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Using Visualization to Enhance Creative Thinking and Decision Making

This paper describes a real-world problem that the documentation team for a major feature of an upcoming product release is currently experiencing. Although there is little doubt that the problem described is prevalent among organizations developing computer software, it is perhaps less clear how this problem arises and how information visualization might offer an effective solution. Therefore, this paper discusses the problem in the context of creative thinking and decision making processes, describes the various types of visualizations that are available to assist project team members performing these complex cognitive tasks, and explains how one aspect of the problem might be improved by using a visualization appropriate to the task.

Real-World Problem Description

Although a Product Requirements Document (PRD) and a functional specification for the new Security Service had been written and distributed last year, the team currently documenting security topics is finding that:

- Desired features and/or functionality needed by other system components are being discovered late in the development cycle and must be retrofit into existing code. This results in a "scope creep scramble," whereby missing components are hastily developed/documented and planned components sacrificed.
- Individual engineers are supplying in their own details for components that were not completely described in planning documents and/or issues that were left unsolved during system design. This results in terminology discrepancies, in compatibility issues between security components (as well as with other system components) that require "documentation fixes," and so on.
- No single engineer has a complete picture of how the security system works that they can communicate to the documentation team. Individual engineers know the details of their component very well, but have limited knowledge about how that component works with others. This makes it extremely difficult to communicate the overall process to customers in the documentation.

Table 1 encapsulates this author's opinion about the causes of these problems in terms of their associated cognitive tasks.

Table 1 Problem Cause and Cognitive Task Matrix

Cause	Cognitive Task
Up front planning that fails to consider all aspects of the problem domain.	Creative thinking/brainstorming.
Feature/functionality trade-offs based on incomplete information.	Decision-making.

Before determining the types of visualizations that may be appropriate to the cognitive tasks listed in Table 1, it is necessary to learn more about them.

Thinking Creatively and Making Better Decisions: Two Sides of the Same Coin

If creative thinking is not encouraged and effectively supported, it is likely that not all aspects of a problem domain will be taken into consideration. More viable possibilities, options, and solutions might never be discovered or evaluated as part of a design activity. Project team members might gravitate toward an offered solution, modifying it and shaping it in iterations, when the initial concept underlying the solution is ill founded. To learn how to stimulate creative thinking while reducing tunnel vision and vertical thinking, one must first look at "creativity."

Creativity and the creative process continue to be rather elusive concepts (Bonnardel, pp. 158) but fortunately, many authors continue to tackle the subject. Shneiderman effectively consolidates discussions on creativity into three perspectives. For the purposes of this paper, Shneiderman's *inspirationalist perspective* is of interest because it is characterized by "Aha! moments;" in other words, the "flash of insight followed by much hard work to produce a practical result." This perspective focuses on developing strategies that inspire, and on methods for perceiving a problem "with fresh eyes." As such, it emphasizes the "brainstorming, free association, and lateral thinking" techniques that can help counteract humans' tendencies toward narrowing behavior (pp. 116-117).

The inspirationalist view of creativity is often described as "playful," and is best supported by loose, low-fidelity visualizations that reduce humans' inclination to organize ideas in a hierarchical or otherwise ordered structure (Shneiderman, pp. 116-117). Sketching information this way not only encourages collaboration and creativity, but also takes advantage of humans' inherent visual capabilities, increasing the probability that they will notice new characteristics, patterns, and trends (Gershon, pp. 9). As Sauter points out, "[creativity and] creative intuition revolves around alternatives, options, [and] possibilities" (pp. 111). Thus, the path for achieving the inspirationalist "Aha! moment" begins by generating as many ideas as possible.

Imagine that a project team thinks creatively and generates many ways to solve a particular problem. Does that "Aha! moment" just happen automatically? Of course not. While there might be "gut feelings" about which is the best solution based on the realm of possibilities, relying on intuition alone to reach conclusions is often dangerous. Our natural gravitation toward cognitive narrowing may simply be disguised by the euphemism of "intuition" (Sauter, pp. 110-111). But while we must constantly be vigilant in our efforts to avoid overly narrowing a problem space, we must also find ways to manage, consider, and sift through the information uncovered by creative thinking/brainstorming to arrive at the best, most feasible answer. Often, time is of the essence for decision-makers, and although much information might have already been discovered (or *constructed*, by some perspectives), it is probably also the case that gaps are still present (Gershon, 10; Sauter, pp. 109).

Like creative thinkers, decision-makers need to see patterns in information, but they also need to "perceive the inner nature of trade-offs [that are] inherent in any complex business situation," recognize assumptions underlying the information, and anticipate consequences (positive or negative) of the remaining unknowns (Sauter, pp. 113-114). Decision-makers must filter out large quantities of information based on other knowledge and criteria—such as requirements defined by other teams within the organization—all without overlooking relevant information (Sauter, pp. 110-112; Tegarden, pp. 3, 8). Although the information visualizations designed for decision-makers have historically been lackluster bar charts, tables, and graphs, even these simple visualizations have been shown to improve the "efficiency and effectiveness" with which people make decisions (Gershon, pp. 10; Tegarden, pp. 3, 8). This is because the visualizations help focus decision-makers' attention on the task of quantitative analysis by appealing to their "natural spatial/visual abilities to determine where further exploration should be done." Thus, "visualization...[allows] the decision-maker to *find the information in the data*" (Tegarden, pp. 6). When decision-makers have selected the best possible solution out of the many ideas generated from creative thinking/brainstorming, *that* is the true "Aha! moment" because it allows others on the team to proceed with confidence.

Using Concept Maps to Support Creative Thinking and Decision-Making Tasks

Although there are literally thousands of ways one can visualize information, little research has been focused on categorizing which types of visualizations are best suited to specific cognitive tasks (Gershon, pp. 10; Tegarden, pp. 30). This need for theory is not simply called for as an academic exercise, but because this research gap negatively impacts the practical (work) world as well. For example, the engineers the documentation team works with to gather information are generally quick to explain technical concepts using visualizations, but the structure and purpose of those visualizations is not always clear. Sometimes the visualizations themselves further confuse the explanation. Thus, it seems likely that the entire project team would benefit from an increased understanding of the methods and primary purposes associated with different visualization types. This section discusses one type of visualization that supports creative thinking and decision-making tasks, explains the theory behind the visualization, and provides instruction on how to create the visualization.

The Concepts Behind Concept Maps

Concept maps provide a way to externally visualize *concepts*, defined as "regularities in events or objects designated by some label" and the relationships between them (Novak and Gowen, pp. 4). Rooted in learning theories proposed by David Ausubel, the assumption underlying concept mapping as a visualization technique is that learning is not solely a process of discovering new ideas (called *reception*), but is also *constructed* through associations made with previously understood concepts (Tomei).

Concepts we already understand are organized by category in our long-term memories and linked by relationships we believe exist between them (Novak and Gowen, pp. 4). This is consistent with research that indicates the "human memory is most likely organized as a network" (Soderston, et. al., pp. 179). When new information is perceived, attempts are made to associate that information with existing concepts and to fit it into the existing conceptual framework. To ensure learning and understanding of new information (i.e. concepts), that information must be anchored "into the learner's already existing cognitive structure [to] make the new concepts recallable" (Bowen). In other words, information "that [has] relation to experience or memories that are firm in the person's memory [is] more likely to be retained" (Thompson).

How Can Concept Maps Help?

Novak and Gowen's work appropriately begins with the sentence: "Sometimes simple ideas are so obvious they are obscure" (pp. 1). This is most likely because the process of assigning meaning to new information and comparing the resulting concept with our existing conceptual framework all takes place in working memory, which has a fairly limited capacity (Soderston, et. al., pp. 180). Concept maps aid thinking, understanding, and learning because they remove some of the burden from working memory by externalizing these activities (Novak and Gowen, pp. 2). Thus, concept maps free up space in working memory, enabling us to use it to establish new connections among seemingly unrelated information (Chiu, pp. 75).

Other purposes of concept mapping that have been cited include: generating new ideas (brainstorming), communicating complex ideas, designing complex structures, assessing understanding, and diagnosing misunderstanding (Lanzing). These benefits of concept mapping have been particularly evident in the context of collaborative and groupware environments. Kremer and Gaines state: "In a multi-user environment, concept maps can provide user interfaces to shared resources supporting a range of group processes such as brain-storming, collaborative planning and joint development of knowledge structures" (pp. 159). Variations of concept maps, called *cognitive maps*, have also been successfully used to "represent conceptual structures underlying decision making" in management fields (Kremer and Gaines, pp. 156). Thus, there is evidence that concept maps can effectively support the cognitive tasks of both creative thinking and decision-making.

Lastly, concept maps do not require creators to use expensive software tools (though they are available), and the method for creating concept maps is easy to use (Karvonen, et. al., pp. 105). Project team members with diverse backgrounds, subject knowledge, or educational levels can all participate and achieve a shared understanding using concept maps (Gershon, pp. 14). Given these benefits, it is not surprising that concept mapping has also been shown to have a "positive effect on both attainment [i.e. learning] and attitude" (Chiu, et. al., pp. 75).

Creating Concept Maps

Explicit instructions about how to create concept maps are often described, but there is really no correct method or formula for visually organizing concepts into graphical maps (Kremer and Gaines, pp. 156-159; Soderston, et. al., pp. 181). The way to create a concept map depends on the information one is mapping. The basic idea, however, is that concepts are labeled and enclosed in a shape (e.g. square, circle) that represents their type, and then connected by lines with brief labels that illustrate the relationships between them. Each concept should be represented only once, and arrows may be used if the direction of the relationship is not clear. It is customary to indicate primary concepts by making them more prominent. While there is some question about whether concepts in a concept map could be sketched hierarchically, it may be easier to glean new associations if this type of organization is initially avoided (Soderston, et. al., pp. 181).

Other Appropriate Visualization Types

This section briefly describes two other visualization types that may be used (instead of or in addition to concept mapping) to support creative thinking and decision-making tasks.

Mind Maps

A mind map is a type of visualization very similar to concept mapping that is used to externally represent the structure of knowledge and ideas. Because of their similarity, the terms *mind map* and *concept map* are often used interchangeably. This is probably because mind maps and concept maps may be similar in appearance, and they do share the same benefits when used to support creative thinking and decision-making tasks. However, the subtle difference between these two visualization techniques is that while concept maps illustrate relationships between *several different concepts*, mind maps focus on aspects of *one, central concept*. Therefore, a “mind map can be represented as a tree, while a concept map may need a network representation” (Lanzing).

The process for creating mind map visualizations (originally conceived and copyrighted by Tony Buzan) can be summarized as follows:

> Draw a central word or concept in the middle of a page, then draw the 5-10 main ideas that relate to the central word around it, and connect these ideas to the central word with lines. Finally, draw the 5-10 main ideas that relate to each of the child words around each child word, and connect these ideas to their associated child word with lines (Bidarra, et. al, pp. 5).

The first part of the problem outlined in “Real-World Problem Description” on page 1 may have been alleviated if the security engineering team produced mind mapping (or concept mapping) visualizations early in the design phase of the project to brainstorm all possible options and make more informed decisions.

Rich Picture Technique

The rich picture technique originated from Soft Systems Methodology (SSM)—a system design methodology developed by Peter Checkland—that focused on identifying and understanding the different (and often conflicting) viewpoints of many actors in a work situation. If stakeholders' concerns are not met, systems with even the most detailed requirements and superb design will not be used. A rich picture, therefore, is a visualization technique that can be used to help system designers externalize and "reason about these divergent concerns" (Monk and Howard, pp. 22).

The benefits of rich pictures are similar to those of mind and concept maps (that is, improved and explicit communication, highlighting of ideas, relationships, missing elements, and so on), but focus more on the personal aspect of system design. As such, rich pictures must take into account *structure* (aspects of work that remain the same), *process* (aspects of work that change), and *concerns*, as described in the following process summary (Monk and Howard, pp. 23-24):

> Interview stakeholders (primary and secondary) about their work in their own environment. Then sketch the primary stakeholder in the center of a page (to avoid creating a hierarchical structure). Next, sketch the secondary stakeholders (those who affect the work of the primary stakeholder) and the structures "needed to explain the process of work." Fill in the process that exists among the stakeholders and the structures. Lastly, add concerns of stakeholders in thought bubbles. You may include a more detailed explanation of the concerns and responsibilities of the stakeholder on a separate sheet of paper (Monk and Howard, pp. 28).

The second part of the problem outlined in "Real-World Problem Description" on page 1 may have been alleviated if the security project team (comprised of representatives from engineering, product management, documentation, quality assurance, and so on) used the rich picture technique.

Sample Visualization

In the third part of the problem outlined in "Real-World Problem Description" on page 1, issues surrounding communication were introduced. "Attachment A: The Authentication Security Subsystem" provides an example of how a concept map visualization might be used to help improve communication among engineers and others on the project team. Although this concept map was created "after-the-fact," this type of visualization would also have been extremely helpful during the design of the security system. Had concept mapping been done during that creative-thinking time, the resulting organization might have been less complex and different trade-offs (decisions) made.

Conclusion

The causes of problems typically encountered during the software development process can be equated with specific cognitive tasks, which in turn may be aided by appropriate types of visualizations. By understanding the relationships between these elements, perhaps much last minute scrambling among project team members can be avoided, higher levels of communication and understanding achieved, and thus, higher quality software (and documentation) produced.

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