

Conceptual Metaphor Theory as a Foundation for Communicative Visualization Design

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ABSTRACT

Interest in communicative visualization has been growing in recent years. However, despite this growth, a solid theoretical foundation has not been established. In this paper I examine the role that conceptual metaphor theory may contribute to such a foundation. I present a brief background on conceptual metaphor theory, including a discussion on image schemas, conceptual metaphors, and embodied cognition. I speculate on the role of conceptual metaphor for explaining and (re)designing communicative visualizations by providing and discussing a small set of examples as anecdotal evidence of the possible value of conceptual metaphor. Finally, I discuss implications of conceptual metaphor theory for communicative visualization design and present some ideas for future research on this topic.

Keywords: Information visualization; image schema; conceptual metaphor; embodied cognition; communication; design.

Index Terms: Human-centered computing—Visualization

1 INTRODUCTION

Visualization for communication has been growing in interest in recent years [1]–[4]. As opposed to visualization for analysis—in which users are often specialists, their goals and tasks are known to designers, and important metrics are performance-related—visualization for communication is often aimed at a wide audience, where users are not necessarily known to designers, are not specialists, may not have wide visualization literacy, and may not have performance-related goals. Thus, designers of communicative visualizations require theories, concepts, and frameworks that help them design appropriate visualizations with communicative intents in mind. However, many of the extant supports for visualization designers were created with analysis—not communication—as the primary focus [3].

One strategy for dealing with such a broad user base is to leverage features of the human perceptual and cognitive systems so that interpretation can be reasonably “intuitive”, not needing to rely on specialist knowledge or in-depth training. While many studies have identified such perceptual features and articulated them in ways that are useful for visualization design, not as many have done so for cognitive features [5]–[9]. Furthermore, most literature on cognition in InfoVis has focused on low-level cognitive processes, rather than on high-level cognitive processes and structures (e.g., mental models, conceptual metaphors, and abstract reasoning) [6], [7], [10]. Because communicative visualizations are used by non-specialists [11]–[13] for more than simple and quick perceptual judgments [14]–[16], it is important to have an understanding of how information can be effectively communicated visually to

general users. This understanding should be based, at least partially, on the high-level cognitive processes and structures with which average users interpret and make sense of visualizations.

Designing and interpreting visualizations both require thinking about abstract information. Designers have to think about mapping abstract data onto visual forms, and users have to think about interpreting the syntax and semantics of how abstract data has been mapped onto visual forms [4], [17]–[20]. When looking to research in cognitive science for a foundation that is suitable for broad audiences, one line of research that is especially relevant is conceptual metaphor theory [21]–[23]. Insights from multiple decades of research suggest that all abstract thought is fundamentally grounded in bodily experience and is enabled via conceptual metaphor [24]. If this claim is true, at least some aspects of visualization design and interpretation—i.e., those pertaining to abstract thinking—must also be grounded in conceptual metaphor. Little extant research has investigated the potentially significant connections between conceptual metaphor and abstract thinking in InfoVis. In this paper, I explore the role that conceptual metaphor theory can serve for communicative visualization design. I suggest that conceptual metaphor can in fact be foundational, as all people rely on conceptual metaphors for abstract reasoning. Thus, communicative visualizations can be designed to leverage basic features of the human conceptual system, potentially making visualizations more “intuitive”, memorable, and learnable.

In section 2, I present a brief background on conceptual metaphor theory, including a discussion on image schemas, conceptual metaphors, and embodied cognition. In section 3, I discuss related work within the InfoVis and HCI literature. In section 4, I speculate on the role of conceptual metaphor for explaining and (re)designing communicative visualizations, and provide a small set of examples as anecdotal evidence of the possible value of conceptual metaphor. Finally, in section 5, I discuss implications for communicative visualization going forward, and present ideas for future work.

2 CONCEPTUAL METAPHOR THEORY

Until the past few decades, the common understanding of metaphor in linguistics and cognitive science was that it was merely a linguistic device, and was of no fundamental significance for cognition in general. Recent research, however, has suggested another view of metaphor: it is a fundamental aspect of thinking, serving as the foundation of all abstract thought [21]. This idea was initially promoted most famously by Lakoff and Johnson with their book *Metaphors We Live By* [23]. Lakoff and Johnson aimed to provide systematic evidence that metaphor was not just a linguistic device, but was rather a fundamental aspect of thought. Furthermore, they argued that metaphors work because they are based on recurring patterns of embodied experience. They claimed that metaphors are shaped by the nature of our brains, bodies, and environments. Metaphors operate by “recruiting” patterns of sensory-motor experience for abstract conceptualization and reasoning [24].

Lakoff and Johnson referred to these recurring patterns of bodily experience as “image schemas” [21], [22]. The basic idea of an image schema is that through experience people become

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familiar with patterns such as up-down, left-right, front-back, containment, balance, center-periphery, and others that recur in our physical bodies and environments. The neural structures responsible for these patterns end up being leveraged by structures used for abstract thinking, allowing for the logic of the source domain to be transferred to the target domain. For instance, the fact that we routinely experience *balance* or *lack of balance* gives rise to a BALANCE schema (the small caps convention will be used when referring to image schemas and conceptual metaphors) which gets recruited and metaphorically mapped onto abstract domains relating to political fairness, mathematical equations, and justice [21].

A conceptual metaphor is thus a mapping from a sensory-motor source domain to an abstract domain. For instance, consider the conceptual metaphors MORE IS UP and LESS IS DOWN. Examples of these can be seen in expressions such as: “speak *up* so I can hear you”, “the company’s stock went *up* this quarter”, “jobs have gone *down* in our state”, and “the temperature is going *down* tonight”. Here the source domain is vertical location (physical) and the target domain is quantity (abstract). Another example is the THINKING IS PERCEIVING metaphor. Examples include “I *see* what you mean”, “your argument is *murky*”, and “I was *left in the dark* about that issue.” Here the source domain is bodily perception (physical) and the target domain is thinking (abstract).

One advantageous feature of conceptual metaphors for abstract reasoning is that knowledge of a source domain can be used to reason about a target domain. Because the source domain is structured via image schemas, there is a pattern of embodied experience available for abstract reasoning. For instance, consider the THINKING IS PERCEIVING metaphor; embodied experience tells us the following: we need light to see; opaque objects can block our vision; it is difficult to navigate in the dark; and so on. If we are told “she had *blinders* on” or “they *stumbled around* the issue until the professor *shed more light* on it”, we know how to interpret the metaphors because we experientially understand the logic of the source domain. Thus, via a cross-domain mapping, the logic of the image schema can be used to think within the target domain.

Considerable research has been done since the introduction of conceptual metaphor theory, and many studies have validated the embodied nature of abstract reasoning via metaphor [25]–[27]. It is worth noting that there are debates among cognitive scientists about image schemas being the foundation of abstract reasoning [28], with certain scholars doubting the value of conceptual metaphor theory as an explanatory construct (e.g., [29]). However, these debates are not relevant for the current discussion, as explanatory models of cognition *per se* are not the focus. Conceptual metaphor theory has received enough validation as a descriptive construct that it is likely to be a valuable lens for discussing abstract thinking in the design and interpretation of visualizations. Although there is a lack of research on this topic, some speculation on possible roles of conceptual metaphors for communicative visualization will be presented in section 4.

3 RELATED WORK

Within the HCI literature, plenty of work has examined the role of general metaphor in interface design (e.g., [17], [30]–[33]). Many such works examine the role of metaphor in helping users understand unfamiliar features by way of familiar ones—a commonly held view on the role of metaphor in HCI. Familiar examples are those intended to help users understand features of operating systems via *desktop*, *folder*, and *trash can* metaphors. Although the role of metaphor in the success of modern interfaces has likely been over stated [34], it is still likely that metaphor has

played an important role. Most of this work has engaged with the general idea of metaphor, with which most people are familiar, and not specifically with conceptual metaphor theory—which, as described above, challenges traditional assumptions about the nature of metaphor. The small set of HCI literature that has engaged with conceptual metaphors (e.g., [34], [35]), however, has not focused on visualization design.

Notably, while some authors have discussed image schema and conceptual metaphor in areas tangentially related to InfoVis—e.g., timelines in cognitive semiotics [36], newspaper cartoons [37], and action comics [38], none of these studies provides general guidance for designing or evaluating information visualizations. Notably, Tversky [39], [40] has discussed the role of metaphor in visualization design, particularly how physical space is used metaphorically to convey meaning. However, she similarly has not attempted to provide actionable insights or comprehensive forms of design support for visualization design.

Within the InfoVis literature, very little research has engaged with conceptual metaphor theory. Some scholars have discussed image schema very briefly or have mentioned it in passing (e.g., while discussing treemaps [41] or legend design for maps [42]). Others have touched on image schema in an InfoVis context, yet in a way that is not related to InfoVis design or interpretation—e.g., for linguistic analysis [43]. Cox [44] has provided a brief overview of conceptual metaphors and discussed the role of visual metaphor in visualization, broadly construed. However, she has not attempted to provide design suggestions for InfoVis based on conceptual metaphor theory. Andreou [45] has provided a brief investigation of some conceptual metaphors used in InfoVis, also without providing any clear support for design. The most substantial investigation was probably undertaken by Risch, in an apparently unpublished paper [46]. Risch examined various image schemas, and discussed their potential roles in interpreting bar charts, Venn diagrams, node-link diagrams, and hierarchical visualizations. However, no systematic follow-up work has been done since the paper was written.

Engelhardt [19] has discussed the role of image schemas in a few different object-to-object relations in the context of general graphical representations, but has not given much detail beyond a few brief comments. Hiniker et al. [47] have investigated the role of conceptual metaphors in designing one particular visualization system, and examined image schemas relevant for their system, but did not make an attempt to generalize beyond their specific concerns. Finally, similar to the HCI work mentioned above, researchers have examined the role of metaphor in InfoVis (e.g., [48], [49]) and diagrams more generally [20], without investigating the cognitive and embodied basis of the metaphors—i.e., the role of image schema or conceptual metaphor.

4 ROLE IN COMMUNICATIVE VISUALIZATION

If Johnson’s [24] claim is true that all abstract thought is possible because of image schemas, it stands to reason that any activity involving thinking about abstract information could benefit from an understanding of image schemas and conceptual metaphor. Communicative visualization certainly involves thinking about abstract information in at least two broadly related—yet somewhat distinct—ways: (1) abstract reasoning while *designing* visualizations, and (2) abstract reasoning while *interpreting* visualizations. Thus, conceptual metaphor theory may be useful for understanding *both how designers think and how users think* in the context of communicative visualization. In the subsection below, I provide some examples to demonstrate how conceptual metaphor theory can support these two activities.

4.1 Examples

In what follows, I provide examples of how conceptual metaphor theory can help to explain how people interpret visualizations, and also how designers can think about designing and re-designing visualizations.

4.1.1 Explanatory role of conceptual metaphor

Risch [46] has discussed the role of image schema in the orientation of bar charts. Figure 1 shows two bar charts that are identical except for their vertical orientation—i.e., in the one on the left, quantity increases from bottom to top, whereas quantity increases from top to bottom in the one on the right. Risch suggests that an increase in quantity corresponding to an increase in height is natural, since it leverages the MORE IS UP schema that is so prevalent in our embodied experience. The MORE IS DOWN schema is not prevalent, and thus does not seem “right” when we see it. If this account is correct, embodied cognition may provide explanations to why certain visualizations seem “intuitive”, why we just appear to prefer certain conventions over others, and possibly why seemingly arbitrary differences may lead to qualitative or quantitative differences in the communicative quality of visualizations.

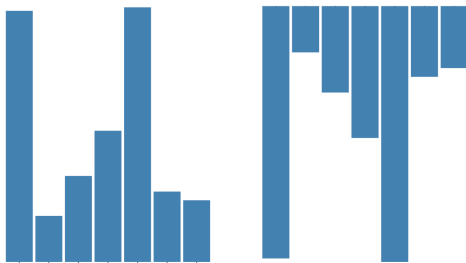


Figure 1. Two bar charts that are identical except for their vertical orientation. On left, quantity increases from bottom to top; on right, quantity increases from top to bottom.

In one of the few instances of image schema being discussed in InfoVis literature, Meirelles [41] posits that the treemap visualization technique exploits two image schemas, namely the CONTAINER and PART-WHOLE schemas. The conceptual metaphors that arise from these two image schemas are CATEGORIES ARE CONTAINERS and, by extension, SUB-CATEGORIES ARE CONTAINED WITHIN SUPER-CATEGORIES. Our experience of containment and its properties (e.g., in/out, boundedness) is one of the most pervasive features of our embodied experience; thus we recruit it easily and unconsciously for abstract reasoning [24]. Consider the treemap in Figure 2; here, Shakespeare’s writings are categorized into comedies, tragedies, and histories. Once the simple syntax and semantics of the treemap are understood, reasoning abstractly about the content works well because the logic of the source domain (physical containers) is appropriated for use in the target domain (categories of Shakespeare’s writings). The spatial relations of physical containers provide the means by which abstract categories can be conceptualized and used in reasoning. Table 1 lists 3 ways in which the logic of physical containers is transferred to the target domain for reasoning about Shakespeare’s writings.

Table 1. Examples of the logic being transferred from source to target domain for reasoning with a treemap visualization.

Source	Target
containers are bounded	categories are bounded
regions in space with interiors and exteriors	regions in space with interiors and exteriors
objects are either inside or outside of a container	writings are either inside or outside of a category
one bounded region can be physically within another	one category can be a subcategory of a larger one

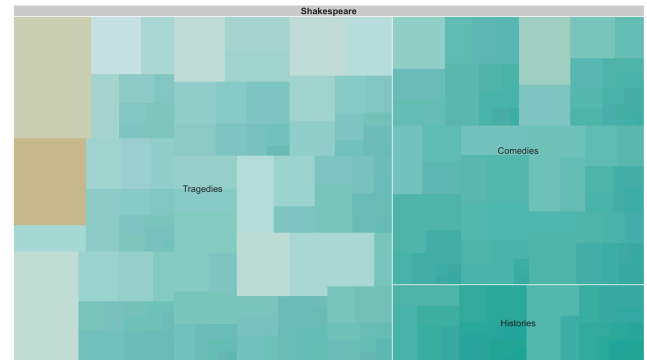


Figure 2. A treemap visualizing Shakespeare’s writings can be explained by its use of image schemas. Treemap from <https://developers.google.com/chart/interactive/docs/gallery/treemap>

While the treemap visualizes mutually exclusive categories, we can also see how conceptual metaphors can be used to explain the interpretability of visualizations such as the Venn diagram in Figure 3. Here the CONTAINER and PART-WHOLE schemas are also used, but the visual mapping is changed so that members of a category can be within multiple categories simultaneously. The same image-schematic logic of containment is used for reasoning about membership, intersection, and so on. Lakoff and Núñez [50] have argued that the logic of sets—and, in fact, all mathematics—is made possible by conceptual metaphors and images schemas rooted in bodily experience.

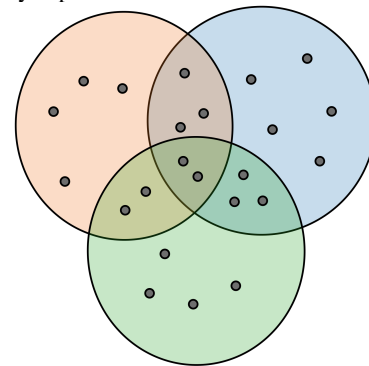


Figure 3. Reasoning with a Venn diagram can be explained using the logic of containment from embodied experience as it gets appropriated for abstract thinking.

Risch [46] has speculated that all visualizations are rooted in conceptual metaphor. Although no systematic research has investigated this idea, it appears valid, at least anecdotally. As another example, consider the Sankey diagram in Figure 4. Sankey diagrams are often used to show flow, branching, and proportion of

information. It is plausible that people enjoy this type of visualization technique due its use of the SOURCE-PATH-GOAL schema. The pattern of something moving along a path from a source to a goal is highly prevalent in our bodily experience throughout our lives. We thus naturally and unconsciously appropriate this recurring pattern for abstract reasoning. The metaphor here is that CONCEPTS ARE OBJECTS (e.g., energy, friction) and ENERGY USE IS MOVEMENT ALONG A PATH. In this particular Sankey diagram there is a source (E_{in}), there are multiple paths that the energy can take, and there are multiple goals (end points) to which the energy can “flow”. Note that energy does not really move along a path in this way, yet the conceptual metaphor is useful for reasoning about the information. Such is the nature of conceptual metaphor—when the metaphor relies on an appropriate image schema, interpreting relationships in the target domain is a tractable exercise due to the deeply understood logic of the source domain.

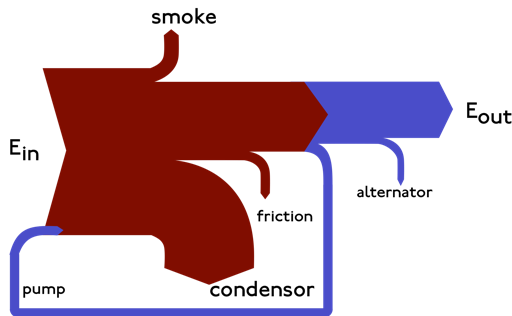


Figure 4. A Sankey diagram is interpreted using the SOURCE-PATH-GOAL image schema. Image from https://en.wikipedia.org/wiki/Sankey_diagram#/media/File:Sankeysteam.png

4.1.2 Role of conceptual metaphor in (re)design of communicative visualizations

Aside from its role in explaining why visualizations can be interpreted, conceptual metaphor theory can aid in the design of new visualizations and the redesign of existing ones. Consider the visualization in Figure 5, which is used by the ACM digital library [51] to show citation networks of papers and patents. The network visualization is showing a particular publication (encoded in the center as a green dot) and other articles related to it. In this case, the node's color is encoding the type of connection and its temporal relation to the target publication—red for publications before and dark blue for publications after. Although the network being visualized is fairly simple, it is not so easy to reason about the temporal relationships within the network. One explanation is that the visualization is not leveraging an appropriate conceptual metaphor regarding the nature of time. As a visualization designer, having access to a catalog of conceptual metaphors may provide inspiration for redesigning this visualization. By consulting such a catalog, the designer may realize that the conceptual metaphors TIME IS SPACE and EVENTS ARE OBJECTS are highly pervasive and fundamental to the ways in which we reason about time. In the visualization in Figure 5, events (publications dates) are encoded as objects, but time is not encoded spatially—rather, it is encoded only by color, with space having no temporal significance. Thus, the visualization could be redesigned to organize temporal events spatially—e.g., using a timeline where objects to the left of the target publication are temporally prior, and objects to the right are temporally subsequent. The redesign would likely be interpreted more easily, as it leverages a fundamental conceptual metaphor that all people use to reason abstractly about time.

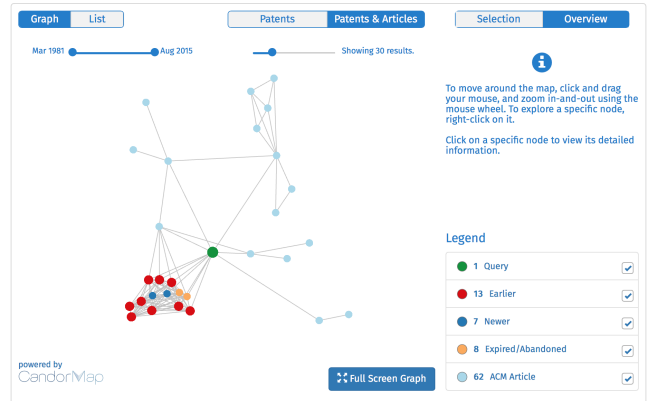


Figure 5. Visualization of a citation network that could be improved by using appropriate conceptual metaphors regarding time.

While this is a simple example, Figure 6 shows a less obvious one. The visualization communicates the breakdown of a book into various sections and conveys possible strategies for reading it. The visualization consists of a main circle with internal circles that encode the different chapters and sections of the book. Two types of relationships are encoded: (1) what chapters and sections refer to each other, using dashed arrows; and (2) the sequential order in which the first two introductory chapters and sections should be read, using two different arrows—one for novice readers and the other for experts. While there are many ways to communicate this kind of information, this particular visualization makes use of the following schemas: CONTAINMENT, LINK, PART-WHOLE, and SOURCE-PATH-GOAL. Sections of the book are contained within others using physical boundaries; some sections are “connected” to others using links; and reading the book is like taking different “paths” to achieve a certain goal. In this case, the same SOURCE-PATH-GOAL schema that helps explain the Sankey diagram in Figure 4 is used by the designer to generate a novel visualization that communicates different ways to read a book. In this case, the “source” is the starting point of reading; the “path” is the order in which pages in the book are read and skipped; and the “goal” is the stopping point of reading for the two introductory chapters.

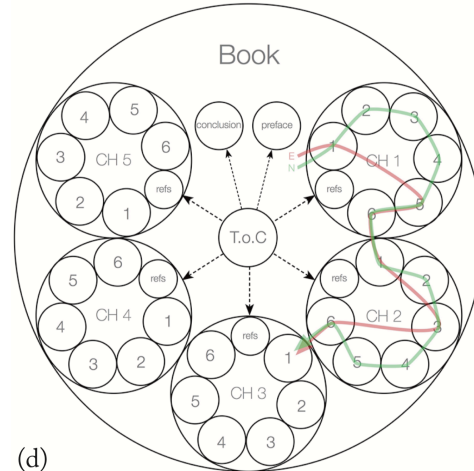


Figure 6. A novel visualization that communicates the structure of a book, and two possible ways to read the first two introductory chapters, using various conceptual metaphors. From Sedig and Parsons [18], adapted from Illinsky [52]

The two examples presented in this section, while anecdotal and only briefly discussed, provide evidence for the possible role of

conceptual metaphor theory in designing or redesigning communicative visualizations. With respect to Figure 6, while the thinking of the original designer is not available to us for analysis, it is plausible the stated image schemas were used (either consciously or unconsciously) while designing the visualization. If visualization designers had access to a catalog of conceptual metaphors that could be leveraged for visual communication, conceptual metaphor theory could be foregrounded to a more visible role in supporting visualization design. Although the development of such a catalog involves a considerable research undertaking far beyond the scope of this paper, one example can be briefly explored here.

Consider a situation in which a designer wants to create a visualization to communicate a particular message regarding taxation data. Taxation is an abstract concept that necessarily relies on various image schemas to be conceptualized and used in reasoning and communication. Established conceptual metaphors for taxation include TAXATION IS A BURDEN, TAXATION IS A FORCE, TAXATION IS INVESTMENT, TAXATION IS PUNISHMENT, and TAXATION IS AN IMPEDIMENT TO MOTION [53]. These metaphors are not all in agreement with one another, and they have different entailments that invoke different conceptual networks. The use of one metaphor over another thus has the ability to significantly frame the communication of the relevant data, influencing how the data is interpreted by users. Although it is not clear at this point how these metaphors can be best translated into visual forms, it is likely that various types of visual embellishments to existing visualization techniques can invoke these metaphors, as could the development of novel visualization techniques. Depending on the message that a designer wishes to communicate, a particular metaphor and its attendant visual forms could be selected from a catalog and employed. Proper framing of information is critical to successful communication in general [22], [24], and it is reasonable to expect that this is also the case for communicative visualization. Without an understanding of the role of embodiment and conceptual metaphor in abstract thinking, it is unlikely that visualization designers can frame information in ways that are most advantageous to their communicative goals.

5 DISCUSSION AND FUTURE WORK

The claim presented here was that conceptual metaphor theory can serve as a foundational theory for communicative visualization design. I have presented anecdotal evidence to suggest that this is plausible. However, at this point, there is not enough research to determine exactly what role conceptual metaphor theory can play in designing and evaluating visualizations.

Future work needs to examine both (1) how designers use conceptual metaphors when they are thinking about communicating abstract information via visualizations; and (2) how users invoke conceptual metaphors when interpreting and making sense of visualizations in communicative contexts. Studies should be conducted to determine which image schemas and conceptual metaphors are relevant for communicative visualization, and the types of information and contexts for which they are most relevant. Studies should also investigate how users interpret various types of visualizations that use different conceptual metaphors for the same types of information. Such studies can lead to the development of design supports (e.g., heuristics, frameworks, catalogs) that designers can use as inspiration and for principled guidance in design situations.

Although the intersection of conceptual metaphor theory and visualization is relatively underexplored, it poses significant potential for both research and practice in communicative

visualization, and is likely worthy of subsequent investigation, especially as visualization for communication grows in interest in the coming years.

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