

Visual Thinking In Action: Visualizations As Used On Whiteboards

Jagoda Walny, Sheelagh Carpendale, Nathalie Henry Riche, Gina Venolia, and Philip Fawcett

Abstract—While it is still most common for information visualization researchers to develop new visualizations from a data- or task-driven perspective, there is growing interest in understanding the types of visualizations people create by themselves for personal use. As part of this recent direction, we have studied a large collection of whiteboards in a research institution, where people make active use of combinations of words, diagrams and various types of visuals to help them further their thought processes. Our goal is to arrive at a better understanding of the nature of visuals that are created spontaneously during brainstorming, thinking, communicating, and general problem solving on whiteboards. We use the qualitative approaches of open coding, interviewing, and affinity diagramming to explore the use of recognizable and novel visuals, and the interplay between visualization and diagrammatic elements with words, numbers and labels. We discuss the potential implications of our findings on information visualization design.

Index Terms—Visualization, diagrams, whiteboards, observational study.

1 INTRODUCTION

Over the centuries the word *visualize* has meant “to form a mental image of” some idea, concept or description. It is only relatively recently that the word *visualization* has become associated with computers. While a visualization can be externalized on a computer, the importance of the link with mental ideation is still strong, as shown in Card et al.’s [10, p. 7] definition of information visualization: “the use of computer-supported, interactive, visual representations of abstract data to amplify cognition”. We explore this link between internal visualizations and external visual representations by studying diagrams and visuals as they have been spontaneously drawn on whiteboards.

If we look back at the work in information visualization over the last few decades, we see that ideas about how to create visualizations have been primarily informed either by how a visualization maps to data or by how a visualization supports a task, or some blend of these two forces. That is, if a visualization is informed by the data then the foremost questions concern how the visualization maps to the data, and how available this mapping is for interpretation. If a visualization is to be informed by the tasks, the primary concerns center around what the tasks are and how the people performing these tasks are to be supported by the visualization. Both of these directions as well as blends of the two have been extensively studied and remain vibrantly active. For example, from a data-driven perspective, research on treemaps [23] and conetrees [41] aimed at finding novel ways to represent hierarchical data. More recently, researchers such as Stasko [2] and Shneiderman [43] approached InfoVis from the task perspective, seeking to understand and inform the creation of information visualizations with a grounding in the tasks that were to be supported. Framing the development of a visualization around tasks has been helpful in finding appropriate methodologies for evaluating InfoVis [12, 38]. Thus InfoVis research to date has been largely data- or task-driven. That is, visualizations are based on the representation of the data or on the task to be performed with the data.

Beyond these carefully designed data- and task-driven visualizations, there is a whole class of visualizations that are created and used every day all around us. People often sketch diagrams to illustrate abstract concepts or data while they are thinking or collaborating, on freeform mediums such as paper or whiteboards. We call such diagrams *spontaneous visualizations*. This opens another possible approach to informing the design of information visualizations. We can examine the visualizations that people make spontaneously while thinking in their day-to-day lives. Studying these spontaneous visualizations can provide us with new insight into the types of visuals people use to think, which can influence information visualization design. In this direction of increasing our understanding of how the general public creates information visualizations, Grammel et al. [21] have investigated the processes used by InfoVis novices when creating information visualizations and the challenges they faced. In a similar vein, van Ham et al. [48] provided recommendations for graph layout algorithms based on preferences observed in human-aided graph layouts.

In a similar vein, our research explores how people create and use their own visual representations on whiteboards to provide insight into new ways of thinking about information visualization. We join extensive research which investigates one media to inform another. For example, in distributed computer supported collaborative work many of the seminal studies were performed in collocated settings [37, 46]. Understanding factors that support the ease of collaborations in collocated settings provided ideas to think about when designing software to support distributed collaboration. In analogy, since whiteboards are well documented as providing support for thinking processes [35, 45], it is possible that we will gain useful insights into how to support these thinking processes in information visualizations by studying whiteboards.

We selected whiteboards for the variety of thinking tasks supported – from personal and collaborative cognition, to group meetings and brainstorming, to planning and organizing. We are interested in understanding what types of visuals are used, whether people develop their own visual representations, what techniques are used in developing visuals, and whether any of the techniques used parallel those developed or studied in information visualization. Developing a richer understanding of the role spontaneous visualizations play in thinking processes raises challenging questions for information visualization.

Our general goal was to study how people create and use visuals in their daily routine. One way that people use visuals is by drawing and writing on whiteboards. While whiteboards have been studied from various perspectives (including software engineering [15], collaboration [25], and designing interactive whiteboards [35, 36]), we analyzed the whiteboards differently – through the lens of information visualization. We recognize that in choosing whiteboards in a work setting we will be looking at a subset of spontaneous visualizations that relate to tasks in the workplace.

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2 RELATED WORK

2.1 Using Visuals to Think

The effectiveness of visuals in helping people to think has been explored in several areas. Arnheim [4] argued that visual perception and thinking are intrinsically linked. Buxton suggests sketching is a way to develop and clarify ideas about designs [9] and also points out that ambiguity in diagrams can be a catalyst for new ideas.

Part of the power of visuals is their ability to act as a visible external memory. Visualizations can draw both on the visual and the spatial working memory system [5, 32]. Chabris and Kosslyn [13] claim that effective diagrams are those that represent information the way our minds do. More complex concept structures can be represented externally in visual displays than can be held in human visual and verbal working memories. In one study of sense-making at large displays [3], the ability of the large display to persistently display artifacts led people to use parts of the display as external memory.

Whiteboards can be a particularly effective medium for visual thinking due to their freeform nature. Several studies of whiteboards have pointed out that the flexible nature of whiteboards allows the possibility of assigning varied meanings to freeform representations [45] and to spatial organization [3, 45]. This indicates that a whiteboard can be a powerful tool for visualizing information.

Although, to our knowledge, no one has studied whiteboards from the perspective of information visualization, several studies have identified whiteboards as a place where thought occurs. Notably, Mynatt found that one of the tasks whiteboards were used for was thinking: *“All manner of incomplete and seemingly vague content was written as participants used their whiteboard as a scratch surface while pondering concepts much larger than their surface representations”* [35].

2.2 Studying Whiteboards in General

Whiteboards are a ubiquitous and flexible tool in knowledge workers’ workspaces. As such, they have been a popular subject of study from various perspectives.

The goal of many whiteboard studies has been to inform the design of digital whiteboards. For instance, Mynatt [35] studied several office workers’ whiteboard usage habits and observed how they managed space and color, what tasks they used whiteboards for, their frequency of usage, and collaboration habits. Additionally, she asked her participants what features they would like in a digital whiteboard. This culminated in the creation of a digital whiteboard software called Flatland [36]. Other digital whiteboard systems include Tivoli [34], which focuses on integrating structured data with a freeform whiteboard environment, and Range [24], which is a public interactive whiteboard system. One theme present across many digital whiteboard systems is analysis of layout and grouping patterns [47].

Several whiteboard systems have been designed to support transitions between analog and digital formats, for instance: The Designer’s Outpost [27] combines paper sticky notes and a digital whiteboard; Brandl et al.’s system [7], which utilizes Anoto (www.anoto.com) pen technology, allows data written on paper to be transferred to a computer; and ReBoard [8] automatically captures images from analog whiteboards and makes them available on personal digital devices or through a Web-based interface. Also, several studies have looked at collaboration and workflow at the whiteboard [25, 45]. In contrast to these studies, the goal of our work is to inform the creation of new information visualizations, rather than electronic whiteboard systems. Thus, while some of our findings confirm those of previous whiteboard studies, we examine these from the perspective of information visualization.

2.3 Studying Low-Level Details of Whiteboards

In order to view whiteboards from an information visualization perspective, we looked at low-level diagrammatic constructs used on the whiteboards.

Several whiteboard studies have examined some low-level features of whiteboard usage, such as specific strokes and diagram layouts, with the express purpose of interpreting what is written on the

digital whiteboard. For instance, Kaiser et al. [26] examine multimodal redundancy during whiteboard use (i.e. similar semantics across what is being written and said) to implement a speech-and-handwriting recognition system. Similarly, Adler et al. [1] examine multimodal interaction to create a digital whiteboard system that recognizes sketches through both speech- and sketch-recognition. Dixon and Sherwood [17] examine the low-level performance bottlenecks that prevent sketch recognition on digital whiteboards from progressing.

More closely aligned with our research, Cherubini et al. [15] studied the types of graphical conventions used in diagrams for software development and found that the box-and-line convention was widely used for software diagrams. While our study also focuses on diagrammatic constructs, we examined a much wider range of features over a broader spectrum of diagram types – including word usage, historical usage, emphasis, and common graphical conventions.

2.4 Studying Everyday Visualizations

In the InfoVis community, there is an increasing interest in how the general public uses information visualizations. There are many InfoVis approaches aiming at reaching a wider population of users, such as emerging approaches for narrative information visualization [42], and tools and toolkits that let novices easily create visualizations with data [49, 22]. More closely related to our research are two studies that investigate how novices, in terms of information visualization, created visualizations. Grammel et al. [21] investigated what kind of help novices needed when using software to create visualizations. van Ham et al. [48] studied human-aided graph drawing layouts. We extend this direction by studying the creation of spontaneous, but largely task-based, visualizations on workplace whiteboards.

3 STUDYING WHITEBOARDS FOR INFOVIS

For the purpose of this study, we wanted to examine a medium that was accessible and freeform enough that people would use it to think without being overly influenced by the constructs or layouts available to them. To this end, both whiteboards, loose papers, and notebooks or sketchbooks would have been an acceptable study medium.

We chose whiteboards for this study over other alternatives for a number of reasons, including their flexibility, availability and the variety of ways they are used. At the research institution where this study was carried out, every office contained a whiteboard. These whiteboards were generally visible from the hallways, making them personal but semi-public spaces. Thus many privacy concerns were mitigated and we were able to rapidly collect a large number of snapshots from a variety of people. A notebook would be more private, and thus, for the purposes of this study, less accessible.

Many whiteboards are used by people that Mynatt [35] refers to as “space-scavengers”: they write where there is available space and erase only on an as-needed basis. Thus the whiteboards often contain a history of representations of thoughts in one snapshot, whereas the same sort of history in a notebook would likely span several pages. In addition, thinking is not something that is only done personally - it is also done collaboratively. And although it is possible to collaborate on a piece of paper with a small number of people, a whiteboard can often serve as a better option for larger groups.

3.1 Methodology

This qualitative study was designed to shed light on the nature of diagrams and visualizations that are used in day-to-day work practices. The goal of our work is to inform the creation of new information visualizations by observing a breadth of constructs used in visual thinking sketches. To this end, we chose to study a large number of sketches created on whiteboards. We collected 82 snapshots of whiteboards from 69 participants, used an open coding approach [44] to perform an in depth analysis of the visual constructs they contained and conducted ten follow-up interviews to determine how our participants described the visual constructs on their whiteboards. These interviews were then transcribed and used to build an affinity diagram of the discussed themes.

Setting. We collected whiteboard samples from a large research institution that houses hundreds of researchers along with their managers and support staff. The vast majority of employees in this research center work inside individual or shared offices. Whiteboards generally had the same size, height, and accessibility, however, a person's office could have between one and three whiteboards. One-person offices were typically large enough to comfortably accommodate groups of up to three people.

Participants. We chose to run this study in a setting that would focus on researchers, since researchers' jobs naturally require them to solve problems, often abstract ones, on a regular basis. Participating researchers were of a diverse range of disciplines, including computer graphics, mathematics, linguistics and theoretical computer science. Participants also included a small number of software engineers, designers, managers, administrators and technical support staff.

3.2 Data Collection and Analysis.

In selection of whiteboards we chose to use an approach inspired by the 'day-in-a-life' approach [33], by photographing available whiteboards during a short period of time. Without pre-announcing our study, over the course of two days, we collected photos of whiteboards in their current state. We only took photos of non-empty whiteboards in occupied offices, with permission. In cases of multiple whiteboards in a single office, we treated these as separate whiteboards. We collected snapshots of 82 whiteboards from 69 individuals. All of our analysis was done on digitally processed versions of the whiteboard photos, so that all boards were viewed from the same angle and had a similar white balance.

In addition, we asked participants to fill out a short survey about their whiteboard usage. This survey was designed to determine how often the participant used the whiteboard in his or her office alone, as opposed to, in small groups (2-3 people), or in large groups, as well as the frequency of their usage.

We coded whiteboard content based on the grounded theory approach [44]. We began by identifying two spectrums of interest. One of these focused on recognizable information visualization constructs such as 1D scales, trees, graphs, tables, and data charts (line, scatter, bar), etc., and characteristics of whiteboards of interest to the information visualization community, such as those related to spatial organization, temporality, and communicative techniques. The other grouping, which considered the relative use of words and diagrams, we refer to as the "words-to-diagrams" spectrum (described in the next section). This spectrum characterized constructs on the board according to whether they were more purely diagrammatic, more heavily word-based or some mixture in between. Since whiteboards most commonly contained many different types of visual and word-based constructs, we did not characterize complete whiteboards, but instead looked for and coded for the variety of constructs present in a given whiteboard. Through the coding process we iteratively refined our categories. We performed the coding in two separate passes. In the first pass, we divided the coding amongst the authors. In the second pass, one of the authors coded all of the photos (for consistency). We then compared the coding from the first and second pass, and resolved any disagreements.

We also conducted ten follow-up interviews with some of our participants to validate the accuracy of our coding and to learn about our participants' whiteboard usage in greater depth. Of necessity, interviews were conducted a few months after the whiteboard photographs were taken; however, participants remembered their whiteboards well. In fact, some welcomed the whiteboard photos back like old friends. For our interviews, we selected participants whose whiteboards collectively contained all the visual constructs for which we had coded. One purpose for these interviews was to validate our coding. We were interested in whether the participants' characterization of the constructs would agree with ours.

Before each interview, we printed three copies of the associated whiteboard photo, annotating one with the results of our coding. We annotated a second copy during the interview and gave the third copy to the participant. Each semi-structured interview was conducted in

the participant's office, lasted approximately 40 minutes, and was audio-recorded. In each interview, we first gave the participant a copy of their whiteboard photo and asked if they could recall that instance of their whiteboard. Next, we asked the participant to describe each portion of the whiteboard: who wrote it, what was the context, and why they used a particular construct. Meanwhile, we marked down whenever the participant's description matched or disagreed with our coding. When appropriate, we asked questions about specific constructs (such as, "what would you call this?") and typical behaviors with visuals (such as, "do you use any mind mapping or visualization software in your work?").

We transcribed each interview's audio recording. We then used affinity diagramming to work with this interview data, grouping similar topics and ideas to discover themes of interest to information visualization.

Our data comes from three sources: the whiteboards and our coded observations; the interviews, their transcription and the resulting affinity diagrams; and the common usage survey.

4 WHITEBOARD CODING

In this section we delineate our coded observations. We coded for occurrences of visual constructs on the whiteboards across two principal groupings. The first grouping we will discuss is the one that looked primarily for information visualization constructs. In this grouping we looked for recognizable information visualizations such as 1D scales, trees, graphs, tables, and charts such as line graphs, scatterplots, and bar graphs. We also coded for spatial organization factors, layering factors, and communicative factors such as emphasis, negation, ellipses, and use of sketchiness. This first grouping provided evidence about the prevalence, degree and nature of use of known visualizations and visualization techniques on whiteboards. In the second grouping we coded for two other factors that were readily apparent: (1) the frequency and characteristics of word usage; (2) the many varied and unique diagrams. Also apparent was the interplay between words and diagrams. Many diagrams were labelled, many words were grouped with diagrammatic elements and there were also many variations of different combinations of constructs made of both words and diagrams. We developed an eight point coding scale ranging on one end from pure words in apparent sentences to the other end with pure diagrams that contained no words.

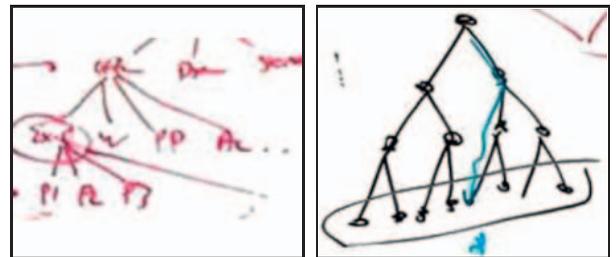
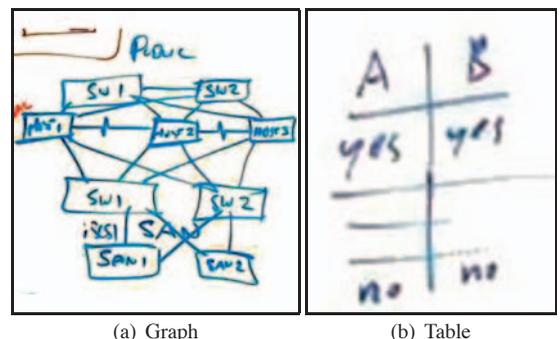


Fig. 1. Example of **trees**, which occurred in 29 of 82 whiteboards (35%).



(a) Graph

(b) Table

Fig. 2. Example of **graphs**, which occurred in 46 of 82 whiteboards (56%), and **tables**, which occurred in 27 whiteboards (33%).

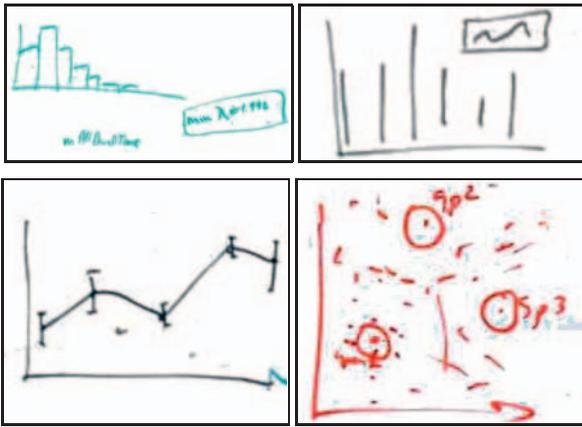


Fig. 3. Examples of **charts**, occurring in 25 of 82 whiteboards (30%).

4.1 Recognizable Information Visualization Constructs

Most (61%) of the whiteboards contained at least one simple, commonly-used, recognizable information visualization, for example, 18% contained one or more simple 1D scale or timeline, and 35% of boards held recognizable trees (for examples see Fig. 1). Graphs, as node-link diagrams, were extremely common, occurring in more than half (56%) of the whiteboards (for examples of graphs Fig. 2). We also saw a great variety of sketched tables (33%). Simple data charts such as line graphs, scatterplots and barcharts occurred in 30% of the boards. Fig. 3 shows four sample charts. These were rarely associated with actual data as numbers but were often associated with some roughed in sketch of what the data might look like.



Fig. 4. Examples of **dense** and **sparse** whiteboards.

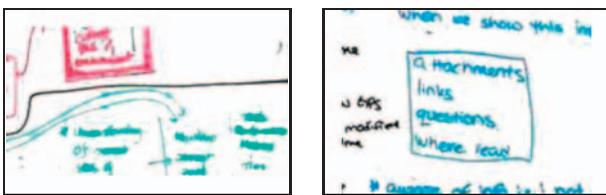


Fig. 5. Examples of **separation** and **grouping**.

4.1.1 Spatial Organization

For spatial organization we looked at board coverage and varying grouping and separation techniques. Whiteboards varied considerably in coverage from extremely dense, through more moderate, to a few relatively sparse boards. A whiteboard was considered dense when it had little whitespace between and within elements on the board. See Fig. 4, left, for an example of a dense whiteboard. 40% of the whiteboards were classified as dense. Similarly to other whiteboard studies [3, 45], we saw many examples of different types of spatial separation and grouping (Fig. 5). Separation (52%) refers to any techniques used to separate parts of a whiteboard regions from each other, including lines, spacing, orientation, or color. Note how the black line separates the red from the green in Fig. 5, left. Grouping (60%), is similar to separation, but groups together two or more objects using a closed shape or brackets (see Fig. 5, right).

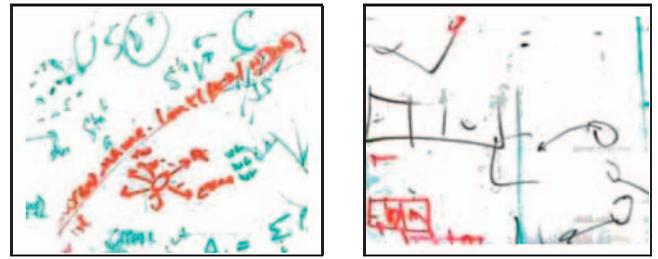


Fig. 6. Examples of **palimpsests**, which are parts or traces of old diagrams visible on a whiteboard. The previous diagrams may have been partially erased and/or written over.



Fig. 7. Examples of **emphasis**, found on 55 boards (67%)

4.1.2 Layering

We saw an interplay between current and historical usage in observing palimpsests and erasing. **Palimpsests** (see Fig. 6) are parts or traces of old diagrams visible through new diagrams. The previous diagrams may have been partially erased and/or written over. These were found on 35 whiteboards (43%). Any whiteboards that had areas that had obviously been erased were coded for **erasing**. This included areas in which the traces of old diagrams were partly or barely visible. We found this in 36 whiteboards (44%).

4.1.3 Communicative Factors

We also saw a number of communicative techniques used on the whiteboards: emphasis, negation, ellipses and sketchiness. **Emphasis** (see Fig. 7), which was found on 67% of the boards, refers to parts of diagrams to which attention has been drawn, for example through the use of arrows, color, starring, or circling. **Negation** (16%) is the crossing out or scratching out of a part of a diagram. This does not include “ticking off” elements of a list, but does include crossing out elements of a list. **Ellipses** (see Fig. 8), found on (44%) of boards, are indicators that something has been omitted from a phrase, sentence, or diagram. The most common type of ellipsis is the triple dot (...). **Sketchiness** (see Fig. 9), which was found on 49% of the boards, refers to a sketchy quality of lines drawn, apparently to indicate low accuracy, low effort, or low certainty. Since most whiteboard drawings are by nature sketchy, we code here for particular signs of sketchiness, such as squiggly lines or lines traced over several times.

4.2 The Words-to-Diagrams Spectrum

The words-to-diagrams spectrum (Fig. 10) characterizes visual constructs according to the importance and ratio of words to diagrammatic constructs (such as lines or circles) in a diagram. Grouping these more broadly gives 54 whiteboards (66%) containing instances of aspects that were mostly words (paragraphs and lists), 68 whiteboards (83%) combined words and diagrams and 63 boards (77%) contained constructs that were mainly diagrammatic. Most whiteboards contained more than one type of visual construct as well as words and lists. For example, a given whiteboard could contain some sections that were



Fig. 8. Examples of **ellipses**, found on 36 whiteboard (44%)

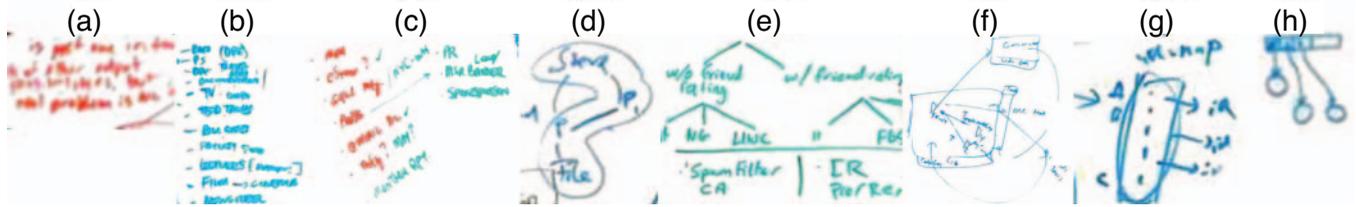


Fig. 10. Samples from the words-to-diagrams spectrum (a) words; (b) lists; (c) words in spatial organizations; (d) words in simple diagrams; (e) words in recognized visual constructs (tree); (f) words and diagrams mixed; (g) diagrams with labels; (h) pure diagrams with no words

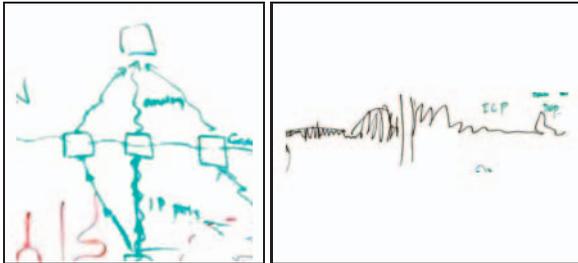


Fig. 9. Examples of *sketchiness*, found on 40 whiteboards (49%)

mostly words and some that were mainly diagrammatic. The following subsection contains explanations for each of the aspects that we coded for in the words-to-diagrams spectrum. Fig. 10 shows a visual example for each point on our words-to-diagrams spectrum.

Sentences and **paragraphs** are the anchor point for one end of this spectrum (see Fig. 10(a)). These are identified through the use of one or more full sentences or long phrases (phrases greater than 5 words in length) in succession. They may stand alone or be connected to other constructs on the whiteboard, for instance they may be surrounded by a box, connected to another construct with a line or arrow, or begin with a bullet point. Words as sentences or in paragraphs were used in 8 of 82 whiteboards (10%).

Word lists are units (words, phrases, or sentences) clearly placed in spatial sequences. Fig. 10(b) shows a bulleted list. These lists were usually arranged vertically but could be set at angled or horizontal comma separated lists. Individual units may be denoted by bullets, dashes, arrows, numbers, or the list could be simply created through spatial separation. Lists were found in 49 whiteboards (60%).

Words in spatial organizations were coded for when words or phrases were placed in some spatial arrangement different from the normal words on a horizontal line. Word spatial arrangements contain no or few diagrammatic elements (such as lines or arrows). Fig. 10(c) shows a sample of this type of construct where the use of spatial positioning helps to show the relationship among the words. Words in spatial organizations were found in 37 of the whiteboards (45%).

Simple diagrammatic constructs exist when words are placed in some meaningful spatial arrangement and connected with some diagrammatic elements (such as lines or arrows). They are recognizable as diagrams, but the type of the diagram is not recognizable; in addition, the spatial arrangement of the words is part of the diagram. Fig. 10(d) shows a construct where words and visuals are both used diagrammatically, however, this is an unusual diagrammatic structure. These were found in 15 whiteboards (18%).

Words in visual constructions occur when words form the major elements of recognizable diagrammatic constructs, for instance when they are the nodes of a tree, or the cells of a table. Fig. 10(e) shows an example of words as nodes in a tree. This type of combination of words and recognizable diagrams occurred in 28 whiteboards (34%).

Mixed words and diagrams occur when a diagrammatic construct includes words as major elements of the diagram in addition to containing diagrammatic elements such as nodes, pictures, symbols, or icons. The words themselves might be used spatially, perhaps to help form the diagram. Fig. 10(f) shows an example where lines, curves, and

arrows combine together to form the visual construct. This type of construct occurred at least once in 29 whiteboards (35%).

Diagrams with labels are diagrammatic constructs in which the major elements are purely diagrammatic, but which include labels that identify some or all of the elements, either through proximity, overlap, or connection. In essence, a diagram with labels would still be the same diagram without the labels, albeit less easily understandable. Fig. 10(g) shows a labeled diagram. Labeled diagrams occurred in 50 (61%) of the whiteboards. These labeled diagrams and lists (49 whiteboards (60%)) were the most common aspects of this spectrum.

Pure diagrams are diagrammatic constructs with no words or labels. People often created diagrams with no associated words. Fig. 10(h) shows a sample. These occurred at least once in 43 whiteboards (52%).

5 INTERVIEW AND SURVEY FINDINGS

Our interviews served two purposes: to validate our coding by checking on participants own coding of their boards; and through use of affinity diagramming, to shed light on themes arising from the participants.

5.1 Interview

In general, the interviews confirmed and agreed with our coding. The few exceptions tended to arise from missed variations rather than from mistaken coding. For example, a sketchily drawn arrow was coded as an arrow, when it was actually a personal symbol for set membership. Another example of a missed variation arose when coding for ellipses. We looked for a mark or series of marks that we felt clearly indicated that something had been omitted or that a series would continue; often these would be the traditional three dots. However, when one interviewee was asked about some empty circles, she explained: “[The empty circle] usually means that there is some entity out there - a program or process that I still don’t know about, and it might be using my stuff”. Clearly her circles were a form of ellipsis. Also, working from static whiteboards we did not assume use of color indicated anything beyond pen availability or contrast (as noted in previous studies [35]) and while most interviewees agreed with this, saying that they did not think about the color they used, one interviewee noted that color could be a form of emphasis “It’s difficult to bold on a whiteboard, so I use colors”. Such variations were very few, usually less than one per whiteboard.

Working with the interview transcripts via affinity diagrams revealed the following themes: use of real vs sketched data; reasons for whiteboard use; whiteboards vs paper; whiteboards vs software; real vs sketched data; and the relationship of words to maturity of thought processes.

5.2 Whiteboard Usage

A third (33%) of our participants used their whiteboard daily. Over half (56%) used it weekly and the rest (12%) used their whiteboard monthly. For most participants usage varied from solo, to small group (2-3 people) to larger groups (more than 3 people). However, a few noted that they only used their whiteboards in groups (see Fig. 11).

Most of the whiteboards in our study were used for both personal and small group work; groups (greater than three people) were less common, usually less than 10% of the time. This was largely influenced by the physical size of the offices; whiteboards were available

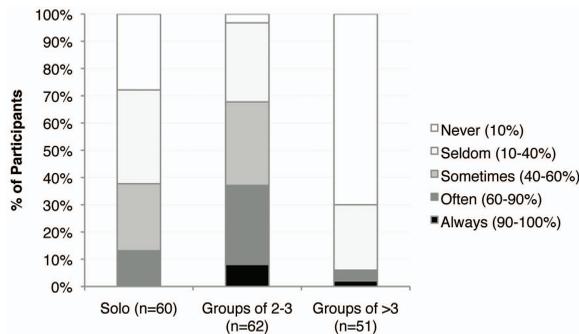


Fig. 11. Whiteboard usage results from the survey. (The n 's varied because not all respondents answered all questions.)

for larger group meetings in other parts of the building. However, notably, a few characterized their whiteboard use as being always in group settings: “like, I don’t use it for my own planning really, it’s really when I have meetings with people and we talk about something. So every single one of these was about a discussion I was having with someone”.

Our interviewees’ comments about their whiteboard usage in general confirmed those of previous whiteboard studies, the most common reasons for usage being: as personal memory aids; as a means of providing visuals in small meetings (organizational, explanatory, and brainstorming); and for personal brainstorming and organization of thought.

While, for most of our interviewees, whiteboard usage was quite sporadic, their comments consistently verified that their whiteboards were used for externalizing their thoughts, brainstorming, or communicating with colleagues. Thus, we feel confident that whiteboards were the right medium for us to study visual thinking in action.

6 DISCUSSION AND IMPLICATIONS

This discussion is based on the interplay between the whiteboard gallery we collected and open-coded and our follow-up interviews and the resulting affinity diagram. The results jelled into three main topics: those factors that were recognizably information visualizations; the results from the words-to-diagrams spectrum and their related comments, which we have termed *thinking diagrams*; and factors that arise from the qualities of whiteboards as a medium.

6.1 Factors Recognizably Information Visualization

People used many factors that were recognizably information visualizations. For discussion we have grouped these under: InfoVis data charts, various types of node-link diagrams, and InfoVis techniques such as focus and context and emphasis techniques. These groupings in themselves raise an interesting question about general InfoVis vocabulary. It seems likely that these types of constructs are well known, while complex InfoVis representations such as parallel coordinates may not be known, or may not be known well enough to find a role in the participants’ thought processes; or they may simply be too complex to draw quickly as part of an active conversation.

6.1.1 InfoVis Data Charts

Many whiteboards had at least one data chart, including scales, bar charts, line graphs, scatterplots and histograms. However, they rarely contained what could be thought of as data with actual numbers and even then only a few numbers were placed (see Fig. 3, bottom, right). All contained some evidence of data, such as sketched lines or data bars. This was a much dwelt-upon topic during the interviews. Participants carefully explained that they did not draw the actual data and gave us several reasons as to why not. These included: that they could not remember the data at the time of drawing; that it would take too long to draw the data carefully; and the most frequent comment was that for the purpose of the conversation or brainstorming that was occurring when it was drawn, indication of the gist or trend was sufficient. “We didn’t replot anything to draw this, we’re just kind of saying, here’s the pattern”, and “I don’t think I put actual data on

whiteboards, which is more about coming up with some abstractions of the data”. Our evidence suggests that people often used the whiteboard either at the early stage of data analysis (sketching a hypothesis of the data, exploring which charts to try out with their data) or at the latest stage (to explain findings to others). However, one participant said that while he did draw such figures and use them in collaborative conversations, he was disturbed about it. He was concerned that the gist or trend could influence the discussion and that it could be false: “can’t look at enough data” and “any small amount of it [data] is going to be very suggestive and possibly be completely misleading”. However, those people who were using trend lines told us that for the types of conversations they were having at the board, trends were sufficient.

Implications. Whiteboards are a powerful tool for performing data exploration because they allow for easy collaboration and through sketching allow easy modifications of any given chart. However, since the whiteboard is not explicitly tied to the data, performing actual data analysis on the whiteboard is tedious. An interesting direction is to augment the whiteboard to support the intermediary step of data analysis: the data exploration. Such a tool would provide access to actual data and the computational power of the machine while maintaining the thought-supporting freedoms of the whiteboard. Some first steps towards this are indicated by NapkinVis [14], which allows for drawing data-backed visualizations in an improvisational way, as on a napkin. Also, the NiCE formula editor [31] computes and visualizes mathematical equations drawn freehand on a large display surface.

6.1.2 Node-Link Drawings

Drawings of trees and graphs were particularly common and were always drawn with familiar node-link structures. This is in line with Cherubini et al.’s observations [15] that software engineers often default to box-and-line diagrams of their systems; the node-link structure is general and familiar to many. The node-link structures we observed occurred in all the flavors of the words-to-diagrams spectrum. Sometimes they were pure diagrams but more commonly they had labels or were clearly drawn words-first, where the node-link aspects were added by grouping words and linking word groups together with lines and arrows. This type of structure seemed to work well for many types of whiteboard activities. We discuss the combinations of words and diagrams further under thinking diagrams (Sec. 6.2).

6.1.3 Focus and Context

The idea of providing context was common in our interviews in that people identified certain aspects of diagrams as indicators that there was more to the whole picture or that the diagram of current focus was set in a bigger context. However, they were rarely drawn in a manner that related to published focus and context techniques. A notable exception is shown in Fig. 12, left. This drawing was also discussed as focus and context drawing “I think that this is more sort of a microscopic view of the things, and this is the general like high-level”. More commonly context was included in a manner that more closely relates to Furnas’ concept of sufficient context [20], where some incomplete indication of context was provided rather than a full but compressed context more usually discussed in distortion viewing [40, 11]. In keeping with this, participants discussed use of ellipses, in the form of dots, dashes, or question marks, as providing an extremely space efficient method for indicating context. This is similar to both Ju et al.’s [25] observations that collaboratively drawn artifacts on whiteboards generally follow the principle of least collaborative effort, showing only what needs to be shown [16], and Mynatt’s [35] observations that “Whiteboard content often seems to be the minimal clues needed for the user to remember the surrounding context and details”.

Participants also included their own diagrammatic elements such as empty circles to indicate missing parts “Well, that usually means that there is some entity out there - a program or process that I still don’t know about, and it might be using my stuff”. However, if one categorizes varying use of angular and scaling patterns as a type of distortion, considerable use of these techniques was present. Scaling was generally used to reflect communication needs, where important

factors were drawn larger. Angular distortions often arose out of space constraints, where items were skewed to fit into an available space. This last relates closely to distortion algorithms, where aspects are skewed to fit into available space. It is interesting to see that people use this in their own hand drawn diagrams and that they do not consider the skewing inconvenient. However, sometimes this type distortion held meaning in itself. For instance, items that were the result of another item were drawn at angle “It [sideways text] kind of radiates from what I was thinking about. So if this [in the middle] was SP then all of this kind of radiates from that” (see Fig. 12, right).

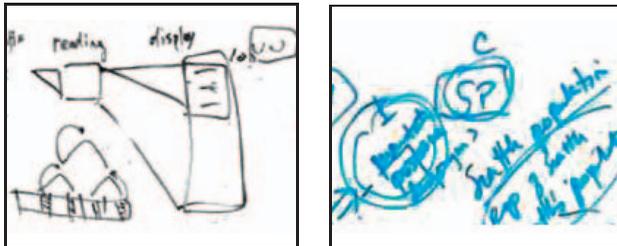


Fig. 12. Left image shows a diagram quite reminiscent of DragMag [50]; Right image shows an example of radiating text

Implications. SpaceTree [39] and Dwyer et al. [18] both used ellipsis to represent the remaining part of a tree or a graph. However, the formalism used in these tools is very different from what we have observed on whiteboards. This formalism, apparently not spontaneously used, may require additional learning from users. Drawing inspiration from the ellipsis commonly used on whiteboards could help us improve such tools. More generally, in comparison to our observed use on whiteboards, ellipsis is underused in information visualizations. Exploring the use of a variety of ellipsis representations in our InfoVis tools and allowing people to create their own ellipsis representations could be a powerful way to indicate context.

6.1.4 Use of Emphasis

Participants used emphasis extensively in all kinds of inventive and freeform ways. Forms of emphases included items drawn larger, bolder, encircled, colored, starred, pointed at, underlined and put in focus in a great variety of imaginative ways (see Fig. 13 and 14). These strongly relate to previous whiteboard studies [45, 35, 36, 25], which, while not mentioning emphasis explicitly, discuss the freeform nature of whiteboards and interaction patterns. Our follow-up interviews indicated that there were other forms of emphasis such as small dark circles drawn adjacent to the item of interest and also that emphasis was often used to overcome the clutter on the whiteboards by making areas of importance or potential tasks more visible. “The double circle usually means that after I wrote this I went through this again, highlighting the important areas that I should be thinking about some more.”

Implications. We observed a great variety of forms of emphasis. Using these representations in our tools and allowing users to freely indicate emphasis in their visualizations for personal use or communication purposes could effectively augment visualizations.

6.1.5 Layering Information

While layering, erasing and palimpsests - each present in nearly half of the whiteboards, have not often been discussed as an information visualization topic, we include them in this section because this was the participants’ way of dealing with temporal information. Palimpsests and partial erasing create a type of clutter that appeared to be easily readable to participants. Our interviewees provided several reasons for their inclusion. Some stated that they were reluctant to erase more than necessary from the boards, and even more reluctant to erase anything from their colleagues’ boards, preferring to use overlays rather than accidentally erasing something important. Others explicitly discussed layers as temporal records that were important for their understanding

of their diagrams. It would appear that people are quite comfortable with layering and quite capable of reading through layers, particularly when they have seen them being created. An interviewee explained that layers could represent the evolution of a thought: “sometimes you don’t want to erase it completely because you want to kind of refer back to it, so instead of erasing it just put something bold so you can actually see both - the current thought and what I was thinking before. So the colors actually tell you temporal information” and “I choose different colors deliberately. If I use all the same colors, I don’t know what my latest thinking was. I tend not to erase my previous thinking because it might turn out that it was right.”

Implications. Layering has been considered in InfoVis via Magic Lenses and ToolGlasses [6], however, the overlays in these tools often replace visuals rather than layering on top of them. Our interviews suggest that layered information can serve as history and collaboration awareness cues. An interesting direction to further investigate is how to enable our tools to help people build these multiple layers of information.

Beyond temporal information present in the layering, participants were interested in longer-term whiteboard history. Some used photographs or their own software to preserve and maintain this history, others were merely keen to have a copy of the photo we showed them of one of their previous whiteboards. There was active interest in having some automated way of preserving whiteboard content. Some exploration of this area has occurred in previous whiteboard studies, for example by Branham et al. [8].

6.2 Thinking Diagrams

There was the huge variety of unique diagrams drawn on these boards (see Fig. 13 and 14 for two examples). Participants had created freeform diagrams as visual representations of their problems, their ideas, and their thought and work processes. These diagrams were hugely inventive and clearly meaningful to participants. There were no apparent feelings of doubt among the participants as to whether they could create good and useful visual representations. There was a clear confidence that they could make a diagram, at any given moment, that would be clear and useful to themselves and their collaborators. These diagrams ranged across the full words-to-diagrams spectrum. Interviewees directly talked about the potential of having their whiteboards interactive. For example, “If it is connected to my machine and it knows, and then I can just say, you know, straighten that or connect that, even as I am drawing it”, and “it would be nice if I could then (laughs) like have the drawing be more alive rather than once I’ve put the [makes a mark], the only thing I can do now is erase it”.

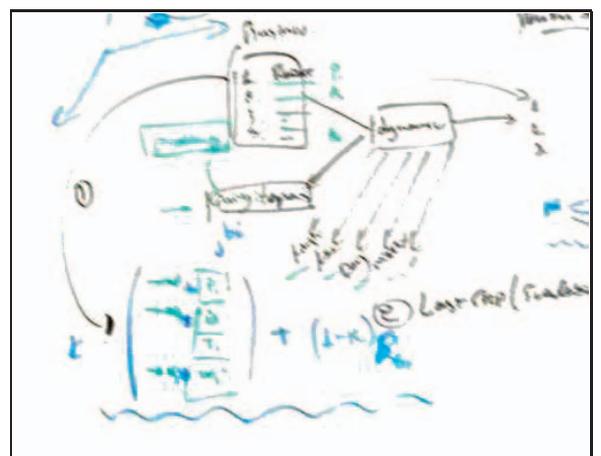


Fig. 13. Examples of *thinking diagrams*

6.2.1 Primarily Word-Based Constructs

The high percentage of whiteboards that used some primarily word-based constructs highlights the importance participants attribute to

6.3.2 Messiness

We saw several forms of clutter on the whiteboards, presumably a side effect of the affordances of a whiteboard: whiteboards are particularly suited to quick, ad-hoc jottings; their presence in offices means that information can be saved long-term with no actions required (such as taking pictures). One interviewee commented that his board often “silt” up, making it more difficult to use, because there was often persistent value to the content. Nearly half (33) of our whiteboards were classified as dense. In some cases, the dense whiteboards were relatively neat, but packed a lot of information onto one board. Often newer drawings were fitted in among previous drawings. In other cases, information was placed on the board in layers over time (sometimes of differing colors, sometimes not), giving the impression of a messy board. On dense boards, negation, emphasis, separation, and groupings were sometimes used to make the important parts more visible at the time of drawing. Some of our follow-up interviewees indicated that during meetings, getting an idea or point across quickly was more important than reducing clutter on the whiteboard; however when organizing their own thoughts some (not all) participants tended to be much neater. This point – working with and actually appreciating clutter and density – is one of the noted factors that is contrary to InfoVis design guidelines.

One interviewee pointed out that there was a dichotomy between what might to others look “messy” on his whiteboard but actually appeared clear to him because it was a good reflection of his mental model, whereas, the software he sometimes reverted to for the sake of permanence might appear “crisper” but was difficult for him because it “messed” with his thought process. “[Software] for me is a lot messier than this [whiteboard]. For me to replicate this [indicates whiteboard], [software] doesn’t give me enough constructs. Kind of messes up my thought process. You start using artificial shapes and places just to fit it in [with the software]. Over here [whiteboard], I can do a lot more thinking. And this [whiteboard] is a lot less stressful.”

Implications. Clutter reduction has been the focus of many researchers in the field of information visualization [19]. Our whiteboard study seems to indicate that some people are able to work with cluttered representations, especially if they have constructed them themselves over time. Our interviews suggest that what might in some conditions be called clutter, actually was being used to allow them to represent more information, in particular contextual and temporal information.

6.3.3 Sketchiness

By the nature of whiteboards as a medium most of the whiteboards’ content was, to some degree, sketchy. That is, the lines and text were not neat, crisp and tidy. Further, some content went beyond this with clearly exaggerated sketchiness used on purpose. This may relate to the much discussed factor in interface design that presenting design sketches that appear too neat and polished seems to discourage discussion [30]. For instance, when creating a new visual representation as part of a discussion, some additional sketchiness might be used to encourage communication and discussion. Sketchiness may be important and appears to be intentional: “[...] explain something to someone, and those are typically communication, un-neat and quick, cluttered.” Sketchiness and loose drawings were also important for indicating evolving personal thought patterns. Neater drawings had often been re-done as thoughts and ideas clarified “[...] I mean, the neater I try to write, the more fleshed out the idea is. And so I would try to write something down quickly and erase it and make sure that I have something that looks neater.”

Implications. Here, our results confirm previous results that sketchiness can help promote discussion. As visualizations become incorporated in software that is designed for collaborative, discussion-based decision processes, a possible research direction would be to inform future visualizations with the research that has been conducted around the use of sketchiness as a communicative aid.

6.3.4 Forgiveness

It is possible that the strong preference expressed for use of whiteboards as a thinking aid, both in solo and collaborative situations may stem at least in part from the general forgiving nature of the medium of whiteboards. For instance, people did not feel required to “get it right” the first time. They felt comfortable keeping partial thoughts up on their whiteboards since these could trigger new thoughts, and “it might turn out that they were right”. Thus mistakes were not thought of as mistakes but as an enriching part of the process. In contrast, comments about why they did not use software such as data-vis software or mind mapping tools included discussions about not liking to work when someone was looking over their shoulder because they might make a mistake. No one seemed to think that several people working at a whiteboard carried this kind of concern for being watched while one worked. Whiteboards have a great facility for being neutral, for letting marks made on their surface simply be marks. In contrast, software interactions are fraught with possibilities of making mistakes that will appear as mistakes in that the software will not respond as intended.

7 CONCLUSION

Through a qualitative study of 82 whiteboards from 69 researchers of a large institution, we have investigated the visual constructs that people spontaneously use on their whiteboards, and examined them from the perspective of information visualization. We demonstrated that examining these spontaneous visualizations that people use to think and communicate can help InfoVis researchers reflect on their practice and inform future designs.

Through this study we observed that the participants possessed the necessary inventive capability to create personal, at-the-moment visual representation of whatever problems, processes or data they wanted to discuss. They did make active use of well-known information visualizations, but the unique freeform diagrams were more common.

Highlights of our results include evidence that people tend to use words as primary objects rather than simply as labels, suggesting that InfoVis systems should attach more importance to the integration of words and diagrams. A brief summary of our implications follows:

- While we were assured that data-based conversations worked with simple sketches showing a suggestion of a data trend, there was some acknowledgment that real data would be better. However, it was clear that the other whiteboard factors such as immediacy and forgiveness were more important.
- It is possible that the use of ellipses is an under-explored opportunity for InfoVis.
- Our observation of use of context is that whiteboard practices for representing context align with the ideas of a just sufficient context [20] and with previous whiteboard studies [35].
- Participants seemed to readily cope with their own clutter. Extensions to InfoVis systems based on this finding could be cautiously considered.
- Mind mapping software tools tend to focus on words and InfoVis software tends to create diagrammatic layouts that are then labeled. Investigating a closer mix between words and diagrams might prove fruitful.
- Interviewees were directly interested in having their whiteboards interactive if this interaction further extended their freeform qualities.
- Participants were interested in the possibility of automated tools to preserve their whiteboard history.
- Freeform emphasis and subtle orientation adjustment seem to be powerful thinking aids that could usefully augment visualizations.

In the future, we are planning to apply some of these findings to the design of novel information visualization systems. We believe that the insights we gained from this study will help our systems to better support the visual thinking process.

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