An Interdisciplinary Model for Graphical Representation: Descriptive and Prescriptive Case Studies

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Abstract. The paper questions whether data-driven and problem-driven models are sufficient for a software to automatically represent a meaningful graphical representation of scientific findings. The paper presents descriptive and prescriptive case studies to understand the benefits and the shortcomings of existing models that aim to provide graphical representations of data-sets. The first case study considers a data-set coming from the field of software metrics and shows that existing models can provide the expected outcomes for descriptive scientific studies. The second case study presents a data-set coming from the field of human mobility and shows that, especially in the case of prescriptive scientific fields requiring interdisciplinary research, a more comprehensive model is needed. Further case studies are then considered for both descriptive/prescriptive scientific aims. An interdisciplinary problem-driven model is therefore proposed to guide the software users, and specifically scientists, to produce meaningful graphical representation of research findings. The proposal is indeed based not only on a data-driven and/or problem-driven model but also on the different domains knowledge and scientific aims of the experts, who can provide the information needed for a higher-order structure of the data, supporting the graphical representation output.

***Keywords*—** Data visualization, data-driven model, problem-driven model.

1 Introduction

Graphical representations of data are fundamental for the understanding of scientific knowledge, as readers often rely on what the experts visually represent in their publications to understand the underlying data-set and interpret their potential scientific meaning. Figures and diagrams not only show the relevant data that support key research findings, but also provide visual information on the interactions among different operations required in scientific reasoning [1]. Being able to adequately and precisely visualize data is also a pillar on which decisions can be made as proposed by different dashboards in the market.

Data visualization has various purposes, such as to make abstract thinking on data series or sets more concrete and (mentally) manipulable, to help readers identify and evaluate some features of the data, to let users see the possible underlying trends, patterns, processes, mechanisms, etc. of the phenomena considered and studied [2]. The way data are visualized can therefore have important epistemic implications for scientific knowledge, as data visualization is not an

“interpretation-free” practice, i.e. a neutral process of data presentation in terms of scientific understanding. There are indeed several ways to transform data into a visual format, each of them entailing different possibilities for data interpretation.

Nowadays data visualization plays a significant role in the large adoption of data-driven and machine learning approaches and techniques. In this frame, the definition of what a visualization is can be object of debate. A visualization could be defined as a reusable component, which is achieved through a dedicated software library. For instance, the most popular one for visualizing data is D3.js. Despite the large amount of tools offered by D3.js, surprisingly, it is left to the practitioner to actually manipulate the data to achieve a ready-to-be-used graphical representation. This paper aims at designing a framework for a software, named Miró, which instead allows the users to produce meaningful graphical representation in an automatic way without the need to manually transform the data. Miró will be based on a visualization engine developed in Pharo and named Roassal [3].

First of all, we aim to verify the benefits and the shortcomings of existing data-driven and problem-driven models, by presenting some case studies. The case studies focus on the problem of visually representing specific data-sets collected in different scientific domains for different (descriptive vs. prescriptive) scientific aims. The case studies suggest that data-driven models can actually provide a visualization that fits the domain knowledge and scientific aims of the experts in the case of descriptive sciences, but present some limitations in the case of prescriptive sciences.

Finally, the paper draws some conclusion from the case studies, presenting an alternative trans-disciplinary perspective for data visualization. A comprehensive model for graphical representation is indeed presented, which integrates a data-driven approach with an approach that guides the experts on a specific domain field to achieve the intended visualization, based on their aims, knowledge and hypotheses.

2 Background

In the field of data visualization computing, researchers proposed different approaches to a comprehensive data-model, i.e. a model able to provide a meaningful graphical representation of a data-set for some scientific aims. Some authors advocate graphical representation techniques or visualization frameworks [4] based on data-driven models. The data-driven model approach is based on the idea that a comprehensive data-model is based on a prior data classification that can guide the automatic creation of a meaningful graphical representation. In general, the data-driven model describes the data characteristics of the data-set, such as the size (the number of rows), the data type (string, number, boolean) and the dimension (the number of the variables to represent), to categorize the data. For instance, Keim [5] proposed a data visualization model based on the data type to be visualized, the visualization technique and the technique of visual interaction with data, ranging from standard and projection to distortion and "link&brush".

Other authors, especially in the context of big data visualization, proposed graphical representation techniques based on a problem-driven model [6]. The problem-driven model provides the researchers with the possibility to perform specific tasks on specific variables of the data-set, such as visualizing a variable distribution, performing a linear regression between two variables to see an eventual relationship via a scatter plot, comparing their composition via a pie chart, etc.

On the one hand, adopting a problem-driven model does not necessarily mean abandoning data-driven models. The problem-driven model may be tightly linked to the data-driven model, because the data-driven model imposes constraints on the graphical representation of data which might conditioning how the problem can be solved. For instance, in the case of time series, there are graphs that are more appropriate than others or that are simply wrong depending on the

data classification: the time data-type is indeed a constraint given or inferred from the data-driven model. On the other hand, a graphical representation guided only by the data-driven model would not allow the users to further act on data to have their final intended graphical representation. In the techniques where a problem-driven model is also envisaged, the user can interfere with the final graphical representation of the data. The user can indeed act on and guide the graphical representation to be produced.

The main disadvantage of the problem-driven model is that it might be negatively influenced by the users' previous hypotheses or scientific aims. On the contrary, a data-driven model is neutral under this respect: of course it is based on a prior classification, but the users might not know it. Without the users' interference, the final graphical output of a data-driven model might indeed have the advantage of questioning the researchers' prior goals and solicit a belief revision. Especially when a graphical output is unexpected and not corresponding to previous scientific goals, it might bring about further research or action.

Both the models assume that the data-set contains the information useful to produce a meaningful graphic representation. This may not always be the case. Scientific studies based on data-sets make use of graphical representations to better interpret their results. Among these studies, it is possible to find descriptive as well as prescriptive studies. The former aim to describe phenomena as they are, observing, recording, classifying, and comparing them [7]. The latter aim to provide the conditions for how phenomena should be, thus supporting inferences for data interpretation and decision and/or action to perform on data. Of course, a scientific domain could be both descriptive and prescriptive, depending on the scientific goals. The development of new decision-aiding technology should be tailored for both [8], also in the case of graphical representation. The paper is therefore driven by the question on how a model should be to provide a meaningful graphical representation of a data-set to support the inferences and/or the decision a researcher wants to draw, in both the case of descriptive and prescriptive scientific studies.

3 Methodology

The paper aims to discuss the strengths and limitations of existing models for data visualization, by considering and discussing two main case studies coming from publications of different scientific knowledge domains and having different scientific aims. We analyze data-sets which are representative of two different scientific approaches: 1) descriptive and 2) prescriptive studies. In particular we provide a detailed analysis of two case studies: 1) A data-set belongs to the work published by Velasco-Montero [9] in the domain of software metrics, in the wider field of AI. 2) A data-set has been published by Faye et al. [10] and it belongs to the field of human mobility. The analysis can be extended to further case studies in different scientific domains.

3.1 Research Questions and Experimental Hypotheses

The research addresses the following questions:
Q1: Are data-driven models sufficient for a software to help the researchers to automatically create the intended visual form for a data-set?
Q2: In the case the data-driven models are not sufficient, what could be the best way to overcome their limitations?
Q3: Can the existing libraries or programs fit a data-driven model perspective and at the same time overcome their shortcomings?

To answer the research questions, we advanced the following hypotheses:

H1: The data-driven models defined by previous literature support the creation of meaningful graphical representation only for some specific scientific aims, such as the researchers' aims to provide a descriptive data analysis.
H2: For scientific aims going beyond descriptive analysis, the existing data-driven models might not be sufficient. The data-driven models might need to be integrated in a more comprehensive and interdisciplinary data-model to overcome their eventual limitations.
H3: Existing software libraries are data-driven and not sufficient to help researchers to find the intended visual form for prescriptive scientific aims. They need further implementation to allow the users to perform different manipulation on data, such as transformation, accommodation and integration with complementary data, to achieve their intended graphical output.

4 Evaluation of the Case Studies

4.1 Descriptive Scientific Study Case

As to descriptive scientific studies, we considered first of all the case of a study on the performance evaluation of different frameworks in AI [9]. The case study proposes a set of meaningful visual representations of a benchmark data-set for the performance evaluation of different Deep Learning (DL) models and frameworks. The Authors calculated the accuracy and the throughput of five classification problems for the DL models and frameworks. The output data-set was made of a series of two categorical data (the name of the framework and the DL model) and two physical data.

We selected this study for three reasons:

- The work aims to provide a significant graphical representation of the performance metrics of different frameworks;
- The work also aims to extend the graphical representation to other frameworks, to be applied to other works and thus be generalized.
- The study's data-set presents a number of variables and categories, which are not trivial to represent as a whole to obtain a meaningful graphical representation [11].

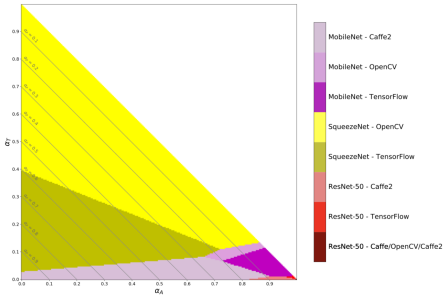


Fig. 1. Optimal network/framework selection according to the accuracy and the throughput [9].

When analyzing the study case, we found that there is a data-driven model, specifically Keim's data-model, that provides us with a significant representation of the data-set, without any accommodation and/or transformation of the data and, more importantly, without any addition of further information by the user. Indeed, by applying Keim's data-model, the data-set is well within multi-dimensional category and so the meaningful graphical representation technique should be a "heat-map graph", where the colour is represented by the categorical data and the two physical data (accuracy and throughput) are represented in a 2D coordinate system. Figure 1 shows the graphical representation chosen by the Authors. Therefore, as to what concerns RQ1, "Do data-driven models support the creation of meangful graphical representation", the answer is positive. As the Keim's data-model is sufficient to have a proper graphical representation, we do not need to cope with RQ2 on how to improve

it for this specific case study. As to what concern RQ3, the existing libraries for producing data visualizations alone cannot give that expected output, even though based on a data-driven model. However, throughout a data-driven model such as the Keim's model and some accommodation of the data, the existing libraries could provide the expected automatic visual representation, starting from the raw data-set. This analysis can be extended to other descriptive case studies in different disciplines (e.g. biology and sociology), where Keim's data-model is sufficient, as well as existing (adjusted) libraries for data visualizations.

4.2 Prescriptive Scientific Study Case

In the case of prescriptive scientific studies we considered an interdisciplinary study on human mobility [10]. The Authors collected the data using smartphones and smartwatches worn by several participants over 2 weeks. Through these devices, they collected three kinds of data: 1) motion sensor data, 2) physiological data, 3) environmental data. For the purposes of this case study, we are interested in the second data-set collecting information about electrocardiographic (ECG) data, such as heart beat and blood pressure. This data-set has the following characteristics: 1) data are multidimensional, as each row of the data set contains both spatial coordinates (longitude and latitude) and physiological data (heart rate, in beats per minute), provided by the optical heart rate sensor of the smartwatch; 2) the row data series consists of over 1 millions of data.

One of the purposes of the research paper was to use physiological data to infer the user's stress and emotion level to identify places within a University campus area that are perceived as dangerous by the majority of participants. We selected this research for the following reasons:

- The research covers different domains: mobile computing, sensing systems, human mobility profiling and cardiology.
- As in the previous case study, the data-set presents a number of variables and categories, which are not trivial to represent in an overall meaningful graphic representation.

If we try to apply the Keim's model to the data-set, the graphic representation will be a "heat-map chart", where the position is represented in a 2D-coordinate system and the heart rate beat is represented by color hue. This type of representation may not be enough meaningful for the aims of the study, when based only on the data-set collected by the devices. Indeed, the data-set is not per se sufficient to have a meaningful representation: the danger zones' classification needs other, additional data, such as the normal resting heart rate range and the dangerous heart rate range, to be properly represented.

Figure 2 shows the graphical representation produced considering the additional data, the normal and dangerous heart rate ranges. These additional data are used to represent the different zones on the map with colors having different opacity (color with opacity 1 for the dangerous zones and transparent color for the zones considered safe).

Therefore, as to what concerns RQ1, the answer is that the data-driven model is not sufficient to give the intended graphic representation. Indeed the authors considered complementary data that are not merely added to the existing categories considered by the data-driven model, but rather organize in a higher-order structure and provide the cues to interpret the data-set to have a meaningful representation of the zones considered dangerous. The complementary data do shape the

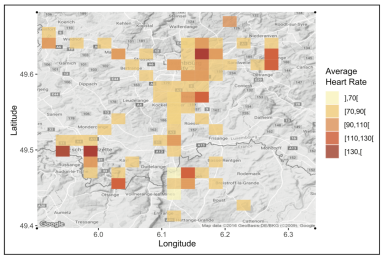


Fig. 2. Places that are perceived as dangerous by the majority of users through the use of colors with different shades.

authors' interpretation of the data-set as they provide
some intervals (the heartbeat rates intervals), as conditions to classify dangerous vs. safety zones. Indeed, the graphical representation 2 can be prescriptively used by experts in urban development for strategic planning to improve safety in public places.

As to RQ2, the solution to overcome the limitations of the data-driven model could be the possibility of inserting further data types into the data-set, relating the average heartbeat rates stored in the original data-set with the heartbeat rates intervals considered normal and dangerous. Furthermore, the data must be re-sampled taking into account the new knowledge, the normal resting heart rate range, coming from a different domain, the cardiology. However, this solution requires specific knowledge from the cardiology domain which may be different from the researchers' knowledge performing the data analysis.

Finally, regarding RQ3, data visualization libraries alone cannot help to obtain the expected output. Indeed, different tasks should be foreseen to achieve the intended outcome through a software, including the data visualization libraries:

- the program should make use of a data-driven model, such as the Keim's model.
- the program should give the user the possibility to add other data type. In the prescriptive case study, the data-type are intervals (conditioning the interpretation of the other data), also coming from a different scientific domain, i.e. cardiology.
- the program should give the researchers the possibility to further categorize the data-set via the additional knowledge. The program must provide the data-set with an higher-order structure to achieve the graphic representation meaningfully corresponding to the authors' scientific aims.
- Once adopting this workflow, the program might use the data visualization library to generate the intended graphic representation.

Other examples of prescriptive studies concern the correlation between air pollution and respiratory illnesses [12]. These research findings are possible thanks to the correlation between data coming from different domains such as prescriptive conditions in health information systems and from descriptive data on particular air pollution electrical sensors. Also in these cases, the prescriptive implications of the findings visualized in Figure 3 can be used to promote a sustainable development program in urban and rural areas.



Fig. 3. Health recommendations using air quality, weather and respiratory medicine data.

5 Proposed Solution

In the field of graphical representation, interdisciplinary models have been proposed to cope with the limitations of both previous data-driven and problem-driven models. For instance, Hall et al. [13] proposed a trans-disciplinary model which allow the experts in a particular domain to be supported by visualization experts. Their work is very interesting as the interaction between experts with skills in different domains could greatly influence the production of meaningful graphical representations to display cues for scientific findings. However, the prescriptive case study examined in this paper cannot be solved through this trans-disciplinary approach. Of course a competence in visualisation is welcome, but cannot per se highlight the conditions of meaningfulness, which come from another scientific domain in the

prescriptive study case. Therefore an interdisciplinary model is needed which integrates knowledge and practice coming from different scientific domains in the process of visualisation. The main elements of the interdisciplinary model we propose can be found in Figure 4.

- The source domain/s is/are the domain/s from which the data are collected.
- The complementary domain/s is/are the domain/s from where to collect the data required to interpret the source domain/s data.
- The blended domain [14] is given by the intersection between the source domain/s and the complementary domain/s, where some new insight could emerge.
- The data model is the model driving the software in the process of data categorization and visualization.

As a solution to the prescriptive case study examined, we propose an interdisciplinary problem-driven approach for the visualisation of data coming from different domains, mobile computing and cardiology, based on Miró data model. For the aims of descriptive studies, the source domain and the data model are usually sufficient to have meaningful graphical representations. The prescriptive case studies instead show the limits of both data-driven and problem-driven model, as there are scientific aims for which it is not sufficient having both the data model and the data coming from a scientific domain to obtain meaningful graphic reports for the research findings.

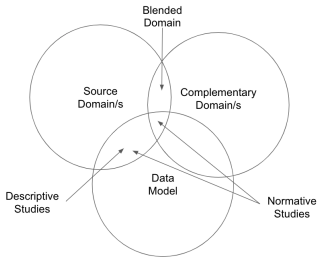


Fig. 4. Interdisciplinary Model

In prescriptive studies, two further processes - not envisaged in previous data-driven and problem-driven models - are needed to have meaningful graphical representations of the source data:

- A selection process: when the data collected by the researchers in the source domain are not sufficient, other specific data selected from a different scientific domain might be needed to interpret the source data. These data might indeed be condition of meaningfulness for data interpretation, and thus for the visual output of the software.
- A transformation process: specific tasks might be needed for the re-interpretation of the data in light of the selected complementary data and the scientific aims of the study. For instance, the source data might need to be re-sampled considering the complementary knowledge.

The scientist's insight needs, therefore, to be entered as complementary data in any software's visual framework, which in turn should make it possible to enter them, interacting with the scientist. In the prescriptive study case, the interdisciplinary approach is driven by the interaction among experts in different domains (mobile computing and cardiology) and guides the production of graphical representations meaningfully representing the areas perceived as dangerous (see Figure 2). However, the insertion of the relevant complementary data might come not only from experts of another domain, but also from online web-based crowd-sourcing selected by the expert users themselves.

This interdisciplinary model might then overcome the limitations of both the data-driven and the problem-drive models, especially if it can automatically propose the complementary data based on the research domain and the scientific aims of the expert. This approach is the framework for Miró, a software intended to be a guide to build meaningful graphical representations for both descriptive and prescriptive studies, based a data-set coming from the source domain/s and on a data model eventually able to provide complementary online data. Differently from softwares

based on previous data-driven and/or problem-driven models, the Miró interdisciplinary model envisages that the user can insert data or select data provided by Miró, coming from complementary domain/s and transform the source data-set to have the intended graphical representation.

6 Conclusion

Although limited in the number of case studies, the paper shows how important it is to distinguish between cases aiming to descriptive vs. prescriptive studies to have a model for a software able to provide meaningful graphical representations of data. In the case of descriptive studies, existing models - data-driven models and/or problem-driven models - might be sufficient to produce meaningful graphical representations when providing the data coming from the source domain/s. In the case of prescriptive studies, the existing models might fail to produce meaningful graphical representations when the collected data coming from the source domain/s are provided. The paper proposed an interdisciplinary approach to overcome the limitations of the existing models via a software-expert interaction. In this framework, the software allows the users to reinterpret and transform the collected source data in the light of the scientific knowledge coming from complementary domain/s. The graphical representation is made meaningful by the blended domain, thus providing a visual support for new findings.

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