Revisiting Graspable User Interfaces

A Design Process for Developing User Interface Metaphors

Mandy Keck, Esther Lapczyna, and Rainer Groh

Chair of Media Design, Technische Universität Dresden, 01062 Dresden, Germany
{mandy.keck,esther.lapczyna,rainer.groh}@tu-dresden.de

Abstract. The use of metaphors can support the understanding of novel interfaces approaches and increase the ease of use. But the design of novel holistic and adaptable metaphors is still challenging for interface designers. While most literature provides no systematic instruction for metaphor design or recommend to use a repertoire of known metaphors, we present a method that focuses on the generation of new metaphors based on the analysis and abstraction of everyday objects and the separate analysis of the given problem domain. Several methods of the field of human-computer interaction and traditional design support these analyzes. The methods presented in this paper are suitable especially for graspable user interfaces and illustrated by examples from several workshops.

Keywords: Metaphor design, Interface design method, Rapid prototyping, Operation metaphor, Graspable User Interfaces.

1 Introduction

Dealing with complex, abstract data and novel devices constantly poses new challenges to interface designers. On the one hand, suitable representations for abstract formless data are required. On the other hand, new interaction techniques have to be developed, which meet the requirements of technological innovations and the user's needs. These problems can be addressed by using metaphors. They can wrap abstract data, which initially has no inherent perceptual form, visual representation or shape. Hence, the use of metaphors within the design process can support the user in understanding novel interface approaches. Furthermore, a complex formless data structure can be made graspable by exploiting a known form repertoire and its associated interaction patterns.

However, it is challenging to create and to integrate a suitable metaphor, which fits well to the specific interaction paradigms of new technological innovations and also transfers the given data into a graspable interface for the user. To address these problems, we will present a method to develop holistic metaphors. This method was developed with a strong focus on didactic aspects and was tested in a series of experimental student workshops. We suggest that our approach is especially suitable for developing graspable interfaces, which require manipulation of finite data using hands, body or gestures.

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Therefore, we have a strong focus on experimenting with everyday objects to deduce materiality, form and affordances from everyday objects. Furthermore, this approach encourages the intuitive, transparent and playful interaction with given data objects to bring joy and excitement to the user interface as demanded by [1].

In this paper, we start with a short introduction to traditional approaches of interface metaphors. Next, we explain our method which focuses on the development of Operation Metaphors for graspable interfaces.

2 Metaphors in Interface Design

Lakoff & Johnson establish the terms of source domain and target domain: “The essence of metaphor is understanding and experiencing one kind of thing in terms of another” [2]. Hence, a whole concept and its structural connections will be assigned from a familiar situation (*source domain*) to an unknown problem (*target-domain*).

Although the concept of metaphor originates from the field of linguistics, it became a common approach in user interface design. When applied correctly, user interface metaphors offer numerous advantages [3]. By grounding user interface actions, tasks, and goals in a familiar framework of concepts that are already understood, the metaphor becomes a powerful tool, which can facilitate learning and understanding of complex content, increase ease of memorization and use, and stimulate user’s interest [3], [4], [5]. Designed inappropriately, there is the risk that metaphors can promote misunderstanding, are not recognized by the user or invite assumptions about the target domain that are not valid [3], [5], [6]. To avoid these problems, it is essential to understand and improve strategies for developing user interface metaphors [5].

It is almost impossible to “find the right metaphor” that covers every aspect of functionality of the target domain [6]. The tension between metaphorical representation based on real-world systems and the need to extend computer functionality beyond real-world source domains entails unavoidable mismatches between the source and target domains [5]. Smith addressed this problem and established the terms “literal” and “magic” features. Literal features are defined to be those that are consistent with the metaphor, whereas magic features are defined to be those capabilities that violate the metaphor in order to provide enhanced functionality [7]. Although adding magical features and functions is unavoidable and appropriate as long as expectations set by the metaphor do not mislead the user, similarities (matches) and dissimilarities (mismatches) between the source and target domain play a prominent role in how metaphors work [5].

2.1 Types of User Interfaces Metaphors

There are several different types of metaphors, which can be transferred to the field of interface design. Lakoff & Johnson provide a taxonomy with a strong philosophical and linguistic view [2]. Barr et al. extend this taxonomy especially for user interface metaphors [8]. They distinguish between Orientational, Ontological and Structural Metaphors, which are divided into Process and Element Metaphors.

Table 1. Types of User Interface Metaphors according to Barr et al. [8], Morville & Rosenfeld [9] and Groh et al. [10]

Barr et al.	Morville & Rosenfeld	Groh et al.
Orientational Metaphor		Orientational Metaphor
Structural Metaphor	Organizational Metaphor	
Process Metaphor	Functional Metaphor	Operation Metaphor
Element Metaphor	Visual Metaphor	
Ontological Metaphor		

A similar classification was established by Morville & Rosenfeld [9]. Their classification of metaphors for web sites distinguishes between Organizational, Functional and Visual Metaphors (see Table 1).

Orientational Metaphors can be characterized as metaphors, which provide a concept with a spatial orientation [2]. Such metaphors are strongly based in the users physical and cultural experiences of the world [8]. Structural and Organizational Metaphors are used in a similar way and transfer a familiar organizational structure to a new system's organization. There are similarities in Process Metaphors and Functional Metaphors as well, which create a link between familiar tasks in the traditional environment and tasks in the new environment [9]. Element Metaphors as well as Visual Metaphors can use familiar graphic elements (in case of Element Metaphors also sounds, text, touch and anything else that the user can perceive through the senses) to create a connection to new interface elements, whereas Ontological Metaphors explain concepts in terms of the very basic categories of our existence [2]. Element Metaphors or Visual Metaphors and Ontological Metaphors are not considered in this paper, because we comprehend the user interface metaphor as a complex holistic system of signs and their relations, which can contain single (or atomic) elements like these.

In the context of developing design methods for a metaphoric interface, we distinguish between two different types of metaphors, depending on the aim of the interaction: the Orientational Metaphor and the Operation Metaphor [10].

The Orientational Metaphor supports orientation in immersive, memorable environments. It enriches the dynamic spatial image with spatial and structural patterns. The Operation Metaphor is used for operational forms of interaction. The relation between the user and the digital artifacts is static in nature and thus be called "emersive" in contrast to the immersive experience in dynamic environments. Whereas the Orientational Metaphor is dominated by the visual perception, the Operation Metaphor should provide affordances, which invite manual interaction with the given limited data set in order to make them graspable.

2.2 Design Process for Interfaces Metaphors

Novel devices that exploit new technologies always change the form and meaning of everyday computing. Digital artifacts in interactive systems are flexible, dynamic and intelligent, in contrast to artifacts in a traditional understanding [11]. This shift in thinking requires an integrated view on interactive systems as a whole, which influences the drafting process. The aesthetic or experiential qualities of these artifacts cannot be fully investigated by current user-centered design approaches, because they do not address analytic approaches and functional qualities of interaction [12]. Recent trends in (HCI) design research take this into account and explore the role of aesthetics and materiality. Lim et al. [11] emphasizes that the aesthetics of an interactive artifact cannot be limited to visual appearance. Rather, it is a matter of the holistic experience of usage.

For this purpose, Jung & Stolterman [12] demand a new theoretical and methodological foundation. Their proposal for a form-driven perspective on interaction design introduces a new interaction design research model through the lens of form and materiality. This Material Turn [13] makes hybrid forms possible. Tangible User Interfaces bridge the mental gap between physical and digital material interaction.

The metaphorical mapping is an important foundation for the creation process of interactive artifacts, because novel technologies influence their interaction patterns and visualization. Marcus provides a systematic approach for metaphor design consisting of five stages: (1) Identify items among data and functions that should be targets, (2) Identify source of metaphorical reference (3), Generate many possible metaphors, (4) Identify and evaluate matches and mismatches, (5) Revise metaphors to strengthen effective matches and reduce harmful mismatches [3]. Neale & Carroll offer a similar approach and point out some guidelines for each stage [5]. However, particularly the stage of generating possible metaphors is described insufficiently or bases on the re-use of known metaphors. In contrast, our method presented in section 3 can be used for developing novel interface metaphors, especially Operation Metaphors. The method has a didactical structure and provides a methodological toolbox, which can be used for analysis and abstraction of source and target domain to generate a holistic, subtle metaphor – according to Marcus, who demanded that a metaphor should be subtle, unconscious, or invisible [3]. In the following section, we will introduce our method and describe the different stages to develop an Operation Metaphor.

3 Developing Operation Metaphors

According to Neale & Carroll [5] the generation of possible metaphors is a heuristic and highly creative process, which is difficult to structure. Our approach enables to discover and prepare suitable metaphors. The underlying hypothesis of our process is: Every morphologically limited metaphor is suitable to every limited gestalt (in terms of an unit object with known states).

Fig. 2 illustrates the metaphor design process. The first part is divided into two columns: the left column characterizes the source domain and the right column describes the target domain. Both columns include methods to analyze and abstract the chosen repertoire as well as the given problem and involve methods of different disciplines to provide systematic instructions. The goal of each column is to generate an abstract model, which is ready for a fusion of the form (left column) to the meaning (right column). The Operation metaphor is the result of the metaphorically mapping from shapes (source domain) to states of the finite data (target domain). The resulting holistic approach empowers the user to understand the meaning beyond the original content. Unlike an iconic association, which links reality and image by similarity, the metaphor is characterized by the assignment of informal, shapeless information and a gestalt, which shows various states of the data. Our method creates a generative, synthetic and programmable shape – a technical image [14].

The source domain represents the repertoire of structures with defined shapes. The exploration of this repertoire provides enormous possibilities. However, not all shapes are suitable to be used. A decisive condition is that both source domain and target domain must be prepared in a comparable form – the same level of abstraction.

3.1 Gestalt Analysis

The gestalt analysis (see Fig. 2, left side) explores the richness and the variability of the selected shape. This sensual contention requires training and an analytical perception. University courses for design and architecture students such as the german "Bauhaus Vorkurse" train these skills in a didactical manner. The origin of their visual contention should be formed by the cognition of formal principles [15], [16], [17] at an elementary level. The traditional design theory provides specific methods for the reduction and decomposition of an object or subject. All of these methods teach the competence of visual thinking und use drawing and sketching as tools to narrow the own perception. They offer an experimental access to become familiar with complex problems [18], [19], [20]. Their didactically motivated methods use the analysis as stimulus within the design process. Possible suggestions to explore the geometrical relationship are to reveal regular states, transitions and relations. Furthermore, different views of the object to deduce a grid or an internal order can be studied.

Depending on the complexity of the chosen object, it can be attributed to one or more gestalt categories. They are distinguished by their dimensionality and require specific methods of formal analysis. To explore the variability of the shape, we used a series of experiments as a methodical tool. They reduce dimensions and analyze inherent interaction patterns and affordances. In a first step, we analyzed the structure and the behavior of malleable substances and their potential for manually tangible interaction. In this context, we developed the experimental setup explore Table [21]. This analysis tool allows the exploration of tangible interaction patterns on a planar surface. Two video cameras, which are attached above and underneath a table with an acryl glass plane, capture the user interaction process (see Fig. 1 – liquids and eggs).

Based on these insights, we elicit spatial affordances, by studying the behavior of substances in a spatial context. The initial outcome of this analysis was the DepthTouch system – an interactive tabletop with an elastic display [22] (see Fig. 1, top right and Fig. 4, right). The aim of these experiments is to create environments that address natural human (anthropomorphic) qualities.

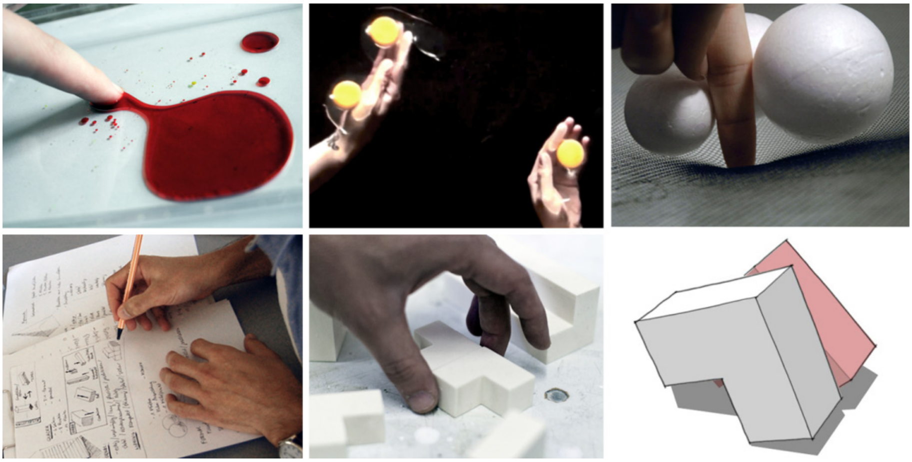

Fig. 1. Examples for gestalt analysis (top): liquids, eggs, fabrics; analysis process (bottom): drafts (left), experimenting with prototypes made of foamcore (middle), exploring different functions in a virtual 3D model (right)

Interaction design for novel interfaces becomes tangible and plastic. To focus this kind of design research, Eschrich et al. introduce a shape-oriented approach to deduce capable, useful interaction mappings from the gestalt analysis [23] (see Fig. 1, below).

It is important to constitute that these experimental studies form the beginning of the method. They sensitize the designer for the broad spectrum of possibilities in order to generate an extensive repertoire. Not all gestalts are equally to be used in an interactive metaphor. Therefore, we established the following criteria to limit the available repertoire by behavior, reversibility, plasticity, granularity, transformability or stability.

Visual Grammar. The gestalt analysis provides a rich repertoire of gestalt characteristics. This unordered result set of the top-down analysis process has to be translated into gestalt patterns and interactive features. A first step to organize the repertoire is a systematical structuring in geometric relations or transitions (evoked by interaction patterns) and material qualities. This categorization can help to fill blank spots in the analysis. This ordered set of graphical elements and their properties – structures and rules of its use – constitute a visual grammar [24].

3.2 Problem Analysis

The target domain is concerned with the problem definition of the design process. The time-dependent multivariate data structures are characterized by different levels of complexity. Naive connections between source and target domain do not support the understanding of the problem domain. The task of the designer is to develop a synthetical image for a problem, which is neither physically nor concrete.

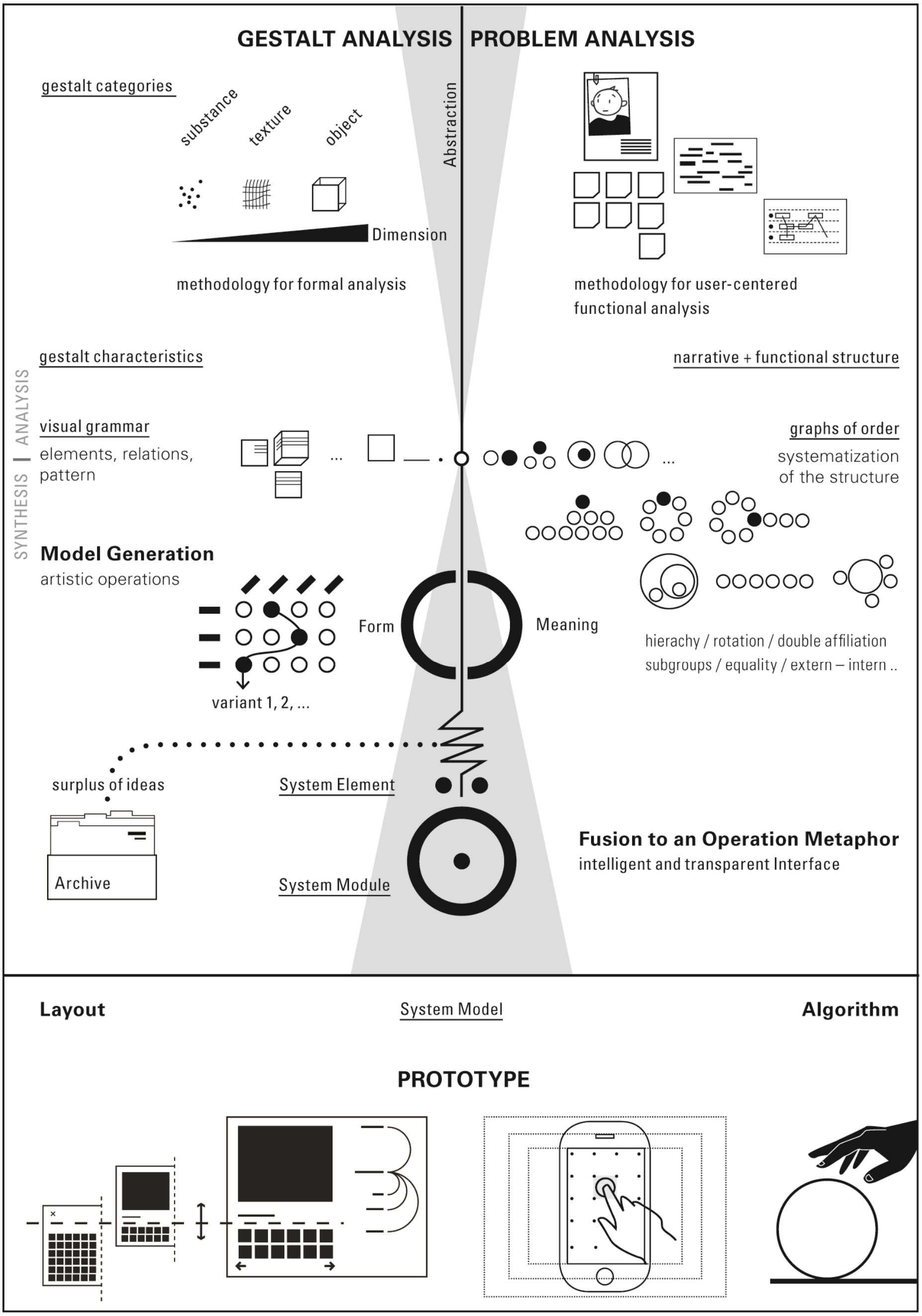

Fig. 2. Method for developing Operation Metaphors

For a successful mapping of the metaphor, the conceptions of source and target domain must be prepared and associated in a similar form. Similar to the gestalt analysis, the source material of the problem has to be analyzed to discover narrative and functional structures. There are different analytical methods that are well known from user-centered design and information architecture [25] such as personas, scenarios and use cases. These methods are not elaborated further in the context of this paper.

Graphs of Order. To transfer this clarification in a comparable degree of abstraction, the results require a visual notation, which creates an order like a pattern language. Graphs of order are such a sign system. The narrative structure of the problem is searched systematically to the following criteria: conditions, proportions, arrangements, figures, directions or typical relations (triangle, symmetry, etc.) Croy [26] and Frutiger [27] make suggestions to record all identified characteristics in a consistent form.

3.3 Model Generation and Fusion

Both data structure and gestalt repertoire were analyzed and abstracted progressively with the visual grammar (source domain) and the graphs of order (target do-main). Based on these elements and their relations or their qualitative and quantitative features of the visual language, the designer synthesizes a conceptual model. The fusion links the model to the graphs of order and creates an Operation Metaphor. This mapping fosters an intelligent and transparent interface that empowers the user to derive an own mental model of the interactive system. The synthesis generates a visual system, which is primarily the result of an elementary variation of the repertoire [28]. The design of interactive artifacts requires a generative design approach, whose elements and design rules are transparent. This holistic thinking is not a new phenomenon. Already progressive thinkers like the protagonists of swiss design in the 60's operated with systematic methods and tools, to derive a systemic relation between elements and the whole [29], [30]. An example for the variety of artificial operations is the morphological box [31] – a heuristic but systematic method, which Gerstner used for his algorithmic problem solutions of design issues [29]. Fig. 3 demonstrates a potential combination of the visual elements and their interactive aspects, but a new combination of several views and states of the gestalt are also possible.

The scheme of the metaphor generation (see Fig. 2) strictly divides between source and target domain. Both sides pose their independent challenges and require different analysis methods. Until both sides are ready to be fused, this separation should be maintained, to avoid rash solutions and ensure the development of universally expandable metaphors. Furthermore, this approach supports a profound and unprejudiced analysis, which generates a large variance. The fusion maps a shape to a set of properties of the data structures. By applying a systemic approach, both system elements become a system module. The whole of these system modules constitutes a system model once the essential graphs of order are linked. Both sides have a dialectic relationship and may have to be varied further.

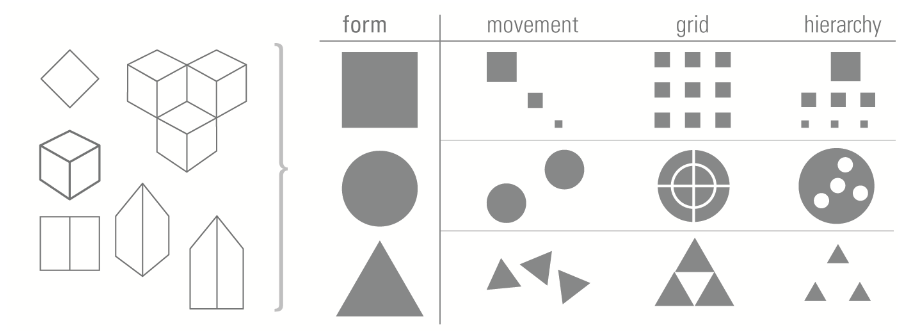

Fig. 3. Model variations (left) and an example for a morphological box (right)

To this end, further suitable experiments with the experimental setup of the gestalt analysis can be helpful. If the fusion between form and meaning is not satisfactory, an iteration loop is possible.

3.4 Prototyping

In the prototyping phase, the generated system model of compatible variants of the gestalt repertoire is developed further into a consistent draft. The goal of this phase is to test and algorithmise different variants and iteratively arrive a final solution by using mockups and prototypes. Until this phase, no technical restrictions are considered to avoid disturbing the creative process. Depending on the chosen technology, various prototyping techniques are suitable. To evaluate different variants, *offline prototypes* such as paper prototypes and mockups made of cardboard or foamcore can be created in a very short period of time. With these low-fidelity prototypes, designers can get a quick idea of a wide variety of different layout and interaction alternatives [32], [33]. In the case of multitouch interaction, we used paper prototypes to map different states of our model to a planar layout. The discovered forms and structures of the previous phases can be arranged into a grid, which structures and encapsulates the states of the interactive system [20]. To ensure that the layout is suitable for direct manipulation, we used different sizes of paper prototypes (in the size of mobile devices, tablets and multitouch monitors) and defined a minimum size for interaction objects of 1 x 1cm (see Fig. 4, left).

With video prototyping, we illustrated how users can interact with the system and get an immediate impression of how various gestures are suited to different devices [34]. Stop motion animations make it relatively easy to create a variety of low-cost special effects e.g. speeding up or reversing time, or give inanimate objects magical properties (e.g. changing the shape of an interaction object when touched) [35].

In contrast, *online prototypes* can be used to give an impression of the final interface in selected scenarios [33]. These high-fidelity prototypes are used to find algorithms for regular forms in the system model and to simulate the behavior of the interaction objects. Moreover, they allow the exploration of haptic and tangible, interactive or multi-sensory qualities [36].

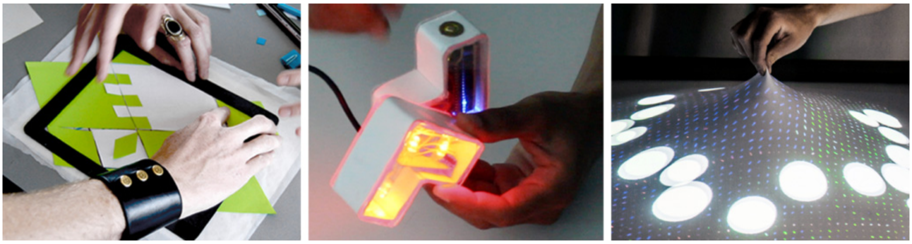

Fig. 4. Paper prototyping for multitouch interfaces (left), online prototypes made of Arduino (middle) and fabrics as flexible projection surface (right)

Fig. 4 shows two online prototypes made of a simple plastic model, sensors and Arduino (middle) or fabrics as flexible projection surface (right) that allow a quick impression of various interaction techniques.

4 Conclusion

The presented method offers a methodological toolbox for developing novel interfaces metaphors. In comparison to the systematic approach of metaphor design provided by Marcus [3] or Neale and Carroll [5], it focuses on the stage of generating new metaphors and merge several interdisciplinary methods of the field of human-computer interaction and traditional design. The method separates the metaphor generation process into two subproblems: the analysis and abstraction of the source domain and the target domain. Both sides can be processed by two different designers. When used for teaching, we suggest to start with the analysis of the source domain to avoid restrictions and rash solutions conveyed by the given problem.

While the methods to identify problems and requirements on the side of the target domain are well described in the literature, we focus on the analysis and abstraction of the source domain and provide several instructions as well as experimental setups. We emphasize that it is important to arrive at the same level of abstraction on both sides in order to create an adaptable, subtle metaphor. The provided method is well-suited for Operation Metaphors because the experimental setup supports the finding of affordances that invite manual interaction with the data set. An extension of the methodological toolbox for the orientation metaphor is part of future work and requires different methods for the analysis of the source domain and additional experiments.

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