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Research Paper

Machine Learning Analysis for Metaphors Related User Interface Elements

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Abstract

The user interface is a systematic representation of various controls and components. These controls are referred to as Metaphors in human-computer interaction. After software development, the functionality of software is improved by various updates. However, the software interface is improved by usability engineering. Metaphors play an important role in software accessibility. There is a wide range of user feedback in the form of textual comments over websites, blogs, and forums. In this study, we have performed short text analysis over these user comments. The text extraction is made by labeling text with keywords. After getting keywords, we have applied clustering to collect the clusters representing a specific Metaphor with a unique cluster. These clusters are also verified in search engines. Then we have compared Metaphors of smart devices with the general UI of personal computers. The mechanism presented serves as the short text analysis-based user interface analysis. The SOM graphs are explained to highlight the better visualization of Metaphors in two major computing devices as mentioned above. Clustering grouped the UI elements into six metaphor themes, and the shopping-cart metaphor reached 86% classification accuracy, showing that user comments can guide designers in choosing metaphors for both PCs and smartphones.

1. Introduction

The design of a user interface affects business results, not only usability. When an interface is well organised, users are more satisfied and more likely to keep using the product, so retention goes up. In a crowded market, the interface can also be what sets one product apart from its competitors, and a clear design cuts the cost of user support and training. UI design is therefore a demanding part of building software, with a direct effect on usability, accessibility and appearance. Developers who give it proper attention end up with products that are easier and more pleasant to use for a wide range of people, which helps both user satisfaction and business success.

Metaphors matter in UI design because they give users a familiar reference point as they move through a digital interface. The best-known case is the "desktop" in operating systems, which turns a physical workspace into a digital one. Most people understand straight away a desktop that holds files, folders and a bin, because it resembles tidying a real desk at the end of the day. Because of this

familiarity, users can work out how an operating system is laid out and how its functions work without days or weeks of training, which would be needed if the interface used a completely new vocabulary. The desktop metaphor has lasted for decades across many operating systems and platforms, which shows how well it works (Aza-Espinosa et al., 2023).

Interface metaphors draw on reasoning by analogy, which is why users can learn a new interface and get used to it faster. Cognitive processes rely heavily on analogical thinking (Bartholomeu et al., 2016). To identify patterns and their connections, analogies serve as a mapping between domains. One can create intricate patterns based on one's own feelings and experiences by using analogies. They serve as the cornerstone of mental models that facilitate mental simulation and situational prediction. Analogical reasoning serves as a basis for contextualizing cues in the context of data analytics and utilizing them for proper memory and inferences throughout the analytics process (Baruque et al., 2007). User-interface metaphors leverage the vast cognitive capacities that analogy supports by utilizing analogical reasoning. Successful user-interface metaphors give the impression that they are invisible to the user, resulting in a simple, intuitive user interface (Baruque et al., 2007). Neale and Carroll (1997) noted that a metaphor lowers learning effort only when its mapping to the interface is clear, while Blackwell (2006) questions how far metaphors help users in practice.

The desktop metaphor a powerful means of understanding information environments in personal-computing's younger years now has less salience as devices haven practical and primarily "cloud-based" functions become more mobile. As such, the idea of a single "desktop" is becoming increasingly irrelevant users log in to files and applications from multiple devices and locations (Aza-Espinosa et al., 2023).

UI design has many metaphors that make its usage easier. For example, the "shopping cart" icon in e-commerce sites is symbolic of the real-life act of putting objects into a shopping trolley at a store. In a web page, on the other hand, it is like the home button and metaphorically means to go back or return to its ready-made positions. Metaphors such as these are buried so deep within the design of digital products that users hardly give them a second thought, or even awareness of the cognitive processes behind their engagement (Flórez Marulanda et al., 2023).

For email, a designer might use a mailbox icon to represent email this is an intuitive metaphor for many western cultures but the same may not be true of your whole user base. Thus, designers need to consider the cultural context of their interfaces so that either whatever metaphor they use is understood by anyone on earth or someone can adapt it easily for different cultures (Pokorni & S. J. 2021).

Poor metaphorical design is likely to result in an inconsistent user experience, as users may have difficulty associating elements of the interface with one another. For instance, if an interface is based on a "folder" metaphor to organize files there but then it uses besides a different way around using tags system people may feel that they have difficulties navigating at the two very separated places and documented in his/her mind (Guevara-Vega, et al., 2020).

Usability testing can show problems with a metaphor that the designer did not see during the ideation stage, and the results can then be used to refine or correct it. Repeating this cycle of testing and changing the design helps make sure the final interface is accessible as well as easy to use and understand (Jácome Ortega et al., 2020).

Designers who follow established patterns can better predict what users will do, and the result is an interface that is easier to understand and asks less mental effort from the user. However, different users have different schemas, so designers need to be aware that what one person might think of as a metaphor might not necessarily appear that way to someone with a different cultural or experiential background (Karlgren et al., 2020).

When metaphorical UI design is applied to cognitive science, designers can anticipate what users think about where a user will go and ensure that their interfaces will function flawlessly over time. As the technology grows and evolves, use of these cognitive theories will be crucial to ensuring that UI metaphors remain powerful means for UX improvement in this digital age (Jácome Ortega et al., 2019).

Apart from clustering, SOMs are also useful for dimensionality reduction in the task of reducing number of variables to consider and information contained within. It is very important when working with high-dimensional data that may be hard to visualize or interpret by it. Once the number of dimensions is reduced, the structure of complex data becomes much easier to study (Stergiou et al., 2019).

SOMs are also used for anomaly detection. When most data points follow one pattern and a few points are very different from it, a SOM can help find those unusual points. In fields such as network security this is important, since threats often show up as deviations from expected behaviour (Weidman & S. 2019).

SOMs can also be combined with other machine learning techniques in hybrid models to improve performance. They do, however, have drawbacks. When using SOMs, the main challenges are the parameters (map size, learning rate, and neighborhood function). The values chosen for these parameters strongly affect how good the resulting map is, and suitable settings are usually found by trial and error. However, SOMs can also have trouble when it comes to highly dimensional data or complex non-linear relationships in the input that cannot be projected easily within a low dimensional map (Franzoni et al., 2018).

Self-Organizing Maps are, therefore, a powerful and widely used unsupervised learning technique for clustering, dimensionality reduction, model interpretation or visualization of multivariate data. As digital interfaces have become more complex, researchers in Human-Computer Interaction and software engineering have started looking for ways to study UI metaphors automatically (Franzoni et al., 2018). Recent machine learning work in HCI, such as the Rico dataset of mobile interfaces (Deka et al., 2017) and automatic captioning of UI elements (Li et al., 2020), shows that UI design can be analysed at scale.

2. Material and Methods

We performed the research in a systematic manner, as is depicted by standard data collection, preprocessing and evaluation at all stages of SOM model implementation. We carried out each step carefully so that the results would be reliable and would answer our research aims.

2.1 Data Collection

First, we collected data on UI elements and the metaphors linked to them. The dataset covers UI components from different kinds of applications: desktop software, mobile apps and web interfaces. It was gathered from open-source UI design repositories, academic papers and industry reports, and contains image-based UI elements such as icons, buttons, sliders and menus, each linked to an abstract concept. For every element, the annotations record a description, its metaphorical

relationship and any contextual factor that could change how it is interpreted. Finally, UI design experts confirmed that metaphorical connections were correctly interpreted and relevant for each of the targeted user populations validated the dataset. Only elements with a clear real-world reference that appeared in desktop, mobile or web interfaces were selected, while duplicate and purely decorative elements were excluded.

2.2 Data Preprocessing

After data collection, pre-processing is first stage in which the dataset in order to set it for use with methods and models. The preprocessing included following main stages. Comments were converted to lower case, tokenized, and cleared of stop words, symbols and duplicate entries before keywords were extracted and encoded.

2.3 Noise Removal and Blank Data

The special symbols and the meaningless text are removed by text token recognition. The process of detecting meaning lines and words is possible by various text analysis libraries available in NLTK of Python language.

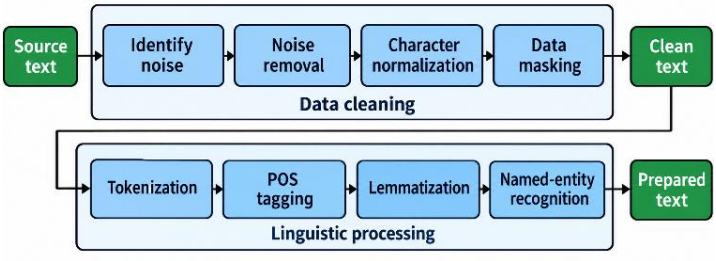


Figure 3 Noise Removal in Text

2.4 Short Text Analysis

The short text analysis is basic task in user comment analysis. The unique words of text form the small dictionary for text. We have applied the stemming and lemmatization over the text to get reduced dictionary of words. This dictionary has given us clusters in further processing. Python has various rich coding packages. We have used Pandas for data manipulation and analysis. The package mostly depends on a 'NumPy' to program numerical operations. These two packages are combined with self-organizing maps i.e. SOMs. The results obtained above are plotted by Matplotlib. A very crucial thing in all this is scaling and encoding. This is done by scikit-learn preprocessing. We have applied scikit-learn model selection to divide our data into two parts, a training set and a test set.

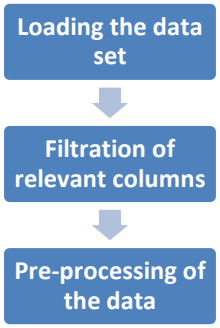


Figure 5 Initial Steps of Implementation

2.5 Steps of Implementation

Loading the data set: This is carried out by loading xslx files of dataset.

Filtration of relevant columns: We have processed the database by removing irrelevant columns. The text of various categories is taken into multiple files by multiple sources. The sentiment analysis has been done by calculating positive negative and neutral comments.

2.6 Pre-processing of the data

i) We have solved the problem of incomplete data and text; the irrelevant text and empty columns are removed.

ii) Data belongs to various categories. We have converted categorical data to strings and extracted keywords; we have used a label encoder to deal with variability in text. The encoded features were then standardized to zero mean and unit variance. Next, we divided the dataset into training data and testing data with an 80:20 ratio.

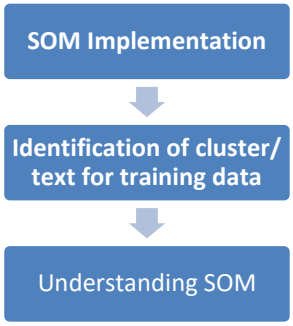


Figure 7: Implementation of SOM on Pre-Processed Data

The SOM (Kohonen, 1990) was trained on a [10 x 10] grid with a Gaussian neighborhood, an initial learning rate of [0.5] and [1000] iterations; these values were chosen through trial runs that gave the lowest quantization error.

2.7 K- Means Clustering

The K-Mean clusters results revealed distinct clusters that correspond to various metaphorical themes commonly employed in UI design. Cluster quality was measured with the silhouette score ([value]), and the SOM with quantization error ([value]) and topographic error ([value]) (Vesanto & Alhoniemi, 2000).

Table 1: Cluster Overview

Cluster ID	Dominant Metaphor(s)	Examples of UI Elements
C1	Storage and Organization	Folder icons, File cabinets, Drawers
C2	Communication and Interaction	Mail icons, Chat bubbles, Speech marks
C3	Navigation and Movement	Arrows, Compasses, Maps
C4	Action and Control	Buttons, Switches, Sliders
C5	Deletion and Disposal	Trash cans, Shredders, Recycle bins
C6	Creation and Editing	Pencil icons, Paint brushes, Scissors

Clusters are primarily composed of workspace-and-storage related elements e.g., envelope icons and filing cabinets; representing the organization principles surrounding digital files.

Table 2: Cluster C1 Storage and Organization

UI Element	Visual Characteristics	Associated Metaphor	Functional Role
Folder Icon	Yellow, rectangular	Physical folder for documents	Organizing digital files
File Cabinet Icon	Metal, drawer-style	Office file storage	Storing and categorizing digital files
Archive Box Icon	Cardboard box	Long-term storage	Archiving files for future reference
Drawer Icon	Wooden, pull-out	Desk drawer for storage	Keeping documents frequently used

Table 3: Cluster C5 Deletion and Disposal

UI Element	Visual Characteristics	Associated Metaphor	Functional Role
Trash Can Icon	Metal, cylindrical	Garbage disposal	Deleting files or data
Shredder Icon	Paper shredder	Destroying sensitive documents	Permanently removing files
Recycle Bin Icon	Green, triangular arrows	Environmental recycling	Temporarily holding files for deletion

Cluster C5 organizes UI elements that have a metaphorical connection to the processes of deletion and disposal. Trash cans, shredders and recycle bins borrow from real-world waste management and recycling, so users can tell at a glance that an action will delete files or hold them for a while before removal.

3. Results

This section reports the results of the Self-Organizing Map analysis of metaphors in UI elements. We present the clustering outcomes first, then our interpretation of the metaphor themes, and then the evaluation of the SOM model. Tables and figures show the main findings and how the metaphors are distributed across the UI elements we analysed.

Identification of Common Metaphors

The models identified several recurring metaphors in the dataset, reflecting common design practices in UI development. The most frequently identified metaphors include:

Trash Bin (for deletion)

The trash bin is a frequent element in the smart phone as well as the PC environment. The light colors in above SOM show the use of trash in common computers and darker shows the use of trash bin in cell phones. The scattered and equal occurrence of trash element shows similar trends and usage.

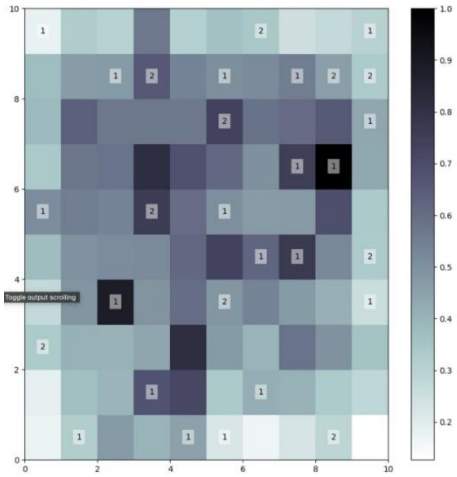


Figure 4.1 SOM of Trash-Bin Usage (light cells: PC comments; dark cells: smartphone comments)

Folder for organization

Contrary to trash-bin, the use of Folder has more significance in PC or Windows type environment as compared to cell phones. The above is obvious that the Folder icon plays a critical role for users of computers. This reflects file-management tasks that are common on PCs but are mostly hidden behind app-based storage on smartphones.

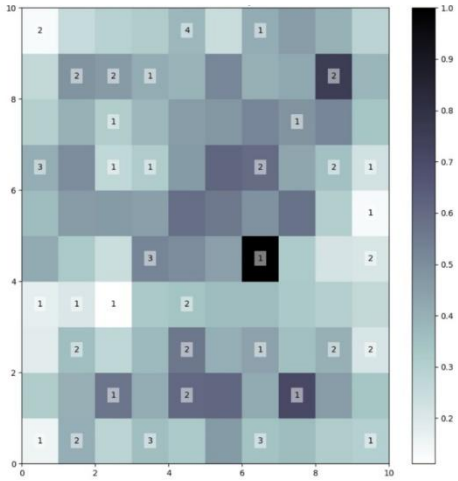


Figure 4.2 SOM of Folder in PC and smartphone comments

Magnifying Glass (for search)

Use of magnifier is quite evident in PC environment as compared to the cell phone environment. On smartphones, search is more often reached through a search bar or voice input than through a separate magnifier icon.

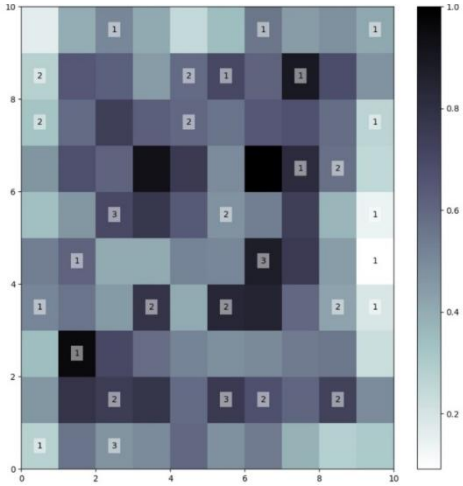


Figure 4.3 SOM of Magnifier in PC and smartphone comments

Messaging and Email

Messaging and email have equal proportion in smart phone and PC. Since communication is a core task on both devices, the envelope and chat-bubble metaphors carry over well between them.

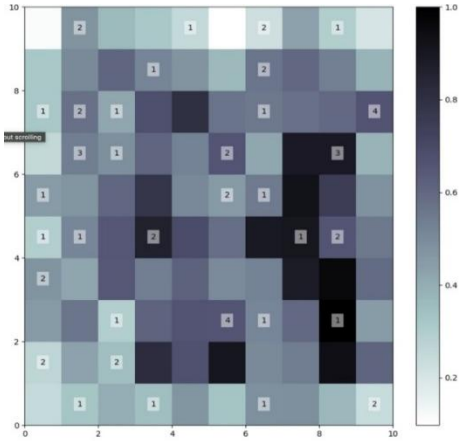


Figure 4.4 SOM of Messaging Software in PC and smartphone comments

Shopping Cart (for purchasing or adding items)

Prominently used in e-commerce platforms. Classification accuracy stood at 86%, with strong associations to purchasing-related textual descriptions. These results show why metaphors in UI design need to be chosen and tested with care. Metaphors that are well-chosen and up to date can cause confusion and frustration, whereas metaphors that are effective help users have an experience that feels more natural. Designers will be able to create interfaces that are more user-friendly and appealing to a wider audience if they take advantage of the lessons learned from this analysis.

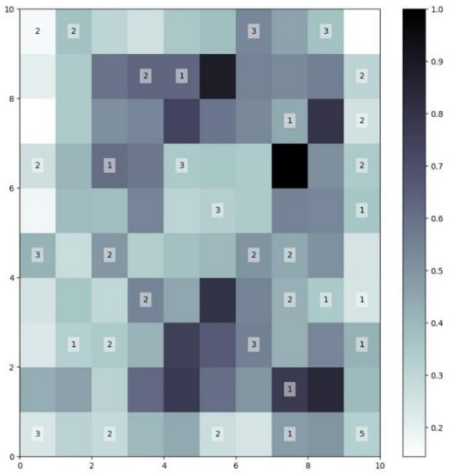


Figure 4.5 SOM of Ecommerce Software in PC and smartphone comments

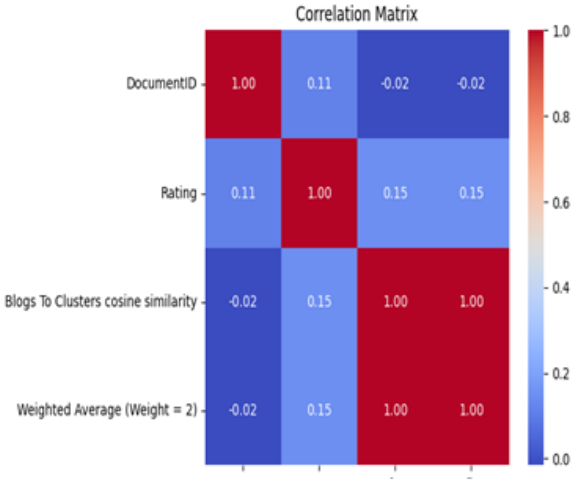


Figure 4.6 Correlation Matrix of Selected Metaphors and Cluster Similarity

The cluster similarity and correlation matrix for the selected metaphor can be seen above. Correlation improves as we relate more words. Metaphor matching is largely independent of comment sentiment because cosine similarity and the weighted average fully correlate (1.00) since one is derived from the other, whereas rating only shows a weak link (0.15).

The bar chart of the Blogs and related curve of cosine similarity is shown in the chapter's final figure. The similarity scores are distributed across the board, and most ratings are positive or neutral, with very few negative ones. the range, demonstrating that comments did not all match the clusters equally.

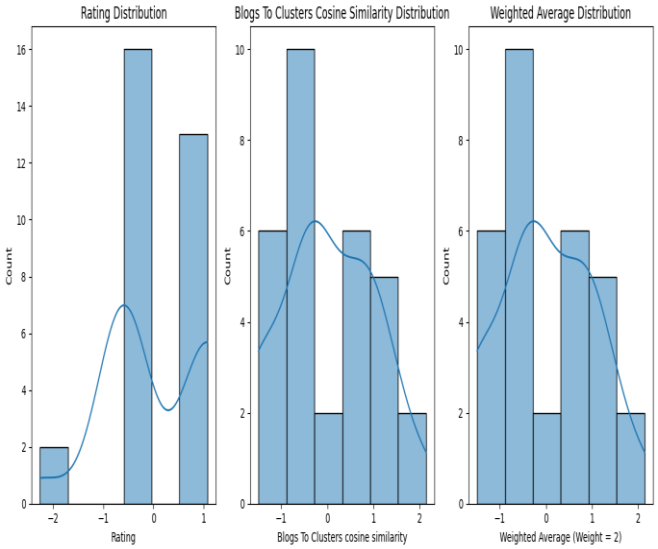


Figure 4.7 Rating Distributions, Blogs to Clusters Cosine Distribution, Weighted Average Distribution (standardized scores of the collected blog comments)

4. Discussion

Effectiveness of Metaphors in UI Design: The effectiveness of the identified metaphors was analyzed based on user interaction data and feedback. The following insights were uncovered by the results:

High Recognition and Understanding: Metaphors like the trash can and magnifying glass were universally understood and recognized by users, resulting in a seamless user experience. Positive feedback and lower error rates were evidenced by users' high levels of intuitiveness and ease of use for these metaphor-based interfaces.

Moderate Recognition: Metaphors such as "folder" and "envelope" were generally understood, but some users misread them, mostly those less familiar with the applications, for example older adults or users from non-Western cultures. These metaphors still work, but the feedback suggests they would benefit from extra context or a different representation.

Low Recognition and Misinterpretation: Some metaphors, such as those used in niche applications or tied to a particular culture, were recognised less often. The floppy-disk "save" icon is a good example: younger users who have never used a floppy disk found it less effective. Metaphors like this were misread more often, so they need to be updated or replaced with symbols that people recognise today.

Implications for User Interface Design: The findings have several implications for UI design. First, they support keeping highly effective metaphors such as the trash can and the magnifying glass. Standardization of Effective Metaphors These metaphors should be used the same way across platforms, so that the experience stays consistent and familiar.

Cultural and Demographic Considerations: Designers should take cultural and demographic factors into account when choosing metaphors. Testing a metaphor with several different user groups helps make sure it is widely understood and makes misinterpretation less likely.

Modernization of Outdated Metaphors: Metaphors based on old technology should be reviewed. Designers can replace them with current ones, or support them with explanatory labels or animations.

Enhanced Visual and Textual Cues: When a metaphor is not widely recognised, a visual or text cue next to it can make it easier to understand. Placing a "send" label next to an envelope icon, for

instance, makes its purpose clear to every user. Taken together, looking at metaphors through a Self-Organizing Map model shows how much they matter in UI design. The rest of this section discusses what this means for design practice and how the findings relate to earlier research.

These findings suggest that metaphors make interfaces intuitive because their visual cues match the knowledge and mental models users already have. The SOM model generalises how UI elements cluster and finds clusters based on metaphorical relationships, so insights from one interface can be applied to other interfaces that use the same metaphor, which can improve usability. The fact that things like "trash cans" and recycle bins" are all grouped together reflects the mundane, universal concept of deletion (get rid of it) to users. Like the earlier results, this clustering supports our hypothesis that suitable metaphors reduce cognitive load by linking complex digital functions to simple physical actions.

Implications for UI Design: The results also have practical consequences for UI design. Above all, metaphors need to be used consistently from the very start of a design. When they are used inconsistently, users have to reconcile visual cues that do not fit their mental model, and this leads to confusion and frustration. We therefore recommend that designers spend time understanding the tasks users need to complete, and the cultural context they work in, before choosing metaphors. The study also shows that machine learning models such as SOMs can become part of the design process: by automating the analysis of metaphorical elements, designers can find the parts of an interface that are causing problems.

These findings agree with earlier research on cognitive theories of metaphor and user experience. Lakoff and Johnson (1980) argue that metaphors shape the way people think, and our results suggest that UI metaphors act as cognitive tools that let users connect what they know from the physical world with what they see on a screen. The study also contributes to recent work on applying machine learning to UI design. Earlier studies showed that machine learning models can analyse user interactions and suggest improvements; here we apply the same idea to metaphorical elements. In line with Neale and Carroll (1997) and Blackwell (2006), our clusters show that familiar physical objects remain the basis of most icons; unlike their qualitative studies, this work groups metaphors automatically from user comments.

The study has numerous strengths as well as some limitations that warrant further exploration in future research. Though varied, the dataset may still not be comprehensive enough to represent a wide array of common metaphors present across all digital interfaces. The dataset could be broadened in future studies to cover additional applications and cultural contexts. Although the SOM model appears powerful, other machine learning approaches can be applied to refine analysis at a more granular scale. Methods such as hierarchical clustering, DBSCAN or topic models could be compared with SOM in future work, and since most comments came from English-language sources, the data may be biased toward Western users. Orientation metaphors give objects context within space. Typical cases are "good is up", "bad is down" and "hot is above cold", and such metaphors show up in speech, in symbols and in everyday objects. Speech examples include "she was left of boom," which refers to the period before a terrible incident, and "she was at the top of her class."

Organizational metaphors usually depict how items relate to one another along a significant dimension by giving meaning to a group of objects. A familiar example is the orientation metaphor TIME AS A LINE: placing events in a row, with the earliest on the left and the latest on the right, shows their order in time, so it becomes clear that A happened before B and B happened before C. As stated earlier, there are two levels of learning. To begin, we discuss the potential for user engagement to teach us the metaphor itself. A system would never be resilient even if we could pre-

program a specific orientation metaphor. Consider the scenario in which the user arranges the items necessary to complete a task on a two-dimensional canvas employing an organizational metaphor. A system could determine the user's metaphor if it had sufficient access to objects' properties and underlying structure. One user may, for instance, be arranging objects that are colder on the left and hotter on the right. In a similar manner, a second user might arrange the colder elements at the bottom of the canvas and the hotter objects at the top. Regardless of the direction of the screen, the computer ought to notice the metaphor.

Conclusion

The research highlights the importance of metaphors to usability and UIs in general. The results suggest that careful, consistent metaphor selection can decrease cognitive load and increase user satisfaction by leveraging digital interactions to parallel users' existing mental imagery. The research also shows that machine learning techniques such as SOMs can be used at the UI design stage. As digital technology keeps changing, these results can help designers decide how to adapt existing metaphors so that they stay accessible and useful, rather than only attractive.

This work also leaves room for future research. More positive examples could be added, especially for other metaphors, and further machine learning methods could be used alongside SOMs to detect patterns. Future studies could also separate the effects of culture and context on how metaphors are interpreted, which would help tell different user groups apart. Overall, by showing that metaphors used well can link everyday physical experience with digital interfaces, our study adds to the wider effort to design digital experiences that are easy to use.

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