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Heterogeneous distributed problem-solving involving visual objects as boundary objects

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Communication involving visualizations in science and applications involves or even requires coordination. Much visualization research focuses on tasks in research or applications and provides valuable insights that help improve these modes and means of communication. That focus and resulting benefits makes a reduction to tasks or defined goals seem amenable for a more thorough consideration of social and cultural aspects. This contribution to the focus topic *Insights in Visual Communication* suggests that the boundary object concept can greatly help deepen considerations of social and cultural heterogeneity and adds insights and perspectives to better consider social and cultural aspects of visual communication. The theoretical concept of boundary objects, originating in heterogeneous distributed problem solving research, offer a pragmatic basis for enhancing visual communication to improve meaning production. The overarching issue for developing this direction in visual communication can be formulated through a broad question: In heterogeneous situations, how can research enhance communication involving visual objects for problem solving through a consideration of social and cultural aspects? I consider an example of cooperative design of maps to show how research can benefit from a consideration of boundary objects. The example highlights a cooperative mode of visual communication used in decision making involving both explicit and implicit goals and aspects from a cognitive perspective. The potential for improvements and better solutions in visual communication can benefit from a stronger consideration of the boundary objects concept.

KEYWORDS

distributed cognition, boundary objects, social and cultural aspects, communication, cognition

1 Introduction

In research and application involving maps, the challenges of finding agreement have remained a substantial challenge (Jankowski et al., 1997; MacEachren and Brewer, 2004; Quintero-Angulo et al., 2020) with different emphasis on either the visual or group aspects and ways to improve tasks or goals. Under consideration of the numerous ways visual objects support decision-making in groups, this contribution starts from Edwin Hutchins', *Cognition in the Wild*, with its widely recognized insight that cognition is distributed and should be studied contextually (Hutchins, 1995). It deepens those insights by considering earlier work from the then-nascent area of artificial intelligence research and engagements with sociologists and anthropologists considering the decision-making process, following on the limited successes of cybernetic approaches (Rowe, 1987; Hayles, 1999). It has lasting impacts on artificial intelligence and science and technology studies.

This earlier work, known then by the term "heterogeneous problem solving," considered how social and cultural aspects of individuals and groups could be even the most decisive factors in decision-making. Out of this research, Susan Leigh Start developed with her co-authors an important pragmatic concept, boundary objects, that emphasizes the underlying challenge of group coordination—small or large. Humans, as social as we are, and with or without technology, regularly struggle to find ways to bring and hold group members to consensus or even just modest acceptance of some common points (Harari, 2014). In this sense, if we accept Hutchins's cognition perspective, social and cultural aspects will be of great importance in all activities involving coordination that use visual objects.

This paper follows this emphasizing the role of visual objects as boundary objects in decision-making processes involving maps or map-like geovisualizations. It refers to graphical objects, yet underlying conceptual differences also need attention. For researchers with a psychology background, a map may be a generic graphic medium using spatializations to aid communication. Researchers from a sociological background emphasize almost solely the medial aspect. Specifically, this contribution connects a situational approach to heterogeneous problem-solving with distributed cognition. It considers social and cultural aspects in developing approaches to solution-finding involving maps in specific situations. The terms "visual objects" and "boundary objects" (explained below) provide important distinctions. The situational approach to knowledge production and distributed problem solving draws on a rich sociological tradition from the 20th century associated with the sociology of work and Grounded Theory (Glaser and Strauss, 1967; Strauss, 1990; Becker, 1992).

2 A task often involves more: heterogeneity in group decision-making processes

2.1 Coordination and distributed cognition

Many situations where visual communication takes on a central role in facilitating decision-making bedevil people through the various ways visual objects are understood: red for one person, orange for the next, blue is purple, a chair is a stool, this city symbol only indicates a town. Encountering such challenges in the wake of fascinations cybernetics and operations research in the 1970s (Rowe, 1987; Hayles, 1999), researchers working on the challenges of heterogeneous problem-solving in the context of artificial intelligence worked from a perspective on distributed cognition that rests on a central concept from social science research: all group activities and many individual activities require coordination. In parallel, it seems, and more widely known among cognitive researchers, Edward Hutchin's many years of research developed a related perspective that cognition is distributed. In his seminal work "Cognition in the Wild," he describes a situation involving multiple people with complex responsibilities and multiple positions who must find ways to ensure the large ship they are on stays on course while entering a harbor and docking. As Hutchins explains, the distribution of cognition is necessary for the activity to be successful. In cognitive research, a task or goal structures and focuses the efforts to coordinate, e.g., navigation of a ship involves diverse processes that make navigation in a harbor challenging. He writes of coordination, but this coordination is subordinate to the task. The perspective in much of the social sciences is that coordination is central and involves more than tasks or goals (Shapiro, 1987; Callon, 1997; Hanseth, 1997; Kotlarsky et al., 2012). The concepts of human action and understanding individual mental capacities have been far apart. However, the positions provide different perspectives on the same issue. In essential ways, they are complementary once assumptions about the mind and social organization are dispatched to consider that every situation is new. Parallels to past situations often exist, as do experiences—yet as the age-old insight goes: you can never step into the same river twice (Heraclitus). While relevant in visual communication, social and cultural aspects add additional complications. The common point remains in all forms of communication: coordination of individual cognitive capabilities and capacities makes complex tasks far more manageable. Coordination is integral to any successful activity involving distributed cognition.

Recalling Edwin Hutchins, *Cognition in the Wild* (Hutchins, 1995), distributed cognition can be studied in context. Heterogeneous distributed problem-solving research. This paper considers the social and cultural aspects central to coordination and complements Hutchin's concept. The emphasis in this particular text is on visual communication involving maps. In Hutchins's work, any complex task requires allocating distributed mental capacities with coordination. In his presentation, coordination involves shared mental representations. This position, reflecting Saussurean concepts of semiotic relationship, is known in visualization research through Bertin's *monosemiotique* approach to visual communication (Bertin, 1983). In hierarchical institutions, like a military or similar, it may be possible to have the requisite agreement and certainty regarding the meaning of visual objects. Complex differences are always likely in most institutions and in most situations in daily life. In general, but also in the context of less well-defined tasks, where social communities and cultural communication skills play an essential role along with various perceptual aptitudes, backgrounds, and professional training, understanding social and cultural aspects of visual objects may be as crucial as understanding cognitive activities. The position that coordination always involves distributed mental representations is the foundation for accounting for the diversity found in visual communication and considering social and cultural aspects of the overarching activities and individual tasks.

Starting from Hutchin's harbor navigation example, consider the critical roles of visual objects in coordination. A complex task (navigating a large ship into a harbor) requires the allocation of mental capacities to be completed. Visual objects involved in coordination are also boundary objects, which are, following Star "those objects that are plastic enough to be adaptable across multiple viewpoints, yet maintain continuity" (Star, 1989) (Kindle version w/o page numbers). In other words, a boundary object on a regional map made by the symbol that indicates a place of worship, that for that community is an essential center in their activities, which it symbolizes, is from the perspective of a government

body merely a structure where the community meets for religious services. Both meanings, despite their differences, coexist. While the meanings can change with political shifts in institutional perspective or over time, they may be agreed upon or rejected in new situations. In a new administrative map of the region, the building's symbolic representation reflects that priority, and for multiple reasons, despite different meanings for the community, it is accepted by them. Boundary objects help find agreements while sustaining differences (Harvey and Chrisman, 1998). In the same way, they facilitate the analysis of the social and cultural aspects and support their inclusion in research or application development. A point is elaborated in more detail in the next section of this article.

Indeed, the complexity of how people use visual objects in even mundane situations makes isolating tasks and goals from the complications of a work situation difficult, even impossible, without considerable investment in studies of the issues. As always, any derivation or identification of activities and tasks abstracts through specific requirements that find multiple interpretations. Because the issues are complex, and the past and present complexity is often beyond the scope or resources of the means available, boundary objects help facilitate research into the immediate known complexities of tasks and their frequent complex contingencies.

There are numerous examples of how visual objects become and develop as boundary objects in visualization research. In terms of maps and geo visualizations, we could return to the twentieth work with Isotype and consider many details of how Marie Neurath developed boundary objects in the design and production of a beautiful series of children's books after World War II (Neurath and Kinross, 2009). It is relevant here, too, to remember that the persistence of boundary objects corresponds to their flexibility: they shift meanings over time. A pond may become a lake at certain times of the year due to flooding. A symbol for a city may also indicate a town in particular contingencies. Of course, these are no "immutable" objects, but while maps and other symbols, once printed, do not change, their meanings can change, disappear, and reappear over time.

3 Many perspectives on visual communication

In visual communication, people will understand objects in multiple ways. Well established in cognitive research, perception faces influences in environmental, physiological, and other factors (Ware, 2008), which are complementary to understanding visual boundary objects influenced by social and cultural aspects.

In the following example that focuses on these aspects, I draw on previous research that considers the work of heterogeneous problem-solving involving maps. They highlight the potential of boundary objects in visualization research to enhance considerations of cultural and social dimensions of collaboration. This example is based on a case published in 2018 (Harvey and Losang, 2019).

In heterogeneous decision-making, visual objects can take on significant roles as boundary objects that provide essential references for agreements in the group and flexibility to find and sustain different understandings. Social and cultural aspects can manifest themselves in various ways. The heterogeneity means that no single social or cultural framework exists for determining or interpreting meanings. Some issues may be agreed to, some may be excluded from consideration, and some meanings may become relevant to finding agreements between involved groups and individuals. The boundary objects belong to the latter group.

Creating a new travel map of the region brings representatives of planners, the regional executive and transportation engineers together. The resulting map should be a reference for government offices, but the main goal is producing, particularly by people visiting the region. Out of long and complex discussions, we focus solely on the social and cultural aspects of roads, especially the classification of roads. Three different types of roads are visually distinguishable on the map and provide a way to distinguish the roads by their quality and suitability for different vehicles and speeds. What this means and how this should refer to specific map users are complicated. The planners suggest the distinctions may be fine for tourists but also agree with the engineers that the role of the roads in the transportation system should also be distinguished to help tourists and residents. They point out that this detail will be helpful for the orientation of visitors to the county and help them choose the best route according to their driving ability and interests to various destinations. An addition of three different road types is proposed that reflects functional distinctions of highway engineering (A, B, C categories) is deliberated in the meeting. The engineers agree but add that the functional distinctions should be the primary distinguishing character, and each road segment, instead of whole road sections, should be differentiated. The person representing the regional executive argues that the additional graphical complexity must be clarified. The compromise proposal emphasizes the distinction between A-roads, B-roads, and C-road categories that primarily helps visitors and residents orientate themselves and plan routes. The specific suggestions for more detail should be considered for a different map. The meeting ends, and the representatives return to their departmental offices until the next meeting will occur in 2 weeks, just before the spring holidays. At the next meeting, final decisions must be made to give the cartographers enough time to prepare the map and get it to the printers for distribution in local hotels, restaurants, tourist attractions and other offices before the summer holidays. A classification discussed there also contains the semantically relevant distinction of poor road conditions while simplifying the visual presentation.

At the next meeting, the engineers say they still agree in principle with the county executives, and they see the necessity of the compromise but do not see how a new map could be made and suggest now making two maps, with the general map adding a category "tourist route" to select roads. Ultimately, as the clock is ticking and many other elements of the map need to be accepted, the others go along with the compromise as long as the symbol for tourist routes does not obscure the symbol for road conditions but postpones the decision on approving the budget for the internal map.

In this example, three visual objects are also boundary objects. First, the different types of roads based on their representation; second, the difference between presenting smaller road segments or longer road sections; and third, creating an additional symbol

for tourist routes. The positions regarding each boundary object are culturally distinct. The engineers want more engineering detail; the planners want more generic symbology for an easily comprehensible overview. The county executive wants a more general map, but more general and less complicated for visitors to the region. The social aspects in this condensed example show how each group positions itself regarding the final compromise. Ultimately, it means creating a map with far more detail for internal government agency use. The resulting symbology for the regional general map is an agreement, a compromise, that can be understood better through these boundary objects. The boundary object concept helps analyse the social and cultural aspects of finding a compromise among different positions.

4 Discussion

When visualizations have roles in coordinating activities, many issue involve social and cultural aspects. They will always be complex, but as this contribution shows, the boundary objects concept extends analytical capacities in research and application development to consider these aspects and support processes of finding agreements. Depending on your point of view, this concept is essential for visual communication to complement or extend the insights of Hutchins's work. Indeed, it is also helpful as a framework in research that helps account for the many factors outside of the task and related cognition. As Bertin (2000) wrote about the issue, "However powerful our rational efforts will be, they will always be swept away in the infinity of irrationality."

In this sense and for consideration as a conclusion, Bertin's insight reminds us that these issues are also matters that we can find in other scientific research contexts and application domains, where different disciplinary perspectives alone can be very significant. Faced with ambiguity, how do different disciplinary perspectives find agreement? Cognition has been central in problem-solving, yet many issues faced in visualization research and application development have decided social and cultural roots. The potential for improvements and better solutions in visual communication can benefit from a more robust consideration of the boundary objects concept.

As a final concluding point, it is helpful to consider that the approach described in this contribution draws on work in the intersection between sociology and AI research. The situational approach in sociology, including the boundary objects concept, to knowledge production and distributed problem-solving draws on significant research from 20th Century sociology. A renewed consideration of these concepts and research may also benefit visual communication research. In particular, considering how in the process of communication individuals and groups make and change meanings of visual objects, analyzed as boundary objects with multi-facetted meanings, may prove a promising direction for future AI-related research, e.g., comparing different tokenizations in LLM-based applications of AI.

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