UNDERSTANDING DIAGRAMS: A POINTER TO THE DEVELOPMENT OF DIAGRAMMING SOFTWARE

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Visible Language 42.3
Fathulla, 265–284

ABSTRACT The richness of diagrams is a characteristic reflected in their continuous use by humans over millennia across many applications and disciplines. Discussion of this richness is often expressed in one of two ways: either in terms of the constraints of the particular application and/or context within which diagrams are used, or through some meta and abstract formalism. Both approaches are grounded in traditional reductionist western scientific ways of understanding reality. The thinking behind such approaches has been instrumental in guiding the design and development of diagramming software. However, there is yet another level of richness of diagrams that could not be adequately accounted for by the constraints of the application or through any single formalism. Most real world diagrams often contain a mixed type of diagrams such as box and line, bar charts, surfaces, routes or shapes dotted around the drawing area. Each has its own distinct set of static and dynamic semantics. Both ways of discussing diagrams mentioned so far do not adequately capture this level of richness. The consequences of this inadequacy impact on the development of diagramming software. Existing diagramming software is either too specialized and therefore cumbersome and difficult to use, or too general, thus of little use in representing knowledge. In both cases the software becomes a hindrance to the user's activity and thinking rather than a help to it. In this paper a meta, non reductionist, framework for understanding diagrams based on symbolic and spatial mappings capable of accounting for this richness is proposed and discussed. The potential of the framework to guide the development of good diagramming software is demonstrated.

ON THE RICHNESS OF DIAGRAMS

The way people use diagrams, irrespective of the application, has been eloquently described by J. D. Watson, Nobel prize winner (1968), who discovered the structure of DNA: "...drawing and thinking are frequently so simultaneous that the graphic image appears almost an organic extension of the thinking process." Barkowsky and Freska (1997) argue that human interaction should be a fundamental approach to understanding maps. Godfrey (1998) acknowledges the richness of diagrams: "Drawing is not just a medium or a technique: it is a human activity with a rich and complicated history." Schön (1995) in the context of architectural drawing calls this the architect "holding a conversation with the drawing." Hetzeberger (1991) says that it must be one's own thoughts that determine a drawing and not the other way round. Norman (1990) argues for the need to move towards the point where the richness of human experience comes to the foreground and computing sits in the background. Bertin (1983) suggests similar viewpoints saying that a diagram "...is not 'drawn' once and for all; it is 'constructed' and 'reconstructed' until it reveals all the relationships constituted in the interplay of data...." "A graphic is never an end in itself, it is a moment in the process of decision making." In the context of their paper on creative design Neislon and Lee (1994) point out that "Design is a revolutionary process in which how a problem is defined in the mind of the designer changes dramatically over time." Schön (1991) characterizes this view of diagramming as the "reflective conversation with the materials" in his discussion of effective designs. Bishop (1994) states that a centuries held assumption that "a drawing-is a drawing-is a drawing" is progressively shown to be invalid. Gombrich (1966) adds to this view by saying that "to see the shape apart from its interpretation is not possible." This ability is referred to in Gombrich's discussion of Leonardo's creative process, he suggested that "...in searching for a new solution Leonardo projected new meanings into the forms he saw in his old discarded sketches."

The above serves to demonstrate the richness of diagrams in the context of human functioning. However, there is another level of richness (see next section) which transcends the human role and is about diagrams themselves.

Richness beyond actual uses of diagrams

Real world diagrams, regardless of their application, are quite complex. Even a simple box and line diagram (*figure 1*), can be messy because a number of mistakes have been crossed out; it can also have some rather crowded areas in which it is difficult to find space to place new shapes. The various boxes are labeled with letters, e.g., A, B, J, etc., for referencing purposes.

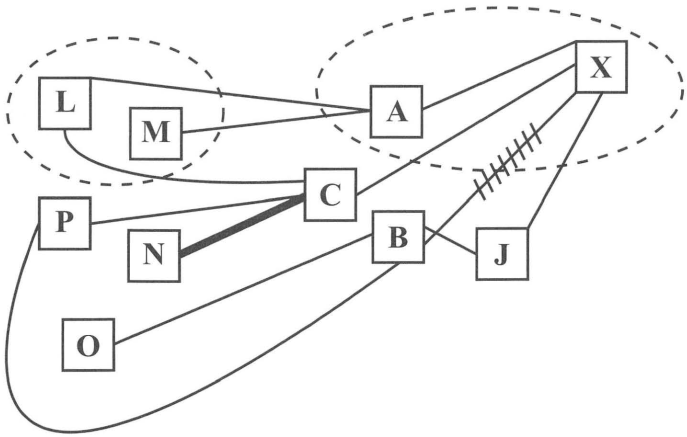


Figure 1 Box and line diagram.

A number of other characteristics of such diagrams are shown in Table 1 (*with reference to figure 1*).

Characteristics	**Diagram feature**
Consisting of visual elements each of which has some symbolic meaning	Boxes and lines, thick lines, circular curves
Expressing several different types of symbolic information	Items and relationships, also specific things like set membership or degree of influence
Containing a number of mixed visual styles to express these different types respectively	Boxes and arrows, circling (Boxes L & M), thickening (Line connecting boxes N & C), and looping (Line connecting boxes B & P)
Growing and changing rather than consideration of a diagram as a finished product	Not applicable
Editing involves replacement of parts that have already been drawn being replaced by others	Line between box B and X
Thinking, or part of it, is inherent in communication	Not applicable
Diagramming process is fluid and refers to active human processes when engaged with a diagram	Not applicable

Table 1 Semantics of real world diagrams

Others have found similar features to the above list; Neilson and Lee (1994) discuss an experiment in which such diagramming process is employed by an architect. I have found similarities between their observations and our list:

> *"changes to the drawing were not necessarily consistent with one another,"*
>
> *"the architect did not maintain a consistent interpretation of the drawing over time,"*
>
> *"the use of 'incomplete' drawings,"*
>
> *"the frequent wholesale reinterpretation of (parts of) drawings,"*
>
> *"common wide divergence in different reinterpretations of essentially different picture elements and relationships,"*

The previous sections served to illustrate that our understanding of diagrams should:

> *1. Evolve around human functioning*
>
> *2. Respect the richness of diagrams that transcends application constraints. Such richness is characterized by the distinctiveness of the various drawing styles expressed through distinct ways in which spatial and symbolic aspects are mapped.*

Having discussed the richness of diagrams the question now focuses on how existing ways or frameworks for understanding diagrams deal with the richness.

Existing ways of understanding diagrams

A number of frameworks for understanding diagrams are listed here to give the reader a flavor of the underlying approaches that drive the topic.

> *– Gombrich (1966) argues that "to see the shape apart from its interpretation is not possible." This ability is referred to in Gombrich's discussion of Leonardo's creative process "in searching for a new solution Leonardo projected new meanings into the forms he saw in his old discarded sketches."*

– Another definition given by Ittelson (1996) depicts diagrams as having no meaning without an interpreter and a communicative intent.

– Bertin (1983) describes diagrams in terms of the relationships between graphical marks.

– Peirce (1931) defines diagrams as signs that have predominantly iconic relations.

– Engelhardt (2002) sees diagrams in terms of cognitive structures.

– A recent definition in Knoespel (2001) considers diagrams as "...simple drawings or figures that we think with or through."

A summary of each definition and its corresponding emphasis is shown in Table 2.

Source	**Emphasis**
Gombrich	Symbolic structures
Ittelson	Symbolic structures
Bertin	Spatial structures
Peirce	Symbolic structures
Engelhardt	Symbolic structures
Knoespel	Symbolic structures

Table 2 Definitions of diagrams and their emphasis

Much of the discussion on the nature of diagrams seems to be influenced by the internal versus external debate. Proponents of the external camp see diagrams as a collection of spatial or visual elements independent of humans. Proponents of the internal camp see diagrams as a collection of symbolic elements. There is emerging dissatisfaction with the potential of these ways of understanding diagrams. Horn (2001) claims that our current ways of understanding diagrams is one of "confusion." Norman (2000) finds existing ways of understanding graphical representations to be unsatisfactory. Bishop (1994) adds to this by questioning our existing ways of understanding diagrams arguing that the centuries held assumption that "a drawing-is a drawing-is a drawing" is progressively shown to be invalid. Kulpa (2003) argues that there is need for a serious study to help us better understand diagrams. A detailed discussion of the role and importance of these two aspects follows.

The importance of the spatial aspect

The spatial aspect is important because it is the aspect that provides the raw material for the creation and transformation of diagrams. Spatial aspect is also important because it forms a prerequisite for other aspects, such as the sensory, to function properly (Jobson et al., 2001). Four reasons are cited for why spatial is important, which all have to do with the fact that the user takes action with the diagram, rather than merely interpreting a displayed product. First, some actions involve only spatial manipulations and are subject only to spatial rules; for example changing a text font may require enlarging and re-positioning boxes in a flowchart (Maulsby et. al., 1989). Second, the user interface gestures with which the user creates the diagram are spatial in nature and must first be managed as such before being translated via the mapping into symbolic aspects. To implement a full set of spatial rules in the software enhances the efficiency and naturalness of drawing. Third, relying only on the symbolic and mapping, as in automated graph layout, leads to the removal of visual cues that are important to the meaning of the diagram (Basden, et. al., 1996). Fourth, having a full and exhaustive account of all spatial phenomena allows certain relaxation of the rules and reinterpretations. This is true in cases where the person diagramming may want to relax certain rules to aid his/her thinking processes. Spatial aspects could be facilitated by rule relaxation while keeping the symbolic meaning true and well formed.

Limitations of a purely spatial/visual framework for understanding diagrams

Kuipers (2000) questions the adequacy of discussing spatial aspects of diagrams in isolation from other human functioning aspects and proposes that a better way of addressing the issue of complex diagrams should acknowledge the many aspects of spatial knowledge that are not inherently visual. Programmers, for example, who use a simple single color, fixed pitch font terminal can get a mental image that aids comprehension from the appearance of the indenting in their code and the relative size of blocks of code.

One of the problems of a purely spatial account of diagrams impacts a diagram's well formed-ness. References to 'label,' 'name,' 'number,' etc. would seem to be symbolic phenomena rather than spatial. One way of making the necessary distinction would be to define all symbolic phenomena in purely spatial terms by the addition of extra rules (e.g., "A label is a row of character-shapes that is placed near another shape") but this solution is too cumbersome and creates immense difficulties particularly in mixed diagrams. Numbers are sometimes used to label items in a list (for example, a bullet list in a multimedia presentation), in such a way that they indicate the order in the list. If an item were to be moved up the list, then we would expect not only that the numbers accompanying the items would be moved with the item (a spatial operation), but that some items would be renumbered (an operation that cannot be accounted for by spatial rules).

A second problem is the rigidity of applying the rules of what constitutes well-formedness. Human designers often relax the rules. Neilson and Lee (1994) include numerous examples of this in their observations of how an architect designs the layout for a kitchen. One of these is that the architect sometimes draws only part of the object to represent the whole; the rectangular outline of a cooker would be drawn with only two lines, in an L shape. Many of the diagrams would be considered ill-formed by the normal rules of the spatial layout of physical objects, yet to the knowledgeable human user of the diagram they are well-formed. Similar criticisms were made by Goel (1992).

Third, a purely spatial perspective on well formed-ness cannot account for what might be called 'doodling.' Basden et al (1996) call it 'tentative action' and give the following example. The user of the Istar toolkit, that employs boxes and arrows as a visual knowledge representation language, would 'pick up' a box and wiggle it about for a time before setting it back in its original position. The spatial result of such actions is often null, so that from the spatial perspective alone, the action itself has zero effect. But, to the user, it was a significant action because it helped him think about the concept that was represented by the box. A definition of well formed-ness based solely on spatial concepts would not be able to account for such important elements of the usability of drawing software.

Some diagrams that seem spatially ill-formed are in fact well formed to the user. For example, Figure 2 shows a box and arrows diagram produced by the Istar visual knowledge representation toolkit (Basden and Brown, 1996). Istar has a facility to hide most of the diagram except those parts connected to a selected box, directly or indirectly. The diagram shows some dangling lines.

A fundamental spatial rule of well formed-ness in a box and arrows diagram is that all arrows must have their ends terminate on boxes, this suggests the diagram is not well formed from a spatial perspective. However, such a diagram was well formed in the user's eyes and found to be useful, because the dangling arrows told them what else the visible boxes connected to. A useful definition of well-formedness such as we wish to implement in software should therefore allow such temporary breaking of the rules of spatial well-formedness, within the overall context of a well-formed diagram. However, it does require that the definition of this fuller notion of well-formedness includes knowledge that would enable spatial well-formedness to be recovered.

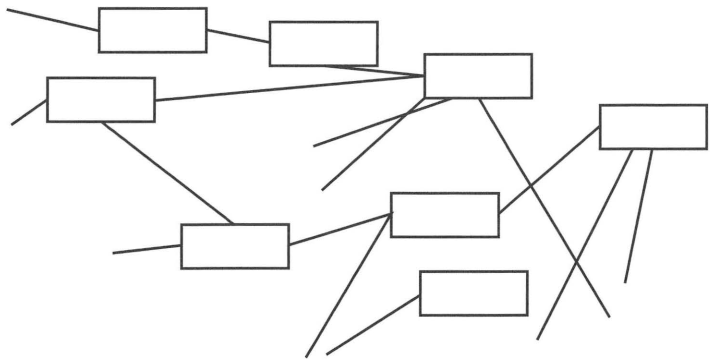


Figure 2 Istar Diagram from Basden and Brown (1996) box and line diagram.

Taylor et al (1984) says that spatial arrangements do not have any inherent significance of their own. Wood (1993) argues that we recognize differences between diagrams not purely based on spatial differences but because they are "structured differently as systems" and because they are "manifestly different landscapes." The point raised by Wood seems to suggest that there is something more to a diagram than just its spatial relations and constraints and that this leads to meaning by bringing in structural differences.

The importance of the symbolic aspect

The importance of the Symbolic aspects is that it gives precision and clears any ambiguity that may be found in diagrams. This is true because many types of diagrams make use of similar spatial phenomena, but what distinguishes them from each other is their Symbolic aspect. When diagrams are partially created from the Spatial aspect alone, their description makes no sense, but such diagrams are useful and important for the person drawing them precisely because of their Symbolic aspect.

Symbolic aspect also allows us to deal with mixed diagrams where the same Spatial aspect of such diagrams could have more than one meaning depending on their use. The London Underground Map is one such case where it is composed of circle and lines. This diagram could express the relationships between the stations or it could express the route taken to go from one place to another. Diagrams may sometimes be ill-structured, where the rules are relaxed such as dangling lines in a box and line diagram. We are able to cope with these features because their well-formedness is still valid through Symbolic aspects.

There may be instances where Spatial aspects are not needed, but there is a purpose behind their absence. An example of such a case is where some terrain is virtually flat such as marsh lands, flood plains, deltas; in this case there is no need to draw contour lines symbolically. However, the blank spatial feature still conveys symbolic meaning relevant to the type of the diagram. There is a need for drawing tools to support the draw-first, interpret-later approach in diagrammatic knowledge acquisition (Cheng, 1996). This seems to suggest the need for the software tool to allow the user to draw, in a spatial sense, first and then interpret symbolic aspects. The Symbolic aspect is also important because not every meaning of a diagram is spatially expressed. Some of the meaning (symbolic) is found in the activity of diagramming. Most architects, whose use of diagrams is crucial to their professional work, find it hard to think without a pencil in their hand (Lawson, 1994).

Limitations of a purely symbolic framework for understanding diagrams

However, by recognizing the importance of Symbolic aspects there is a temptation to consider it as the aspect that is sufficient to account for the nature of diagrams. There are a number of problems with this view. First, from a general point of view, Symbolic aspects alone would not allow us to distinguish diagrams from other constructs made by humans that are used to convey information—what is symbolic about a book, a web page, a letter, for example. Second, guiding our thinking of what Symbolic aspects ought to be about would be based on our existing knowledge of the variety of diagram types in use and this would inhibit us from developing new types of diagrams. Yet, in reality we find that people are very creative and able to always produce new types of diagrams. This suggests that Symbolic aspects alone are not sufficient. This suggests that we cannot in advance anticipate what Symbolic aspects cover because this is about human agency and the potential for creative expression of meaning. Finally, some useful diagramming activities (Spatial aspect) carries no symbolic meaning such as cleaning up and tidying activities people often deploy in complex messy diagrams. The effect of Symbolic aspect alone would not facilitate the recognition of such activities because they are of a different nature characterized by the kinematic aspect.

The need for a different approach

Focus on spatial or geometric representations helps with interpretation, but it largely ignores the human processes of creation and interpretation, though it is often employed in their service, and it excludes any consideration of symbolic meaning. It treats the spatial phenomena as static entities that can be combined by special logics, rather than as flowing, growing things. When understanding diagrams is motivated by cognitive or psychological perspectives then it can in principle handle mixed diagrams, but in practice rarely does so, as it has no basis for understanding the differences in the mixture. It considers only the interpreter of diagrams, and ignores the creator, it assumes that diagrams are static, rather than growing, and it has no place to consider the purpose of the diagram. It might employ geometric concepts, but does not understand the relationships between them. Finally, when focus is on structure (especially syntactic and lexical), this ignores the generation or growing of diagrams and it does not give much attention to which spatial or geometric phenomena can support symbolic meaning. There is often difficulty in dealing with mixed diagrams, because they assume a particular type of semantics and seem unable to provide any basis for software support. The narrow focus of most of these approaches means that they can address certain problems, but cannot integrate them with consideration for other problems. When faced with theories or solutions relevant to the situation with which this paper started, the response is often "So what!" and reject both funding applications and access to academic literature.

The approach taken in this paper differs from existing ways in that it recognizes the importance and need for both the Symbolic and Spatial aspects in working out a good way to understand diagrams capable of handling both construction and interpretation tasks. This recognition, even though it has philosophical underpinnings (Fathulla, 2006), nevertheless agrees with our intuitive understanding of diagrams. Diagrams that are used to communicate some purpose or meaning do so through distinct spatial elements, properties, constraints and relationships. The approach advocated in this paper is based on the Mapping between Symbolic and Spatial aspects, SySpM. The term aspect refers to a constellation of meaning, rich and diverse and as such it includes all phenomena that matter when discussing reality; in the case of diagrams these include elements, properties, constraints, operations and relationships.

The SySpM Framework

The central thrust of this framework is: Separating symbolic from spatial but allowing for their mapping. The framework is based on the notion that Symbolic aspects are distinct and separate from Spatial aspects and are irreducible to it. From this framework individual SySpM's can be constructed. The term "a SySpM" is used to denote a distinct (particular) collection of Symbolic and Spatial aspects and a distinct Mapping between the two collections. Synonymous with this term are drawing styles or types of diagrams. Table 3 shows eight such SySpMs (Fathulla, 2006).

We grouped the symbolic and spatial terms into primary and secondary lists. The former includes symbolic and spatial terms that

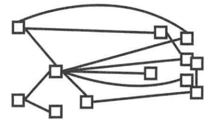
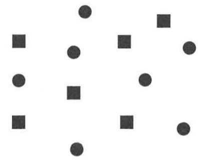
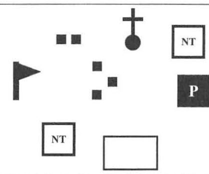
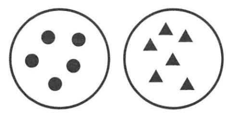
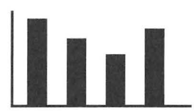
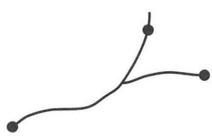
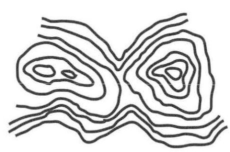
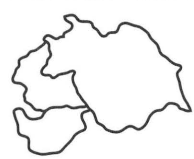
No.	The SySpM	Mapping	Example diagram
1	Boxes and Lines	Item mapped onto box, relationship mapped onto line	
2	Communicating Similarity	A collection of items mapped onto a collection of shapes	
3	Map of Objects	Item iocation mapped onto icon position	
4	Set Membership	A shape inside a loop mapped onto member of a set	
5	Bar Charts	Magnitude mapped onto length of a bar	
6	Route Maps	Route mapped onto curvilinear line	
7	Contour Maps	The set of location with the same quantitative value mapped onto closed continuous curve	
8	Surface Coverage	Region mapped onto area	

Table 3 SySpM's developed in Fathulla (2006).

are used in the simplest or basic form of the SySpM. This category of symbolic and spatial is also in all instances of diagrams of the relevant SySpM. The latter includes terms that are used in complex diagrams of the relevant SySpM and it also includes things that have to do with the relationships or interaction between the various symbolic things of the relevant SySpM. Development of each SySpM also includes a list of spatial features that do not map onto any Symbolic aspect, these are known as redundant Spatial features. These could then become available for other SySpM's thus forming mixed diagrams or list constraints, i.e., why they occur and list events or changes relevant to the SySpM under consideration. Special features of a SySpM use redundant spatial features to bring in secondary spatial features rather than another SySpM as mixed diagrams. An example of this in a Box and Arrow SySpM is when lines are allowed to cross other lines. This happens when one line is given a kink or a gap to indicate clearly that one is passing over or under the other rather than connecting to it, e.g., electronic circuits. Sub types are diagrams in which the original and simple SySpM is constrained or complicated because of specific needs usually associated with a type of application. This is achieved by bringing in an extra symbolic constraint that, owing to mapping, also gives a different spatial feel to the diagram. There are at least three different ways symbolic sub types can be depicted in a Box and Arrow SySpM: networks, lists, and trees. For each SySpM there might be special cases that do not 'fit' well. Many spatial applications involve several of such special cases such as holes, discontinuity and other irregularities. We need to identify these and explain the problems they generate, that is, what constraints they break, either spatial (as here) or symbolic.

A SySpM could contain features that are outside the range of its base symbolic types. This recognizes that each SySpM will be able to express only a subset of the symbol level, not all of it. To express the whole extensive range of things at the symbolic level requires several different SySpM's. Within this context two types of mixed-ness are identified. One is when several SySpM's are present in a diagram, but none dominates the overall meaning of the diagram. An example of this is the diagram depicting the fate of Napoleon's army during its march on Moscow (*see figure 3*).

This type of mixed-ness is referred to as "True mixed diagrams." The other type is referred to as "Augmented diagrams." This type of mixed-ness has one SySpM occupying a primary importance while other SySpMs are added in and have secondary importance. This type of mixed-ness occurs when redundant spatial features of a SySpM are used to bring in symbolic aspects from other SySpMs. For example, in a Box and Arrow SySpM thickness of line could be used to bring in quantitative value from Bar Chart SySpM.

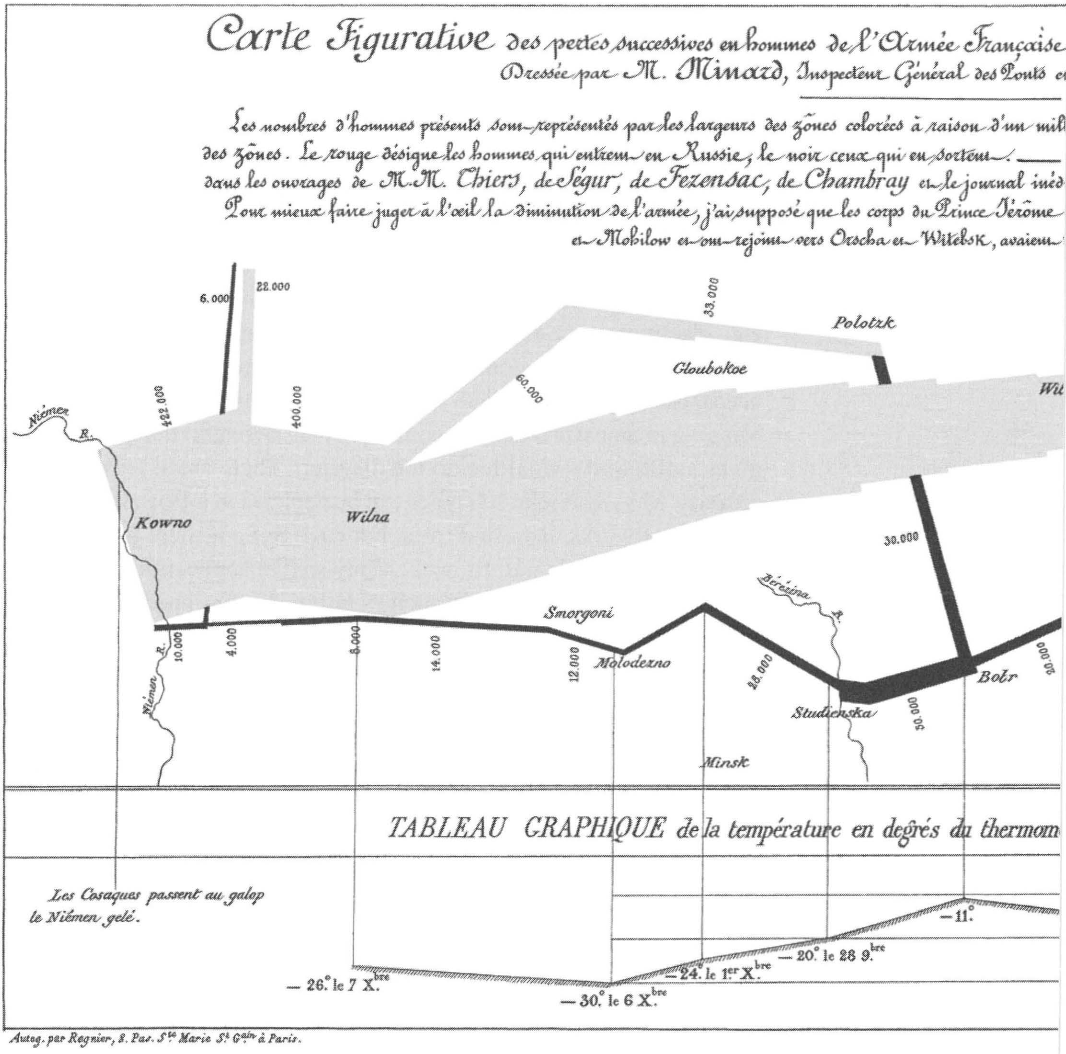
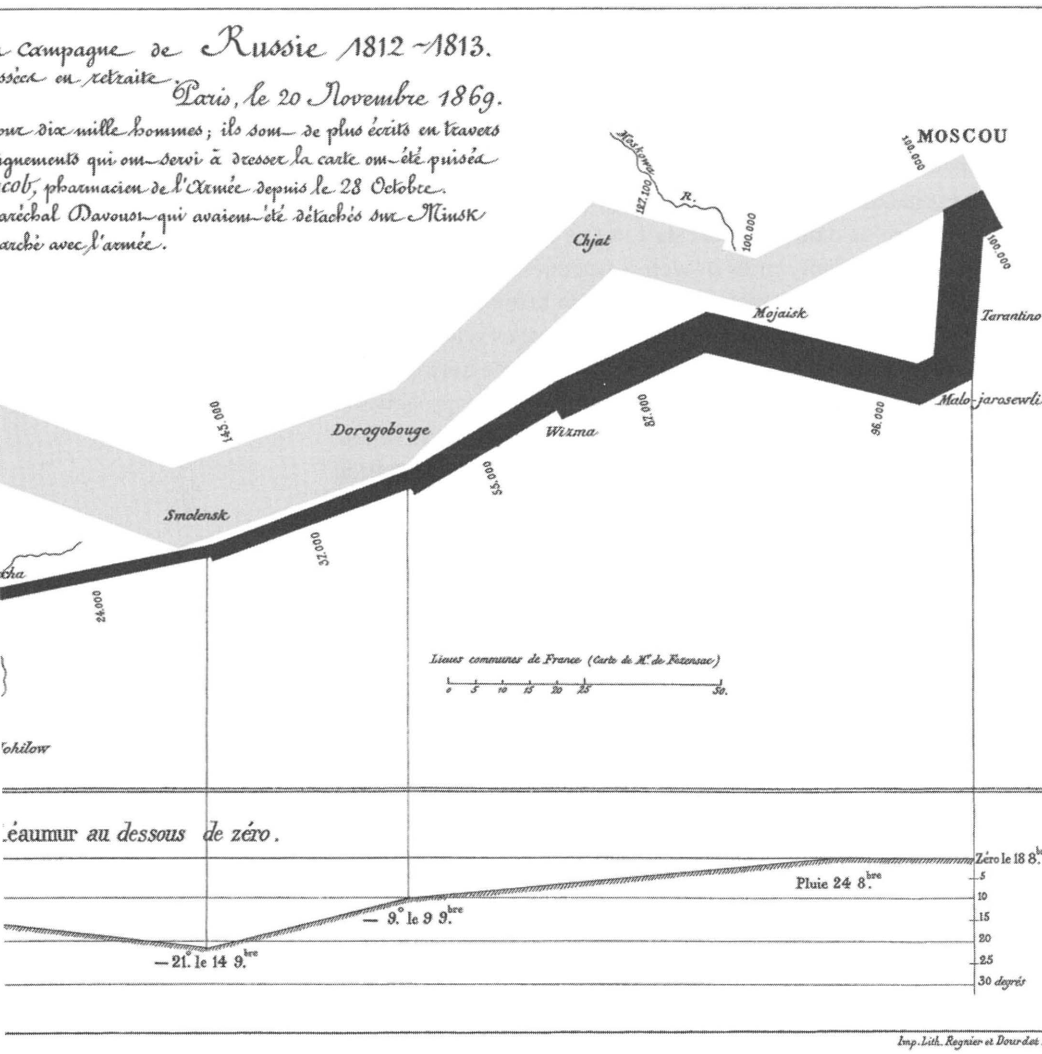


Figure 3 Charles Joseph Minard's graphical representation of the story of Napoleon's advance and retreat into Russia in 1812. Source: "Collection Ecole des ponts" avec la cote ENPC du ou des documents.


campagne de Russie 1812–1813.
ssée en retraite.
Paris, le 20 Novembre 1869.
our dix mille hommes; ils sont de plus écrits en travers
ignements qui ont servi à dresser la carte ont été puisés
cob, pharmacien de l'Armée depuis le 28 Octobre.
aréchal Davoust qui avaient été détachés sur Minsk
arché avec l'armée.
MOSCOU
100.000
127.100
100.000
Chjat
Mojaisk
Tarantino
Malo-jarosewli
96.000
87.000
Wixma
55.000
Dorogobouge
145.000
Smolensk
37.000
24.000
ohilow
Lieues communes de France (Carte de M. de Fezensac)
0 5 10 15 20 25 50.
éaumur au dessous de zéro.
Zéro le 18 8.bre
Pluie 24 8.bre
— 9.° le 9 9.bre
—21.° le 14 9.bre
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Imp. Lith. Regnier et Dourdet.

Current drawing software tools

Drawing software is used to generate diagrams. But it is all too easy for the user to produce a diagram that is ill-formed. Myers (1991), for example, draws our attention to the fact that in using a generic drawing package (e.g. MacDraw or Claris Draw) to create a box and arrow diagram, the user might move a box without moving its arrows, leaving them dangling. Extra work is needed to correct such mistakes. Damm et al (2000), Edmonds and Moran (1997), Serrano (1995), Weible and Buttenfield (1992), Ryall et al (1996) have all discussed limitations of drawing software. Computational systems are often developed based on psychological studies with the aim of automating the generation of diagrams (Zhang, 1997). This aspect of computational approaches makes them less likely to support the characteristics of diagram richness as outlined at the start of this paper. Computational approaches tend to apply rules of well-formedness in a rigid way thus making them less suitable to support such features. Cheng and Cupit (2001) also add that existing drawing packages seldom support the activity of marking the significance of a distance between two points. This suggests the limitation of computational approaches to account for the problem of variety of types of symbolic information found in most real world diagrams. In general automatic generation of diagrams bypasses most of the characteristics of diagram richness. Computational approaches place a great deal of significance on the issue of efficiency. This emphasis leads to the generated diagram missing most or some of the meaningful spatial and visual features that were of importance to the diagrammer. Based on work carried out in Fathulla (2006) and Fathulla and Basden (2007), we argue that the difficulties people experience with diagramming software tools point to an underlying issue of how we understand diagrams. A vision of how better diagramming tools could be developed based on the framework of SySpM is presented.

SySpM: A framework for designing diagramming software

The author believes that the SySpM concept can help in the design of software that will aid users, because it offers the designer a principled guide for constructing software. Each module is built with a purpose in mind to support a particular type of SySpM, with sub-modules to handle the Spatial, the Symbolic and the Mapping between them. If these can be 'plugged in' then the user has immediate access to different SySpM's, and thus a support is provided for a variety of ways of thinking. Drawing actions that are not applicable in any SySpM are not meaningful and therefore automatically forbidden by the software. The definition of objects, activities, relationships and constraints in both symbolic and spatial terms helps in the design of the data structures to be implemented. So that the interface does not "get in the way of the user's thinking" (Norman, 1990), Basden et al (1996) developed principles of proximal user interface that may be invoked in its design. But these must be instantiated by the specific requirements of the software; for example the principle of graded effort implies distinguishing frequent from infrequent operations. A well designed SySpM can provide such information. The linkage between various SySpM's via redundant spatial features, thus forming mixed diagrams, provides users with continuity of the diagramming activity that is essential, especially when such activity aids the thinking processes.

Feasibility of implementing SySpM in software is brought about through recognizing the need to work out three distinct data structures for each SySpM. Each data structure will implement the features worked out thus far for each SySpM. Fluidity of the drawing process is seen as a central issue in diagramming when used as an aid to thinking. We will demonstrate this quality of SySpM to draw a line of varying width. Such lines are common in route maps. To draw this line with the various widths and angles using existing software packages would be time consuming and often frustrating involving several interruptions to ensure the continuity of the line, the various widths and changes in direction. These interruptions occur because such software recognizes diagrams as graphical shape manipulation. However, building drawing software which has knowledge of the different symbolic meanings, namely routes or quantitative values would enable such drawing to take place with a minimum degree of interruption. The user would have to instruct the software regarding which SySpM's to activate, either during the diagramming activity or right at the start of the process.

The three distinct and yet integrated aspects of the SySpM framework allow for software to be designed such that data structures can be implemented to support each SySpM. The way software could achieve this is by developing a data structure for each graphical piece. Such data structures would hold for each SySpM, not only spatial information such as position, size, shape, etc., but also which SySpM's relate to its several parts. For example, a rectangle has a top, bottom, right, left, inside and four corners. In Bar Chart, the top and bottom 'belong' to the Bar Chart SySpM but the right and left are unused and may be used for another SySpM. Then, whichever part the mouse is over, the software finds from this data structure which SySpM is the one to supply the relevant rules to guide the visual/spatial and symbolic aspects of its modification. An early version of this kind of user interface has been implemented in Basden et al (1996), but only for the Box and Arrow SySpM.

However, it might be argued by some that construction of software based on the SySpM would add yet more complexity in what is already too complex, and thus exacerbate problems of maintenance. This perception is wrong. In many cases, software is designed on the basis of too simple a view of real world needs and then has facilities bolted on in a way that is alien to its underlying architecture so that usability is impaired and maintenance problems are exacerbated. For example, in box and arrow software, the constraint that lines must always attach to boxes can be implemented as a purely spatial constraint, but when it is discovered that users require the ability to show part diagrams with what appear to be dangling lines, the existing data structures cannot easily accommodate the desired facility. In real life situations there seems to be a 'requisite variety' (Ashby, 1956) that we cannot escape; a high quality SySpM analysis would highlight what this variety is, so that the architecture can be designed, right from the start, to accommodate the necessary facilities. An early prototype version of a diagramming software, called Istar, (Basden et al., 1996), capturing a limited scope of the above proposal, has already been developed.

CONCLUSION

This paper investigates the difficulties faced by people using existing diagramming software tools. It argues that diagrams produced by people express richness that is rarely captured fully by these tools. The root causes of the problems are linked to our understanding of diagrams. A proposed framework for a better understanding of diagrams is outlined and its potential for developing better and more intuitive diagramming tools are discussed. The work carried out here is part of an ongoing research that aims to develop drawing software based on the framework of SySpM.

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