (b) structured visual narratives of aggregates of people, and (c) a fully exploratory visualisation without the use of any visual-narrative techniques acting as a control condition.

The two slightly different experiments were conducted to account for the fact that prompting participants with questions about immigration before they were exposed to the stimulus might bias the results: in *experiment 1*, participants were asked questions about immigration both before and after the stimulus (pre-post-test design), while in *experiment 2* they were asked these questions after the stimulus only (post-test design).

When considering the distinction between inside-out and outside-in approaches, which was established in Section 2.2.1.6, this experiment uses an outside-in approach to assess the effect of two established narrative techniques (structure and empathy) in a visualisation. As previously stated, this angle can reveal insights about the mechanisms of storytelling as a whole, thus expanding the space of visual data storytelling. For example, the outside-in approach was used to create a set of 16 narrative patterns for data-driven storytelling (the NAPA Cards[5]) (Riche et al., 2018) based primarily on narrative techniques from film and literature. The outside-in approach made it possible to identify five categories of narrative patterns (flow, empathy, framing, argument, and engagement). Techniques listed in this project, mainly ones belonging to the categories flow (structure) and empathy, were used in this investigation.

Only to recall, previous studies that have assessed the effects of **structure** or **empathy**, or that are related to **attitude** in the context of visual data storytelling are briefly summarised. The background chapter provides a comprehensive discussion of previous work and studies in visual data storytelling.

[4]https://www.europeansocialsurvey.org/
[5]http://napa-cards.net/

Visual-Narrative techniques for structure: A first group of studies have looked at the *overall structure and sequencing* of visual narratives. Badawood and Wood (2014) found that delivery mode (author-driven vs. reader-driven, Segel and Heer (2010)) has a small effect on participants' story reconstruction. Hullman et al. (2017) found that participants created and preferred hierarchical structures for sequencing, based primarily on space, and not on time or measure. Hullman et al. (2013), in a study about transition types, found that sequences with parallelism – repeating patterns of transition types – as a structural device are beneficial for memorability. McKenna et al. (2017) found that visualisations (compared to just text) and animated transitions (triggered through stepper buttons and scrolling) improve reader-perceived engagement.

A second group of studies investigated the effect of *providing structure by adding narrative sections* to common visualisations. Boy et al. (2015) found that adding visual data storytelling before exposing people to a visualisation did not increase their activity levels and immersion. Dimara et al. (2017) found that adding backstory narratives to crowdsourcing evaluations of visualisation tools did not result in higher accuracy and attention for the tasks they tested and does not provide subjective benefits in terms of confidence, enjoyability, and perceived easiness and usefulness. Diakopoulos Diakopoulos (2010) found that asking quiz questions to structure an exploratory stimulus encouraged people to interact more.

A third group of studies have looked at the effect of *visual structure*. Borkin et al. (2013, 2016) found that the use of human-recognisable objects such as pictograms may enhance memorability, comprehension, and recall. Amini et al. Amini et al. (2018) found higher viewer engagement levels for animated data videos and clips with pictograms compared to static standard charts. While animated pictograms were preferred to the other conditions, static standard charts tended to be preferred to static pictograms and animated standard charts.

Visual-Narrative techniques for empathy: To date, only Boy et al. (2017) have investigated empathy. They ran a series of crowdsourced experiments comparing anthropomorphised data to standard charts embedded in a narrative context. They found no conclusive evidence that emotion-evoking narratives have an effect on people's empathy.

Studies related to attitude: Studies in persuasive visualization Pandey et al. (2014) and cartography Muehlenhaus (2012) found that visualisation types (e.g., bar charts, line charts, and tables) or map styles (e.g., propagandist, authoritative, and sensational) can influence the visually conveyed message. By utilising persuasion theory models, attitude and attitude change have been used as proxies to measure persuasiveness O'Keefe (2016);

Pandey et al. (2014). Kong et al. Kong et al. (2018) showed that persuasively worded titles of visualisations on controversial topics could influence the perceived message but do not have a meaningful effect on attitude change.

Many of the related studies, tend to report relatively small effects, often contrary to initial expectations (e.g., Badawood and Wood (2014); Boy et al. (2015, 2017); Dimara et al. (2017)). Other fields investigating narrative persuasion face this challenge as well (e.g., psychology, advertisement, and health) (Dillard and Shen, 2012; O'Keefe, 2016).

This study, unfortunately, joins these studies. While statistically significant effects were found in this study, the magnitudes of the effect sizes are small. Contrary to what was expected, neither personal narratives designed to generate empathy nor structured narrative designed to help people understand facts influenced participants' attitudes strongly. The findings suggest that the visualisation community needs to be more careful when it comes to their expectations about the effects visual data storytelling can have on attitudes.

5.2 Experiment Rationale and Materials

To investigate the effect of visual-narrative techniques used in visual data storytelling on attitude, a dataset on the contentious topic of immigration was selected. An **interactive flow map** (see Figure 5.1) was designed to explore the data and generate narratives for use in two other designs.

In order to isolate the effect of each visual-narrative technique, diverging visual narratives concerning two categories of visual-narrative techniques (*empathy* and *structure*) were created. For example, while the **empathy** design (see Figure 5.2) has a first-person perspective and an unstructured story flow, the **structure** design (see Figure 5.3) uses a third-person perspective and a structured story flow. The aim was to create two distinguishable visual-narrative designs without reusing techniques. Next, the selection of the story topic and data, the three studied designs, and how values and attitudes are tested in the ESS are described.

5.2.1 Selection of Story Topic and Data

The topic of immigration was selected because it is regarded as contentious, and people's beliefs towards immigration are strongly held. A dataset based on the International

Passenger Survey[6] about long-term migration was used. The data offer enough detail to create meaningful visual narratives (i.e., it includes the reasons why people migrate, and it covers a relatively long period on a global scale).

For the study, several adjustments were applied to the dataset to reduce the visual and thematic complexity. In order to ensure the significance of the topic, at a time where immigration is at the heart of discussion (with 'Brexit', in particular), only people born and living in the UK were targeted to participate in the study. Thus, only the migration data between the UK and other countries in the European Union (EU) were selected for the visualisation designs. Additionally, missing values were interpolated, and massive migration flows were truncated to make values more comparable overall (e.g., Poland in 2007).

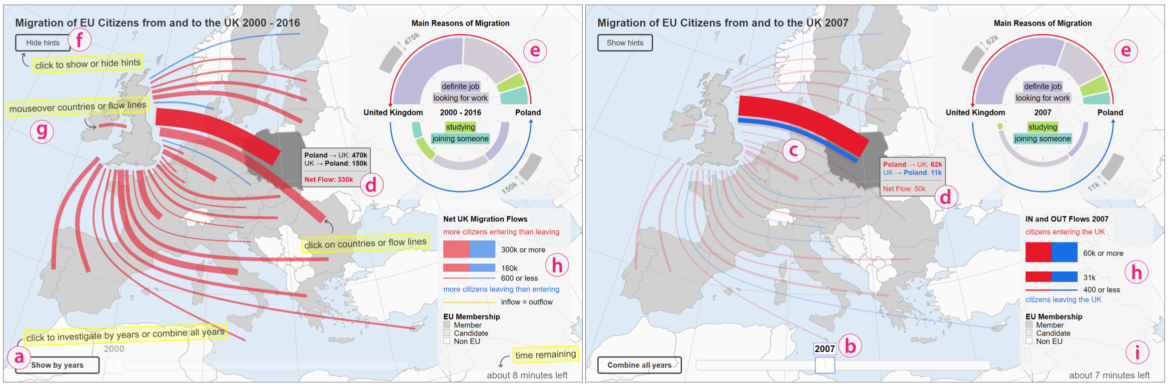
5.2.2 Baseline Design: *Interactive Flow Map*

Figure 5.1 shows a radial flow map of migration data between the UK and other EU countries. Interactions allow to show the data by year or aggregated, obtain details about specific countries, see inflow and outflow migration volumes and see the primary reasons for migration to and from the UK. Based on design principles for origin-destination flow maps (Jenny et al., 2016c), line intersections were avoided, symmetrically curved line shapes were used, and an angular distribution at nodes where many flow lines intersected were used (i.e., around the UK). Geospatial flow maps were used because (1) they are a familiar and suitable way to display migration data, and (2) the concepts of space and time are essential both in movement visualisation and in narration. In (geographic) visualisation, any movement always has a spatial and a temporal component. In narration, time (e.g., allowing to move a story forward) and space (e.g., as a framing device with its metaphorical or emotive potential (Herman et al., 2010)) also play essential roles.

5.2.3 Visual-Narrative Design 1: *Empathy*

In the empathy design, clicking on one of the six available fictional "heroes" makes them tell their personal migration journey, using a direct speech from a first-person perspective. Each narrative unfolds in a chronological order using text boxes. For example, Figure 5.2 shows part of Jakub's journey, which started when he was unable to find work in his

[6] https://www.ons.gov.uk/



Migration data aggregated over all years (from 2000 to 2016) with the mouse hovering over Poland

Migration data for the current year (2007) with Poland being selected

Figure 5.1: ***Interactive flow map:*** On the left is the default view. A radial flow map shows aggregated net migration flows (outflow minus inflow) between the UK and other EU countries for 2000 to 2016. A red line means more people are arriving than leaving the UK, and a blue line means more people are leaving than arriving. Line thickness encodes net migration flow volume. Clicking on **button (a)** switches between the aggregated view on the left and the detailed view on the right. The detailed view shows the data for a single year, that can be set using a **time slider (b)**. Here, Poland has been selected (by clicking on the country or its corresponding flow line). This replaces the net migration flow between the UK and Poland with the inflow (in red) and outflow (in blue) for that country **(c)**. Animations reinforce the direction of movement, already encoded with red and blue colours. Hovering over lines and countries shows an **annotation box (d)** with migration numbers. The doughnut-like chart **(e)** shows the distribution of the four major reasons for migration for the selected country, or all countries if no country is selected. **Button (f)** shows and hides **hints (g)** on how to use the interactive map. The dynamic **legend (h)** provides information about how to read the map elements. A text-based **countdown (i)** shows remaining exploration time.

hometown in Poland and migrated to the UK to find a job. All personas and their stories are fictional and were created for the study.

The motivation behind the migration, the act of migrating, and the situation in the UK, is mirrored in a visual form using isotype-like characters (e.g., for Jakub: , , ,). Two of the six characters go back to their home country in their stories to reflect the fact that migrations happen in both directions.

Following the idea of the NAPA Card 'humans-behind-the-dot', the six narratives of migration were used to show that individuals with personal stories are the foundation of the data shown in the interactive flow map. This technique is used to *"make abstract data more relatable, and possibly establish an emotional connection between the viewer and the fate of the entities"* (Riche et al., 2018). Anthropomorphised data graphics were used to represent each stage of a story, despite no evidence that this elicits empathy (Boy et al., 2015). For example, to communicate that Jakub was unhappy when unemployed, an icon of a sitting person with a hanging head was used. Additionally, visual hooks through

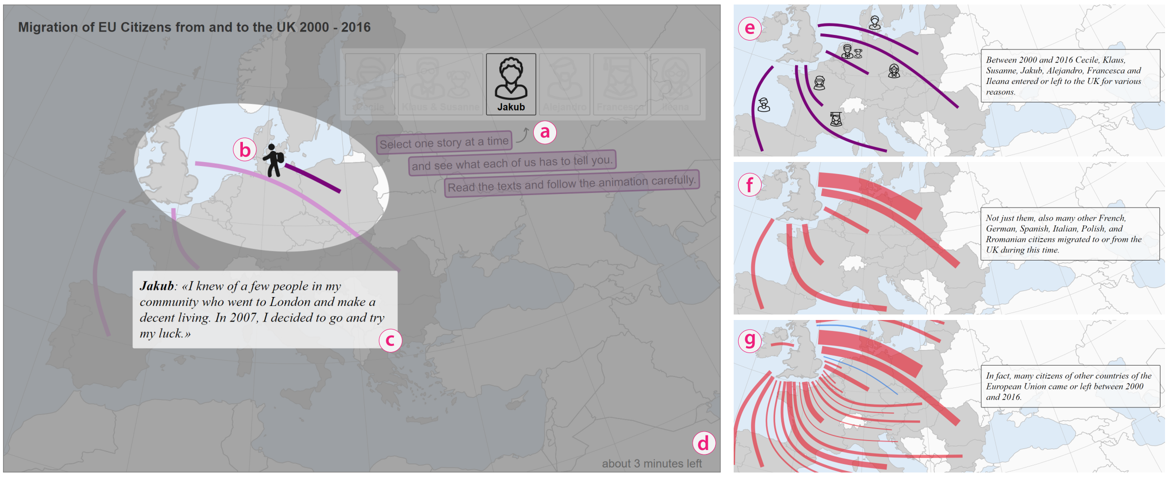


Figure 5.2: ***Empathy* design:** Selecting one of the six **personal narratives (a)**, plays back the narrative on the map using **animated flow lines and isotype-like characters (b)**. In a **text box (c)**, the character tells her or his personal migration story from a first-person perspective. When the text-based **countdown (d)** in the lower right corner expires, a **transition sequence (e–g)** transforms the view into the interactive flow map.

abstract faces and names common in each hero's country of origin (see Figure 5.2(a)) were implemented, based on ideas and findings from memorability research Borkin et al. (2013, 2016). Finally, "story focus" was used, a technique used in narrative maps Mocnik and Fairbairn (2017) that draws attention to a specific part of the display. In this study, the area between the UK and the other country in the narrative was emphasised (see Figure 5.2).

A 30-second-long, non-interactive transition transforms the empathy design into the interactive flow map. During that transition, the lines representing personas morph into the net flow lines of their respective countries (see Figure 5.2(e–f)), then the flow lines of all countries which were not part of the narratives fade in (see Figure 5.2(f–g)). This transition was designed to communicate that there are many more individual migration journeys than the six presented.

While each personal narrative possesses a narrative structure, the design is overall unstructured: viewers decide the order in which they want to see the stories. Narrative sequencing techniques are the focus of the next design.

5.2.4 Visual-Narrative Design 2: *Structure*

The structure design, illustrated in Figure 5.3 differs from the empathy design in that it presents a structured narrative, uses a third-person narration style, and shows aggregated groups of people (citizens of countries) rather than individuals.

The structure design consists of six thematically-ordered stages. The first stage provides background information about the data and the map. The following four stages (or 'quiz' stages) each discuss a theme based on one or several countries: The first two discuss the growth of the EU, the third how several countries have had stable migration for a long time, and the fourth the differences between positive and negative net flows. Each quiz stage first shows a narration that introduces the topic, then asks a question related to this topic. The second part of the quiz stage reveals the solution to the question and shows additional information about the flow volumes and the major reasons for migration. The last stage is a transition to the interactive flow map, similar to the one for the empathy design.

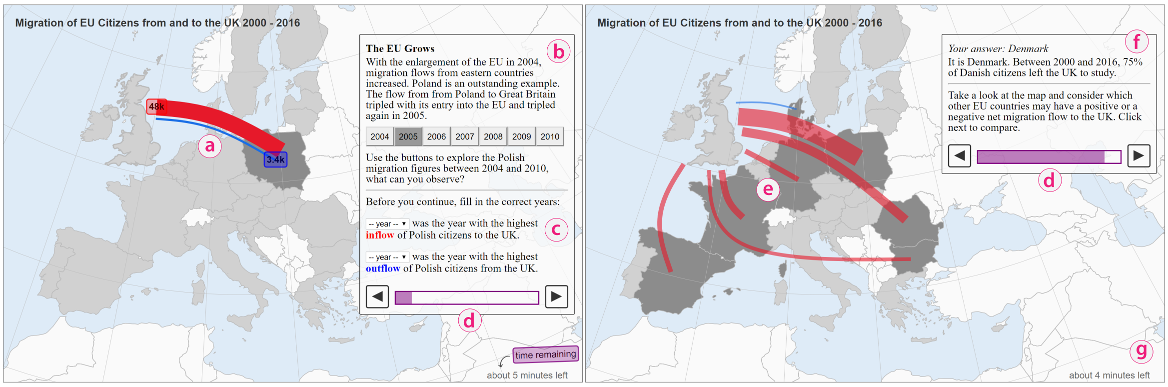
Using repetitions of transitions (in this case, question and answer transitions in the quiz stages) was found to be beneficial for memory (Hullman et al., 2013). Besides providing a structure through narrative sequencing, these questions ensured that participants would actively engage with the data space (Diakopoulos, 2010) and avoid them clicking through the story quickly.

Because stepper and scroll stories with animated transitions increase the level of engagement and immersion (McKenna et al., 2017), the participants had control over reading speed and the ability to go back in the narrative with the progress bar shown in Figure 5.3(d). This design was also informed by the NAPA Card 'gradual visual reveal', a technique that helps *"the story unfold in the viewer's mind while reading the graphic, to chunk the material, and to make it easier to absorb"* (Riche et al., 2018).

The next explains how people's attitudes are subject to variation when exposed to stimuli, making attitudes a promising dimension to explore further.

5.2.5 Values, Attitudes, and the European Social Survey

In this section, *human values* and *attitude* are described to explain why and how this investigation assessed the effect visual data storytelling can have on attitude towards a sensitive topic, and why immigration was used in particular.



First part of first quizz stage 'The EU grows' — Second part of fourth quizz stage 'Inflow vs. Outflow'

Figure 5.3: ***Structure* design:** The image on the **left** shows the first part of the first quiz stage of the structure design, showing the **inflow and outflow (a)** of Poland, with labels showing the numeric values at the end of the flow lines, also indicating direction. The panel on the right-hand side contains: a **text-based narration (b)**; interactive elements to update the map (buttons to select a year in that page); and a **question (c)** that the interactive elements in the panel can help to answer. The **navigation element (d)** at the bottom of the panel has the appearance of a progress bar and can be used to go forward and backwards in the narration. The image on the **right** shows the second part of the last quiz stage, showing **net migration flows (e)** for selected countries. Each second part of a quiz stage provides the **answer (f)** to the question asked in the first part. When the text-based **countdown (g)** in the lower right corner expires, a **transition sequence** transforms the view into the interactive flow map.

Human values are *general principles in life, or basic broadly immutable beliefs, that inform more mutable attitudes and opinions* (Davidov and Meuleman, 2012; O'Keefe, 2016). **Attitude** refers to *an individual's evaluative judgement about a stimulus object, which can be anything that is liked or disliked (e.g., individuals, groups, events, products and abstract concepts)* (Maio and Haddock, 2015). While values are quite stable over time, attitudes can be influenced in various contexts and situations (Davidov and Meuleman, 2012). This characteristic makes attitude a good measure to study, given its potential sensitivity to external stimuli.

Human values and attitudes have been collected and analysed by the European Social Survey[7] (ESS) across Europe since 2002 (Jowell et al., 2007). The ESS is a face-to-face survey measuring attitudes towards various aspects of our daily lives (e.g., political engagement, moral and social values, well-being and security). The ESS is relevant to this work because it measures both human values and attitudes towards immigration.

The ESS uses 21 questions to measure ten values from the human value scale (Schwartz, 2007) (e.g., universalism, benevolence, tradition and security), which can be aggregated

[7] https://www.europeansocialsurvey.org/

into two bipolar dimensions (from *self-transcendence* to *self-enhancement*, and from *openness to change* to *conservation*) (Davidov and Meuleman, 2012; Schwartz, 2007).

To measure attitudes towards immigration, the ESS contains seven questions[8] that identify respondents' opposition to different groups of migrants (Davidov and Meuleman, 2012), as well as the extent to which they perceive immigration as a threat (Markaki and Longhi, 2013). Research in social sciences (Davidov and Meuleman, 2012; Davidov et al., 2008, 2014) used the ESS data to show that attitudes towards immigration can be explained by some of these human value dimensions, along with demographic and contextual variables. Previous work found that self-transcendent individuals have a more positive attitude towards immigration, while more conservative people have a more negative attitude towards immigration (Davidov and Meuleman, 2012; Davidov et al., 2014).

This work is based on the assumption that in addition to the relation between less mutable values and more mutable attitudes established in social sciences, visualisation – especially the ability visual narratives have to engage with a topic – can play a role in shaping attitude.

5.3 Studying the Effects of Structure and Empathy on Attitude

In order to test whether the structure and empathy visual-narrative techniques are effecting attitude towards immigration, two between-subject experiments with three conditions each were designed. Both experiments are identical except in experiment 1 a pre-post-test design to assess attitudes towards immigration was used before and after the stimulus; while in experiment 2 a post-test design to assess attitudes towards immigration was used after the stimulus only (see Figure 5.5). The design of experiment 1 makes it possible to measure the change in attitudes, thus yields more experimental power. The design of experiment 2 yields less power but accounts for conservatism bias (Nissani, 1994; Oechssler et al., 2009). Indeed, asking participants questions about immigration before the stimulus is likely to act as a confounding factor affecting the results.

The mentioned related studies test either (a) *objective performance measures* including accuracy, correctness, recall, activeness or time (e.g., Borkin et al. (2013, 2016); Boy et al. (2015)), or (b) *subjective metrics* based on self-reported perceptions of engagement, enjoyability, preferences or comprehension (e.g.,Amini et al. (2018); Figueiras (2014a); Hullman

[8] https://essedunet.nsd.no/cms/topics/immigration/1/2.html

et al. (2017); McKenna et al. (2017)), or (c) a combination of them (e.g., Dimara et al. (2017); Hullman et al. (2013)). Such studies often use between-subject designs (e.g., Boy et al. (2015); Diakopoulos (2010); Muehlenhaus (2012)) that imitate realistic settings. This study follows this approach by providing a single, complex and long enough stimulus to each participant, which allows controlling for learning effects when assessing attitudes.

Next, the conditions, the study procedure, the data collected, and the participants are described. Supplemental material, the questionnaire and the interactive conditions are provided online[9].

5.3.1 Experimental Conditions

The three conditions are based on the designs presented in Section 5.2. In the **Exploration** condition, participants explored the interactive flow map for 8 minutes. In the **Empathy** condition, they interacted with the empathy design for 4.5 minutes, and then the 30-second-long animation transitioned to the baseline design, which they could explore for 3 minutes. In the **Structure** condition, they interacted with the structure design for 5 minutes, and then a 2-second-long animation transitioned to the baseline design, which they could explore for 3 minutes. These timings ensured that participants in each condition were exposed to the data for the same amount of time (8 minutes). To ensure that they were also exposed to the same level of detail of information, both storytelling conditions transitioned to the interactive flow map after 5 minutes. The stories in the storytelling conditions focus on the same countries, and they reflect the major reasons for migration in a balanced way.

Before deploying the study, a pilot study with 13 experts in visualization and cartography was run. Piloting helped to adjust the timings so the experiment was neither too short (and frustrating for the participants) or too long (and participants would likely lose focus). Also, qualitative feedback was collected that helped to clarify the instructions.

5.3.2 Questionnaire Design

In order to measure participants' human values and attitudes towards immigration, as described in Section 5.2.5, 28 questions were designed. All questions had a "Prefer not to say" option, but participants were asked only to use that option if they were uncomfortable

[9] https://flowstory.github.io/attitudes/

answering the question. Because of the sensitivity of the topic, they were reminded that all information provided was anonymous.

The first 21 questions assess human values, from which one can derive two bipolar dimensions: one from self-transcendence to self-enhancement; one from openness to change to conservation (Davidov and Meuleman, 2012). The questions are statements describing a person, such as, “She thinks it is important that every person in the world be treated equally. She believes everyone should have equal opportunities in life”. Participants then indicated to what extent they are similar to the described person on a six-point scale ranging from “not like me at all” (1) to “very much like me” (6). The gender of the person in the statement was adapted to the participant’s gender from the demographics questionnaire (or female if a participant did not disclose the gender).

The last seven questions are from the UK version of the ESS and assess attitudes on immigration. Four questions assess *opposition to immigration* by asking how many people of certain groups should be allowed to come to the UK on a four-point scale ranging from “allow many” (1) to “allow none” (4). The groups asked about are people “of same ethnicity”, “of different ethnicity”, “from poorer countries outside Europe”, and “from poorer countries inside Europe.” The other three questions assess *perceived immigration threats* on an 11 point scale ranging from “no threat” (0) to “high threat” (10). These questions ask whether immigration is good or bad for the economy, if immigration enriches or undermines cultural life, and if immigration makes a place better or worse to live.

Participants were asked to answer demographic questions used by models linking human values with attitudes towards immigration (Davidov and Meuleman, 2012; Davidov et al., 2014) including gender, age, the highest level of education, subjective income, religion and political preferences. In the next section participants (i.e., recruitment, filtering, and) are described in more detail.

5.3.3 Participants

For each experiment, 300 participants were recruited through Prolific[10], a UK based crowdsourcing platform focusing on academic studies. Since Prolific users can decide if they want to take part in a listed study, it is a self-selected sample. Nevertheless, Prolific’s pre-screening tool was used to constrain the participation to adults (*age* 18 or older) who are UK *citizens*, were *born* and currently *reside* in the UK, and whose first language is

[10] https://www.prolific.co/

English. These *UK criteria* were used because the topic, dataset, and questionnaire were selected with the UK in mind.

To ensure a high quality of results, only participants who had previously participated in five or more studies (participants of this experiment had participated in around 90 studies on average) with an approval rate of 80% or higher were eligible to take part in the study (over 80% of participants had a 100% approval rate, minimum was 90%). Since all participants lived in the UK, participants were paid 2.50 GBP, which is the UK minimum wage [11] for 20 minutes of work (90% of the participants finished within 20 minutes).

Besides this initial filtering, **participants were discarded** based on (a) failing to answer all filter questions, (b) how quickly they answered individual questionnaires, (c) how often participants selected the same category, and (d) how often they selected ‘prefer not to say’. While thresholds for (b) were based on the pilot study, the thresholds used for (c) and (d) were recommended by the ESS. Applying these filters, discarded 10% of participants of experiment 1 and 6% of experiment 2, which were distributed evenly across the conditions. The filters were defined and applied before taking a closer look at the responses or running any analysis. The breakdown of numbers and detailed rationales for these filters are listed in Table 5.1.

Overall, the differences in the demographic structure were small across conditions for each experiment. In both experiments and across all three conditions, the **male to female ratio** was around 4:6, which is similar to the ESS data. The **age** distribution is comparable across conditions and experiments. In experiment 1 participants of the exploration group were slightly older on average. In experiment 2 participants of the empathy group were younger on average. Compared to the ESS data, the participants of the experiments were, on average more than ten years younger. Compared to the ESS data, the participants of both experiments have a higher **level of education** on average, but are very similar across conditions for each experiment. The majority of participants can cope or live comfortably on their current household **income**. More participants of the ESS tend to live comfortably on their present income than the participants of the experiments. Overall participants of both experiments are not very **religious**. In experiment 2 participants of the structure conditions are more religious than participants of the other conditions (mean difference of around 15%). In average participants placed themselves on the centre-left side of the **political spectrum**. Participants of the exploration condition of experiment 2 were slightly more left. Figure 5.4 shows the results of the demographic questionnaire.

[11] https://www.gov.uk/national-minimum-wage-rates

Table 5.1: Filter descriptions and rationales for excluding participants.

Filter	Experiment 1	Experiment 2
Filter questions		
Participants who failed to answer all 3 filter questions correctly, because they would not have engaged with the stimulus.	2	3
Timing		
Participants who answered more than 7 questions about human values in less than two seconds each.	5	4
Participants who answered more than 2 questions about immigration in less than two seconds each.	pre: 0 / post: 15	2
Participants who answered all 21 human value questions in less than a minute overall ($21 questions \times 3 seconds = 63 seconds$).	4	4
Participants who answered all 7 immigration questions in less than 21 seconds overall ($7 questions \times 3 seconds = 21 seconds$).	pre: 0 / post: 14	5
Based on the pilot study, it was determined that it is not possible to respond carefully to these questions in less than three seconds on average.		
Contradiction and 'prefer not to say'		
Participants who selected the same category for more than 16 questions of the human values. This would imply the participant provided contradictory answers.	2	1
Participants who selected 'prefer not to say' to more than 5 of the human values questions.	1	0
Participants who selected 'prefer not to say' to more than 2 of the 4 opposition to immigration questions.	pre: 4 / post: 2	3
Participants who selected that option to more than 1 of the 3 perceived immigration threat questions.	pre: 0 / post: 1	1
Averaging too few responses could distort the results. The thresholds used are those recommended by the ESS.		
Number of occasions filters applied	50	23
Participants discarded by more than one rule	19	5
Overall filtered participants	**31**	**18**
Numbers of recruited participants	304	300
Numbers of selected participants for condition …	**273**	**282**
… Empathy	91	91
… Structure	92	97
… Exploration	90	94

5.3.4 Procedure

The study had three phases (see Figure 5.5): pre-stimulus, stimulus, and post-stimulus. The pre-stimulus phase in experiment 1 included the pre-test to assess attitudes towards immigration before the stimulus, while experiment 2 did not. The post-stimulus phase was identical across experiments and conditions.

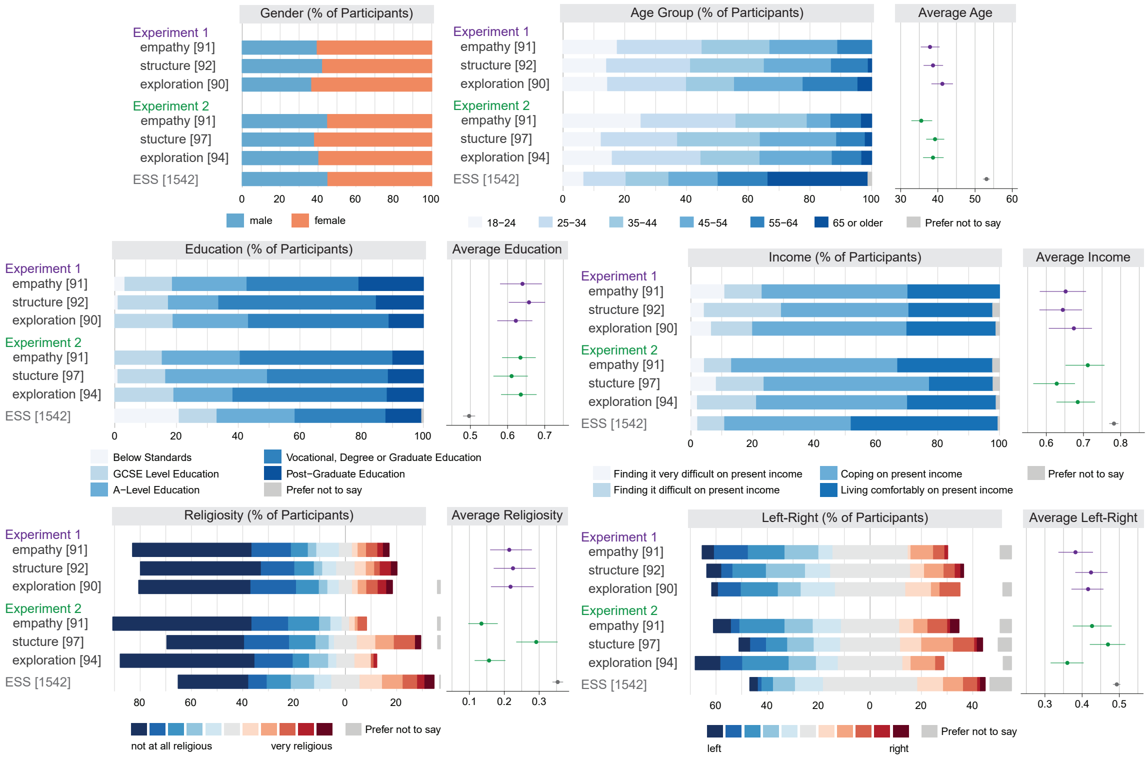


Figure 5.4: Results of demographic questionnaire across experiments and conditions. The Likert plots show the distribution of gender, age groups, level of education, income, religiosity, and political orientation. The plots on the right show the average values together with 95% BCa confidence intervals (CIs).

5.3.4.1 Phase I: Pre-Stimulus

Participants were redirected to the Qualtrics[12] experiment after they had selected the study in Prolific. Using meta information collected by Qualtrics, it was checked that participants were using a desktop or a laptop computer, and a compatible web browser. Participants who did not fulfil these requirements were asked to open the study on an accepted device or with a compatible browser.

After reading through and accepting the informed consent form, participants were informed of the study duration and their tasks. They were told that they would be asked to answer demographic questions, engage actively with a visualisation, and answer a set of questions demonstrating that they understood and remembered what they had seen and learned while interacting with the visualisation. The latter instruction was added to encourage participants to actively engage with the stimulus. To ensure consistency of stimuli, participants were asked to maximize their browser window and adjust its zoom

[12] https://www.qualtrics.com/

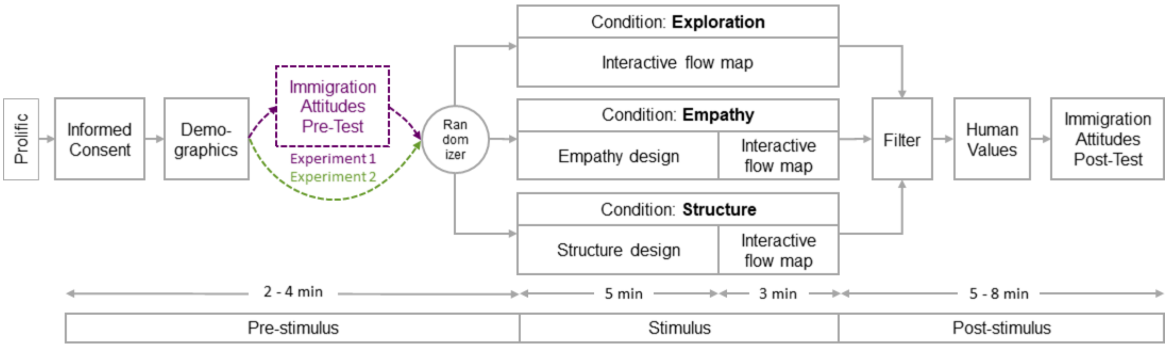


Figure 5.5: Procedure for both experiments: participant recruitment through Prolific; informed consent and instructions, demographic questions, attitudes towards immigration questions (experiment 1 only), stimuli, filter questions, questions about human values and attitudes towards immigration.

level so that a red frame indicating the size of the visual stimuli was fully visible. Participants were also reminded to stay in front of the computer during the study, and to not switch tabs or browser windows.

Participants then answered the demographic questionnaire. Participants of experiment 1 then answered the seven questions about attitudes towards immigration in a pre-test. They were then informed that the next screen would show the visualisation and that they would have a few minutes to interact with it. They were also informed that their remaining time would be indicated in the bottom right corner of the display.

5.3.4.2 Phase II: Stimulus

Participants were randomly assigned to one of the three conditions (Exploration, Structure, and Empathy). They spent 8 minutes interacting with their assigned stimulus, as described in Section 5.3.1.

5.3.4.3 Phase III: Post-Stimulus

The post-stimulus phase started with three filter questions asking the colour used for the migration inflow (red), the country with the greatest migration flow to the UK over the entire time (Poland), and the primary reason for migration (labour). Participants were then asked to answer the 21 questions about human values and seven questions about attitudes towards immigration. The immigration items introduced a repeated-measure element in the between-subject design for experiment 1. Each question was shown on its own page.

The questions were worded and ordered in the same manner as the ESS questionnaire. The human values questionnaire was not placed before the visual stimulus because of its repetitive form and length. The goal was to keep the concentration high when participants were interacting with the visual stimulus. Although there is the chance the visual stimulus also influenced how participants answered the human values questions, human values tend to be stable over time. The immigration attitudes questions were placed at the end, to be not too close to the visual stimulus.

Once participants had answered all questions, they were informed that the study was designed to test the influence of visualisation on attitudes towards immigration. This detail was deliberately withheld until the end to not bias the study by priming participants. Lastly, participants could leave free-form comments in a text field, and then they received a code to use within Prolific to claim their financial compensation.

5.3.5 Hypotheses

The expectation was to observe differences between the three conditions, with respect to attitudes towards immigration. Specifically, the hypotheses were as follows:

$H_{empathy}$: Participants in the empathy condition will be more positive towards immigration than participants in the structure and exploration conditions. The rationale is that the visual-narrative techniques used let participants relate to the individual fates reported.

$H_{structure}$: Participants in the structure condition will be more positive towards immigration than participants in the exploration condition. The rationale is that a view dependent on narrated information rather than assumptions about immigration (when exploring data) might lead to more positive views, and that a structured navigation might lead one to understand the information more clearly.

5.4 Analysis and Results

Before running any analysis, participants were filtered regarding multiple criteria, as described in Section 5.3.3. The analysis was conducted in two stages. After the confirmatory analysis investigating the expectations, an exploratory analysis phase added additional perspective for the discussion.

While participants answered on ordinal scales, the concepts and phenomena (attitudes towards immigration and human values) behind them are considered continuous in the social science literature (e.g., Davidov et al. (2008, 2014)). Therefore, the results were treated as continuous variables.

The results of the attitudes towards immigration variables **opposition** and **perceived threat**, and the **human values** are reported for each experiment and condition. For experiment 1, the pairwise average difference between the pre-stimulus and the post-stimulus attitudes was calculated as well. The figures in both result sections show the normalized sample means together with 95% BCa confidence intervals (CIs) based on 10,000 bootstrap replicates. For the interpretation of the statistical significance of the overlap of CI error bars, please see Krzywinski and Altman (2013).

5.4.1 Confirmatory Analysis

The four higher-order variables of the **human values** (e.g., openness to change, and conservation) are similar across conditions for both experiments and are within the range of the ESS. The plots in Figure 5.6 show that the differences across conditions within an experimental run of the human values are 5% or less, and therefore comparable.

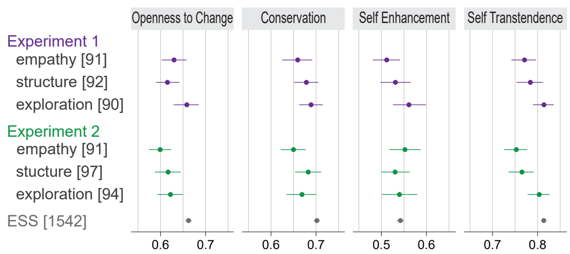


Figure 5.6: Normalized [0..1] higher-order values "Openness to Change", "Conservation", "Self Enhancement", and "Self Transtendence" by conditions and experiments.

Across both experiments, all conditions, and both variables the attitudes of participants towards immigration ranged from 0.35 to 0.45 (on a $[0-1]$ range), which means relatively positive to moderate. The range of these results is similar to UK results from the latest 2016/2017 ESS. However, since the ESS is conducted in a different setting (a one-hour personal interview), no conclusions were made based on the comparison between the results of this survey and the ESS.

In experiment 1, participants in both storytelling conditions are more similar in their attitudes towards immigration than participants in the exploration condition. However,

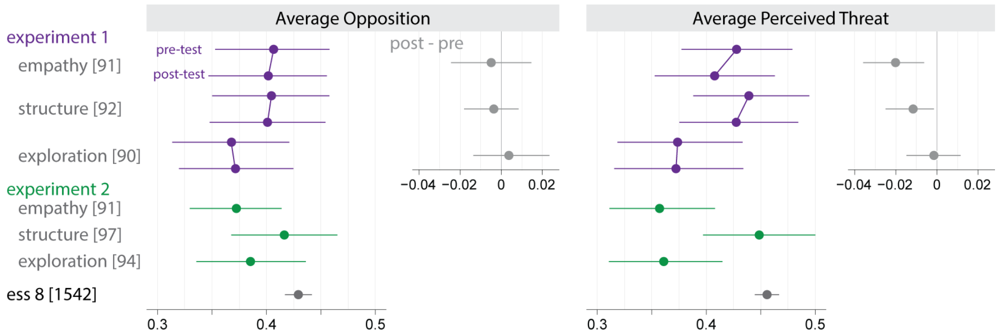


Figure 5.7: Normalized sample means with 95% BCa CIs for the latent variables *opposition to immigration* and *perceived immigration threat* for experiment 1 (pre-test and post-test) and experiment 2 (only post-test) for the three survey conditions and the ESS run in 2016/2017.

in experiment 2 participants in the empathy condition and the exploration condition are more similar than participants in the structured condition. While these tendencies can be seen in both variables, only the differences in the perceived threat variable have some statistical significance looking at the overlap of the CI error bars.

The confirmatory analysis neither supports $\mathbf{H_{empathy}}$ nor $\mathbf{H_{structure}}$. Instead, the following two major results were obtained, both concerning the *perceived threat* variable, which provides more nuanced answers to the initial questions.

Result 1: experiment 1 shows a significant but small effect of condition on perceived threat. With the pre-post-test design of experiment 1, both storytelling conditions had a small but clear effect on participants' attitude change towards immigration (their corresponding $post - pre$ confidence intervals in Figure 5.7 do not cross the 0 vertical line). Participants in these two conditions perceive immigration less a threat after seeing the stimulus. While this effect can be described as *significant*, it is also small, with a point estimate smaller than 2% for both storytelling conditions.

Result 2: experiment 2 shows a large effect of condition on perceived threat. Participants in the structure condition scored higher on that scale than participants in the two other conditions. The likely difference is one order of magnitude larger than in experiment 1, with a difference of approximately 10% between the participants in the structure condition and the participants in the other conditions.

5.4.2 Exploratory Analysis

In order to inform the discussion and provide more context to the confirmatory analysis, a further exploratory analysis was conducted. Specifically, perspective was added to **result 1** and **result 2** by looking at demographics and human values. The figures in this section present the conditions and variables relevant to these two results. More detailed figures of the exploratory analysis, including the average opposition variable, are part of Appendix C.3.

Result 1: The demographic variables shed some additional light on the observed attitude changes concerning the average perceived threat variable in experiment 1. Following Figure 5.8 (top row), in the empathy design, participants that are female, in the middle-age cohort, can cope or comfortably live on their income, have a centre-left political orientation or are relatively more religious, showed more significant attitude change. For the structure design participants that are female, have a higher education, are relatively more religious, or have a central political orientation showed more meaningful attitude change. Regarding human values (Figure 5.9, top row), one can observe that in the empathy design, the effect is similar for both conservative and open participants. This is different for the structured condition, where only conservative participants significantly changed their attitude.

Result 2: The demographic variables provide additional context to the adversarial effect of the structure condition on the perceived threat variable in experiment 2. Following Figure 5.8 (bottom row), this effect applied mainly to male participants. One also can see that older participants contribute more to the observed effect than younger participants; that the effect appears to be irrespective of the level of education; that those who can cope with their current income are more affected than those who find it challenging to live comfortably on their income; moreover ,that more religious participants and participants with right political orientation contribute to the effect in the structured condition. With regards to human values, the effect is similar for both conservative and open participants, but mostly self-transcendent people contribute to the effect.

5.5 Discussion

In this section, these unexpected results are interpreted and possible explanations are discussed.

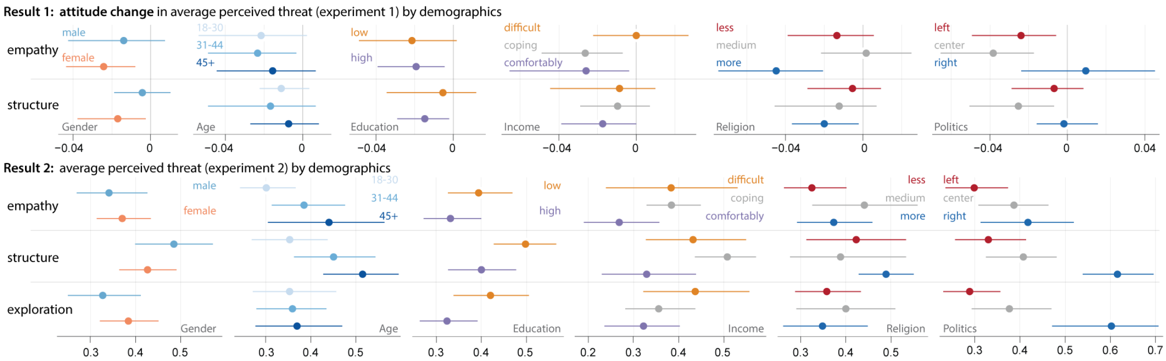


Figure 5.8: Exploratory analysis for **Result 1** and **Result 2** by **demographic variable** for the relevant conditions. **Gender** compares ***male*** and ***female*** participants (none answered 'prefer not to say'). **Age** is grouped by thirds. **Education** bins *Below Standards, GCSE Level Education*, and *A-Level Education* into ***low***, and *Degree or Graduate Education* and *Post-Graduate Education* into ***high***. **Income** groups participants finding it *very difficult* or *difficult* to live on present income into ***difficult***, and uses the other two original groups ***coping*** and living ***comfortably*** on income. Due to unbalanced distribution is the binning of **Religion**,three bins of equal size were used: ***less religious***, ***medium religious*** and ***more religious***. **Politics** separates participants orientation on the ***left*** and the ***right*** spectrum, and all participants who selected the ***center*** option.

5.5.1 Can Visual Anthropomorphism Elicit Empathy?

Result 1 shows a small but significant average change of immigration attitudes in the empathy condition. While this meets expectations regarding $\mathbf{H}_{\mathbf{empathy}}$, the results of experiment 2 overall did not confirm this effect. This contradiction, together with the small effects observed, is the second attempt after Boy et al. Boy et al. (2017)'s study that fails at clearly demonstrating the benefits of designing for empathy in visual data storytelling. That stands in contradiction to the common and reasonable belief that empathy in visual data storytelling might affect viewers of the visualisation.

It might be that using anthropomorphised data graphics does not trigger empathy as much as one would like; but it might also be, with a narrower implication, that empathy does not influence people's attitudes towards immigration in general. The exploratory analysis regarding result 1 showed that different demographics tend to be more influenced by the empathy design than others. On the other hand, participants with differences in human values tend to be influenced equally by the empathy design. This calls for further studies investigating the intertwining of data storytelling, anthropomorphism, empathy, and attitudes.

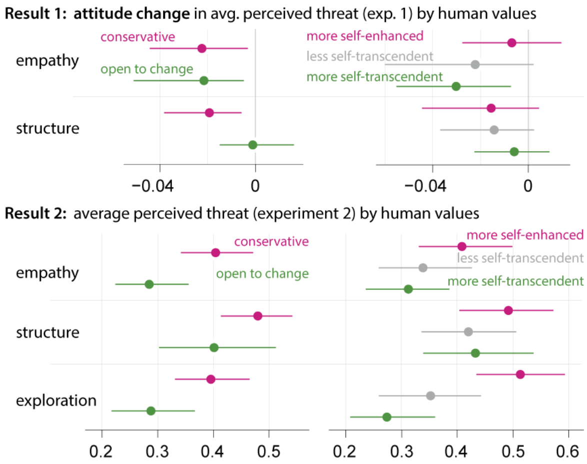


Figure 5.9: Exploratory results for confirmatory results by **higher-order human values**. One dimension contrasts ***conservative*** participants with people ***open to change***. The second dimension, contrasting self-enhancement and self-transcendence, is a relative comparison due to unbalanced distribution. The participants are grouped in three bins: ***more self-enhanced***, ***less self-transcendent***, and ***more self-transcendent***.

5.5.2 Could Structure Act Against Evidence-Based Understanding?

$\mathbf{H_{structure}}$ was formulated assuming that a view depending on evidence rather than (potentially prejudiced) assumptions about immigration might lead to more positive attitudes; and that a structured navigation through the data might lead one to understand data-evidence more clearly; which would by transitivity result in the structure condition leading to more positive attitudes towards immigration.

While results from experiment 1 go in the direction of this hypothesis in terms of perceived threat, the effect size is small. Concerning result 1, the exploratory analysis stressed that the effect depends more on demographics with the empathy design than with the structure design.

In contrast, the results for the perceived threat variable in experiment 2 indicate that participants in the structure condition perceived immigration on average as more a threat than those in the empathy and exploration conditions. Assuming homogeneity of the population between the different conditions, as one usually does in between-participant studies (and excluding the possibility that prior beliefs rather than the storytelling mode shaped the results), then it appears that the structure condition had an effect opposite to what was expected. As the exploratory analysis showed, the effect is equally pronounced across most of the demographic variables. The common assumption that structured navigation assists in people's understanding of facts, especially as challenged by these findings, has interesting implications for visualisation design (e.g., structure leading reader down a certain line of thought). One plausible explanation for these observations, one may call this *datasplaining*, is discussed next.

5.5.3 Storytelling or Datasplaining?

The effects of visual-narrative techniques on people's attitudes towards immigration may be smaller than expected because participants perceived the storytelling visualizations as patronizing. The term *datasplaining* is used in reference to mansplaining, *a situation where data used to explain something to someone would be considered as condescending or patronizing*. While there is no strong evidence to support this suggestion, especially the (possibly datasplaining) author-driven approach in the structure condition might play a role in participants' responses. In contrast to the structure condition, the exploration condition lets people freely explore the data, without being constrained to the sequence decided by the author of the visualization. The empathy condition enables participants to choose in which order they want to explore the individual narratives, and has a narrative style that might be less perceived as patronizing.

Two observations in the exploratory analysis regarding human values support this perspective. In theory, people open to change and self-transcendent people are expected to be more positive towards immigration. However, with result 1, participants open to change in experiment 1 did not change their attitude (perceived threat) or had a more negative attitude (opposition) after being exposed to the structure design - contrary to the empathy design. Additionally, the effect described in result 2 applies to participants that are more self-transcendent. Whether or not datasplaining played a role in the results of this study, it is an avenue worth exploring in the future, especially with sensitive topics such as immigration. However, there is also the possibility that unconscious biases were introduced in the study, as discussed next.

5.5.4 Potential Experimenter Biases

Data and (narrative) visualisation can be used to communicate information in a biased way, trying to influence people's attitudes. This is problematic if happening wittingly. Providing credits, the provenance of the data and details of the design process can allow one to form one's own opinion. New design approaches like *Literate Visualisation* (Wood et al., 2019) might help to communicate design decisions effectively. While such information was not disclosed in the study for better control, particular attention was paid at keeping the message neutral and balanced.

In hindsight, however, it is possible that the structure design might have emphasised the migration from eastern countries. This *content bias* could explain the higher scores in the perceived threat variable in the structured condition. This could be attributed to the fact that labour migration is the predominant theme associated with immigration in the UK, and the primary reason why people migrate in general. Although labour migration was present in all conditions, it was perhaps more emphasised in the structure condition, which could explain this difference. Indeed, two of the four stages of the structure design were about the growth of the EU, the first one using the example of Poland and the second one the examples of Romania and Bulgaria. Both stages explained that the main reason for immigration is labour.

Another *unconscious bias* that might have been made is the assumption in the hypothesis that the evidence provided in the visual-narrative designs suggests that migration is not a threat. This bias is associated with the content bias, as these assumptions were made on the basis of a balanced and neutral narrative of both visual-narrative designs, and what was expected the techniques used could afford.

Finally, for empirical testing, visual-narrative stimuli have to be complex enough to imitate realistic settings, which could lead to biased complexities across stimuli influencing understanding. However, the results of the filter questions (used as a proxy) do not indicate that the different designs had an impact on understanding.

5.5.5 Pre-Post vs. Post-Only

The different results of the post-stimulus assessments between the experiments can have various reasons. It could simply be (1) statistical noise, (2) that the two sampled groups of participants vary to a large extent (e.g., in their prior beliefs), or (3) due to the different experimental design, i.e., people respond differently because they are asked the question twice - or a mix of those reasons. Assuming the pre-test can influence participants, the experimental design 1 is, in a way, inferior to the experimental design 2 where participants were not primed. It is superior in other ways (e.g., more statistical power). The reasons why participants of experiment 1 were not prompted to change their minds could be that: (a) they were not influenced by the stimuli or (b) that they were subject to conservatism bias. The second experiment, only assessing post-stimulus attitudes, resulted in different attitudes towards immigration compared to the post-test in the first experiment, suggesting that including a pre-test indeed *does* affect the results.

The confirmatory analysis was not adjusted for demographic or other variables (e.g., human values) due to a large number of participants and the random group allocation, as recommended in health sciences Mutz et al. (2018); Senn (2013) for example. Nevertheless, one cannot exclude the possibility that differences observed in experiment 2 are due to differences in prior beliefs and personal views rather than the visual-narrative techniques, which would be indicated by experiment 1. The exploratory results suggest that there are small differences in the demographic variables (Figure 5.8). Nevertheless, further research is required to investigate these variables in isolation.

5.5.6 Limitations and Future Work

As any study attempting to quantify some human characteristics, this work has several limitations.

In both visual-narrative designs, text-based narration was used, which competes with other visual elements. Audio-based narration would reduce the load on the visual channel, which could lead to other results. Similar to the first experiment (Chapter 4), the online crowdsourcing approach does not allow to control over an individual's setup (e.g., over the noise level, or audio quality). Future 'in-house' experiments could make use of the audio channel to investigate effects in multimedia data storytelling.

In a world without monetary constraints, one could have implemented additional conditions. Other designs using narrative techniques targeting the same categories as used here (structure and empathy) could have been created to confirm the study findings. Furthermore, designs implementing narrative techniques that target other categories (e.g., framing, argument, engagement/immersion) could have been included to test their influences on attitudes. Alternative study designs may lead to stronger conclusions. For example, combining the empathy and the structure designs as an additional condition may bring an improved significance to the results. A design that compares user interfaces that either inform or persuade participants with the assessment of attitudes and prior knowledge could also add value to the findings.

Based on result 2 – the adversarial effect observed in the structured condition in experiment 2 – one can conduct additional research on different narrative structuring techniques and their influence on attitudes. Such studies could, for example, facilitate work on narrative sequencing preferences Hullman et al. (2013, 2017) or argument structure Kosara (2017a). Additional studies are required before one can generalize the presented findings and draw broader conclusions and guidelines for designing visual narratives that can influence people's attitudes.

5.5.7 Conclusion

Compared to the popularity and the widespread use of visual data storytelling, visualisation research analysing the mechanisms of storytelling (i.e., the effect on people) is underrepresented. This work contributes to improving the overall understanding of visual data storytelling, as it is the first study within this field, testing if different visual-narrative techniques can influence attitude.

The investigated storytelling modes in this research did not strongly influence people's attitudes. No clear evidence was found to support the initial assumptions that empathy-evoking and structured narrative visualisations elicit more positive attitudes towards immigration than non-narrative displays in the context of the migration of EU citizens to and from the UK. Although significant differences were found, the magnitudes of the tested effect sizes were small. The outcomes of the experiments also have methodological implications. When assessing attitudes that tend to be strongly held, priming participants through pre-stimulus assessments is likely to be problematic as it might introduce conservatism bias.

These findings help to anticipate the effects of narrative techniques used in visualisation over people's attitudes towards topics regarded as contentious and strongly held, which can be used to design further experiments investigating the use of visual-narrative techniques.

Chapter 6

Summary, Discussion, and Conclusion

The aim of this work was to gain greater insight into how storytelling techniques can be introduced to flow and movement visualisations to create Flowstories and to design more comprehensible visualisations. Furthermore, the research investigated to what extent selected storytelling techniques used in information visualisation displays can achieve expected results. Storytelling is believed to be beneficial for better memorability and understanding and to be able to influence opinions. These underlying beliefs are often unchallenged, meriting further investigation, and have shaped the research aims and objectives of this work. The limited number of empirical evaluations within the research field was one of the major drivers for the presented PhD work and the methodological approaches taken.

In an extensive design space study (Chapter 3), the two main topics of the thesis, flow and movement visualisation and storytelling, were brought closer together and investigated in combination. The conducted experimental evaluations investigate to what extent selected narrative techniques have the ability to influence (a) memorability and understanding (Chapter 4), and (b) attitudes towards the topic of immigration (Chapter 5).

Based on the results, the studies join the growing set of studies investigating the role of visual data storytelling finding small or unexpected effects when testing different visual-narrative techniques or visual communication modes. However, results which do not confirm our hypotheses nor support common assumptions, are important contributions to our research field as they prevent us from relying on plausible but unchallenged assumptions.

In this final chapter, I reflect on the aims and objectives that were defined at the outset of the thesis, I provide a high-level discussion of aspects that derived from my research and provide an overall conclusion.

6.1 Reflecting on Aims and Objectives

At the outset of the thesis, five objectives were defined to achieve the overall aims. In the following section, I reflect on those objectives by providing a summary and describing how the objectives were addressed, which findings and contributions resulted from the work.

6.1.1 O1: Define and Review Scope

Objective 1: Define and review the design space of (a) flow and movement visualisations and (b) storytelling techniques in respect of the ability to be studied jointly.

In order to conduct the planned research on a well-founded basis, it was essential to first investigate the two subject matters of this work (i.e., flow and movement visualisation and visual data storytelling). The background section provides a comprehensive review of the available literature of visual data storytelling and the visualisation of flow and movement data, focusing on geographic visualisation. The systematic structure of the review reflects the structure developed in the Flowstory design space study (see next section). As part of the related work section, a small survey provides a summary of the state of the art of empirical evaluation research of storytelling in visualisation. In a final step of reviewing different research approaches in visual data storytelling, the distinction between inside-out and outside-in approaches was introduced (Section 2.2.1.6). Within the thesis both approaches were used. The design space study (Chapter 3) mainly used an inside-out approach. It is explored how elements of flow and movement visualisations (inside) aid narrative (out). In the evaluation contributions (Chapters 4 and 5), an outside-in approach was used to assess concepts and ideas derived from outside visualisation. Outside-in approaches can reveal more about the mechanisms of storytelling as a whole, enabling the space of visual data storytelling to expand. Inside-out approaches are better suited for evaluating the effects of specific visualisation elements on storytelling.

The understanding of storytelling and narrative was adopted from modern cognitive narrative theory. There narrative is described as a combination of story and discourse. A story is a narrative's mental representation, a cognitive construct in the reader's mind. The discourse deals with the ability of materialised representations (e.g., text or a visualisation) to constitute or evoke a story in a viewer's mind, which was further described with the concept of narrativity (see Section 2.1.2). The use of this perspective made it possible to overcome boundaries that arose from a classical understanding of what storytelling in visualisation can be (i.e., a story has a beginning, a middle, and an end).

6.1.2 O2: Flowstory Design Space

Objective 2: Interweave the design spaces of flow and movement visualisations and visual data storytelling by building a taxonomy of Flowstories, which reflects to what extent including storytelling techniques in flow and movement visualisations is applicable. Respectively, how elements of such visualisations can foster storytelling.

Based on a qualitative thematic analysis of more than 100 examples of flow and movement visualisations and existing work and theory from both areas, several design space categories were developed. These are characterising the visual and narrative design components of the taxonomy.

It was demonstrated how the design space serves as a mental framework, helping to (1) analyse existing visualisations (3.3 Design Space Case Studies) and (2) create new Flowstories or derive empirical evaluations (3.4 Using the Design Space Generatively). The framework allows others to bring elements from one discipline into the other when making visual-narrative design considerations.

The entire design space is based on the consideration that space and time are essential concepts in both narration and data visualisation. This is especially true for the visualisation of flow and movement data, where movement in geographic or any other space is always linked to a temporal component. From a narrative perspective, time is an integral component that provides structure and moves a story forward. Space also plays an essential role in narration, for example, as a framing device or by capitalizing on its metaphorical or emotive potential (Herman et al. (2010)).

While Flowstories are not a new invention, as demonstrated by the numerous examples used in this project, the design space survey was the first study investigating flow and movement visualisation and visual data storytelling explicitly in combination.

6.1.3 O3: Emplotment, Memorability, and Comprehensibility

Objective 3: Investigate to what extent the degree of *narrativity* expressed through *emplotment* influences a visualisation consumer's ability to comprehend, memorise, recall, and apply gathered knowledge.

The project was motivated by the identified gap of empirical evaluations that demonstrate the clear benefits of storytelling in visualisation and the theoretical considerations made in the design space. A crowdsourced, mixed-methods, between-subject survey with two independent conditions and two iterations (i.e., a primary and a follow-up run) was conducted (Chapter 4). The two conditions were based on two different visual-narrative designs (Section 4.2.2) using two different text-based emplotments (the arrangement of events into a sequence with a specific plot structure), creating different degrees of narrativity. While one visual-narrative design was a fictional, tale-like narrative, the other design was a more technical description of the depicted particle animation.

The results could not confirm the initial assumption that a tale-like emplotment with a dedicated narrative arc is superior to a descriptive emplotment regarding memorability and comprehensibility. The differences found, although sometimes statistically significant, were small. Nevertheless, patterns in the results suggest that text-based anthropomorphisation and objectification can lead to a better overall understanding but can, on the other hand, hinder visual processing. The findings have implications on the design of Flowstories, and can lead to further investigation regarding the integration of text-based elements conveying contextual information in an animated display.

6.1.4 O4: Structure, Empathy, and Attitudes

Objective 4: Investigate to what extent commonly used storytelling techniques that generate empathy or provide structure influence people's attitudes towards a topic regarded as contentious or strongly held, like immigration.

To address this objective, a crowdsourced between-subject experiment was conducted (Chapter 5). The survey compared the influence of (a) personal visual narratives designed to generate empathy, (b) structured visual narratives of aggregates of people, and (c) a fully exploratory visualisation without narrative acting as a control. Established scales from the social sciences were used to measure immigration attitudes and general beliefs. It is an epistemological contribution in the sense that the understanding of the social sciences of attitudes (what they are and how they are formed) was applied to explain the effect of visualisation.

However, the investigated storytelling modes in this research did not strongly influence people's attitudes. No clear evidence was found to support the initial assumptions that empathy-evoking and structured narrative visualisations elicit more positive attitudes towards immigration than non-narrative displays in the context of the migration of EU citizens to and from the UK. Although significant differences were found, the magnitudes of the tested effect sizes were small. While the results of the emplotment study suggest that text-based anthropomorphism can have an effect, the results of this study can not clearly demonstrate the benefits of designing for empathy in visual data storytelling using visual anthropomorphism. The results of both surveys provide indications that designing visualisations with a strong narrative structure can influence the line of thought.

This work contributes to improving the overall understanding of visual data storytelling, as it is the first study within this field, testing if different visual-narrative techniques can influence attitude. The findings help to better anticipate the effects of narrative techniques used in visualisation and provide evidence that the research community should not trust common, but unchallenged assumptions about the benefits of storytelling in visualisation without careful consideration.

6.1.5 O5: Evaluating Evaluation

Objective 5: Based on the findings of the above objectives, one goal was to derive a set of guidelines for the creation of Flowstories. However, the results limited the extent to which this could be accomplished in this research, thereby shifting the focus to methodological reflections and considerations for future evaluation approaches.

The observations made and discussed in Chapter 3 (Flowstory Design Space) can be understood as recommendations for authoring Flowstories as demonstrated in the case studies (Section 3.3) or the GeoBlob project (Section 3.4.1.2). However, the outcome of the two experiments (Chapters 4 and 5) provoked a shift towards a discussion of evaluation in storytelling research. The reflection below (Section 6.4) is a preliminary discussion of why I believe that new research directions for evaluation of storytelling in visualisation are plausible next steps, which is planned to be expanded in future work (6.5). Identified methodological implications can guide future research and experiments in the area of storytelling and visualisation.

6.2 Storytelling or Just Well Designed Data Visualisations?

Following the argument that any visualisation can evoke a story in someone's mind, the question arises whether there is a difference between *narrative visualisations* and *visualisations in general.*

In my opinion, there is a difference, but this is not an *either-or* question. I think different visualisation designs (ranging from highly narrative to fully explorative visualisations) represent a continuum of narrative possibilities. Hence, the binary distinction if a visualisation is a narrative or not, is not very meaningful. Following modern narrative theory (Ryan, 2004), it makes more sense to ask to what extent a visualisation has narrativity rather than asking if a visualisation is a narrative. It is a possible perspective that can exist in parallel with other definitions. This understanding of visual data storytelling can help to evolve the debate about the legitimacy of storytelling in visualisation rather than denying any legitimacy from the beginning[1]. Moreover, visualisation researchers across various domains should accept a certain degree of multiple, differing definitions of narrative and storytelling. Although having emerged over a half-century ago, narrative theory does not have a rigorous domain-specific ontology. Since I do not identify the difference between narrative and conventional visualisations in their visualisation design, the difference can be found in the authorial intent of a visualisation.

This perspective (i.e., a visualisation has narrativity rather than is a narrative) aligns with the discussion of *exploration* and *explanation* in the Chapter 3 of the recently published data-driven storytelling book (Riche et al., 2018). The distinction between exploration and explanation are often understood as opposing areas in visualisation. Storytelling and narrative visualisations are usually associated with the explanatory realm. Visualisations with very high narrativity are, for example, well suited within journalistic or educational contexts like in museums or schools, where communicating a particular message is the aim. However, it does not mean that such contexts exclude exploration. Exploration capabilities are often part of an explanation (as described with the distinction of author-driven and user-driven narratives by Segel and Heer (2010)).

Furthermore, narrative considerations and opportunities are not limited to explanations when designing visualisations. Narrative techniques can be integrated into explorative setups (narrativisation). As demonstrated across the design space chapter, techniques can be used to support the conveyed argument (e.g., emphasising an important visual mark), evoke emotions (e.g., through the use of associative colours), or can help to immerse the

[1] https://www.perceptualedge.com/blog/?p=2568, http://www.perceptualedge.com/blog/?p=2910

audience. This often happens subliminally, without the aim to tell a story in a classical sense.

However, the degree to which narrative techniques are used in an exploration set-up has to be carefully considered. Findings of both empirical studies (Chapters 4 and 5) suggest that high narrativity might force a reader into a line of thought and hinder creative thinking. However, it depends on the authorial intent, whether guiding someone's thoughts is a desirable effect or not. These observations lead to ethical considerations in the context of visual data storytelling.

6.3 Ethical Considerations in Visual Data Storytelling

There are two different aspects discussed in this section: (1) ethical considerations related to the authorial intent of a visual data narrative, and (2) ethics considerations related to the experimental evaluation. While (1) is specific to visualisations and storytelling in visualisation, (2) applies to evaluation research with human participants in general.

As the study results indicated, a high degree of narrativity can provoke certain associations guiding a reader's line of thought (Section 4.5.2) or constrain the perspective onto the data (5.5.3 Storytelling or Datasplaining?). Furthermore, the Flowstory collection includes examples, where data and its (narrative) visualisations were used to communicate information in a biased way trying to influence people's opinions, often in a geopolitical context (e.g., *FS_044 – FS_047*). This is problematic if happening wittingly, as in the case of propaganda. A recent impressive, yet sad example of a propagandistic Flowstory emerged from the Hurricane Dorian–Alabama controversy[2]. While in this dilettantish example the intention might have been evident to many, data transformations and visual mappings can be used in a more subtle way to influence and distort a visualisation's message (Riche et al., 2018) (see also Chapters 2 and 3). Providing data credits, data provenance, and information on the data transformations, being transparent about the design process, are possible actions to *"build a more trustworthy craft of honest visual data storytelling"* (Riche et al., 2018).

For better experimental control, such details were deliberately not disclosed in both of the presented studies. However, particular attention was paid at keeping the message neutral and balanced. Nevertheless, in light of recent far-reaching and media-discussed data pro-

[2]https://en.wikipedia.org/wiki/Hurricane_Dorian%E2%80%93Alabama_controversy

tection violations (e.g., the Facebook–Cambridge Analytica data scandal[3] from early 2018), people might be less willing to share data and opinions, especially on sensitive topics such as immigration attitude (Chapter 5). Even though these surveys are anonymous, people might start to question to which extent this is actually the case; and it might, consciously or not, affect how people respond to these types of questions now. While the responses of the attitude study were collected before this event became publicly known and show a very low non-response rate, future academic work on assessing contentious/political attitudes might become more difficult for this reason.

Therefore, it is crucial to provide adequate information on the research process (e.g., data handling or anonymisation). In this context, it is important, and will probably be of increasing importance, for us as a research community to remind participants about the ethical considerations made, during the design of experiments and surveys. In the European Union a new regulation, "The General Data Protection Regulation", was introduced in May 2018. *"It sets out the rights of the individual and establishes the obligations of those processing* [...] *the data. It also establishes the methods for ensuring compliance as well as the scope of sanctions for those in breach of the rules"*[4]. The regulation increased the efforts required to collect participant data in academic and non-academic projects, but more importantly, this ensures that participants' data privacy is respected.

Hence, before conducting any research involving human participants during my PhD, it was crucial to apply for a research ethics review and receive approval to protect the interests of both participants and researchers. The applications for each experiment presented in this work included information about the research goals, and the tasks participants were asked to do during the survey. It also described the type, storage, accessibility, and usage of the collected data. The Computer Science Research Ethics Committee (CSREC) approved both experimental set-up and research plans.

Besides these ethical considerations, there are many, even more crucial, methodological considerations involved when evaluating the effects of visual data storytelling on people.

[3]https://en.wikipedia.org/wiki/Facebook%E2%80%93Cambridge_Analytica_data_scandal
[4]https://www.consilium.europa.eu/en/policies/data-protection-reform/data-protection-regulation/

6.4 Evaluation and Storytelling - Tellable or Tale?

First of all, I want to emphasise that I do not distrust the methods that have been used and the results and findings that have been produced by studies evaluating the effect of visual data storytelling on people (including the presented experiments in the Chapters 4 and 5).

However, the observation and own experience that many of these studies come to results that are contrary to the stated expectations, find only small or negligible effects, or just partially provide evidence raises the question whether the idea of storytelling in visualisation truly has benefits (it is a tellable story) or is overrated (it is a tale).

Besides the two presented studies in this work (Chapters 4 and 5), several other studies were not able to demonstrate the benefits of visual data storytelling clearly (compare Section 2.2.3 for more details). Examples include: Boy et al. (2015) found no effect of initial narrative tutorials on user-engagement (activeness). Boy et al. (2017) found no difference between anthropomorphised data graphics and standard charts with regard to empathy and pro-social behaviour. Dimara et al. (2017) found backstory narratives (compared to non-narrative data semantics) used in crowdsourcing studies not beneficial for subjective measures (e.g., confidence, perceived easiness, enjoyability, and perceived usefulness of the visualisation). Badawood and Wood (2014) found no difference between delivery models (author-driven vs reader-driven) on re-telling a story. Kong et al. (2018) found that deliberately biased visualisation titles can influence the interpretation of the main message but contrary to expectations found no effect on attitude change.

Such ambiguous results are not only found in visualisation research, they align, for example, with findings from fields investigating narrative persuasion that are facing similar challenges (e.g., psychology, advertisement, and health) (Dillard and Shen, 2012; O'Keefe, 2016).

Developing visual-narrative stimuli for empirical testing is a balancing act. Testing too isolated aspects out of context might due to limited ecological validity reduce the relevance of any results in a real world setting, which makes long, complex, and realistic enough stimuli important. In contrast to perceptual studies, investigating the effects of narrative techniques involves complex mechanisms, interactions, and cognitive processes that are impossible to fully control. As a result, isolating and measuring a particular effect is challenging, which is one possible reason why the investigated effects are small or weak.

It might be that the expectations towards visual data storytelling are inflated. For a more nuanced view, it might be necessary to put results into further context. With regard to the attitude study presented in Chapter 5, one can argue that attitudes towards immigration are believed to be strong attitudes (research in attitude strength distinguishes between strong and weak attitudes (Maio and Haddock, 2015)). Consequently, it is unlikely to observe large effects on these strongly held attitudes and small but notable effects, in this context, might be more important than they look. However, this can easily lead to speculations without providing evidence. On the other hand, using a topic where people tend to have weak attitudes might lead to more variable results but would open up for criticism of testing the obvious.

In a wider context, the authoring, and the perception, of visual narratives are very subjective (Thudt et al., 2017). The same data, observations, and facts often allow different interpretations and yield different narratives (Cruz and Machado, 2011; Phillips, 2012) in the form of different designs or in the form of different mental images. This is fully acceptable and can be seen as a strength of narrative approaches and as an advantage to visualisation designers; but it also makes it difficult to quantify effects in experimental set-ups, and even more to generalize results.

Most of the techniques we use to evaluate visualisation come from the field of HCI (human-computer interaction) and the HCI methods come from psychology. In other words, they were designed for entirely different subjects and matters. These methods, designed to isolate and compare or measure a simple, dependent variable while controlling for everything else, might simply be ill-suited to measure complex mechanisms such as the ones studied in visual data storytelling. Considering quantitative, qualitative, and mixed methods (e.g., Braun and Clarke (2013); Creswell and Creswell (2018); Oates (2006)), evaluative research in visual data storytelling may be closer to observational and qualitative studies. Trying to avoid to oversimplify the researched concepts with quantitative methods, or at least not relying solely on them seems to be essential.

Several studies, including the emplotment study (Chapter 4), did use mixed and qualitative methods. They include focus groups (Figueiras, 2014b), observations and structured interviews (McKenna et al., 2017), more advanced interview techniques (Nowak et al., 2018), or story reconstruction tasks (Badawood and Wood, 2014). Often such studies are conducted in controlled lab settings, but are less common than quantitative evaluations in this context. One reason might be that they are more time consuming and require more resources. With regard to the crowdsourcing studies conducted for this work, it would have been interesting to adapt the experiments for smaller observational lab studies to investigate if results would replicate.

However, qualitative measures used to evaluate effects of storytelling are often subjective and based on self-reporting (e.g., likability, enjoyability, or engagement). While they are essential to assess these aspect and provide valuable information for a better understanding of evaluated narrative visualisations, such measures alone can not reveal deeper insight regarding narrative understanding.

In summary, the described results may indicate that (a) there are no measurable or just negligible effects of storytelling in visualisation, (b) we ask the wrong questions, or (c) the applied assessment methods are not appropriate to answer those questions. If (a) is the case, then we either have to accept that expected benefits do not exist, or we have to scrutinise the questions asked. If (b) is the case, a solution may be to see which questions are asked by narratologists when investigating the effect of texts. However, many of the above surveys are based on concepts from narrative disciplines (e.g., story reconstruction tasks). So there is no strong evidence that (b) is the case. Hence, this would leave (c) as a plausible explanation. As discussed above, the methods used to date may not be well-suited or not sufficient enough on their own to capture the complex mechanisms behind storytelling in visualisation. This perspective aligns with (Dimara et al., 2017)'s conclusion that *"narratives may have complex and unanticipated effects, calling for more studies in this area"*.

I also see the need for more studies in this field before stronger claims can be made regarding the benefits of visual data storytelling. Moreover, we have to critically reflect the goals we have when conducting such evaluations and consequently investigate additional evaluation approaches. Those methods, for example coming from psychology or narratology will be new and might be unusual for computer scientists; suggestions and first attempts have been made.

For example, Dove and Jones (2012) suggested a new direction by enhancing the information visualisation studies with methods from neuroscience, such as electroencephalography and functional magnetic resonance imaging, to evaluate narrative visualisation. However, to date, no such study has been conducted in the context of narrative visualisations.

Based on the fact that narrative visualisations have effects on multiple levels, are complex, and trigger both cognitive and affective reactions, Nowak et al. (2018) recently advocated for using qualitative evaluation approaches. Nowak et al. adopted a psychological interview and analysis method that can identify implicit aspects of experiences made when engaging with a narrative visualisation. Nowak et al. found that this method can *"capture* *rich emotional and sensory experiences and reveal sense-making processes, personal reflections, and meaning-making processes that occur when viewing narrative visualisations."*

These two examples show that an interdisciplinary approach is essential. Visualisation research in general and visual data storytelling research, in particular, have always been interdisciplinary. For example, the data-driven storytelling book (Riche et al., 2018) emerged from a Dagstuhl[5] seminar where computer scientists, visualisation researchers and practitioners, journalists, and psychologists collaboratively worked on an exhaustive foundation for our field.

However, I see an enormous potential to seek additional collaboration with narratologists. For example, experts of narrative theory and geographers collaboratively investigated the intersection of both fields (Ryan et al., 2016). While Ryan et al. (2016) did not empirically assess the effect of narrative maps on people, looking closer into the methods of cognitive narrative theory to assess narrative understanding or its effects on memory (Herman, 2006; Herman et al., 2010) seems promising. The belief that our field would benefit from such a collaboration, one of the many learning processes I underwent during my PhD, manifested based on discussions with digital humanities (DH) scholars at the DH conference 2019[6].

In order to advance the discussion in visual data storytelling evaluation, I see the consideration of new methods and collaborations with narrative experts as the inevitable next step. In the next section, a possible first project to initiate this process is described.

6.5 Future Work and Publication Plan

Like the two empirical surveys conducted in this work, many other empirical evaluations in this area do not find definite results that clearly demonstrate the advantages of storytelling in visualisation. This ambiguity of results alone merits further investigations and evaluation studies. As discussed in several sections (e.g., Sections 3.4.2 and 5.5.6), countless possibilities of future research lie ahead.

However, in order to achieve clearer results in the future, I see the need to compare and aggregate the previous studies in a kind of meta-analysis. This can help to avoid pitfalls in the future and in consequence, to investigate new directions in the evaluation of visual data storytelling. The meta-analysis could use available preregistration templates[7] as a

[5] https://www.dagstuhl.de/
[6] https://dh2019.adho.org/
[7] https://osf.io/prereg, http://www.cos.io/prereg

comparative research tool. A possible approach is to systematically structure the analysis according to preregistration categories (i.e., study information, design plan, sampling plan, variables, analysis plan) and map them to a comparison of expectations and outcome of the experiments. This reflective synthesis can help to strengthen our understanding of evaluation of visual data storytelling, before we extend our methods. Based on the Sections 2.2.3 and 6.4 the publication may be titled "Tellable or Tale - A Meta-Analysis of Evaluation Studies in Visual Data Storytelling". While I was not aware of these tools (preregistration) when conducting the two presented evaluation studies, I am convinced that future evaluations in visual data storytelling (and in visualisation research in general) can benefit from this practice.

More imminently, I plan to write three papers based on the projects conducted during the PhD. While a manuscript about the attitude study is, at the time of writing, under revision (TVCG[8]), I plan to transform the Flowstory design space study and the emplotment experiment into two publications. While the design space chapter provides an extensive perspective, the paper will focus on flow and location marks and how they can support narrative aspects. The paper will be based on the idea that space and time are the two concepts combining narrative and the visualisation of flow and movement data. The emplotment paper will focus on the qualitative analysis of the responses to the open-ended questions. From all the responses captured in the study, it is the closest measure revealing participants' mental story (even though it is just a verbal mapping from their mind). Both manuscripts fit into the scope of IEEE VIS[9]. Furthermore, the design space project could be transformed into a EuroVis STAR[10] submission, or edited for The Cartographic Journal[11] focusing on geovisualisation aspects.

Furthermore, the GeoBlob project, from which aspects were presented as posters (Liem et al., 2018b, 2019a), an exhibition (Liem et al., 2018a), in a short talk[12], and during a discussion panel (Butterworth et al., 2019), will be prepared as a comprehensive manuscript. Depending on the target venue, it will either focus on the depicted content or the technical aspects. It is suitable either for a digital humanities conference (e.g., DH[13], DH4VIS[14]) or a cartographic journal (e.g., Journal of Maps[15]).

[8]https://www.computer.org/csdl/journal/tg
[9]http://ieeevis.org/
[10]https://conferences.eg.org/egev20/for-submitters/eurovis-for-submitters/eurovis-stars/
[11]https://www.tandfonline.com/loi/ycaj20
[12]https://fyi-conference.com/
[13]https://dh2020.adho.org/
[14]http://vis4dh.dbvis.de/
[15]https://www.tandfonline.com/loi/tjom20

Together with colleagues of the giCentre, the *Stories of Algorithm* project[16] that revolves around narratives in the context of interpretable machine learning and AI explainability, was initiated. An initial descriptive framework that helps to identify narrative patterns and other characteristics of algorithm-related stories was presented at EUROVIS 2019 (Liem et al., 2019b). Although the project is not a part of the presented PhD work, it demonstrates how the understanding of narrative gained in this work can be transferred to related areas.

In the final section, I provide an overall conclusion and implications of the work presented in this thesis.

6.6 Conclusion

In this doctoral research, I investigated visualisation of flow and movement in combination with visual data storytelling. In a design space study, I demonstrated how elements of flow and movement visualisations can aid narrative communication and how narrative techniques can be used within visualisations. The resulting Flowstory design space can be used to analyse and generate flow and movement visualisations in a narrative context. The framework can act as a bridge between, on the one hand, people with a computing background (e.g., data scientists or visualisation experts), who often have experience in visualization but often lack know-how in storytelling and, on the other hand, people with expertise in telling compelling stories (e.g., data journalists), who often do not have a technical background but also use visualisation as a means of communication. Both groups can use the design space to find a common language and bring elements from one discipline into the other when making visual-narrative design consideration.

In two empirical evaluation studies, selected aspects of visual data storytelling in the context of flow and movement visualisation were investigated. First, the effect of text-based emplotments on memorability and comprehensibility was investigated. Second, visual-narrative techniques believed to evoke empathy or provide structure were studied. I investigated the effect of these techniques on immigration attitudes.

Both experiments join the growing set of studies investigating the role of visual data storytelling that tend to find small or unexpected effects when testing different visual-narrative techniques or visual communication modes. The results of the first experiment indicate, that a high narrativity, in form of text-based anthropomorphisation and objectification, can foster the overall understanding but can hinder visual processing, might force a reader

[16] https://algostories.github.io/

into a certain line of thought, and can hinder creative thinking. The results of the second experiment suggest that visual anthropomorphisation appears not to elicit empathy effectively and that a strong narrative structure can act against evidence-based understanding and can influence the line of thought. Findings which do not support common assumptions, are important contributions, as they prevent us from relying on plausible but unchallenged expectations, especially in an emerging area of research. These findings can lead to further work investigating the mechanisms behind visual-narrative techniques and their effect on viewers.

Currently, the field is in a very interesting place. Although the benefits of storytelling seem often obvious, we still don't know what the effect on people really is. Therefore, I stress the need to gather more empirical evidence before making strong claims regarding the benefits of storytelling in visualisation. Benefits that have been demonstrated in other disciplines might not necessarily apply to the field of visualisation.

Based on the experimental results presented in this thesis in combination with findings from other studies, I believe and conclude that the visualisation community needs to consider developing alternative approaches for evaluating visual data storytelling, and thereby extending our methodological foundation. While I do not dismiss the methods used to date, they often oversimplify the subject's complexity and seem incapable of delivering robust results.

By embedding this work in concepts of modern narrative theory, I laid out a foundation for a possible future direction of this field of research. In order to advance the discussion in visual data storytelling evaluation, I advocate the development of new methods by seeking close collaboration with narrative experts as the inevitable next step.

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Appendix A

Flowstory Design Space

Additional material can be found online: https://flowstory.github.io/

A.1 Flowstory Collection Index

Flowstory unique ID, title, author, source

FS_001, The Globe of Bird Migration Oliver Queck, 2015, http://www.globeofbirdmigration.com/, https://vimeo.com/15417645
FS_002 The Global Flow of People Nikola Sander, Guy J. Abel and Ramon Bauer, 2014, http://www.global-migration.info/, http://www.global-migration.info/VID*FS_003*, People Movin: Migration Flows Across the World. Carlo Zapponi 2011, http://peoplemov.in/
FS_004 Migration: Wo die Einwanderer dieser Welt leben und woher sie kommen, Jochen Lott 2013, http://www.faz.net/aktuell/wirtschaft/wirtschaftswissen/ein-und-auswanderung-migranten-woher-sie-kommen-und-wohin-sie-gehen-13083236.html, http://www.faz.net/aktuell/wirtschaft/wirtschaftswissen/ein-und-auswanderung-migranten-woher-sie-kommen-und-wohin-sie-gehen-13083236/migration-wo-die-einwanderer-dieser-welt-leben-13059046.html
FS_005, The Flow Towards Europe Ville Saarinen and Juho Ojala 2015, https://www.lucify.com/the-flow-towards-europe/
FS_006, Global Trends in Migration, Sajit Thomas/ESRI 2017, http://coolmaps.esri.com/#10, https://www.youtube.com/watch
FS_007, Lisbon Blood Flow Pedro Cruz, 2013, http://pmcruz.com/information-visualization/lisbons-blood-vessels, http://pmcruz.com/information-visualization/traffic-in-lisbon-condensed-in-one-day, https://vimeo.com/31031656
FS_008, Casa da Lusofonia Pedro Cruz, 2013, http://pmcruz.com/work/casa-da-lusofonia, https://vimeo.com/117007630
FS_009, Digital Attack Map: Top Daily DDoS Attacks Worldwide, Google Ideas and Arbor Networks 2013, http://www.digitalattackmap.com/
FS_010, A Year In The Life Of Earth's CO_2 Jenny et al., 2014, http://co2.digitalcartography.org/, http://www.tandfonline.com/doi
FS_011, Mapping the World's Immigration Flows, Country-by-Country, Max Galka 2016, http://metrocosm.com/global-immigration-map/, https://www.youtube.com/watch?v=uSM74Pqi288

FS_012, Everyone Who Has Emigrated to the United States Since 1820, Max Galka 2016, http://metrocosm.com/animated-immigration-map/, https://www.youtube.com/watch?v=fiPq7C06zjQ
FS_013, Excerpt from "Dynamic Earth", NASA/Goddard Space Flight Center, 2012, https://svs.gsfc.nasa.gov/11003
FS_014, A visual tour of the world's CO2 emissions, Joss Fong and Joe Posner/vox.com, 2014, https://www.youtube.com/watch?v=fJ
FS_015, Charting Culture, Alison Abbott/Nature News 2014, http://www.nature.com/news/humanity-s-cultural-history-captured-in-5-minute-film-1.15650, http://science.sciencemag.org/content/345/6196/558, https://www.youtube.com/watch?v=4gIhRkCcD4U
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Appendix B

Emplotment, Memorability, and Comprehensibility Study

Additional material can be found online: https://flowstory.github.io/

B.1 Qualtrics Study Primary Iteration

Flowstory: Storytelling in Flow Visualization
Informed Consent Form

Introduction
This study attempts to collect information about the use of storytelling in the visualization of flow data. This survey is part of a doctoral research study at City University London (see contact at the bottom).

Procedures
The experiment is composed of two separate HITs. This first HIT will take approximately 25 minutes and includes the following tasks:

1. You will be shown a **video of an animated simulation** with a text-based description.
2. You will be asked to complete a **spatial reasoning test**.
3. Next, you will be asked to answer **questions about the video** and **facts you observed** while watching it.
4. In a second set of questions, you will be asked to **estimate the outcome** of new setups of the animated simulation you have watched in the beginning.
5. Before you receive the **survey code for AMT** please provide some information about your person and any additional comments you have about the survey.

If you finish this first HIT you will be invited to participate in an additional HIT **around ten days later**, which will take approximately 10 minutes.

Risks/Discomforts
There are no known risks for involvement in this study.

Benefits
Except for the financial compensation, there are no direct benefits for participants. However, it is hoped that through your participation, researchers will learn more about storytelling in visualization.

Confidentiality
All data obtained from participants will be kept confidential and will only be stored and reported in an anonymized format. No one other than the PhD research student and his supervisors listed below will have access to the raw data.

Participation
Participation in this research study is completely voluntary and does not require any prior knowledge about the research topic. You have the right to withdraw at any time. If you desire to withdraw, please close your internet browser. You may only complete this first HIT once. You are allowed to participate in the second follow-up HIT, only if you successfully finish this first HIT.

Compensation
You will be financially compensated for participating in this experiment. After you successfully finished this HIT you will receive USD 2.00. If you return and complete the much shorter second HIT around ten days later you will receive an additional USD 2.20.

Contact and Questions about the Research
If you have any questions regarding this study, you may contact the PhD research student Johannes Liem at johannes.liem@city.ac.uk
(Supervisors: Professor Jo Wood, j.d.wood@city.ac.uk, Dr. Greg Slabaugh, gregory.slabaugh.1@city.ac.uk).

Button: Please print this consent form for your own record.

Consent
I have read and understood the above informed consent form and desire of my own free will to participate in this study.

O Yes – O No Button: Next

[Pagebreak]

For the next three minutes you will be shown an animation. Please follow the animation and the text in the gray box below carefully. Before you start please enter the full screen mode of your browser:
Button: Full Screen
If the Button is not working, please use your browser menu to enter full screen mode (e.g. View > Enter Full

Screen).

Please click next to start the animation when you are ready.
Button: Next

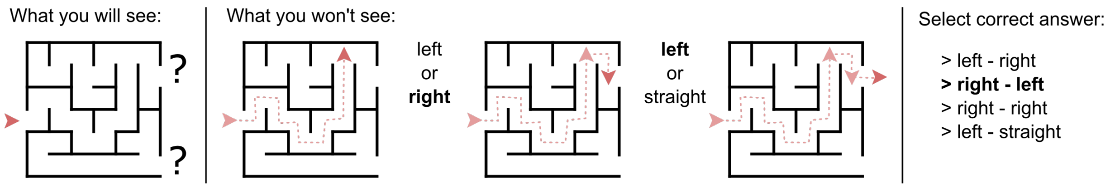
Screening of the video of simulated animation.

Video: Animated Simulation
Loading the video may take a while - please be patient.

Button: Next (appears when video finished)

Well done so far. Now lets move on.
Please help a little arrow to find its way through a maze.

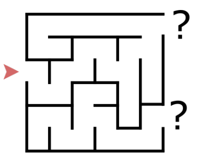
How does it work: What are the correct directions to route the arrow through the maze?



- Possible directions the arrow can go: turn right, turn left, go straight.
- Important: Consider a change of direction only if the arrow has more than one option to go.
- There are three different mazes.
- After a time displayed by a countdown, the next maze loads automatically.
- Please select your answer within the given time.

When you are ready to start, click Next.
Button: Next

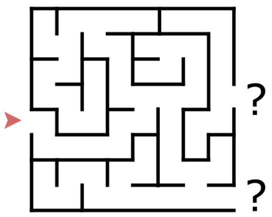
What are the correct directions to route the arrow through the maze?
Please select the correct answer:



- left - left - right
- left - right - right
- left - left - left
- right - right - straight
- left - straight - left

Auto-advance after 30 seconds.

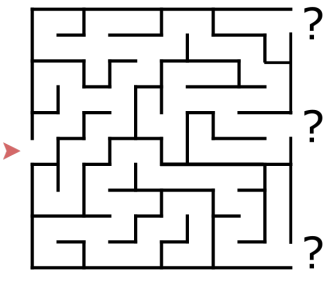
What are the correct directions to route the arrow through the maze?
Please select the correct answer:



- right - right - right - left
- right - right - straight - left
- right - left - right - left
- right - straight - left - right
- left - straight - right - left

Auto-advance after 40 seconds.

What are the correct directions to route the arrow through the maze?
Please select the correct answer:



- right - left - right - left - straight
- right - left - left - left - straight
- right - left - right - right - straight
- left - straight - right - right - left
- left - right - right - left - straight

Auto-advance after 45 seconds.

In the next six questions you will be asked questions about the animation you saw in the beginning.

Please click Next to continue.
Button: Next

Plot:
What shape do citizens have?

NonPlot:
What shape do particles have?

- circle
- square
- diamond
- cross
- triangle

Button: Next

Plot:
What color do citizens have?

NonPlot:
What color do particles have?

- red
- green
- yellow
- purple
- orange

Button: Next

Plot:
What color do walls have?

NonPlot:
What color do barriers have?

- red
- green
- brown
- purple
- orange

Button: Next

Plot:
What shape does the sea particle have?

NonPlot:
What shape do dark objects have?

- circle
- square
- diamond
- cross
- triangle

Button: Next

Plot:
What shape do guards have?

NonPlot:
What shape do red objects have?

- circle
- square
- diamond
- cross
- triangle

Button: Next

Plot:
What shape do weapons have?

NonPlot:
What shape do purple objects have?

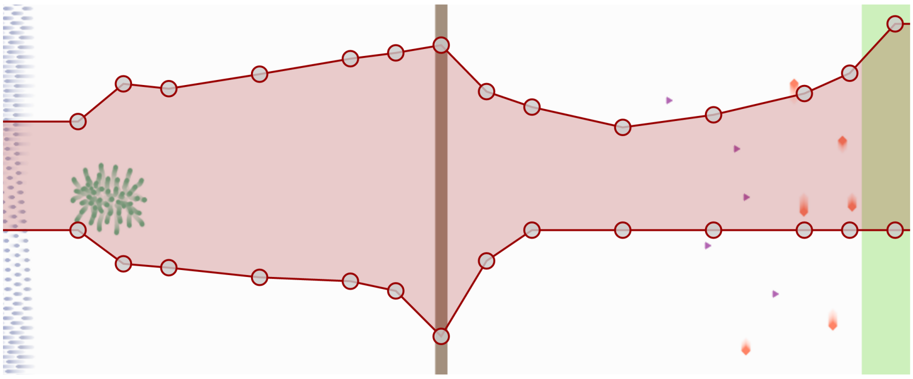
- circle
- square
- diamond
- cross
- triangle

Button: Next

Plot:
Please indicate the maximum vertical extent of the path the group of citizens went in the simulation.

NonPlot:
Please indicate the maximum vertical extent of the path the group of green particles went in the simulation.

To define the upper and lower bound drag the handles up and down:



Check if true: I did change the extent with the handles above based on my memory.

Please indicate the percentage by using the sliders to answer the following questions about the animation you saw in the beginning:

Plot:
How many (in %) of the 200 citizens reached the safe land?

NonPlot:
How many (in %) of the 200 particles reached the green area?

Slider Input [0;100]

Plot:
If, how many (in %) of the 200 citizens were killed by the sea?

NonPlot:
If, how many (in %) of the 200 particles were removed by black objects?

Slider Input [0;100]

Plot:
If, how many (in %) of the 200 citizens were killed by guards?

NonPlot:
If, how many (in %) of the 200 particles were removed by red objects?

Slider Input [0;100]

Button: Next

Please indicate when the following events happend during the animation you saw in the beginning by using the sliders:

Plot:
When did the citizens break through the wall?

NonPlot:
When did the particles break through the barrier?

Slider Input [0;100] with labels: Start - Middle - End

Plot:
When did guards appear?

NonPlot:
When did red objects appear?

Slider Input [0;100] with labels: Start - Middle - End

Plot:
When did weapons appear?

NonPlot:
When did purple objects appear?

Slider Input [0;100] with labels: Start - Middle - End

Button: Next

In the next section you will be introduced to **three new setups** of the initial animation.

Plot:
In each of the three rounds you will see a **static snapshot** of the situation - with citizens, walls, guards and/or weapons. You will be asked to **give estimations about the possible progress** of the animation and explain why you think the animation will progress this certain way.

NonPlot:
In each of the three rounds you will see a **static snapshot** of the situation - with particles, barriers, red objects and/or purple objects. You will be asked to **give estimations about the possible progress** of the animation and explain why you think the animation will progress this certain way.

There is no time limit.

At the end of each round you will see the actual animation.

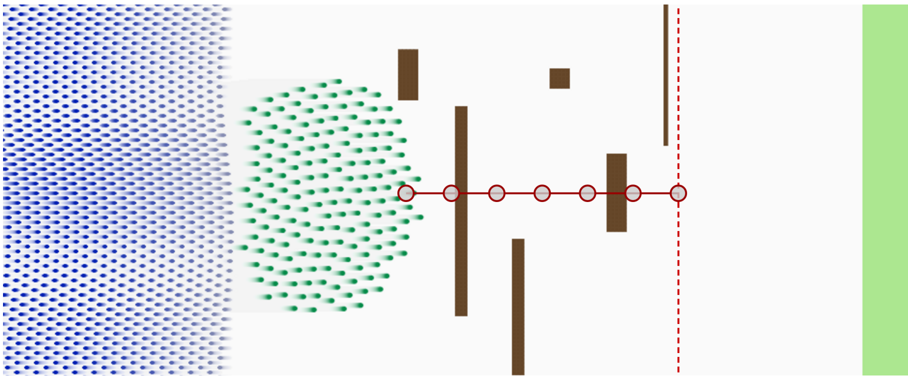
Please click Next when you are ready to start with round one.

Button: Next

Plot:
Please estimate the path of the citizen, who will most likely reach the dashed red line first.

NonPlot:
Please estimate the path of the particle, which will most likely reach the dashed red line first.

To define the path drag the handles up and down:

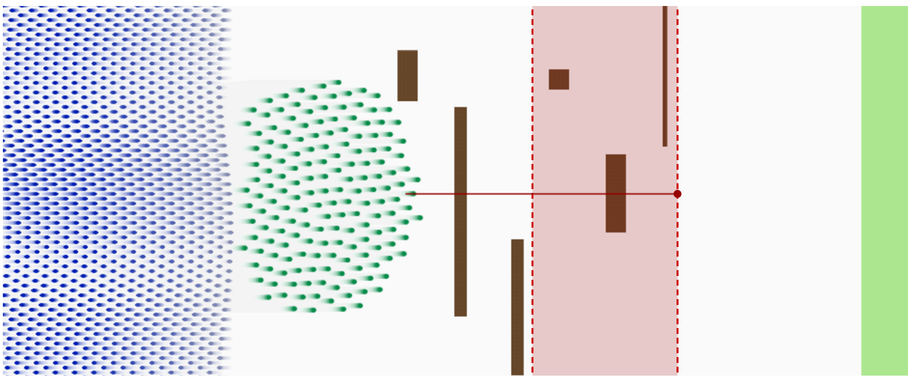


Plot:
Please explain in your own words why you think the citizen, who will most likely reach the dashed red line first, will take the indicated route?

NonPlot:
Please explain in your own words why you think the particle, which will most likely reach the dashed red line first, will take the indicated route?

Text Input

Button: Next



Please use the sliders to answer the following questions - just make your best guess:

Plot:
How many (in %) of the 171 alive citizens will be within the red area when the first citizen reaches the right dashed red line?

NonPlot:
How many (in %) of the 171 visible particles will be within the red area when the first particle reaches the right dashed red line?

Slider Input [0;100]

Plot:
How many (in %) of the 171 alive citizens will have died when the first citizen reaches the right dashed red line?

NonPlot:
How many (in %) of the 171 visible particles will have been removed when the first particle reaches the right dashed red line?

Slider Input [0;100]

Plot:
Please explain in your own words why you think the selected percentage of citizens will be within the red area when the first citizen reaches the right dashed red line:

NonPlot:
Please explain in your own words why you think the selected percentage of particles will be within the red area when the first particle reaches the right dashed red line:

Text Input

Plot:
Please argue why and how you think the specified percentage of particles were removed when the first particle reaches the right dashed red line:

NonPlot:
Please explain in your own words why you think the selected percentage of particles will be within the red area when the first particle reaches the right dashed red line:

Text Input

Button: Next

Screening of the solution video of setup A.

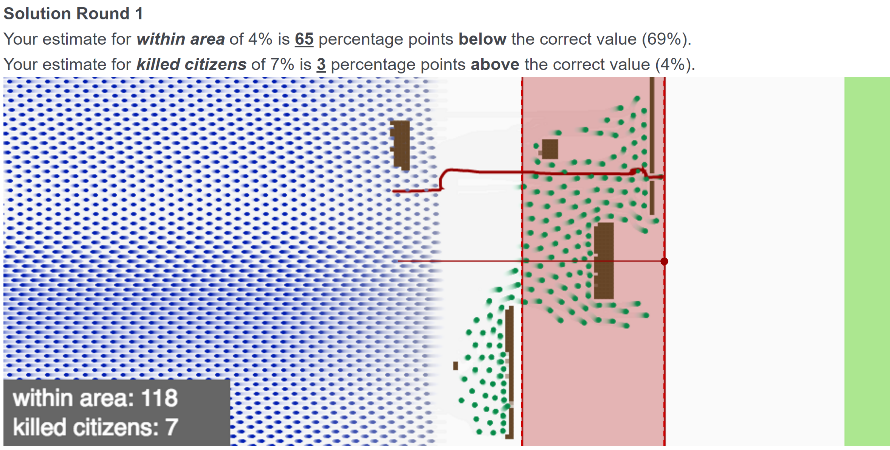
Video: Animated Simulation of Setup A

Loading the video may take a while - please be patient.

After the video reached the end, the following information gets displayed:

Button: Next

Well done!

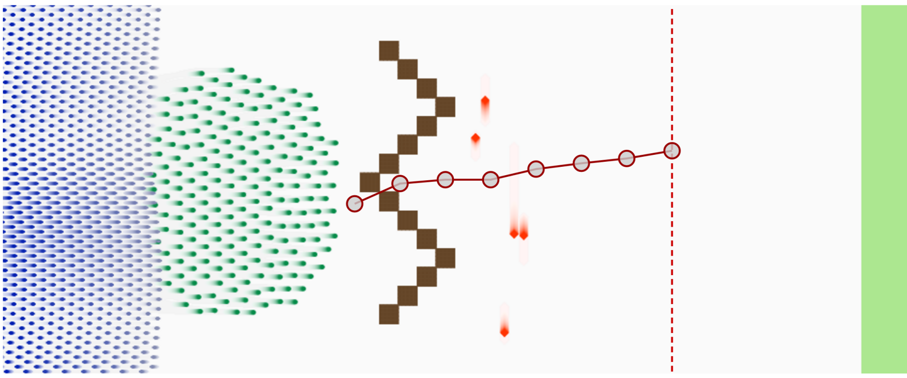


Please, click Next when you are ready to continue with round two.

[Button: Next]

Summary of round two.

Same set of questions with a new setup B:



[Citizens alive | Particles visible] at initial situation: 199

Solution setup B:

One more round to go.

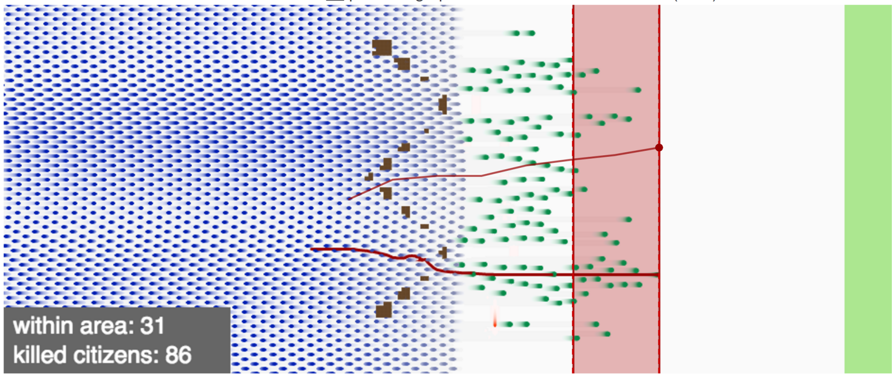
Please, click Next when you are ready to continue with round three.

[Button: Next]

Solution Round 2

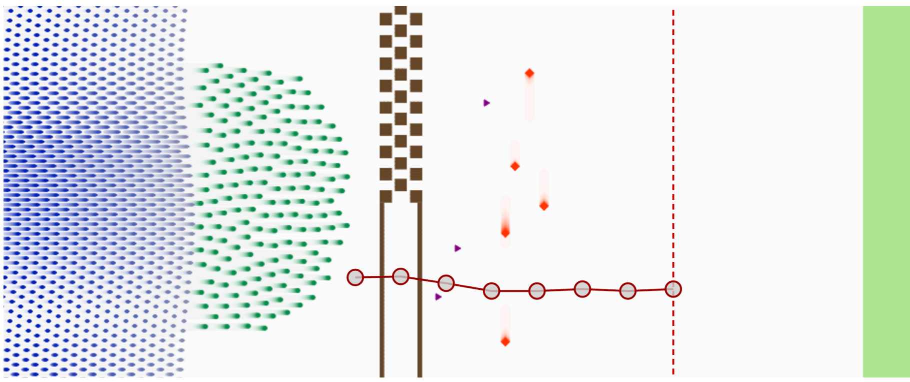
Your estimate for ***within area*** of 30% is 14 percentage points **above** the correct value (16%).

Your estimate for ***killed citizens*** of 32% is 11 percentage points **below** the correct value (43%).



Summary of round three.

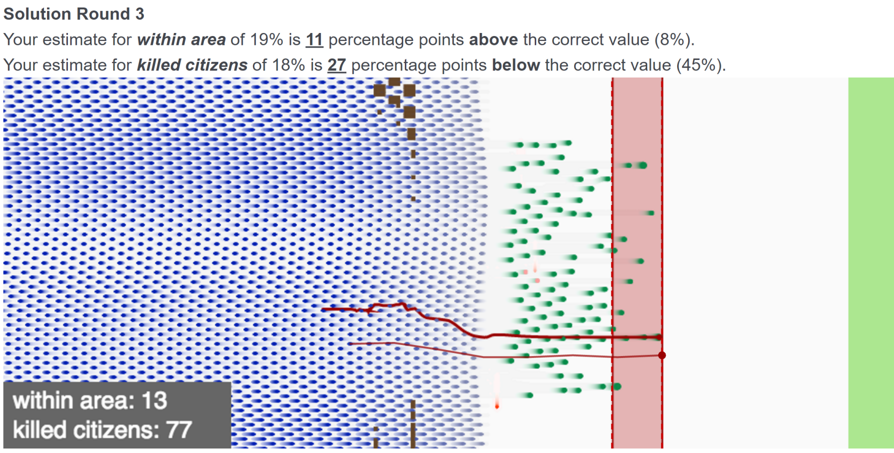
Same set of questions with a new setup C:



[Citizens alive | Particles visible] at initial situation: 172

Solution setup C:

Which of the following statements are true (Select if so)?



Plot:

- Citizens can kill guards if they collect a weapon.
- A citizen gets stronger when collecting a weapon.
- Citizens can destroy a wall when working together.
- The sea kills citizens.
- Guards lose their strength when killing citizens.
- Citizens are not able to destroy walls.
- There are always more weapons than citizens.
- Guards just move horizontally.
- I just randomly click answers.
- Guards can collect weapons.

NonPlot:

- Particles can remove red objects if they collect a purple object.
- A particle gets bigger when collecting a purple object.
- Particle can break a barrier when accumulating.
- Black objects remove particles.
- Red objects get smaller when removing particles.
- Particles are not able to break barriers.
- There are always more purple objects than particles.
- Red objects just move horizontally.
- I just randomly click answers.
- Red objects can collect purple objects.

Button: Next

Plot:
The sea stopped advancing during the animations. But why? Please explain a possible reason (there is no right or wrong):

NonPlot:
The black objects stopped advancing during the animations. But why? Please explain a possible reason (there is no right or wrong):

Text Input

Button: Next

Select the following statements about the animations, which in your opinion are correct:

Plot:

- Strong citizens can kill guards.
- Citizens can drown in the sea.
- Normal citizens tend to follow strong citizens.
- After Guards killed some citizens they die.
- Weapons help citizens to fight guards.
- Strong citizens are faster than normal citizens.
- I paid attention during the survey.
- The sea kills guards.
- Guards move in all directions.
- Weapons just move vertically.

NonPlot:

- Bigger particles can remove red objects.
- Particles can be removed by black objects.
- Normal particles tend to follow bigger particles.
- After red objects removed some particles, they disappear.
- Purple objects allow particles to remove red objects.
- Bigger particles are faster than normal particles.
- I paid attention during the survey.
- Black objects remove red objects.
- Red objects move in all directions.
- Purple objects just move vertically.

Button: Next

Please name additional observations you made while watching the animations:

Text Input

Button: Next

How old are you?

- 18 - 23
- 24 - 29
- 30 - 39
- 40 - 49
- 50 - 59
- 60 or older
- Prefer not to say

What is your gender?

- Male
- Female
- Prefer not to say

What is your highest education?

- Less than high school
- High school graduate / GED
- Some college, no degree

- Bachelors degree
- Masters degree
- Doctoral degree
- Professional degree (JD, MD)
- Other
- Prefer not to say

What is your country of residence? (If you moved within the last five years, please select the country in which you lived the longest).

Combo Box with List of Countries.

From a professional point of view, how familiar are you with Information Visualization?

- Not at all familiar
- Slightly familiar
- Somewhat familiar
- Moderately familiar
- Extremely familiar
- Prefer not to say

Please leave any additional comments to any aspect of the survey below:

Text Input

Button: Next

Thank You for your time taking our survey.

Following up, there will be a second much shorter round in about 7 to 10 days from now.

If you are interested in the **research results** please note down **flowstory.digitalcartography.org** (Expect results later this year).

Finally please copy and paste your personal survey code into the AMT page and submit.

Survey Code: XYZ

B.2 Qualtrics Study Follow-Up Iteration

Flowstory: Storytelling in Flow Visualization - FOLLOW-UP
Informed Consent Form

Introduction
This study attempts to collect information about the use of storytelling in the visualization of flow data. This survey is part of a doctoral research study at City University London (see contact at the bottom).

Procedures
The experiment is composed of two separate HITs.
You successfully finished the first HIT last week - thank you for returning!

This **second HIT** will take approximately 10 minutes and includes the following tasks:

1. You will be asked to **summarize the story** of the first round of the survey (from last week).
2. In a second set of questions, you will be asked to **estimate the outcome** of new setups of the animated simulation you have watched during the first round of the survey.
3. Before you receive the **survey code for AMT** please provide some information about your person and any additional comments you have about the survey.

Risks/Discomforts
There are no known risks for involvement in this study.

Benefits
Except for the financial compensation, there are no direct benefits for participants. However, it is hoped that through your participation, researchers will learn more about storytelling in visualization.

Confidentiality
All data obtained from participants will be kept confidential and will only be stored and reported in an anonymized format. No one other than the PhD research student and his supervisors listed below will have access to the raw data.

Participation
Participation in this research study is completely voluntary and does not require any prior knowledge about the research topic. You have the right to withdraw at any time. If you desire to withdraw, please close your internet browser. You may only complete this HIT once. You are allowed to participate in this second follow-up HIT, because you successfully finished the first HIT.

Compensation
You will be financially compensated for participating in this experiment. After you successfully finished the first HIT last week and returned to complete this much shorter second HIT you will receive an additional USD 2.20.

Contact and Questions about the Research
If you have any questions regarding this study, you may contact the PhD research student Johannes Liem at johannes.liem@city.ac.uk (Supervisors: Professor Jo Wood, j.d.wood@city.ac.uk, Dr. Greg Slabaugh, gregory.slabaugh.1@city.ac.uk).

Button: Please print this consent form for your own record.

Consent
I have read and understood the above informed consent form and desire of my own free will to participate in this study.

O Yes – O No Button: Next

Plot:
About two weeks ago you participated in the first round of our survey. Please **summarize** in a few sentences **what happened during the animations you saw** - tell the story of the **citizens** in your own words and be as specific as possible (but do not spend more than 2 minutes on this task):

NonPlot:
About two weeks ago you participated in the first round of our survey. Please **summarize** in a few sentences **what happened during the animations you saw** - tell the story of the **green particles** in your own words and be as specific as possible (but do not spend more than 2 minutes on this task):

Text Input

Button: Next

In the next section, you will be introduced to **four setups** of the animation from the previous week.

Plot:
In each of the four rounds, you will see a **static snapshot** of the situation - with citizens, walls, guards and/or weapons. You will be asked to **give estimations about the possible progress** of the animation and explain why you think the animation will progress this certain way.

NonPlot:
In each of the four rounds, you will see a **static snapshot** of the situation - with particles, barriers, red objects and/or purple objects. You will be asked to **give estimations about the possible progress** of the animation and explain why you think the animation will progress this certain way.

There is no time limit.

This time, there is **no solution video** at the end.

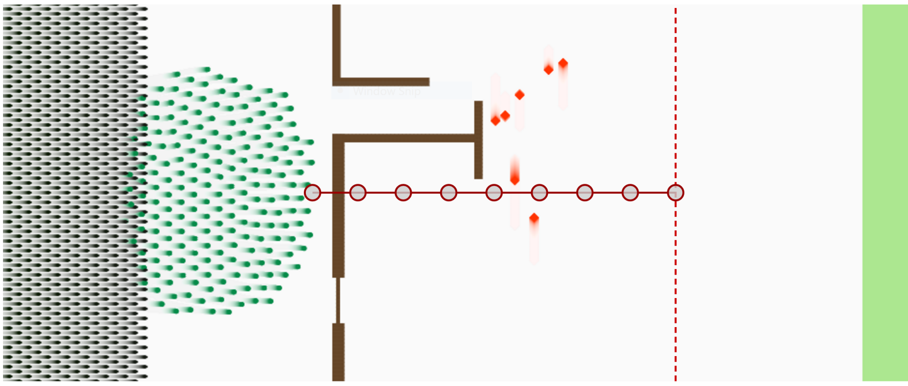
Please click Next when you are ready to start.
Button: Next

Round 1: see Main Run Round 2 (setup B)

Round 2: Setup D

Summary of round three.

Same set of questions as in Main Run with a new setup D:

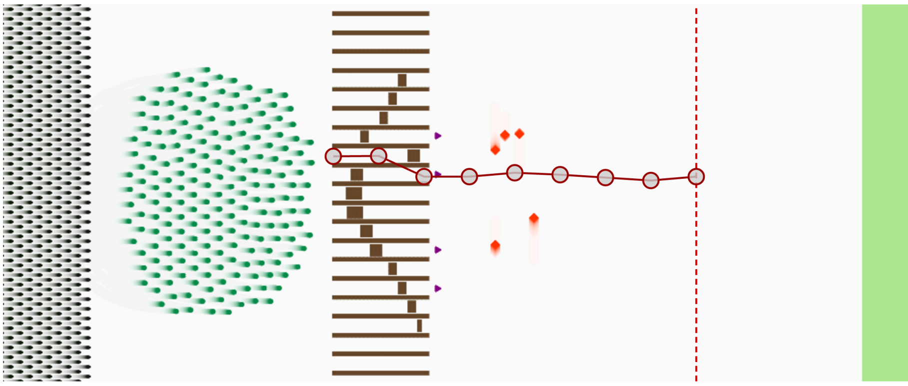


[Citizens alive | Particles visible] at initial situation: 199

Round 3: see Main Run Round 3 (setup C)

Round 4: Setup E
Summary of round four.

Same set of questions as in Main Run with a new setup E:



[Citizens alive | Particles visible] at initial situation: 199

How old are you?

- 18 - 23

- 24 - 29
- 30 - 39
- 40 - 49
- 50 - 59
- 60 or older
- Prefer not to say

What is your gender?

- Male
- Female
- Prefer not to say

Please leave any additional comments to any aspect of the survey below:

Text Input

Button: Next

Thank You for your time taking our survey.

If you are interested in the research results please note down flowstory.digitalcartography.org (Expect results later this year).

Finally please copy and paste your personal survey code into the AMT page and submit.

Survey Code: XYZ

Appendix C

Structure, Empathy, and Attitude Study

Additional material can be found online: https://flowstory.github.io/

C.1 Qualtrics Study

Informed Consent

Storytelling in Visualisation
Informed Consent Form

Introduction
This study attempts to collect information about the use of storytelling in data visualisation. The survey is part of a doctoral research project at City, University of London (see contact at the bottom).

Procedures
This survey will take **20 minutes or less** and includes the following tasks:

1. Read through brief instructions and adjust your browser (we provide some help).
2. Answer questions about your personal characteristics.
3. Engage with an interactive visualisation.
4. Answer a second set of questions about the visualisation.
5. **Receive a completion code for prolific.**

Risks/Discomforts
There are no known risks for involvement in this study.

Benefits
Except for the financial compensation, there are no direct benefits for participating. However, it is hoped that through your participation, researchers will learn more about storytelling in data visualisation.

Confidentiality
All data obtained through your participation will only be stored and reported in an anonymised format.

Participation
Participation in this research study is **completely voluntary** and does not require any prior knowledge of the research topic. You have the right to **withdraw at any time**. If you desire to withdraw, please close your internet browser.

Compensation
When you successfully finish the survey you will be **financially compensated with £2.50** via prolific. Please be aware that you can only participate and be paid once.

Contact and Questions about the Research
If you have any questions regarding this study, you may contact the PhD research student Johannes Liem at johannes.liem@city.ac.uk (Supervisors: Professor Jo Wood, j.d.wood@city.ac.uk, Dr. Charles Perin, charles.perin@city.ac.uk).

Who has reviewed the study?
This study has been approved by the Computer Science Research Ethics Committee from City, University of London (ID: CSREC171212JL).

Consent
I have read and understood the above information. It is the desire of my own free will to participate in this study.

- Yes, I give consent and want to start the survey.
- No, I do not want to participate in the survey.

Instructions
Thank you for taking the survey.

Please complete the following tasks, which will take you 20 minutes or less:

1. Answer a few questions about your personal characteristics, for example, your age and gender.
2. Engage actively with an interactive map visualisation for several minutes.

3. Answer a set of detailed questions demonstrating that you understood and remembered what you have seen and learned while interacting with the visualisation.

Please maximise the browser window or switch to full-screen mode. Use the zoom function of your browser to enlarge or shrink the red, dashed frame. Adjust it so you can see the entire red frame on your screen. [Keyboard shortcuts: Cmd/Ctrl and +/-]

Please try to stay focused and in front of your computer during the survey. Please do not switch tabs or browser windows.

Click "Start the Survey" button when you are ready.

Demographic Questions
Please answer the following questions.

With which gender do you identify yourself?

- Male
- Female
- Prefer not to say

How old are you?

- 18 – 24
- 25 – 34
- 35 – 44
- 45 – 54
- 55 – 64
- 65 or older
- Prefer not to say

What is your highest level of education (if you education was outside the UK, pick the appropriate equivalent)?

- GCSE Level education (e.g., GCSE, O-Levels or Standards)
- A-Level education (e.g., A, AS, S-Levels, Highers)
- Degree or Graduate education (e.g., BSc, BA)
- Post-graduate education (e.g., PhD, MSc, MA)
- Vocational education (e.g., NVQ, HNC, HND)
- Non of the above
- Prefer not to say

How would you rate your religious belief on the following scale?

- *11 point scale:* not at all religious — very religious
- Prefer not to say

Can you live on the combined household income obtaining at present?

- Living comfortably on present income
- Coping on present income
- Finding it difficult on present income
- Finding it very difficult on present income
- Prefer not to say

Where would you place yourself on a political spectrum using the following scale?

- *11 point scale:* left — right
- Prefer not to say

Pre-Test: Immigration Attitudes *Experiment 1 Only*
Each question was displayed on a separate page.

In the next seven questions we ask you about people from other countries who come to live in the UK.

To what extent do you think the UK should allow people of the **same race or ethnic group** as most of the UK's people to come and live here?

UK's policy should be to ...

- Allow many to come and live here
- Allow some
- Allow a few
- Allow none
- Prefer not to say

The following questions have the same answer options as the question above.

- How about people of a **different race or ethnic group** from most people in the UK?
- How about people from the **poorer countries in Europe?**
- How about people from the **poorer countries outside Europe?**

Would you say it is generally bad or good for the UK's economy that people come to live here from other countries?

- *11 point scale:* Bad for the economy — Good for the economy
- Prefer not to say

Would you say that the UK's cultural life is generally undermined or enriched by people coming to live here from other countries?

- *11 point scale:* Cultural life undermined — Cultural life enriched
- Prefer not to say

Is the UK made a worse or a better place to live by people coming to live here from other countries?

- *11 point scale:* Worse place to live — Better place to live
- Prefer not to say

Stimulus Briefing

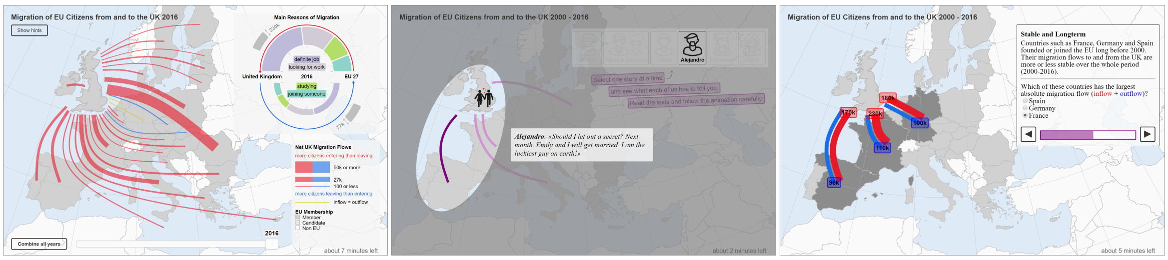
The next screen will show a visualisation of some data. You will have a few minutes to interact with it, after which a number of questions will be asked.

In the bottom right corner, you will see how much time you have.

Click Next when you are ready to continue.

Stimulus

Participants were randomly but equally allocated across the three conditions.



Interactive flow map (non-narrative visualization) | Personal visual story designed to generate empathy | Structured visual narrative of aggregates of people

Figure C.1: Three experimental conditions: exploratory (left), empathy (center), structure (right).

Blow the visual stimulus we placed a reminder:

Remember: We will ask you to answer a set of detailed questions demonstrating that you understood and remembered what you have seen and learned while interacting with the visualisation. Use the available time to engage with the map.

Filter Questions

Please answer the following question: What colour was used in the visualisation to show migration inflow to the UK?

- green
- red
- yellow

- blue
- purple

Please answer the following question: From which EU country did the most people move to the UK between 2000 and 2016?

- Austria
- Bulgaria
- France
- Poland
- Denmark

Please answer the following question: What was the main reason for people from the EU to come to live in the UK?

- work
- study
- the health system
- retire
- join someone

Questionnaire Briefing
In the final section, we ask you to answer 28 questions. Please select the appropriate answer.

You always have the option to select "Prefer not to say". Please try to provide an answer and only use the option if you feel uncomfortable answering the question. Remember: all information you provide is anonymous.

Click Next when you are ready to continue.

Human Values Questions
Depending on the answer to the question of gender, the person descriptions were adapted to the corresponding gender. The following statement describes a person.

Thinking up new ideas and being creative is important to her. She likes to do things in her own original way.

Select how much the person is or is not like you.

- Very much like me
- Like me
- Somewhat like me
- A little like me

- Not like me
- Not like me at all
- Prefer not to say

The following questions had the same answer options as the question above.

- It is important to her to be rich. She wants to have a lot of money and expensive things.
- She thinks it is important that every person in the world should be treated equally. She believes everyone should have equal opportunities in life.
- It's important to her to show her abilities. She wants people to admire what she does.
- It is important to her to live in secure surroundings. She avoids anything that might endanger her safety.
- She likes surprises and is always looking for new things to do. She thinks it is important to do lots of different things in life.
- She believes that people should do what they're told. She thinks people should follow rules at all times, even when no-one is watching.
- It is important to her to listen to people who are different from her. Even when she disagrees with them, she still wants to understand them.
- It is important to her to be humble and modest. She tries not to draw attention to herself.
- Having a good time is important to her. She likes to "spoil" herself.
- It is important to her to make her own decisions about what she does. She likes to be free and not depend on others.
- It's very important to her to help the people around her. She wants to care for their well-being.
- Being very successful is important to her. She hopes people will recognise her achievements.
- It is important to her that the government ensures her safety against all threats. She wants the state to be strong so it can defend its citizens.
- She looks for adventures and likes to take risks. She wants to have an exciting life.
- It is important to her always to behave properly. She wants to avoid doing anything people would say is wrong.
- It is important to her to get respect from others. She wants people to do what she says.
- It is important to her to be loyal to her friends. She wants to devote herself to people close to her.
- She strongly believes that people should care for nature. Looking after the environment is important to her.
- Tradition is important to her. She tries to follow the customs handed down by her religion or her family.
- She seeks every chance she can to have fun. It is important to her to do things that give her pleasure.

Post-Test: Immigration Attitudes
In the remaining seven questions we ask you about people from other countries who come to live in the UK.

See the Section "Pre-Test: Immigration Attitudes".

Feedback and Survey End

Thank you for taking the time to do our survey!

Maybe you have the feeling that all these questions you just answered didn't really address the visualisation you engaged in.

You are right! The goal of the experiment is to see if different types of visualisations – you only saw one out of three – influence the outcome of all these questions you answered. To avoid priming your thoughts we didn't mention much of this at the beginning of the survey. But it is just fair to inform you about this now.

If you are interested in the research results, please note down flowstory.digitalcartography.org (Expect results in fall of 2018).

Thank you again for your valuable contribution, and feel free to leave any comments or thoughts you have:

Textbox provided here.

C.2 Results: Immigration Attitudes by Items

The Figures C.2 and C.3 show the distribution of participants responses for each of the seven questions of opposition to migration and perceived immigration threat, respectively. Results are grouped by condition showing the results of the pre test of experiment 1 and the post tests of both experiments.

Opposition to Immigration

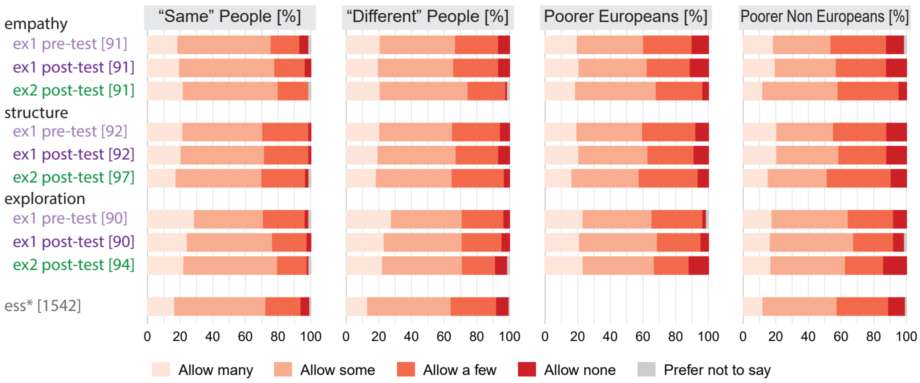


Figure C.2: Distributions of participant responses in percent for *opposition to immigration* by item, condition, and experiment On an 4 point scale, participants were asked how many migrants the UK should allow to come if they are from the *same* or *different* ethnicity as the UK's majority; and if they are from *poorer* countries *inside EU* or *outside EU*. The values on the right show the total numbers of responses. (*) Item was dropped in the most recent ESS round.

Perceived Immigration Threat

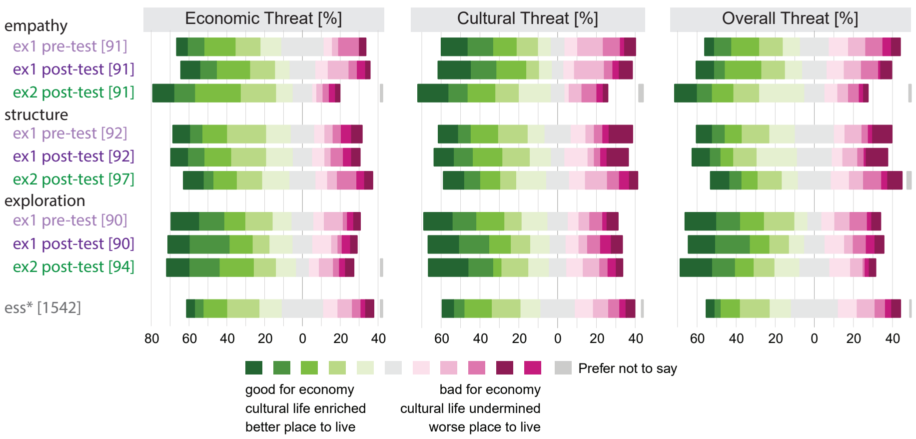


Figure C.3: Distributions of participant responses in percent for *perceived immigration threat* by item, condition and experiment. On an 11 point scale, participants were asked whether immigration is good or bad for *economy*, whether immigration enriches or undermines *cultural* life, and whether *overall* immigration makes UK a better or a worse place to live. The values on the right show the total numbers of responses.

C.3 Exploratory Results

To inform our discussion and provide more context to the confirmatory analysis we conducted further exploratory analysis. Specifically, we add perspective to **result 1** and **result 2** by looking at demographics and human values. In the paper we just present the conditions and variables relevant to these results. Here we provide the results of the exploratory analysis for all conditions and variables.

Immigration Attitudes by Demographics

Immigration Attitudes by Gender

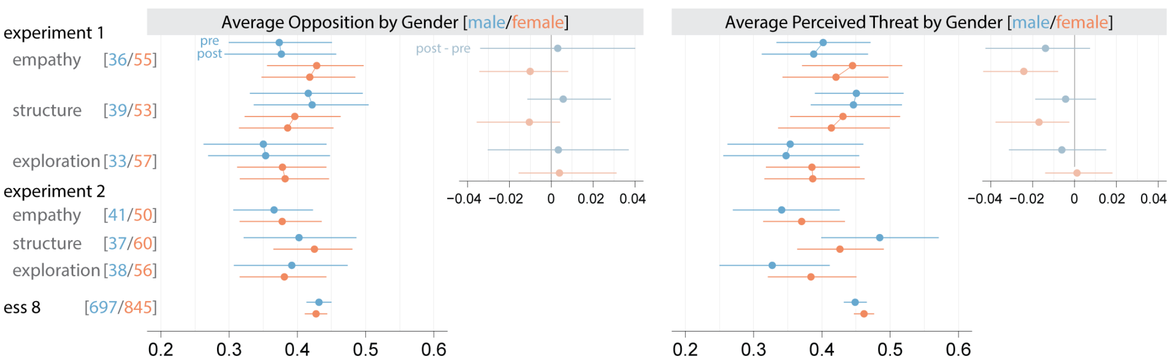


Figure C.4: Exploratory results of average opposition and average perceived threat by **Gender**. The plots compare ***male*** and ***female*** participants (none answered ‘prefer not to say‘).

Immigration Attitudes by Age

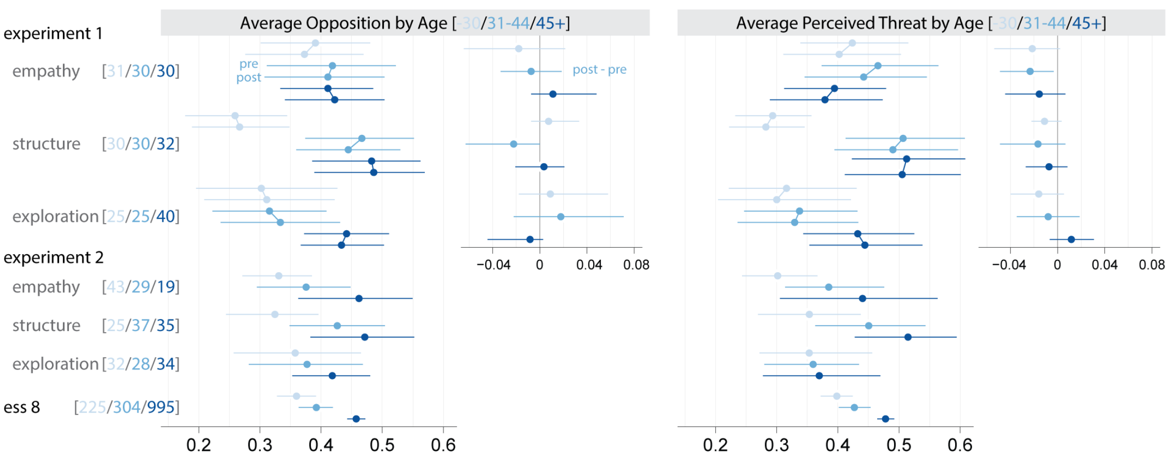


Figure C.5: Exploratory results of average opposition and average perceived threat by **Age**. The participants are grouped by thirds.

Immigration Attitudes by Education

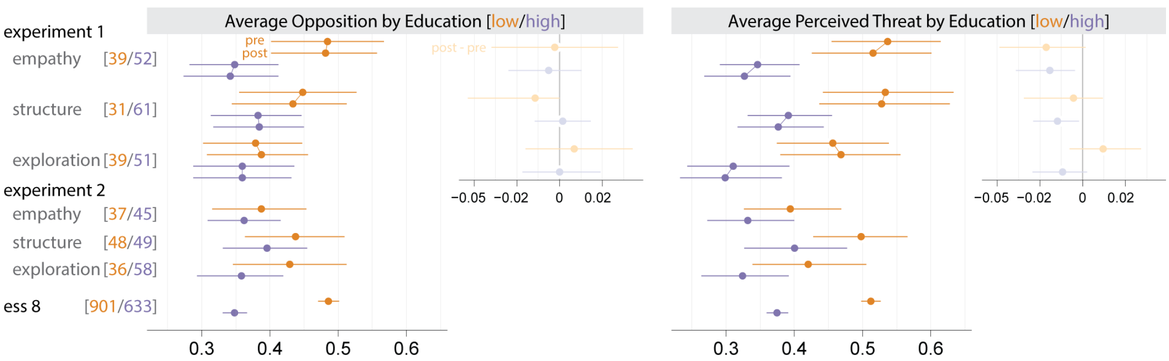


Figure C.6: Exploratory results of average opposition and average perceived threat by **Education**. The answer options *Below Standards*, *GCSE Level Education*, and *A-Level Education* are binned into ***low***, and *Degree or Graduate Education* and *Post-Graduate Education* into ***high***.

Immigration Attitudes by Income

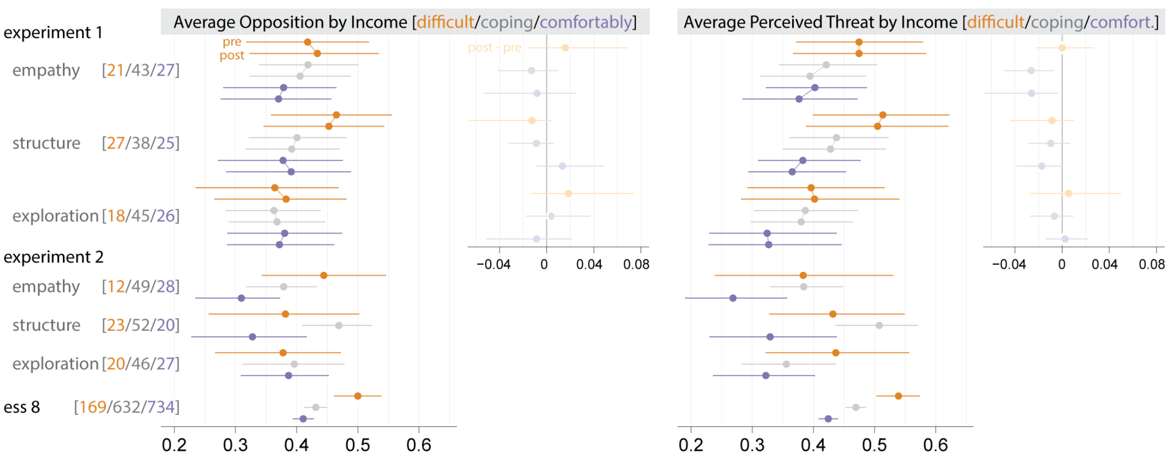


Figure C.7: Exploratory results of average opposition and average perceived threat by **Income**. We group participants finding it *very difficult* or *difficult* to live on present income into ***difficult***, and use the other two original groups ***coping*** and living ***comfortably*** on income.

Immigration Attitudes by Religion

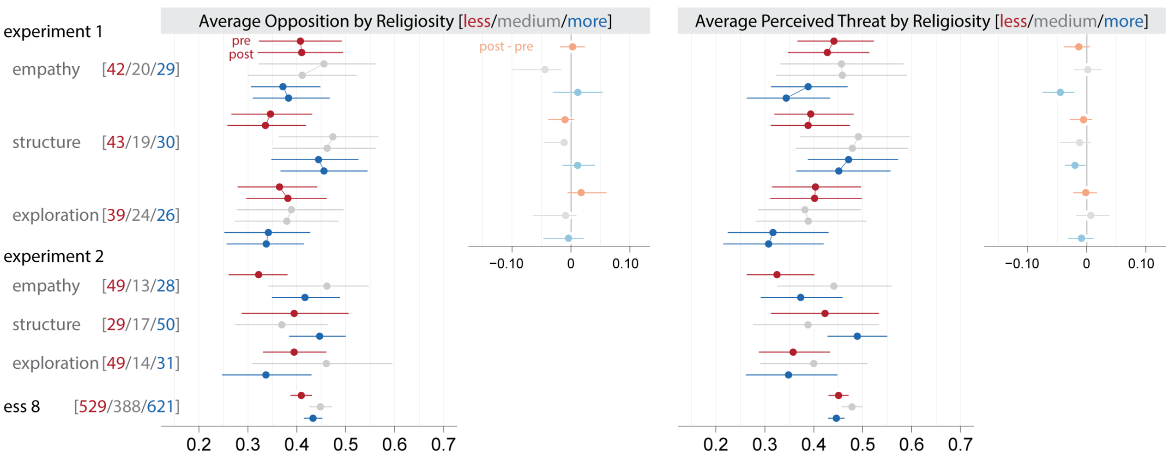


Figure C.8: Exploratory results of average opposition and average perceived threat by **Religion**. Due to unbalanced distribution is the binning of this topic relative, we created three bins of equal size (as good as possible): ***less religious***, ***medium religious*** and ***more religious***.

Immigration Attitudes by Politics

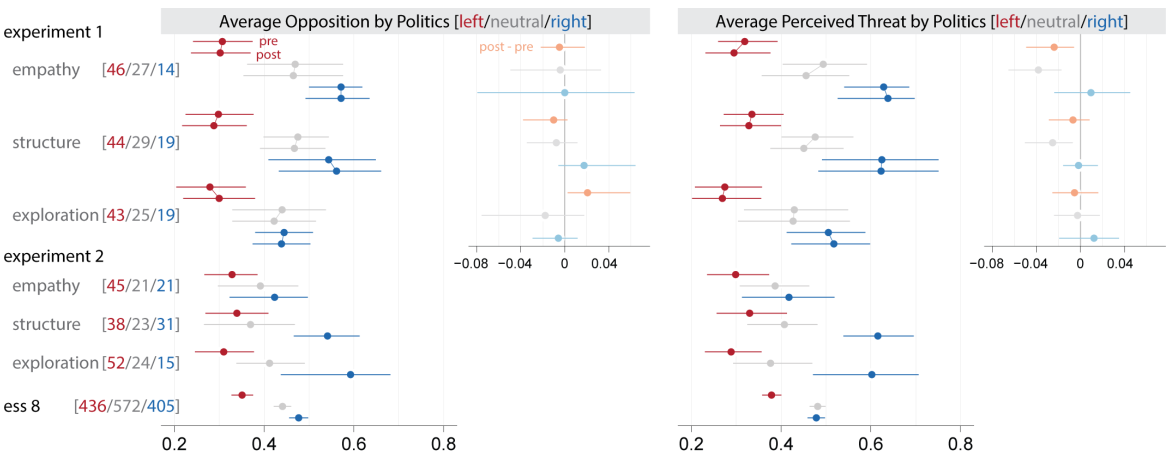


Figure C.9: Exploratory results of average opposition and average perceived threat by **Politics**. The binning separates participants orientation on the ***left*** and the ***right*** spectrum, and all participants who selected the ***center/neutral*** option.

Immigration Attitudes by Human Values

Immigration Attitudes by Conservation vs. Openness to Change

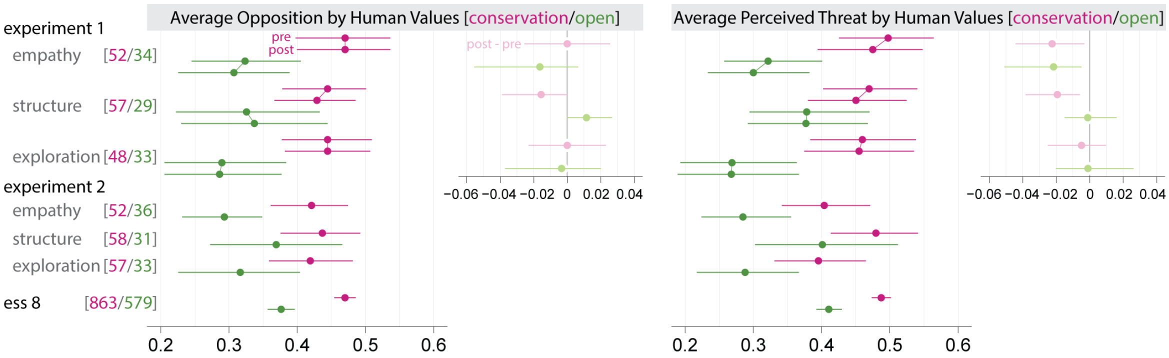


Figure C.10: Exploratory results for confirmatory results by **higher-order human values**. The dimension contrasts ***conservative*** participants with people ***open to change***.

Immigration Attitudes by Self-Enhancement vs. Self-Transtendence

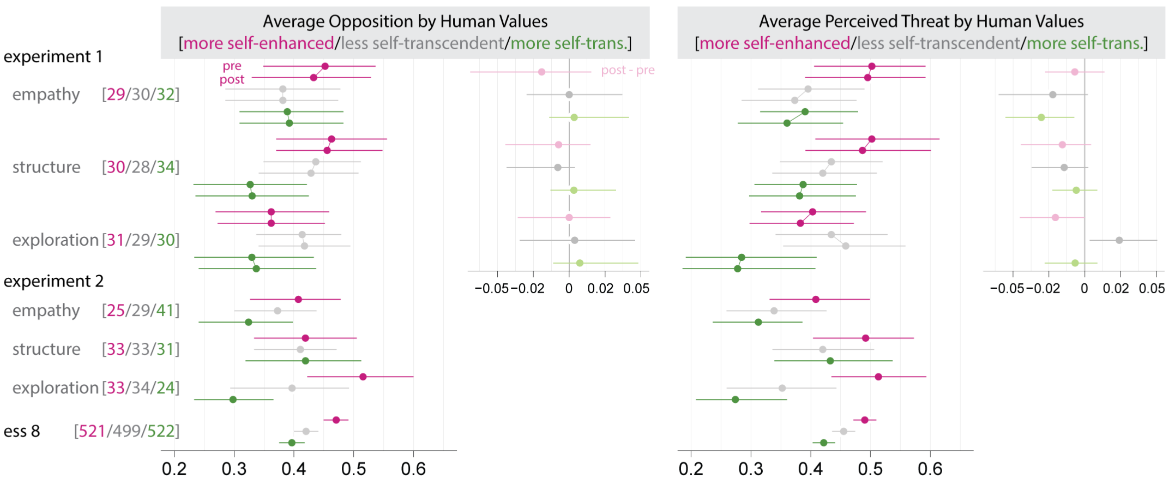


Figure C.11: Exploratory results for confirmatory results by **higher-order human values**. The dimension, contrasting self-enhancement and self-transcendence, is a relative comparison due to unbalanced distribution. The participants are grouped in three bins: ***more self-enhanced***, ***less self-transcendent***, and ***more self-transcendent***.

Immigration Attitudes by Time

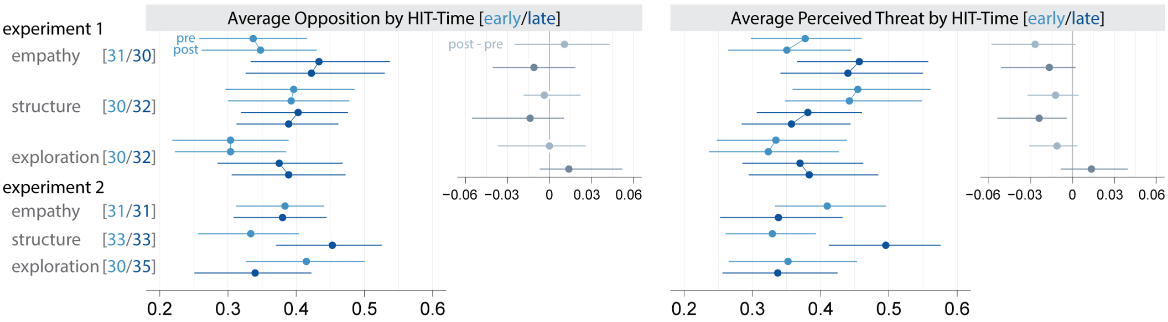


Figure C.12: Comparing the first third of submissions and the last third.