Cognitive Methods for Visualizing Space, Time, and Agents

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Abstract. Visualizations of space, time, and agents (or objects) are ubiquitous in science, business, and everyday life, from weather maps to scheduling meetings. Effective communications, including visual ones, emerge from use in the field, but no conventional visualization form has yet emerged for this confluence of information. The real-world spiral of production, comprehension, and use that fine-tunes communications can be accelerated in the laboratory. Here we do so in search of effective visualizations of space, time, and agents. Users' production, preference, and performance aligned to favor matrix representations with time as rows or columns and space and agents as entries. Both the diagram type and the technique have broader applications.

Keywords: diagram, space, time, agent, production, comprehension, preference.

Visual communications are some of the oldest as well as the newest form of communication, from local maps inscribed in stone to glitzy graphs in daily papers. They have been found in diverse cultures and preceded written language. Despite their prevalence, visualizations of the non-visible, notably data, are a recent phenomenon. Although many, such as the periodic table or Minard's depiction of Napoleon's unsuccessful campaign against Russia, are praised for their clarity, others are opaque and confusing. Designing good graphics is a challenge. Many common graphics, such as route maps, developed through practice in a community of users, a process that fine-tunes the graphics and improves communicative efficacy. That process can be accelerated in the laboratory, and used to reveal design principles in specific domains [1]. Users produce visualizations, and those visualizations are tested for performance and preference in other users. When there is convergence, that is, when the same visualizations prevail in all three tasks, design principles can be extracted.

This user-as-designer method was applied here to a common visualization problem, simultaneously communicating information about space, time, and agent, using the paradigmatic task of visualizing the changing locations of agents in time. Users' spontaneous graphic productions yielded strong consensus on a tabular or matrix representation of that information. Moreover, respondents put time on an axis, but placed people and locations equally on an axis or in the cells.

The performance and preference tasks assessed two main variants and two subvariants of matrices. The performance task was verification of many kinds of assertions

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possible from the visualizations, the kinds of information that might naturally be ascertained. Were certain people in the same place at the same time? Did a person go from one specific place to another? Did people congregate in a particular place? In the main variant of the visualization, table entries were color-coded dots; in the other, they were color-coded lines connecting cell entries (Fig. 1). In both cases, cell entries represented people. The visualizations also varied on the orientation of time, vertical or horizontal. To assess performance, participants verified whether a large set of relations among space, time, and agent were true or not, using the different variants of the visualization. Afterwards, they were asked which visualization they preferred for verifying a range of assertions of space, time, agent relations.

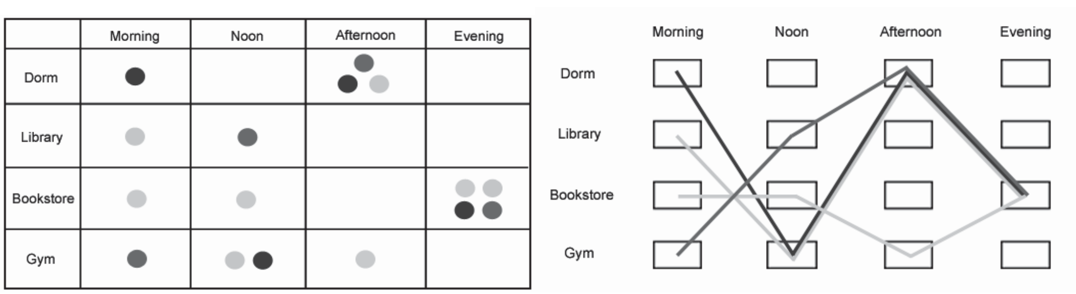

Fig. 1. Example stimuli

One expectation was that the lines would facilitate assessment of the relations of the people, specifically, their temporal paths. This prediction derived from previous work where lines encouraged trend interpretations [2]. The lines connected the people across time and place. Lines, however, clutter, making it more difficult to discern cell entries. Hence, other comparisons should be facilitated by unconnected dots as cell entries. The predictions for the orientation of time are less clear. On the one hand, earlier work on spontaneous graphic productions in children and adults found that they arrayed time horizontally more frequently than vertically [3]. This is, of course, the standard in graphs. Moreover, horizontal is often preferred for neutral dimensions, such as time, and the vertical for evaluative dimensions, such as preference, perhaps because the horizontal dimension is more neutral than the vertical.

Performance was better for matrices with dots than for matrices with lines ($F(1,126) = 52.29$, $p < .001$; Fig. 2) for nearly all statement types. The exception was statements of temporal sequence, such as "Alex went directly from the dorm to the

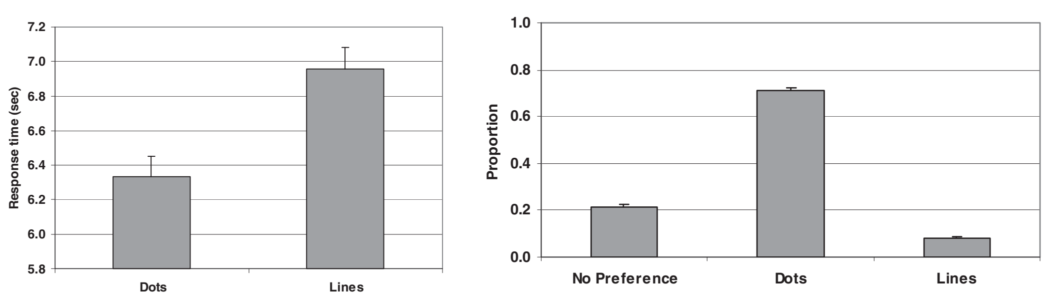

Fig. 2. Response times and preferences. Error bars represent standard errors of the means.

gym." As for the orientation of time, verification performance was equally good when time was vertical as when it was horizontal. Participants' preferences were in alignment with their performance. That is, they preferred matrices with dots for all question types ($\chi_2{}^2$s > 34.33; *ps* < .001) except for temporal sequence, and these preferences held whether time was oriented vertically or horizontally.

Thus, production, performance, and preference for visualizing time, space, and agents converged on a tabular representation with dots for entries, except for temporal sequences, where lines may be better. There was also convergence that time should be an axis, though there was no preference for the orientation of the axis, vertical or horizontal. This may be because there are strong correspondences of time to both vertical and horizontal in common visualizations. Graphs typically plot time horizontally, as do time lines. However, calendars and date books display time vertically, with earlier times at the top and later ones at the bottom. Because participants have undoubtedly used both tools, they are used to imagining time both vertically and horizontally.

The users-as-designers paradigm produced consensus on visualizations of time, space, and agent. This paradigm has been used successfully in other domains, namely diagrams of routes and assembly [1]. Together, the projects provide support for this set of procedures as a general tool for designing tools for human use. There are undoubtedly limitations to this design tool. In all of these situations, users had some familiarity with the task and with visualizations of the task. Thus, there is reason to believe that users can serve as effective designers only when they have some domain expertise, that is, past experience in comprehending and perhaps even in producing relevant visualizations, and in thinking more abstractly about the information. With that caveat, co-opting users to be designers and tweaking and testing their designs looks promising as part of a program for creating effective designs.

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