Identifying Commonly-Used Gestalt Principles as a Design Framework for Multi-Sensory Displays

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Abstract—The multi-sensory display of abstract data is a new and emerging area of study in the area of computer interfaces. One broad application of multi-sensory displays is to display abstract data using multiple senses in such a way that the user might detect useful patterns in the data. Gestalt theory explains how humans organize individual elements into groups and how humans perceive and recognize patterns. Because we are interested in the design of information displays that allow users to find patterns, Gestalt principles suggest themselves as one possible framework for collating useful design guidelines. This paper begins with a brief discussion of perception. This is followed by a short historical survey of major developments in perceptual theory. This paper surveys a number of theoretical and applied research works that concern Gestalt principles. From this survey the most commonly used principles are identified and relevant work to do with multi-sensory display is discussed. Finally, some opportunities to extend existing knowledge in the area of haptic display are identified.

I. INTRODUCTION

MUltI-SENSORY displays attempt to take advantage of a range of human senses. For example, such displays would include not only visual information but also auditory and haptic (tactile) feedback. This is a new and emerging computer discipline. One broad application of such displays is to display abstract data using multiple senses in such a way that the user might detect useful patterns in the data. This can be thought of as ‘perceptual data mining’. The primary motivation for using multi-sensory displays for such applications is that they offer more channels on which information can be displayed.

Unfortunately the design of multi-sensory displays is complex, as it is necessary to carefully consider the perceptual capabilities of humans. Indeed the understanding of how we perceive and process multi-sensory perceptions is still not well understood [65].

Gestalt theory is one of the well-known perceptual theories for perceptual organisation. Gestalt theory explains how humans organise individual elements into groups and how humans perceive and recognise patterns. In the applications we are interested in, designing displays that allow users to find patterns is a key feature.

As a result, Gestalt principles suggest themselves as one framework for grouping multi-sensory display guidelines.

Indeed such a framework based on Gestalt principles has been proposed in previous work [12]. One important question that arises is, “What are the most commonly used Gestalt principles?”. This paper is designed to address this question in some detail by identifying the most ‘commonly used Gestalt principles’ from a survey of existing literature.

This paper begins with a brief history of major developments in perceptual theory. This paper then introduces Gestalt theory and identifies the commonly used Gestalt principles. During this review we also discuss whether it is appropriate to apply these principles in the sensory modalities of vision, hearing and touch. We also comment on the previous application of these principles in a diverse range of research areas.

II. PERCEPTION AND ITS HISTORICAL DEVELOPMENTS

Perception has been studied as far back as the ancient Greek philosopher Aristotle (384-322 B.C.) [21]. At this time two opposite viewpoints about perceptual organisation were proposed. Some ancient Greek philosophers suggested that the central cognition of information was most important [13]. For example, Plato (300 B.C.) argued that humans should perceive elements with the mind rather than the sensory organs [13] and Epicharmus (450 B.C.) suggested that “The mind sees and the mind hears. The rest is blind and deaf.” [51].

By contrast, other Greek philosophers believed that the peripheral sensory organs themselves received the correct information. An example can be found from a statement made by Protagoras (450 B.C.), “Man is nothing but a bundle of sensations” [16].

Since then, there have been different theoretical approaches to studying perception in psychological and scientific contexts. A number of perceptual researchers have focused on a physiological framework for perception. Such an approach is sometimes described as biological reductionism as it relies on the study of specific neural units for understanding specific sensory experiences [14]. This type of biological approach is used by Livingstone and Hubel [30] to investigate the ability of primates to segregate visual qualities such as form, colour, movement and depth. This biological approach is again used by Sekuler and Blake [47] to investigate the range of human sensory perception including sight, hearing, touch, smell and taste.

In contrast, Goldstein [20] adopts a more balanced approach studying both behaviour and physiology to explain perception. Behavioural evidence for perceptual
perceptions also human memory. This implies that the way we perceive the world is learned rather than innate. Empiricism is the basis for Constructivist theory, which is also described as classical perceptual psychology. The focus in this approach is on the way we internally put together or construct our perception from the individual sensory inputs. For example, given the way an image is formed on the retina, what information or cues are used to create our perceptual experience of that image. Constructivists investigated many perceptual cues and sensory illusions and relied on a psychophysical approach to understanding perception. Psychophysics attempts to understand perception by describing quantitative relationships between external physical stimuli and our psychological experience of those stimuli [3]. Notably for multi-sensory display, Constructivism also highlights the ambiguous nature of sensory inputs which must be resolved to create a correct perception.

Gestalt psychology was in many ways a reaction to the constructivist suggestion that perception could be understood by studying the individual parts or sensory cues. A major idea of Gestalt psychology is that the "whole is greater than the sum of parts". This important concept is explained with the two following quotes from Wertherimer's seminal work on Gestalt psychology [60].

Another major figure in perceptual psychology was Gibson (1904-1979). Gibson introduced the idea that our human organs receive information directly and that this information is complete. Thus, it is through this direct sensing that we become aware of the world and not through any cognitive model [14]. This view runs counter to cognitive psychologists who propose that, as we move about in the world, we create an internal cognitive model of how the world works. This model or percept can change as we move about the world and take in new sensations.

Gibson [19] suggests three general processes to explain the way we create our perceptions. They are: 'innate rational powers (theoretical nativism)', 'the storehouse of memory (empiricism)' or 'form-fields (Gestalt theory)'. Thus, Gibson [18], [19] supported the idea that Gestalt theory was a useful way to explain how we integrate the sensations of the world into our perceptions.

Another important approach to explaining perception theory was put forth by Marr in 1982. Marr [31] uses the visual senses to study complex information processing systems and in so doing has influenced computational theories of perception. His work is an integration of ideas from the fields of psychology, physiology and also computer science. Marr attempts to account for the roles of direct perception, constructivist cues, and Gestalt theory within a computational model [14].

While no single theory of perception is completely accepted, we adopt the view that the Gestalt approach is well supported. For example, Geldard [17] incorporated Gestalt principles into his perceptual theory and Wyburn et al. [64] also used the Gestalt principles to explain perception of space, size and distance. More recently Harper [21] proposed that visual perception would not be complete without Gestalt theory and emphasized it's importance for explaining how we organize patterns. Rock [44] also used Gestalt grouping principles to explain the impact of orientation on form perception [45]. Moreover, Styles [52], discusses how Gestalt principles can explain how we group visual and auditory elements.

Despite this acceptance, it is noted that some criticisms exist for the Gestalt approach, namely the lack of a computational theory to explain how it works and the shortage of an identified physiology to explain the theory. Despite this we believe that Gestalt theory still provides a useful framework for designers of multi-sensory information displays. Since Gestalt theory tries to explain how we interpret groupings we also suggest this approach is particularly valid when the primary aim of the designer is to assist pattern recognition or group elements.

This paper now presents a more detailed history and description of Gestalt theory. Over time Gestalt theory has given rise to a number of principles and has often focused on the visual perception. The questions we address in this paper are 'What are the most commonly-used principles?' and 'How Gestalt principles can be applied across sensory modalities?'

III. BACKGROUND TO GESTALT THEORY

The Gestalt school of psychology was originally described by Wolfgang Köhler and Max Wertherimer [26], [61]. Initially, this theory solely belonged to the domain of psychology studies [61], but over the years the concepts have influenced many other research and study areas. These include: image retrieval [23], [58], visual screen design [1], [11], [34], graph drawing [37], musical studies [6] and the design of auditory displays [7], [36], [59], [62]. Gestalt theory has even been used to explain the psychological patterns of gamblers [46].

Gestalt is a German word and its meaning can be roughly translated into English as "form, shape, [or] pattern" [10]. Every individual perceptual element has its own nature and characteristics, but the nature of individual elements alone cannot account for how a group of elements will be perceived. The essential point of Gestalt theory is that the perception of the whole pattern (or gestalt) cannot be explained from the sum of its parts. This is often stated as the whole are "more than the sum of their parts" [26, pp.17]. Gestalt theory developed principles that try to explain how we organize individual elements into groups.

A key part of Gestalt theory are a number of principles first introduced by Max Wertheimer [60] and later elaborated on by Kurt Koffka [25]. Wertheimer [60] identified a numbers of foundational Gestalt principles
for perceptual grouping such as the principles of Closure, Common Fate, Continuation, Proximity and Similarity. Koffka [25] studied three more principles for perceptual organization: the principles of Figure-Ground, Pragnanz and Simplicity. A number of authors discuss the Gestalt principles of perceptual organization in books dealing with perception [14], [20], [47], [52]. In so doing they describe the theoretical background of, and provide figures to explain, the Gestalt principles. Brief discussions of some of these key principles are provided later in the paper. The next section examines some of the areas that these Gestalt principles have been applied.

IV. APPLYING GESTALT PRINCIPLES

Gestalt principles have been applied in a number of research areas. Vecera et al. [56] demonstrated how exogenous spatial attention influences the principle of Figure-Ground. Woodman et al. [63] report experimental results which explain the influence of the Gestalt principles over visual working memory. Furthermore, van der Helm’s [55] psychological research examines the principle of Pragnanz, and Brosnan et al. [8] applies the Gestalt principles to study autism.

Most people are able to identify patterns and group familiar elements. However, people with a disability such as row blindness have difficulties in grouping row elements. By applying the principles of Similarity and Proximity, the experiments of Lewis and Frick [28] reveal that people who suffer from row blindness cannot group rows elements. A related problem also causes some individuals difficulty when processing English language text.

Gestalt principles have been adopted as a fundamental theory for explaining visual illusions. This covers the areas of painting, sculpture and graphic design. Katz and Tyson [24] utilise simple points and lines to explain the Gestalt principles in visual grouping. Arnheim [1] also uses a simple illustration to explain Gestalt principles in the visual perceptual process. Pinna [42] examines the watercolour illusion by applying the principles of Similarity and Figure-Ground.

Riddell [43] believes in the importance of studying visual education for designers and applies the Gestalt principles into other design professions, such as industrial, graphic and textile design. Bevlin [4] also explores the elements of design by using the Gestalt principles to explain the design theory for painting, sculpting and photography. Trimmel [54] applies Gestalt theory to understand the relationship between shape and colour as the two primary parts of a geometric composition.

Gestalt principles have also been used in the design of instructional multimedia for education. For example, Heinich et al. [22] describes the way in which Gestalt principles influence the visual design process in instructional design. Moore and Fitz simplify the complicated instructional design [34], and they also design documenting and graphic layouts [35] by using the Gestalt principles. The principles of Gestalt theory have also been used to assist designers develop multimedia applications [11], [49] and improve instructional screen design [50]. Another example of using Gestalt principles as a framework to design screen layouts is in the work of Ngo et al. [38], who adopt a mathematical approach in conducting experiments and analyzing data. They present detailed algorithms to measure the designed screen layouts. Szabo and Kanuka [53] examine whether the Gestalt principles influence the learning process. The results of their experiments show that using Gestalt principles can improve the learning process in the delivery of instructional material.

Gestalt principles can also be used in graph drawing for visual perceptual grouping. Nesbitt and Friedrich [37] demonstrate how to use the Gestalt principles to find similar patterns in graph drawing. Each principle is described through graph drawing examples. Shimaya [48] also studies how complex line drawings are perceived through the Gestalt principles. Shimaya’s experiments indicate that the proposed method performs better than structural information theory.

Palmer [39] studies the original Gestalt principles that are identified by Max Wertheimer and proposed the principle of Common Region, a new principle of perceptual grouping. The principle of Common Region is used to perceive depth relations after some depth perceptual process has been achieved. After investigating the Gestalt works of Max Wertheimer, Palmer and Rock [40] proposed another new grouping principle called the principle of Element Connectedness. Palmer et al. [41] describe the grouping effects from different points of view and explain how and why the grouping starts.

Gestalt principles have also been studied in the domain of image retrieval. For example, Wardhani and Gonzalez [57] develop an approach in image structure analysis for a content-based image retrieval system by implementing various Gestalt principles to detect groupings. Iqbal and Aggarwal [23] also apply five Gestalt principles and examine perceptual grouping applied to image structure extraction. Cao [9] proposes a new algorithm to detect regular curves in images. These results show the principle of continuation can be applied in most objects.

The Gestalt principles have contributed not only to the understanding of visual perceptual grouping but also auditory perceptual grouping. For example, Albert Bregman began his research on the perceptual organization of sound in the late 1960s. Bregman [7] introduces Gestalt psychology to explain the difference between auditory and visual perception detailing examples of his experiments. He also studies the auditory streaming effect and uses the Gestalt principles to explain how we group auditory elements.

Williams [62] simplified the complex sound relationship by using the Gestalt principles as the basis for perceptual principles to explain sound grouping. This work investigates sound grouping and introduces the STEAMER computational model along with experimental methods that support the development of this model.
Melih and Gonzalez [33] apply the Gestalt principles as perceptual considerations during stream segregation in order to develop a structured representation for audio content-based retrieval and browsing. Brattico and Sassanelli [6] apply the Gestalt principles to describe the recognition of objects in musical studies.

Furthermore, Moore [36] believes that the Gestalt principle “govern the perceptual organization of the auditory world”. Moore points out that these principles can be generally used together as opposed to using a single principle for perceptual grouping.

Besides the Gestalt principles used in the grouping of visual and auditory elements, Li et al. [29] apply the Gestalt principles in geographical studies. The methodology and results which they present are based on the Gestalt principles for building developments.

The next section examines the most commonly used Gestalt principles and the following section discusses their application to multi-sensory display.

### TABLE 1

<table>
<thead>
<tr>
<th>Gestalt Principle</th>
<th>References (Visual Mode)</th>
<th>References (Auditory Mode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance</td>
<td>1, 4, 5, 11, 14, 22, 23, 27, 34, 35, 38, 43, 47, 48, 50, 53, 57</td>
<td>6, 7, 33, 36, 62</td>
</tr>
<tr>
<td>Belongingness</td>
<td>8, 11, 14, 23, 24, 25, 29, 34, 35, 39, 41, 47, 50, 60, 64</td>
<td>6, 7, 36, 62</td>
</tr>
<tr>
<td>Common Fate</td>
<td>14, 20, 24, 29, 31, 37, 41, 52, 57, 60</td>
<td>6, 33, 36, 62</td>
</tr>
<tr>
<td>Continuation</td>
<td>9, 11, 14, 20, 23, 24, 25, 28, 29, 34, 35, 37, 39, 41, 47, 48, 57, 60</td>
<td>6, 7, 33, 36, 62</td>
</tr>
<tr>
<td>Figure-Ground</td>
<td>2, 11, 14, 20, 22, 25, 34, 35, 42, 49, 50, 56, 64</td>
<td>7, 36</td>
</tr>
<tr>
<td>Focal Point</td>
<td>11, 27, 43, 53</td>
<td></td>
</tr>
<tr>
<td>Habit</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Isomorphic</td>
<td>11, 24, 64</td>
<td></td>
</tr>
<tr>
<td>Pragnanz</td>
<td>5, 11, 14, 25, 55, 64</td>
<td></td>
</tr>
<tr>
<td>Proximity</td>
<td>8, 11, 14, 20, 22, 23, 24, 25, 28, 29, 34, 35, 37, 39, 41, 47, 49, 50, 52, 57, 60, 63</td>
<td>7, 60, 62</td>
</tr>
<tr>
<td>Similarity</td>
<td>1, 11, 14, 20, 23, 24, 28, 29, 34, 35, 37, 39, 41, 42, 47, 48, 49, 50, 52, 57, 60</td>
<td>6, 7, 20, 33, 36, 60, 62</td>
</tr>
<tr>
<td>Simplicity</td>
<td>1, 11, 14, 25, 37, 38, 49, 50, 54</td>
<td></td>
</tr>
<tr>
<td>Unity</td>
<td>4, 11, 38, 43, 53</td>
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</table>

### TABLE 2

<table>
<thead>
<tr>
<th>The Number of Times Each Gestalt Principle Was Used</th>
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<tbody>
<tr>
<td>Gestalt principle</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Similarity</td>
</tr>
<tr>
<td>Proximity</td>
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<tr>
<td>Continuation</td>
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<td>Closure</td>
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<td>Habit</td>
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#### A. Similarity

Elements will tend to be grouped together if their attributes are perceived as related [20], [36]. For example, with visual displays elements will be grouped together, if the lightness (Figure 1), hue, size, orientations or shape are closely related with each other [20], [41]. People also group similar sounds together if the timbre, pitch, subjective location or loudness is closely related to each other [7]. With haptic perception, it is also possible to group similar shapes, forces, surface textures, weights and vibrations.

![Fig. 1. The elements in this figure are visually grouped by the similar lightness into four groups of black circles and three groups of grey circles.](image1)

![Fig. 2. In this image we typically perceive two distinct groups based on their visual proximity.](image2)

#### B. Proximity

The principle of Proximity states that elements which are close to each other will be grouped together (Figure 2) [15], [20]. Sound events are also grouped together if the sounds are related to one another in time [7]. For example, three flute sounds playing the same melody at the same
time that are close together temporally will be grouped together. If they were to play the melody in an unsynchronised way then the three flutes would form separate groups.

C. Continuation

People tend to perceive a smooth and continuous outline between points rather than lines with sudden or irregular changes in direction. Thus elements will be grouped together if a continuous pattern can be interpreted and this pattern will be assumed to continue even if some parts are hidden [34].

For example, if a sound slowly changes in pitch, loudness or timbre in a very smooth manner then the sound will still be perceived as the one sound [36]. When we use the sense of touch we tend to perceive a smooth and continuous outline even though some parts are hidden with unfamiliar patterns.

D. Closure

The principle of Closure describes our natural tendency when a signal is perceived [15]. It is useful as it allows people to ignore missing information and use our experience to group disconnected, but related, objects together (Figure 3).

![Closure](image)

**Fig. 3.** To complete unfinished forms, people will tend to fill in the empty spaces for each letter with familiar patterns.

E. Balance

The principle of Balance is also known as the principle of ‘Symmetry’. The idea of the principle of Balance is to achieve an ‘equal weighting’ of attributes when elements are displayed [5], [27]. There are two ways to achieve balance: symmetric balance (Figure 4) and asymmetric balance (Figure 5).

![Symmetric](image)

**Fig. 4.** An example of symmetric balance: people perceive the two circles are evenly placed both vertically and horizontally.

![Asymmetric](image)

**Fig. 5.** An example of asymmetric balance: people perceive that the two circles of different sizes are not evenly placed around a central axis, but the visual weight is still equally distributed on both sides.

F. Figure-Ground

It is natural for humans to distinguish between foreground and background when they receive information [2]. For example, people can read text from the newspaper because people perceive text as figure and the other as ground [20]. Also, when we are listening a symphony, we will tend to separate primary streams (figure) from background harmony (ground) [36]. Braille is a form of writing for the visually impaired that relies on haptic perception and the Figure-Ground principle to allow characters to be distinguished (Figure 6).

![Braille letters](image)

**Fig. 6.** Braille letters are perceived as figures against the ground.

![Visual elements](image)

**Fig. 7.** If you can imagine these visual elements moving as indicated by the arrows you will group the elements based on their common fate.

G. Common Fate

The principle of Common Fate suggests that display elements that change at the same time or move in a similar way will be grouped together [20]. For example, animated visual elements that move in the same direction, with the same speed will be seen as related (Figure 7). In auditory displays, people tend to group sounds together if they change in pitch in a similar way. Sounds that begin and finish at the same time are also likely to be perceived as related [36].

VI. CONCLUSION AND FUTURE WORK

Most early studies of perception have focused on the visual sense. This is also true for studies of Gestalt theory, where the early works looked at principles for grouping elements and also figure recognition in vision. More recently we find that Gestalt theory has been applied to the study of auditory perception. However one finding from this paper is the lack of applied Gestalt research in the haptic (tactile) domain. Furthermore, Gestalt principles have not been applied to understanding the way patterns are perceived by multiple senses. One of the motivations for this research is to apply Gestalt principles into the new domain of multi-sensory display.

The authors have identified a set of commonly used Gestalt principles which can be used as a framework to assist designers of multi-sensory displays. Future work will focus on gathering and evaluating relevant guidelines for multi-sensory display within this framework.

REFERENCES


