Meta Design Studies: A Structured Approach for Deriving Domain-Oriented Visualization Recommendation Strategies

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ABSTRACT

We introduce the concept of a meta design study as a structured approach to extract information from design study papers for the development of generalized tools in specific problem areas or domains. We explore the potential of meta design studies for creating domain-oriented visualization recommendation (VisRec) strategies. To demonstrate this concept, we present RSVP, a system derived from a meta design study conducted on Visual Parameter Space Analysis (VPSA). We outline the individual steps of the meta design study, highlight key concepts of the resulting VisRec strategy, and present a non-obtrusive implementation of this approach in RSVP.

Index Terms: Human-centered computing—Visualization—Visualization theory, concepts, and paradigms; Human-centered computing—Visualization—Visualization systems and tools

1 INTRODUCTION

Visualization Recommendation (VisRec) algorithms frequently embed visualization expertise, yet the origin and authenticity of this expert knowledge often remain ambiguous. It is essential to recognize that preferred visualizations and their practical utility can vary significantly across different domains and problem areas. Consequently, specific domains may require unique sets of visualizations that differ from those used in other domains. Indeed, it is crucial to acknowledge that different user groups may have divergent needs, and these ought to be incorporated directly into the Visualization Design Space as well as the VisRec strategy. By considering these diverse requirements during the design process, a more practical and effective VisRec strategy can be achieved, enhancing the usability and relevance for the intended audience.

We introduce the concept of a *meta design study* and demonstrate its application in developing practical, domain-oriented visualization recommendation strategies.

2 THE THEORY OF META DESIGN STUDIES

A meta design study offers a structured way to derive a visualization recommendation strategy from a literature survey using *axial coding* [2]. Following, we will describe *why* and *how* this is possible.

The conventional framework for design studies [8] follows the steps of the nested model of visualization design [5] in a top-down manner [6]. A visualization researcher is *learning about the domain situation* L1 by collaborating with domain scientists on a specific real-world problem. This joint effort culminates in the abstraction of both data and tasks L2. The visualization expert then uses the gained knowledge to select appropriate *visual encoding idioms* L3 adept at addressing the associated challenges. Finally, the visualization researcher needs to determine or, in some cases, even design *algorithms* L4 capable of presenting the visualizations in a timely and acceptable manner.

From a particular viewpoint, the visualization researcher in this scenario serves as a VisRec oracle [9]. The researcher leverages their knowledge and insights regarding the domain, data, and tasks to transform a wide *Consideration Space* into a narrow *Proposal Space* [8] comprising visualization alternatives. This insight aligns with MacLean et al.'s finding, which states that a complete design space consists of a *Decision Space* (in our context, the available visualization options and their variations) and an *Evaluation Space* (criteria for selecting appropriate options from the Decision Space) [4].

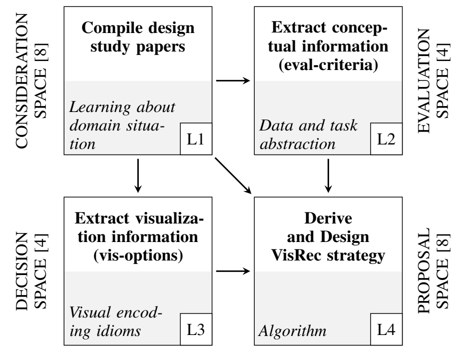

Figure 1: Overview of the individual steps involved in a meta design study.

A meta design study does not involve collaboration with a domain scientist except for evaluation purposes. Furthermore, a system designed in such a way tries to offer solutions for a wide array of real-world challenges instead of a specific problem. The absence of a dedicated visualization expert places the responsibility on the domain scientist to select an appropriate set of visualizations for a given problem. Consequently, the tool itself must fulfill the role of the visualization expert and offer the qualities of a VisRec oracle.

Based on the previous observations, a meta design study provides all the necessary components to formulate a visualization recommendation strategy (see Fig. 1). To begin, the visualization researcher **compiles design study papers** L1 relevant to the investigated problem area. This compilation defines the domain- or problem-specific boundaries of the design space, which we refer to as the *Consideration Space* [8]. Afterward, the researcher **extracts conceptual information** L2 primarily from the problem description and requirement analysis presented in the paper. This will help gain a better understanding of the domain under investigation and the data and tasks involved. The insights obtained regarding the data and tasks can then serve as evaluation criteria for the VisRec strategy, forming what is referred to as the *Evaluation Space* [4]. Next, the researcher proceeds with **extracting visualization information** L3. They analyze the applications described in the paper to identify the visualizations, interactions, and utilized visualization channels. These options and their variations constitute the *Decision Space* [4].

All the information gathered up to this point can now be utilized to **derive and design a VisRec strategy** L 4. The information gets entered into a coding table [1], where the individual applications make up the rows, and the information about the data and tasks (the Evaluation Space) as well as the information about the visualizations and channels utilized (the Decision Space) is represented by columns. This arrangement facilitates filtering based on evaluation criteria, resulting in a selection of applications and their corresponding visualization information that aligns with the specified criteria. The insights obtained from this process can be utilized to formulate practical rules for a VisRec strategy (the *Proposal Space*) [8].

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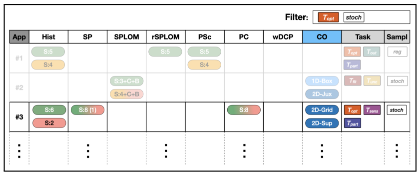

Figure 2: Visually enhanced excerpt of the coding table derived from a VPSA meta design study. White/blue headers represent visualization options, lightgray headers evaluation criteria. Two applications are currently filtered out based on the selected criteria T_{opt} and stoch.

Task	Strategy	MDMV		Complex Object
T_{opt}	Overview	Channel-based	Spatial expressivity	*1D-Line, 2D-Grid*
T_{fit}	Affiliation		Overview + Color	*2D-Jux*
T_{unc}	Attenuation		Overview + Brightness	*1D-Box*
T_{out}	Separation	Mark-based	Point-based (0D-mark)	*(1D-Line)*
T_{sens}	Con-/Divergence		Line-base (1D-mark)	*1D-Hist, 2D-Sup*
T_{part}	Summarization		Area-based (2D-mark)	*2D-Grid*$^{(-)}$

Table 1: High-level overview of the derived rules for the task-oriented part of the VisRec strategy for VPSA applications.

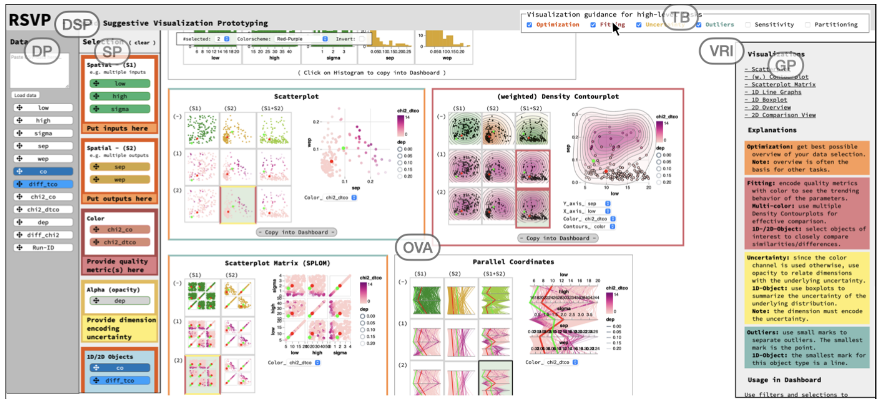

Figure 3: RSVP's overview area (OVA) displays available visualization options for currently encoded dimensions in the data-selection panel (DSP). It utilizes small multiple displays to demonstrate data variations for inputs, outputs, and derived values. The visualization recommendation interface (VRI) consists of the taskbar (TB) for task selection and the guidance panel (GP) for providing context and explanations. Each task is assigned a distinct categorical color. Recommendations are then presented as accordingly (multi-)colored frames around visualizations and channels in (OVA) and (SP) respectively. Currently recommendations for T_{opt}, T_{fit}, T_{unc}, and T_{out} are shown.

3 Practical Example

We conducted a meta design study on the subject of Visual Parameter Space Analysis (VPSA) [7]. We've gathered and examined forty-five design study papers utilizing VPSA strategies L1, establishing the boundaries of the domain-oriented *Consideration Space*.

Our analysis of data and tasks L2 corroborated existing research in this area [7]. The majority of the applications we reviewed involved simultaneous analysis of five to fifteen dimensions. The input-output models were usually sampled using either regular reg or stochastic stoch methods, and typically, only a few hundred samples were produced for the visual analysis. The analytical tasks users commonly tried to solve were Optimization T_{opt} (finding the best parameter settings); Fitting T_{fit} (finding where actual model data occurs); Uncertainty T_{unc} (determining the reliability of the output); Outliers T_{out} (discerning odd or special outputs); Sensitivity T_{sens} (identifying input regions that have low or high impact on the outputs); and Partitioning T_{part} (grouping different types of model behaviour). These findings reprise the *Evaluation Space*.

Analyzing the applications allowed us to discern thirteen different commonly employed visualization options L3, which were comprised of seven *multi-dimensional / multi-variate* and six *complex object* visualizations. Furthermore, visualizations were frequently divided for data representing inputs and direct outputs of the model. We also monitored if outputs were additionally derived. All these elements are essential parts of the *Decision Space*.

We recorded all the information in a coding table (see Fig. 2), following the procedure outlined in Sect. 2. This enabled us to utilize criteria from the Evaluation Space for filtering, allowing us to find applications and the corresponding sets of visualizations meeting the data constraints and supporting the chosen tasks. Using this approach, we were able to derive a rule-based data- and task-oriented VisRec strategy for multi-view recommendations L4. This strategy essentially defines the *Proposal Space*.

The high-level overview is presented in Tab. 1. We observed that the rules exhibited common high-level solving strategies that were independent of the underlying data type. Moreover, the rules derived from the analysis showed a remarkable degree of distinction in terms of the marks and channels employed for different tasks. These rules also adhered to widely accepted visualization guidelines [6], rendering them highly interpretable and easily explainable.

RSVP [3], depicted in Fig. 3, implements this VisRec strategy in a non-obtrusive manner. The system offers users guidance on encoding dimensions for a selected set of tasks and helps them choose appropriate visualizations from the available alternatives. Selected visualizations can be copied into a dashboard that links various views, enabling interactive analysis of the model data. Although the system proposes recommended visualizations for copying into the dashboard, users have the flexibility to override them easily.

4 Conclusion and Future Outlook

We introduced the concept of a meta design study and applied it to derive domain-specific data- and task-oriented VisRec strategies. Further, we presented RSVP, a system that implements a VisRec strategy derived from a meta design study for VPSA problems.

In future research, we aim to expand the application of meta design studies to other domains, further enhancing theoretical and practical foundations. Additionally, we seek to explore the potential of learning decision boundaries for recommendations directly from sparse coding data, reducing or even eliminating manual derivation.

Acknowledgement: Some of the presented contents are currently under submission [3].

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