

# Diagrams and problem solving

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diagrams, problem solving

The use of diagrams as external aids to facilitate cognitive abilities is not new. This paper looks into cognitive studies for insight into when, why and how diagrams are effective in problem solving. A case study examines the use of diagrammatic representations as thinking tools and tools for communicating information. The purpose is to examine whether diagramming could be used as a design method, as part of the designer's creative process.

## Introduction

The need for organizing and visualizing large amounts of data and complex systems has increased in recent years in all domains. Designers now face challenges that are new to the visual communication discipline such as the development of interactive interfaces and computer software.

As a researcher and educator in Information Design, I am constantly looking for procedures and methods of dealing with complexity. Literature on cognitive sciences suggests that key to problem solving is finding the "right" representation: 'solving a problem simply means representing it so as to make the solution transparent.' (Simon, 1981, p. 153)

How to find the appropriate representation for a complex problem? How to move from an unclear, complex situation into clear, direct action? How to develop structural insight?

This paper investigates diagramming as a method for facilitating problem solving. It starts with a brief description of cognitive studies on the role of diagrammatic representations in problem solving. It is followed by a case study examining the use of diagrams as thinking tools and for communication purposes in a classroom assignment: "Mapping Movies."

## Visual artifacts as cognitive aids

Cognitive research has shown that when we are solving problems we use both internal representations —stored in the brain—, and external representations —stored in the form of artifacts (i.e., Pinker, 1985; Larkin & Simon, 1987). This paper is exclusively concerned with the latter:

The power of unaided mind is highly overrated. Without external aids, memory, thought, and reasoning are all constrained. But human intelligence is highly flexible and adaptive, superb at inventing procedures and objects that overcome its own limits. The real powers come from devising external aids that enhance cognitive abilities. How we increase memory, thought, and reasoning? By the invention of external aids: It is things that make us smart. Some assistance comes [...] through the development of tools of thought—cognitive artifacts—that complement abilities and strengthen mental powers. (Norman, 1993, p. 43)

The use of diagrams as external aids to facilitate cognitive abilities is not new. Diagrams have been extensively used in problem solving in different domains, from physics and engineering to music and design. It is well known that scientists throughout time have made use of diagrams to solve complex problems. Familiar examples are those of Galileo, Einstein and Henri Poincaré, just to mention three (i.e., Wertheimer, 1959; Miller, 2000). In the design discipline well known examples are interactive projects (i.e., Card, 1999; Kahn & Lenk, 2001). It is clear that it would be hard, if not impossible, to develop web sites without diagrammatic representations, in that one is dealing with complex systems that are multi-dimensional and nonexistent in physical space. In such projects, diagrams are also often used as tools to help solving conceptual and structural problems: 'the planning diagram is an artifact of the design

process. [...] it is a critical part of the design' (Kahn & Lenk, 2001, p. 35).

It is perhaps no coincidence that there are many overlaps between the definitions of the verbs "to see" and "to understand:"

**see verb 1.** *I can see the house* make out, catch sight of, glimpse, spot, notice, observe, view, **perceive**, **discern**, espy, descry, distinguish, identify, **recognize**. [...] **4. see what they mean understand, grasp.** get, **comprehend**, follow, take in, **know**, realize, get the drift of, **make out, fathom**; *inf. latch on to*. **5. go and see what he wants** find out, discover, **learn**, ascertain, determine, ask, inquire, make inquiries into/about, investigate. **6. we will have to see think**, consider, reflect, deliberate, give thought, have a think.

**understand verb 1.** *understand his meaning / understand what he says* **comprehend**, apprehend, **grasp, see**, take in, **perceive, discern, make out**, glean, **recognize**, appreciate, get to know, follow, **fathom**, get to the bottom of, penetrate, interpret; *inf.* get the hang/drift of, catch on, **latch on to**, figure out. [...] **3. I understand that he has left** gather, hear, be informed, **learn**, believe, **think**, conclude.

(*The Oxford American Thesaurus of Current English*, 1999, italics in original, my bold italics)

## Cognitive research on problem solving

Cognitive research on how visual representations facilitate problem solving offers insight into when, why and how diagrams are effective. Larkin and Simon (1987) carried a series of studies comparing sentential to diagrammatic representations in computational problem solving. The two representations differ fundamentally in how data structure is indexed: in a verbal description by position in a sequence, and in a diagrammatic representation by location in the plane. They propose that a representation is effective to problem solving when it facilitates: search, recognition and inference.

The examples described by Larkin and Simon were of problems in physics and geometry. Results showed that a key advantage of diagrammatic representations was that they preserved explicitly relevant aspects of the problem (i.e., topological and geometric relations among components) implicit in the verbal descriptions. Another important aspect was that the spatial organization of diagrams allowed all information needed for future inference to be grouped and located together, thus facilitating search and reducing working memory. Recognition was also enhanced, in that diagrams supported a large number of perceptual inferences, which were easy for humans.

Even though, in the examples examined, the diagrammatic representations were superior to the verbal descriptions, Larkin and Simon caution that an arbitrary diagram doesn't guarantee efficiency in problem solving. Moreover, that a problem solver needs the knowledge of how to construct a diagram that would be efficient for the task in case, for which the advantages discussed could serve as guidelines. In other words, essential to problem solving is finding an appropriate representation with which to solve the problem. A representation that is "right" will foster new knowledge, insights and creations.

Thus, it could be said that diagrammatic representations facilitate problem solving in two distinct, though interconnected ways:

- using (an effective) diagrammatic representation to solve a problem (instead of, or in conjunction with a verbal description);
- finding (the right) diagrammatic representation with which to solve the problem (from the stated description in whatever given form).

Research on the cognitive operations a person executes in the process of reading a graph yields interesting results that contribute to the critical issue of finding the right representation. Pinker (1990) examined these operations in relation to quantitative graphs. A key component of his proposition is that 'people create schemas for specific types of graphs using a *general graph schema*, embodying their knowledge of what graphs are for and how they are interpreted in general' (Pinker, 1990, pp. 104, italics in original). He suggests that the theory can be easily extended to charts and diagrams used to represent qualitative information, where again, the reader would use schemas to mediate between perception and memory. Efficiency would be provided to the extent that the schema allows for correspondences between conceptual information and visual attributes and in so far as the visual attributes are encoded reliably.

The two studies mentioned as well as literature on Information Design (i.e., Bertin, 1967/1983; Card, 1999; Ware, 2000) suggest that effective diagrammatic representations use perception to amplify cognition. The fact that diagrams make use of spatial and perceptual encoding of information into a schema makes the system —elements and relations— and the patterns within the system readily visible, explicit and easily perceived. It also allows the problem to be viewed simultaneously as a whole (in relation to both global and local levels).

Key to structural representations is the understanding of visual organizational principles, which again serve as guidelines for effective construction of diagrams. A fundamental set of principles governing how individual units are integrated into a coherent percept is offered by the Gestalt laws of perceptual organization (Wertheimer, 1923/1950): proximity, similarity, common fate, good continuation, closure, symmetry, and differentiation between figure and ground.

The Gestalt laws can also be viewed as operations employed in thinking processes. Wertheimer (1945/1959) argues that grouping, reorganizing, centering, etc., are essential to problem solving in that they relate to the whole-characteristics of the situation. For him, “productive thinking” happens when a problem is viewed not as piecemeal, rather when it is considered as a whole, in its structural requirements. For Wertheimer thinking consists in:

Envisaging, realizing structural features and structural requirements; proceeding in accordance with, and determined by, these requirements; thereby changing the situation in the direction of structural improvements, [...]; realizing structural transposability, structural hierarchy, and separating structurally peripheral from fundamental features—a special case of grouping; looking for structural rather than piecemeal truth. (Wertheimer, 1945/1959, pp. 235-236)

Diagramming as a thinking tool involves two interrelated processes: segregation —selecting, identifying essential elements and subsystems, etc.; and integration —organizing, grouping, finding connections and relations between and within the elements of the system. Also relevant is that the function and adequacy of diagrammatic representations in problem solving is task-dependent, context-related.

In relation to the encoding and decoding of entities as visual attributes (symbols) Bertin (1967/1983 and 1977/1981) offers a good set of principles he called “retinal variables.” These graphical variables are organized into spatial and object properties and examined in relation to whether they are effective in expressing extent of a scale or as differentiating marks. Graphic notation is essential to the effectiveness of diagrams, especially when used for communication. For the purpose of this paper, these issues will not be discussed.

## Some definitions

The case study examines a problem involving the representation of a complex system. This paper adopts Simon’s definition of a complex system that is:

One made up of a large number of parts that interact in a nonsimple way. In such systems the whole is more than the sum of the parts, not in an ultimate, metaphysical sense but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole. (Simon, 1981, p. 195)

According to Simon (1981) complex systems are hierarchic (in a broader sense than simply representing relations of subordination), nearly decomposable and redundant structures. These properties allow for achieving the simplification of complexity, which, as he suggests, is only possible by finding the right representation.

This paper considers a diagrammatic representation to be a schematic spatial representation of a system, of collections of data or concepts. Diagrams are purpose-specific and, most of the time, domain-specific representations. The schema is a compound of objects (elements, subsystems) and the relations between and within the objects. In other words, elements, properties and relations in a domain (e.g., philosophy, chemistry, music) are represented symbolically as spatial relations between visual objects in a diagram.

## Case study

### The problem

The assignment "Mapping Movies" was created for the course Information Architecture in Spring 2004, required for junior level Graphic Design majors in my institution. Similar to other information design assignments, the objective was twofold: to explore methods and procedures used in structuring information and, to examine design solutions that make complex information easier to understand and to use by a specific audience.

To deal with complex information is not an easy task (not only to my undergraduate students). The challenge was thus to find ways to deal with complexity without the overwhelming accompanying factors. The solution was to choose a subject that would be complex enough and at the same time fun to work with.

The topic of the assignment is a cinematic narrative. Students have to select a film from a list of movies that were specifically chosen for their non-linearity features. Thus, complexity is given not only by the amount of information in a film, but also by the fact that the selected movies have unusual cinematic structures. A movie is a linear series of events happening in space and time. Similar to a sentential representation, the data structure of a movie is indexed by position in a sequence.

The assignment's requirements were:

- **task:** to create an informational diagram/map of a cinematic narrative
- **goal:** to visually represent and communicate the film structure by organizing the narrative and the patterns within it: plot, characters, events in the story (or stories), etc.
- **audience:** undergraduate film students

It is relevant to mention that the task was not to represent how one experiences the movie as a viewer, such as the sequence of events in which they happen. Rather, to communicate how the film was constructed: the whole structural organization, the essential features and their interactions.

Three students were selected for the present discussion. The analysis starts with a description of the process, and is followed by a brief examination of the final solutions. For the sake of understanding the individual trajectories, images were kept grouped by student.

### The process

Description of the process is based on my empirical observations of the patterns in students behaviors along the course of three semesters (total of 54 students). The images presented, however, will only be from work of the selected students.

The design process will be divided in two phases. The first involves finding the "right" representation with which to solve the problem; and the second, how that representation was used to design the final output.

The first step of the first phase consisted of familiarizing oneself with the content: watching the selected movie. It was followed predominantly by note taking while watching the movie again, often times more than once (Figures 1; 5; 9). In few cases note taking was combined with diagrammatic attempts. At this stage it was clear that students were searching for the essential components, distilling, segregating peripheral from fundamental features. The third step was fundamentally attempts at diagrammatic representations. These diagrams involved grouping, organizing and making connections between the elements. Students at this point were searching for the structural features, integrating the parts within the whole (Figures 2; 6; 10). Once the representation "fitted" the problem, students then started phase two of the process.

Phase two involved design decisions of how to communicate the structural features for the specific audience. Among them were issues related to: how the entities would be graphically represented (if symbolically, typographically, photographically, or combinations, etc.); how to make the relationships among the entities visible (methods of layering, grouping, perceptual

clues, etc); final format of the solution (for previous versions see Figures 3; 7; 11; for final solutions see Figures 4; 8; 12); etc.

The process suggests that diagrammatic representations served different purposes and changed function: diagrams in the first phase were mainly used as tools for one's own reasoning, discovery and decision making, whereas in the second phase, they served as communication tools, towards presenting and informing the essence and structure of the movie to the audience.

One could speculate that students used diagrams in their processes because the task induced their usage. On the other hand, it is possible to argue that the limited ability of the mind to keep track of complex systems presented linearly (in this case a movie) might have caused the need for the creation of diagrams as external cognitive aids (such as those in the first phase). Even though students started with written notes, mostly lists of events in the order in which they appeared in the movie, soon after they were creating a series of diagrammatic representations. These representations mainly deal with structural and conceptual organization of the movie, where the "real" sequence of events is no longer relevant, on the contrary. By representing spatially the critical features and structure of the movie, by making explicit relevant components and relations within the system, students enhanced the process of interpretation, translation and analysis, which was essential to the successful achievement of the task.

## Student 1

student: Jonathan Rissmeyer

film: *Mystery Train* by Jim Jarmusch

Figure 1: Notes taken while watching movie and few initial sketches (used with permission of Rissmeyer)



Figure 2: Sketch of structural features of the movie using a circular schema. This schema ended up being the diagrammatic representation adopted in the final solution (used with permission of Rissmeyer)

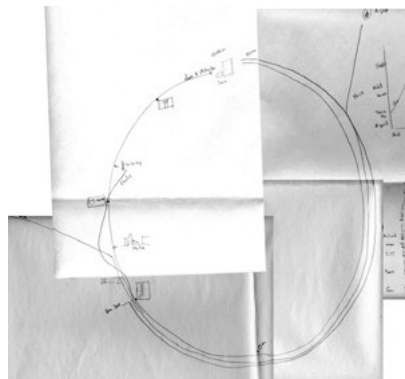


Figure 3: First attempt to map the movie in a circular schema (used with permission of Rissmeyer)



Figure 4: Photo of final solution: a moving wheel. Each ring presents a sequence of main events of a character. The rings are color-coded and grouped by story. By moving the rings it is possible to make connections between the three stories according to the following categories: time, space and sound (used with permission of Rissmeyer)



## Student 2

student: Kevin Longo

film: *The Hours* by Stephen Daldry

Figure 5: Notes taken while watching movie (used with permission of Longo)



Figure 6: Initial diagrammatic sketch mapping events for each character, in this case, Virginia Woolf. Also first attempt at creating symbolic language to represent connections between characters (used with permission of Longo)



Figure 7: First attempt at using a linear schema to structure the whole movie with symbols representing the connections (used with permission of Longo)

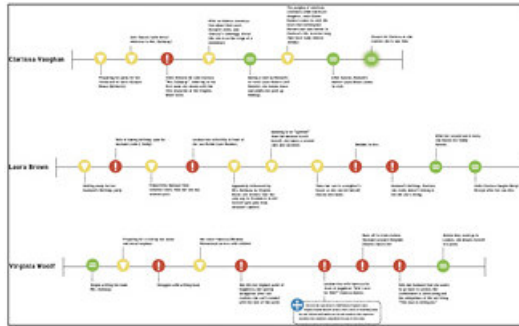
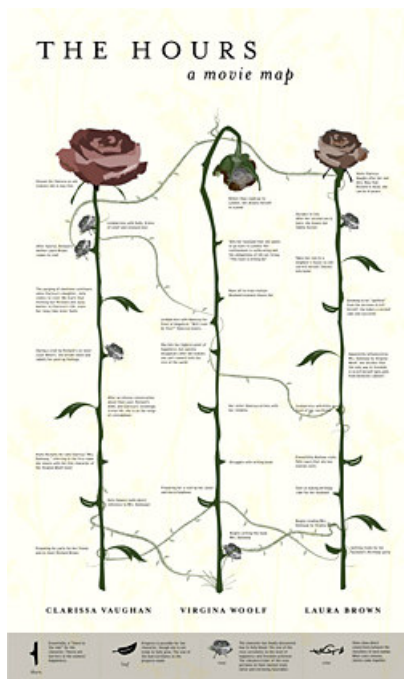


Figure 8: Final solution: a movie map. The solution uses the metaphor of a garden, where each character is represented as a flower and the connections as vines. Main events for each character are represented symbolically and verbally in the vertical axis. Events are coded in relation to three main categories: problems, progress and happiness (used with permission of Longo)



### Student 3

student: Tomoko Yokoyama

film: *Rashomon* by Akira Kurosawa

Figure 9: Notes taken while watching movie and few initial sketches (used with permission of Yokoyama)



Figure 10: A series of diagrammatic sketches trying to represent the movie structure and events in the story. The top diagram shows events organized by time. The others are different attempts at finding the "right" diagrammatic representation (used with permission of Yokoyama)

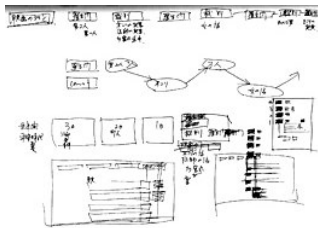


Figure 11: First attempt to map the structure of the movie using the matrix schema discovered earlier (used with permission of Yokoyama)





Figure 12: Final solution: a bilingual matrix representing the structural features of the movie. Time is represented vertically and to the far left. The main events are positioned sequentially in the horizontal axis at the top of the matrix. The characters are organized vertically and their versions are aligned with the main topics (at the top of the matrix). Color was used to code specific types of events (used with permission of Yokoyama)



## Conclusion

Research has shown that in general (within the constraints described), diagrammatic representations are effective in facilitating problem solving. However, in the visual communication discipline diagramming is not a common education practice outside information design courses.

Frascara (2001) points out that diagrams haven't penetrated education, where verbal language, and thus linear-thinking, is the paradigm:

Instead of looking at isolated events in a linear, language-based, binary way, a more responsible and intelligent approach to knowledge would be to look at diagrams as tools that foster the understanding of ecologies of information, and as instruments that assist the development of intelligence. (Frascara, 2001, p.169)

It remains to be investigated whether diagramming would facilitate other design problems. The research described in this paper indicates that diagramming facilitates problem solving especially when dealing with complexity and systems presented linearly. The examples provided show that diagrammatic representations have been used in the search for the "right" representation with which to solve a problem. Norman (1993) points out that the powers of cognition come from abstraction and representation: 'We expand the mind's representational power through the use of external structures and representations, through cognitive artifacts' (Norman, 1993, p.127).

Furthermore, Sims-Knight (1992) discusses in detail that the designer's intuition is not enough, and can many times be misleading, in achieving effective communication solutions.

Empirical and scientific evidence (i.e., Larkin & Simon, 1987; Pinker, 1990; Ware, 2000; Frascara, 2004) suggest that diagrams represent and communicate information in a way that is easy to perceive and reason because they tend to exploit general cognitive and perceptual mechanisms effectively.

Finally, it can be suggested that diagramming as a design method, as part of the designer's creative process, can help achieving analytically derived solutions that are visually effective and clearly communicate information.

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