Aalto University
School of Science
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# Tools for Visualizing Geographical Data on the Web

## Reducing the Work Needed by Eliminating Boilerplate

Master's Thesis
Espoo, October 14, 2014

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# Abbreviations and Acronyms

| | |
|---|---|
| API | Application Programming Interface |
| CC | Cyclomatic Complexity |
| COCOMO | COnstructive COst MOdel |
| CSS | Cascading Style Sheets |
| CSS3 | Cascading Style Sheets level 3 |
| CSV | Comma-Separated Values |
| ECMA | European Computer Manufacturers Association |
| GeoJSON | Geographic JavaScript Object Notation |
| GIS | Geographic Information System |
| HD | Halstead Difficulty |
| HE | Halstead Effort |
| HTML | HyperText Markup Language |
| HTML5 | HyperText Markup Language version 5 |
| JSON | JavaScript Object Notation |
| LOC | Lines of Code |
| LLOC | Logical Lines of Code |
| POI | Point of Interest; a piece of data with geospatial dimension |
| REST | Representational State Transfer |
| SPA | Single-Page Application |
| UI | User Interface |

# Contents

# Chapter 1

# Introduction

We are confronted with a quickly increasing amount of data every day. We also increasingly need to use the data as a basis for our actions and thoughts. *Visualization* enables us to obtain insight about data quickly and efficiently (van Wijk, 2005), making it crucial in the modern world.

An estimated 95 % of all digital data contains geographical references (Perkins, 2010). Visualizing this data helps users perceive geospatial relationships and patterns. Additionally, we can use geographical visualizations for determining information on distances, directions and areas (Kraak and Ormeling, 2011, chap. 1.1). Using geographical visualizations, it is also possible to organize data spatially and visually, allowing more efficient memorization of data.

Geographical data is data with geospatial dimension, such as Point of Interest (POI) with location data as coordinates (Kraak and Ormeling, 2011, chap. 1.2). The most natural method for visualizing geographical data is usually with various maps. In the past, geographical data was predominantly visualized by cartographers. However, research indicates that that the situation has changed (Kraak and MacEachren, 1999). At present, people from increasing number of fields have a need – and the possibility (Slocum and McMaster, 2014, chap. 1) – to visualize geographical data. Moreover, the popularity of Google Maps (Google, 2005b) along with its Application Programming Interface (API) (Google, 2005a) has proved that the target audience has changed. In addition to experts of other academic fields, there

is a definite demand for web map visualizations within consumers as well.

The web makes publishing and bundling map visualizations extraordinarily straightforward when compared to traditional desktop-based Geographic Information System (GIS) applications. Traditional desktop-based GIS requires an installation of the GIS application and often additional tools and accounts for publishing the visualization. On the other hand, using web-based mapping software ideally requires no additional software or tools or even accounts. This is especially important when the visualizations are made by non-cartographers. Typically, non-cartographers only make visualizations occasionally and lack the needed resources and experience for more complex publishing process (Miller, 2006). However, the web platform is primarily designed for static documents (Berners-Lee, 1989; Berners-Lee et al., 1992) instead of dynamic applications (Jazayeri, 2007). Consequently, there are some additional concerns to address when making a complex data visualization on the web.

## 1.1 Problem Statement

Currently, there are several libraries available for displaying maps and simple visualizations on the web (Google, 2005a; Agafonkin, 2011; MetaCarta, 2006). However, the problem is that none of the mainstream libraries is of sufficiently high abstraction level for building map visualizations efficiently. This results in the need for writing *boilerplate* code that does not directly contribute to the visualization. Moreover, the libraries are not designed primarily for visualizations. Therefore, they do not encourage or push the visualizer to create visually and cognitively effective visualizations. Typically, this results in subpar visualizations (Slocum and McMaster, 2014, chap. 1).

## 1.2 Objectives and Scope

My primary objective is to make creating map visualizations for the web more efficient. I plan to do this by building a reusable higher abstraction level software system for map visualizations, and to evaluate the efficiency

benefits of the system. This system should provide the structure for creating the visualization as well as the features commonly needed in modern web applications. My secondary objective is to encourage more effective visualizations by considering the cognitive requirements of visualizations when building the system.

In order to find the solution for the problem, it is necessary to study geographical visualizations and software reuse. I also need to study the process of making geographical visualizations to ensure that the system encourages creating *effective* visualizations. In addition, software reuse should be studied in order to be able to create versatile visualizations *efficiently*. Therefore, to evaluate the objectives, I select the following research questions for this thesis:

RQ1 How does a reusable software system affect the *efficiency* of building geographical visualizations?

RQ2 How does a reusable software system affect the *effectiveness* of geographical visualizations?

In the scope of this thesis, I adopt the process definitions of van Wijk (2005) by making the difference between an efficient and an effective process. *By an efficient process, I mean a process which requires as little as possible effort and other resources to complete. By an effective process, I mean a process which reaches its objectives sufficiently.* Therefore, building a visualization efficiently indicates that the building process is as effortless as possible. Building an effective visualization indicates that the resulting visualization conveys its intended message appropriately.

## 1.3 Approach

In order to build an efficient system for visualizing geographical data, it is needed to study (a) how to visualize geographical data and (b) how to build reusable software. I begin by first studying the basics of data visualization with an emphasis on geographical data, maps and the visualization process. After visualization, I study the essence of software reuse, focusing on building

and evaluating reusable software. Based on suggestions from earlier research, I proceed to create a reusable visualization tool and evaluate its effect on visualization effectiveness and efficiency of the building process.

## 1.4 Structure of the Thesis

Chapter 1 (this introduction) presents the motivation for this thesis as well as the problem statement. Chapter 2 presents the essence of software reuse, concentrating on success factors and methods for reuse. Chapter 3 describes the fundamentals of data visualizations with an emphasis on geographic data and thematic mapping. In chapter 4, I discuss the research on data visualization reuse along with its shortcomings, and argue about the need for this research.

In chapter 5, I present some of the most prominent methods for evaluating software reuse and visualization effectiveness, selecting the most suitable methods for this work. In chapter 6, I describe the implementation of the tool designed to address the shortcomings presented in chapter 4. In chapter 7, I evaluate the implementation based on the methods presented in chapter 5 and analyze the evaluation results. In chapter 8, I interpret the evaluation results along with their applicability, shortcomings and generalizability. I also propose topics for further research based on this work. In chapter 9, I conclude the findings and other implications of the thesis.

# Chapter 2

# Software Reuse

In this chapter, I conduct a brief study of software reuse. In the study, I concentrate on different reuse techniques and their characteristics, advantages and disadvantages. I also study the success factors of software reuse and methods for analyzing and evaluating software reuse.

Krueger (1992) presents software reuse as a process of reusing existing software code (applications, libraries, functions or single lines) when building new software. On the other hand, according to Mohagheghi and Conradi (2008), reuse is not restricted to code, but can also refer to other software assets such as design. However, both agree that software reuse combines several different existing pieces of code (and possibly other assets) along with new assets which are specific for the application in question. According to Mcilroy (1969) and Boehm (1999), it is one of the most effective techniques of reducing the development time and cost of complex software products.

## 2.1 Software Reuse Advantages & Disadvantages

When used appropriately, software reuse has several benefits. In their overview of multiple case studies, Mohagheghi and Conradi (2008) discovered that in most cases, using reused software components resulted in a considerably lower number of software defects and better productivity. Several of the studies implied that reusing software is also beneficial for software complexity and

product time-to-market. However, it should be noted that since the overview only addresses case studies, its results should not be considered universally applicable.

The majority of software reuse studies indicate that software reuse decreases the effort needed (e.g., Mcilroy 1969; Boehm 1999; Mohagheghi and Conradi 2008). However, concrete evidence for this is difficult to find (Mohagheghi and Conradi, 2008).

Given its lucrative advantages, software reuse is definitely beneficial for many software systems. However, according to Krueger (1992), software reuse can be problematic and even disadvantageous. Learning to use a specific piece of reusable software often takes considerable effort. Moreover, finding suitable code fragments may also prove to be a challenge. For uncomplicated software systems and especially reusable components, it may not be worth the effort. Therefore, developer needs to carefully consider all sides of reusing when building a software system. According to Krueger (1992, chap. 1.3), for successful software reuse scenario, the amount of intellectual effort between the concept and implementation of the system must be as low as possible. In practice, this means that the value of the reused component must be as high as possible for the developed system, while the implementation cost (resources needed to take the reusable component into use) should be relatively low.

## 2.2 Factors for Successful Software Reuse

Frakes and Isoda (1994) present six critical factors for successful software reuse: management, measurement, legal, economics, design for reuse, and libraries. Some of the factors are relevant only for a corporate-level reuse program, but many are critical for smaller scale reuse as well.

Successful reuse requires the **management** to commit to a long-term, top-down support, because reusing software may require years to pay off the costs. Also, **measurement** of reuse is vital to reuse software successfully. Both *reuse level* (the ratio of reused software to total software) and *reuse factors* (things affecting the increase of reuse) should be measured.

**Legal** issues are also important to consider when reusing software. Specif-

ically, the stakeholders should agree on the rights and responsibilities of providers and consumers of reusable software. Moreover, using software with conflicting licenses may cause problems.

**Economics** present a challenge in systematic reuse scenarios. Measuring reuse costs is not straightforward. Frequently, the costs of creating a reusable component are compensated by benefits in some other project using the component.

**Designing for reuse** requires a degree of domain knowledge. This necessitates the study of the domain when creating *domain-specific* reusable software. In addition to that, reusable software design requires effort on encapsulation, abstraction and interfaces.

Lastly, reusable software **libraries** are required to fully benefit from the reusability effort. Libraries enable storing, retrieving and finding the reusable software.

## 2.3 Analyzing Software Reuse

According to Krueger (1992), in order to analyze software reuse techniques, the specific technique should be analyzed using four *dimensions*: *abstraction, selection, specialization and integration.* I present the dimensions below.

**Abstraction** is the process of making a piece of software more generic, thus making it applicable to a wider range of software projects. Software reuse is almost always based on abstraction, but according to Krueger (1992), raising the abstraction level has proven to be difficul. Therefore, building reusable software is a challenging process.

**Selection** facilitates finding, comparing and choosing suitable pieces of software. For example, libraries or frameworks aid selection by bundling and structuring the software components.

**Specialization** is the process of making the abstracted component more specific. Usually, reusable pieces of software achieve specialization by parameterizing the software or making it transformable.

**Integration** facilitates providing the software with reusable components, for example with a mechanism to import relevant modules or functions to the software.

## 2.4 Software Reuse Methods

Software reuse is not a single, uniform procedure or technique. Several different reuse techniques exist to cater different needs. Consequently, different reuse methods excel at different areas. In order to describe the advantages and disadvantages of the methods, I describe them using the reuse dimensions presented in the previous section.

Krueger (1992) and Sametinger (1997), among others, present and analyze software reuse methods. From these, I have selected the most relevant for web environment, presenting those below.

### 2.4.1 High-Level Languages

High-level languages denote programming languages which are designed to be on a high abstraction level. In practice, this means that such languages contain features which are not necessary for a programming language but benefit or speed up the development. Traditional examples of these kind of features are automatic memory allocation (Krueger, 1992) and language constructs such as exceptions (Mitchell, 2003). More modern high-level language features are value type checking systems and abstracted support for parallel operations using futures (Totoo et al., 2012).

It should be noted that the high-levelness of a language is a *relative* property. Therefore, it is not possible to determine the requirements for a high-level language per se, only high-levelness of languages compared to other languages. For example, Krueger (1992) considers all programming languages above the abstraction level of an assembly language[1] high-level languages. On the other hand, Carro et al. (2006) consider, e.g., lack of automatic memory management or type system a sign of lower-level language.

[1] A low-level language with one-to-one translation to machine code instructions for a computer architecture (Salomon, 1993)

High-level languages *abstract* frequently used procedures into seemingly uncomplicated operations, thus reducing the work and cognitive capacity needed for developing the application. (Krueger, 1992, chap. 3)

The number of elementary high-level language constructs is usually relatively low. Therefore, it is possible for programmers to master the use of those constructs with sufficiently little effort. In practice, this renders *selection* of the constructs unproblematic. (Krueger, 1992, chap. 3)

The developer can achieve the *specialization* of high-level language features by parameterizing the constructs, either implicitly or explicitly. For example, when instantiating a class in Java, the only parameterization needed for memory management is the actual object instance. However, e.g., exception handling always requires at least the logic needed for handling the exception. (Krueger, 1992, chap. 3)

*Integration* of high-level language features is automatically done when compiling the software code. However, due to the nature of high-level languages, it is usually not possible to mix-and-match different programming languages easily in the same program. (Krueger, 1992, chap. 3)

The advantages of high-level languages consist mainly of the decreased need for manually developing frequently needed procedures. In practice, high-level languages provide a seemingly simple interface to complex functionality. This effectively makes them reusable software components. In practice, using high-level languages can yield a productivity gain up to 500 %. (Krueger, 1992, chap. 3)

The main disadvantage of using high-level languages is the potential decrease in performance. As with any software reuse, high-level programming languages abstract the supported procedures by making them more generic. This often leads to additional complexity and unnecessary operations on the compiled program. However, several compile-time optimization procedures exist for decreasing the effect. (Carro et al., 2006)

On the web, the technologies used on the client-side are inherently fixed to descendants of HyperText Markup Language (HTML)[2], Cascading Style

[2] `http://www.w3.org/TR/html5/`

Sheets (CSS)[3] and ECMAScript[4]. Therefore, web application languages are relatively high-level by definition. However, web developers can still raise the abstraction level by using, e.g., CoffeeScript (Ashkenas, 2009) instead of JavaScript or LESS (Sellier, 2009) instead of CSS.

### 2.4.2 Design and Code Scavenging

Design and Code scavenging refers to the technique of scavenging pieces of software *ad hoc* from existing software systems for use in a new software system (Krueger, 1992, chap. 4). The aim of this technique is to reduce the amount of work needed to build the system. For example, when building an User Interface (UI) component for choosing a date, the developer may scavenge the code for a calendar from an older software system.

Scavenging can be performed by using one of the two different approaches. The developer can perform the scavenging without modifications to the code in the target code base (code scavenging). Alternatively, scavenging can be performed by modifying the details of the scavenged code (design scavenging) (Krueger, 1992, chap. 4). The *abstraction* gained by scavenging is therefore mostly informal and in some cases even its existence is questionable (Sametinger, 1997, chap. 3). Usually, there is no "hidden part" of the abstraction but the developer must maintain the functionality of all the code himself (Sametinger, 1997, chap. 3).

Usually there is no formal mechanism or support for *selecting* pieces of software to be scavenged. Therefore, the developer must rely on his memory, experience and word-of-mouth in order to find suitable pieces of software. (Sametinger, 1997, chap. 3)

The developer *specializes* the scavenged assets by manually editing the scavenged source code. While it is often the fastest method of acquiring results, this requires the developer to deeply understand the scavenged implementation. It can also lead to fragmentation and maintainability issues in the future. (Krueger, 1992, chap. 4)

Typically, the developer *integrates* the scavenged code by copying and

[3] `http://www.w3.org/Style/CSS/`

[4] `http://www.ecma-international.org/ecma-262/5.1/`

pasting the code to the target source code file. This may lead to namespace collisions between original and scavenged code. This, in turn, may result in the need for refactoring the code. (Krueger, 1992, chap. 4)

The main advantages of design and code scavenging are the ability to quickly include existing functionality to new software systems (Krueger, 1992, chap. 4). Moreover, it is usually not needed to prepare the code to be scavenged before scavenging it. Therefore, practically all available code is reusable by scavenging. Consequently, the number of scavengable pieces of software is often significantly larger than when using any other reuse method.

However, finding suitable pieces of software for scavenging is hard. Moreover, scavenging pieces of software often does not decrease the *cognitive distance* between the target and implementation of the system. It may also create issues with maintainability of the software. (Krueger, 1992, chap. 4)

### 2.4.3 Source Code Components

Using source code components is a method of reuse which enables choosing and using software components from a component repository (Sametinger, 1997, chap. 3). Software component can be any piece of code, but in practice, components usually consist of one or more functions, modules or classes (Sametinger, 1997, chap. 3). An example of a source code component is a trigonometry module which contains functions for sine, cosine and tangent calculations. When the developer needs to calculate sines in her program, she searches a component repository for trigonometry components and utilizes the component found in her own program (Krueger, 1992, chap. 5).

Ideally, source code components *abstract* the implementation details of the component inside. This means that the required cognitive distance between the concept and the implementation of the software system is lower when using source code components instead of, e.g., code scavenging.

In order to use the component, the developer must be able to find it and to know what it does (Krueger, 1992, chap. 5). Therefore, in order to be *selectable*, source code components should be accompanied by abstract names (function names) and descriptions of the functionality provided (Krueger, 1992, chap. 5). The names should describe *what* the component does instead

of *how* it does it (Krueger, 1992, chap. 5). The developer can then use these names for reasoning about the purpose of the component and finding the component in source code component repositories.

The developer can *specialize* the source code component by modifying the source code Krueger (1992, chap. 5). However, this technique yields unwanted consequences explained in the previous section. Therefore, many components support specialization by parameterization. For example, the programmer could provide the sine function the angle in question. Additionally, when integrating the trigonometry module to her software system, the programmer could specify if the functions should use degrees or radians. In some cases, the developer can specialize the components via subclassing (Krueger, 1992, chap. 5).

All modern programming languages support *integration* of reusable source code components written in the same language. Usually, the procedure is a very simple addition of source code files, which requires little to no effort on the programmer side. However, all source code components can't be used in the same program due to conflicts, e.g., in naming and value types (Krueger, 1992, chap. 5).

The main advantages of using source code components are the abstraction provided and the organized nature of the component repositories. Ideally, the repositories provide a search functionality so that even developers with no previous experience on the component domain can find the components needed. Moreover, the abstraction level and the hiding of implementation details decreases the cognitive distance between the concept and the implementation of the system. They also reduce the size of source code needed to be written.

The main disadvantages of the source code components lie in the fact that the functionality must be deliberately designed to support reuse. The abstraction of the components is a major challenge (Krueger, 1992, chap. 5) in designing source code components. Additionally, the component repositories need administration and maintenance.

### 2.4.4 Application Generators

Application generators are usually domain-specific generators which take very high level instructions (specifications) as input and then output significantly lower level software code (implementation) (Cleaveland, 1988; Krueger, 1992, chap. 7). On fundamental level, application generators differ from high-level language compilers mainly by being designed to work on a narrow domain. Consequently, appplication generators are generally able to support considerably higher-level instructions (Krueger, 1992, chap. 7). Unlike source code components, the reused components generated by application generators are typically not encapsulated or separated (Sametinger, 1997, chap. 3).

Application generators *abstract* the concept or specification of the software system, hiding the actual implementation completely from the user of the generator (Cleaveland, 1988). However, in some cases the developer may need to modify the output of the generator which essentially removes the abstraction.

The abstraction level of application generators is usually very high, rendering reasoning about the purpose of the generator fairly easy (Krueger, 1992, chap. 7). Therefore, in principle, *selecting* application generators is moderately easy. However, since application generators are usually suited for a very narrow domain, it may be difficult to find a suitable generator (Krueger, 1992, chap. 7).

Typically, software systems generated with application generators consist of variant and invariant parts (Krueger, 1992, chap. 7). Invariant part is the part of the program which the developer using the generator can't modify. The developer *specializes* the program by modifying the variant part. There are several methods of modifying the variant part. One of the simplest may be straightforward parameterization: the developer chooses the parameters of the system from a predefined set of alternatives. This method makes using the generation extraordinarily easy. However, it also limits the resulting application considerably.

On the other end of the spectrum, the application generator may require the variant parts to be inputted using a domain-specific or a general-purpose

programming language. This makes the application generator incredibly versatile, but requires both more domain-specific and programming knowledge.

Typically, application generators generate complete applications which do not require further *integration* (Krueger, 1992, chap. 7). However, occasionally, the resulting applications are not independent per se, but require integration to other systems. This may be an issue since often it is not possible to select the integration interfaces freely, but to use the ones provided by the generator.

One of the main advantages of the application generators is the abstraction they provide. In some cases, the application generators may even require no programming language knowledge as long as the user has relevant domain-specific knowledge (Horowitz et al., 1985). Moreover, application generators excel when there is a need for building multiple similar applications (Krueger, 1992, chap. 7).

However, application generators require an unambiguous mapping between the specifications and implementation details (Krueger, 1992, chap. 7). Moreover, building application generators requires a reliable, generic implementation and user interfaces for developers (Cleaveland, 1988). Therefore, building application generators requires comprehensive domain-specific knowledge in addition to extensive software development expertise.

### 2.4.5 Software Frameworks

Software frameworks are a reuse technique which combines the use of software components and programming patterns (Johnson, 1997). Therefore, Johnson (1997) argues that software frameworks enable creating reusable software design. Unlike software components, frameworks are designed to be extended by providing case-specific functionality (Lambeau, 2011). Another definition of software frameworks is that they are a collection of consolidated components, i.e., components which share the design, interfaces, and, to some degree, implementations (Johnson, 1997). It should also be noted that software frameworks are typically strictly object-oriented reuse technique (Johnson, 1997).

Largely, software frameworks *abstract* the implementation details the

same way that components do, i.e., providing a higher-level interface for the low-level operations. In addition to that, frameworks abstract software *design patterns* used to provide a more complete architecture and functionality.

Typically, the number of applicable frameworks is considerably smaller than, e.g., the number of applicable source code components (Fayad and Hamu, 2000). Therefore, the *selection* of frameworks may seem relatively straightforward. However, as frameworks are by definition more complex than single software components (Johnson, 1997), selecting the right framework of a purpose may be considerably more difficult (Fayad and Hamu, 2000).

*Specializing* frameworks is greatly dependent on the purpose and design of the framework. As some frameworks are designed as domain-specific (Johnson, 1997), it is typically not needed to specialize the system extensively. According to Brugali et al. (1997), frameworks can usually be specialized in an object-oriented fashion: using parameters and subclasses to fine-tune functionality (Brugali et al., 1997).

Typically, software frameworks are *integrated* to other frameworks and to larger software systems. However, the majority of frameworks are designed for adaptation instead of integration (Mattsson et al., 1999). This leads to integration problems. Mattsson et al. (1999) describe several framework integration problems, e.g., architecture, design and pattern mismatches. Nonetheless, the developer can overcome most of the problems by using a number of solutions, such as separating the concerns clearly and wrapping the functionality to compliant components (Mattsson et al., 1999).

One of the main advantages of frameworks is that they enable a complete, potentially opinionated approach for reusing software while preserving the possibility for customization (Johnson, 1997). The main disadvantages of using software frameworks consist of occasional steep learning curve and challenges in integration (Fayad and Schmidt, 1997).

## 2.5 Evaluating Software Reuse

In section 2.2, I concluded that it is critical to analyze and measure software reuse. Frakes and Terry (1996) divides reuse evaluation methods to high-level and low-level methods. High-level methods emphasize the development process and higher-level properties of software, while low-level methods consist of the methods for measuring individual software projects. In addition, I present several metrics for measuring software code properties needed by the higher-level methods.

### 2.5.1 High-level Evaluation

Several methods for high-level software reuse analysis exist. Frakes and Terry (1996) present six methods for high-level analysis: *cost-benefit analysis*, *maturity assessment* models, *amount-of-reuse* models, *failure modes analysis*, *reusability assessment* models and *reuse library metrics*. Cost-benefit analysis models consider both development costs for the reusable component and the reuse productivity and quality benefits. Maturity assessment models categorize the matureness of a systematic software reuse program. Amount of reuse metrics assess the proportion of reused software in the software system created. Software reuse failure modes model introduces a set of reuse failures which are then used to assess a systematic reuse program. Reusability assessment models aim to analyze various software attributes to assess the reusability of a piece of code. Reuse library metrics concentrate on the reusability of software component libraries instead of single components.

Different methods are suitable for different use cases. For instance, maturity assessment models assess a reuse program as a whole instead of single reusable piece of software. On the other hand, cost-benefit models can also be used for assessing single piece of software.

### 2.5.2 Low-level Evaluation

The models presented above are high-level analysis tools which do not take a stance on how to measure the detailed data required by the measurements.

Hence, the models need to be complemented with lower-level, more detail-oriented methods. In their review of multiple studies, Mohagheghi and Conradi (2007) list several methods for software reuse analysis. Of them, notable ones include *controlled experiments*, *case studies*, *surveys* and *experience reports*. In controlled experiments, a large set of projects, some of which employ the evaluated method, is analyzed. Case studies concentrate on fewer studies but often involve a more thorough analysis of each case. Surveys and experience reports involve qualitative analysis of the cases.

One method for performing a case study is the sister project comparison. According to Kitchenham and Pickard (1998), in sister project comparison, a minimum of two different, but sufficiently similar software projects are observed. In at least one of the projects, a new method is employed, while in at least one project, the old method is in use. All other practices and aspects should be left unchanged. Mohagheghi and Conradi (2007) argue that this kind of comparison is applicable for analyzing software reuse effectiveness for a specific piece of software. The sister project case study is appropriate when no systematic reuse program exists or when there are other barriers impeding the use of other models presented by Mohagheghi and Conradi (2007). Moreover, it is possible to create the sister project synthetically by building the same kind of application twice, once with and once without the evaluated method.

### 2.5.3 Software Code Metrics

As presented above, in the higher abstraction level, analyzing projects is fairly straightforward. However, the actual low-level measurements for reusing software are much more complex. Mohagheghi and Conradi (2007) argue that measuring software reuse effectiveness precisely is difficult due to the following factors: 1) Metrics are difficult to validate since there is no universally accepted definition of "quality" in software products, and 2) the productivity of development is difficult to measure. Therefore, according to Mohagheghi and Conradi (2007), many projects employ highly subjective, vague or even erroneous metrics.

Both Frakes and Terry (1996) and Mohagheghi and Conradi (2007) agree

that the size of the code needed to be written correlates inversely to the development productivity. However, according to Fenton and Pfleeger (1998), the number of lines in program source code is only one perspective for program size. It should be complemented by measuring the functionality and complexity of the program. Moreover, research by Banker et al. (1993); Gill and Kemerer (1991) show that software code complexity correlates inversely to the software maintenance productivity. *Therefore, it seems evident that in order to enable productive use of reusable software, the new code to be written should be made simple and concise.*

The evaluator can measure the conciseness of the code with several different metrics. According to Fenton and Pfleeger (1998), the most commonly used metric for program size is its length, i.e., the number of lines of source code. The metric can be refined by only considering effective lines, ignoring lines consisting of comments and whitespace. However, Fenton and Pfleeger (1998) encourage the use of both effective and physical line counts to determine the size of a program.

The evaluator can determine the functionality of the program with several different metrics. Fenton and Pfleeger (1998) present the function point, object point and bang metric approaches. *Function point* approach uses the number and complexity of external inputs and outputs. *Object point* approach uses the number of different screens and reports involved in the application. *Bang metrics* use the total number of primitives in the data-flow diagram of the program. According to Fenton and Pfleeger, all of these methods are highly subjective and only provide speculative metrics.

Also the complexity of the program can be determined with several different techniques. According to Fenton and Pfleeger (1998), the complexity of the program (i.e., solution to a problem) should ideally be not higher than the problem complexity. According to them, in the ideal case it is possible to determine the complexity of the program by determining the complexity of the problem. However, this is not usually the case in real-life applications. McCabe (1976) presents a computational approach for determining the complexity of an application implementation. His *cyclomatic complexity* method involves counting the number of cycles in the program flow graph to approximate the program complexity. The advantage of this approach when

compared to the method presented by Fenton and Pfleeger (1998) is that it can be used to compute complexity differences of multiple implementations of the same problem.

In addition to the metrics presented above, Halstead (1977) presents a number of complexity measures. These measures can be used to estimate software size, difficulty level and the needed effort solely based on the code. The methods involve determining the number of operators (e.g., function calls) and operands (e.g., variables) in the program source code. These properties are then used to to approximate the higher-level software properties. Unlike the metrics of McCabe or Fenton and Pfleeger, Halstead metrics include an explicit measure for development effort.

Another approach for estimating program size is using the COnstructive COst MOdel (COCOMO) (Boehm, 1981). While COCOMO is most typically used for beforehand software project cost estimation, it can also be used to estimate effort. Several variants of the model exist. All variants provide an approximate measure of a software project effort based on the line counts of software code and, optionally, a number of project-specific factors. However, COCOMO and its variants are either too vague (Basic COCOMO 81) or too process-centric (Intermediate and Detailed COCOMO 81, COCOMO II) for effective use in a generic case with no personnel or schedule specified.

# Chapter 3

# Data Visualization

In this chapter, I define data visualizations and present several principles for successful data visualization. I also describe processes and methods for visualizing geographical data along with some guidelines for assessing the quality of geovisualizations.

## 3.1 Definition

According to Kosara (2007, chap. 3), there is no universally accepted definition of visualization. He proposes the following for a "minimal set of requirements for any visualization":

- It is based on (non-visual) data
- It produces an image
- The results are readable and recognizable

According to him, visualizations can also have other properties or qualities, such as interaction or visual efficiency. However, the requirements above are the ones needed for technical definition of the term. Moreover, it should be emphasized that according to this definition, visualization is the *process* itself, not the result of it.

Kosara (2007, chap. 4) separates visualization into two types, *pragmatic* and *artistic* visualization. Pragmatic visualization focuses on the analysis of the data in order to show its relevant characteristics as efficiently as possible.

Artistic visualization on the other hand concentrates on the communication of a concern, not the display of the actual data. Therefore, artistic visualizations may emphasize or even exaggerate some of the features of the data. Kosara states that while these types focus on the opposite sides of the visualization spectrum, it may be possible to close the gap using, e.g., interaction.

The first requirement for visualizations by Kosara (2007) dictates that the visualization is based on data. This is in alignment with the principle of Tufte (1986) which states that visualizations should, above all else, show the data. This is an essential characteristic of *data* visualizations: the visualization is a function which takes data as an input and produces a visual object as an output. In less technical terms, this means that the visualization turns data into visual, effortlessly and efficiently digestible format.

This leads to the fact that the data and visualization are not inherently tied to each other; the visualization "function" can be independent of the data. Therefore, it may be possible to create a visualization framework or platform which is able to function on a potentially wide range of data.

The characteristic of turning data into effortlessly digestible format makes visualization extremely important as "modern society is confronted with a data explosion" (van Wijk, 2005). Not only do we have access to unprecedented amount of data, we also need to increasingly base our actions and thoughts on the data (van Wijk, 2005). Without visualization, this approach would not be possible. *Therefore, one of the most important objectives of visualization is to facilitate better understanding of the data.*

## 3.2 Principles for Successful Data Visualization

The requirements presented in the previous section are sufficient for the definition of data visualization. However, they do not convey any information about visualization quality. In order to discover the characteristics for successful data visualization, additional principles are needed. Tufte (1986, p. 13) states that excellent graphics (i.e., results of visualizations) consist of "complex ideas communicated with clarity, precision and efficiency". In practice, this means that the graphics should emphasize the actual data and its nuances above everything else, while serving a clear purpose.

In addition to graphics principles presented in the previous paragraph, Tufte (1986, p. 93) presents the concept of *data-ink*. Data-ink represents the ink used for displaying the data in a visualization. He argues that in an excellent visualization, most, if not all, ink used should contribute to display of the data. However, research by Inbar et al. (2007) suggests that maximizing the share of data-ink may not be beneficial to the user experience of the visualization. E.g., axis lines in a chart are not data-ink according to the definition of Tufte. However, they may be beneficial to the user experience of the chart by providing visual structure.

The principles presented above are essential, but too abstract in order to be used as a sole basis for defining a good visualization. However, when combined with Kosara's data visualization definition stated above, the principles become considerably more useful and concrete. Azzam and Evergreen (2013) propose an adapted version of the definition by Kosara (2007). According to them, "Data visualization is a process that (a) is based on qualitative or quantitative data and (b) results in an image that is representative of raw data, which is (c) readable by viewers and supports exploration, examination and communication of the data". The most significant differences are that the definition complements the second requirement of Kosara ("It produces an image") by requiring the produced image to represent the data truthfully. It also requires the visualization to be enlightening instead of just readable. This definition effectively combines the definition by Kosara (2007) with the principle of showing data introduced by Tufte (1986). The adapted definition facilitates the process of creating a successful data visualization by offering a more concrete version of Tufte's principles. It gives the developer of the visualization a slightly more concrete checklist for representing the data: make sure the representation does not (a) omit or (b) overrepresent any information, and (c) helps the viewer gain knowledge (Azzam and Evergreen, 2013).

For the most concrete principles, Zuk et al. (2006) provide a list of heuristics for visualizations established in perceptual, cognitive and usability research. The list combines several heuristics from multiple heuristics sets by Shneiderman (1996); Zuk and Carpendale (2006); Amar and Stasko (2004). While the combination results in potentially conflicting or redundant heuristics, it nevertheless provides a concrete checklist for making successful visu-

| **Identifier** | **Description** |
|---|---|
| Visual variable | Ensure visual variable has sufficient length |
| Color order | Don't expect a reading order from color |
| Color size | Color perception varies with size of colored item |
| Local contrast | Local contrast affects color |
| Color blindness | Consider people with color blindness |
| Preattentive benefits | Preattentive benefits increase with field of view |
| Size variation | Quantitative assessment requires position or size variation |
| Graphic dimensionality | Preserve data to graphic dimensionality |
| Most data | Put the most data in the least space |
| No extra ink | Remove the extraneous (ink) |
| Gestalt laws | Consider Gestalt Laws |
| Levels of detail | Provide multiple levels of detail |
| Integrate text | Integrate text wherever relevant |
| Overview first | Provide overview first |
| Zoom and filter | Zoom and filter out uninteresting data |
| Details on demand | Provide details on demand |
| Relate | Consider relationships among items |
| Extract | Allow extraction of data and its subsets |
| History | Keep history of actions |
| Uncertainty | Expose uncertainty |
| Relationships | Concretize relationships |
| Domain Parameters | Determination of domain parameters |
| Multivariate | Provide multivariate explanation |
| Cause & effect | Formulate cause & effect |
| Hypotheses | Confirm Hypotheses |

Table 3.1: Heuristics presented by Zuk et al. (2006) with generated identifiers.

alizations. I present the heuristics, along with generated identifiers for easier referring, in table 3.1.

## 3.3 Visualizing Geographical Data

As geographic data is associated with a specific location, the most natural way of visualizing it is by using a map (Kraak, 1998; Kraak and Ormeling, 2011, chap. 1). This technique is called *thematic mapping* (Slocum and McMaster, 2014, chap. 1). Thematic mapping does not require any specific format of data, except for the geographical dimension (Kraak and Ormeling, 2011, chap. 1). However, the nature of the data has a great effect on the method, or type, of thematic mapping.

### 3.3.1 Methods for Thematic Mapping

As I state above, there are several types of geographical data. Many of the types are fundamentally different requiring different visualization methods. Therefore, cartographers have developed several different thematic mapping methods. Slocum and McMaster (2014, chap. 14-18) list some of the most typical ones:

**Choropleth Map** Choropleth maps are used primarily for visualizing data which coincides with predefined enumeration units. This method is the most natural one for situations when the enumeration units are directly linked to data results, such as votes in an election for each voting area. However, choropleth maps are also used to depict "typical" values for an area even when in reality, the area is heterogeneous in relation to the measured quality. Typical visualization of choropleth maps is by grouping a specified area using a constant color or a common symbol. Figure 3.1 depicts an example of a choropleth map. (Ibid.)

**Isarithmic Map** Isarithmic maps are map visualizations depicting continuous or smooth phenomena. Therefore, isarithmic maps excel at visualizing natural properties such as elevation. The most commonly used type of

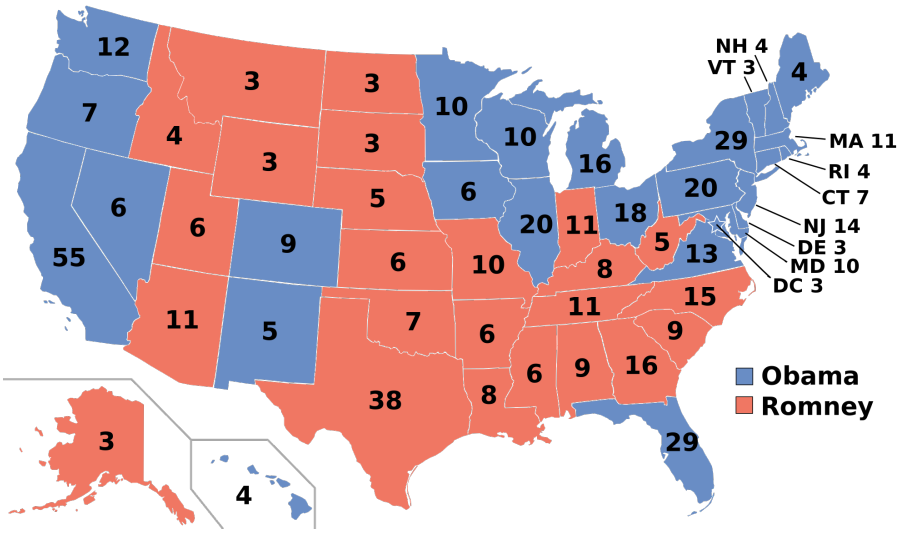



Figure 3.1: A choropleth map depicting the composition of the Electoral College in the United States presidential election of 2012 (Skidmore, 2012)

isarithmic mapping is the contour map. Contour maps consist of the measured property visualized as gradient colors in addition to *contour lines* used as value symbolization. Figure 3.2 contains an example of the isarithmic mapping method. (Ibid.)

**Dasymetric Map** Dasymetric mapping is closely related to choropleth mapping, with the exception that in dasymetric mapping, the enumeration units are not predefined, but rather defined by the data coherency. When creating dasymetric maps computationally, the visualizer can approximate the properties by using a number of techniques, as presented in chapter 6.2.2. Dasymetric mapping is most naturally used for data with several internally cohesive blocks of area, such as land use (i.e., the distribution of roads, cities, forests etc.). Figure 3.3 presents an example of a dasymetric map. (Ibid.)

**Dot Map** Dot maps are used to represent data which is associated with locations. With dot maps, the data used can be *true* (truly associated with a single point) or *conceptual* (aggregated to a point). Moreover, the visualizer can cluster or combine data points for less cluttered visualization. Dot maps

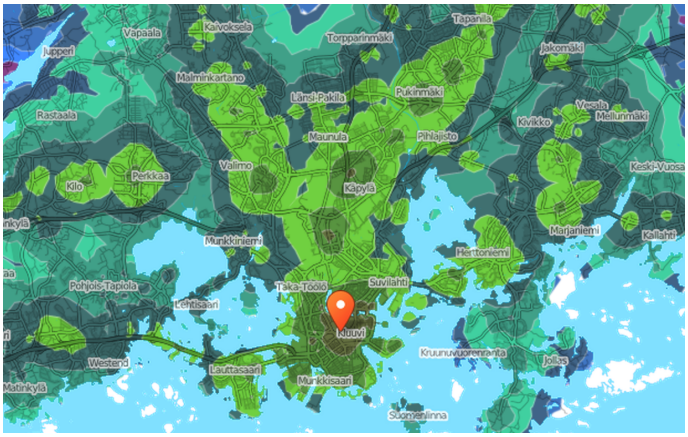



Figure 3.2: An isarithmic map depicting travel times to Helsinki center. (HSL, 2014)

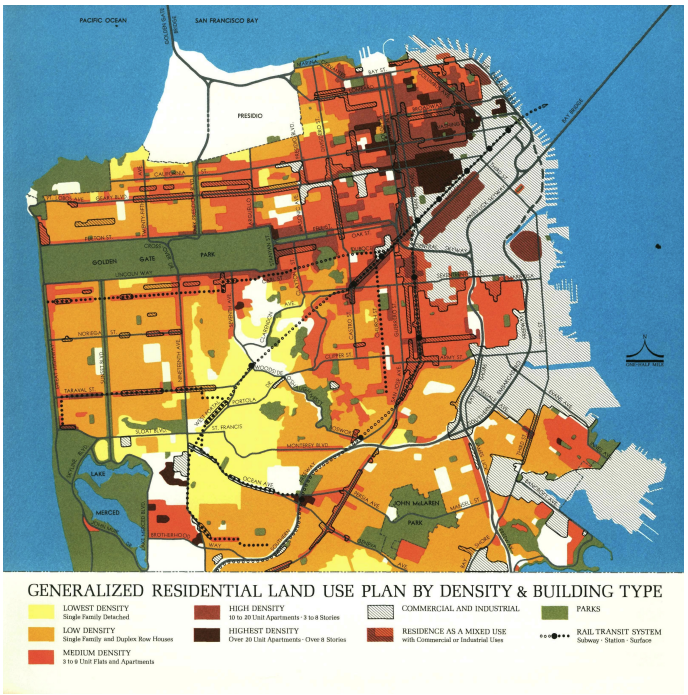



Figure 3.3: Dasymetric map depicting land use density in San Francisco (Fischer, 2012).

can be used for visualizing, e.g., store locations or the number of homicides in different cities. Figure 3.4 presents an example of a dot map. (Ibid.)


Figure 3.4: Dot map depicting cholera cases during the London epidemic of 1854 (Snow, 1854).

**Proportional Symbol Map** Proportional symbol maps are closely related to dot maps. The typical use case for a proportional symbol map is visualizing ratio variables associated with a location. Unlike dots in dot maps, the symbols on a proportional symbol map are sized proportionally to the data. Symbols can be geometric or pictorial. In addition, their sizes can be determined using several different methods, e.g., purely mathematical scaling or perceptual scaling which takes human visual inaccuracy into account. Figure 3.5 presents an example of a proportional symbol map. (Ibid.)

**Multivariate Mapping** Multivariate mapping denotes displaying multiple attributes simultaneously. Visualizers can create multivariate maps in several ways. She can visualize the relevant attributes either with a single map or using a separate map for each attribute. Additionally, she can overlay (place on top of each other) the attributes or combine them (using a

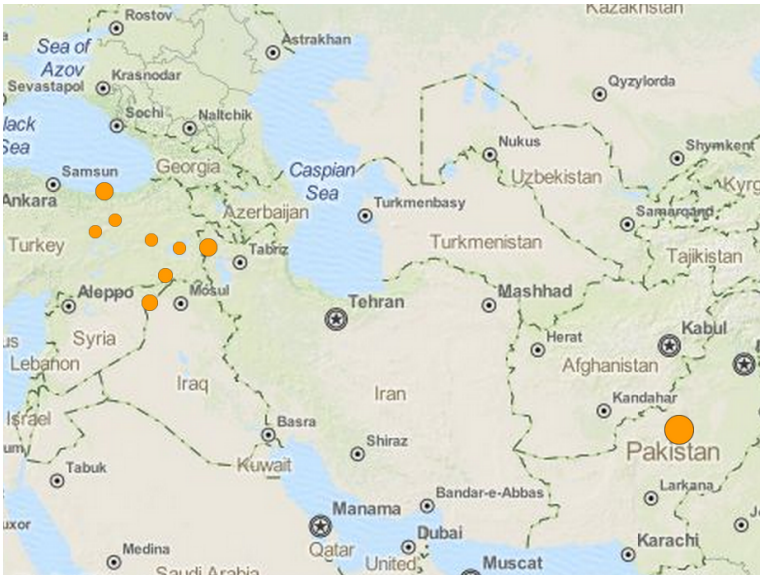



Figure 3.5: Proportional symbol map depicting the location and magnitude of earthquakes in the Middle East. (GlobalIncidentMap, 2014)

single symbol depicting all attributes). Figure 3.6 presents an example of a multivariate map. (Ibid.)

**Cartogram** Cartograms are used to distort the map based on the data. Therefore, visualizers can use cartograms to communicate relative sizes of an attribute in several areas, such as population in each country. This is advantageous when the geographical sizes and attribute values do not correlate, e.g., when some areas with high attribute value are extremely small in size. Figure 3.7 depicts an example of a cartogram. (Ibid.)

**Flow Map** Flow maps are maps with lines or arrows of varying width from one location to another. Therefore, flow maps excel at displaying movement-related attributes such as immigration from one country to another or wind speed and direction. Figure 3.8 depicts an example of a flow map. (Ibid.)

Users often use even a single thematic map for multiple different purposes (Schlichtmann, 2002, chap. 2). For instance, a single map can be read on the

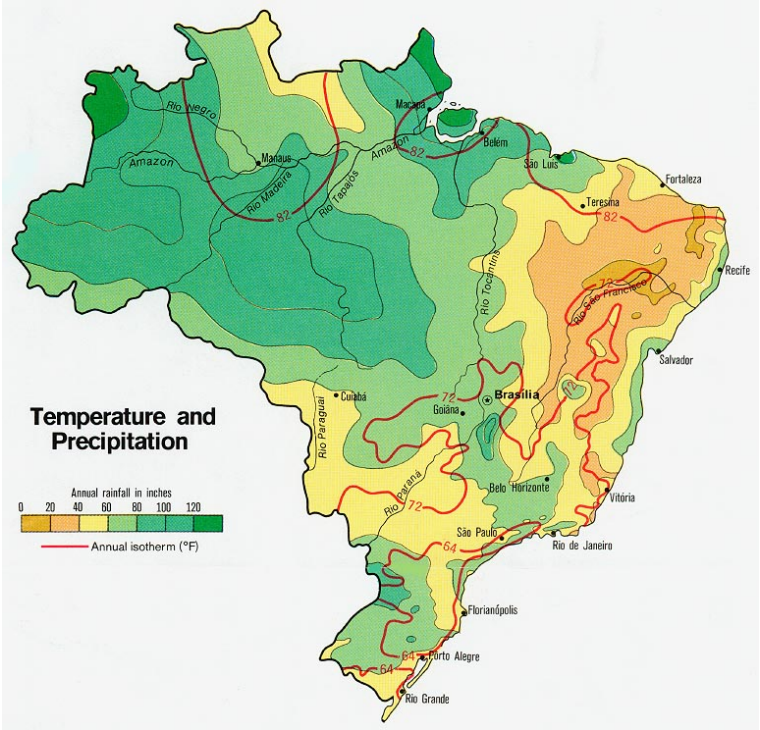



Figure 3.6: Multivariate map depicting the average temperature and precipitation of Brazil (Central Intelligence Agency, 1977).

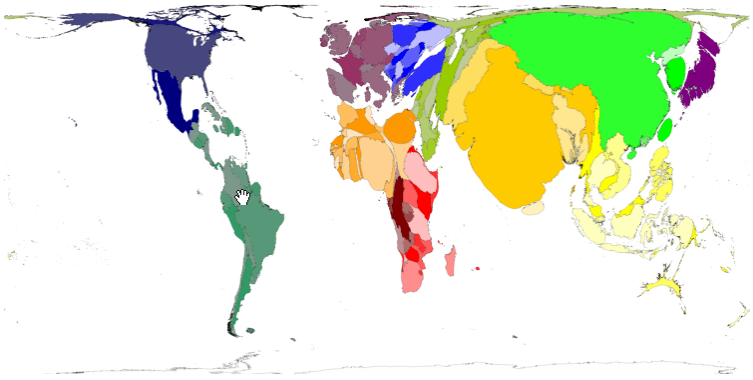
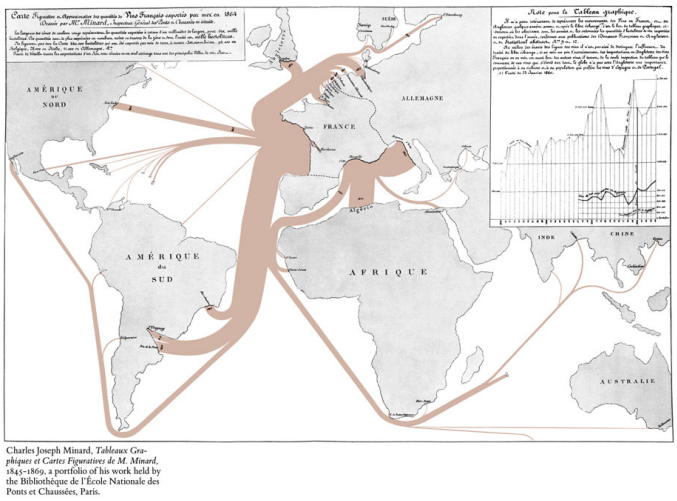


Figure 3.7: Cartogram depicting the population of the world (Hennig, 2014).




Charles Joseph Minard, *Tableaux Graphiques et Cartes Figuratives de M. Minard*, 1845-1869, a portfolio of his work held by the Bibliothèque de l'École Nationale des Ponts et Chaussées, Paris.

Figure 3.8: Flow map displaying the French wine exports in 1864 (Minard, 1865).

*overall level* ("where are the primary schools located in Helsinki metropolitan area?") and *elementary level* ("is there a primary school in Punavuori?"). Furthermore, some possible uses for a thematic map are "what is the ratio and distribution of Finnish schools compared to Swedish schools in Helsinki" or "what is the spatial distribution of sizes of schools in Helsinki". Therefore, an effective map visualization should not lock the user to any single perspective.

### 3.3.2 Effective Thematic Maps

While the map visualizations adhere to general visualization principles, cartographers have refined the principles by specifying a set of guidelines for maps specifically. Koeman (1969 quoted by Kraak 1998, p. 12) defines the guidelines for map visualization process as *"How do I say what to whom"*. *How* refers to the mapping methods and techniques used. *What* refers to the data used and its characteristics. *Whom* refers to the target audience of the visualization. Kraak (1998) complements the guidelines with *"and is it effective"*, referring to the self-reflective and iterative nature of visualization.

All the elements above are important to acknowledge when creating a thematic map. While they do not provide an exact formula for determining

the effectiveness of a visualization, the elements are incredibly beneficial for creating an effective visualization. Therefore, visualizers can also examine the created visualizations with the help of the elements.

## 3.4 How Thematic Maps Are Made

Schlichtmann (2002) describes making thematic maps as a six-step process. I present the steps below:

1. Decide what is the knowledge the viewer should gain from viewing the visualization
2. Decide on the information to be entered to the visualization
3. Procure the data needed
4. Procure a base with the required geometrical characteristics
5. Select the appropriate graphic means and transcribe the information as necessary
6. Explain the transcription in a legend

Slocum and McMaster (2014, chap. 1) present an alternative process for thematic visualization. The process consists of five steps. I present the steps below:

1. Consider what the real-world distribution of the phenomenon might look like
2. Determine the purpose of the map and its intended audience
3. Collect data appropriate for the map's purpose
4. Design and construct the map
5. Determine whether users find the map useful and informative

In practice, the processes described by Schlichtmann and Slocum and McMaster concentrate on different perspectives of thematic mapping. Schlichtmann begins the process by defining the goal of the visualization while Slocum and McMaster provides a data-centric approach starting with phenomenon definition. Unlike Schlichtmann, Slocum and McMaster emphasize

an iterative approach of the visualization. Both processes emphasize defining and designing the visualization, the actual visualization (turning the data into visual representation) being addressed in only one of the steps.

Slocum and McMaster (2014, chap. 1) express their concern on the utilization of the processes defined above. According to them, it is likely that naive visualizers do not follow the steps, but take shortcuts when designing the visualizations, resulting in subpar visualizations. Therefore, visualization tools may need to nudge the visualizers towards using (one of) the processes when building a visualization.

The steps are used to produce a visual representation (graphic) of the data. Additionally, Schlichtmann (2002) identifies several objectives for the resulting graphic. I present the objectives in table 3.2.

| **Name** | **Description** |
|---|---|
| Clarification | Making the map clear and readable. In practice, this means that the topemes (symbols) in a map should be easily detectable and distinguishable from each other |
| Emphasis | Making topemes and other important characteristics of the visualization to stand out visually |
| Types of Entries | Having a clearly distinguishable type for each topeme. |
| Sets of Types | Grouping data points and symbols with similar traits in order to make them belong together visually. Ideally, the visual similarity should be related to the conceptual similarity. |
| Cross-Relations | Visually indicating the potential relations and similarities between different types or between entries of different types. |
| Local Syntax | Aligning visual properties of the topemes to prevent unintentional emphasis of single topemes. |

| Name | Description |
|---|---|
| Local Ensembles | Supporting topemes with multiple properties (such as the numbers of children and adults in an area) so that the topeme visually reflect both the individual properties and the combination of all properties. |
| Multilocal Ensembles | Supporting topemes with multiple geographical properties (such as spatial distribution of people) |
| Addable and Non-Addable Quantities | Differentiating addable and non-addable properties. Typically absolute quantitative properties are addable while relative and qualitative properties are non-addable. Addable properties should be visualized in a way that cognitively supports addition (e.g., with sizes of elements) while non-addable quantities should be visualized without said feature (e.g., with colors.) |
| The Surface Illusion | Creating an illusion of surface on the map. This can be achieved for example by using illumination and shadowing. These visual traits can convey a meaning themselves and often naturally do so. |

Table 3.2: Map visualization objectives as per Schlichtmann (2002)

The objectives above are important when visualizing geographical data on a map. Therefore, when creating a visualization tool, the developer needs to take those into account. Considering the objectives helps the developer to enable or encourage the visualizers to reach as many of the objectives as possible.

# Chapter 4

# Reuse in Data Visualization

In this chapter, I present a number of visualization reuse cases in order to demonstrate the feasibility of such approach in general. I also discuss the lack of tools and studies of software reuse in the field of geographic data visualization.

## 4.1 Reuse Cases in Literature

Several studies have used software reuse successfully in the field of data visualization. Fekete (2004) introduces InfoVis ToolKit, a reusable library for efficient building of information visualizations. He claims that building visualizations with the toolkit is efficient, typically taking only hours. However, he does not verify this claim in any way, e.g., by comparing the efficiency to building visualizations without the toolkit.

InfoVis ToolKit consists of several different visualization components, enabling scatter plots, time series and tree maps among others. Additionally, the toolkit includes interaction components and data structures suited for visualization. According to Fekete, the primary benefits of the toolkit include simplifying the usage of the most common information visualization methods. Also the toolkit benefits implementation of supplementary visualization methods by providing the structure and utilities required.

Heer et al. (2005) reported significant benefits in the effort needed for building data visualizations using Prefuse, a reusable visualization toolkit.

Using the toolkit, they were able to reduce the development time from days or weeks to minutes.

Prefuse provides a composable, modular and extendable toolkit for data visualizations. According to Heer et al. (2005), it provides a highly customizable set of building blocks which can be combined and composed to create a wide variety of visualizations. However, the blocks provided do not involve functionality for efficient building of geographical visualizations.

Bostock and Heer (2009) present Protovis, a graphical toolkit for visualization. Protovis provides a data-centric approach for displaying visualizations bottom-up, favoring minimalistic graphics. In their study, Bostock and Heer state that the choice of visualization tool may affect the effectiveness of visualization. According to them, the approach of Protovis discourages "chartjunk" and encourages building effective visualizations. However, they do no validate the claim. Nonetheless, their study indicates that Protovis benefits the visualization by providing a concise notation for building visualizations while still allowing thorough customization.

## 4.2 Research Gap

Currently, research on geographic or map visualization is abundant (e.g., Kraak 1998; Kraak and Ormeling 2011; Slocum and McMaster 2014; Schlichtmann 2002). Moreover, several studies report successful use of software reuse for making data visualization development more efficient (Heer et al., 2005; Bostock and Heer, 2009). However, research on the effects of reuse on geographical visualization is scant. Additionally, few reusable web geovisualization tools exist, none of which is sufficiently high-level for enabling efficient building of effective geovisualizations. This implies that there is room for improvement in both research and implementation related to geovisualization software.

To address this shortcoming, I decided to attempt creating a reusable geovisualization tool for the web. I also evaluated the tool in order to obtain knowledge about its benefits when compared to building geographic visualizations from the beginning using lower-level tools. According to the software reuse literature (e.g., Mohagheghi and Conradi 2008; Boehm 1999), software

reuse may reduce the needed effort dramatically for building new software. Moreover, effectiveness is one of the most important properties of a visualization (Kraak, 1998). Therefore, I decided to concentrate on evaluation of the effects related to effort and visualization effectiveness.

# Chapter 5

# Methods

In this chapter, I describe the methodological approach I use for finding the answers to my research questions. I also argue about the reasons for selecting the methods, and reasons for excluding the other methods presented in section 2.5.

*From a broad methodological perspective, this study follows the constructive approach. This means that a system is implemented and evaluated (Järvinen and Järvinen, 2012). In more detail, I evaluated the implementation system through six case studies. In the evaluation stage, I employed both quantitative and qualitative data gathering and analysis methods.* I measure the evaluation of process efficiency (RQ1) quantitatively, examining the numeric characteristics of several case studies. However, I measure the visualization effectiveness (RQ2) qualitatively, analyzing whether the tool encourages the visualizer to conform to visualization guidelines.

Next, I will describe the methodological setting in more detail.

## 5.1 Constructive Study

*In order to find answers to the research questions*[1][2]*, I decided to conduct a constructive study by implementing and evaluating a reusable geovisualization tool.* Constructive research excels at finding answers to questions of type "how useful is system X" (Järvinen and Järvinen, 2012), making it the most suitable research type for this thesis.

In practice, conducting a constructive study involves designing an artifact and evaluating its effect (Järvinen and Järvinen, 2012). *In this study, I built a reusable geographical visualization tool*, evaluating its effect on the effectiveness of the visualization and the efficiency of building the visualization. This can be done by performing a *case study*, i.e., observing one or more visualization cases and evaluating the relevant properties in those cases. In this study, I selected six visualization cases to evaluate the effect of the implemented tool on effectiveness and efficiency of visualization. The cases were: 1) store map depicting the locations of Alko stores, 2) map of earthquakes in California after January 1, 1900, 3) regional voter turnout in the Finnish presidential election of 2012, 4) regional share of people with no secondary education in Finland, 5) travel times to a single destination in Helsinki metropolitan area, and 6) average travel times to multiple destinations in Helsinki metropolitan area. To enable as realistic evaluation as possible, all cases presented use real-life data in formats obtainable from the Web.

## 5.2 Evaluating Software Reuse Effectiveness

In section 2.2, I concluded that it is critical to analyze and measure software reuse. In this study, I utilized both high-level and low-level analysis methods. High-level methods emphasize the development process and higher-level properties of software. Low-level methods are more concerned with the

[1] How does a reusable software system affect the *efficiency* of building geographical visualizations?

[2] How does a reusable software system affect the *effectiveness* of geographical visualizations?

methods for measuring individual software projects. In addition, I select the metrics for measuring software code properties needed by the higher-level methods.

### 5.2.1 High-level Evaluation

As presented in section 2.5, several methods for high-level software reuse analysis exist. *In this study, I used the cost-benefit analysis method.* Cost-benefit analysis models consider both development costs for the reusable component and the reuse productivity and quality benefits. Unlike the other methods I presented, such as the maturity assessment model, it is suitable for assessing a single piece of software instead of a complete software reuse program or a reusable software library.

### 5.2.2 Low-level Evaluation

The models I present above are high-level analysis tools. They do not take a stance on how to measure the detailed data required by the measurements. Hence, for this study, I need to complement the models with lower-level, more detail-oriented methods. *Of the methods presented by Mohagheghi and Conradi (2007), I decided to use the case study method.* As the scope of this work does not allow for large sample sizes required by controlled experiment method, it is not a feasible alternative for this study. Moreover, using experience reports requires a considerable experience on creating and using reusable software which is not possible to achieve for this work.

*I conducted the case studies through the sister project comparison method.* According to Mohagheghi and Conradi (2007), it is suitable for evaluating a specific piece of reusable software. For the evaluation, I built several visualizations with and without the reusable tool, evaluating the difference in approaches.

### 5.2.3 Software Code Metrics

As I describe in section 2.5, software code properties can be measured with several different metrics. In order to achieve as reliable evaluation as possible,

I decided to use a diverse set of different software code metrics. As Fenton and Pfleeger (1998) suggest, I evaluated the implementations by measuring the number of both physical and effective lines of code.

According to Fenton and Pfleeger (1998), software code line counts should be complemented with metrics related to functionality and complexity of the software. *Therefore, I decided to use the cyclomatic complexity measure of McCabe (1976) for determining the application complexity.* The method is superior to other methods presented mainly because it provides a computable measure with which it is possible to measure implementation details of a program. As discussed in chapter 2.5, the "problem complexity" approach of Fenton and Pfleeger (1998) is not appropriate for evaluating different implementations of the same problem. Therefore, I did not use it for the evaluation.

*In addition to the metrics presented above, I decided to employ the Halstead metrics for difficulty and effort.* The main advantage of these methods when compared to the previous methods is that they provide an explicit, direct measure for the properties. Like the metric of McCabe, Halstead metrics are computable from the program source code, making them effective for this study.

The COCOMO approaches of Boehm (1981) were not used because they are either too vague (Basic COCOMO 81) or too process-centric (Intermediate and Detailed COCOMO 81, COCOMO II) for this study.

## 5.3 Evaluating the Effectiveness of a Visualization

I decided to examine whether the reusable visualization tool is advantageous to the effectiveness of the visualization. In practice, I examine whether visualizations built with the tool are likely to be more effective in conveying the information than visualizations built without the tool. To some degree, this can be done with several different methods. *In this study, I decided to use visualization heuristics by Zuk et al. (2006) and thematic mapping objectives by Schlichtmann (2002) due to the fact that those are the most concrete guidelines presented.*

In addition to the methods selected, several other methods exist. While some of the methods are more concrete than others, it is notable that none of the methods provides formal, computable means for evaluation. According to Kraak (1998), *evaluating geographical visualizations is predominantly done by estimating the visualization subjectively in relation to its context.* This makes objective effectiveness evaluation complicated.

Visualizers can use the principles by Tufte (1986), such as data-ink ratio presented in section 3.2, to evaluate the visualization. Azzam and Evergreen (2013) present another method for evaluation. However, several studies dispute the correctness of these methods (Kosslyn, 1985; Inbar et al., 2007). Moreover, the methods are too abstract for effective formal evaluation.

Visualization heuristics by Zuk et al. (2006) presented in section 3.2 are significantly more concrete than the methods presented in the previous paragraph. Thus, visualizers can use the heuristics for efficiently analyzing a visualization. *Therefore, I decided to use the heuristics for evaluating the tool's effect on visualization effectiveness.*

Geovisualization-specific evaluation methods consist of the methods of Kraak (1998) and Schlichtmann (2002). While the former is useful for designing a visualization, it is too abstract for assessing visualizations effectively. The latter consists of a number of mapping objectives presented in section 3.3.2. When compared to the former, it is considerably more concrete, enabling more effective formal evaluation. *Therefore, I decided to complement the heuristics presented in the previous paragraph with the mapping objectives by Schlichtmann (2002).*

Due to the fact that the sister project method selected for efficiency evaluation aims to produce as similar results as possible, I deemed it unpractical to use the sister projects for evaluating the visualization effectiveness. *Therefore, I decided to evaluate the tool qualitatively by examining whether it benefits the visualizer in terms of conforming to the heuristics and achieving the objectives.* This conforms to the statement of Kraak (1998) related to subjective evaluation of geovisualization.

# Chapter 6

# Thematic.js - a Reusable Visualization Tool

As I discuss in chapter 2, reusing software typically leads to increased productivity and better quality. Therefore, to achieve the targets of this thesis, I decided to implement a reusable visualization tool. As the tool is designed to benefit building geographical visualizations, or thematic maps, on the web, I decided to name the tool Thematic.js.

## 6.1 Problem Setting

Current mainstream web mapping libraries provide only low abstraction level APIs for visualization. Hence, when building a visualization for geographical data, it is unnecessarily laborious to develop the visualization from the beginning. The effect is emphasized with more complicated visualization methods such as isarithmic maps. Consequently, it may be infeasible to build effective visualizations in those situations. *This encourages visualizers to use a simpler, yet less suitable methods such as dot maps.*

Second, when building web-based geographical visualizations, the visualizer typically needs to build the whole visualization architecture using web technology such as HTML[1] and ECMAScript[2]. Therefore, an astonishing

[1] `http://www.w3.org/TR/html5/`

[2] `http://www.ecma-international.org/ecma-262/5.1/`

amount of knowledge of such technology is required to even develop a simple map visualization.

## 6.2 Application Requirements and Design

I started the implementation process by analyzing the requirements of the different geographic visualization methods presented in chapter 3.3.1. Specifically, I analyzed the underlying structure of the visualizations in order to abstract the applicable parts as reusable components. For this, I adopted the "hot spot" method by Schmid (1997) for detecting similarities and dissimilarities in software.

*In order to solve both problems presented in the previous section, I decided to implement a dual approach for visualization.* As one of the problems related to visualizations is the amount of application architecture work needed, the tool should provide a so-called whole-page scaffold architecture (Jazayeri, 2007). The scaffold architecture contains the needed page-specific architecture. I call this part of the system *framework*. However, the framework approach involves challenges regarding integrations. Therefore, I decided to also implement an independent visualization component in order to support integration of the visualization in existing web pages. I call this part *library*. When referring to both of the parts of the system, I use the term *application*.

### 6.2.1 Reuse Methods

I gathered the analyzed data about the requirements in addition to problems discussed in the previous chapter. Then, I determined the forms of reuse applicable in this case. Since the techniques are not mutually exclusive and each has its own benefits, I decided to use a combination of multiple techniques.

The visualizer can use the application with the JavaScript language, which is a relatively high-level programming language. The scaffold architecture uses the framework method for enabling the visualizer to get started with the visualization quickly while allowing thorough customization later if needed. I built the visualization library as a collection of software compo-

nents, which allow versatile functionality and composability while abstracting the implementation details. Moreover, the developer can use the provided example visualizations as a starting point for building visualizations using the design and code scavenging method.

### 6.2.2 Supported visualization methods

As discussed in the chapter 3.3.1, several different thematic mapping methods exist. As some of these methods are fundamentally different in implementation, I needed to explicitly consider the requirements of each method. I also needed to decide whether to implement support for each method. I had to drop the support for some of the methods in order to manage the application complexity and the scope of this work. In order to support the most frequent use cases, I decided to implement support for the following visualization methods:

- Choropleth maps
- Dasymetric maps
- Isarithmic maps
- Dot maps
- Proportional Symbol maps

Of the visualization methods presented in section 3.3.1, I decided to exclude explicit multivariate maps, cartograms and flow maps. I made the decision primarily due to the fact that of the methods presented, these are the least frequently used. Moreover, there are several fundamentally different design options for some of the methods, such as multivariate maps. Therefore, it is considerably more difficult to abstract the implementation details to provide a general-purpose visualization module. However, it should be noted that the modular architecture of the application enables easy extendability to support these types of visualizations in the future. Additionally, visualizers can achieve multivariate maps to some degree by using several of the implemented map methods simultaneously.

## 6.3 Application Architecture

In the highest level, the application architecture consists of two parts: the visualization framework and the visualization library. While the framework uses the library for visualization, it also consists of other functionality and the library can be used separately of the framework. Figure 6.1 presents the architecture of the framework.

Framework consists of a Single-Page Web Application (SPA) which embeds the visualization library along with other functionality necessary or beneficial for user experience. Notably, the application uses HTML and CSS for displaying the page correctly and HTML5 Application Cache[3] for offline availability and faster loading times. Application also contains functionality for displaying the visualization correctly on devices of different sizes and capabilities.

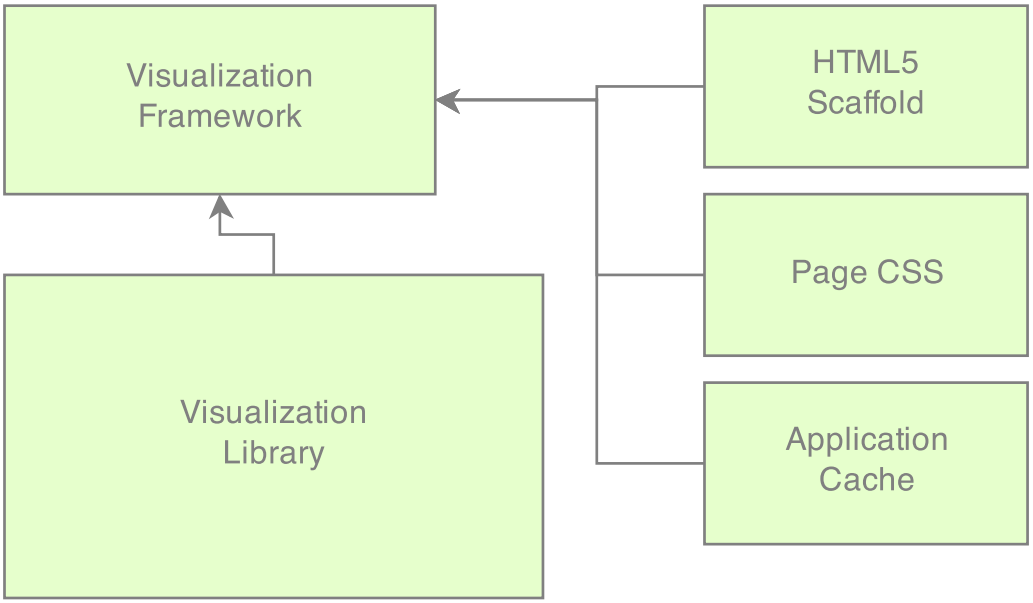



Figure 6.1: The architecture of the Thematic.js framework.

The architecture of the library is described in figure 6.2. The library consists of a map component, mapping modules, data aggregators and data

[3] http://www.w3.org/TR/html5/browsers.html

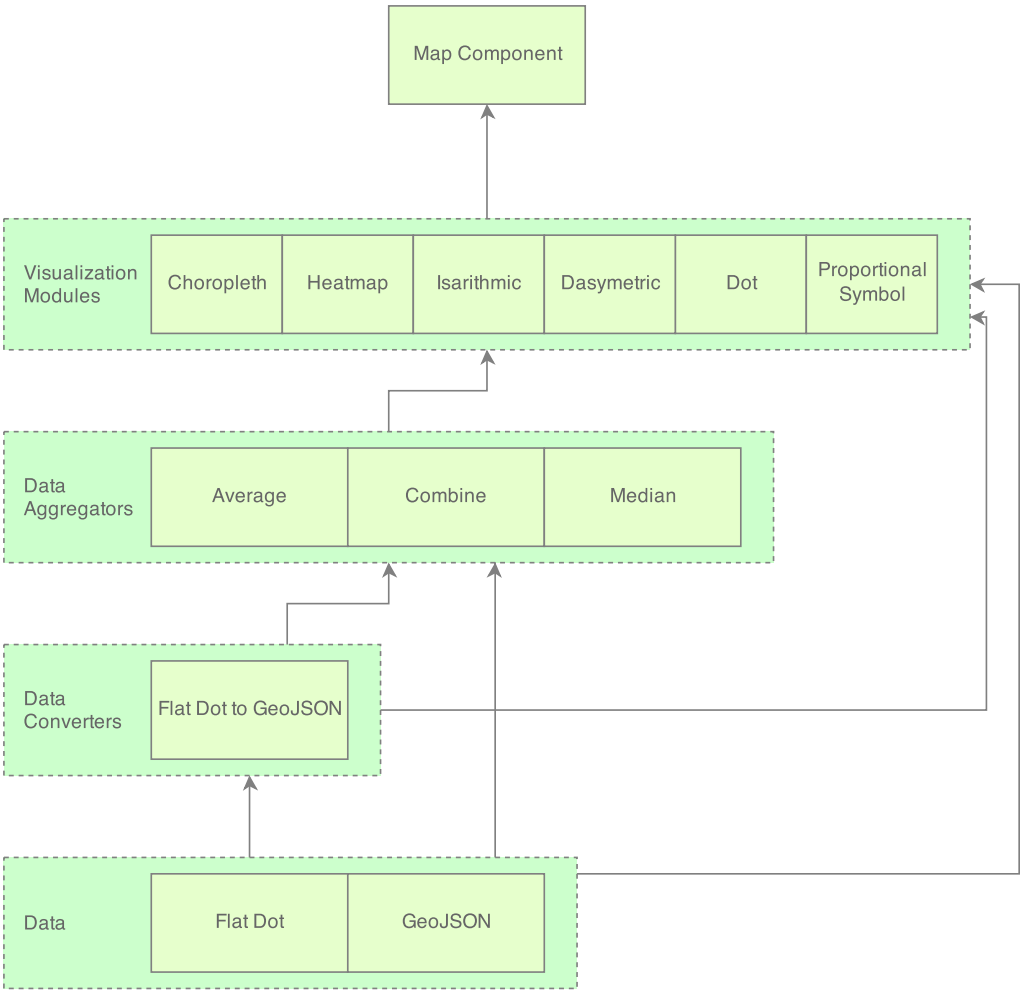



Figure 6.2: The architecture of the Thematic.js library. Arrows denote the flow of data.

converters. The map component is used for displaying the map layer and for managing mapping modules. The component can be added to any block-level element on a web page. Internally, the map is displayed using Leaflet[4].

Individual mapping modules are added to the map as Leaflet layers. For convenience and maintainability, I created an abstract mapping module for handling system-specific procedures such as keeping module status. Mapping module developers should use the abstract module as an object prototype for all newly-developed mapping modules. Individual mapping modules each support a mapping method, but all can be customized to a degree. Currently, the modules only support GeoJSON[5] data, but there are no technical restrictions on using any format of data.

Typically use cases involve using mapping modules with some external data. The data is often in a non-standard format as presented in section 7.1. For this, the visualizer should use a data converter. Data converters are straightforward stateless components which transform data from a non-standard format to format supported by the mapping modules. For example, the library provides a converter from "flat dot" JSON format (see appendix A) to standard GeoJSON FeatureCollections.

Aggregators are similar to converters in the sense that both transform data. However, while converters do 1-to-1 conversions, aggregators combine several grouped data sets into one by, e.g., calculating an average of the values in sets.

The visualizer is not required to use converters or aggregators when creating a visualization if the data is in the correct format. However, when using non-standard data formats, the components help bring a structured way of transforming the data into an appropriate format.

## 6.4 Supported Platforms

I developed the application using standard web technology. Theoretically, this means that the app supports all HTML5, CSS3 and ECMAScript 6 compliant browsers. However, in practice, none of the widely used browsers

[4] `http://leafletjs.com/`

[5] Geographic JavaScript Object Notation, `http://www.geojson.org`

support the standards completely (Manian et al., 2011). Therefore, I have tested the application on some the most widely used modern web browsers. The browsers and versions are: Google Chrome 38, Mozilla Firefox 33, Apple Safari 8, Opera 25, Microsoft Internet Explorer 11[6], Apple iOS Safari 8 and Google Android Chrome 38. All browser versions are the latest ones available currently. In total, this represents the browsers of 66 % of Internet users (StatCounter, 2014).

While the application is most naturally run in a web environment, visualizers may also embed the system to various native applications using a web view component. Web view components are available on at least Windows (Small, 2012), Mac OS X (Hunter, 2014), Android (Google, 2014) and iOS (Apple, 2014) platforms.

As I describe in chapter 6.2, the application employs a dual approach architecture. Therefore, visualizers can integrate the application in almost any existing web application, using almost any framework and library. However, due to a possibility of a namespace collision, other libraries using global namespaces `L` (Leaflet), `_` (underscore), or `thematic` may cause an incompatibility with the application as described in Osmani (2011).

## 6.5 Implemented Functionality

The following sections present the most important application functionality, namely supported mapping methods, managing input formats and values, and modularity for supporting future extensions.

### 6.5.1 Choropleth Maps

Visualizers can use choropleth maps for visualizing enumerated or areally aggregated data (Dent et al., 2008, chap. 6). According to Slocum and McMaster (2014, chap. 14), it is the most frequently used mapping method. Therefore, implementing choropleth mapping functionality is essential for a successful mapping tool.

[6]Internet Explorer 11 requires additional ES6 Promises polyfill, `https://github.com/jakearchibald/es6-promise`

To use choropleth mapping, visualizer uses the choropleth mapping module of the application. If the user already has the relevant data in GeoJSON format, nothing else is required. However, the relevant data may be stored separately of the designated area definitions. In those cases, the user needs to use the *combine* aggregator provided by the application. The aggregator associates the data with the area definition in question and outputs the data in GeoJSON format supported by the mapping module. Listing 6.1 presents an example code for using the choropleth module.

```
var Choropleth = thematic.modules.Choropleth;
map.addModule('voting', new Choropleth({field: 'value'})
    .setScale(scaleFn)
    .setData(data));
```

Listing 6.1: Using the choropleth mapping module with Thematic.js.

### 6.5.2 Dasymetric Maps

The application supports dasymetric maps in an approximated fashion. The dasymetric mapping module approximates dasymetric data by using the floating grid method as presented by Langford and Unwin (1994). The visualizer needs to provide the application with the grid of dots in GeoJSON format as data. The application uses the data to generate an appropriate dasymetric map approximation. The visualizer can also aggregate and convert the data using any of the supplied aggregators and converters.

### 6.5.3 Isarithmic Maps

The application provides two isarithmic mapping modules: the Isarithmic module enables approximated isarithmic mapping while the Heatmap module enables heat map visualizations. Heatmap method is more accurate than the approximated isarithmic method, but requires a dot-like data set in order to provide best results. The approximated isarithmic module employs the floating grid method of Langford and Unwin (1994).

### 6.5.4 Dot Maps and Proportional Symbol Maps

The application supports producing dot and proportional symbol maps by providing the Dot mapping module. With default configuration, the module produces dot maps, but the visualizer may provide an option for calculating and using proportional symbol values. For enabling the user to get more information about data points, the system can provide the user click-triggered information bubbles. The module also supports using customized symbols for data points, the default being a simple Leaflet marker.

### 6.5.5 Input Formats

All implemented mapping modules use GeoJSON as their input format. GeoJSON is the *de facto* format for transmitting geographical data on the web (Bostock and Davies, 2013). There is also great support for GeoJSON data in the existing software, for example in the Leaflet map library used by the application. However, due to its verboseness, GeoJSON may be unsuitable for simpler data sets and visualizations such as dot maps. Therefore, I have specified and implemented support for converters for transforming data to GeoJSON format. Currently, the application only supports converting "flat dot" (see appendix A) format. An example of the format converter functionality is presented in listing 6.2.

```
var data = fetch('markers.json')
  .then(function(resp) { return resp.json(); })
  .then(thematic.converters.flatToGeoJSON);
module.setData(data);
```

Listing 6.2: An example code for using the flat dot input format converter.

Typically, the visualizer provides the data asynchronously using an external resource (external API or a separate JSON file). Therefore, the modules support using ECMAScript Promises[7] to pass visualized data. However, the modules also support synchronous data (such as using data defined in the

[7] https://developer.mozilla.org/en/docs/Web/JavaScript/Reference/Global_Objects/Promise

source code file) by wrapping the values in Promise objects.

### 6.5.6 Value Normalization

When visualizing a metric such as average temperature of an area, the scale of values is completely different from when visualizing, say, population density. Therefore, in order to provide general-purpose map visualization tools, the system needs to support displaying a wide variety of values and scales.

For this application, I decided to implement a highly versatile normalization functionality which allows the visualizer to work on virtually any scale. Instead of transforming the input values into a predefined value set, the application transforms the input values directly to a visualizable value. For example, the visualizable value can be "red" for a choropleth map, or "10px" for a proportional symbol map. Moreover, this mechanism is compatible with, e.g., scaling functionality of D3.js[8] visualization library. Therefore, the visualizer can leverage the sophisticated scaling functionality of external libraries. An example of a Thematic.js scale functionality is presented in listing 6.3

```
// a standalone scale function
var scale = function(value) {
  var colors = [
    {time: 30, color: 'green'},
    {time: 40, color: 'yellowgreen'},
    {time: 50, color: 'yellow'},
    {time: 60, color: 'orange'},
    {time: 80, color: 'red'},
    {time: 100, color: 'purple'},
    {time: 120, color: 'blue'}
  ];

  return _.find(colors,
    color => value <= color.time) || _.last(colors);
```

[8] http://d3js.org/, https://github.com/mbostock/d3/wiki/Scales

```
}

module.setScale(scale);

// a scale function using the d3.js library
var d3scale = d3.scale.linear()
  .domain([60, 65, 70])
  .range(['#e5f5f9', '#99d8c9', '#2ca25f']);

module2.setScale(d3scale):
```

Listing 6.3: An example of Thematic.js scale functionality.

### 6.5.7 Modularity and Extendability

It is hardly possible to cover the whole area of geographic visualizations. Therefore, I did not attempt supporting every visualization method possible. Instead, I implemented the architecture of the application so that it is as straightforward as possible to extend the functionality.

As a result of this, developers can easily extend visualization methods by adding tailored mapping modules to the application. Additionally, it is possible to create customized aggregators, converters and scales and bundle these as an extension to the application.

# Chapter 7

# Evaluation

In this chapter, I describe the evaluation of the tool built. I performed the evaluation by using two separate methods. I evaluated the efficiency of development process with the software effort and complexity metrics presented in chapter 5. In addition, I evaluated the visualization effectiveness with heuristics by Zuk et al. (2006) complemented by mapping objectives by Schlichtmann (2002) presented in chapter 3.2. As the first of the methods requires a baseline project, I decided to implement a number of sister projects as defined by Kitchenham and Pickard (1998). In this chapter, I refer to the visualizations built during sister projects with "reference visualization" and the visualizations built using Thematic.js with "Thematic.js visualization".

The most important findings of the evaluation are that 1) *typically, Thematic.js improves the efficiency of building geographic visualizations significantly*, and 2) *Thematic.js likely encourages creating effective visualizations*.

## 7.1 Defining the Evaluated Cases

The visualization tool should be able to visualize a large variety of data. Moreover, the benefits of reusable software are typically emphasized when examining a large number of relatively similar cases (Frakes and Terry, 1996). However, in order to keep the scope of this work manageable, I decided to evaluate a set of visualization cases listed below.

**Alko stores in Finland** Alko provides an unsupported representational state transfer (REST) API[1] for fetching data of Alko stores. The data is in a non-standard "flat dot" format (see appendix A). Therefore, I decided to visualize Alko store locations using a dot map. The resulting visualization should display all Alko stores in an effective fashion. The visualization should also provide clustering support for markers in order to avoid map cluttering. Figure 7.1 depicts the desired visualization result. This case is later referred to as "store map".

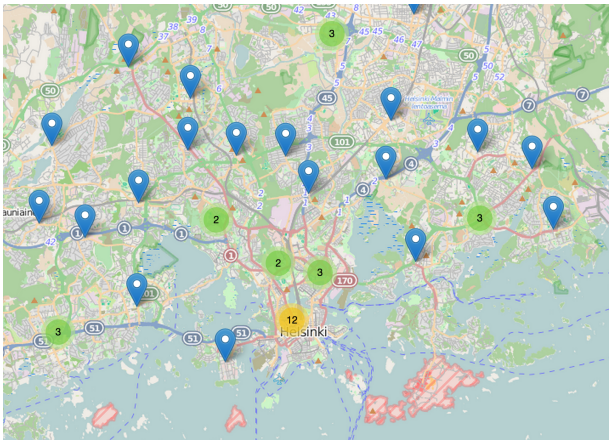



Figure 7.1: A dot map depicting the desired result of the store map visualization.

**Earthquakes in California** Earthquakes have two fundamental data axes: location and magnitude. Therefore, earthquakes are best visualized using a proportional symbol map with the size of the symbol representing magnitude. United States Geological Survey provides historical earthquake data[2], and I decided to visualize earthquakes in the state of California since January 1, 1900. The data is available in a Comma-Separated Values (CSV) format which is can be trivially transformed to "flat dot" JSON format. Figure 7.2 depicts the desired visualization result. This case is later referred to as "earthquake map".

[1] `http://www.alko.fi/api/store/mapmarkers?language=fi`
[2] `http://earthquake.usgs.gov/earthquakes/search/`

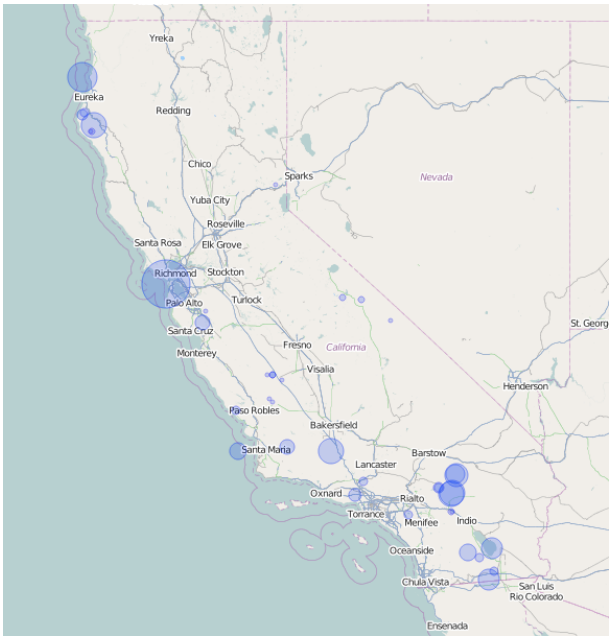



Figure 7.2: A proportional symbol map depicting the desired result of the earthquake map visualization.

**Voter Turnout in Finnish Presidential Election of 2012** The Finnish Ministry of Interior provides regional voter turnout data of the presidential election of 2012[3]. This data is provided in electoral district and municipality level. I decided to visualize the turnout in municipality level, using municipality data by the Finnish Land Survey[4]. The municipality data is provided in GeoJSON format by Teemu Tiilikainen[5]. The visualization should combine these data to create an effective choropleth visualization of regional turnout. The visualization should normalize the data in quantized fashion, i.e., using thresholds to create a discrete color range. Figure 7.3 depicts the desired visualization result. This case is later referred to as "election map".

[3] `http://tulospalvelu.vaalit.fi/TP2012K2/s/aanaktiivisuus/aanestys1.htm`

[4] `http://www.maanmittauslaitos.fi/en/opendata`

[5] `https://github.com/varmais/maakunnat`

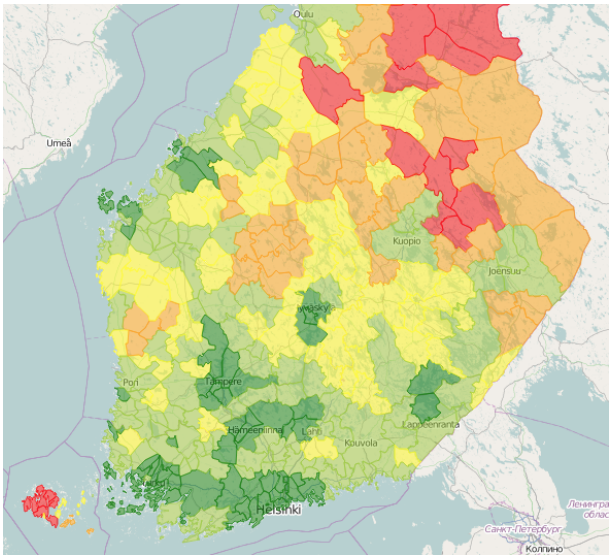



Figure 7.3: A choropleth map depicting the desired result of the regional voter turnout visualization.

**Share of People with No Secondary Education in Finland** Statistics Finland[6] provides provincial data on the education of the population of Finland in CSV format. The visualization should combine this with province data by the Finnish Land Survey[7] to create an effective choropleth visualization. The visualization should normalize the data in linear fashion, i.e., using a continuous color range. Figure 7.4 depicts the desired visualization result. This case is later referred to as "education map".

**Travel Times to a Single Destination** Travel times to a destination can be visualized using an isarithmic map. I decided to visualize travel times to Futurice headquarters[8] using public transport. The travel times can be obtained by using Travel Time Visualization Utility for HSL Reittiopas[9]. The utility provides the data in an approximated "flat dot" format. The visualization should normalize the data in a quantized fashion to emphasize

[6] `http://www.tilastokeskus.fi/`
[7] `http://www.maanmittauslaitos.fi/en/opendata`
[8] `http://futurice.com/contact#helsinki`
[9] `https://github.com/pyryk/reittiopas-travel-times`

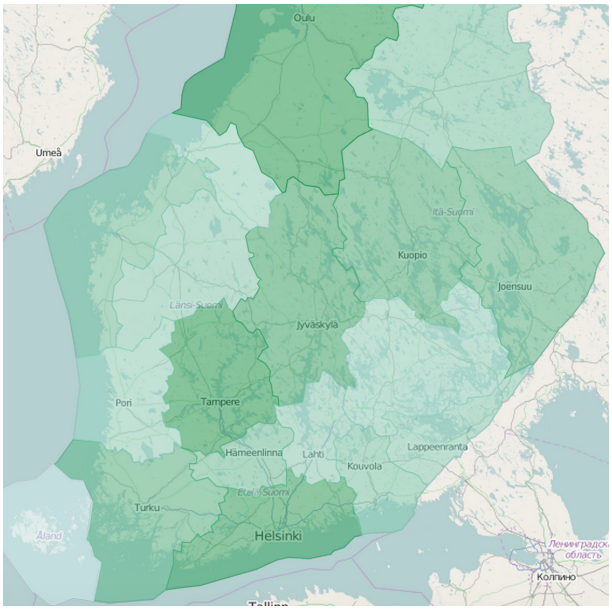



Figure 7.4: A choropleth map depicting the desired result of the secondary education visualization.

isarithmic contours. Figure 7.5 depicts the desired visualization result. This case is later referred to as "simple travel times map".

**Travel Times to Multiple Destinations** In addition to visualizing travel times to a single destination, I decided to evaluate a case for displaying travel times to multiple destinations. The visualization should obtain the travel time data with the method defined in the previous paragraph, and combined using a weighted average method. Like in the previous case, the visualization should normalize the data in a quantized fashion. Figure 7.6 depicts the desired visualization result. This case is later referred to as "complex travel times map".

While I selected the visualized data arbitrarily, I picked the cases to reflect the typical usage of visualizations. Choropleth map and isarithmic map are the most frequently used thematic mapping methods (Slocum and McMaster, 2014, chap. 14-15). Therefore, it is beneficial to the evaluation to examine

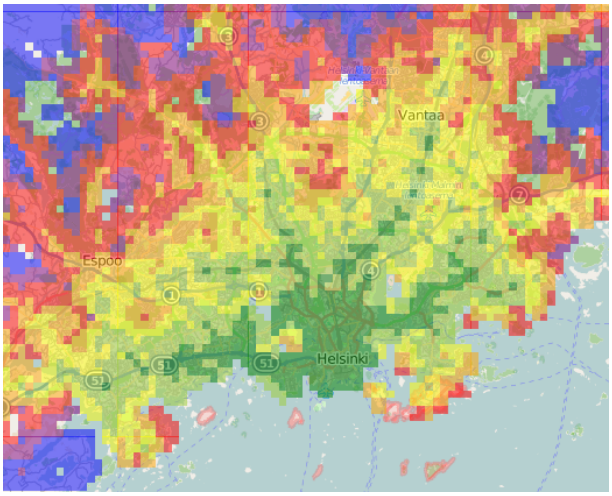



Figure 7.5: An approximated isarithmic map depicting travel times to Helsinki center.

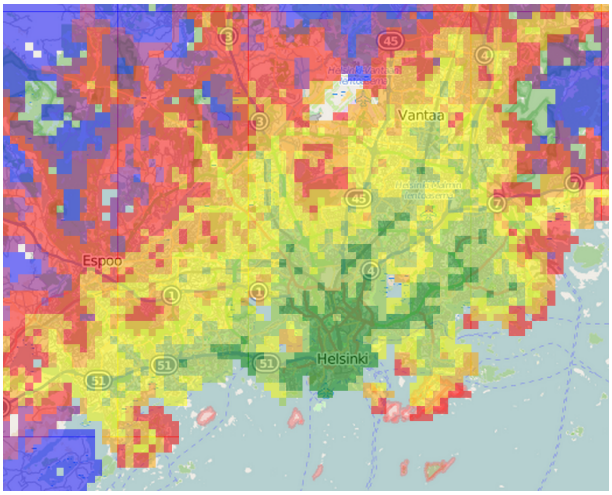



Figure 7.6: An approximated isarithmic map depicting travel times to multiple destinations.

multiple visualizations with those methods.

The visualization cases include also a generic application structure and HTML features such as application caching and bookmarking support. These features are highly beneficial for web applications. I chose this approach in order to better model typical real-life use cases, and to be usable on the web.

## 7.2 Implementing Sister Projects

I implemented six separate sister project visualizations with no visualization library to compare to the visualization cases as defined in the previous section. The functionality of the visualizations was designed to reflect the functionality of the Thematic.js visualizations as accurately as possible. Sister visualizations were implemented using HTML, CSS and JavaScript to enable straightforward comparison to the evaluated visualization cases. I did not use any visualization library for the sister projects. However, I deemed using a generic mapping library such as Leaflet.js appropriate, because typically, creating map visualizations is not feasible without using one. Moreover, also Thematic.js uses Leaflet.js as a mapping library.

In order to better reflect the actual situations involving building visualizations, I implemented the sister projects in *ad hoc* fashion. In practice, this means that I did not plan the design or architecture of the applications extensively beforehand. Also, I did not plan reuse of any form between visualizations. However, during implementation, I performed some design and code scavenging in order to speed up the development process. The sister project code is located in `https://github.com/pyryk/thesis-reference-implementations`.

## 7.3 Evaluating Efficiency of Development

I evaluated the efficiency of development by several metrics: software code length (number of physical (LOC) and logical (LLOC) lines of code), cyclomatic complexity (CC), Halstead difficulty (HD) and Halstead effort (HE). For measurements, I used ESComplex[10] for analyzing JavaScript programs.

[10] `https://github.com/philbooth/escomplex`

As the visualizations are implemented as single-page applications, the majority of the functionality lies within JavaScript. Only small part of the functionality involves HTML code and CSS definitions. Therefore, I decided to exclude HTML and CSS from the evaluation.

I began the evaluation by measuring the aforementioned metrics for the visualizations. It should be noted that for these measurements, I did not include code from Thematic.js or other third party libraries. The measurements are shown in table 7.1.

| **Visualization** | **LOC** | **LLOC** | **CC** | **HD** | **HE** |
|---|---|---|---|---|---|
| Thematic.js store | 12 | 12 | 1 | 7.31 | 4600 |
| Reference store | 126 | 85 | 10 | 23.6 | 96500 |
| Thematic.js earthquake | 15 | 14 | 1 | 8.38 | 6280 |
| Reference earthquake | 79 | 121 | 10 | 23.5 | 87400 |
| Thematic.js election | 26 | 29 | 2 | 10.9 | 12800 |
| Reference election | 141 | 101 | 14 | 23.8 | 107000 |
| Thematic.js education | 17 | 17 | 1 | 10.2 | 10200 |
| Reference education | 129 | 87 | 10 | 27.8 | 109000 |
| Thematic.js travel times simple | 27 | 28 | 2 | 10.8 | 9840 |
| Reference travel times simple | 184 | 129 | 12 | 29.4 | 182000 |
| Thematic.js travel times complex | 30 | 30 | 2 | 11.6 | 13300 |
| Reference travel times complex | 193 | 144 | 12 | 34.5 | 255000 |

Table 7.1: Measurements for developed visualizations, including only visualization-specific code. The lower the value the better.

*According to the results, using Thematic.js yields significantly lower complexity, difficulty and effort values when compared to using no visualization library.* This is likely a direct result of Thematic.js providing an extensive map-specific visualization functionality, allowing the visualizer to concentrate on the visualized data. In practice, this means that it is significantly more efficient to use a library such as Thematic.js than to write the map visualization from the ground up.

However, it is likely that the results do not describe the most typical real-life scenarios completely accurately. It can be assumed that typically,

visualizers do not possess knowledge of Thematic.js functionality beforehand. Therefore, effort for each line of code is considerably higher than when building the visualization from the ground up. In the results, this is reflected in rather high values for relative difficulty for Thematic.js visualizations as seen in figure 7.7.

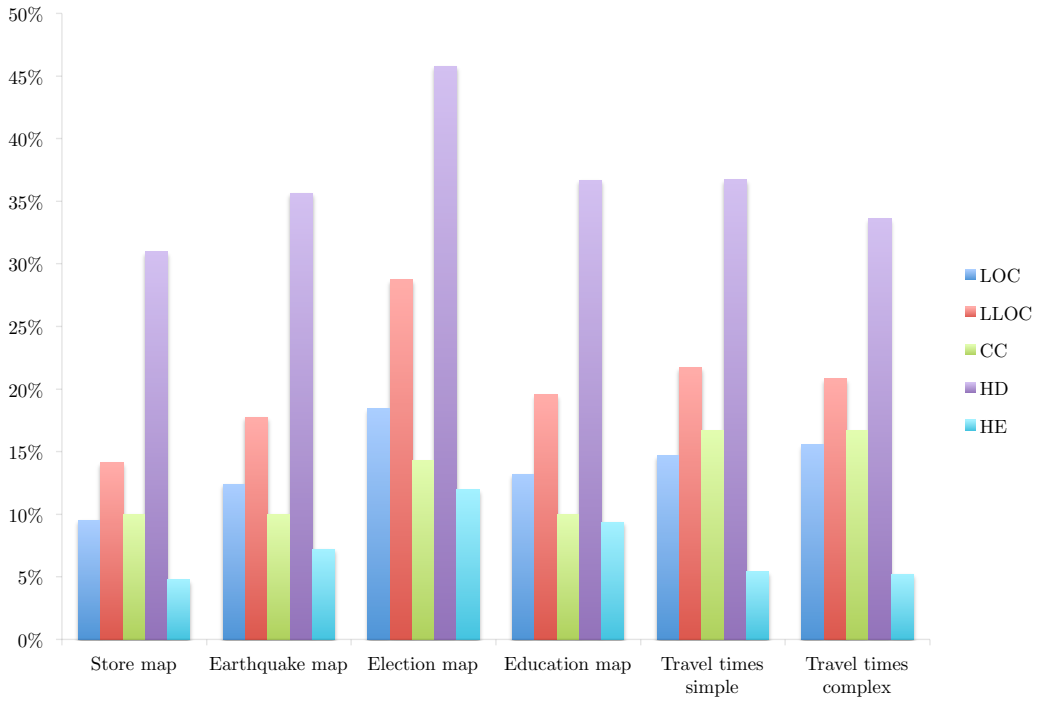



Figure 7.7: Thematic.js visualization metrics for each case as a percentage of the corresponding reference visualization metric. The percentages are calculated using the values for each visualization case in table 7.1

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Figure 7.7 displays the ratio of Thematic.js visualization metrics for each visualization case to reference visualizations. I calculated these values using the determined absolute values for each visualization case as presented in table 7.1. The resulting metrics provide a good overview of the effort needed for Thematic.js visualizations compared to using no visualization library.

Perhaps surprisingly, according to the results, using Thematic.js yields relatively high benefits for all metrics for the dot map visualization (store map). This may be surprising as dot map is an inherently simple mapping

method. The reason for this may be that, e.g., error handling and marker clustering support add complexity to the reference implementation. Moreover, the Thematic.js visualization implementation for dot map visualization consists of only 12 lines of relatively simple code. Consequently, the boilerplate code needed in the reference implementation causes the relative metrics to be notably low.

Relative metrics of proportional symbol (earthquake) map are approximately similar to the metrics of dot map. However, the proportional symbol map is missing clustering support but involves symbol scaling functionality which is also needed in the Thematic.js implementation. Therefore, the relative metrics are slightly more favorable to the reference implementation than in the dot map case. Nevertheless, also in the proportional symbol case, using Thematic.js yields significant benefits compared to using no visualization framework. For example, Halstead effort measurement in Thematic.js implementation is under 10 % of the corresponding measurement in the reference implementation.

Election map case yields the least benefits of all the evaluated cases. In this case, the Halstead difficulty is almost 50 % and the Halstead effort over 10 % of the value for the reference implementation. This is likely due to the fact that the Leaflet.js mapping library provides a comprehensive GeoJSON polygon support used with choropleth visualizations. Therefore, the additional manual implementation needed for the reference case is relatively straightforward. In this implementation, the most effort needed is related to the coloring and showing values. These features need to be implemented manually also in the Thematic.js implementation. That being said, even a simple choropleth map like this benefits considerably from the Thematic.js library.

In the education map case, using Thematic.js yields slightly greater benefits than in the election map. Like the election map, the education map uses choropleth mapping technique for visualization. However, the data in this case is already combined in GeoJSON format, so no manual combining is required. In both Thematic.js and reference implementations, an external coloring functionality is used, which reduces the size of the code bases. Especially the use of external coloring functionality reduces the Thematic.js

relative complexity considerably. This results in more significant gains when using the library than in the election map case.

Both travel time maps yield highly similar results in measurements. This is likely due to the fact that both maps use isarithmic mapping method with relatively similar data. The only difference between the cases is the need for combining several data sources in the complex case. The data combining likely results in slightly lower values in Halstead difficulty and effort. However, in both of these cases, the Halstead effort metric is notably low. This indicates that the effort for visualizing with Thematic.js taking only 5 % of the effort of the reference implementation. This is probably due to the fact that even approximated isarithmic visualization requires a complex graphics implementation not supported directly by any mapping library.

Across all cases, the Thematic.js measurements indicate more significant differences in physical lines of code than logical lines of code. This is likely due to the fact that I designed the Thematic.js API to encourage functional-style, chainable operations. Unlike in Thematic.js, traditional JavaScript APIs typically are imperative and non-chainable. The difference is demonstrated in listing 7.1. Visualizers can use the chainable version without line breaks, resulting in only 1 physical line of code. With the API format in second example, it is not customary to combine the lines using only source code line. However, in practice, this has little effect on the actual effort needed as the underlying functionality stays largely similar.

```
// chainable API supported by Thematic.js
map.addModule('voting', new Choropleth('percentage')
        .setScale(scale)
        .setData(data));

// non-chainable API typical for traditional
// JavaScript libraries
var module = new Choropleth('percentage');
module.setScale(scale);
module.setData(data);
```

```
map.addModule('voting', module);
```

Listing 7.1: Thematic.js API format. The code has been simplified to increase readability.

Additionally, in all the cases, Halstead effort measurements in Thematic.js implementations are 4 to 12 % of the reference implementations. However, corresponding Halstead difficulty measurements are 30 to 50 % of the reference implementations. *This reflects the fact that the reference implementations consist largely of straightforward but laborious boilerplate code such as initializing the map. Thematic.js implementations consist mostly of data-specific initialization of the visualization, which is typically less straightforward but considerably more concise.*

The results are statistically significant assuming the individual measurements are distributed normally. Using the dependent samples t-test, I determined that the difference in every evaluated metric is significant using the significance level of 1 %.

Lastly, it should be noted that while the measurements are suitable for comparing different cases, as absolute metrics they are approximate at best. In practice, this means that it is not sensible to assume that using Thematic.js reduces the effort needed to 10 % of the original. *However, in light of these results, it seems extremely likely that using the library for visualizations similar to the evaluated cases yields considerable benefits over building the visualizations from the ground up.* For more details about the measurements, see appendix B.

## 7.4 Evaluating Effectiveness of Visualizations

In order to allow as reliable effort comparison as possible, I decided to implement the same functionality to reference visualizations as in Thematic.js visualizations. In practice, this results in the reference visualization being as similar feature-wise and visually to the Thematic.js visualization as possible. Therefore, it is not reasonable to compare the effectiveness of the corresponding reference and Thematic.js visualizations. Instead, I decided to evaluate the Thematic.js visualizations qualitatively, concentrating on how the library

encourages the visualizer to create effective visualizations.

*The results of the evaluation suggest that using Thematic.js may benefit the effectiveness of the visualization especially when used by inexperienced visualizers.* According to the evaluation, Thematic.js yields positive results related to 12 of the 25 visualization heuristics and 4 of the 10 objectives. The application yields negative results with only 1 of the 25 heuristics and none of the 10 objectives.

### 7.4.1 Visualization Heuristics

Zuk et al. (2006) provide a list of 25 heuristics for data visualizations. I describe the heuristics in more detail in section 3.2. I decided to use the heuristics as a basis for evaluating the created visualizations and Thematic.js functionality. I evaluated Thematic.js using a three-step scale for each heuristic. I deemed the result positive if the system has a positive effect (encourages conforming to the heuristic) when compared to using no visualization library. I deemed the result neutral if the system has no effect, and negative if the system encourages creating ineffective visualizations. I chose the approach to reduce the effects of the inherently subjective research method. With only three steps, the results are explicitly approximate but less likely to suffer from subjective evaluation. The evaluation results are outlined here. The full results, along with the reasoning, can be seen in appendix C.

Almost all heuristics yield a nonnegative result. According to the results, Thematic.js yields a positive result (encourages the visualizer to conform to the heuristic) in 12 of the 25 criteria. Examples of these criteria are preserving action history and displaying details of the data on demand using popups. Using Thematic.js yields a neutral result (has no effect on conforming to the heuristic) in another 12 cases. I deemed only one case negative. In some cases, Thematic.js encourages the visualizer to unnecessarily increase graphical dimensionality by visualizing scalar data in a non-scalar fashion. In practice, this is the case when using the proportional symbol method. The overview of the heuristics evaluation can be seen in table 7.2.

*The heuristics evaluation indicates that using Thematic.js may be beneficial to the effectiveness of the visualization. However, this is likely dependent*

| Positive | Neutral | Negative |
|---|---|---|
| Size variation | Visual variable | Graphic dimensionality |
| Most data | Color order | |
| No extra ink | Color size | |
| Gestalt laws | Local contrast | |
| Levels of detail | Color blindness | |
| Integrate text | Preattentive benefits | |
| Overview first | Zoom and filter | |
| Details on demand | Relate | |
| Extract | Uncertainty | |
| History | Relationships | |
| Multivariate | Domain Parameters | |
| Hypotheses | Cause & effect | |

Table 7.2: The overview of evaluation based on the 25 heuristics presented by Zuk et al. (2006).

*on the visualizer.* An experienced visualizer will probably build visualizations which conform to the heuristics as well or even better without the library. However, for inexperienced visualizers, using the library is likely beneficial for building effective visualizations.

### 7.4.2 Thematic Mapping Objectives

Schlichtmann (2002) provide a list of objectives for thematic mapping. I cover the objectives in more detail in section 3.4. I evaluated the Thematic.js library by examining whether the library encourages the visualizer to achieve the objectives or not. Like in the previous section with heuristics, I employed a three-step scale for evaluation. Result for each objective is regarded as *positive* if the library encourages achieving the objectives better than a typical non-visualization mapping library does. Result is regarded as *neutral* if using Thematic.js has no effect on achieving the objective, and *negative* if Thematic.js discourages the visualizer to achieve the objective. I present the results in full detail in appendix D, with overview below.

Table 7.3 displays the number of positive, neutral and negative results related to the objectives. I regarded the most of the results as neutral. This is likely due to the fact that many mapping libraries, such as Leaflet.js, already provide satisfactory level of support for many of the objectives. Therefore, using Thematic.js provides no additional benefit related to these objectives. Nevertheless, Thematic.js achieves a positive result for 4 out of 10 objectives. These are mostly due to providing explicit support for features encouraging effective visualizations, such as defining different symbols for different topeme types. It is also notable that I regarded none of the results as negative.

| **Positive** | **Neutral** | **Negative** |
|---|---|---|
| Clarification | Emphasis | |
| Types of entries | Sets of Types | |
| Cross-relations | Local syntax | |
| Addable and non-addable quantities | Local ensembles | |
| | Multilocal ensembles | |
| | The surface illusion | |

Table 7.3: The overview of evaluation based on objectives presented by Schlichtmann (2002).

*Thematic mapping objective evaluation hints that using Thematic.js may be beneficial to the effectiveness of resulting visualizations.* However, as with the heuristics results, this does not imply that Thematic.js is beneficial for every visualizer. An experienced visualizer may not benefit from the library in terms of effectiveness. However, especially for less experienced visualizers who might not recognize the objectives by heart, Thematic.js is probably beneficial.

# Chapter 8

# Discussion

In this chapter, I discuss the applicability and validity of the results along with potential shortcomings of this thesis. By internal validity, I mean the validity and appropriateness of the used methods for evaluating the use cases. By external validity, I mean the generalizability of the results, i.e., whether the evaluation results can be generalized for other use cases. I also define a number of relevant aspects not covered by this research to be further studied in the future.

## 8.1 Interpretation of Results

*Thematic.js proves that it is possible to create a reusable tool for geographical visualization.* Moreover, the results of the evaluation indicate that such tool can benefit a) the effectiveness, and b) the efficiency of visualizations. Therefore, using a tool such as Thematic.js is most likely beneficial in typical visualization cases, such as the ones demonstrated in chapter 7.

As Boehm (1999) and Mohagheghi and Conradi (2007), among others, conclude, software reuse is likely to benefit the resulting software in terms of effort. This is in line with my findings. Moreover, the study by Bostock and Heer (2009) suggests that when applied appropriately, reuse may have a positive effect on the effectiveness of the visualizations. My evaluation indicates that this is also applicable to geographical visualizations. By considering the visualization effectiveness when building the geovisualization tool, it is possi-

ble to enable visualizers using the tool to build more effective visualizations. A tool can achieve this by encouraging the visualizers to adhere to heuristics for effective visualization and to achieve the objectives of thematic mapping.

## 8.2 Applicability of Results

*Thematic.js provides two primary benefits for the visualizer. First, it makes building the visualization more efficient.* This quality is emphasized for less-experienced web developers as I discuss in chapter 7.3. *Second, it enables building more effective visualizations.* These characteristics make using the library beneficial especially for less-experienced visualizers as I discuss in chapter 7.4.

At its current state, Thematic.js provides only a predefined set of visualization methods and thus it is not suitable for all visualization cases. Therefore, Thematic.js is most effectively used in systems requiring some of the visualization methods provided out-of-the-box. In those cases, it is highly effective in reducing the effort needed and providing high quality visualization methods. Typically, reduction in the effort needed also reduces software development costs, making Thematic.js beneficial for business purposes.

According to a study by Nambisan and Wang (1999), a major adoption barrier for web technology is the lack of knowledge about the requirements for development. Moreover, Butler and Sellbom (2002) describe time to learn new technology and difficulty in using the technology as major obstacles for adopting new technology. Therefore, it is possible that enabling easy creation of quality visualizations may increase the number of visualizations built for all purposes. In the bigger picture, this likely benefits the general understanding of complex geographical phenomena.

Furthermore, the evaluation results related to benefits for effectiveness of Thematic.js suggest that visualization reuse may be highly beneficial also in the general level. It is possible for the developer of reusable software to enforce good software practices such as architecture (Mohagheghi and Conradi, 2007). Similarly, it may be possible for the developer of reusable visualization tool to enforce "good" visualization practices.

## 8.3 Internal Validity of the Study

According to most of the literature presented in chapter 2, measuring software reuse is extraordinarily difficult. I identified several aspects potentially hindering the reusability evaluation and its validity.

The evaluation metrics used assume that the visualizer is equally acquainted with all the libraries and APIs used. However, in practice, this is unlikely. I assume that a typical visualizer creating web geovisualizations possesses at least an elementary knowledge of JavaScript APIs. Some visualizers may also have experience on using Leaflet or other mapping libraries. On the other hand, it can safely be assumed that most developers do not possess knowledge of Thematic.js beforehand.

Therefore, it is likely that for a typical visualizer, difference in effort between using and not using Thematic.js is smaller than what is indicated in the evaluation results. In order to address this issue, a study of typical web visualizers' experience would be needed. However, due to the scope of this work, I was unable to conduct this study.

Furthermore, as literature (e.g., Frakes and Isoda 1994; Mohagheghi and Conradi 2007) indicates, it is unclear how the reusable parts of software should be taken into consideration when measuring characteristics of a software system. While some sources (including, e.g., Frakes and Terry 1996; Selby 2005) advocate including (parts of) reused software in the calculations, I decided to exclude third-party libraries. I chose the approach primarily because I assumed that Thematic.js or other libraries were not to be modified internally. Therefore, to an external developer, they appear similar to, e.g., the standard JavaScript API. In order for this assumption to be reasonable, the documentation and functionality of the library must be thorough and reliable. Secondarily, the costs incurred while developing the library are considered as sunken and therefore do not affect the calculations.

I also decided to exclude any HTML or CSS code from the calculations. I did this primarily due to two reasons. First, in the example cases, the HTML and CSS included was almost identical. This is primarily because of similar requirements and the fact that Thematic.js does not provide almost any HTML-level functionality. Second, in reality, the requirements for HTML

and CSS may vary considerably due to, e.g., integrating the visualizations to an existing web application. Additionally, no widely established method for measuring effort needed for building single-page web applications exists. E.g., Mendes et al. (2001) propose a metric for estimating total web development effort. However, the metric is mainly suitable for traditional multi-page web documents instead of single-page web applications.

For evaluation, I implemented several different geovisualizations. However, all evaluation cases were implemented by a developer who knows the library functionality along with evaluation methods and metrics. This introduces a potential selection bias which may have an influence on the results as Kitchenham and Pickard (1998) correctly observe. A better alternative for this would be repeating the evaluation with several external developers. However, different developers likely have different abilities and experience on JavaScript, mapping and geovisualizations. Therefore, as Mohagheghi and Conradi (2007) argue, for this kind of study to be reliable, the sample size should be increased considerably. I deemed this infeasible in the scope of this thesis.

As Schlichtmann (2002) and Slocum and McMaster (2014) state, designing and building a visualization involves considerably more than just the technical construction of the map. Schlichtmann provides a six-step process of which only steps 4 and 5 involve the actual building of the visualization. Similarly, of the five-step process of Slocum and McMaster, only step 5 involves building the visualization. The remaining steps were not considered in any way in the evaluation part of this work. While it can be argued that the technical means used do not affect the remaining steps, the claim could be validated for extra credibility.

## 8.4 External Validity of the Study

In addition to potential issues with the methods used, I have identified a number of potential issues regarding the generalizability of the results. These issues are discussed below.

I built Thematic.js along with its visualization methods using geovisualization literature to determine the visualization methods and functionality.

I also used partly the same literature to evaluate the library. Therefore, the results are likely slightly biased towards preferring Thematic.js. While this is unfortunate, it is an essential side-effect for using the most comprehensive literature for both implementing and assessing the functionality. Moreover, for the evaluation, I complemented the criteria with additional literature sources, namely heuristics of Zuk et al. (2006), to minimize the bias.

Second, the selection of visualization cases for evaluation likely has an effect on the results. For the evaluation of Thematic.js, I selected a rather small number of cases using different mapping methods in order to keep the scope manageable. However, as Frakes and Isoda (1994) point out, benefits of software reuse typically increase with larger sample sets. Therefore, using, e.g., a large number of relatively similar visualization cases, the perceived benefits of the library would likely increase considerably. On the other hand, using a number of cases with mapping methods not supported directly by Thematic.js, the perceived benefits would diminish. I did not discover means to overcome this issue. Instead, I decided to keep the number of cases rather small, while ensuring large variety among cases, and address the concern here.

Third, the visualization cases represented in evaluation are inherently simple. None of the cases employ multiple different mapping methods. Furthermore, none of the cases require complex interaction. These have also an effect on the evaluation results. Visualization implementations need additional functionality to cover the complexity and interaction. Therefore, with more complex visualization and interaction methods, the perceived relative benefits of the library will likely diminish. This concern could be addressed by developing more advanced mapping module functionality to the library.

## 8.5 Further Research

According to software reuse literature (e.g., Mohagheghi and Conradi 2007; Frakes and Isoda 1994), reuse typically benefits other software (process) properties than effort, such as quality or maintainability. The evaluation of the cases in this work also suggested that this could apply in this case. However, I did not conduct an extensive study or analysis related to these qualities.

However, as, e.g., Kitchenham and Pfleeger (1996) point out, software quality and maintainability are essential characteristics of a successful software system. Therefore, it would be highly beneficial to study the effect of reuse on these properties in the future.

Thematic.js library does not provide means for implementing interaction other than navigating the map. However, Andrienko and Andrienko (1999), and Slocum and McMaster (2014, chap. 21), among others, argue that visualization interaction greatly benefits especially exploratory data analysis. Due to the scope of this work, I decided not to consider interactions when defining or implementing Thematic.js. Therefore, it would be valuable to extend the tool in terms of interactivity in the future.

As concluded in chapter 7, the profile of visualizer affects the suitability of Thematic.js for visualization. When evaluating the tool, I made two assumptions about the potential users of the tool. I assumed that visualizers possess an elementary level of web development experience. I also assumed that they possess at least some cartography experience. However, I did not base these assumptions on any specific study. While, e.g., Slocum and McMaster (2014) argue that the typical geovisualizer is no longer necessarily a cartographer, they do not provide any specific data about visualizers. Therefore, it would benefit the development of reusable visualization tools to conduct a study on the demographics of geographic visualizers.

# Chapter 9

# Conclusions

In this thesis, I studied the effects of a reusable web geovisualization tool on the effort needed for building visualizations, and on the quality of the resulting visualizations. In order to do this, I studied software reuse and geovisualizations, implemented a reusable web geovisualization tool and evaluated the tool against visualizations built without it. *My principal findings were that the tool enables visualizers to build more effective visualizations more efficiently at least in certain situations.* According to my findings, the tool is beneficial especially for inexperienced visualizers and visualizers with data which is naturally visualized using the most frequently used mapping methods.

Geographical data is data with a geospatial dimension, such as Point of Interest with location data as coordinates. When such data is visualized based on the geospatial dimension, the resulting visualization is called *geographical visualization* (or *geovisualization*). Most typically, geographical visualization is done with a map using the process called *thematic mapping*. In the past, thematic maps were predominantly made by cartographers. However, recently, the advent of web-based mapping tools has enabled non-cartographers to create various map visualizations. Currently, it is estimated that the majority of web map visualizations are made by laymen with no education related to cartography.

Before this work, apart from general-purpose mapping libraries, practically no libraries exist for building geovisualizations on the web. General-

purpose mapping libraries such as Google Maps API support building visualizations to some degree. However, these libraries are of too low abstraction level to allow building more complex visualizations efficiently. Moreover, as the libraries are not designed for building visualizations, they do not encourage building effective visualizations. Therefore, it is both laborious and difficult to build effective map visualizations with general-purpose mapping tools. Moreover, research on the effect of software reuse on the quality of visualization is scant.

During this work, I implemented Thematic.js, a reusable visualization application for the web. A visualizer can use the application independently as a single-page application, or as a part of other JavaScript applications. The application is designed to support the most frequently used thematic mapping methods and relevant utility functionality. Additionally, the application architecture is designed to be modular for efficient extensibility.

I evaluated the implemented application by defining several use cases depicting typical geovisualization use. Then, I implemented the cases using Thematic.js, and reference implementations for comparison using Leaflet.js, a general-purpose mapping library. These implementations were then compared using several metrics for software development effort. Additionally, I evaluated the Thematic.js implementations according to the visualization heuristics of Zuk et al. (2006) and mapping objectives of Schlichtmann (2002).

*The evaluation results indicated that using Thematic.js, building geographic visualizations is significantly less laborious.* In the test cases evaluated, implementations built with Thematic.js required an average of 7 % of the effort needed for the reference implementation. Moreover, Thematic.js implementations used only 14 % of physical and 20 % of logical lines of code, introduced 13 % of the complexity and 37 % difficulty when compared to reference implementations. The results are statistically significant using the Student's t-test with a significance level of 1 %.

Additionally, I deemed using Thematic.js beneficial regarding 16 of 35 visualization effectiveness guidelines (heuristics and objectives), with only 1 of 35 guidelines deemed negative. *This indicates that Thematic.js is beneficial to the effectiveness of the visualization at least in certain cases.*

Thus, I can conclude the findings in relation to the research questions

selected:

RQ1 How does a reusable software system affect the *efficiency* of building geographical visualizations?

A1 According to my findings, a reusable software system such as Thematic.js increases the efficiency of building geographical visualizations considerably.

RQ2 Can a reusable software system enable creating *effective* geographical visualizations?

A2 According to my findings, a reusable software system such as Thematic.js encourages visualizers to create effective geographical visualizations.

While the results look highly promising, reliable effort measurement is incredibly hard. Therefore, I presented a number of concerns regarding the validity of results. First, the correct level of inclusion of reusable parts of a software system for measurements is disputed. I decided to exclude the reusable parts. Measurements with reusable parts included would likely yield more negative results regarding the effort needed. Second, the metrics do not take into consideration different experience levels of visualizers and thus the results may vary greatly depending on the visualizer. Third, while I selected the use cases according to approximate usage of visualization methods, using different methods would probably yield highly different results. Evaluating methods which are not supported by Thematic.js is likely to yield considerably less promising results.

To conclude, I suggest that visualizers consider using Thematic.js in projects requiring web-based geographical visualizations. It is likely that Thematic.js benefits such projects regarding both development efficiency and visualization effectiveness.

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# Appendix A

# Flat Dot Format

Flat dot format is a simple, but non-standard format used by a number of web mapping applications such as the Store Finder of Alko[1]. Format consists of a JSON[2] file representing an array of zero or more objects. The objects must contain latitude and longitude properties, and may contain a number of other properties. An example of the format is depicted below.

```
[
  {
    "number": 2,
    "name": "Destination",
    "latitude": 60.314322,
    "longitude": 24.554067
  },
  {
    "number": 0,
    "name": "Departure",
    "latitude": 60.314041,
    "longitude": 24.551678
  },
  {
    "number": 1,
```

[1] http://www.alko.fi/myymalat/
[2] http://www.json.org/

```
    "name": "Pit stop",
    "latitude": 60.316474,
    "longitude": 24.556554
  }
]
```

# Appendix B

# ESComplex Results for Visualizations

For the sake of conciseness, I omitted the full output of ESComplex[1] tool for evaluated cases in JSON format. The output contains additional details about the measurements, such as the full operator and operand lists. The full results are available in `https://github.com/pyryk/thesis-evaluation-results`.

[1] `https://github.com/philbooth/escomplex`

# Appendix C

# Visualization Heuristics Evaluation

Thematic.js evaluation results based on the visualization heuristics presented by Zuk et al. (2006) are displayed in table C.1. I performed the evaluation using a tree-step scale. I evaluated each heuristic *positive* if Thematic.js encourages conforming to the heuristic when compared to using no visualization library. I evaluated a heuristic *neutral* if using Thematic.js has no effect, and *negative* if Thematic.js discourages conforming to the heuristic.

| **Heuristic** | **Evaluation** | **Reasoning** |
|---|---|---|
| Visual variable | Neutral | Of map visualizations, this concerns mostly choropleth maps. Thematic.js choropleth maps do not ensure minimum geographical size for areas. However, using the default line weight ensures a minimum screen size of several pixels. |

| **Heuristic** | **Evaluation** | **Reasoning** |
|---|---|---|
| Color order | Neutral | Thematic.js choropleth, dasymetric and isarithmic maps are primarily based on coloring the map. Moreover, the visualizer is given the possibility of freely choosing the colors. This may lead to situations when the visualizer chooses the colors inappropriately for displaying order. However, this situation is not different from the alternative situation of the visualizer creating the visualization without using a visualization library. |
| Color size | Neutral | Thematic.js does not provide any color-adjusting mechanisms based on the size of the element. |
| Local contrast | Neutral | Thematic.js does not provide any color-adjusting mechanisms based on contrast. |
| Color blindness | Neutral | Thematic.js does not provide any advice regarding color blindness. |
| Preattentive benefits | Neutral | Thematic.js provides and enforces spacial positioning of the data. However, this is fundamental to any geovisualization, and therefore, cannot be considered a positive trait of the library. |
| Size variation | Positive | Thematic.js provides size variation in proportional symbol mapping to encourage the visualizer to emphasize quantitative variation in data. |

| **Heuristic** | **Evaluation** | **Reasoning** |
|---|---|---|
| Graphic dimensionality | Negative | Thematic.js does not enforce preserving dimensionality of the data. In some cases, such as when using a proportional symbol map, it encourages the visualizer to increase dimensionality by displaying scalar values using proportional symbols. |
| Most data | Positive | Thematic.js encourages the visualizer to maximize data shown by providing support for several different mapping methods suitable for different kind of data. |
| No extra ink | Positive | Thematic.js provides data aggregation functionality to combine the relevant data. |
| Gestalt laws | Positive | Thematic.js provides functionality to support Gestalt laws of grouping, such as using different symbols and sizes for different data points. However, not all Gestalt laws are considered. |
| Levels of detail | Positive | Thematic.js provides clustering functionality of dots and symbols. While currently there is no support for levels of detail for other mapping methods, the library does not prevent implementing this in the future. |
| Integrate text | Positive | Thematic.js supports attaching popups with textual content to data points, such as markers or choropleth areas. |

| **Heuristic** | **Evaluation** | **Reasoning** |
|---|---|---|
| Overview first | Positive | Thematic.js supports overview-first approach in most of the mapping methods. Dot and proportional symbol maps support marker clustering and choropleth, isarithmic and dasymetric maps support zooming for displaying the details. |
| Zoom and filter | Neutral | Thematic.js supports zooming of the map. However, support for filtering data on view-level is not provided. |
| Details on demand | Positive | Thematic.js supports attaching popups to data points for displaying additional details. |
| Relate | Neutral | Thematic.js does not support any method of emphasizing relationships between entries other than spacial distribution. |
| Extract | Positive | While Thematic.js does not support physical saving of data subsets, it provides bookmarking and linking support which effectively provide similar benefits. |
| History | Positive | Thematic.js supports using the back and forward buttons of the browser to undo and redo actions. |
| Uncertainty | Neutral | Thematic.js does not encourage the visualizer to display the uncertainties in data. |
| Relationships | Neutral | Thematic.js does not encourage concretizing relations between data points. |
| Domain Parameters | Neutral | While Thematic.js modules require explicitly stating the used parameters, there is no guarantee about the importance of selected parameters. |

| **Heuristic** | **Evaluation** | **Reasoning** |
|---|---|---|
| Multivariate | Positive | Thematic.js provides aggregation functionality in order enable easy experimenting about relationships between variables. Moreover, the modular structure of the library results in the possibility to easily combine several visualization methods to highlight different aspects of the data. |
| Cause & effect | Neutral | Thematic.js does not provide additional means for determining or displaying cause and effect. |
| Hypotheses | Positive | The availability of several different mapping methods of Thematic.js encourage the visualizer to better display and evaluate hypotheses. |

Table C.1: Evaluation of Thematic.js according to heuristics presented by Zuk et al. (2006).

# Appendix D

# Mapping Objectives Evaluation

Evaluation results of Thematic.js regarding thematic mapping objectives of Schlichtmann (2002) are presented in table D.1. I performed the evaluation with a three-step scale. I regarded the result for each objective as *positive* if the library encourages achieving the objectives better than typical mapping library does. I regarded the result as *neutral* if using Thematic.js has no effect on achieving the objective, and *negative* if Thematic.js discourages the visualizer to achieve the objective.

| **Name** | **Evaluation** | **Reasoning** |
|---|---|---|
| Clarification | Positive | Thematic.js benefits the clarification of the visualization by, e.g., providing clustering functionality of the markers |
| Emphasis | Neutral | Thematic.js uses visual markers in dot maps. However, this is typically achieved with any mapping library even with no visualization library. |
| Types of Entries | Positive | Thematic.js provides support for using different markers for different types of topemes. |
| Sets of Types | Neutral | Thematic.js does neither encourage nor discourage consolidating types of topemes according to mutual similarities. |

| Name | Evaluation | Reasoning |
|---|---|---|
| Cross-Relations | Positive | Several of the mapping methods, especially proportional symbol method, support indicating similarities between different types of entries. |
| Local Syntax | Neutral | Thematic.js pays no special attention to managing lower-order units within topemes. |
| Local Ensembles | Neutral | Local ensembles are not supported in any of the current mapping methods of Thematic.js. |
| Multilocal Ensembles | Neutral | Multilocal ensembles are not supported in any of the current mapping methods of Thematic.js. |
| Addable and Non-Addable Quantities | Positive | Thematic.js separates between addable and non-addable quantities by separating between different mapping methods. |
| The Surface Illusion | Neutral | Thematic.js provides no additional means of achieving the surface illusion when compared to, e.g., the underlying Leaflet.js mapping library. |

Table D.1: Evaluation of Thematic.js according to the map visualization objectives of Schlichtmann (2002).