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# CMAP READABILITY: PROPOSITIONAL PARSIMONY, MAP LAYOUT AND SEMANTIC CLARITY AND FLOW

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**Abstract**. In our experience of introducing concept maps (Cmaps) to practitioners, we have seen a vastly positive reception of the tool's capability as an analytic support, however only a lukewarm response to using Cmaps for communicating information to decision makers. In this paper we focus on the map reader and human factors of Cmap readability. We look into what makes a Cmap reader-friendly in terms of its scope and organization, and examine three aspects of map readability – propositional complexity, map layout, and semantic flow and clarity. We draw on some basic principles of human information processing, such as working memory capacity and Gestalt principles of perceptual organization to better understand how maps can be designed to help readers extract information from them with less effort. The application of these principles encourages greater use of the (largely underutilized) "visual" aspect of Cmaps through modification of their layout, which in turn can facilitate semantic clarity and flow of the map content. The application of perceptual organization principles to Cmap design can facilitate chunking of map elements and, thereby can help reducing cognitive load and simplifying processing of the presented information.
**Keywords:** Concept Mapping, Cmap analysis, Cognitive load

## 1 Introduction

Since its development in the 70s, Concept mapping (Cmapping) has seen growth both in its theoretical development (e.g., Cañas & Novak, 2006; Miller & Cañas, 2008; Novak, 1994; Safayeni et al, 2005) and its practical application (e.g., Cañas et al., 2012; Daley et al., 2008; Moon et al. 2011; Nesbit & Adesope, 2006). For a number of years now, we have been introducing Cmapping to Canadian civilian and military public service professionals emphasizing their analytic and communication functions. In our experience, we have encountered mostly positive reaction towards using Cmaps for their analytic support capability, i.e., as a way to structure, externalize and advance their own understanding of a topic or a problem through building a map. However, we have seen a variety of reactions from decision makers when they were presented with critical information in a Cmap format. In these situations, the primary purpose of the Cmaps was to provide a decision maker with the necessary information to improve their situational awareness and to enable them to make better decisions. The decision makers did not participate in the creation of the maps, they were only map readers, and their reactions to this communication format ranged from the immediate embrace to the rejection of the idea.

There could be many reasons for some practitioners' lukewarm reception or even rejection of Cmaps as a communication medium. Some of these reasons could be due to individual preferences/differences of the map readers, other reasons could be due to compatibility/congruity between the medium and the content. For example, expressing ideas in a Cmap form that could be better expressed in another format. On the other hand, the Cmap might be an optimal medium, but inadequate human factors design of the product can compromise its usefulness. The human factors of map design plays an important role in how map readers perceive Cmaps and, subsequently how effectively maps can communicate information to their readers.

In this paper we focus on the map reader and human factors of Cmap readability. We consider what makes a Cmap reader-friendly in terms of its scope and organization and examine the possibility of facilitating readers' acceptance of Cmaps as a communication tool through improving their design and layout. We draw on some basic principles of human perception and information processing (e.g., Miller, 1956; Wertheimer, 1958) to better understand how maps can be designed to help readers extract information from them with less effort. This paper mainly presents theoretical arguments and it does not provide any empirical evidence for the arguments made. Empirical tests of the presented ideas are subject of future research.

## 2 Aspects of Cmap readability

Reader's acceptance of a CMap as a source of information and the amount of effort that he or she will be willing to invest into traversing the map depends to a great extent on how easy it is to extract information from the map, i.e., its readability. Different aspects of the map content and design contribute to its readability. For the purpose

of our subsequent discussion we would like to emphasize three map properties that in our view are closely related to map readability: Propositional complexity, semantic flow and clarity, and map layout.

- *Propositional complexity* refers to the number of concepts and relationships in the map.
- *Semantic flow and clarity refers to the expression of concept labels and linking phrases and the map reading flow.*
- *Layout refers to the spatial organization of the map elements and their visual properties.*

These three properties are not independent of each other. For example, map's propositional complexity constrains semantic flow and the range of possible layouts. However, each of them highlights a different aspect of the overall map and contributes to its readability in a different way. Therefore, it is worth examining them individually.

*Propositional complexity* determines the overall scope of the map, and thus the amount of effort that will be required on the part of the reader to traverse and understand it. The more complex a map is the more effort a map reader will need to invest into traversing it. In a map designed for communication, a fine balance between inclusiveness of the content and parsimony needs to be maintained. It is possible to connect every imaginable pair of concepts in a map with a linking phrase, however not all of these connections are required to answer the map's focus question. Often, secondary relationships included in the map unnecessarily increase its propositional complexity and obstruct (as opposed to facilitate) comprehension. Ideally, a map will contain all the necessary information to answer its focus question, but not more than that. In other words, propositional parsimony in the map design is highly desirable.

*Semantic clarity and flow* focus on the articulation of map elements and reading simplicity. Labelling precision of the map elements, brevity, ensuring and maintaining a natural reading flow can significantly improve map readability. Semantic clarity and flow depends on the choice of words and grammatical structures of propositions and their consistency with the visual information conveyed through the map structure and directionality of the relationships. For example, a proposition phrased in active voice is easier to comprehend than a proposition phrased in passive voice (e.g., APA, 2001; Silvia, 2007). In addition, a proposition stated in passive voice goes against the visual flow of the arrow line on which it is stated, thus creating an incongruity between the visual and semantic information in the graph, thus disrupting the flow.

*Map layout* property focuses on the arrangement of map elements in the available space with the aim of visually emphasizing map's content without altering its semantics. Traversing a Cmap is predominantly a reading task with most of the information being communicated through the labels of the map elements. Map structure transmits some information (e.g., Carvajal & Cañas, 2006); however the visual capabilities of a map as a *graphic representation tool* are often underutilized to a large extent. We believe that making greater use of map's graphic nature can facilitate its readability and reader's acceptance.

The scope of this paper does not permit an in-depth discussion of all aspects of each of these properties, and we did not attempt to provide a comprehensive coverage. Instead, in the remainder of this paper we discuss how some basic principles of human information processing, such as working memory capacity and principles of perceptual organization, can be applied to the above properties to facilitate map readability.

## 3 Propositional parsimony and working memory capacity

Propositional complexity in Cmapping as we define it refers to the number of concepts and relationships represented in a map. While a map needs to include all the relevant information to provide an answer to its focus question, there is always a tradeoff between inclusiveness and readability. When the primary purpose of the map is self-inquiry, i.e. the map is intended for clarifying one's own thoughts, but not for communicating to someone else, then map's readability is not a major concern. However, when the primary purpose of the map is communication, this tradeoff becomes especially salient, because after a certain threshold there is an inverse relationship between the map size – its propositional complexity – and its readability.

Cmap readability is closely related to people's ability to process information. The amount of information that people can manipulate in their working memory (WM) is limited (Miller, 1956). The WM capacity limitation has implications for Cmap design especially when a map is intended to communicate information. Ideally, a well-designed map should not overwhelm its reader's WM. A commonly cited rule of thumb for WM capacity is the famous 7 ± 2 (Miller, 1956). This rule of thumb implies that the amount of information that a person can manipulate at a time roughly varies between about five and nine "chunks" of information. The notion

of "chunk" is critical here, because the way the information is organized (or chunked) determines how much of it we can process.

To cope with the multitude of information in the environment, our mind organizes the information it perceives, it groups elements that go together into units for more efficient processing (Wertheimer, 1958). For example, consider the following string of letters "L-F-O-W-T-M-O-T-B-L-E-H-O-H-L-E-R-L-S". The string contains 19 letters, and an average person will have difficulty remembering and reproducing this string one letter a time, because the size of the string exceeds our WM capacity. However, if we unscramble the string and group the letters into the following words – chunks – "FOR WHOM THE BELL TOLLS", the same 19 letters become much more manageable and easier to remember. If we go a step further and present a set of five other Hemingway's titles, then a person familiar with his writing will see each title as a single chunk, and remembering six familiar titles will not be a problem. As a result, the array of letters that a person can manipulate when they are grouped in such manner is much larger than a set of individual letters.

Same applies to reading a Cmap – map reader's capacity to process map's content depends on how he or she chunks information in the map. A Cmap consists of elements - concepts and linking phrases – that could be naturally grouped into propositions – concept-link-concept triads. If no further higher-order grouping is done beyond propositions, then a map with nine propositions already approaches the WM capacity limit. Nine propositions is not that many – a fairly small Cmap with six reasonably connected concepts can easily contain nine propositions. In this light, propositional parsimony achieved through careful discrimination in selecting propositions to be included in the map designed for communication becomes extremely important.

Is it possible to convey all the necessary information to the reader with six concepts and nine or so propositions? In some cases perhaps yes, but most likely nine propositions will not be sufficient. How then can we design maps to convey all the necessary information without overloading the reader? One solution could be to create multiple small maps or knowledge models. Creation of knowledge models is a very interesting topic that requires a discussion of its own; however it is beyond the scope of this paper. Instead we will focus our attention on examining how we can relax propositional parsimony through facilitating higher-order chunking of the map elements to allow for a more efficient processing of the map's content.

Higher-order chunking goes beyond individual propositions and refers to grouping of two or more propositions together, which are then processed as a single unit. This is similar to the grouping of words into a novel's title in the letter-string example above. A reader is able to process more propositions when they are grouped into bigger chunks than when these propositions are processed individually before reaching his or her WM capacity limitation. Grouping reduces the amount of effort a reader needs to put into processing the content. In other words, higher-order grouping might allow the map builder to relax some propositional parsimony, and include more propositions without overloading the reader. Map readability depends on the interplay between propositional complexity and the way the reader intuitively groups them.

The letter-string example above suggests that chunking information draws on the person's prior knowledge and the ability to see patterns. For example, someone who does not speak English will not be able to group the letters in the letter-string example into English words, but he or she might be able to group the letters in some other way. Therefore, understanding the map audience's prior knowledge is critical for not only excluding familiar and redundant information from the map, but also for anticipating how the reader will be able to chunk the information presented in the map.

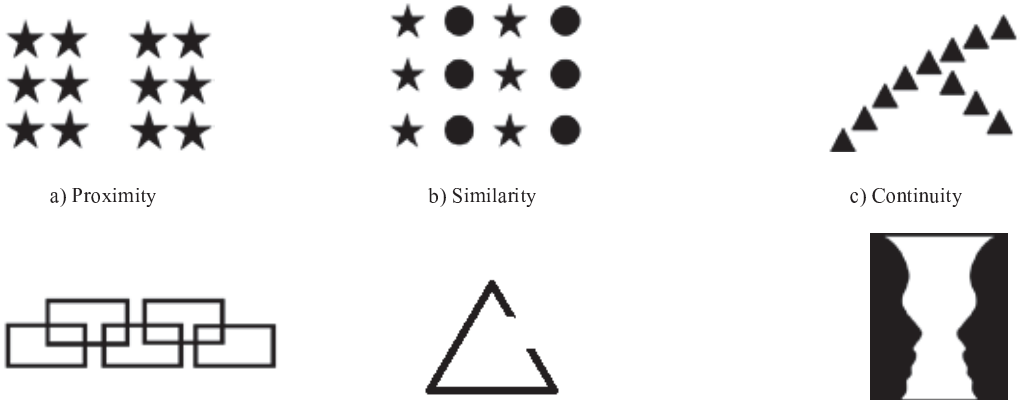
The way the reader perceives and groups propositions in a map greatly depends on his or her background, and it could be outside of the map creator's control. However, the map creator can employ certain mechanisms in the design and layout of the map that can facilitate or discourage certain grouping. The way the information is presented and visually organized significantly influences its readability and the amount of effort required by the reader. For example, in writing we put letters that form a word close together and separate each word from other letters and words with a space on each side. This creates a visual chunk that we recognize as a word. Visual presentation of information could be a powerful chunking mechanism, which is especially relevant to Cmapping, because Cmaps rely on spatial layout. In the following section we examine what contributes to grouping of map elements and how to facilitate semantic flow and higher-order chunking in Cmaps through their layout.

## 4 Map layout and semantic flow

Cmaps are *visual* graphs. However, most of the maps that we have seen rely on their semantic content (i.e., concept and linking labels) for communication and largely underutilize the communication capabilities of graph's visual properties. We argue that map layout and its visual features can be used to augment map's semantic content with information that can help establishing further relationships among concepts. To achieve this, Cmap design and layout can leverage basic principles of human perception, to make greater use of the "visual" aspect of Cmaps. Enhanced visual layout of a map can encourage higher-order chunking of map elements, help establishing a smoother semantic flow in the map and facilitate readability and comprehension of its content (Miller, 1956; Wallace et al. 1998).

Gestalt psychologists laid out several principles of human perceptual organization that describe general tendencies of how the visual system organizes or makes sense of the world (e.g., Wertheimer, 1958). The main idea behind these principles is that, whenever possible, we see patterns and larger units, as opposed to a disorganized array of information. This tendency to organize our visual field allows us to cope with the vast multitude of information in our environment. First, we briefly review seven Gestalt principles of perceptual organization, and after that we discuss how each of them can be used to facilitate Cmap layout and reading flow.

- *Law of proximity* states that elements close to each other tend to be perceived as a group. For example, in Figure 1 a) people tend to see two columns of stars that are closer together as a group. Another example is separation of letters that form a word from other letters with a space on each side, thus using proximity to encourage grouping of the letters into a word.
- *Law of similarity* states that elements that are similar to each other tend to be perceived as a group. In Figure 1 b) people tend to see columns of stars and circles, as opposed to rows of alternating starts and circles.
- *Law of continuity* states that objects that are aligned with each other tend to be grouped into wholes. In Figure 1 c) people tend to see two intersecting lines consisting of triangles.
- *Law of common fate* – states that elements moving in the same direction tend to be grouped together. Demonstration of this law requires a dynamic image and no illustration is included.
- *Law of Pragnanz* – or the law of good figure (good Gestalt) – states that ambiguity in the input is reduced in favor of the simplest form possible, in other words, elements tend to be grouped together if they are parts of a simple, orderly, coherent pattern, which is a good Gestalt. In Figure 1 d) people tend to see five rectangles – the simplest shape to which the image can be reduced.
- *Law of closure* – we tend to ignore gaps and fill in the missing information. Although, the triangle in Figure 1 e) is not complete on one side, people still tend to see that shape as a triangle, by filling in the missing information.
- *Figure-ground articulation* states that images are perceived as articulation of the figure on the ground. While the figure is the focus of attention, background defines how the figure is perceived. Figure 1 f) is a classic example of the figure-ground paradox – vase and two faces. Depending on which aspect of the image the viewer is focusing he or she will either see the white vase or two black profiles. In either case the background of the image defines the figure.



a) Proximity b) Similarity c) Continuity

d) Pragnanz e) Closure f) Figure-ground[1]

**Figure 1:** Illustrations of Gestalt principles of perceptual organization

[1] The image is by Bryan Derksen [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/)], via Wikimedia Commons

We see natural connections between some of these principles, and Cmap design. Below we explore how some these principles in relation to Cmap design and examine how they can be leveraged through Cmap layout to facilitate grouping and semantic flow.

The *law of proximity* is the most natural principle in the Cmapping context. This law implies that map elements that are put closer together are more likely to be grouped together. Therefore, map's spatial layout, specifically, reducing or increasing the distance between the elements, can be used to encourage grouping of some concepts and propositions and to differentiate them from other elements. Spatial layout can be used to articulate branches (or domains) in a map. For example, in Figure 2 concepts *B*, *C*, *D* and *E* are likely to be perceived as a group because of their proximity to each other, as well as concepts *G*, *I* and *J* are likely to be grouped together. The proximity principle also suggests that if the two concepts from the same proposition are spaced far apart, it will be more difficult for the reader to see them as a unit. For example, in Figure 2 concepts *A* and *J* belong to the same proposition, but they are less likely to be grouped together because of their distance.

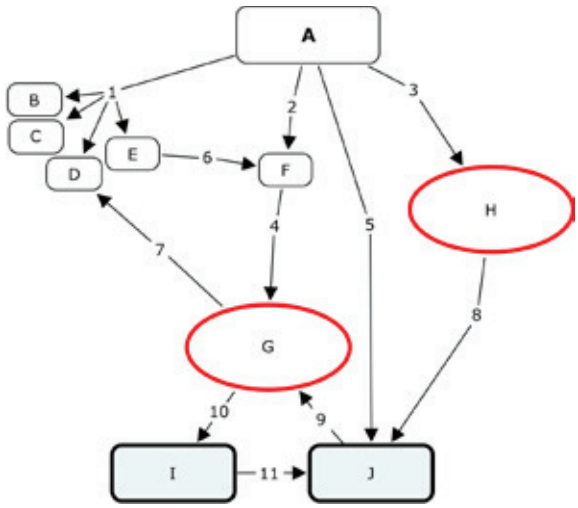



**Figure 2:** Example of applying some of the Gestalt principles to Cmap design.

The *law of similarity* implies that Cmap elements that share visual features will be grouped together. Similarity of elements in CMaps can be reinforced through the use of color, size, shape type, border style, font style – the use of all capital letters in concept or link labels. Although in their preliminary investigation, Carvajal and Cañas (2006) did not find an impact of color on the perception of Cmap quality, we believe that color can be effectively used to reinforce the Gestalt law of similarity in a CMap and to facilitate Cmap readability. For example, a certain color could be used to differentiate types of concepts, e.g., using red color to highlight the most dangerous elements in a situation. For example, in Figure 2 concepts *G* and *H* are likely to be perceived as a group because of the similarity of their features, similarly, concepts *I* and *J* are likely to form a group too.

The *law of continuity* in the Cmapping context can be translated into the flow of the map's content and the agreement between the visual structure and semantics. Propositions that follow smooth reading flow will be more likely grouped together. Smooth reading flow in a map can be achieved by reducing some of the flow disturbances due to the choice of semantics and their relationship to the map structure, arrow directions and structural dead ends. Below we discuss three considerations in map reading flow: a) the use of active and passive voice in linking phrases; b) adhering to the natural reading flow direction; c) reducing the number of sink concepts[2].

- Active and passive voice. Cmaps have unrestricted semantics, which makes them a very flexible representation tool. Unrestricted semantics means that linking phrases can be stated both in active and passive voice, for example, see Figure 3. Passive voice can emphasize certain elements of a sentence, however in the Cmapping context, a linking phrase in passive voice contradicts the flow of the relationship and the direction of the arrow on which it is stated. That is, the starting concept in a passive voice proposition is actually the end concept of the relationship. In the "John loves Mary" example of Figure 3, the direction of the relationship between John and Mary starts from John and ends with Mary as shown in Figure 2 a), i.e., John is the actor. However, if we use passive voice in the linking phrase,

[2] The term *"sink" concept* is borrowed from graph theory that defines sink vertex as a vertex with outdegree of zero, i.e., with no outgoing connections.

as in Figure 3 b), then we have to reverse the direction of the arrow, which visually contradicts the actual nature of their relationship and implies that Mary is the actor. Thus, the use of passive voice in linking phrases creates a flow disturbance between the semantic content and its visual presentation.

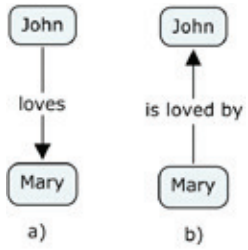



**Figure 3:** Example of a proposition stated in active (a) and passive (b) voice.

- Natural reading flow. The natural reading convention of most western languages is from top to bottom and left to right. A more natural reading flow will presumably require less effort on the reader's part. CMap's hierarchical organization naturally encourages the flow of relationships from top to bottom. The more a map adheres to these flow conventions the easier (i.e., requiring less cognitive work) it should be for the reader to traverse the map. For example, in Figure 2, reading proposition $A \rightarrow 3 \rightarrow H$ is probably slightly more natural than reading proposition $G \rightarrow 7 \rightarrow D$.
- Continuous flow. Continuous flow in a Cmap refers to its reading flow that progresses from concept to concept through their linking phrase and continues to the next proposition without interruption. For example, in Figure 2 the sequence of concepts $A \rightarrow E \rightarrow F \rightarrow G \rightarrow I$ forms a single continuous sequence. The flow is maintained through concepts' outgoing relationships and it is disrupted by the presence of sink concepts – concepts that do not have any outgoing relationships, but only incoming, e.g., concepts *B*, *C*, and *D* in Figure 2. Upon reaching a sink concept the reader has no choice but to stop traversing the map and start again from somewhere else in the map. Naturally, this breaks the reading flow. Such reading interruptions are unavoidable in Cmaps, but there are ways to reduce their number, for example by adding a connection. An effort to reduce the number of sink concepts can also encourage connecting concepts in other areas of the map, potentially creating cross-links and loops, both of which are considered to be desirable properties in maps (e.g., Miller, 2008).

The *law of common fate* can be operationalized in the Cmapping context through the use of branching linking phrases (Miller, 2008). A branching linking phrase connects one concept to several other concepts, e.g., in Figure 2 linking phrase *1* is a branching linking phrase that connects concept *A* with *B*, *C*, *D*, and *E*, therefore one linking phrase represents four propositions: *A-B*, *A-C*, *A-D* and *A-E*. Such linking phrases act as natural grouping nodes for the group of concepts (in our example, boxes *B*, *C*, *D*, and *E*) on the basis of their identical relationship to the single concept (in our example, concept *A*). This grouping can also be reinforced with the relative proximity of the concepts in the group as in Figure 2.

*Figure-ground articulation***.** Many maps that we have seen lack articulation – all boxes and arrows have the same format and are more or less uniformly spread out (or bunched up) on the available real estate of the map. The entire map looks like a uniform network of boxes and arrows with no focal points. In such situation the reader (especially a novice Cmapper) cannot discern much information about the map by simply glancing at it. For instance, it is not obvious to the reader which concepts are more important, what domains the map consists of, and how to traverse it. Visual features (such as size, color, font, line thickness, etc.) could help to differentiate some elements in a map from the rest, making them more salient and directing the reader's attention. For example, in Figure 2 concepts *G* and *H* attract attention due to their unique shape and red outline. Also, several regions in the Figure 2 map emerge visually: *B-C-D-E* group; *G-I-J* group, *G-H* group, as well as standalone concepts *A* and *F*.

The direct application of the *law of pragnanz* and *closure* to the Cmapping context is not as apparent. The law of *pragnanz* emphasizes the organization of the visual field into simple coherent forms. However, it is not entirely clear what this entails for Cmap design. Perhaps, it could imply that a map needs to have easily recognizable regions and have a structure consistent with its content. The law of *closure* states that people tend to fill in the missing information to complete a good Gestalt. Again, it is not clear how the *law of closure* can be easily applied here. These two laws may not be relevant in the Cmapping context

The example in Figure 2 demonstrates several of the above ideas. This map does not contain any real concept and linking labels to demonstrate how visual properties of map elements and map layout can encourage

grouping in a map and articulate some of its components. For examples, the laws of *proximity*, *similarity* and *common fate* reinforce the grouping of concepts *B*, *C*, *D* and *E*; the law of *similarity* encourages grouping concepts *G* and *H* and concepts *I* and *J*; concepts *I*, *J* and *G* can also form a group reinforced with the law of *proximity*. A few distinct segments emerge in the map and they can guide reader's traversing of the map. Although, the map contains ten concepts and 14 propositions, it seems to be quite manageable because of the grouping of the map elements.

In terms of the reading flow, the map in Figure 2 has several continuous reading paths: e.g., using the numbers used on the linking phrases, one possible path is *1-6-4-10-11-9-7*, another one is *3-8-9-10-11-9-7*, yet another one is *2-4-10-11-9-7*. A couple of relationships – *7* and *9* – go against the top-bottom convention, however in one case – *7* – the relationship connects visually different segments of the map; and in the other case – *9* – it facilitates the continuity of the flow. The map contains several sink concepts – *B*, *C*, and *D*, however these concepts are part of a *B-C-D-E* chunk, which has an outgoing relationship through concept *E*.

The suggested visual map modifications are fairly easy to implement with the available software, such as CmapTools (Canas et al., 2004). CmapTools provides a rich repertoire for enhancing visual features of boxes, lines and text in maps including manipulation of their font, type, color, style, shape and fill. Other aspects of map reading flow, such as active voice linking phrases and directionality and connectivity of concepts require examination of map content and making necessary structural and semantic adjustments.

## 5 Conclusion

As a knowledge representation tool, Cmaps have much to offer – they are a flexible tool that helps to externalize and articulate knowledge in a concise manner. The analytical power of Cmapping is fairly easy to see with even a brief introduction to the method. Cmaps can also be a powerful communication tool; however, their communication capability can be obscured with propositional excessiveness, poor layout, obstructed flow and a lack of articulation. We argue that in order to take advantage of Cmaps's communication capability the map creator needs to pay special attention to map readability. CMap readability mainly concerns with the ease with which a map reader can extract information from the map.

Map readability is a multi-faceted concept, and this paper examined three (of the potentially many) of its aspects – propositional parsimony, map layout and semantic flow and clarity. We argue that human working memory capacity limitation is a major factor in determining the amount of effort the reader will need to invest into traversing the map. Propositional parsimony in a map is required in order to not to overwhelm readers' working memory. However, the WM capacity limit can be stretched by encouraging higher-order chunking of map elements. Manipulating the design and layout of the map while relying on some of the Gestalt principles of perceptual organization can facilitate more advanced grouping of map elements. Such Gestalt principles as figure-ground articulation, the law of proximity, similarity and common fate are particularly applicable in the Cmapping context. In other words, an effective map layout can allow including greater number of propositions in a map without overloading the reader, which allows relaxing, to some extent, the requirement of propositional parsimony.

Another aspect of Cmap readability is semantic flow and clarity. We argue that smooth reading flow can reduce the amount of effort on the part of the reader. Relying on active voice in labelling linking phrases, reducing the number of sink concepts, and adhering to the natural reading direction can help achieving smooth reading flow in a map. While it is quite possible to completely avoid the use of passive voice in a map, it is not possible to completely eliminate sink concepts and design all propositions in the direction from top to bottom and left to right. However, a map designer aware of these issues can try to minimize disturbances in the map reading flow. Semantic clarity in a Cmap goes beyond map's reading flow. It also concerns the construction and articulation of concept labels and linking phrases. We briefly touched on one aspect of linking phrase articulation; however, we did not discuss the construction and articulation of concepts. This is an important topic that requires extensive examination, but it is outside the scope of this paper.

This paper presents theoretical arguments. We have not empirically tested these ideas; however, this could be done. For example, a test can be devised in which participants have to study the same Cmap in either a plain layout or in enhanced layout. A number of measures can be collected, such as time to traverse the map, content retention, perceived cognitive effort, subjective evaluation of the map, etc. Such empirical investigations are subject of future research.

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