Applying Gestalt Principles to Animated Visualizations of Network Data

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Abstract

Graphs are a commonly used data structure for representing relational information. Drawings of these structures, as node and link diagrams, can provide a useful visualization of the underlying abstract data. This makes drawings of graphs a useful tool in information visualization. Indeed graph drawing has been applied in many application areas including software engineering, knowledge management and for depicting communication networks. The spatial layout can help the user build up a cognitive model or 'mental map' of the information structure. Many automatic algorithms for producing drawings of a graph have been implemented. In many domains it is also common for the underlying information to be dynamic and this means the graph drawing must be updated. Unfortunately, even small changes to the underlying data can result in dramatic changes to the final drawing and this means the user may totally lose their previous 'mental map'. Animation between the two versions of the layout is one approach that can assist the user to make the transition between the two drawings. We have been examining how to apply the Gestalt principles of organisation to this animation phase. The aim is to assist the user in understanding the structural and visual changes that have occurred in the layout. Results of that work are described here with relevant examples.

1. Introduction

Visualising data as a graph is a common requirement in many application domains. Node and link diagrams are extensively used to model software systems [1], represent knowledge maps [2] and to describe communication networks [3]. Many algorithms have been developed to automatically produce graph drawings [4]. These drawings can help the user to build a cognitive model of the information by providing a structured spatial representation of the abstract data. This cognitive model is often called a "mental map" [5]. It is very common for the data to change with time. For example, nodes in a communication network may be added or removed or a software system is modified. A new layout can be automatically computed but this new layout may have a very different spatial arrangement, even for parts of the graph that did not change. Even when the data does not change the user might want to change the way a graph is drawn. For example in a graph depicting the employees of a company a user might want to switch from a top-down view showing the hierarchy in the company to a proximity view which draws people close to together if they interact a lot. This may cause the user to lose the existing "mental map" as the new drawing may bear little resemblance to the previous one.

One approach to help the user in maintaining the "mental map" is to provide an animation of the graph between layouts. This allows the user to follow the movement of nodes and links as they change. This approach has been used for example to help navigate web maps [6]. While a simple translation between node positions seems like an elegant solution it does not work in practice for complex graphs where hundreds of nodes may be changing position. A more sophisticated approach is to decompose the positional changes into structured motions like rotations, translations, etc. and then apply them serially in the animation [7]. A brief review of this animation technique is provided in section 3.

Even with animation between drawings the user may have difficulty perceiving the structural change that has taken place. In an attempt to help the user understand the structural transitions we have explored the use of the Gestalt principles of organisation in designing better animations.

In this paper we utilise the Gestalt principles to help the user identify organisationally structured motions in graph animations. Ideally these animations should be naturally and simply understood by the brain and so allow even very complex transformations to be followed.

Gestalt principles describe how the perceptual system organizes or groups disjoint visual elements into coherent

Proceedings of the Sixth International Conference on Information Visualisation (IV'02)
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structures, forms or 'Gestalten' (Figure 1). These principles are described in Section 2. Their relevance to animated graphs and how they can be applied are then discussed in Section 4. Finally a range of other perceptual issues and direction for future work are discussed in Section 5.

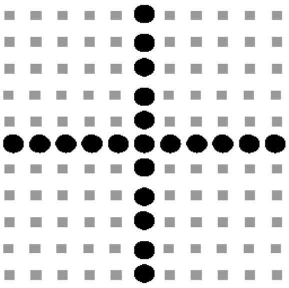

Figure 1. Shows how objects similar in shape, size and colour tend to be grouped together. The disjoint visual elements (circles) are perceived as a larger visual form (a cross).

2. Gestalt Principles of Organisation

Perception of visual structure and form, even in stationary images is difficult. A complicated issue is that the overall picture we perceive often seems unrelated to its component parts. This phenomenon is often described by the saying "the whole is more than the sum of the parts", or in terms of graph drawing, “by looking at individual nodes we don’t necessarily learn much about the overall structure of the graph”. The Gestalt principles were developed to help explain these holistic characteristics of perception. One of the most appealing things about these principles is that they are themselves simple to state, understand and apply.

Gestalt Psychology developed in the 1900's to help counter the associationist view that stimuli are perceived as parts and then built into complete images. About 1910, German researchers Max Wertheimer, Wolfgang Köhler, and Kurt Koffka rejected the prevailing models of scientific analysis in psychology and used the principles of field theory to explain cognitive processes, which could not previously be explained without a holistic viewpoint [8]. In particular Werthheimer studied the illusion of motion pictures or "apparent motion".

Gestalt is the German word for form. The Gestaltists proposed a theory of pattern perception that relies on the overall form and is not predictable by considering its components. Factors that impact on the perception of form and impact on how parts are grouped into structural forms are captured in what are called the "Gestalt Principles of Organization". The importance of these concepts to art and design were explored at the Bauhaus by such artists as Paul Klee, Wassily Kandinsky and Josef Albers.

The "mental map" of information provided by a graph drawing is very dependent on the perceived form or structure in the overall layout. Gestalt principles describe how many elements presented together tend to become grouped into distinct patterns. Hence these principles strongly influence how the components of a network drawing, the nodes and links are organised and perceived as a whole.

We wish to assist the user maintain a consistent mental map through animated transitions of these network drawings. The hypothesis is, that by applying these Gestalt principles during animation we can encourage the perception of a more consistent structure. This should better allow the user to understand the relation between the before and after drawings of the network and so make appropriate adjustments to their mental map.

The Gestalt principles [9] of organisation that we have considered are:
1. The Law of Simplicity
2. The Law of Familiarity
3. The Law of Similarity
4. The Law of Good Continuation
5. The Law of Proximity
6. The Law of Common Fate
7. The Law of Connectedness

In the following section we illustrate these principles briefly with examples taken from the domain of graph drawing. To demonstrate the significance of the Gestalt principles some examples (Figures 2, 3, 4, 5, 6, 7, 8) were especially designed in a way that the perceived structure is not equivalent to the real structure of the graph as defined by the edge relations.

2.1 The Law of Simplicity

"*Every stimulus pattern is seen in such a way that the resulting structure is as simple as possible*" (Figure 2).

2.2 The Law of Familiarity

"Things are more likely to form groups if the groups appear familiar or meaningful." (Figure 3).

2.3 The Law of Similarity

"*Similar things appear to be grouped together*" (Figure 4).

2.4 The Law of Good Continuation

"*Points that, when connected, result in straight or smoothly curving lines, are seen as belonging together, and the lines tend to be seen in such a way as to follow the smoothest path*" (Figure 5).

2.5 The Law of Connectedness

"*Things that are physically connected are perceived as a unit*." (Figure 6).

2.6 The Law of Proximity

"*Things that are near to each other appear to be grouped together*" (Figure 7).

2.7 The Law of Common Fate

"*Things that are moving in the same direction appear to be grouped together*" (Figure 8).

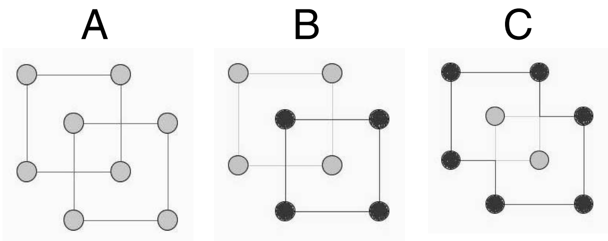

Figure 2. The law of simplicity states that we perceive an ambiguous structure [a] to be made up of simple shapes [b] and not the more complicated possibilities [c]. This is also related to the law of good continuation as the edges in [c] make sharp turns which violate this law, where as the straight lines in [b] are a more natural interpretation.

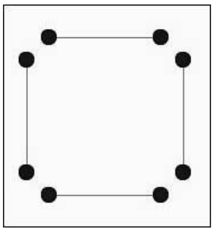

Figure 3. The law of familiarity states that we perceive structures that appear familiar such as a rectangle in this figure.

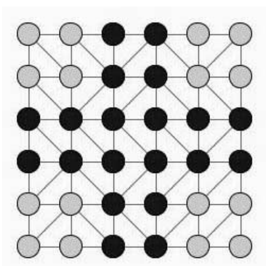

Figure 4. The law of similarity states that similar things, such as the black nodes in this graph tend to be grouped together.

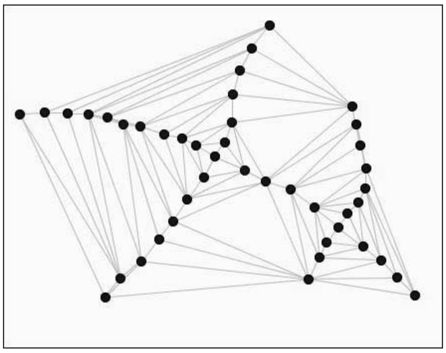

Figure 5. The law of good continuation states that we perceive smoothly curving lines and straight lines in smooth paths. In this graph we perceive the nodes as part of smooth curves and straight lines.

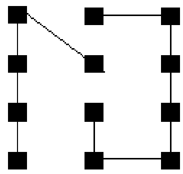

Figure 6. The law of connectedness states that we perceive connected objects as a single structure. Hence we see here two connected graph components.

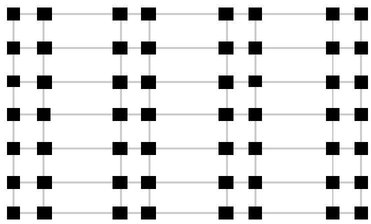

Figure 7. The law of proximity states that we perceive objects that are close in space to be part of the same structure. Here the spatial arrangement means we normally perceive four groups of paired columns even though it is possible to devise other groupings, for example, by row.

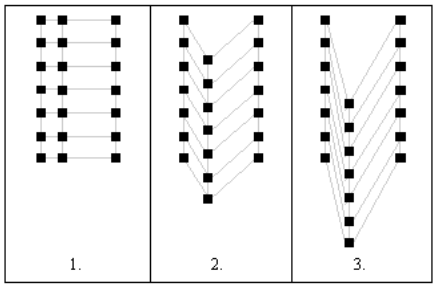

Figure 8. The law of common fate states that we perceive objects that move together to be part of the same structure (the second column).

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3. Animated Networks

Graphs are a common way to visualise relational data. In many systems the drawing of a graph can change according to program or user actions. If the changes are big it is usually very hard for the user to maintain a mental map of the graph (Figure 9). Showing the transition from the initial drawing to the new drawing as an animation can significantly increase the user's ability to preserve the mental map (Figure 10).

An animation is a sequence of images where consecutive images differ in a subtle but highly structured way. If the images are shown to a human in consecutive order and at adequate speed the objects in the images will be perceived as moving. This effect is known as apparent motion.

In graph animation we move the nodes and edges of the graph to transform it from one drawing to another. For any two drawings of a graph there is an infinite number of ways to transform the initial drawing into the final drawing. The quality of the animation has a huge impact on how well the user is able to understand the changes.

The human brain is specialised to recognise and interpret certain kinds of structured movements especially motions that have a physical, an organisational, or a biological interpretation. This is partly ecological and partly learned. The brain has evolved to aid survival in the world and so tends to perceive or assume biological motions. The brain while developing also learns to recognise familiar patterns, structure and motion that it encounters in the physical world.

Friedrich and Eades proposed an algorithm that tries to exploit the ability of the human brain to interpret physical motions. Given an initial and final drawing of a graph the approach tries to find an animation that would be interpreted by the brain as the movement of three-dimensional objects in space [7]. This algorithm first divided the animation into a series of translation, rotation, scaling, and shearing operations. These operations define the set of two-dimensional affine linear transformations which is identical to the projection of motions of rigid bodies in space onto a plane. Applying an interpolation of these operations to the original graph provides an "easy to follow" animation from the original to the near final graph structure. A final step involving some linear interpolation is often required to reach the final graph drawing. This is because not all modifications can be described by affine linear transformations [7].

Unfortunately, exploiting the ability of the brain to understand biological motion in graph drawing seems very hard.

In the following we propose guidelines on how to generate and evaluate graph animations focusing on using the ability of the brain to interpreted organisationally structured motion.

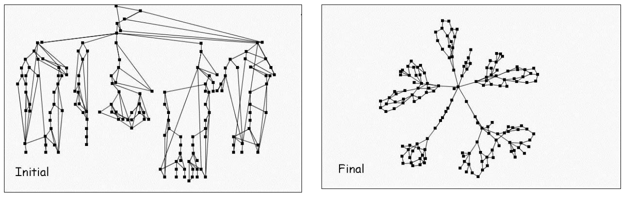

Figure 9. An automatic layout algorithm can dramatically alter the drawing of a graph. Figure 9 shows the "*Initial*" and "*Final*" drawing of a graph which has been automatically redrawn using a force directed algorithm. It is difficult to relate the two drawings.

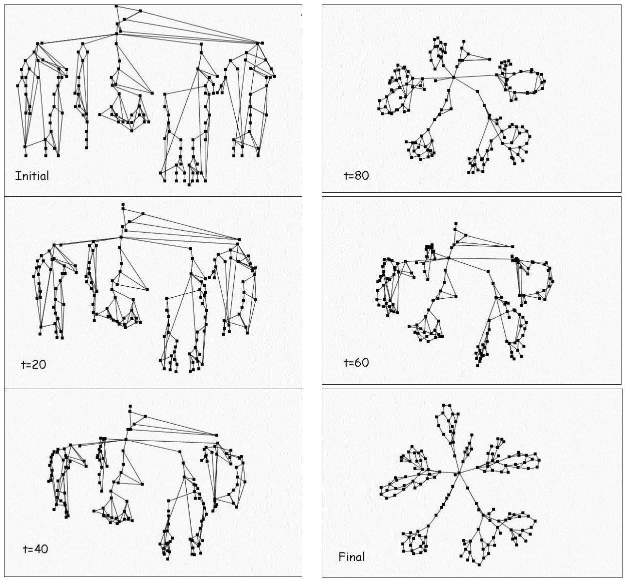

Figure 10. Shown here a some key frames from an 100-step animation from the initial to the final drawing of figure 9. The animation significantly increases the users ability to preserve the mental map.

4. Applying the Gestalt Principles

In this section we examine how Gestalt principles can be applied when creating graph animations. The goal of graph animation is to communicate changes in the structure and appearance of a graph to the user in a way that allows the user to maintain a *mental map* of the graph. As the Gestalt principles determine how we perceive a drawing, we aim to exploit this characteristic to draw the users attention to important parts of the graph and help the user identify groups of nodes and edges that move similarly. In the following we look at each law and propose ways to use its properties. These recommendations are of a very general nature and we are aware that an implementation in some cases would be very challenging. This section should therefore be understood as a set of design guidelines or criteria for evaluation of animations rather than as a proposal of design methods. However, we give suggestions about how some of the ideas could be implemented or what heuristics might give promising approximations. Some further, more detailed approaches, on determining *Gestalt* clusters in graph drawings can be found in [11].

4.1 The Law of Simplicity

"*Every stimulus pattern is seen in such a way that the resulting structure is as simple as possible*."

4.2 The Law of Familiarity

"*Things are more likely to form groups if the groups appear familiar or meaningful*."

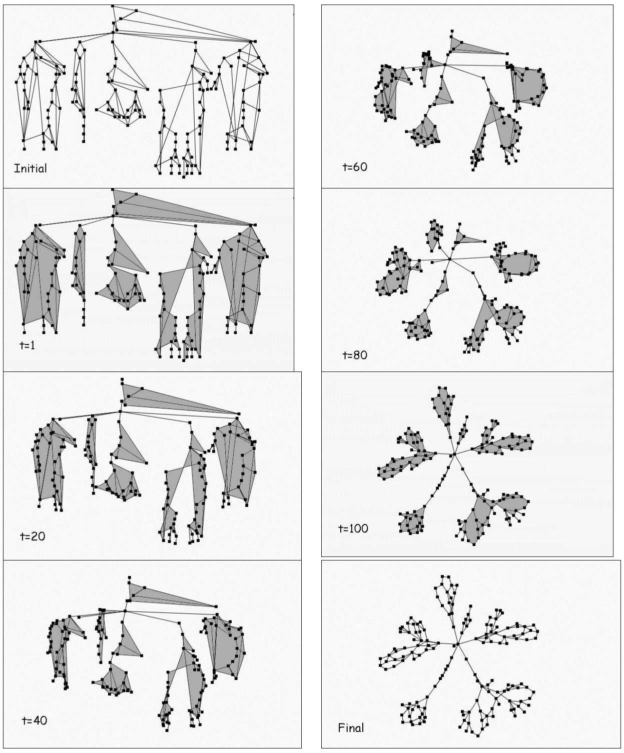

Figure 11. By shading the polygons formed by the graph edges we highlight the "simple and familiar" structure in the graph. This figure shows some key frames in the 100-step animation.

We propose to apply these two principles together. To help, highlight simple and familiar structures in the graph. For example before animation the original drawing is decomposed into familiar and simple geometric shapes. These can, for example, be major geometrical clusters in the graph. These shapes can be incorporated into the graph drawing as background elements or even completely replace the nodes of the clusters. These elements are then transformed during the animation along with the nodes and edges (Figure 11).

A first preference would be for very simple shapes like squares, circles and triangle. However, regular polygons that enclose the major clusters are more common in graphs. We can also imagine more anthromorphic or biological shapes like deformed ellipsoids or spirals that may occur.

A possible approach is to combine smaller faces of the graph to polygons or compute the convex hulls of geometric clusters and then shade them (Figure 11). This produces pleasing results, is feasible to implement, but relies on the perceptual bias to pick out the familiar and simple shapes in the graph.

4.2 The Law of Similarity

"*Similar things appear to be grouped together.*"

The law of similarity can be simply applied. For example colouring key nodes in red, or colour coding nodes based on clusters. This help to preserve the structure during animation. It also has the benefit that it provides landmarks within the structure that help the user navigate the new mental map (figure 12).

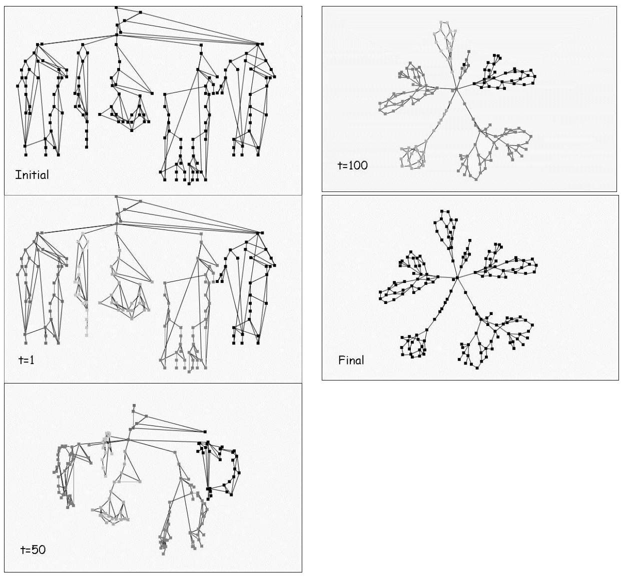

Figure 12. Each cluster in the graph is colour-coded to be made 'similar'. Even with the few time steps from this 100-frame animation shown here it is obvious that the clusters are now easier to follow during the reconfiguration. Note

that one node which is part of far right cluster in the initial drawing actually changes clusters during the animation.

4.3 The Law of Good Continuation

"*Points that, when connected, result in straight or smoothly curving lines, are seen as belonging together, and the lines tend to be seen in such a way as to follow the smoothest path.*"

4. 4 The Law of Connectedness

"*Things that are physically connected are perceived as a unit.*"

We suggest supporting these principles by highlighting key structural edges in the graph. These need not be semantically important edges but could just be edges that are perceptually dominant. We would expect, for example, line connection "clusters", straight lines, horizontal, vertical, and at various key angles such as 45 degrees that straight lines would stand out to the user. Similarly, we would expect biological-like curves to be dominant.

We propose to make these edges more dominant by overlaying a thicker line. One way to do this is to treat the nodes as points in a 2-D space and then apply standard statistical methods to find lines. More complex curves might be suggested by using key nodes to describe a nurb. Another pragmatic approach would be to apply edge detection algorithms from the image-processing domain so that edges or different orientation are emphasized (figure 13).

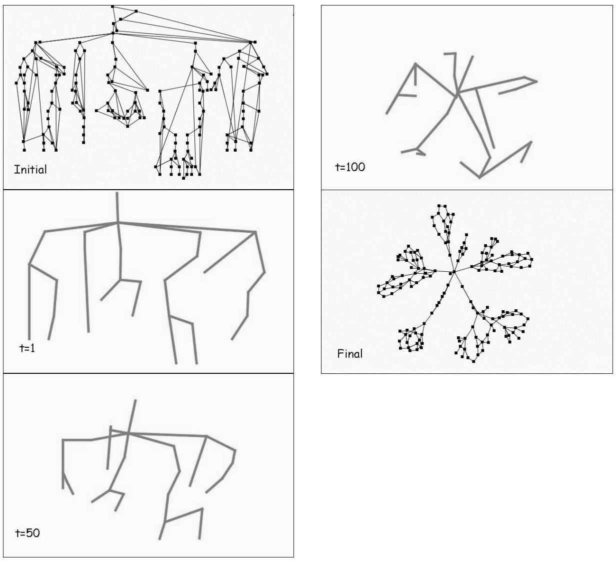

Figure 13. A horizontal edge detection algorithm (followed by a contouring effect to invert the image) is applied to the same graph in Figure 11. Key frames from the 100-step animation are shown. Note how key structural connections are enhanced.

4.5 The Law of Proximity

"*Things that are near to each other appear to be grouped together*".

When computing an animation we should aim to maintain proximity as much as possible. That means that if nodes or edges are close to each other in the initial and final drawing the animation should keep them close together during the whole animation. The expected effect would be that the brain of the user groups nodes and edges automatically to clusters according to proximity. If we avoid breaking these clusters during the animation the visual complexity of the animation is lower than if we do. Thereby enhancing the quality of the animation. It is also thinkable to shrink clusters before the animation to assist the user in perceiving them as an entity.

4.6 The Law of Common Fate

"*Things that are moving in the same direction appear to be grouped together.*"

We found that this law not only holds for objects moving in the same direction, but even for objects which move in any structured way. Examples for structured motions where objects do not move in the same direction would be rotations and scalings. The effect of applying this law coincides with the results of previous work found in [7].

5. Discussions and Future Work

It is possible to construct scenarios where principles conflict. For example nodes could be coloured the same on some clustering criteria and hence are perceived as grouped by the "Law of Similarity". Yet when the nodes move the clustering may break. We found that in animations it seems as though the "Law of Common Fate" takes some precedence. Imagine the nodes previously grouped together moving to two new clusters that are separated in the new structure. In this case the "Law of Common Fate" will at some stage override the "Similarity Law" or "Proximity law" as the animation proceeds.

There are a number of obvious directions future work can take. This paper proposes a number of ways to apply the principle but they are yet to be completely implemented and tested. However our informal evaluations suggest they will be useful at least in some graph animations. Of course a number of areas will require more formal human factors experiments to measure user performance and understanding.

We discussed briefly the role of conflicting perceptual cues. It is possible that where the Gestalt laws present conflicting information that this may be confusing to the user. However it may still provide useful information about the way the structure has changed because it helps the user map the changes. For example, the user might think, "the red nodes have moved position but I remember where they were located in the original drawing and can see where they have been placed in the new drawing".

It is of course possible to construct more complex examples. These could involve multiple conflicting laws and more work needs to be done to determine when and where this might be useful or indeed detrimental to user understanding.

Our work has involved abstract graph drawings with little consideration of the domain for which the drawings are being applied. Yet it is very likely that different application domains may suggest unique applications of the principles. These may be highly task specific. For example when navigating graphs of web pages, it is normal to colour recently visited web pages. These similarly coloured nodes could be useful structural cues suggested by the "Law of Similarity".

Software system models often show important base classes, which could be depicted as differently shaped or coloured nodes in the graph. Other information such as level in an inheritance hierarchy could also be used to colour or shape similar nodes. Readily calculated information such as edge degree could be used to enhance edges from these important classes and hence assist in applying the "Law of Connectedness". Indeed standard UML notation already uses shapes such as triangles and diamonds to label different edge types like composition (diamonds) and inheritance (triangles). At different times a software engineer may wish to maintain different "structural views" and so we could apply different Gestalt rules to different parts of the software graph depending on their task.

Semantic Maps are a more general form of knowledge representation, but like software models they may have key concepts, which are important in determining the overall structure of the graph. Again these might be recognised automatically by the number of edges that connect into a node or could be more tightly under user control. The user might for example select the important nodes in the graph that is those they wish to follow. These could be coloured red for example before the animation occurs.

The Gestalt principles apply not just for visual perception but are also to our perception of sounds. For example this helps us recognise patterns in music and to segregate sound into discrete streams [10]. Sound can provide useful grouping cues and it may be possible to integrate sound cues to assist users in transforming their mental map.

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