Visualization Research Based on Cognitive Design Principles

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Appendix

Designing visualization systems based on cognitive design principles is not a new methodology. Visualization researchers have applied similar strategies in a variety of data domains. As in our work, these researchers borrow results from the perception and cognition community. In some cases they conduct new user studies to identify the appropriate design principles and to evaluate the effectiveness of the resulting visual representations. Here we consider several notable examples of research that has followed this methodology.

In the domain of photography, books on photographic techniques have outlined a wide variety of design principles for creating good composition and effective lighting [13, 16]. These books explain that photographs are most pleasing when the subject is placed according to geometric criteria such as centering, the rule of thirds, or fifths, and the golden ratio. They describe how to position light sources to emphasize shape and material properties of objects. Recent techniques for automated photo cropping [18, 21] and image relighting [1, 8] are based directly on such principles.

In domains where the design principles are not stated so directly, one common approach is to identify the relevant prior research in perception and cognition and then synthesize a set of design principles based on this earlier research. While we used this strategy to develop our route map and tourist map visualization systems, others have applied this approach in different domains. For example, researchers have applied research on human perception of shape from image cues [11, 22] such as texture, shading and lighting to develop new non-photorealistic rendering techniques that emphasize the shape of a 3D object via texture [10], suggestive contours [7], or exaggerated shading [17]. The key contribution in this style of research is to connect the relevant studies on perception and cognition of visual displays with the algorithmic techniques for generating such displays.

Another approach to generating good visualizations is to conduct studies comparing the effectiveness of two or more visual representations for the same information. In the domain of information visualization for example, Bertin [2] developed the theoretical foundation for encoding data using visual variables such as position, length, angle, color, and shape. Subsequent human-subject experiments on *graphical perception* have rigorously tested the effectiveness of these variables [3]. For example, studies comparing bar charts versus pie charts have generally found that the length judgments required in bar charts are faster and more accurate than the angle judgments required in pie charts [4, 19, 20]. Other studies have investigated shape discrimination of scatter plot symbols [12, 23] and the tradeoff between the size and resolution in time-series visualizations [9]. Based on such experiments, Mackinlay [14] rank ordered the effectiveness of the visual variables (i.e. length is more effective than angle for encoding quantitative data). His APT [14] and ShowMe [15] systems for automatically designing effective charts and graphs choose the appropriate visual encoding for nominal, ordinal and quantitative data based on this rank ordering. Ware [24] has collected many of these findings in his textbook on Information Visualization.

Cole et al. [5, 6] have applied a similar approach to producing line drawings that best convey the shape of a 3D object. They asked artists to manually draw lines to convey the shape of 3D objects and then analyzed how often the artists drew similar sets of lines. Based on this analysis they suggest algorithmic techniques for producing effective line drawings [5]. More recently they have conducted an evaluation checking how well people perceive shape from line drawings, thereby closing the loop and validating the effectiveness of algorithmic line drawing techniques for conveying shape [6]. The primary challenge in this style of work is to develop experiments that will yield useful design principles for creating effective visual representations.

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