THE RELATIONSHIP BETWEEN VISUAL INTERFACE AESTHETICS, TASK PERFORMANCE, AND PREFERENCE

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Abstract

The purpose of this thesis was to develop a conceptual framework that shows the relationship between aesthetics, performance, and preference in computer interface design. To investigate this relationship, the thesis focused on investigating the effect of layout aesthetics on visual search performance and preference.

This thesis begins with a literature review of related work followed by the rationale for conducting this research, in particular, defining what it meant by visual aesthetics in the context of interface design.

Chapter 4 focused on investigating the effect of layout aesthetics on performance and preference. The results show that response time performance and preference increased with increasing aesthetic level. Preference and performance were found to be highly correlated.

Chapter 5 focused on investigating users' layout preference when they were not involved with a performance-based task. The results showed, surprisingly, that preference was highest with a "moderate" level of layout aesthetics and lowest with "high" and "low" levels of aesthetics.

Chapter 6 focused on investigating visual effort by measuring eye movement pattern during task performance. The results showed that visual effort increased with a decreasing level of aesthetics.

Chapter 7 extended the experiment in Chapter 4 using more "ecologically valid" stimuli. The results essentially replicated the results produced in Chapter 4.

Chapter 8 focused on investigating the relationship between so-called "classical" aesthetics and background "expressive" aesthetics. The results showed that task performance using classical aesthetics was highest with high and low levels of aesthetics and worst with medium levels of aesthetics. Performance with expressive aesthetics increased with decreasing aesthetic levels.

This thesis concludes with a conceptual framework for aesthetic design to help interface designers design interfaces that look aesthetically pleasing while at the same time supporting good task performance.

Acknowledgements

Firstly, I would like to thank my supervisors Helen C. Purchase for guiding me and for continually inspiring me throughout my PhD.

Thanks also to my second supervisor, David R. Simmons, for all of his input and bringing a different point of view to the table.

Special thanks go to Stephen Brewster for acting as a supervisor during the first year of this research, supporting my research.

Last but not least, I would like to offer many thanks to my family and friends for helping me throughout my PhD with lots of encouragement and support.

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Declaration

The contents of this thesis are entirely the author’s own personal work. This thesis only makes use of parts of papers that are directly attributable to the author. All other material has been referenced and given full acknowledgement in the text.

The experiment reported in Chapter 4 has been published in 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries, co-authored by Helen C. Purchase, David R. Simmons, and Stephen A. Brewster [120].

The experiment reported in Chapter 5 has been published in BCS '10 Proceedings of the 24th BCS Interaction Specialist Group Conference, co-authored by Helen C. Purchase, David R. Simmons, and Stephen A. Brewster [121].

The experiment reported in Chapter 7 has been published in abstract form in Perception 40 ECVP, co-authored by Helen C. Purchase and David R. Simmons [119].

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List of Abbreviations

ATM	Automatic teller machine
BM	Balance
CBT	Computer based tutorial
CM	Cohesion
DM	Density
ECM	Economy
EM	Equilibrium
GUIs	Graphical user interface
HAL	High aesthetics
HCI	Human computer interaction
HE	High expressive
HM	Homogeneity
LAL	Low aesthetics
LE	Low expressive
MAL	Medium aesthetics
ME	Medium expressive
OM	Order and complexity
PEU	Perceived ease of use
PM	Proportion
PU	Perceived usefulness
RHM	Rhythm
RM	Regularity
RQ1	Research question 1
RQ2	Research question 2
RQ3	Research question 3
SD	Standard deviation
SMM	Simplicity
SQM	Sequence
SYM	Symmetry
TAM	Technology acceptance model
UM	Unity

Chapter 1

Introduction

The purpose of this chapter is to provide the research background, motivation, thesis statement, research objectives, research questions, and to state the significance of the thesis.

1.1 Research background

Attractive things work better – Donald Norman[99]

The important role of visual aesthetics in interface design has been highlighted in many studies. Most studies found that an “aesthetically designed” interface is perceived as “better quality” than a less aesthetic interface. Such qualities include perceived ease of use (PEU), perceived usefulness (PU), trustworthiness, greater satisfaction, more interest, more enjoyment, etc.

In the original version of Technology Acceptance Model (TAM) by Davis [33], PEU and PU were identified as the main determinant for user acceptance and usage of information systems. Over the years, TAM has been revised extensively resulting in the discovery of other important determining factors for technology acceptance besides PEU and PU such as social influence, utility, etc. (see for example [78,56]). Although opinion varies on the most important factors for technology acceptance, most of the studies recognise the importance of PEU and PU on technology acceptance.

What makes an information system perceived as easy to use or useful? Several studies [65,137,139,144] found that PEU and PU are strongly related to aesthetics. An aesthetically designed interface is perceived as easy to use and useful compared to less aesthetic interface.

While there is substantial evidence that aesthetic design enhances perceptions of, and attitudes toward, various computing products [65,137,122,75,98,144,76,103,138,21], whether aesthetic design also enhances actual task performance is unclear due to the limited and inconsistent findings of studies that investigate the relationship between aesthetics and task performance.

For example, the results of a study by Szabo and Kanuka [133] on a computer-based tutorial (CBT), suggest that learning time and task completion rate can be improved significantly by good design principles such as balance, unity, and focus. Their claim was supported by Sonderegger and Sauer [129] who conducted a study on mobile phones and found that task completion times were better with attractive models than unattractive models. Further support can be found in Moshagen et al. [90] who conducted a study on websites and found that webpages with aesthetic design enhanced users' performance when users were required to visit many different pages to get the information they needed.

While studies such as those discussed above suggest that aesthetics support performance, other studies contradicted this idea. Nakarada-Kordic and Lobb [93] for example, suggested that aesthetic design does not support task effectiveness or efficiency but it does make users more patient and keeps them interested. In another study by Chawda et al. [24] where they compared the performance of several data visualization techniques, they found that there was no difference between search time and the number of errors between aesthetic and non-aesthetic design and concluded that although attractive things are perceived to work better they do not necessarily actually work better than unattractive things. A similar finding was found by Ben-Bassat et al. [10] who conducted a study on an electronic phone book and found that the amount of data entered in a specific given time was no different with a less aesthetic design. Ben-Bassat's finding however was claimed by Moshagen et al. [90] to be biased due to the fixed number of steps that the participants had to follow to complete the task and not due to the design of the interface.

The different findings of these studies are likely to be related to a difference in methodology. Some studies focused on the layout, others on the colour combinations, or simply on the graphical design of the interface. Although these studies focused on different aspects of the interface, they all are similar in one aspect. All of them rely on subjective judgment to measure the aesthetics of the interface. While subjective judgment is indeed an effective way to determine the aesthetics of an interface, an objective, automatable metric of screen design is an essential aid [98].

There are several metrics in the literature for screen design. For example, Streveler and Wasserman [132] proposed metrics for assessing the spatial properties of alphanumeric screens such as symmetry, balance, percentage of screen used, and average distance between groups of items. Streveler and Wasserman however did not apply or test these metrics. Tullis [141] also proposed four metrics (density, local density, grouping, layout complexity) for assessing the spatial properties of alphanumeric screens. The applicability of these metrics on Graphical User Interfaces (GUIs) however has not been tested. Sears [125] developed a task layout metric called “layout appropriateness” which measured the efficiency of widget (i.e. buttons, boxes, and lists) placement in computer interfaces. However, how this metric matches with visual aesthetic perception is not known. Although the metrics proposed by these studies [132,141,125] are carefully developed, the objective measures proposed by Ngo et. al [98] can be considered as the most comprehensive as they synthesize the guidelines for spatial layout from many studies. The robustness of Ngo et. al [98] to measure the aesthetic layout of the interface is also supported in other studies: see for example [104,156].

Lavie and Tractinsky [67] proposed that the aesthetics of an interface can be classified into two dimensions: classical aesthetics and expressive aesthetics. The findings of De-Angeli et al. [3] suggested that the selection of these dimensions should be based on context of use and target population and suggested classical aesthetics for serious tasks and with adult users, and expressive aesthetics for leisure tasks and with young users. This suggestion was supported by Van Schaik and Ling [145]. According to Van Schaik and Ling, users expect an interface with classical aesthetics for goal-oriented products and expressive aesthetics for action/activity/leisure-oriented products. While the use of these two dimensions is often recommended, no studies have investigated which one of them supports better performance.

1.2 Motivation

This study is motivated by three considerations. First, only a few studies have investigated the relationship between visual aesthetics, task performance, and preference. Second, prior studies that have examined the role of visual aesthetics on performance and preference have found mixed results, making it difficult to draw firm conclusions. Third, none of the prior studies have used an objective measure to measure the aesthetics of the interface and at the same time investigate the effect of the design on task performance and preference.

1.3 Thesis statement

An empirically validated framework for the aesthetic design of visual interfaces is helpful to understand the relationships between layout aesthetics, task performance, and user preference in Human Computer Interaction.

1.4 Research objectives

The main objective of this study is to develop a conceptual framework that shows the relationship between aesthetics of interface design, task performance, and user preference.

1.5 Research questions

To meet the objective of this study, the following questions were addressed:

RQ1: What is the relationship between the aesthetics of interface design and task performance?

RQ2: What is the relationship between the aesthetics of interface design and user preference?

RQ3: Is there any relationship between user preference and task performance?

1.6 Significance of research

This study provides a conceptual framework for the aesthetic design of an interface based on empirical evidence and which could be used as a reference by researchers, practitioners, interface designers, or anyone else interested in designing aesthetic interfaces that support task performance and user preference.

1.7 Overview of thesis

Chapter 2, *Literature review*, reviews related work on visual aesthetics in Human Computer Interaction (HCI). This chapter places the work of this thesis in context by summarising related work and identifying an area which has received little attention.

Chapter 3, *Rationale of study*, discusses the rationale of this thesis and also the rationale of each individual experiment.

Chapter 4, *Layout aesthetics vs. performance and preference I*, reports the results of an experiment investigating the effect of layout aesthetics on performance and preference using simple stimuli (upright and inverted triangles).

Chapter 5, *Layout aesthetics vs. preference*, reports the results of an experiment investigating the effect of layout aesthetics and preference using the same simple stimuli.

Chapter 6, *Layout aesthetics vs. visual effort*, reports the results of an experiment investigating the effect of layout aesthetics on visual effort by measuring eye movement patterns when viewing the same simple stimuli.

Chapter 7, *Layout aesthetics vs. performance and preference II*, reports the results of an experiment investigating the effect of layout aesthetics on performance and preference with more complex stimuli (small photographs). The task was similar to finding images using a standard interface such as Google™ images or icons on a typical computer desktop.

Chapter 8, *Classical layout aesthetics and background image expressivity*, reports the results of an experiment investigating the effect of classical aesthetics and expressive aesthetics on performance and preference, again using small photographs.

Chapter 9, *Discussion and conclusion*, reviews the work presented in the thesis and its novel contributions in terms of the research questions outlined in the introduction. A conceptual framework which synthesises the findings of all experiments in this thesis is included to illustrate the relationships between visual aesthetics, task performance and preference. Finally, the limitations of the experiments are outlined, along with suggested areas of further research to be conducted.

Chapter 2

Literature review

The aim of this research is to investigate the relationships between visual aesthetics, task performance, and preference. Therefore, the purpose of this chapter is to provide an overview of existing research on visual aesthetics in Human Computer Interaction (HCI) to place the contributions of this thesis in context. Although there is a vast amount of literature on the topic of visual aesthetics, this review will focus mainly on HCI and ignores research in other areas such as philosophy, and history of art.

The chapter begins by discussing the various definitions and theories of aesthetics, and how visual elements of computer interfaces can be perceived as aesthetic. The remainder of the chapter reviews the existing research on visual aesthetics with respect to perceived usability, task performance, and preference, and identifies research gaps.

Research Questions in this chapter are:

1. How should we define aesthetics?
2. How should we apply aesthetics to computer interfaces?
3. What is the current state of research on visual aesthetics in HCI?

2.1 Definitions and theories of aesthetics

Given that this research focuses on investigating the relationships between aesthetics, task performance, and preference, the first step is to know and understand the definition of aesthetics and how people perceive the aesthetics of interfaces. This section discusses various definitions and theories of aesthetics.

2.1.1 Definitions of aesthetics

The term aesthetics is derived from a Greek word αισθητικη (pronounced "aisthitiki"), meaning, "thing perceivable to the sense". Cambridge's online dictionary [1] defines aesthetics as "the formal study of art, especially in relation to the idea of beauty".

In HCI, the term aesthetics is defined in many ways:

- *Beauty* (Tractinsky [137]).
- *Visual appeal* (Lindgaard et al. [76]).
- *Visual appeal and appropriateness* (Avery [5]).
- *An artistically beautiful or pleasing appearance* (Lavie and Tracktinsky [67]).
- *The objective design aspects of a product, including form, tone, colour, and texture* (Postrel, cited in [129]).
- *Those elements of an interactive design that are carefully orchestrated to enhance and heighten the learner experience* (Miller [88]).

Although these authors differ in their definitions of aesthetics, a common factor in all of these studies is that they define aesthetic features as those characteristics of an interface which are perceived as pleasing or appealing to the viewer. This will be the working definition used in this thesis.

2.1.2 Theories of aesthetics: what makes an interface aesthetically pleasing?

There are many theories in the literature of what makes an interface aesthetically pleasing. Berlyne [12], suggested that preference for any stimulus is determined by its arousal potential in an inverted-U shape, that is, moderate complexity was preferred over simple or extremely complex stimuli (Figure 1).

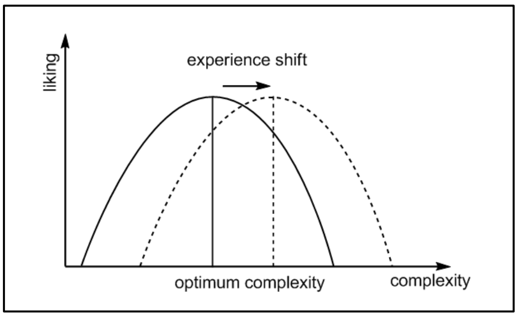


Figure 1. Berlyne's model of aesthetics (taken from [69])

Berlyne's arousal potential consists of:

- Psychophysical properties referring to the physical properties of the stimulus such as intensity, pitch, hue, or brightness.
- Ecological properties referring to the "meaningfulness" or "learned associations" of a work of art or an object. So, a person may be aroused by an object or a work of art because it brings to mind an event that happened in the past.
- Collative properties relating to higher-order attributes such as novelty, complexity, surprise, etc.

Berlyne highlighted collative properties such as complexity (i.e. the amount of variety or diversity in a stimulus pattern) as the most important predictor for preference.

Although Berlyne's predictive model has received much support (see for example [136,48,117]), several studies have found otherwise. For example, Martindale et al. [83] suggested that preference is related to stimulus arousal potential by a monotonic or U-shaped pattern instead of an inverted U-shaped pattern, and highlighted semantic factors (meaningfulness) as more important than the collative properties in aesthetic preference. Other studies which used concrete real-world stimuli such as paintings, buildings, and furniture suggested that representativeness is an effective predictor of preference (cited in[74]). In another study by Pandir and Knight [103], in which they investigated the relationship between complexity, pleasure and interestingness of webpages, they found that there was a negative correlation between complexity and pleasure in website perception. Pandir and Knight highlighted individual differences in taste and lifestyle as factors that underlie preference.

A slightly different view, presented in the influential work by Lavie and Tractinsky [67], suggested that people perceive the aesthetics of interfaces in two different ways: via "classical" aesthetics and "expressive" aesthetics. Classical aesthetics refers to the orderliness and clarity of the design and is closely related to many of the design rules advocated by usability experts (e.g. pleasant, clean, clear, symmetrical) whereas expressive aesthetics refers to the designers' creativity and originality and the ability to break design conventions (e.g. perceived creativity, use of special effects, originality, sophistication, fascination). These two dimensions were similar to those proposed by Nasar (cited in [67]) as visual clarity and visual richness, respectively.

In a more recent study by Thielsch [91], it was suggested that there are four facets of visual aesthetics: simplicity, diversity, colourfulness, and craftsmanship. Simplicity and diversity are similar to what Lavie and Tractinsky [67] termed as classical aesthetics and expressive aesthetics respectively, colours are the property of the objects, and craftsmanship refers to the skilful and coherent integration of the relevant design dimensions [91].

The findings of these studies [12,83,67,103,91] showed that the perception of aesthetics can be based on many factors such as the level of complexity, meaningfulness of the design, representativeness, interestingness, and aesthetic dimensions.

2.2 The influence of culture on the perception of aesthetics

Culture plays significant influence on how people perceive the aesthetics of the interface [51,42]. Culture according to Robbins and Stylianou [116] refers to “a set of values that influence societal perceptions, attitudes, preferences and responses”. Different cultures perceive aesthetics differently: an interface which is perceived as aesthetic by other cultures might not be perceived as aesthetic by others.

A study by Masuda et al. [84] suggested that Westerners used more analytic styles whereas East Asians used more holistic styles when processing aesthetics and social information involving face stimuli. Their claim was based on their evaluation of the photographs taken by American and Japanese participants where they found that the photographs taken by the American participants focused more on the face and the object of the photograph rather than the background, whereas the photograph taken by the Japanese participants focused largely on the background rather than the face. Their finding was supported by Huang and Park [55] who extended Masuda et al.’s study using Facebook’s photographs, and found that East Asian users had lower intensity of facial expressions than Americans on their photographs.

Besides processing style, the reading direction habit was also found to significantly influence the perception of aesthetics. In a study by Chokron and Agostini [25], their finding revealed that subjects preferred pictures possessing the same directionality as their reading habit. Bennete et al. [11] later suggested that the expressiveness of pictures are affected by directionality.

In a cross-cultural study investigating the aesthetic perception of websites, many studies found significant differences across different cultures. In Cyr et al.'s [31] study, for example, they found that Canadians, Americans, Germans, and Japanese have different preferences for website design, including screen design (e.g. navigability, layout, and graphical elements). In another study investigating the colour appeal of an e-commerce website, Cyr et al. [32] found that Canadians have a strong preference for a grey colour scheme when compared to Germans and Japanese, whereas Germans, on the other hand, showed a stronger preference for a blue colour scheme and were more sensitive to jarring, unnatural or unappealing colours. Cyr et al. also highlighted the importance of knowing the colour appeal of a specific culture to keep users interested in the website.

Although the perception of aesthetics varies across cultures, according to Hume (cited in [103]), it is possible to have "standard of taste". He suggests that "the general principles of taste are uniform in human nature". This is why, *"The same Homer, who pleased at Athens and Rome 2000 years ago, is still admired at Paris and at London. All the changes of climate, government, religion, and language, have not been able to obscure his glory*" (as cited in [103]).

2.3 Visual search

Visual search refers to the act of visually scanning a scene, searching for a particular target object among irrelevant non-target objects [36,89]. The standard visual search involves participants looking for a target item among many distractor items [152] (target-absent search). Others require participants to look for more than one target (see, for example, [150,53]). Figure 2 shows an example of stimulus used in visual search where the subject was asked to find the letter X and T.

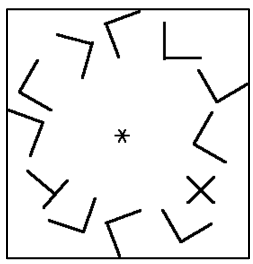


Figure 2. Find the X and T (adapted from [152])

The objects in visual search are normally simple and well-defined such as letters (e.g. T, F, S) [41,58], geometric shapes (e.g. circle, cross, square, triangle, etc.) [126,108,111], oriented bars [130,72], pictures (e.g. artifacts, animal, flowers, etc.) [70,77], etc. The target may differ from the non-targets on a single feature (e.g. blue shape presented among red and greens) or combination of more than one feature (e.g. blue O presented among red Os and green Xs). Visual search difficulty depends on the discriminability of targets and non-targets, the harder it is to discriminate targets from the non-targets the search task becomes more difficult [36].

There are several theories of the visual search task. The most popular theories, including Posner's visual orienting theory [110], Treisman's feature integration [140] and Wolfe's guided search [153]. Posner's visual orienting theory emphasizes the movement of an attentional spotlight across space [110]. In Treisman's feature integration theory, visual information is processed in at least two successive stages: pre-attentive and attentive. In the pre-attentive stage, the visual system focuses the attention on salient or "pop-out" and processes a limited set of basic features such as colour, size, motion, and orientation in parallel. In the attentive stage, it processes more detail features, one at a time. In guided search theory, attention is directed to objects serially in order of priority [39] based on top-down and bottom-up activation. Top-down activation is based on the similarity between the stimulus and the known properties of the target whereas bottom-up is based on the difference between the stimulus and the known properties of the target. The two activations are combined to produce an attention map.

Subitizing

Subitizing means "instantly seeing how many" [27]. There are two types of subitizing: perceptual subitizing and conceptual subitizing. Perceptual subitizing occurs when we recognise a number without counting (fewer than 5 [131]). For example, when we see three dots, we automatically know it is three dots without counting. Conceptual subitizing on the other hand refers to the ability to combine small sets of numbers. For example, it requires conceptual ability to know that three dots if combine with two dots equal to five dots. Several studies [27,149] suggest that subitizing is faster with canonical presentation than random presentation (Figure 3). Others [154] suggest that pattern-recognition process for a larger number of items also helped in subitizing.

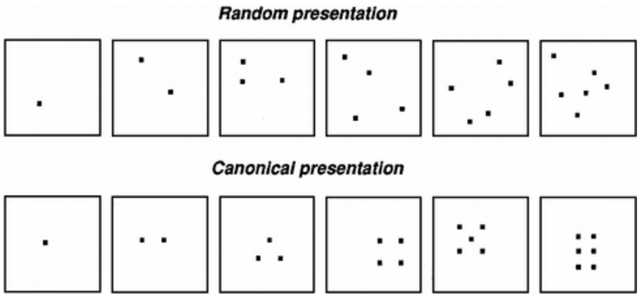


Figure 3. Canonical vs. random presentation (taken from [34])

Segmentation

Segmentation refers to the grouping of elements that exhibit "similar" characteristics [13]. It occurs pre-attentively as it is effortlessly perceived from the background. According to Turner [142], pre-attentive segmentation occurs strongly for simple properties such as brightness, colour, size, and the slopes of lines composing figures. Figure 4 illustrates examples of stimuli with segmentation and without segmentation.

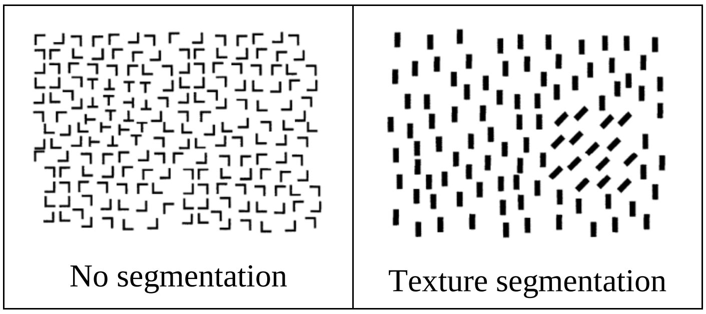


Figure 4. Segmentation vs. no segmentation (taken from [151])

In visual search, where finding a target among distractors is not influenced by the number of distractors, both target and distractors are processed in parallel. As segmentation involves pre-attentive stage, it is most likely linked to parallel processing. Wolfe [151] however, argued that segmentation and parallel visual search do not always co-operate: Parallel processing can occur with stimuli that do not support effortless texture segmentation and vice versa.

2.4 Visual Elements and Aesthetic Impressions

Before designing an aesthetic interface it is necessary to gain an understanding of how the visual elements of an interface evoke aesthetic impressions. This section discusses how three elements of interfaces can be designed with aesthetics in mind: spatial layout, shape, and colour.

2.4.1 Spatial layout

Spatial layout refers to the physical location and relative positioning of visual media elements on the computer interface [6]. In creating an aesthetic layout, many studies have referred to the Gestalt laws [114,65,137,133,139,22,46]. Although Gestalt theory originated in the field of psychology, it has influenced many other disciplines including HCI. The word Gestalt means the “form” or “shape” that emerges when the part of a perceived object is grouped to form a perceptual whole [22]. The key to Gestalt laws is typically summarized in the mantra “the whole is greater than the sum of its parts”.

There are many Gestalt laws, however only a few are applicable to computer interface design. Chang et al. [22] for instance, identified eleven Gestalt laws, such as balance or symmetry, continuation, closure, figure-ground, focal point, isomorphic correspondence, *prägnanz*, proximity, similarity, simplicity, and unity or harmony. Reilly and Roach [114] proposed five principles for visual design: proportion, sequence, emphasis, unity, and balance, and Szabo and Kanuka [133] used three design principles: balance, unity, and focus.

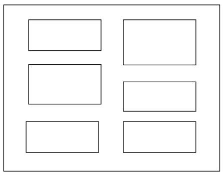
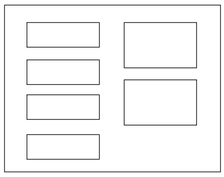
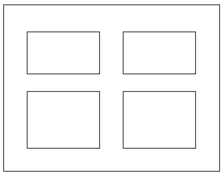
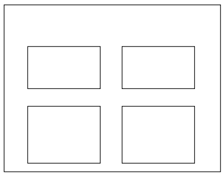
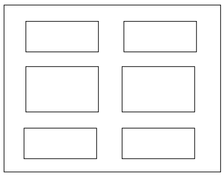
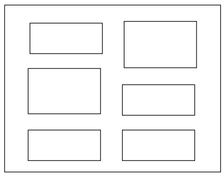
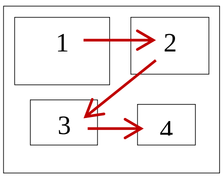
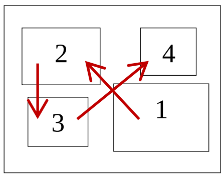
Some studies created mathematical formulae from the Gestalt principles to enable automatic design of screen layout. For example Bauerly and Liu [9] developed two metrics: symmetry and balance and Ngo et. al [98] developed fourteen mathematical formulae to measure balance, equilibrium, symmetry, sequence, cohesion, unity, proportion, simplicity, density, regularity, economy, homogeneity, rhythm and order and complexity.

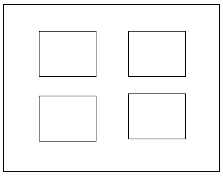
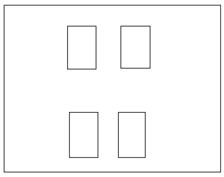
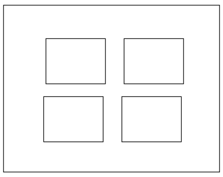
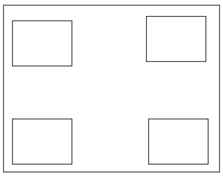
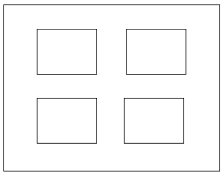
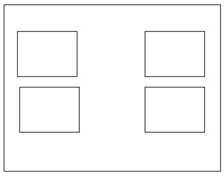
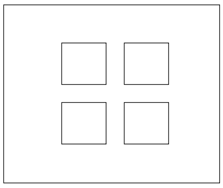
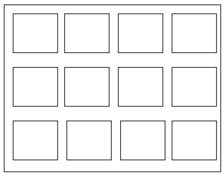
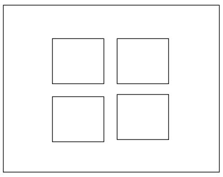
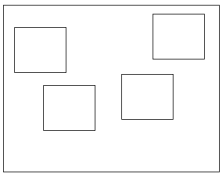
Besides the objective measures proposed by Bauerly and Liu, and Ngo et. al, other studies which introduced objective measures include Streveler and Wasserman [132] who proposed metrics for assessing the spatial properties of alphanumeric screens such as symmetry, balance, percentage of screen used, and average distance between groups of items; Tullis [141] who proposed four metrics (density, local density, grouping, layout complexity) for assessing the spatial properties of alphanumeric screens and Sears [125] who developed a task layout metric called “layout appropriateness” which measures the efficiency of widget (i.e. buttons, boxes, and lists) placement in computer interfaces.

While there are many objective measures in the literature, Ngo et. al's objective measure is the most comprehensive as it synthesizes the findings of other studies.

Ngo et. al layout metrics

Table 1 shows a brief description and diagrams of each of the fourteen aesthetic measures developed by Ngo et. al (see [98] for the complete mathematical formulae for each of these fourteen measures).

Balance (BM) is the distribution of optical weight in a picture. Optical weight refers to the perception that some objects appear heavier than others. Larger objects are heavier, whereas smaller objects are lighter. **BM** in interface design is achieved by providing an equal weight of interface elements, left and right, top and bottom.	 A balanced interface  Unbalanced interface
Equilibrium (EM) is a stabilisation, a suspension around the midpoint. **EM** on a screen is accomplished through centring the layout itself. The centre of the layout coincides with that of the frame.	 A stable interface  Unstable interface
Symmetry (SYM) is the extent to which the screen is symmetrical in three directions: vertical, horizontal, and diagonal. SYM is achieved by replicating the elements vertically, horizontally and radially of the interface centre line. Vertical symmetry refers to the balanced arrangement of equivalent elements about a vertical axis, and horizontal symmetry about a horizontal axis. Radial symmetry consists of equivalent elements balanced about two or more axes that intersect at a central point.	 A symmetrical interface  Asymmetrical interface
Sequence (SQM) is a measure of how information in a display is ordered in relation to the reading pattern that is most common in Western cultures. **SQM** is achieved by arranging elements to guide the eye through the screen in a left-to-right, top-to-bottom pattern.	 A sequential interface  Random interface

Cohesion (CM) is a measure of how cohesive the screen is. Similar aspect ratios promote cohesion. The term aspect ratio refers to the relationship of width to height. **CM** is achieved by maintaining the aspect ratio of a visual field.	 High cohesion interface  Low cohesion interface
Unity (UM) is coherence, a totality of elements that is visually "all one piece". With unity, the elements seem to belong together, to dovetail or merge so completely that they are seen as one thing. They are grouped. **UM** is achieved by using similar sizes and leaving less space between elements of a interface than the space left at the margins.	 A unified interface  Fragmented screen
Proportion (PM) is the comparative relationship between the dimensions of the interface components and canonical shapes. **PM** is achieved by following shapes such as: square (1:1), square root of two (1:1.414), golden rectangle (1:1.618), square root of three (1:1.732), and double square (1:2)	 A proportionate interface  Disproportionate interface
Density (DM) is the extent to which the screen is covered with objects. **DM** is achieved by restricting screen density levels to an optimal percentage.	 A spacious interface  Dense interface
Simplicity (SMM) is directness and singleness of form, a combination of elements that results in ease in comprehending the meaning of a pattern. **SMM** in screen design is achieved by optimizing the number of elements on an interface and minimizing the alignment points.	 A simple interface  Complex interface

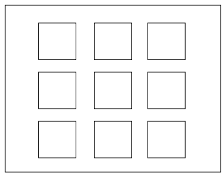
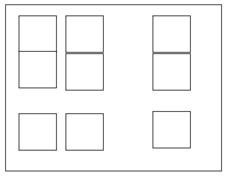
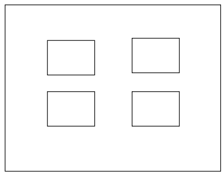
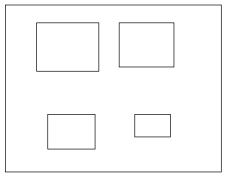
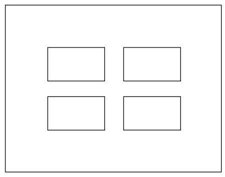
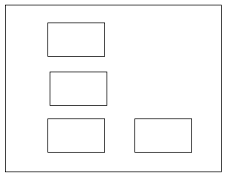
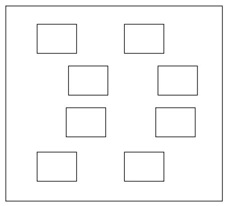
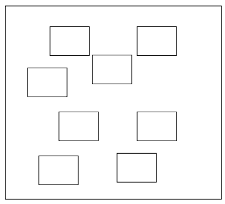
Regularity (RM) is a uniformity of elements based on some principle or plan. **RM** in interface design is achieved by establishing standard and consistently spaced horizontal and vertical alignment points for interface elements, and minimizing the alignment points.	 A regular interface  Irregular interface
Economy (ECM) is the careful and discreet use of display elements to get the message across as simply as possible. **ECM** is achieved by using as few sizes as possible.	 An economical interface  Intricate interface
Homogeneity (HM) is a measure of how evenly the objects are distributed among the quadrants. **HM** is achieved by distributing the objects evenly on the four quadrants of the screen.	 A homogeneous interface  Uneven interface
Rhythm (RHM) refers to regular patterns of changes in the elements **RHM** is accomplished through ordered variation of arrangement, dimension, number and form of the elements.	 A rhythmic interface  Disorganised interface
Order and Complexity (OM) is an aggregate (mean) of the above measures.	

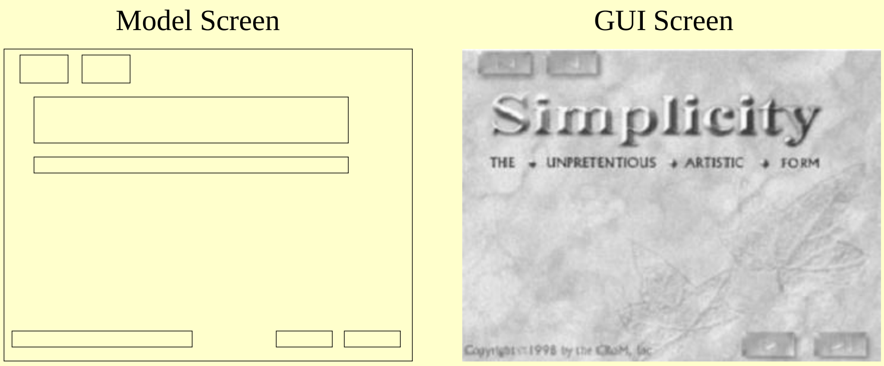
Table 1. The fourteen measures of aesthetic layout (adapted from [94,97,98])

The aesthetics of the layout of objects on a two-dimensional plane can be given a number between 0 (worst) and 1 (best). This number is termed the *aesthetics value* and can be high, medium, or low (the *aesthetics level*). Table 2 shows the aesthetics value range for each level of aesthetics.

Aesthetics Level	**Value range**
Low	$0.0 \leq$ OM based on 13 metrics < 0.5
Medium	$0.5 \leq$ OM based on 13 metrics < 0.7
High	$0.7 \leq$ OM based on 13 metrics ≤ 1.0

Table 2. High, medium, and low aesthetic level (taken from [94])

The overall aesthetics value of an interface is determined by OM (see Table 1), that is, the aggregate of the thirteen layout metrics. Figure 5 shows an example of how the aesthetics of an interface is measured by the fourteen layout metrics. As shown in Figure 5 the aesthetics value of the interface is 0.374 which is considered to be a low aesthetics value.



Measures	Values	Comments
Balance	0.357	Unbalanced
Economy	0.802	Stable
Symmetry	0.451	Asymmetrical
Sequence	0.500	Random
Cohesion	0.679	Cohesive
Unity	0.107	Fragmented
Proportion	0.734	Proportionate
Density	0.142	Complex
Simplicity	0.415	Cramped
Regularity	0.083	Irregular
Economy	0.142	Intricate
Homogeneity	0.000	Uneven
Rhythm	0.453	Disorganized
Order and complexity	0.374	Bad

Figure 5. An example output from the analysis program for a poorly designed screen (adapted from [94,97]).

In Ngo et. al's study, they did not explain how they chose the aesthetics value range for each level of aesthetics. Noticeably the value ranges of the three levels of aesthetics are uneven where the value range of low aesthetics level is larger than the value range of medium and high aesthetics. Ngo et. al justified the validity of these boundaries by comparing the computed value of an interface with the subjective ratings of human views in which they found a perfect match (i.e. what considered high, medium, or low aesthetics by the computational method was also considered as high, medium, or low aesthetics by human views).

The validation of Ngo et. al's metrics was carried out by comparing the computed value of OM (not each of the 13 layout metrics) with subjective rating of human views in a series of three separate experiments:

1. Experiment 1[95]: 6 professional GUI designers were recruited to rate 7 model screens printed on a hardcopy regarding how beautiful they were (0-worst, 3-best). The result showed that the computed value of OM of the layouts was in line with subjecting rating of the participants.

2. Experiment 2 [96]: There were 180 undergraduate students in this experiment. The stimuli were 7 greyscale GUI screens. The stimuli were projected in a large classroom using an overhead projector, one at a time for 20s, and the participants were asked to rate on a low–medium–high scale regarding how beautify it was. The result showed that the computed value of OM of each of the five GUI screens was in line with subjecting rating of the participants.

3. Experiment 3 [98]: This experiment was conducted in two parts: In part 1, there were 79 participants where in part 2 there were participants 180. None of the participants participated in part 1 took part in part 2. All participants were undergraduate students which received credit for participation. The stimuli in part 1 were 5 model screens. These 5 model screens were used in part 2 but filled with content to make it real screens (GUI screens) which means that the stimuli in part 2 have the same OM as in part 1. In both parts, the stimuli were projected in a large classroom using an overhead projector, one at a time for 20s and the participants were asked to rate each stimulus on a low–medium–high scale regarding how beautify it was. The result showed that, the computed value of OM of the stimuli in part 1 was in line with the participants' subjective rating. The result in part 1 was replicated in part 2.

Based on the three experiments discussed above, the strengths of the validation of Ngo et. al's formulae lie on three factors. First, the lack of difference of subjective rating between the model screen and GUI screen shows that the formulae are appropriate for measuring the aesthetics of real screens. Second, the large number of participants provides more accurate prediction. Third, the validation of the formulae stimuli were carried out from the perspective of professional designers and users.

2.4.2 Shapes

There are many types of shape or forms of an object. Previous studies [7,8,66] have reported that there is a higher preference for smoothly curved objects, as compared to sharp-angled (i.e. V-shaped corner) objects. The disliking of sharp-angled objects is thought to stem from a feeling of threat. For instance, an edge that resembles a knife is perceived as dangerous because it could be used for cutting. Although sharp-angled objects are more disliked, they are nevertheless more rapidly noticed [66].

2.4.3 Colours

Colours are a critical property of aesthetic objects. The ability to handle colours effectively is crucial as the use of colour could make the interface look either aesthetically pleasant or very unpleasant [91]. To choose the appropriate colour that will produce the intended aesthetic response from the viewers, it is important to consider colour preference and the relationship between colour and emotion.

Colour preference

The literature on colour preference is variable and contradictory, however, in general, many studies have found that blues are the most preferred hues and yellow-greens are the least preferred [20,101,80].

Kaya and Epps [60] suggested that colour preferences are associated with whether a colour elicits positive or negative feelings. These positive and negative feelings may depend on the association of colour with past experiences. For example, some people preferred a red colour because it reminded them of being in love, of Valentine’s day and the shape of a heart, while others did not because it reminded them of evil, Satan, and blood.

Age has also been identified as an important factor that influences colour preference. Dittmar [35] found that colour preference changes with the advancement of age. With advancing age, the preference for blue decreased steadily, whereas the popularity of green and red increased. This is thought to be due to alterations in colour discrimination and visual imagery, the yellowing of the crystalline lens, and the decreased function of the blue cone mechanism with ageing.

Perhaps one of the most discussed factors that influences colour preference is cultural difference. A cross-cultural study by Saito [87] investigating colour preferences in

Japan and its neighbouring countries, revealed that there was a strong preference for white; white was associated with image of being clean, pure, harmonious, refreshing, beautiful, cheer, gentle, and natural. Similarly, in western culture, white is often associated with purity, elegance and frankness. In other studies by Jacob et al. (cited in [78]), they found consistent agreement between Japan, China, South Korea, and United States that blue is associated with high quality, red with love, and black with being expensive and powerful. Although there are similarities across culture, there are also differences. For example, in Chinese culture, there is a high preference for red [78,56]. For the Chinese, red stands for “good luck”, joyfulness, and happiness, and it is considered as the country’s basic cultural colour, which is often used in wedding invitations and dresses, New Year events, ribbon-cutting ceremonies, etc. In western culture however, red often symbolizes danger and alarm, violence, war, cruelty, etc. Other conflicting use of colour is white. In Chinese culture, white means lifeless performance, and death, thus people often wear white during funerals whereas in western culture, instead of white, black symbolizes death and mourning [59].

Colour-emotion relationship

The association of colour with emotions has been investigated in many studies [61,92,127]. The findings of these studies suggest that certain colours can induce certain emotions in the viewer.

In a study by Kaya and Epps [61], investigating the emotion responses to five principal hues (i.e., red, yellow, green, blue, purple), five intermediate hues (i.e. yellow-red, green-yellow, blue-green, purple-blue, and red-purple), and three achromatic colours (white, grey, and black), they found that the principal hues comprised the highest number of positive emotional responses, followed by the intermediate hues and the achromatic colours.

Kaya and Epps [61] suggested that the emotion elicited from colour is very much dependent on preference and past experience. For example, the colour green was found to evoke mainly positive emotions such as relaxation and comfort because it reminded most of the respondents of nature. The colour green-yellow had the lowest number of positive responses because it was associated with vomit and elicited the feelings of sickness and disgust.

Another study by Simmons [127] investigated two affective dimensions of colour: pleasant-unpleasant and arousing-calming, and revealed that saturated blues and purples are the most pleasant colours and greenish and yellowish brown colours are the most unpleasant. Saturated reds and yellows were the most arousing colours, whereas the most calming were pale (whitish) blues and purples. Simmons' findings were quite similar with the previous study [143] that found blue and green as the most pleasant colour, and yellow as the most unpleasant colour but emerged to be the most arousing colour.

2.4.4 Summary

This section has discussed how visual elements of interfaces should be designed to create more favourable aesthetic impressions. More specifically it focused on three elements of interfaces: spatial layout, shape, and colour. The most common reference in spatial layout aesthetics is to Gestalt principles. Several studies have introduced descriptive references to Gestalt theory while others transform Gestalt principles into objective measures such as mathematical formulae. While there are many objective measures in the literature, Ngo et. al's objective measure is the most comprehensive as it synthesizes the findings of other studies. In term of shape, curved edges are more preferable than sharp-edged objects. In term of colour, in general many studies agreed that the most preferred colour is blue and the least preferred colour is yellow-green. Besides the ordering of colour preference, other factor such as the relationship between colour and emotion should also be considered when choosing colour (see also [101,102]).

2.5 Visual aesthetics in HCI

This section discusses three major areas which have been explored by HCI researchers while investigating aesthetics: perceived usability, task performance, and preference.

2.5.1 Aesthetics and perceived usability

Usability

Historically, HCI research focused mainly on aspects of interface usability [46]. The standard definition of usability is given by ISO 9241-11 that is “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”. Table 3 shows the comparison of the definition given by ISO 9241-11 and other usability experts. Notice that their opinions were different; however, all seem to agree that high usability consists of three main components: effectiveness, efficiency, and satisfaction.

- Effectiveness refers to the accuracy and completeness with which users achieve specified goals.
- Efficiency refers to the extent to which time is well used to achieve specified goals.
- Satisfaction is freedom from discomfort, and positive attitudes towards the use of the product.

	ISO 9241:11	Shneiderman	Nielsen	Quesenbery
Components of usability	Efficiency	Speed of performance	Efficiency	Efficient
		Time to learn	Learnability	Easy to learn
		Retention	Memorability	
	Effectiveness	Rate of errors by users	Errors	Effective
				Error tolerant
	Satisfaction	Subjective satisfaction	Satisfaction	Engaging

Table 3. Components of usability (adapted from [146,46])

Designing an interface that possesses such qualities (see Table 3) is quite challenging, however, there are many guidelines in the literature that can help the designer in designing usable systems. The most popular and recommended guidelines are Norman's seven principles for transforming difficult tasks into simple ones, Jakob Nielsen's ten usability heuristics and Ben Sneiderman's eight golden rules (cited in [146]). While each expert proposed their own guidelines, their guidelines are almost identical to one another and general enough to be applicable to use for any type of system.

Aesthetics and perceived usability

The popularity of visual aesthetics in HCI started when Kurosu and Kashimura found a strong correlation between aesthetics and perceived usability. In their study, conducted in Japan, 156 participants were asked to rate the aesthetics and usability of 26 layouts of an Automatic Teller Machine (ATM). The result showed that ATM which were rated as having high aesthetics were also rated as having high usability and ATM which were rated as having low aesthetics were also rated as having low usability. Kurosu and Kashimura's findings were confirmed by Tractinsky as pan-cultural influence as they replicated the study with Israeli participants and found not only a similar but a stronger result. This is significant because Japanese culture is known for its aesthetic traditions whereas Israeli culture is known for its action orientation.

The main criticism of Kurosu and Kashimura's and Tractinsky's result was that the rating of aesthetics and usability was elicited without the participants using the ATM. Thus, it could be speculated that the rating of usability was influenced by the aesthetic appearance of the interface. This speculation however was unsupported in the later study of Tractinsky et al. who extended the previous study to investigate whether the strong correlation between aesthetics and perceived usability elicited before using the ATM remained intact after using the ATM. In their study, 9 of the 26 ATM layouts from the previous study were selected and used as the screen for an ATM simulation programmed on a computer. Participants were asked to use the ATM simulation (i.e. withdrawing money, account enquiry) and rate the ATMs for aesthetics and usability before and after using them. The result showed that the strong correlation between aesthetics and perceived usability elicited before using the ATM remained intact after using the ATM. The consistency of users' perception of aesthetics and usability before and after using the ATMs showed that the association between aesthetics and usability was a genuine phenomenon. The finding provoked them to conclude that "what is beautiful is usable".

Further support of the strong effect of aesthetics on perceived usability can be found in the study by Van der Heijen who conducted a survey investigating factors that influence the usage of a generic portal website in the Netherlands with 825 participants; it was found that, perceived ease of use and perceived usefulness which were identified as the main factors of technology acceptance [33], and perceived enjoyment, were highly influenced by the aesthetic appearance of the interface.

The ability of an aesthetic interface to induce positive perception of usability was explained by Norman as being due to the positive emotional state whilst viewing attractive interfaces. According to Norman aesthetic appearance has a large impact on the emotional state of the viewer. If people feel good and happy, this in turn makes them think more creatively thus finding a solution to a problem becomes easier. Using this theory, Norman boldly claimed that "attractive things work better".

Not all studies agree that aesthetics is a strong predictor for usability. Hassenzhal for instance, argued that aesthetics is not a strong predictor for usability as he found no prominent relationship between aesthetics and usability. In his study where he investigated MP3 player "skins" before and after use, he found that MP3 player skins perceived as more beautiful were not necessarily perceived as more usable, and MP3 skins perceived as ugly were not necessarily perceived as not usable. Hassenzahl pointed out that the perception of usability was influenced by goodness rather than beautiful appearance. Goodness, according to Hassenzahl, is strongly affected by pragmatic attributes (e.g. perceived usability), hedonic attributes (e.g. identification, stimulation), and mental effort (actual use of the system), and beauty is solely affected by the hedonic factor. The terms "goodness" and "beauty" in Hassenzahl's study however are unclear and confusing [100].

Similarly, De Angeli et al. [3] also disagreed that aesthetics is a strong predictor for usability. They conducted a study investigating users' preference of two websites which have the same content but different interaction styles: a menu-based style and a metaphor-based style. The participants were asked to perform information-retrieval tasks on these two websites. While performing the tasks, the participants were invited to describe the usability errors they encountered and rate their severity. After completing the task, the participants briefly revisited the site and completed a heuristics test that assessed the attractiveness of the site. The result of the study showed that the metaphor-based interface was perceived as having better expressive aesthetics, but it was perceived as having more usability problems than the menu-based interface. Their results suggest that the perception of usability is influenced by interaction style and not by the aesthetic appearance of the interface.

2.5.2 Aesthetics and task performance

To date, the studies investigating aesthetics and task performance are few, and findings are contradictory, which makes it difficult to agree or disagree with the assertions "what is beautiful is usable" and "attractive things work better".

In one such study, Szabo and Kanuka [133] investigated the effect of violating screen design principles of balance, unity, and focus, on recall learning, study time, and completion rates. In their study, 44 participants were asked to complete a tutorial lesson on a Computer Based Tutorial (CBT) that had "good" design principles and 43 participants were asked to complete a tutorial lesson on CBTs that had "poor" design principles. After completing the tutorial lesson, participants were asked to perform information recall tasks. The results showed that study times and completion rates of CBTs with “good” design principles were higher than for CBTs with “poor” design principles. There was, however, no significant difference between CBTs with “good” design principles and CBTs with “poor” design principles in terms of information recall scores. Szabo and Kanuka suggested that interfaces with “good” screen design enables automatic processing, thus more efficient processing; whereas interfaces with “poor” screen designs encourage a manual and, therefore, less efficient processing.

The positive effect of aesthetics on performance was also mentioned in Cawthon and Moere [21] who investigated the effect of aesthetics on the usability of data visualization (graphical representation of abstract data). In their study, 285 online participants were recruited to rate the aesthetics of 11 data visualization techniques (e.g. TreeMap, SpaceTree, Windows Explorer, etc.) on a scale from “ugly” to “beautiful”, and perform information retrieval tasks. The results showed that data visualization techniques that received the highest aesthetic rating performed relatively high in metrics of effectiveness, low in task abandonment, and low latency of erroneous response which suggests that users approach aesthetic visualizations more thoroughly and with greater patience [44].

Greater patience as a result of working with aesthetic interfaces was also mentioned in Nakarada-Kordic and Lobb [93]. In their study, 19 participants were asked to order six websites which differed only in colour scheme, from least attractive to most attractive and subsequently perform a visual search task on two of the six websites that they ranked as the most attractive and the least attractive. The results showed that the response time and the number of errors made were not significantly different between the most attractive website and the least attractive website. However, the length of time spent searching for a target that was not present was higher on the most attractive website than the least attractive website. Thus, Nakarada-Kordic and Lobb concluded that aesthetic interfaces do not make users work effectively or efficiently but they do keep users’ attention for a longer time by creating an engaging atmosphere.

Nakarada-Kordic and Lobb’s view of aesthetics and task performance was supported by Chawda et al. [23]. In their study, 12 participants were recruited to perform a search task using data visualizations. Participants’ judgment of aesthetics and usability of the data visualizations were elicited before and after usage. The result showed that judgment of aesthetics and usability before and after usage were exactly as reported in

Tractinsky et al.'s study [139]; however there was no primary relation found between pre-aesthetic judgement and error made or completion time. Thus, they concluded that “attractive things are perceived to work better” but that they do not necessarily work better than “unattractive things”.

Their findings were also shared by Van Schaik and Ling. In their study, whose primary purpose was to investigate the effect of context on the stability of aesthetic perception, 115 participants were recruited to perform information retrieval on two versions of websites which were identical but differed in terms of the colour combinations used for its texts, links, and background. Perception of aesthetics was elicited after brief exposure, self-paced exposure, and after the site was used. The results showed that there was no relation between perception of aesthetics and task performance.

In another study by Sonderegger and Sauer [129], however, they found different results. In their study, 60 participants were recruited to perform typical tasks on a mobile phone (i.e. sending texts, changing the phone settings) on one of two versions of a computer-simulated mobile phone: highly appealing, and not appealing. The two phones differed in terms of form and colour setting. The highly appealing phone had the typical form of a mobile phone and was coloured with harmonious colours whereas the unappealing phone was the opposite. Participants’ judgments of aesthetics and usability of the phones were elicited before and after usage. Similar with the findings of, for example [65,137,144], the results showed that participants perceived the appealing phone as more usable than the unappealing phone. The participants using the appealing phone also took less time to complete the task, needed fewer clicks to complete their tasks, and committed fewer errors than participants who used the unappealing phone.

The finding by Sonderegger and Sauer however was not in line with Ben-Bassat et al. [10]. In their study, whose primary purpose was to compare monetary incentives and questionnaire methods to evaluate the aesthetics and usability of a system, 150 students were recruited to perform data entry on four versions of computer-simulated phone books and subsequently evaluate the perceived aesthetics and perceived usability. The aesthetics were manipulated by the graphical design (mainly decorative) of its background and the usability was manipulated by the number of keystrokes required to complete the task. The results showed that participants perceived aesthetic interfaces as more usable, however there was no effect of aesthetics on performance as measured by the number of items entered in a given time period. Moshagen et al. [90], however, suggested that the lack of effect of aesthetics on performance in Ben-Bassat et al.'s study may have been caused by the fixed number of steps that the participants needed to follow in order to complete the task and not because they were having difficulties with the design of the interface[90].

In another study by Moshagen et al. [90], they recruited 257 participants to perform a search task and subsequently rate the aesthetics and usability of four websites which differed in terms of aesthetics and usability (high aesthetics/high usability, high aesthetics/low usability, low aesthetics/high usability, low aesthetics/high usability). The aesthetics were manipulated by varying colour schemes whereas the usability was manipulated by the number of links that the participants needed to click to find the information. Unlike the other studies e.g. [65,144], the results showed that participants did not perceive the aesthetic interface as more usable. Moshagen et al. speculated that this might be because the participants use cognitive effort to measure usability rather than performance. The results also showed that there was no effect on accuracy but the completion time was faster in the poor usability condition. Their result confirms Norman’s theory that attractiveness makes people more productive in finding solutions.

2.5.3 Aesthetics and user preference

There are many theories of what factors influence user preference of an interface. However, it is undeniable that most of the time user visual perception of interfaces is the main determinant of users’ preference. This means that it is crucial that the design of the interface creates a good impression. User impressions according to Lindgaard et al. [76], are formed very quickly, that is, as fast as 50 milliseconds and this rapid first impression is unlikely to change after a longer time [138].

In a study by Schenkman and Jönsson [122], they claimed that user preference for a web page is strongly influenced by the visual appeal of the interface. Their claim was based on the pairwise comparisons of 13 different web pages by 18 students which showed that web pages perceived as more beautiful were more preferred than other web pages which were perceived as less beautiful. They also indicated that web pages which were mostly illustrated were more preferred than web pages which were mostly text. Schenkman and Jönsson’s finding was supported by Hall and Hanna [50] whose study's finding also showed a strong relation between aesthetics and preference where they found that preferred colours lead to higher ratings of aesthetic quality.

The simple and straight-forward relationship between aesthetics and preference as mentioned in [122,50] however was not confirmed in De Angeli et al.'s [3] study. According to De Angeli et al., user preference depends on target populations and scenario of use. Their claim was based on the evaluation of two websites which have the same content but different interface styles: menu-based and metaphor-based. They found that interfaces with menu-based styles were more suitable for mature and knowledgeable users and interfaces with metaphor styles were more suitable for children interacting at home but not in a classroom.

De Angeli, et al.'s claim was supported by Van Schaik and Ling [145]. Van Schaik and Ling suggested that interface preference was highly dependent on mode of use: *goal mode*, or *action mode*. Goal mode is a state where users emphasize accomplishment of the goal and in this case efficiency and effectiveness is very important. Action mode is a state where users focus on actions rather than goal accomplishment thus efficiency and effectiveness is less important [145]. Van Schaik and Ling found that users in goal mode preferred classical aesthetics and users in action mode preferred expressive aesthetics (see [67] for a detailed explanation of classical aesthetics and expressive aesthetics). The high preference for classical aesthetics in the context of goal mode was closely related to its high usability features (order and familiarity) which boosted task effectiveness and efficiency, whereas the high preference for expressive aesthetics in the context of action mode was closely related to its high arousal features.

On the other hand, Lee and Koubek [68] suggested that perceived aesthetic quality has a strong influence on user preference before using a system but not after using a system. In their study, investigating the effect of perceived aesthetic quality and perceived usability before and after usage on user preference, they found that, prior to using a system, user preference was strongly affected by perceived aesthetic quality and only marginally by perceived usability. However, after using a system, user preference was equally influenced by perceived aesthetics and perceived usability. Their findings were contradicted by the findings of [3,145] who showed that an aesthetic interface is still preferred over a less aesthetic interface even if it has usability issues. They also pointed out that user preference was more influenced by the organizational structure and layout of the interface rather than by aesthetic aspects, such as colour and typography.

While many studies propose theories trying to determine which factors influence user preference, Pandir and Knight [103] warned that researching aesthetics preferences is challenging and subject to individual differences, personal interests, and subjectivity.

2.6 Discussion

Section 2.5 has discussed the findings of studies which investigated aesthetics with respect to perceived usability, task performance, and preference. This section identifies research gaps that need to be filled in order to reveal the relationship between aesthetics, task performance, and preference.

2.6.1 Aesthetics and usability

All studies on aesthetics and usability (see Section 2.5.1) focused on subjective evaluation of usability using methods such as questionnaires, rating scales, and interviews. None of the studies have investigated usability of aesthetic design using an objective method such as eye movement analysis.

Subjective evaluation is a good evaluation method to reveal users' perceptions about the interface. However, this method is also time consuming, expensive, resource-intensive [147,157], and prone to multiple biases such as cultural effects. Furthermore, it may not correspond to actual experience because participants respond only what they think the experimenter wishes to hear [73]. These limitations can be addressed by objective evaluation [115]

The main advantages of eye tracking over conventional usability methods lies in its potential to provide a proper assessment by minimizing behavioural biases of users such as social expectations, political correctness or simply to give a good impression [123]. More importantly eye tracking provides concrete data that represent the cognitive states of individuals or the visual effort (the amount of attention devoted to a particular area of the screen [123]) required from the users while interacting with the interface [38,86].

More details of eye tracking are discussed in Chapter 6.

2.6.2 Aesthetics and task performance

The findings of these studies (see Section 2.5.2) are varied and contradictory, which is likely due to the different methodological approaches used, such as the way the aesthetics of the interface was defined and the type of task. Even so, it is obvious that the majority of these studies (see for example [93,90,145,129]) used colour as the main focus in defining the aesthetics of the interface.

The importance of colour to interface aesthetics is undeniable [91]. However, it is not the only interface attribute that contributes. Many studies (see for example [65,137,138,46]) have found that, besides colour, the layout of the interface has a significant influence on the perception of aesthetic quality. Despite this, very few studies have focused on the aesthetics of layout while investigating the effect of aesthetics on task performance and no studies have assessed the aesthetics of the layout based on an objective measure.

As discussed in Section 2.4.1there are several metrics available in the literature. However, the metrics proposed by Ngo et. al [98] are the most comprehensive and their validity has been tested using subjective ratings by human observers as well as being cited by several studies. Nevertheless, although the robustness of Ngo et. al's metrics in measuring the aesthetics of the layout has been validated, no studies have investigated how they affect task performance.

Another important issue that has not been investigated in previous studies is whether task performance is influenced by the aid of a mouse pointer as well as the aesthetics of the interface. The study of aesthetics and performance has mostly involved visual search tasks or information retrieval tasks: which often involve the use of a mouse pointer in real world tasks. Cox [30] claimed that the use of mouse pointing is likely to aid interactive search, while Hornof [54] reported that the layout design of the interface influences mouse movements. This raises the question of whether performance in visual search tasks is influenced more by mouse movement than by the design of interface. This is an important relationship to investigate because the design of the interface will affect mouse movement, which in turn will affect the process of visual search. If the mouse movements are complex, then performance in the visual search tasks will be impaired. If, when using a mouse to aid the visual search, the performance using a high aesthetic layout proves to be better than that with a low aesthetic layout, this means that performance is more influenced by design than the use of a mouse.

2.6.3 Aesthetics and user preference

Although user preference for interface design seems to have been well investigated in the studies discussed above (see Section 2.5.3), a deeper look at these studies revealed that preference has not been investigated deeply with respect to specific visual elements of interfaces (e.g. layout, texts, colours). The most common practice in these studies is asking participants to choose an interface that they preferred the most without pointing to specific features of the interface.

The importance of recognizing visual elements that are more appropriate or responsible for evoking aesthetic responses has been highlighted in Park et al.'s [105] study. According to Park et al., aesthetic fidelity (the degree to which users feel the target impressions intended by designers) depends greatly on the ability of the designers to identify specific visual elements responsible for evoking aesthetic responses. Besides increasing the aesthetic fidelity, knowing exactly how specific visual elements affect users' preferences helps designers to select visual elements that are relevant to the intended aesthetic responses [105].

2.7 Conclusion

This chapter has discussed various definitions and theories of aesthetics (see Section 2.1), how visual elements of interfaces such as spatial layout, colour, and shape evoke aesthetic impressions (see Section 2.4), and the findings of studies which investigated the effect of aesthetics on perceived usability, task performance, and preference (see Section 2.5).

1. How should we define aesthetics?

   Aesthetics is defined as the characteristics of an interface that evoke positive impressions (e.g. pleasure, contentment).

2. How should we apply aesthetics to computer interfaces?

   These findings suggest that to make aesthetic interfaces, it is important to know how visual elements of interfaces such as spatial layout, shape, and colour, create aesthetic impressions. To create aesthetic layouts, most studies employ Gestalt principles as a reference. Gestalt principles have been quantified descriptively or with objective metrics. Ngo et. al's [98] metrics of Gestalt principles are the most comprehensive as they synthesize the findings of other studies and have been well validated. In terms of colour, most studies have found that blue is the most preferred and yellow-green is the least preferred. Other factors such as the relationship between colour and emotion should also be considered while choosing the appropriate colour scheme for an interface. As for shape, an object with curved edges is considered as more aesthetically pleasing than a sharp-edged object.

3. What is the current state of research on visual aesthetics in HCI?

   There are three areas which have captured the attention of researchers while investigating aesthetics in HCI: usability, task performance, and preference. The study of usability however has been limited to subjective measures (e.g. questionnaire, interview, survey). Task performance has mostly been investigated with interfaces in which aesthetics was quantified in terms of the colour scheme (e.g. complementary colours vs. non-complementary colours) and graphical design with very little focus on layout design. In terms of preference, preference judgments have been made based on the general appearance rather than specific attributes of the interface.

This chapter has revealed that there has been much research in aesthetics that has investigated perceived usability, but little on task performance and preference. Given that task performance is crucial in HCI, it is important to investigate the relationship between aesthetics, task performance and preference in order to help designers create interfaces which are both pleasing to look at and easy to use.

Chapter 3

Rationale for the Study

The purpose of this chapter is to discuss the rationale for the study, the reasons behind the selection of just 6 over 13 layout metrics, and overviews of each five experiments in Chapter 4, 5, 6, 7, and 8.

3.1 Rationale for the Study

The important role of visual aesthetics in interface design has been widely discussed in the literature (see Chapter 2). It was reported that an interface with an aesthetic design is perceived as having better quality (e.g. more satisfactory, more trustworthy) and is an important factor that determines users' enjoyment, acceptance and usage of the information system (IS) [144]. A few studies (see Chapter 2 section 2.5) have investigated the influence of aesthetic design on task performance and user preference. The findings of these studies were inconsistent, which indicates the need for further investigation.

One of the main issues in the rationale for this study was the opportunity to study the pattern of users' performance where it might be confounded with users' liking or disliking of the interface. Although it is most likely that liking an interface might lead users to spend more time (sign of engagement) and disliking might lead users to spend less time (sign of disengagement), the duration of time spent might also indicate the quality of design. For example, a longer time spent might indicate that the design of the interface is confusing thus users take a longer time to complete the task, or that the design of the interface is so enjoyable that users spend more time interacting with it.

Similarly, a short time spent might indicate that the design of the interface is so good that users took less time to complete the task or that the design of the interface is so unpleasant that users spend less time interacting with it.

The study of visual aesthetics in interface design has concentrated on websites with the aesthetics measured subjectively based on the overall appearance of the interface and not based on specific attributes of the interface such as layout design. There is, therefore, a need for the relationship between aesthetics, task performance, and preference to be investigated with a focus on specific attributes of the interface and using objective measures to quantify aesthetics.

The assessment of visual aesthetics as an important factor for performance and preference can be done by using a typical interface design, that is an interface which combines many attributes such as colours, layout, blocks of text, etc., and measuring the aesthetics subjectively. Almost all of the research on the association of aesthetics with performance and preference has been conducted in this way. However, it would be more useful to investigate the association of aesthetics with performance and preference using an interface where the design focuses on one specific attribute. Each attribute of the interface affects task performance and preference differently; therefore, it would be useful to show the effect of each attribute separately in order to find the best way to combine them in order to support performance and preference.

The main purpose of this thesis was to investigate the effect of layout aesthetics on performance and preference. The aesthetics of the layout was measured objectively using mathematical formulae proposed by Ngo et al. [98].

3.2 Layout aesthetics

This section discusses the layout metrics of Ngo et. aesthetic layout (see Chapter 2 Section 2.4.1 for the precise definitions of Ngo et. al's [98] metrics) and the reason behind the selection of seven metrics instead of the fourteen metrics proposed in the original paper.

3.2.1 The selected layout metrics

Seven layout metrics (*cohesion, economy, regularity, sequence, symmetry, unity, order and complexity*) out of the original fourteen were chosen. The selection of the seven layout metrics was encouraged by several studies (see [104,156]) which used only a few of the metrics instead of all fourteen metrics to measure the aesthetics of the layout of interface, and more importantly, based on an analysis of Ngo et. al's descriptions and diagrams of each aesthetic measure (see Table 1) which revealed that most of the variability in an interface layout could be captured by using just seven of the measures.

1. Cohesion

According to Ngo et. al's formulae, *cohesion* is achieved by using the same aspect ratio (i.e. the relationship of height to width) for the *objects, layout,* and *frame.* For example, if the height of an object is greater than its width, then the heights of the layout and the frame must also greater than their widths. The diagram which was used in Ngo et. al's study to illustrate cohesion was almost identical with the diagram which was used to illustrate proportion (Figure 6). Therefore, it was assumed that *cohesion* would cover *proportion*.

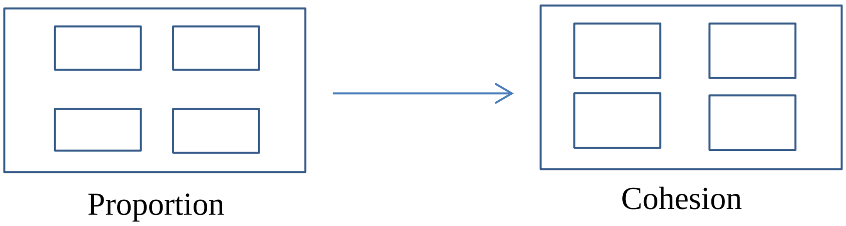


Figure 6. Examples of diagram of *cohesion* and *proportion* (taken from [97])

Further analysis of the characteristics of proportion revealed that *proportion* can easily covered by *cohesion.* How? *Proportion* refers to "the comparative relationship between the dimensions of the screen components and proportional shapes [98]". According to Ngo et. al's formulae, *proportion* is achieved when the dimensions of the screen components follow the proportional shapes suggested by Marcus [81] (i.e. square (1:1), square root of two (1:1.414, golden rectangle (1:1.618), square root of three (1:1.732), double square (1:2)). If the dimensions of objects and layout in a high *cohesion* interface are 1:1.414 and 1:1.732 respectively, it can also be considered as a high *proportion* interface.

2. Economy

Economy is achieved by using only one size. Due to the consistent size of objects, an interface with high economy can be easily distinguished from an interface designed with other metrics. Therefore it can be suggested that economy stands by itself.

3. Regularity

Regularity is defined as "uniformity of elements based on some principle or plan [98]" and according to Ngo et. al's formulae, *regularity* is achieved by "establishing standard and consistently spaced horizontal and vertical alignment points for screen elements, and minimizing the alignment points [98]". Based on these characteristics, it is more likely that *regularity* can also cover the aesthetic measures of *rhythm*, *simplicity* and *density* (Figure 7). How?

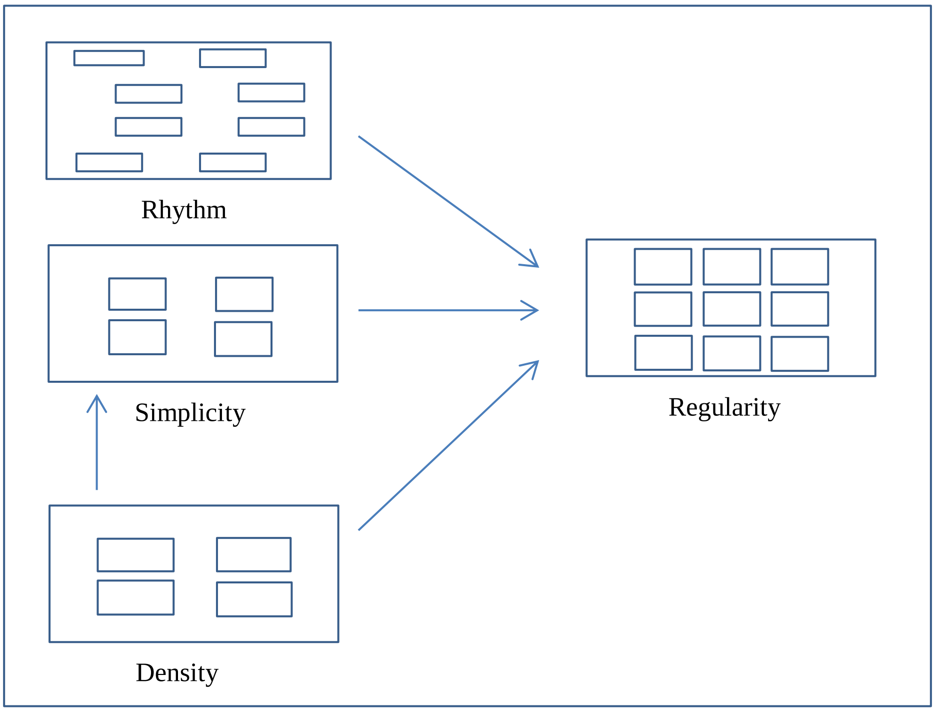


Figure 7. Examples of *regularity*, *rhythm*, *simplicity*, and *density* (taken from [96])

Rhythm refers to "regular patterns of changes in the elements [98]" and it is achieved by systematic ordering of the elements. Note that as *rhythm* is archived through systematic ordering of the elements, it is in fact already covered by *regularity* as the elements in *regularity* are also arranged systematically (Figure 7).

Besides *rhythm*, *regularity* also covers the aesthetic measure of *simplicity*. Ngo et. al define *simplicity* as "the directness and singleness of form, a combination of elements that results in ease in comprehending the meaning of a pattern [98]" and suggest that *simplicity* in screen design is achieved by "optimising the number of elements on a screen and minimising the alignment points [98]".

Note that, both *simplicity* and *regularity* depend on the vertical and horizontal alignment points. Although *simplicity* is less sensitive to the numbers of elements on the screen as compared to *regularity*, the layout patterns produced with the metric of *simplicity* are practically similar with *regularity* (Figure 7). Therefore, it can be suggested that a simple interface can also be considered as a regular interface.

Note that, the key to simplicity is the lack of complexity. One way to minimize complexity is to be careful with density (i.e. the number of objects that cover the interface). Ngo et. al [96] suggested that the optimal density for an interface is 50% of the size of the frame. More than 50% is considered as too much and confusing. With less than 50% of the frame covered with objects, the interface looks spacious and is describable in terms of "content simplicity" (Figure 7).

4. Sequence

Sequence is achieved by "arranging elements to guide the eye though the screen in a left-to-right, top-to-bottom pattern [98]" (Figure 8a). That means, screen elements should be heaviest on the upper-left quadrant and steadily decrease toward the upper-right quadrant, lower-left quadrant, and lightest on the lower-right quadrant (Figure 8b). Compared to other aesthetic measures, *sequence* is considered unique as it is the only metric of the fourteen metrics which focus on the eye directions.

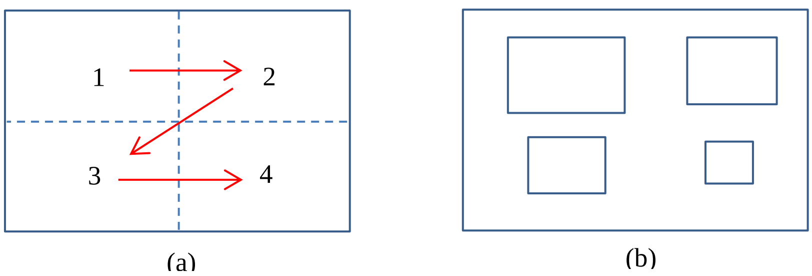


Figure 8. Sequence

5. Symmetry

According to Ngo et. al, *symmetry* in screen design is achieved by replicating the elements vertically, horizontally and radially of the interface centre line (Figure 9a). Based on this description, it seems that the screen elements on the four quadrants of *symmetry* are more likely to be identical (Figure 9b). An interface with identical elements on each of the four quadrants can also be considered as *equilibrium*, *balance* and *homogeneity*. This is because, based on Ngo et. al's formulae, *equilibrium* is achieved through centering the layout itself, *balance* in the other hand is achieved by providing an equal weight of screen elements, left and right, top and bottom, and *homogeneity* is achieved by equally distribute the screen elements among the four quadrants. Note that all of the characteristics of *equilibrium*, *balance* and *homogeneity* are well covered in the diagram of *symmetry* (Figure 9b).

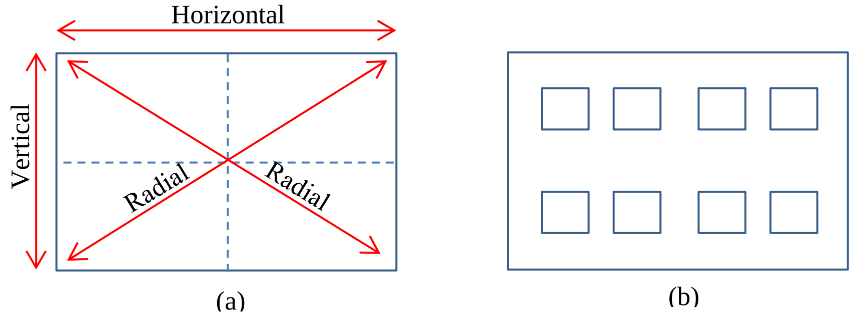


Figure 9. Symmetry

6. Unity

Unity, refers to "the extent to which the screen elements seem to belong together [98]". *Unity* is achieved by "using similar sizes and leaving less space between elements of a screen than the space left at the margins [98]". The metric of unity stands by itself as it is the only metric that makes the visual elements perceivable as "one single piece".

7. Order and complexity

Order and complexity is the aggregate of the thirteen layout metrics, therefore in this study, *order and complexity* is used as the aggregate of the six metrics discussed above.

Figure 10 shows the thirteen diagrams used in Ngo et. al's study to illustrate each of the thirteen aesthetic measures. As shown in Figure 10, *cohesion* can cover *proportion*, *regularity* can cover *rhythm*, *simplicity*, and *density*, *symmetry* can cover *balance*, *equilibrium* and *homogeneity*, whereas *economy*, *sequence*, and *unity* stand by themselves.

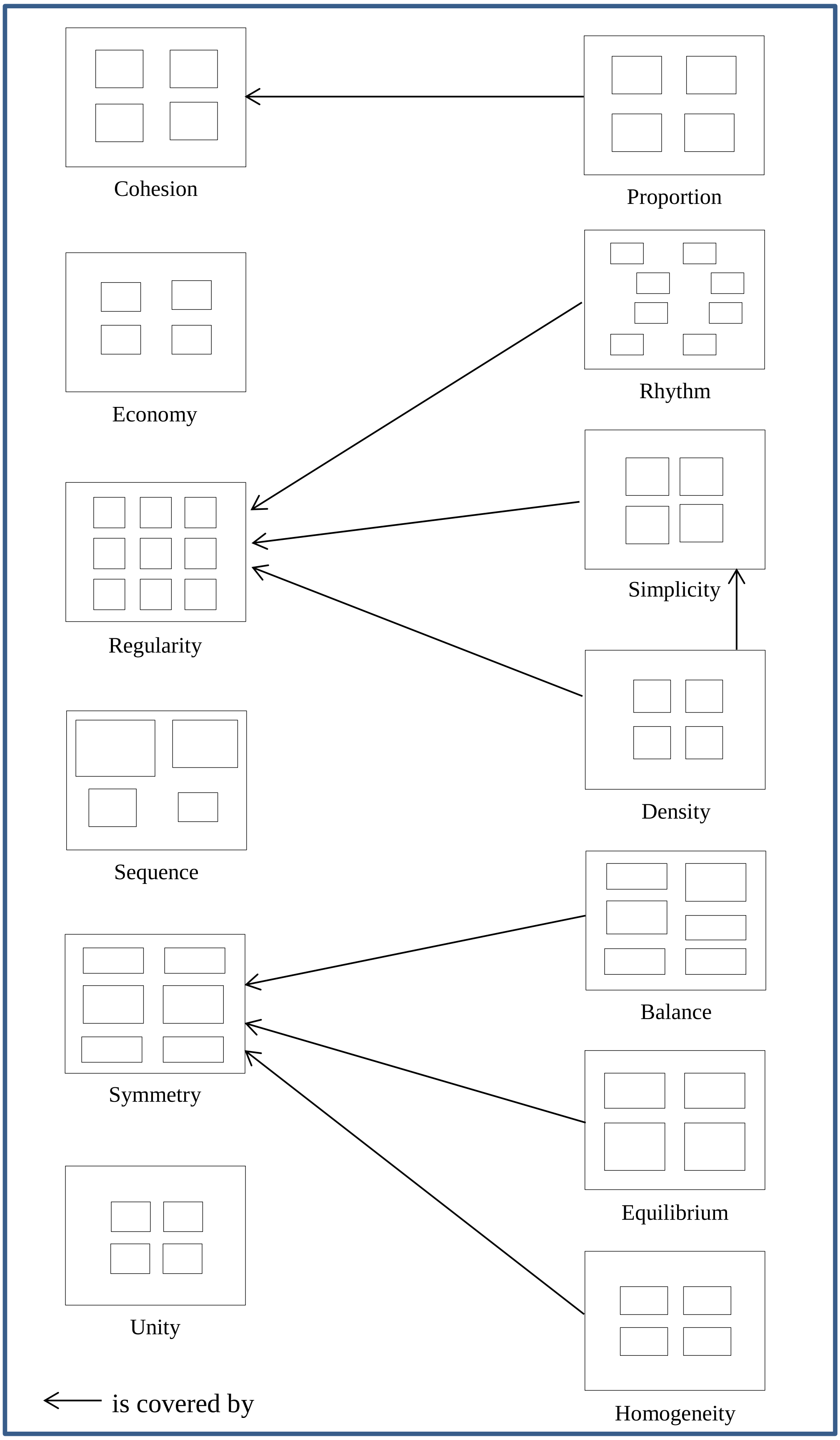


Figure 10. Six layout metrics can account for all the variability in the thirteen layout metrics

The assumption of this research that the aesthetics of interface can be captured by just seven layout metrics and not all fourteen layout metrics was further supported by an analysis on the computed value of OM based on the aggregate of 13 and 6 metrics for each of the 6 layouts in Ngo et. al's study. The analysis showed that there was a linear relationship between the OM of each of the 6 layouts based on 13 and 6 metrics (Figure 11).

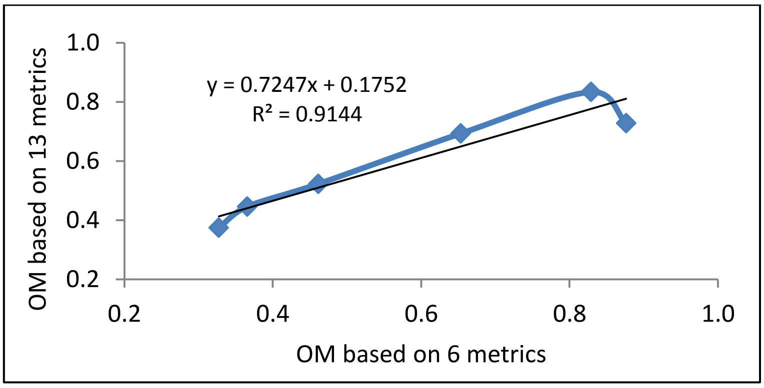


Figure 11. The OM of 6 layouts based on 6 and 13 layout metrics

3.2.2 The mathematical formulae of the seven layout metrics

The mathematical formulae of each of the seven layout metrics are as shown in Figures 5 – 11 (taken from [98]). It is important to note that the term *layout* used in the formulae below refers to the form and position of interface objects relative to other objects and their placement within a *frame* (i.e. the allocated space for the objects) and that these formulae only tested on a rectangular screen.

Cohesion (CM)

In screen design, similar aspect ratios promote cohesion. The term "aspect ratio" refers to the relationship between width and height. Typical paper sizes are higher than they are wide, while the opposite is true for typical VDU displays. Changing the aspect ratio of a visual field may affect eye movement patterns sufficiently to account for performance differences. The aspect ratio of a visual field should stay the same during the scanning of a display. Cohesion, by definition, is a measure of how cohesive the screen is and is given by:

$$\mathrm{CM} = \frac{|\mathrm{CM}_{\mathrm{fl}}| + |\mathrm{CM}_{\mathrm{lo}}|}{2} \quad (1)$$

$\mathrm{CM}_{\mathrm{fl}}$ is a relative measure of the ratios of the layout and screen with

$$\mathrm{CM}_{\mathrm{fl}} = \begin{cases} c_{\mathrm{fl}} & \text{if } c_{\mathrm{fl}} \le 1 \\ \dfrac{1}{c_{\mathrm{fl}}} & \text{otherwise} \end{cases} \quad (2)$$

with

$$c = \frac{h_{layout}/b_{layout}}{h_{frame}/b_{frame}} \quad (3)$$

where b_{layout} and h_{layout} and b_{frame} and h_{frame} are the widths and heights of the layout and the frame, respectively. $\mathrm{CM}_{\mathrm{lo}}$ is a relative measure of the ratios of the objects and layout with

$$\mathrm{CM}_{\mathrm{lo}} = \frac{\sum_{\mathrm{i}}^{n} t_{\mathrm{i}}}{n} \quad (4)$$

with

$$t_i = \begin{cases} c_{\mathrm{i}} & \text{if } c_{\mathrm{i}} \le 1 \\ \dfrac{1}{c_i} & \text{otherwise} \end{cases} \quad (5)$$

with

$$c = \frac{h_i/b_i}{h_{\mathrm{layout}}/b_{\mathrm{layout}}} \quad (6)$$

where b_i and h_i the width and height of object *i* and *n* is the number of objects on the frame.

Figure 12. Mathematical formulae for *cohesion* (taken from [98])

Economy (ECM)

Economy is the careful and discreet use of display elements to get the message across as simply as possible. Economy is achieved by using as few sizes as possible. Economy, by definition, is a measure of how economical the screen is and is given by

$$\mathrm{ECM} = \frac{1}{n_{size}} \in [0,1] \quad (7)$$

where n_{size} is the number of different sized objects

Figure 13. Mathematical formulae for *economy* (taken from [98])

Regularity (RM)

Regularity is a uniformity of elements based on some principle or plan. Regularity in screen design is achieved by establishing standard and consistently spaced horizontal and vertical alignment points for screen elements, and minimising the alignment points. Regularity, by definition, is a measure of how regular the screen is and is given by

$$\mathrm{RM} = \frac{\left|\mathrm{RM}_{alignment}\right| + \left|\mathrm{RM}_{spacing}\right|}{2} \in [0,1] \tag{8}$$

$\mathrm{RM}_{alignment}$ the extent to which the alignment points are minimized with

$$\mathrm{RM}_{alignment} = \begin{cases} 1 & \text{if } n = 1 \\ 1 - \dfrac{n_{vap} + n_{hap}}{2n} & \text{otherwise} \end{cases} \tag{9}$$

and $\mathrm{RM}_{spacing}$ is the extent to which the alignment points are consistently spaced with

$$\mathrm{RM}_{spacing} = \begin{cases} 1 & \text{if } n = 1 \\ 1 - \dfrac{n_{spacing} - 1}{2(n-1)} & \text{otherwise} \end{cases} \tag{10}$$

where n_{vap} and n_{hap} are the numbers of vertical and horizontal alignment points, n_{spacing} is the number of distinct distances between column and row starting points and n is the number of objects on the frame.

Figure 14. Mathematical formulae for *regularity* (taken from [98])

Sequence (SQM)

Sequence in design refers to the arrangement of objects in a layout in a way that facilitates the movement of the eye through the information displayed. Normally the eye, trained by reading, starts from the upper left and moves back and forth across the display to the lower right. Sequence, by definition, is a measure of how information in a display is ordered in relation to a reading pattern that is common in Western cultures and is given by,

$$\mathrm{SQM} = 1 - \frac{\sum_{j=\mathrm{UL.UR,LL,LR}} |q_j - v_j|}{8} \in [0,1] \quad (11)$$

with

$$\{\mathrm{qUL}, \mathrm{qUR}, \mathrm{qLL}, \mathrm{qLR}\} = \{4,3,2,1\}$$

$$\mathrm{RM}_{alignment} = \begin{cases} 1 & \text{if } n = 1 \\ 1 - \dfrac{n_{vap} + n_{hap}}{2n} & \text{otherwise} \end{cases} \quad (12)$$

$$v_j = \begin{cases} 4 \text{ if } \mathrm{w_j} \text{ is the biggest in } w \\ 3 \text{ if } \mathrm{w_j} \text{ is the 2nd biggest in } w \\ 2 \text{ if } \mathrm{w_j} \text{ is the 3rd biggest in } w \\ 1 \text{ if } \mathrm{w_j} \text{ is the 4th biggest in } w \end{cases} \qquad j = UL, UR, LL, LR \quad (13)$$

with

$$w_{\mathrm{j}} = q_j \sum_i^{nj} a_{ij} \, j = UL, UR, LL, LR \quad (14)$$

$$w = \{w_{UL}, w_{UR,} w_{LL,} w_{LR}\} \quad (15)$$

where UL, UR, LL, and LR stand for upper-left, upper-right, lower-left, and lower-right, respectively; and a_{ij} is the area of object *i* on quadrant *j*. Each quadrant is given a weighting in *q*.

Figure 15. Mathematical formulae for *sequence* (taken from [98])

Symmetry (SYM)

Symmetry is axial duplication: a unit on one side of the centre line is exactly replicated on the other side. Vertical symmetry refers to the balanced arrangement of equivalent elements about a vertical axis, and horizontal symmetry about a horizontal axis. Radial symmetry consists of equivalent elements balanced about two or more axes that intersect at a central point. Symmetry, by definition, is the extent to which the screen is symmetrical in three directions: vertical, horizontal, and diagonal and is given by

$$\mathrm{SYM} = 1 - \frac{|\mathrm{SYM}_{vertical}| + |\mathrm{SYM}_{horizontal}| + |\mathrm{SYM}_{radial}|}{3} \in [0,1] \quad (16)$$

$\mathrm{SYM}_{\mathrm{vertical}}$, $\mathrm{SYM}_{\mathrm{horizontal}}$, and $\mathrm{SYM}_{\mathrm{radial}}$ are, respectively, the vertical, horizontal, and radial symmetries with

$$\text{SYM}_{vertical} = \frac{\begin{array}{c}|X'_{UL}-X'_{UR}| + |X'_{LL}-X'_{LR}| + |Y'_{UL}-Y'_{UR}| + |Y'_{UL}-Y'_{UR}| \\ |H'_{UL}-H'_{UR}| + |H'_{LL}-H'_{LR}| + |B'_{UL}-B'_{UR}| + |B'_{UL}-B'_{UR}| \\ |\Theta'_{UL}-\Theta'_{UR}| + |\Theta'_{LL}-\Theta'_{LR}| + |R'_{UL}-R'_{UR}| + |R'_{UL}-R'_{UR}|\end{array}}{12} \tag{17}$$

$$\text{SYM}_{horizontal} = \frac{\begin{array}{c}|X'_{UL}-X'_{LL}| + |X'_{UR}-X'_{LR}| + |Y'_{UL}-Y'_{LL}| + |Y'_{UR}-Y'_{LR}| \\ |H'_{UL}-H'_{LL}| + |H'_{UR}-H'_{LR}| + |B'_{UL}-B'_{LL}| + |B'_{UR}-B'_{LR}| \\ |\Theta'_{UL}-\Theta'_{LL}| + |\Theta'_{UR}-\Theta'_{LR}| + |R'_{UL}-R'_{LL}| + |R'_{UR}-R'_{LR}|\end{array}}{12} \tag{18}$$

$$\text{SYM}_{radial} = \frac{\begin{array}{c}|X'_{UL}-X'_{LR}| + |X'_{UR}-X'_{LL}| + |Y'_{UL}-Y'_{LR}| + |Y'_{UR}-Y'_{LL}| \\ |H'_{UL}-H'_{LR}| + |H'_{UR}-H'_{LL}| + |B'_{UL}-B'_{LR}| + |B'_{UR}-B'_{LL}| \\ |\Theta'_{UL}-\Theta'_{LR}| + |\Theta'_{UR}-\Theta'_{LL}| + |R'_{UL}-R'_{LR}| + |R'_{UR}-R'_{LL}|\end{array}}{12} \tag{19}$$

$X'_j, Y'_j, H'_j, B'_j, \Theta'_j$ and R'_j are, respectively, the normalised values of

$$X_j = \sum_i^{n_j} |x_{ij} - x_c| \quad j = \text{UL, UR, LL, LR} \tag{20}$$

$$Y_j = \sum_i^{n_j} |y_{ij} - y_c| \quad j = \text{UL, UR, LL, LR} \tag{21}$$

$$H_j = \sum_i^{n_j} h_{ij} \; j = \text{UL, UR, LL, LR} \tag{22}$$

$$B_j = \sum_i^{n_j} b_{ij} \; j = \text{UL, UR, LL, LR} \tag{23}$$

$$\Theta_j = \sum_i^{n_j} \left| \frac{y_{ij} - y_c}{x_{ij} - x_c} \right| \quad j = \text{UL, UR, LL, LR} \tag{24}$$

$$R_j = \sum_i^{n_j} \sqrt{(x_{ij} - x_c)^2 - (y_{ij} - y_c)^2} \; j = \text{UL, UR, LL, LR} \tag{26}$$

where UL, UR, LL and LR stand for upper-left, upper-right, lower-left and lower-right, respectively (x_{ij},y_{ij}) and (x_c,y_c) are the co-ordinates of the centres of object *i* on quadrant *j* and the frame; b_{ij} and h_{ij} are the width and height of the object and n_j is the total number of objects on the quadrant

Figure 16. Mathematical formulae for *symmetry* (taken from [98])

Unity (UM)

Unity is coherence, a totality of elements that is visually all one piece. With unity, the elements seem to belong together, to dovetail so completely that they are seen as one thing. Unity in screen design is achieved by using similar sizes and leaving less space between elements of a screen than the space left at the margins. Unity, by definition, is the extent to which the screen elements seem to belong together and is given by

$$\mathrm{UM} = \frac{|\mathrm{UM}_{form}| + |\mathrm{UM}_{space}|}{2} \in [0,1] \quad (27)$$

$\mathrm{UM}_{\mathrm{form}}$ is the extent to which the objects are related in size with

$$\mathrm{UM}_{form} = 1 - \frac{n_{size} - 1}{n} \quad (28)$$

and UMspace is a relative measurement, which means that the space left at the margins (the margin area of the screen) is related to the space between elements of the screen (the between-component area) with

$$\mathrm{UM}_{space} = 1 - \frac{a_{layout} - \sum_i^n a_i}{a_{frame} - \sum_i^n a_i} \quad (29)$$

where a_i, a_{layout}, and a_{frame} are the areas of object *i*, the layout, and the frame, respectively; n_{size} is the number of sizes used; and *n* is the number of objects on the frame.

Figure 17. Mathematical formulae for *Unity* (reproduced from [98])

Order and complexity (OM)

The measure of order is written as an aggregate of the above measures for a layout. The opposite pole on the continuum is complexity. The scale created may also be considered a scale of complexity, with extreme complexity at one end and minimal complexity (order) at the other. The general form of the measure is given by

$$\mathrm{OM} = g\{f_i(M_i)\} \in [0,1] \quad (30)$$

with

$$\{M_1, M_2, M_3, M_4, M_5, M_6\} = \{CM, ECM, RM, SQM, SYM, UM\} \quad (31)$$

where f_i is a function of M_i and is functionally related to the measurable criteria which characterise g{} and CM is given by (1), ECM by (7), RM by (8), SQM by (11), SYM by (16), and UM by (27)

Figure 18. Mathematical formulae for *Order and complexity* (taken from [98])

3.3 Overview of experiments

There were five experiments conducted in this study, which are reported in Chapters 4, 5, 6, 7, and 8. Figure 19 shows the purpose and the research questions addressed in each experiment.

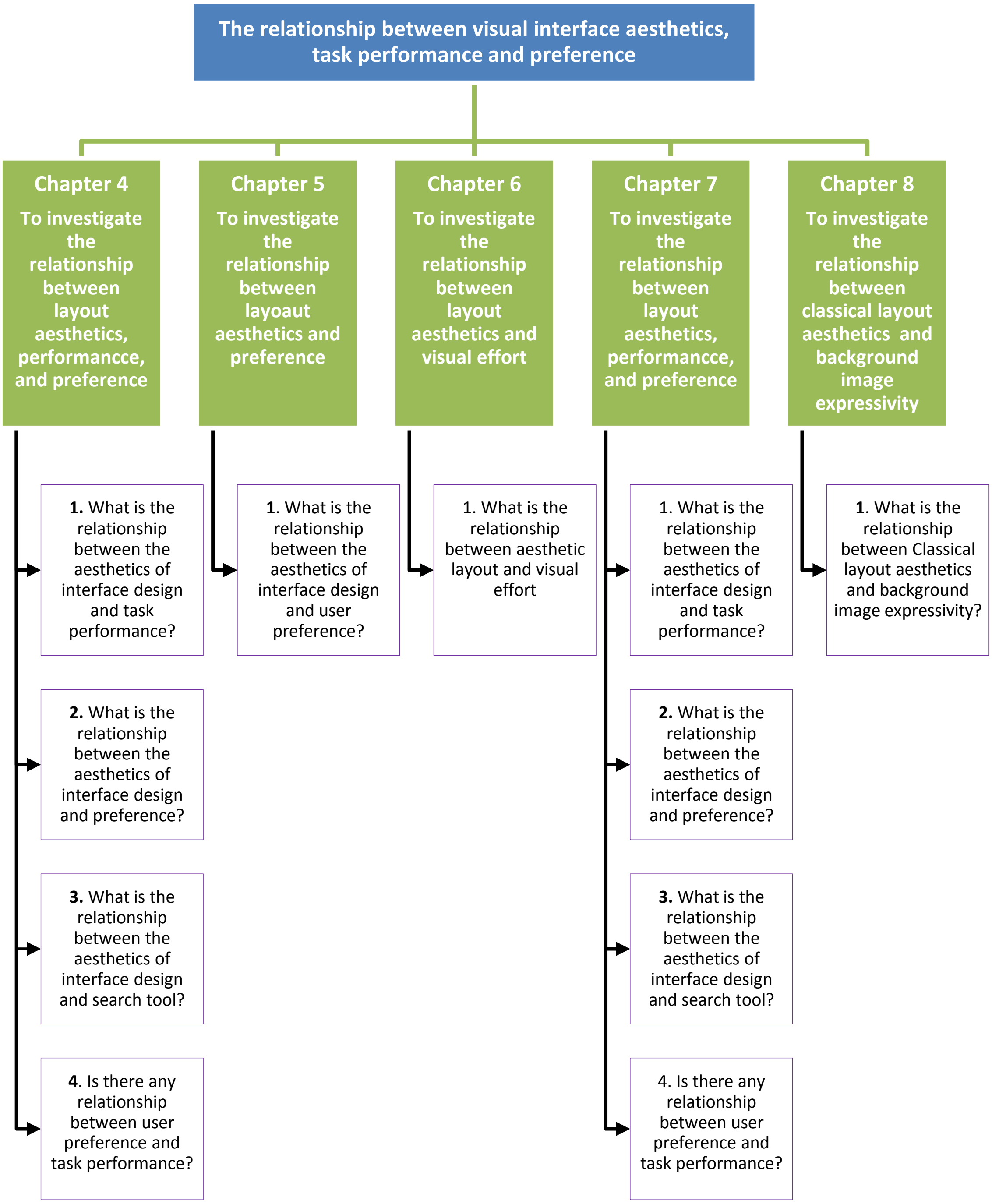


Figure 19. Summary of the experiment reported in Chapters 4, 5, 6, 7, and 8

3.4 Summary

This Chapter discusses the rationale of: the study, the selection of just 6 over the 13 layout metrics proposed by Ngo et al. and each of the five experiments.

This study was conducted to investigate the relationship between layout aesthetics, task performance, and preference. The aesthetics of the layout was measured objectively using 6 layout metrics (cohesion, economy, regularity, sequence, symmetry, unity) proposed by Ngo et al. [98]. The 6 layout metrics were chosen over 13 layout metrics based on an analysis of Ngo et al.'s descriptions and diagrams of each aesthetic measure, which revealed that most of the variability in an interface layout could be captured by using just 6 of the measures.

There were five experiments conducted in this study, which are reported in Chapters 4, 5, 6, 7, and 8. Chapter 4 investigated the relationship between layout aesthetics, task performance, and preference. Chapter 5 investigated the relationship between layout aesthetics and preference. Unlike the preference task in Chapter 4, no performance-based task involved in this experiment to ensure that the participants were in "leisure mode". Chapter 6 investigated the relationship between layout aesthetics and visual effort. The result of this experiment provides concrete evidence of the usability of layout aesthetics. Chapter 7 was carried out to test the robustness of the result produced in Chapter 4 using more "ecologically valid" stimuli. Chapter 8 was carried out to investigate how the expressivity of the background affects the performance of layout aesthetics.

Chapter 4

Layout Aesthetics vs. Performance and Preference I

In Chapter 2 an extensive literature review on visual aesthetics in HCI was conducted. It was noted that there is a need for more studies investigating the relationship between interface design aesthetics, task performance, and preference, and the reliability of objective measures of aesthetics such that proposed by Ngo et. al [98]. In Chapter 3, an extensive analysis of Ngo et al.'s 13 layout metrics was conducted and concluded that 6 of the 13 layout metrics are sufficient to characterize an interface layout: *cohesion, economy, regularity, sequence, symmetry,* and *unity.*

This chapter reports an experiment investigating the relationship between aesthetic layout, task performance, and preference using “abstract” interfaces. The aesthetics of the layout is measured using the 6 layout metrics identified in Chapter 3. The experiment was motivated by three factors. Firstly, the inconsistency of findings from of previous studies about the effect of aesthetics on performance and preference. Secondly, the claim by Ngo et al. (which was further confirmed in several studies [104,156]) that subjectivity of aesthetics can be measured in an objective manner, and thirdly, the lack of studies on performance and preference that used objective aesthetic measures of interfaces.

The following research questions are addressed in this chapter:

1. What is the relationship between the aesthetics of interface design and task performance?

2. What is the relationship between the aesthetics of interface design and preference?
3. What is the relationship between the aesthetics of interface design and search tool?
4. Is there any relationship between user preference and task performance?

4.1 Aims

In order to find the answers of the questions mentioned above, the following aims are addressed:

1. to investigate the relationship between aesthetic layout and task performance
2. to investigate the relationship between aesthetic layout and preference
3. to investigate the relationship between aesthetic layout and search tool
4. to investigate the relationship between preference and task performance

4.2 Experimental design

4.2.1 Interface components

The interface comprises geometric shapes (upright and inverted triangles). The triangles were drawn using black lines on a white background and were 5 - 25 mm in height and 50 - 25 mm in width. Since the main focus of this experiment was on the layout aesthetics, the colours were limited to black (colour of the triangle line) and white (background) to avoid the effects of confounding factors. Figure 20 shows an example of how the upright and inverted triangles were placed on the screen.

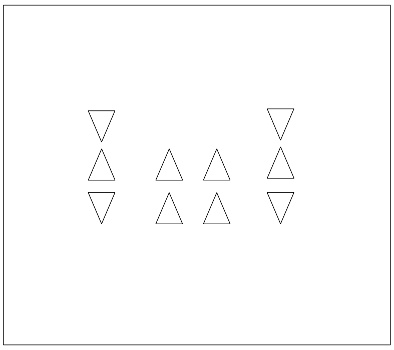


Figure 20. Interface components

The use of geometric shapes makes the interface look rather abstract. The reason of using just upright and inverted triangles instead of a combination of many geometric shapes, blocks of text, images, icons, etc., were to minimize confounding effects caused by having too many features in the interface, and to make sure that the difference between objects was not salient for visual search and thus avoided “pop-out” effects (Pop-out occurs when a target can be found among multiple distractors without attentional effort [118]).

The following are the advantages of choosing triangles instead of other geometric shapes:

- Its sharp angles make it more rapidly noticeable with minimal details required compared to objects with curved angles [7,66].
- Compared to other objects with sharp angles such as a square, the striking pointing edges of the triangles make it more salient.
- A triangle is much simpler than other objects with striking pointing edges (e.g. stars).

The characteristics of the triangle as mentioned above play an important role in reducing the cognitive load in the visual search task.

4.2.2 Measuring aesthetics

The aesthetics of the layout of objects was measured using the 6 layout metrics proposed by Ngo et. al [98]: *cohesion*, *economy*, *regularity*, *sequence*, *symmetry*, and *unity* (see Chapter 3 for rationale of this selection).The *order and complexity* (OM) are the aggregate of 6 layout metrics used to determine the aesthetics level of the layout. The aesthetics of the layout categorized into three levels: high, medium, low. Table 4 shows the aesthetic value range for each level of aesthetics. The value range for each label was as suggested in Ngo et al.’s study.

Aesthetics Level	**Value range**
High (HAL)	0.7 ≤ *Order and complexity* ≤ 1.0
Medium (MAL)	0.5 ≤ *Order and complexity* < 0.7
Low (LAL)	0.0 ≤ *Order and complexity* < 0.5

Table 4. High, medium, and low aesthetic level (taken from [94])

4.2.3 The tasks

Visual search task

A visual search task was chosen to investigate performance because the demands the task makes on cognitive processes are relatively low [57], requiring only the ability to find upright triangles among inverted triangles. It was important that the task did not require high cognitive demand to avoid fatigue due to the high number of stimuli to be viewed.

In this task, the participants were asked to find the upright triangles and ignore the inverted triangles. An upright triangle was chosen as a target instead of an inverted triangle to minimize the possibility that the content of the target might engage their attention and thus distract from navigating the layout.

The visual search task was repeated twice under two different conditions: with mouse pointing and without mouse pointing. The main reason for conducting the visual search task in two different conditions was to investigate the difference in pattern of performance when the participants had the aid of a mouse pointer and when the participants did not. A similar pattern of performance using both search tools would indicate a strong influence of layout aesthetics on performance whereas a different pattern would indicate weak influence of layout aesthetics on performance.

Preference task

The preference task was conducted using direct ranking (also known as rank ordering [15]), where the participants indicated their preferences by rank ordering the stimuli from least to most preferred. Direct ranking is an intuitive task and easy for the participants to understand [16].

4.2.4 The Java program

The program that created the stimuli

The stimuli were created using a custom written Java program. To create a stimulus, the experimenter set the program to produce a stimulus with a specific aesthetics value range ($0 \leq$ *Order and complexity* < 0.5; $0.5 \leq$ *Order and complexity* < 0.7; or $0.7 \leq$ *Order and complexity* ≤ 1.0). The value range set by the experimenter was the desired average value of the six layout metrics. The program drew triangles and adjusted the sizes and locations of the triangles (with no overlapping) within the dimension of 600 x

600 pixels, until the layout met the aesthetic value range set by the experimenter (Figure 21). The experimenter had no direct control over the layout of objects or the final aesthetics value of the stimulus. The information on the stimuli sets (i.e. screen image library used, actual value of aesthetic parameters, Java pseudocode) can be found in Appendix 1 and Appendix 2.

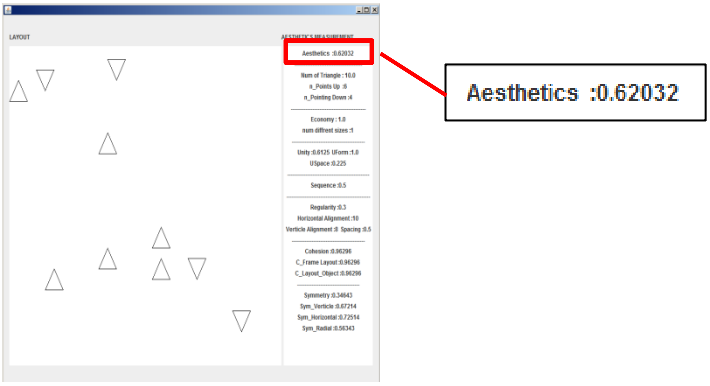


Figure 21. A screen shot of the Java program that created the stimuli

The program that presented the stimuli

Visual search task

The stimuli for the search task were presented to the participants using a custom written Java experimental program (different from the program that created the stimuli) (Figure 22). The program displayed the stimuli and recorded response time and answers from the participants. The program consisted of three main displays: the instruction, stimulus, and answer buttons. The location of display of the instruction and the answer buttons remained unchanged during the visual search task. A new stimulus was displayed when the participant clicked on an answer button.

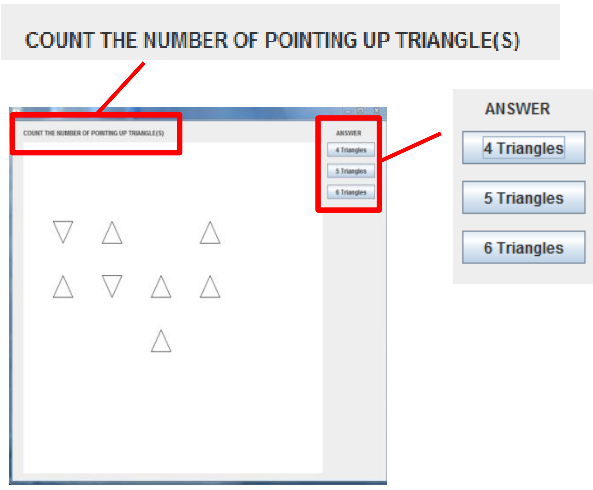


Figure 22. Screen shot of the Java program that presented the stimuli

Preference task

The stimuli in the preference task were presented to the participants using two sheets of A4 paper. Each sheet was printed with three and six layouts respectively. As the number of stimuli used in the preference task was very small, it did not require computational aids beyond paper-and-pencil. The paper-and-pencil technique makes the task simple and easy (e.g. no mouse clicking, no typing, no scrolling down, etc.). Although the use of computational aid such as computer screen display is very useful, it is mostly required for a large number of stimuli due to its ability to record a large amount of data systematically.

4.3 Methodology

4.3.1 Tasks

The participants were asked to perform two tasks: a visual search task and a preference task. The visual search task was always performed before the preference task.

- Visual search task – The participants were asked to find and report the number of upright triangles.
- Preference task – The participants were asked to rank order several layouts from least preferred to the most preferred.

4.3.2 Variables

- Dependent variables – Response time, errors, preference
- Independent variables – Aesthetic levels (high, medium, low)

4.3.3 Participants

Twenty two (11 male and 11 female) undergraduate and postgraduate students of the University of Glasgow from a variety of backgrounds (e.g. Computer Science, Accountancy & Finance, Accounting and Statistics, Economics, Business and Management etc.) participated in the experiment. All the participants were computer literate and used computers daily. The participants received no remuneration for their participation.

4.3.4 Stimuli

An overview of the design of stimuli

Each stimulus consisted of 8 – 10 inverted and upright triangles. There were 4 – 6 upright triangles on each stimulus and the remaining were inverted triangles. The total number of triangles and the number of upright and inverted triangles for each stimulus were randomly determined by the program. The small number of triangles was intentional to avoid fatigue. In a pilot study, it was found that fatigue started to become a problem when the total number of triangles exceeded 10. Constraining the number of triangles on the screen to 10 or less was found to reduce these fatigue effects.

Visual search task

There were 90 different stimuli created for the search task. As the search task was relatively easy and each stimulus took approximately only 3 - 10 seconds to complete, a total number of 90 stimuli gave a reasonable experimental duration (10 - 15 minutes). The 90 stimuli were equally divided into the three aesthetics level (HAL, MAL, LAL) shown in Table 4.

Preference task

The stimuli in the preference task were presented to the participants using two sheets of A4 paper. The first sheet of paper contained 3 layouts (Figure 23) and the second sheet of paper contained 6 layouts (Figure 24). The layouts in the first sheet of paper represented the three levels of aesthetics and the layouts in the second sheet of paper represented the six layout metrics.

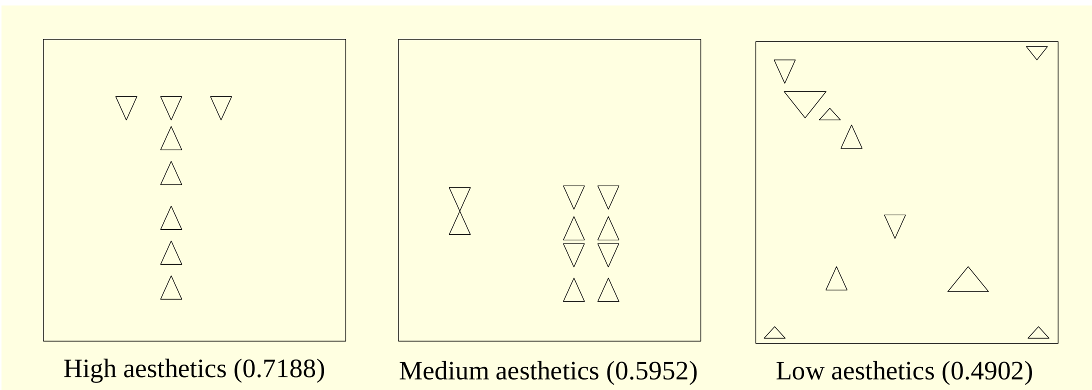


Figure 23. The 1st sheet of paper consisted of three layouts

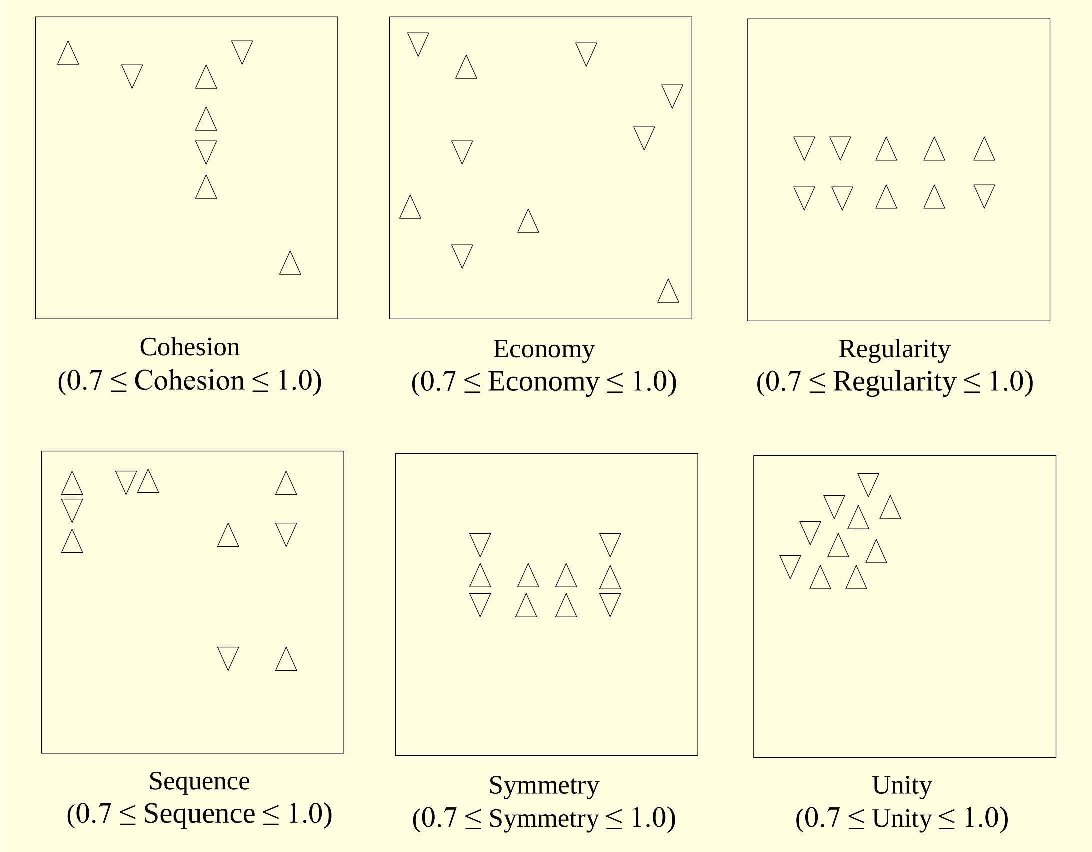


Figure 24. The 2nd sheet of paper consisted of six layouts

4.3.5 Procedure

Standard procedure

At the beginning of the experiment session, the participants received written instructions about the experiment, signed a consent form and filled in a demographic questionnaire. The participants were then seated in front of a laptop screen (screen size of 12 inches with resolution of 1024 x 768 pixels) with their eyes approximately 60 cm from the screen. The laptop screen was tilted to a position that each participant felt comfortable working with to ensure that no light reflection occurred that could prevent the participants from seeing the stimuli on the screen.

The participants were first asked to perform the visual search task and upon completing the visual search task, the participants were given a short break before performing the preference task.

Visual search

The stimuli for the search task were presented to the participants using a custom written Java experimental program (different from the program that created the stimuli, see Figure 22). The program displayed the stimuli and recorded response time and answers from the participants. To minimize any learning effects, the program randomized the sequence of the stimuli for every participant.

The participants were asked to count the number of upright triangles carefully and as fast as possible and to give their answer by clicking on one of the three answer buttons provided on the right of the stimulus (see Figure 22). The stimulus changed when the participant clicked on an answer button, until all 90 stimuli had been presented. A message box was presented after the 90th stimulus to inform the participants that the task was complete.

The search task was conducted under two conditions: with mouse pointing, without mouse pointing.

- With mouse pointing - The participants were allowed to use the mouse pointer to hover over the stimulus to assist them in finding the targets, and to click on the answer button. There was no effect of clicking on the stimulus.
- Without mouse pointing - The participants were not allowed to use the mouse pointer to hover over the stimulus. They were only allowed to use the mouse pointer to click on an answer button.

The participants were randomly assigned to perform either condition 1 or condition 2 first before proceeding to the next task. The task for each condition took approximately 10 - 15 minutes to complete. To avoid tiredness, the participants were allowed to take a short break before continuing to the next condition.

There were 90 stimuli used in each condition which makes the total number of stimuli viewed by the participants 180. The sequence of stimuli in both conditions was randomized to minimize learning effects. The stimuli used in both conditions were identical thus there might be a possibility that the participants would remember their answers for some of the stimuli. This possibility however was low as the participants were not informed that the same stimuli would be used in the next round of the task, and because of the large number of stimuli. Thus, it is unlikely that the participants were “trying to memorize” their answers.

In each condition, the participants were allowed to practise before starting the experiment proper. There was no specific time duration or number of stimuli for the practice session. The participants simply stopped practising when they thought they were ready for data collection. Based on experimenter observation, the participants spent less than a minute on practice, and the number of stimuli used was between 5 and 10. The stimuli used in the practice task were also used in the experiment proper, but randomization limited the possibility for participants to remember their answers. The data from the practice task were not included in the analysis of the data.

Preference task

The preference task was conducted after the participants completed the visual search task. The participants were given two sheets of A4 paper and a pen. The 1st sheet of paper contained three layouts (see Figure 23) and the 2nd sheet of paper contained six layouts (see Figure 24).

On the 1st sheet of paper, which contained three layouts, the participants were asked to rank the layouts from 1 to 3 (1-least preferred, 3-most preferred). On the 2nd sheet of paper, which contained six layouts, the participants were asked to rank the layout from 1 to 6 (1-least preferred, 6-most preferred).

After finishing the task, the participants handed the papers to the experimenter and were briefly asked their reasons for their ranking choices.

4.4 Results

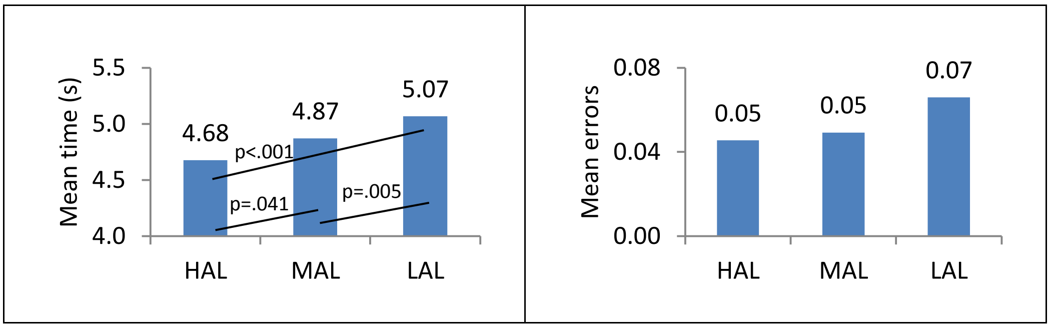
The data from the visual search task were analysed using SPSS version 18 with ANOVA (analysis of variance) repeated measures procedure followed by post-hoc t-tests with Bonferroni adjustment for multiple comparisons (significance level α=0.05). Bonferroni correction was used to eliminate false positives derived from multiple comparisons.

The assumption of Sphericity (i.e. the equality of variances of the differences between various conditions [124]) was tested using Mauchly's test and it was found that none of the variables violated the Sphericity assumption. The violation of Sphericity is serious for the Repeated Measures ANOVA as it can increase the Type I error rate (incorrect rejection of a true null hypothesis).

The data for the preference task were analysed using the Friedman test. A Friedman test was used because the preference data were ranks [71].

4.4.1 Layout aesthetics vs. performance

There was a significant main effect of aesthetic levels on response time ($F_{2, 42} = 16.311$, $p<.001$) but not for errors ($F_{2, 42} = 3.184$, $p=.052$). The pairwise comparisons showed that all possible pairs for response time were significantly different at $p<0.05$ where response time for the HAL was significantly lower than those at MAL and LAL (Figure 25).



*lines indicate where pair-wise significance is found

Figure 25. Mean response time and errors on high, medium, and low aesthetics

4.4.2 Layout aesthetics vs. search tool

Response time

There was a significant main effect of search tool ($F_{1, 21}= 6.64$ $p<.001$) and aesthetics level ($F_{2, 42} = 16.3$ $p<.001$) on response time. The interaction between search tool and aesthetics level for response time was not significant ($F_{2, 42} = 0.702$, $p=0.501$) (Figure 26).

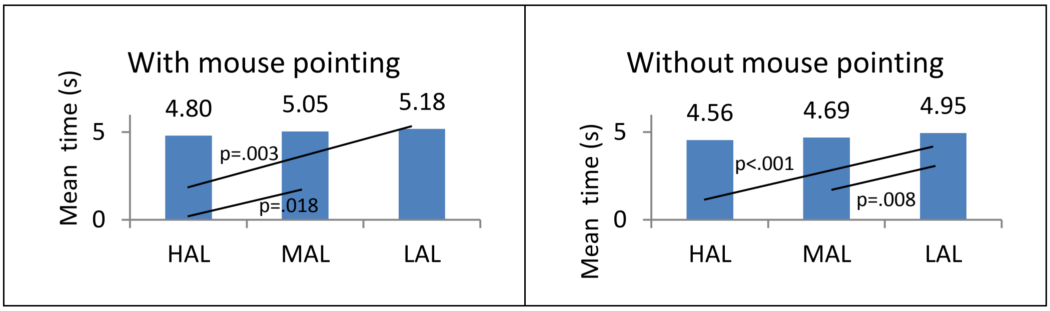


Figure 26. Mean response time with mouse pointing and without mouse pointing

- With mouse pointing

  There was a significant main effect of aesthetics level on response time with mouse pointing $F_{2,\ 42} = 7.64$, p<.001. All possible pairs of the three levels of aesthetics were significantly different except for the pair of MAL and LAL.

- Without mouse pointing

  There was a significant main effect of aesthetics level on response time without mouse pointing $F_{2,\ 42} = 13.0$, p<.001. Pairwise comparisons showed that all pairs were significantly different except for the pair of HAL and MAL.

Errors

There was no significant main effect of search tool ($F_{1,\ 21} = 0.092$, p=0.765) and aesthetics level ($F_{2,\ 42} = 3.18$, p=0.052) on errors. The interaction between search tool and aesthetics level for error was also not significant ($F_{2,\ 42} = 0.496$, p=0.612) (Figure 27)

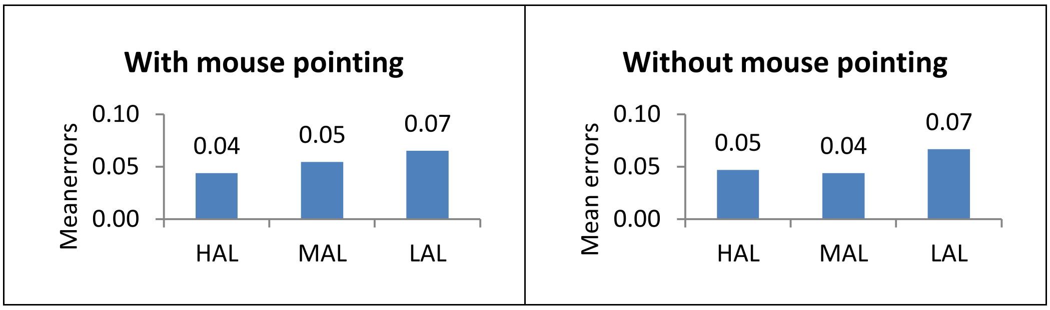


Figure 27. Mean errors with mouse pointing and without mouse pointing

4.4.3 Layout aesthetics vs. preference

High, medium, and low aesthetics

The Friedman test on high, medium, and low aesthetics showed that there was a significant difference in preference between HAL, MAL, and LAL ($\chi 2 = 26.273$, df = 2, p<.001), where a higher level of aesthetic layout was more preferred than a lower level of aesthetic layout (28).

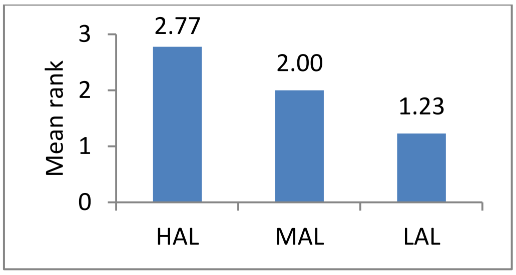


Figure 28. Preference ranking of HAL, MAL, and LAL

Cohesion, Economy, Regularity, Sequence, Symmetry, Unity

Similarly, the Friedman test showed that there was a significant difference between the six layout metrics ($\chi 2$ = 57.974, df = 5, p< .001) in which it showed high preference for *symmetry*, followed by *regularity*, *unity*, *sequence*, *cohesion*, and *economy*.

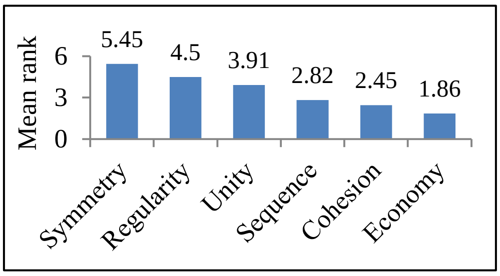


Figure 29. Preference ranking of the six layout metrics

4.4.4 Preference vs. performance

The relationship between preference and performance was analysed using Spearman's rho correlation.

High, medium, and low aesthetics

There was a perfect relationship between response time and preference for HAL, MAL, and LAL, *r* =1.000, *p*<.001 and a positive relationship between errors and preference for HAL, MAL, and LAL, *r*=.866, *p* =.333 (Table 5).

LAYOUT METRICS	ACTUAL DATA			RANK		
	Rank	Errors	Time	Rank	Errors	Time
HAL	2.77	0.0227	4.0909	3	2.5	3
MAL	2.00	0.0227	4.2821	2	2.5	2
LAL	1.23	0.1818	6.4373	1	1	1

1 = worst, 3 = best

Table 5. Preference and performance ranks of three aesthetic levels

Cohesion, Economy, Regularity, Sequence, Symmetry, Unity

There was a negative relationship between response time and preference for the six layout metrics, r = -.257, p=.623. Similarly, there was a negative relationship between errors and preference for the six layout metrics, r=-.353, p =.492.

LAYOUT METRICS	ACTUAL DATA			RANK		
	Rank	Errors	Time	Rank	Errors	Time
Cohesion	4.50	0.045	4.782	5	2	5
Economy	1.86	0	6.067	1	6	2
Regularity	2.45	0.023	4.457	2	4	6
Sequence	2.82	0.136	5.609	3	1	4
Symmetry	5.45	0.023	7.227	6	4	1
Unity	3.91	0.045	5.946	4	2	3

1 = worst, 6 = best

Table 6. Preference and performance ranks of six layout metrics

4.5 Analysis and Discussion

This section analyses and discusses the results of this experiment based on the four aims of this chapter. Section 4.5.1 discusses the task performance, followed by Section 4.5.2 which discusses the performance using two different search tools. Section 4.5.3 discusses the preference data, and finally Section 4.5.4 discusses the interaction between preference and performance.

4.5.1 Aesthetic layout vs. performance

The result shows that HAL produced a shorter response time compared to MAL and LAL. The number of errors between HAL, MAL, and LAL however were not significantly different. This result means that it has been demonstrated that a higher aesthetics layout supports response time performance but not necessarily accuracy performance.

Although the finding of this study that an aesthetic interface supports better task performance has been claimed in previous studies (see for example [133,90,129]), the focus and method used to measure the aesthetics of the interface was different. In this experiment, the focus was on the aesthetics of the layout and the aesthetics was measured objectively rather than subjectively.

What makes the response time performance with HAL higher than with MAL and LAL? To answer this question it is important to examine the layout design of HAL, MAL, and LAL. In an informal interview with the participants, the participants described the characteristics of stimuli with HAL using terms such as “well-structured”, “organized”, “tidy”, and “orderly”, and the stimuli with LAL as having the opposite characteristics such as “unstructured”, “unorganized”, “untidy”, and “disorderly”.

The description of HAL as given by the participants matches the characteristics of interfaces with low levels of complexity such as grid layouts whereas the description of MAL and LAL matches the characteristics of an interface with high levels of complexity such as non-grid layouts [28]. Figure 30 shows examples of two extreme complexities.

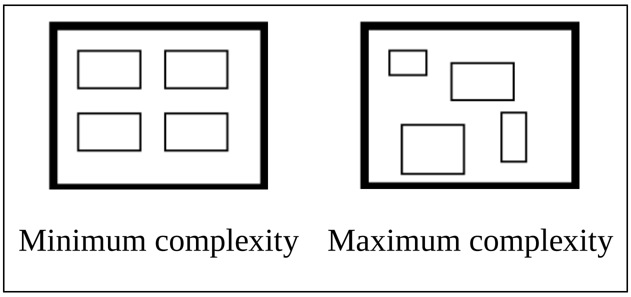


Figure 30. Examples of two extreme complexities (taken from [28])

But how does complexity influence task performance? An interface with high complexity is perceived as visually cluttered, whereas an interface with low complexity is perceived as visually clean [18]. The level of clutter in an interface influences user’s cognitive workload, where cluttered interfaces require more cognitive effort compared to uncluttered interfaces by increasing retrieval demands on memory [2]. A high level of cognitive effort is more likely to result in both feelings of frustration and decreased performance [85] whereas a low level of cognitive effort leads to more enjoyable interaction and increased performance.

It might be asked, how does the emotional state of the user (e.g. frustration, happiness) influences performance? This question is best answered by the theory proposed by Norman [99] “attractive things work better”. According to Norman, attractive things make people happy whereas unattractive things make people unhappy. The state of emotions such as happiness or unhappiness can have a strong influence on how effectively or efficiently people perform in their task. Happy people are more productive and efficient because they do not ponder excessively over a problem but actively find an alternative solution whereas unhappy people focus on one way to solve a problem and are therefore prone to making more mistakes [99].

Thus, the answer to the question “what makes the response time performance of HAL higher than MAL and LAL” could be that HAL has low complexity which minimizes the cognitive workload.

4.5.2 Layout aesthetics vs. search tool

Visual search aided by mouse pointing produced significantly longer response times than visual search without mouse pointing (Figure 26). However, there was no significant difference in terms of errors (Figure 27). Although the response time performance for these two search tools was different, both search tools showed the same pattern of performance (i.e. HAL produced longer response times than MAL or LAL). No significant interaction was found between search tool and aesthetics level.

These results could mean that the use of mouse pointing is a drawback to visual search performance as it slows down the searching process and does not improve task accuracy. Certainly, irrespective of the type of search tool used in visual search, an interface with higher aesthetic layout will support better performance. Although the finding of this experiment that the use of mouse pointing increases response time has been found in Cox and Silva [30], the study by Cox and Silva was limited to investigating the effect of mouse pointing in interactive search using a single-page web menu in which the aesthetic condition of the interface was not defined.

The lack of significant difference of the number of errors between the two search tools was not expected. It was expected that participants would make fewer errors when using mouse pointing than when just relying on eye movements to navigate the layout. This expectation was based on the findings of previous studies [54,4,30] which demonstrated that mouse pointing significantly aids a search by enabling the user to visually tag the object, while the eyes move elsewhere scanning for necessary information required for the task. The tagged object acts as a reference point and reduces the possibility of miscounts or recounts of previously identified objects, which in turn reduces the number of errors.

There are two possible explanations for why this experiment did not replicate the findings of previous studies. First, there was a limited number of objects (8-10 triangles) that formed the layout and second, the participants might just “hover” and not “tag” the objects. Previous studies have suggested that mouse pointing significantly aids a visual search when there are large numbers of distractors competing with the target objects.

While it is useful to know that the use of mouse pointing degrades response time performance and does not contribute to accuracy performance, what is more important from the results of this experiment is to show that user performance is highly influenced by the aesthetics of the interface, whatever the search tool.

4.5.3 Layout Aesthetics vs. Preference

HAL, MAL, and LAL

Among the three levels of layout aesthetics, HAL was the most preferred and LAL was the least preferred (28). This result means that preference increases with increasing aesthetic level.

The result of this experiment corroborates the work of Martindale et al. [83] who suggested that preference is monotonically related to a stimulus' arousal potential. However, unlike Martindale et al who suggested that preference is influenced by semantic factors such as meaningfulness, preference in this experiment was more likely to have been influenced by collective properties such as complexity as suggested by Berlyne [12] (see Section 4.4.1).

Why does preference increase with increasing aesthetics level? To answer this question it is important to look at the “mode of use” of the participants, and whether it is “goal mode” or “action/activity mode”. This is because mode of use has a significant influence on how people perceive the quality of the product [145] (see Chapter 2 Section 2.5.3 for details of mode of use).

In this preference task, it could be suggested that the participants were in a “goal mode” state. This is because, before the preference task, the participants were involved with a performance-based task (i.e. visual search) where goal accomplishment with high effectiveness and efficiency was very important. Thus, there is a strong possibility that the goal mode mood which was formed during the visual search task was carried through to the preference task.

People in “goal mode” state are looking for a design which promotes high effectiveness and efficiency [145]. That means an ideal design is one that has low complexity and with minimum or no ambiguity because this type of design requires a low level of cognitive effort (e.g. symmetrical layout). An interface which requires low level of cognitive effort prevents both frustration and decreased performance [18]. For example, an online banking website with a well-structured layout allows users to happily navigate through the interface because it is easy to find the items they need.

The description of HAL given by the participants during the informal post-experiment interview matches the description of an interface with low complexity. Thus, the answer to the question “why does preference increase with increasing aesthetics level?” is, because performance is more likely to increase with increasing aesthetics level due to the low level of complexity which leads to low cognitive effort.

The result of this experiment which showed higher preference for the lowest level of complexity is contrary to the finding of Berlyne [12], which showed that preference is highest at the moderate level of complexity. It also contradicts the claim made by Gaver et al. [47] who suggested that an interface with ambiguity is sometimes more preferred than an interface with no ambiguity as it can be intriguing, mysterious, and delightful and can encourage close personal engagement.

It should be noted that in Berlyne’s study, the preference task was not preceded by a performance task. Thus, it could be suggested that in Berlyne’s study participants were in an action/activity/leisure mode and not in goal mode as in this experiment. People in action/activity/leisure mode have different goals from people in goal mode. People in action/activity/leisure mode are looking for a design that interests them and not merely helps them to perform the task at the maximum level of effectiveness or efficiency [145].

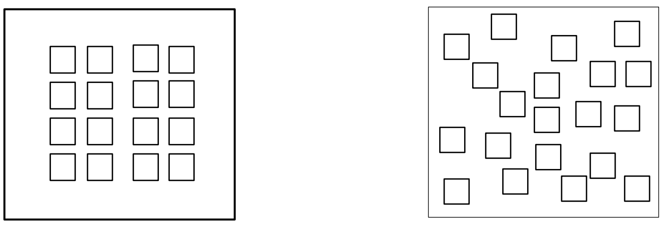
But what makes a moderate level of complexity more preferred than the lowest and highest level of complexity in action/activity/leisure mode? This question will be investigated in the next experiment (see Chapter 5).

It is clear from the result of this preference task that preferences for interfaces are very much influenced by layout aesthetics, where HAL is more preferred due to its low complexity which helps user to perform the task more effectively and efficiently.

Cohesion, Economy, Regularity, Sequence, Symmetry, Unity

Among the six layout metrics, *symmetry* was the most preferred and *economy* was the least preferred. An observation on the six stimuli that were used to represent the six metrics however showed that, the triangles which formed the layout of each stimulus were all the same size (see Figure 24). This means that, technically, all stimuli can be considered as high *economy* (This subtlety was not noticed until after the data collection was complete). Thus, in this analysis, *economy* will be ignored and *cohesion* will be considered as the least preferred.

The high preference for *symmetry* indicates that people prefer a layout with high predictability. How does *symmetry* make a layout highly predictable? The rigidity of *symmetry* makes it very predictable. For example, once the participants have seen one half of the stimulus, they will know what the other half is like. This can be illustrated in Figure 31. Both figures contain the same number of boxes (16). However, as the boxes in Figure 31a are arranged symmetrically, counting the number of boxes is much quicker than in Figure 31b.

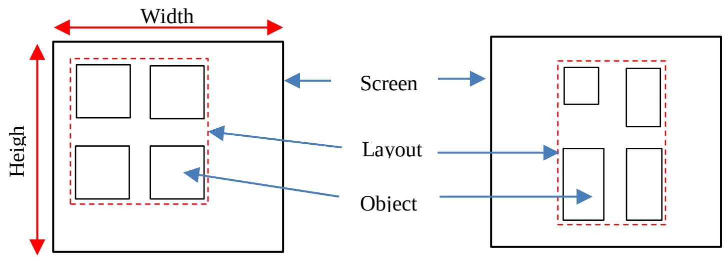


a) Symmetric b) Non-symmetric

Figure 31. Example of symmetric and non-symmetric layouts

The low preference for *cohesion* indicates that consistency of aspect ratio of visual field is least important for users. It has been suggested that performance is better when the aspect ratio of the visual field stays the same during scanning of the display [98]. This raises an interesting question as to why the participants in this experiment disliked *cohesion* the most. To find the answer to this question it is important to examine what cohesive and non-cohesive interfaces look like.

Figure 32 illustrates examples of cohesive and non-cohesive interface. Figure 32a is highly cohesive because the aspect ratios of the objects, layout, and screen are similar whereas Figure 32b is not because of the dissimilarity of the aspect ratios of the objects, layout, and screen. As shown in Figure 32a, a cohesive interface is “restful to the eyes” because the eye movement pattern does not change much due to the consistency of aspect ratio of the objects, layout, and screen. However, although it is “restful to the eyes” other metrics might appear to be more “restful to the eyes”. For example, “symmetry” is more restful as it is predictable.



(a) Cohesive (b) Non-cohesive

Figure 32. Examples of cohesive and non-cohesive layouts

4.5.4 Preference vs. performance

There was a significant and perfect correlation between preference and response time performance of HAL, MAL, and LAL. There was, however, no significant correlation found for the stimuli representing the six layout metrics. These results suggest that interface preference can accurately predict users’ response time performance when the aesthetics of the interface measured by the average value of the six layout metrics but not by any individual metric.

This finding supports the notion of Tractinsky et al. [139] that “what is beautiful usable”. This experiment however was different from the study by Tractinsky et al. in that it was based on participants’ preferences rather than their perception of usability.

4.6 Conclusion

This chapter presented an experiment which investigated the relationship between layout aesthetics, task performance, and preference. Two tasks were performed: visual search task and preference task. These tasks were performed using “abstract” stimuli ensuring the interfaces to be ‘less informative and context free’, which was important to ensure that the users main focus was on the layout and not on the content.

The answers to the questions posed earlier in this chapter are as follow:

1. What is the relationship between aesthetics of interface design and task performance?

   A potential answer to this question is provided by the result from the experiment in Section 4.4.1 - 4.4.2 where it was found that, irrespective of the search tool used, performance (as represented by response time) increases with increasing aesthetics level. This evidence provides strong support for the implementation of aesthetic layout principles in interface design.

2. What is the relationship between aesthetics of interface design and preference?

   A potential answer to this research question is provided by the result from the experiment in Section 4.4.3 where it was found that preference increases with increasing aesthetics level as well as that there was a high preference for symmetrical layouts and a low preference for cohesive layouts. Given that a performance-based task was conducted before the preference task, it could be suggested that preference judgments were strongly influenced by the ability of the layout to assist the users to accomplish the task more effectively and efficiently.

3. What is the relationship between aesthetics of interface design and search tools?

   An answer to this question is provided in Section 4.4.2 where it was found that there was a similar pattern of performance between the two search tools: performance increases with increasing aesthetics level. Therefore, it can be suggested that regardless of the search tools used, performance is better with high aesthetics interface.

4. Is there any relationship between preference and task performance?

   A potential answer to this question is provided by the result from the experiment in Section 4.4.4 where it was found that preference and performance were highly correlated when the layout aesthetics of the interface were measured using a composite measure of the six layout metrics rather than an individual metric. It is obvious that the interface which was preferred most supported the best performance. In other words, performance can be predicted using users' interface preferences.

The most interesting aspect of this finding was that a high aesthetics layout was regarded as beneficial for performance, rather than detrimental to performance, as previously assumed by many usability experts. The novel aspect of this experiment was that the results were obtained with interfaces where the layout aesthetics were measured objectively rather than subjectively, unlike most studies in the literature. This suggests that besides subjective measures interface designers can also rely on objective measures to assess the aesthetics of interfaces.

The next step of this research is to investigate users' preference of layout under "leisure mode", as in this experiment, the participants were potentially in a "goal mode" as they were involved with a performance-based task (i.e. visual search task) prior to the preference task. This is an important issue to investigate to see whether preference would be differed according to "mode of use". This would be investigated in the next chapter, Chapter 5.

Chapter 5

Layout aesthetics vs. preference

In Chapter 4 it was found that preference increases with increasing aesthetics level. It was argued, however, that this finding was potentially biased by the preceding goal-oriented task. Therefore this chapter will focus on investigating users' preferences for layouts in "leisure-oriented" interfaces. The theoretical background on visual aesthetics and preference can be found in the literature review in Chapter 2.

The second research question of this thesis, which has already been partially addressed in Chapter 4, is readdressed in this chapter.

The research question of this chapter is:

1. What is the relationship between the aesthetics of interface design and user preference?

5.1 Aims

The aim of this experiment was to investigate users' preferences for layouts with the intention of producing a ranked list. Furthermore, the broad backgrounds of the participants allowed an additional investigation into the effects of culture, which has not been done before apart from in the work of Tractinsky [137].

5.2 Experimental design

5.2.1 Interface components

The interface components were similar to those used in Chapter 4 (see Figure 20).

5.2.2 Measuring aesthetics

In Chapter 4, the aesthetics of the interface was represented by the aggregates of six layout metrics. This means that there was a possibility that different metrics had the same level of aesthetics, making it difficult to determine which layout metric was the most influential. In this experiment, this issue was addressed by changing the way the aesthetics was measured using the following methods:

1. All six layout metrics had the same aesthetics level (high, medium, or low, see Table 7, Category 1-3)
2. Only one metric had a high aesthetics level and the remaining five layout metrics had low aesthetics levels (see Table 7, Category 4-9)
3. Only one metric had a medium aesthetics level and the remaining five layout metrics had low aesthetics levels (see Table 7, Category 10-15)

Table 7 shows a summary of how the aesthetics level of the interfaces were specified in this experiment.

CATEGORY	LAYOUT METRICS					
	Cohesion	**Economy**	**Regularity**	**Sequence**	**Symmetry**	**Unity**
1. High aesthetics (HAL)	High	High	High	High	High	High
2. Medium aesthetics (MAL)	Medium	Medium	Medium	Medium	Medium	Medium
3. Low aesthetics (LAL)	Low	Low	Low	Low	Low	Low
4. High cohesion	**High**	Low	Low	Low	Low	Low
5. High economy	Low	**High**	Low	Low	Low	Low
6. High regularity	Low	Low	**High**	Low	Low	Low
7. High sequence	Low	Low	Low	**High**	Low	Low
8. High symmetry	Low	Low	Low	Low	**High**	Low
9. High unity	Low	Low	Low	Low	Low	**High**
10. Medium cohesion	**Medium**	Low	Low	Low	Low	Low
11. Medium economy	Low	**Medium**	Low	Low	Low	Low
12. Medium regularity	Low	Low	**Medium**	Low	Low	Low
13. Medium sequence	Low	Low	Low	**Medium**	Low	Low
14. Medium symmetry	Low	Low	Low	Low	**Medium**	Low
15. Medium unity	Low	Low	Low	Low	Low	**Medium**
$0.7 \leq$ High ≤ 1.0, $0.5 \leq$ Medium < 0.7, $0.0 \leq$ Low < 0.5						

Table 7. Summary of how the aesthetics of the interfaces were specified

5.2.3 The Java program

The program that created the stimuli

The program that created the stimuli was similar to the program that created the stimuli for the experiment described in Chapter 4 (see Figure 21). The only difference was the way that the aesthetics of the stimuli was specified. The program created one stimulus for each category in Table 7, resulting 15 stimuli in total for this experiment. The information on the stimuli sets (i.e. screen image library used, actual value of aesthetic parameters, Java pseudocode) can be found in Appendix1 and Appendix 2.

The program that presented the stimuli

The stimuli were presented to the participants using a Java program (Figure 33). This Java program was different from the program that created the stimuli as it only displays the stimuli created beforehand by other Java programs. The program displayed the stimuli one at a time for two seconds each before the participants made their choice. The participants were not allowed to back-track. This is to make sure that the participants spend an equal length of time on each stimulus thus giving similar levels of attention. It was also a forced-choice task in that the participants were required to choose exactly one stimulus (i.e. Picture A or Picture B).

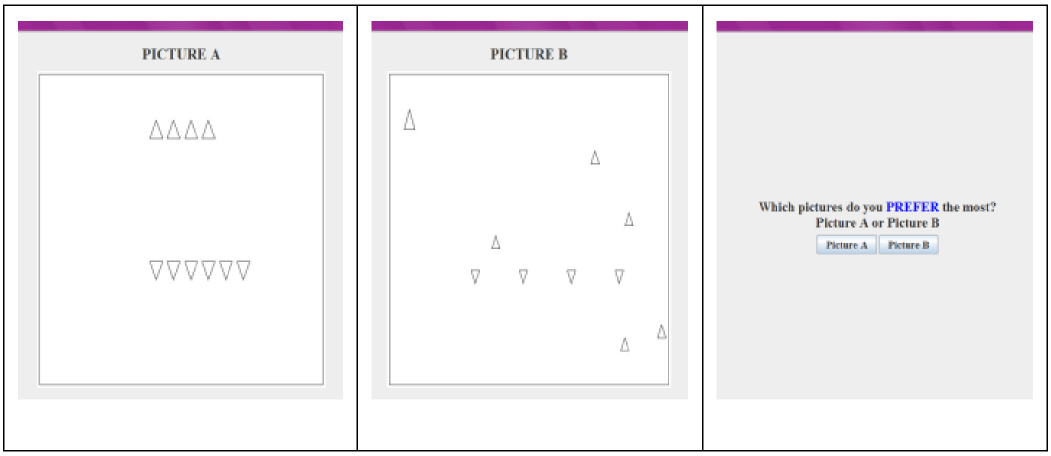


Figure 33. The computer program that was used to present the stimuli (Note that each panel of the figure was presented separately in order from left to right)

5.3 Methodology

5.3.1 Task

The participants were presented with a series of 105 pairs of pictures. For each pair they were required to choose which pair they preferred the most. The 105 pairs of pictures were as a result for pairing 15 stimuli.

5.3.2 Variables

- Dependent variables
    - Preference choice
- Independent variables
    - High, medium, low aesthetics
    - (High or medium) *cohesion, economy, regularity, sequence, symmetry,* and *unity.*

5.3.3 Participants

A total of 72 participants participated in this experiment, of which 26 participants classified themselves as Asian, 42 as Western, and 4 as “other”. From the total of 72 participants, data from 15 participants (5 Asian, 10 Western) were discarded due to the high number of circular triads in their data (see below for an explanation). All the participants were computer literate and used computers daily. The participants received no remuneration for their participation.

5.3.4 Stimuli

The design of the stimuli for this experiment was similar to the design of the stimuli in Chapter 4. The only difference was the number of stimuli and how the aesthetics level was specified.

15 stimuli

There were 15 stimuli created for this experiment: one stimulus for each category in Table 7. The program that created the stimuli and the program that presented the stimuli to the participants were different. That means the stimuli viewed by the participants during the preference task were not created in real time. Thus, preventing any delay in viewing the stimuli during the preference task as the Java program took sometimes to create the stimuli according to the intended aesthetic properties (see Table 7).

The number of stimuli created for this experiment was higher than the number of stimuli used in the preference task in Chapter 4. The difference in the number of stimuli was a result of the different experimental focus on how the aesthetics of the stimuli was specified. In Chapter 4, the layout aesthetics were measured using a composite metric, whereas in this experiment, the layout aesthetics were measured using an individual metric.

5.3.5 Procedure

The standard experimental procedure was implemented before starting the experiment (see Chapter 4 – standard procedure)

A computer program, written in JAVA was used to present the stimuli and accept the participants' choices of the pictures (see Figure 33). This program was different from the program that created the stimuli (Figure 21).

After completing the standard procedure, the participants were shown a demonstration of how to do the task. The purpose of the demonstration was to ensure that the participant was familiar and comfortable with the task before starting the experiment proper. After the demonstration, the participants were allowed to practise the task. The data from the practice task were not included in the analysis.

In the experiment proper, the participants were presented with a pair of pictures, labelled as picture A and picture B. Picture A was displayed first followed by picture B, one at a time. Each picture was displayed for two seconds each, before the participants made their choice of which of the two pictures they preferred the most. According to Lindgaard et al. [76], judgement of an interface is made very quickly, that is, as fast as 50 milliseconds. Two seconds was chosen as the display time for each picture because it is a sufficient amount of time for an individual to make their choice. The task was a forced-choice paired comparison, where the participants were required to make their choice even if they did not like either of the pictures.

The choice screen (see Figure 33) had two buttons ("Picture A" and "Picture B") on it without the stimuli being visible and there was no facility for the participants to back-track. This screen was untimed. The next pair of stimuli was shown automatically after the participants clicked on the answer button. This process continued until all 105 pairs of pictures were shown (15 stimuli each shown 14 times with each of the other stimuli). The order of the pairs and the orders of the pictures in each pair were both randomized to minimize learning effects.

5.4 Results

The data from the preference task were analysed using Dunn-Rankin et al's [37] TRICIR software. The use of Dunn-Rankin et al's software can also be found in several studies investigating users' perceptions using paired-comparison (see for example [52,26,17]). The program analyses the circular triad of paired comparison data and provides information on circular triads' probabilities for individual participants and objects, as well as participant and object groups, performs object scaling according to the simplified rank method, and calculates Kendall's coefficients of consistency (*w*) and Kendall's coefficients of concordance (W).

w indicates the consistency of the participant in making their choices as measured by the extent of circular triads. A circular triad is an inconsistency in choices of paired comparisons. For example, three objects A, B, and C will produce three possible pairs AB, AC, and BC. If a participants was asked to choose for each pair which object their preferred the most, if the participant chose A over B, and B over C, the choice of the third pair should be A over C and not C over A. A circular triad occurs when C is chosen over A. It can be shown by the relationship below:

$A > B, \quad B > C, \quad C > A$ where > means "is chosen over"

w is measured within the range from 0 to 1. A *w* value closer to 0 means the participant was either responding carelessly or was not competent in the task (and therefore produced a large number of circular triads) and a *w* value closer to 1 means the participant made careful choices and that their view of the stimuli is sufficiently different to enable a reasonably consistent set of preferences to be recorded. The cut-off of *w* used in this experiment was 0.50 and below. This cut-off was as suggested by [64].

The *W* is the measure of agreement in the object rankings among the participants. The *W* was measured within the range from 0 to 1. *W* closer to 1 means there is a close agreement between the participants on which object is the most preferred, and a *W* value closer to 0 means that there is great deal of variation in the preference data among the participants.

5.4.1 Kendall's coefficient of consistency (w)

Data from 15 participants (5 Asian and 10 Western) from 72 participants were discarded as the value of *w* was less than 0.5 (Figure 34). The low value of *w* showed that the choices made by these participants included a large number of circular triads. The remaining 57 participants were highly consistent with a mean *w* of 0.7016. The number of circular triads for each of the remaining 57 participants ranged from 9 to 69 with a mean of 41.772 and standard deviation of 15.107.

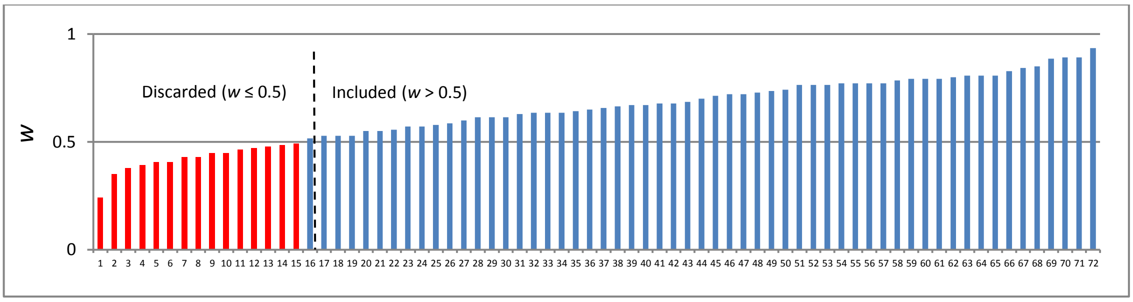


Figure 34. The coefficient consistency (*w*) of 72 participants

5.4.2 All participants

Kendall's coefficients of concordance (W)

The *W* for the 15 stimuli was low, *W* =0.1023 (of possible 1.0). The low number of *W* means that there was not much agreement on which one of these 15 stimuli was the most preferred.

Preference ranking of 15 stimuli

Figure 35 shows the preference ranking of the 15 stimuli based on the number of votes given by 57 participants. The stimulus with the most votes was the most preferred layout whereas the stimulus with the least votes was the least preferred layout.

As shown in Figure 35, HAL was the least preferred layout (286 votes) whereas medium *symmetry* was the most preferred layout (499 votes). The maximum number of votes a stimulus could get was 798 (14 stimuli x 57 participants).

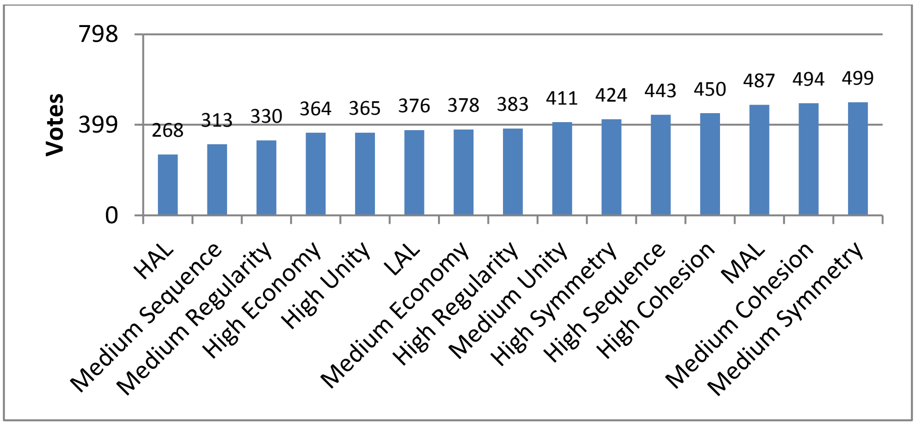


Figure 35. The preference ranking of 15 stimuli based on participants' votes

Test of significance

The critical range is the product of the expected standard deviation E(S) and a value from the range distribution Q_a [37]. Finding the critical range is important in order to find stimuli that are chosen significantly more or less than chance. An illustration of the calculation of the critical range for the sample of 57 participants and 15 stimuli where the .05 probability level is chosen is shown below.

$$E(S) = \sqrt{N(K)(K+1)/12}$$

Where K= number of the parameters and N = number of participants. As K = 15 and N = 57 then,

$$= \sqrt{57(15)(16)/12}$$

$$= 33.764$$

Q_a is the studentized range (the difference between the largest and smallest data in a sample measured in units of sample standard deviations) for K treatments and infinite *df*. For N = 57, K = 15 and *p*=.05, the value, is 4.796 (Obtained from the studentized table in [37])

$$\text{Critical range} = E(S)\,Q_{.05}$$

$$= (33.764)\,(4.796)$$

$$= 161.93$$

The conclusion of this analysis is that any difference in the number of votes between different stimuli which is greater than or equal to 162 is statistically significant. Table 8 presents a matrix of rank differences for the preference data shown in Table 8, in which the significant values are shown in bold. Table 8 shows that 10 pairs of the 15 stimuli were significantly different at the .05 probability level.

		HAL	Medium sequence	Medium regularity	High economy	High unity	LAL	Medium economy	High regularity	Medium unity	High symmetry	High sequence	High cohesion	MAL	Medium cohesion	Medium symmetry
	R_i	268	313	330	364	365	376	378	383	411	424	443	450	487	494	499
HAL	268	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Medium sequence	313	45	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Medium regularity	330	62	17	-	-	-	-	-	-	-	-	-	-	-	-	-
High economy	364	96	51	34	-	-	-	-	-	-	-	-	-	-	-	-
High unity	365	97	52	35	1	-	-	-	-	-	-	-	-	-	-	-
LAL	376	108	63	46	12	11	-	-	-	-	-	-	-	-	-	-
Medium economy	378	110	65	48	14	13	2	-	-	-	-	-	-	-	-	-
High regularity	383	115	70	53	19	18	7	5	-	-	-	-	-	-	-	-
Medium unity	411	143	98	81	47	46	35	33	28	-	-	-	-	-	-	-
High symmetry	424	156	111	94	60	59	48	46	41	13	-	-	-	-	-	-
High sequence	443	**175**	130	113	79	78	67	65	60	32	19	-	-	-	-	-
High cohesion	450	**182**	137	120	86	85	74	72	67	-39	26	7	-	-	-	-
MAL	487	**219**	**174**	157	123	122	111	109	104	76	63	44	37	-	-	-
Medium cohesion	494	**226**	**181**	**164**	130	129	118	116	111	83	70	51	44	7	-	-
Medium symmetry	499	**231**	**186**	**169**	135	134	123	121	116	88	75	56	49	12	5	-

Bold numbers are significant at the .05 level (critical range = 162)

Table 8. Matrix of rank differences for all participants

5.4.3 Asian participants

Kendall's coefficients of concordance (*W*)

The *W* for 15 stimuli for 21 Asian participants was very low *W* =.1859 (of a possible 1.0). The low number of *W* means that there was not much agreement on which one of these 15 stimuli was the most preferred.

Preference ranking of 15 layout metrics

Figure 36 shows the preference ranking (the least preferred to the most preferred) of 15 stimuli based on the number of votes by 21 Asian participants. As shown in Figure 36, the least preferred stimulus was HAL with 72 votes and the most preferred stimulus was medium *symmetry* with 211 votes. The maximum number of votes a stimulus could get was 294 (14 aesthetic parameters x 21 participants).

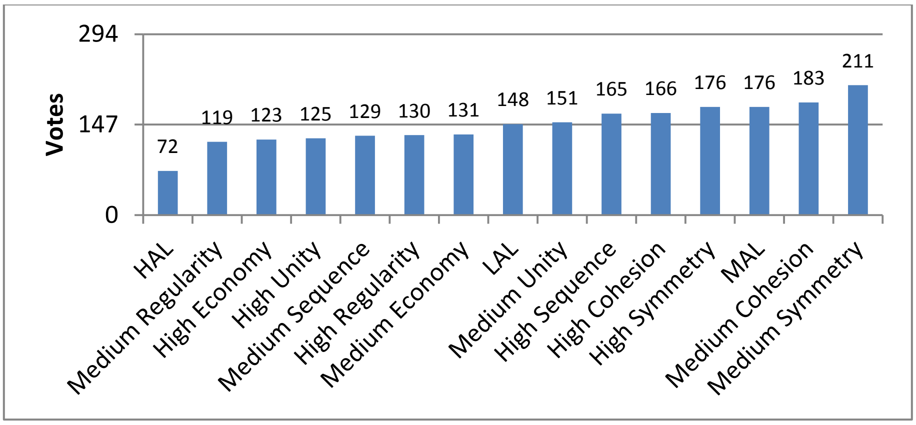


Figure 36. The Asian participants' votes for each of the 15 stimuli

Test of significance

As K= 15 and N=21 then,

$$E(S) = \sqrt{N(K)(K+1)/12}$$

$$= \sqrt{21(15)(16)/12}$$

$$= 20.49$$

For N = 21, K = 15 and p=.05, the value, was 4.796 (Obtained from the studentized table in [37])

$$\text{Critical range} = E(S)\ Q_{.05}$$

$$= (20.49)\ (4.796)$$

$$= 98.27$$

Any difference in the number of votes between different stimuli which is greater than or equal to 98 is statistically significant. Table 9 presents a matrix of rank differences for the preference data shown in Figure 36 in which the significant values are shown in bold. Table 9 shows that 4 pairs of the 15 stimuli were significantly different at the .05 probability level.

	R_i	HAL	Medium Regularity	High Economy	High Unity	Medium Sequence	High Regularity	Medium Economy	LAL	Medium Unity	High Sequence	High Cohesion	High Symmetry	MAL	Medium Cohesion	Medium s Symmetry
		72	119	123	125	129	130	131	148	151	165	166	176	176	183	211
HAL	72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Medium regularity	119	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-
High economy	123	51	4	-	-	-	-	-	-	-	-	-	-	-	-	-
High unity	125	53	6	2			-	-	-	-	-	-	-	-	-	-
Medium sequence	129	57	10	6	4		-	-	-	-	-	-	-	-	-	-
Medium regularity	130	58	11	7	5	1	-	-	-	-	-	-	-	-	-	-
Medium economy	131	59	12	8	6	2	1	-	-	-	-	-	-	-	-	-
LAL	148	76	29	25	23	19	18	17	-	-	-	-	-	-	-	-
Medium unity	151	79	32	28	26	22	21	20	3	-	-	-	-	-	-	-
High sequence	165	93	46	42	40	36	35	34	17	14	-	-	-	-	-	-
High cohesion	166	94	47	43	41	37	36	35	18	15	1	-	-	-	-	-
High Symmetry	176	**104**	57	53	51	47	46	45	28	25	11	10	-	-	-	-
MAL	176	**104**	57	53	51	47	46	45	28	25	11	10	0	-	-	-
Medium cohesion	183	**111**	64	60	58	54	53	52	35	32	18	17	7	7	-	-
Medium symmetry	211	**139**	92	88	86	82	81	80	63	60	46	45	35	35	28	

Bold numbers are significant at the .05 level (critical range = 98)

Table 9. Matrix of rank differences of the 15 stimuli for Asian participants

5.4.4 Western participants

Kendall's coefficients of concordance (*W*)

The *W* for 15 parameters for 32 Western participants was very low, *W* =.0843 (of possible 1.0). The low number of *W* means that there was not much agreement on which one of these 15 stimuli was the most preferred.

Preference ranking of 15 stimuli

Figure 37 shows the preference ranking of the 15 stimuli based on the number of votes by 32 participants. The stimulus with the most votes was the most preferred layout whereas the stimulus with the least votes was the least preferred layout. As shown in Figure 37, HAL was the least preferred stimulus with 157 votes and medium *cohesion* as the most preferred stimulus with 280 votes. The maximum number of votes a stimulus could get was 448 (14 stimuli X 32 participants).

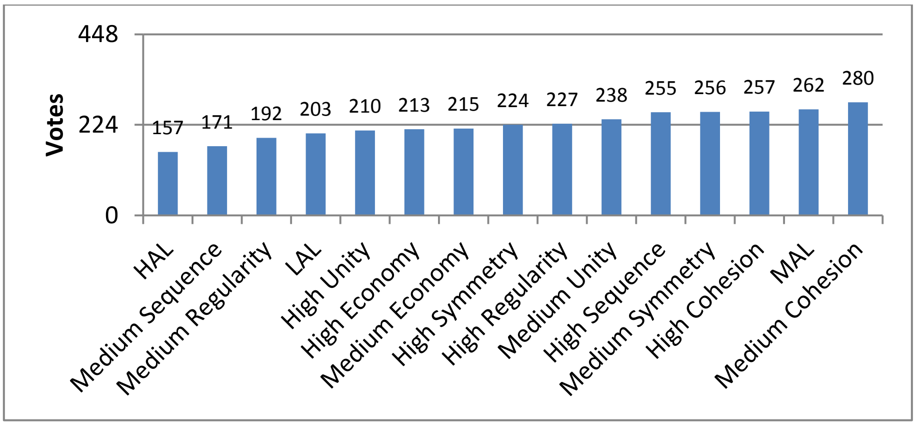


Figure 37. The western participants' votes for each of the 15 stimuli

Test of significance

As K= 15 and N=32 then,

$$E(S) = \sqrt{N(K)(K+1)/12}$$
$$= \sqrt{32(15)(16)/12}$$
$$= 25.303$$

For N = 32, K = 15 and p=.05, the value, was 4.796 (Obtained from the studentized table in [37])

$$\text{Critical range} = E(S)\ Q_{.05}$$
$$= (25.30)\ (4.796)$$
$$= 121.34$$

Any difference in the number of votes between different stimuli which is equal to or greater than 121 is statistically significant. Table 10 presents a matrix of rank differences for the preference data shown in Figure 37, in which the significant values are shown in bold. Table 10, only 1 pair was significantly different at the .05 probability level.

	R_i	All High	Medium sequence	Medium regularity	All low	High unity	High economy	Medium economy	High symmetry	High regularity	Medium unity	High sequence	Medium symmetry	High cohesion	All medium	Medium cohesion
		157	171	192	203	210	213	215	224	227	238	255	256	257	262	280
HAL	157	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Medium sequence	171	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Medium regularity	192	35	21	-	-	-	-	-	-	-	-	-	-	-	-	-
LAL	203	46	32	11	-	-	-	-	-	-	-	-	-	-	-	-
High unity	210	53	39	18	7	-	-	-	-	-	-	-	-	-	-	-
High economy	213	56	42	21	10	3	-	-	-	-	-	-	-	-	-	-
Medium economy	215	58	44	23	12	5	2	-	-	-	-	-	-	-	-	-
High symmetry	224	67	53	32	21	14	11	9	-	-	-	-	-	-	-	-
High regularity	227	70	56	35	24	17	14	12	3	-	-	-	-	-	-	-
Medium unity	238	81	67	46	35	28	25	23	14	11	-	-	-	-	-	-
High sequence	255	98	84	63	52	45	42	40	31	28	17	-	-	-	-	-
Medium symmetry	256	99	85	64	53	46	43	41	32	29	18	1	-	-	-	-
High cohesion	257	100	86	65	54	47	44	42	33	30	19	2	1	-	-	-
MAL	262	105	91	70	59	52	49	47	38	35	24	7	6	5	-	-
Medium cohesion	280	**123**	109	88	77	70	67	65	56	53	42	25	24	23	18	-

* **Bold** numbers are significant at the .05 level (critical range = 121)

Table 10. Matrix of rank differences

5.5 Analysis and Discussion

5.5.1 HAL, MAL, and LAL

The results of this experiment show that there was a high preference for MAL compared to HAL and LAL. This result means that preference is highest at the medium aesthetics levels.

The result of this experiment corroborates the work of Berlyne [12], who suggested that preference is related to a stimulus' arousal potential in an inverted-U shape. That is, preference is highest at a moderate level of complexity (see Figure 35).

The result of this experiment was unexpected. It was expected that the result would replicate the result from Chapter 4 which showed preference increasing with increasing aesthetics level. Why is the result of this experiment different from that described in Chapter 4? A possible explanation for this might be that the participants in the two experiments had different expectations of interface design due to the different modes of use they were set in: goal mode vs. leisure mode [145].

The participants in Chapter 4 were probably in a goal-mode state as they were previously involved in a performance-based task before the preference task. This could have influenced the participants to make their preference judgments based on how the design of the interface assisted them to perform the task at the maximum level of effectiveness and efficiency (i.e. finding the target quickly and accurately). As discussed previously in Chapter 4 people in goal mode will choose an interface with high aesthetics as the design is less complex and requires low cognitive effort.

While the participants in Chapter 4 were in goal mode, the participants in this experiment were probably in action/activity/leisure mode. This is because the participants were not involved in any performance-based task before the preference task. That means the preference judgment was made purely based on what was pleasing to their eyes.

Why is it that in action/activity/leisure mode preference is highest for medium aesthetics levels? To find an answer to this question, it is important to review the characteristics of HAL, MAL, and LAL. In Chapter 4 it was found that increases in aesthetics level mean decreases in complexity which leads to a decrease in cognitive effort. Based on this characteristic, it could be suggested that high aesthetics means a simple interface and low aesthetics means a complex interface. Medium aesthetics, on the other hand, sits in the middle between simple and complex interfaces.

High aesthetics could lead users to boredom due to its extreme simplicity. For example, an interface with a symmetrical layout could make users bored as it is too ordinary and predictable. Low aesthetics could lead users to stress or anxiety due to its extreme complexity. For example, an interface with an extremely unsymmetrical layout could make users stressful as it is too complicated and difficult. Medium aesthetics, on the other hand, could lead users towards enjoyment of the design, as the interface is neither too simple nor too complex.

Gaver et al. [47] suggested that ambiguity in an interface is not always bad. It can be "intriguing, mysterious, and delightful" and can encourage close personal engagement with the system. Gaver et al however did not mention to what extent ambiguity in an interface may be perceived as "intriguing, mysterious, and delightful", rather than discomforting: it is clear that a balance between intrigue and discomfort is needed.

The high preference for MAL compared to HAL and LAL indicates that extremely ‘beautiful’ or ‘ugly’ appearance does not necessarily interest users. The design of the interface should be neither too ordinary nor too extraordinary. An interface that is too ordinary or too extraordinary can affect the aesthetic experience negatively, resulting in participants abandoning it.

5.5.2 Cohesion, economy, regularity, sequence, symmetry, unity

The most preferred layout was medium *symmetry* (499 votes) and the least preferred layout was medium *sequence* (313 votes) (see Figure 35, Table 8). With the exception of the HAL condition, the effects of variations in the layout conditions were relatively modest. The overall co-efficient of agreement among the participants was low W=.1023.

The result of this experiment was unexpected. It was expected that preference would be high for the highly symmetrical stimulus compared to other layout metrics. This expectation was based on the finding of a previous study by Reber et al. [113] who suggested that symmetry has a high level of perceptual fluency (e.g. the ease of identifying the physical identity of the stimulus) which is responsible for positive aesthetic judgements. According to Reber et al. [113], symmetrical patterns contain less information which makes it easier to process hence increasing the speed of processing fluency (Garner,1974 as cited by [113]). The higher the processing speed of perceptual fluency, the more positive the aesthetic judgments.

A possible explanation of the high preference for medium *symmetry* instead of high *symmetry* could be that high *symmetry* looks too ordinary and predictable. As mentioned in Section 4.5.3, predictable stimuli are not interesting as they lack a “mysterious” effect which is an important feature for keeping users’ interest in the interface. A details analysis of the significance test in Table 8 showed that although medium *symmetry* received more votes than high *symmetry* these two metrics were not in themselves significantly different. Thus, it could be suggested that an interface in which the layout is slightly symmetrical or highly symmetrical is preferred equally by users.

The low preference for medium *sequence* indicates interface in which the layout only just approximately follows the most common eye movement pattern (upper left → upper right → lower left → lower right) on a computer display does not interest users. Further analysis of the significance tests in Table 8 showed that medium *sequence* was not significantly preferred over high *sequence*. This indicates that interfaces in which layout design follows the common reading pattern is not particularly important for users.

5.5.3 Cultural difference: Asian vs. western

For Asian participants, there was a strong preference for the medium *symmetry* stimuli and a weak preference for the HAL stimuli. The overall co-efficient of agreement among the Asian participants however was low W=.1859 which indicates low agreement among the participants as to which stimulus was the most preferred. The test of significance shows that medium *symmetry* was significantly more preferred only over HAL but not over other metrics, whereas the preference for HAL was significantly different from medium *symmetry*, medium *cohesion*, MAL, and high *symmetry*.

As for Western participants the result shows that there was a strong preference for the medium *cohesion* stimuli and a weak preference for the HAL stimuli. Similar to the Asian participants, the overall co-efficient of agreement among the Western participants was also very low W=.0843. The test of significance shows that medium *cohesion* was significantly more preferred only over HAL but not over other metrics.

The results from both Asian and Western participants were unexpected.

It was expected that Asian participants would prefer high *symmetry* instead of medium *symmetry* or the other layout metrics. This expectation was based on previous finding that preference for *symmetry* is universal across cultures. It was also expected that Asian participants would least prefer high *sequence* stimuli as it was assumed that in some Asian cultures (for example Taiwanese) the writing direction system is not from left to right but from top to bottom [62]. As for the Western participants it was expected that they would prefer high *sequence* instead of medium *cohesion* or the other metrics. This expectation was based on the assumption that westerners are more comfortable with their common direction of writing (upper left→upper right→lower left→lower right).

A possible explanation for the strong preference of medium *symmetry* among the Asian participants can be found in section 0. The reason behind the strong preference for medium *cohesion* among the Western participants is hard to explain. The strong preference could be because of medium *cohesion* layout is restful to the eyes due to the consistency of the aspect ratio within the visual field which prevents frequent changes in eye movement patterns.

A comparison of Asian and Western participants in this experiment indicates that variations in preference due to cultural background were relatively modest. Asian participants as a group were more consistent with each other, with a higher co-efficient of agreement than the Western participants, although this could be partially confounded by the smaller sample size. Whilst both groups demonstrated the lack of preference for HAL, only the Asian participants showed any significant preferences for other layouts, with medium *symmetry* being ranked as the highest. As *sequence* layouts were not the least preferred among the Asian participants, it is possible that the common western direction of writing is now widely acceptable across cultures.

5.6 Conclusion

This chapter reported an experiment investigating the relationship between layout aesthetics and preference. The preference task was conducted using pairwise comparisons where the participants chose one stimulus from each of 105 pairs of stimuli. Preference data which contained a very large number of circular triads were discarded from the analysis.

The results from this experiment are relevant to Research Question 2 in this thesis and could be used to answer the question raised in Chapter 4.

1. What is the relationship between the aesthetics of interface design and user preference?

   This chapter has found that in leisure-based interfaces there was very little agreement in preferences. However, preference was highest with medium levels of aesthetics and lowest with medium *symmetry*. The strong preference for medium level of aesthetics appears to contradict the finding in Chapter 4 which demonstrated stronger preference with increasing aesthetics levels. The main reason for this discrepancy could be that leisure interface users are not looking for better performance but they are interested in higher arousal.

   Based on the result of this experiment, it shows that the preference differences between Asians and Westerners are relatively modest. Asians preferred medium *symmetry* and Westerners preferred medium *cohesion* the most. Both Asians and Westerners showed least preference for high aesthetics layout. As the preference difference between the six layout metrics and between Asians and Westerners are relatively modest, focus should be more on composite metrics and not on specific layout metrics or on culture.

The novel aspect of this study was that it showed that high aesthetics layouts are strongly preferred in goal-oriented interfaces but not in leisure-oriented interfaces.

The next step of this research is to investigate the effect of layout aesthetics on visual effort. The better performance with high aesthetics layouts as found in Chapter 4 was most likely attributable to their low complexity, which led to low cognitive demand. The validity of this claim is discussed in the next chapter, Chapter 6, using more concrete evidence using data from eye tracking experiment.

Chapter 6

Layout Aesthetics and Visual Effort

As discussed in Chapter 4, performance and preference, at least in goal-mode, increases with increasing aesthetics level. Based on the analysis of the visual structure of high aesthetics layouts it was then speculated that the good performance obtained with these layouts was influenced by the lower complexity of the interface, which minimized the cognitive effort and thus allowed users to perform better. This speculation implies that high aesthetics layouts demand less visual effort (are "easy on the eye") when navigating the interface. Although this speculation is quite reasonable, it was not supported by concrete evidence which shows that high aesthetics levels really are "easy on the eye".

Therefore, this chapter discusses an experiment using eye tracking. Eye tracking is an excellent method to find the extent of visual effort demanded as it provides information on the efficiency of information searching and information processing. This experiment focuses on investigating the eye movement behaviour for each of the three levels of aesthetics (high, medium, low) and the six layout metrics (*cohesion, economy, regularity*, *sequence*, *symmetry*, *unity*).

Section 6.1 discusses the theoretical background of eye tracking in HCI, Section 6.2 discusses the eye tracking metrics used in the experiment, Section 6.3 highlights the aim of this chapter, Section 6.5 covers the details of the experiment conducted to investigate eye movement behaviour for each of the three levels of aesthetics and the six layout metrics, and section 6.6 reveals the results of the experiment.

This chapter addresses the research questions posed in Chapter 4.

1. What is the relationship between aesthetic layout and visual effort?

This research question 1 is addressed through a discussion in Section 6.7. Section 6.8 concludes this chapter, drawing general conclusions from this work, and discussing how the findings of this experiment answer the research questions posed in Chapter 4.

6.1 Introduction

Eye-tracking is a technique whereby eye movements are recorded whilst the user is looking at a stimulus [40]. The use of eye tracking in HCI is not new. It has been widely used to enhance the conventional evaluation of usability (e.g. questionnaires, thinking aloud, heuristic evaluation) and for capturing people's eye movements as an input mechanism to drive system interaction [109]. An advantage of the eye tracking method over conventional methods of usability evaluation highlighted by Schiessl et al. lies in its ability to provide a proper assessment by minimizing the biases that affect self-report measures (e.g. social expectations, political correctness or simply the desire to give a good impression) and, more importantly, it provides concrete data that represent the cognitive states of individuals.

There are large numbers of eye tracking metrics. These metrics represent the visual effort (the amount of attention devoted to a particular area of the screen [14]) required by the interface in terms of information searching and information processing [49]. Goldberg and Kotval [49] have identified a number of eye tracking measures for assessing usability. They proposed seven metrics to assess information searching (scan path length and duration, convex hull area, spatial density, transition matrix, number of saccades, and saccadic amplitude) and five metrics to assess information processing (the number of fixations, fixation durations/gaze times, scan path lengths, and scan path durations). The work by Goldberg and Kotval can be considered as the most influential as it has been cited by many studies investigating usability of interfaces (see e.g. [106]).

One of the studies that investigated the usability of interfaces using eye tracking methods is Parush et al. [106]. Parush et al conducted a study investigating how the quantity of links, alignment, grouping indications, and density of webpages affect eye movements. They found that eye movement performance was at its best with fewer links and uniform density, and at its worst with good alignment. A website with fewer links and uniform density resulted in either no improvement or even a degrading effect whereas an interface with both few links and good alignment decreased search durations.

In another study by Simonin et al. [128], the effect of four different layouts (matrix, elliptic, radial, and random) on visual search efficiency and comfort was investigated. Each layout was formed from 30 realistic colour photographs. Participants were asked to find a pre-viewed photo on each layout as fast as possible. Data from eye tracking revealed that elliptic layout (two concentric ellipses) provided better visual comfort (i.e. shorter scan path length) than other types of layout and was more efficient (i.e. shorter search times) than the matrix layout (2D array). This study, however, was limited to a very small sample size (5 participants).

In a slightly different study, Michailidou et al. [86] investigated users' browsing behaviour on web pages, and their results provide useful information on which page areas users glance at first, for how long and in which order. Although their study required participants to state their liking of the websites, they did not report whether there was a difference in terms of visual effort between most preferred websites and least preferred websites.

While the use of eye tracking in the evaluation of computer interfaces in HCI is not new, as discussed above, the use of eye tracking particularly in the evaluation of visual aesthetics has been limited or perhaps has not been addressed at all. Data from eye tracking experiments is important to understand how an aesthetic interface and a non-aesthetic interface differ in terms of the amount of visual effort they require. Such understanding is important because it provides explanations as to why users perform better with an aesthetic interface but not with a less aesthetic interface as demonstrated in Chapter 4 and by other similar studies [90,129]. Such understanding can also help to explain users' perception and preference of aesthetics (see Chapter 5, [122,103]).

6.2 Eye Tracking

Although there are many metrics available in the literature on eye tracking, this experiment focused on the four most popular metrics: scan path length, scan path duration, the number of eye fixations, and fixation duration/gaze time (see for example [49,106]) (Figure 38).

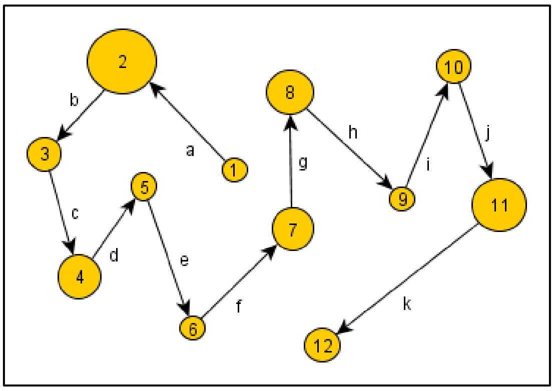


Figure 38. Example computations for scan path duration, scan path length, number of fixation, and fixation duration

6.2.1 Measures of search

- Scan path length indicates how productive or efficient the scanning process is. A lengthy scan path indicates less efficient scanning behaviour and short scan paths indicate more efficient scanning behaviour. The scan path length is measured in screen pixels. In Figure 38 the scan path length is:

  Scan path length = a + b + c + d + e + f + g + h + i + j + k

- Scan path duration is the length of time taken for the whole scan path; it indicates the processing complexity. Longer scan path duration indicates that the participant has performed extensive searching of the screen. In Figure 38 the scan path duration is:

  Scan path duration = 12 x 16.67 millisecond = 200 millisecond

6.2.2 Measures of processing

- Eye fixation refers to spatially stable gazes lasting for approximately 200-300 milliseconds, during which visual attention is directed to a specific area of the visual display [86]. A large number of fixations indicates a large degree of difficulty in extracting information. In Figure 38 the number of fixation is 12.

- Fixation duration/Gaze time is the sum of all fixation durations. A long gaze time implies that the participant has spent a long time interpreting the information. In

Figure 38 the fixation durations are indicated by the size of the circle: large circles mean longer fixation duration whereas smaller circles mean shorter duration.

6.3 Aims

The aim of this experiment was to investigate the relationship between layout aesthetics and visual effort.

6.4 Experimental design

6.4.1 Interface components

The interface components were similar to those used in Chapter 4 where it used inverted and upright triangles to form the layout (see Figure 20).

6.4.2 Measuring aesthetics

The aesthetics of the interface was measured using the following method in Chapter 5 (see Table 7, Category 1 - 9).

6.4.3 The Java program

The program that created the stimuli

The program that created the interfaces was similar to the program that created the stimuli in Chapter 4 (Figure 21). The information on the stimuli sets (i.e. screen image library used, actual value of aesthetic parameters, Java pseudocode) can be found in Appendix 1 and Appendix 2.

The program that presented the stimuli

The stimuli were presented using a MATLAB program on a Computer desktop (19" monitor with screen resolution of 800 x 600 pixels) which accompanied with a desk-mounted Eyelink 2K tracking system. The distance between participants and the Desktop is approximately 70 cm.

6.5 Methodology

6.5.1 Tasks

The task in this experiment was similar to Chapter 4 where the participants were asked to find and report the number of upright triangles in pictures of mixed upright and inverted triangles.

6.5.2 Variables

- Dependent variables – scan path length, and scan path duration, the number of fixations, fixation duration/gaze time,
- Independent variables – Aesthetics levels (high, medium, low), layout metrics (cohesion, economy, regularity, sequence, symmetry, unity).

6.5.3 Participants

Participants were 21 undergraduate and postgraduate students enrolled in various courses at the University of Glasgow (16 Western, 3 Asian, 4 others) who received course credit for their participation, or who volunteered to participate. All the participants were computer literate and used computers daily.

6.5.4 Stimuli

The design of the stimuli was similar to the design of stimuli in Chapter 4 (Figure 20) where it contained inverted and upright triangles. The number of triangles in each stimulus was fixed at 10. There were 90 stimuli created for this experiment: 10 stimuli for each of the Category of Table 11.

CATEGORY	**LAYOUT METRICS**					
	Cohesion	**Economy**	**Regularity**	**Sequence**	**Symmetry**	**Unity**
1. HAL	High	High	High	High	High	High
2. MAL	Medium	Medium	Medium	Medium	Medium	Medium
3. LAL	Low	Low	Low	Low	Low	Low
4. High cohesion	**High**	Low	Low	Low	Low	Low
5. High economy	Low	**High**	Low	Low	Low	Low
6. High regularity	Low	Low	**High**	Low	Low	Low
7. High sequence	Low	Low	Low	**High**	Low	Low
8. High symmetry	Low	Low	Low	Low	**High**	Low
9. High unity	Low	Low	Low	Low	Low	**High**
$0.7 \leq$ High ≤ 1.0, $0.5 \leq$ Medium < 0.7, $0.0 \leq$ Low < 0.5						

Table 11. The aesthetic properties of the 90 stimuli

6.5.5 Procedure

At the beginning of the experiment session, the participants received written instructions, signed a consent form and filled in a demographic questionnaire.

After the participants signed the consent form and filled in the demographic questionnaire the participants were briefed about the experimental task. The participants were informed that they would be presented with a series of pictures of triangles and for each picture the movements of their eyes would be recorded. The participants were instructed to count the total number of upright triangles carefully and as fast as possible, and press only the designated key (0) on the keyboard with the index finger of their right hand side as soon as they knew the total number of upright triangles on the screen, and to say their answer loudly. The designated key (0) stopped the response time measurement for that particular stimulus.

After the briefing session, the participants were brought into the experimental room and seated in front of a desktop display which presented the stimuli. During this task, the eye movements of the participants were recorded using a desk-mounted Eyelink 2K tracking system.

In another room, which was just beside the experimental room, the experimenter manually recorded the participant's verbal answers on an Excel spread sheet, and pressed a control key to change the display on the participant's screen to a new stimulus. This process continued until all 90 stimuli were presented to the participants.

Before the experiment started, standard procedures for eye-tracking experiments were performed, namely, calibrating the computer screen using test trials. Each test trial started with the presentation of a central fixation cross. Then four crosses were presented, one in the middle of each of the four quadrants of the computer screen. These crosses allowed the experimenter to check that the calibration was still accurate. In that way, calibration was validated between each test trial. Following this check, a final central fixation cross that served to monitor drift correction (an adjustment of the calibration [148]) was displayed. Finally, a stimulus was then presented on the computer screen.

6.6 Results

Figure 39 shows an example output of participant X's from the eye tracking measurement system. Four types of data were extracted from this output: scan path length, scan path duration, the number of fixations, and fixation duration/gaze time (see 6.2 for details of these metrics). These data were analysed using ANOVA - General Linear Model with repeated measure analysis followed by pairwise t-tests corrected for multiple comparisons ($p<0.025$).

The data were analysed based on the three levels of aesthetics (high, medium, low) and the six layout metrics (*cohesion*, *economy*, *regularity*, *sequence*, *symmetry*, *unity*)

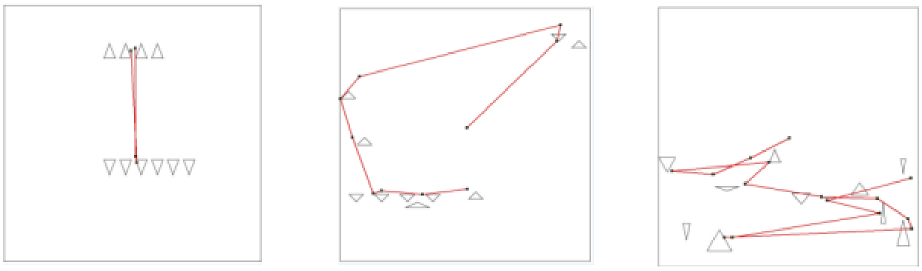
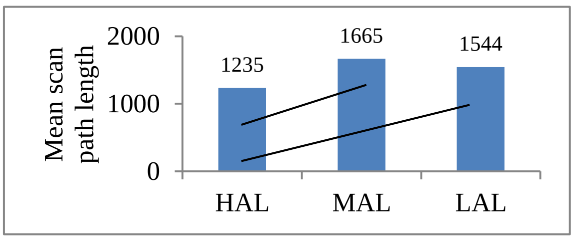


Figure 39. Participant X's scan path for high, medium, and low aesthetic interfaces

6.6.1 HAL, MAL, LAL

Scan path length

There was a significant effect of aesthetics level on scan path length ($F_{1,\,20} = 15.469$, $p<.001$, Table 4). HAL produced the shortest length (mean = 1234.84 pixel, SD = 216.70) and interfaces with MAL produced the longest scan path length (mean = 1665.02 pixel, SD = 407.96). Table 15 shows pairs which were significantly different at $p<.025$.



*lines indicate where pair-wise significance is found

Figure 40. The mean scan path length of HAL, MAL, and LAL

	MAL	LAL
HAL	.000*	.001*
MAL	-	.059

Table 12. The pairs of HAL, MAL, and LAL for scan path length

Scan path duration

There was a significant effect of aesthetics level on scan path durations ($F_{2,40} = 69.193$, $p<.001$, Figure 41). HAL produced the shortest scan path durations (mean = 2.91s, SD = 0.69) and LAL produced the longest scan path durations (mean = 4.40s, SD = 1.05). Table 13 shows pairs which were significantly different at $p<.025$.

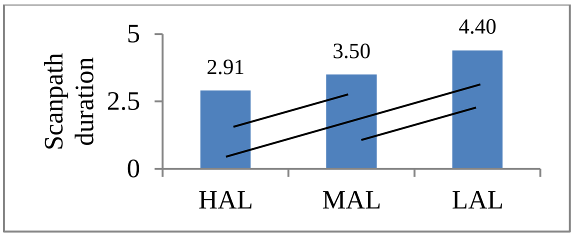


Figure 41. The mean scan path duration of HAL, MAL, and LAL

	MAL	LAL
HAL	.000*	.000*
MAL		.000*

Table 13. The pairs of HAL, MAL, and LAL for scan path duration

The number of fixations

There was a significant effect of aesthetics level on the overall number of fixations ($F_{2,40} = 49.228$, $p<.001$, Figure 42). HAL produced the least number of fixations (mean = 10.36, SD = 1.80) and LAL produced the highest number of fixations (mean = 14.86, SD = 3.36). The pairwise comparisons showed that all possible pairs were significantly different at $p<.025$ (Table 14).

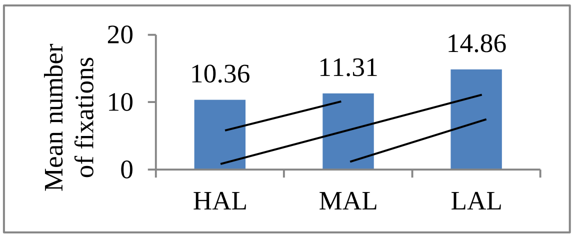


Figure 42. The mean number of fixations of HAL, MAL, and LAL

	MAL	LAL
HAL	.019*	.001*
MAL	-	.001*

Table 14. The pairs of the HAL, MAL, and LAL for the number of fixations

Fixation duration/Gaze time

There was a significant effect of aesthetics level on gaze times (the sum of fixation duration) ($F_{2,40}$ =50.963, p<.001, Figure 43). HAL produced the shortest gaze times (mean = 2.28s, SD = 0.40s) and LAL produced the longest gaze times (mean = 3.27s, SD = 0.65s). Table 15 shows pairs which were significantly different at p<.025.

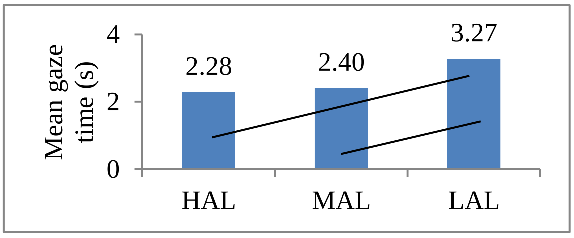


Figure 43. The mean fixation duration/gaze times of HAL, MAL, and LAL

	MAL	LAL
HAL	.211	.001*
MAL	-	.001*

Table 15. The pairs of HAL, MAL, and LAL for fixation duration/gaze time

6.6.2 Cohesion, Economy, Regularity, Sequence, Symmetry, and Unity

Scan path length

There were significant differences in scan path length between the six aesthetic measures ($F_{5,100}$ = 24.538, *p*<.001, Figure 44). Interfaces with high *cohesion* produced the longest scan paths (mean = 1796.98 pixel, SD = 372.36) and interfaces with high *unity* produced the shortest scan path (mean = 1168.36 pixel, SD = 135.98). Table 16 show pairs which were significantly different at *p*<.025.

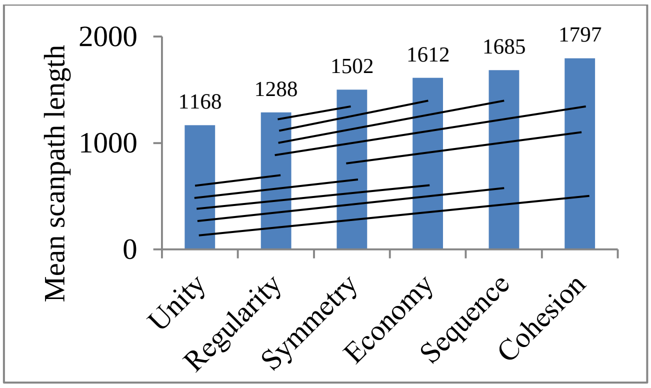


Figure 44. The mean scan path length of the six layout metrics

	Cohesion	Economy	Regularity	Sequence	Symmetry	Unity
Cohesion	-	.013	.001*	.089	.000*	.000*
Economy		-	.001*	.391	.391	.000*
Regularity			-	.000*	.000*	.009*
Sequence				-	.045	.000*
Symmetry					-	.001*

Table 16. The pairs of the six layout metrics for scan path length

Scan path durations

There was a significant difference between the scan path durations produced between the six aesthetic measures ($F_{3.481,69.620}$ = 24.878, p<.001,Figure 45). Interfaces with high *regularity* produced the shortest scan path durations (mean = 3.58s, SD = 0.76) and high *cohesion* produced the longest scan durations (mean = 4.28, SD = 0.89). Table 17 shows pairs which were significantly different at p<.025.

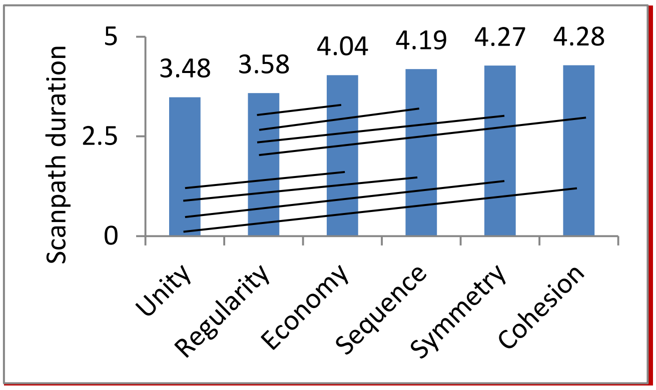


Figure 45. The mean scan path duration of the six layout metrics

	Cohesion	Economy	Regularity	Sequence	Symmetry	Unity
Cohesion	-	.054	.000*	.04	.873	.000*
Economy		-	.002*	.175	.015	.000*
Regularity			-	.000*	.000*	.165

	Cohesion	Economy	Regularity	Sequence	Symmetry	Unity
Sequence				-	.353	.000*
Symmetry					-	.000*

Table 17. The pairs of the six layout metrics for scan path durations

The number of fixations

There was a significant effect on the overall number of fixations produced by the six layout metrics ($F_{5,\ 100}$ = 4.748, p<.05, Figure 46). Interfaces with high *regularity* produced the least number of fixations (mean = 11.67, SD = 2.74) and interfaces with high *sequence* produced the largest number of fixations (mean = 13.40, SD = 3.52). The pairwise comparisons showed that 7 pairs were significantly different at p<.025 (Table 18).

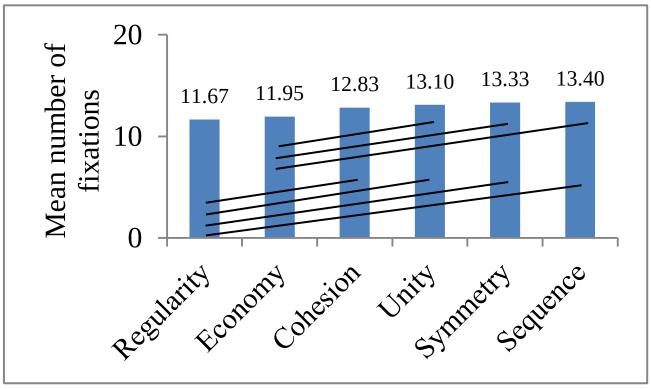


Figure 46. The mean number of fixations of the six layout metrics

	Cohesion	Economy	Regularity	Sequence	Symmetry	Unity
Cohesion	-	.034	.016*	.279	.279	.564
Economy		-	.318	.021*	.006*	.008*
Regularity			-	.011*	.000*	.002*
Sequence				-	.904	.618
Symmetry					-	.586

Table 18. The pairs of the six layout metrics for the number of fixation

Fixation duration/Gaze times

There was a significant difference in gaze times (the sum of fixation duration) between the six aesthetic measures ($F_{5,\ 100}$ =2.710, p<.05, Figure 47). Interfaces with high *economy* produced the shortest gaze times (mean = 2.59s, SD = 0.59) and interfaces with high *symmetry* produced the longest gaze times (mean = 2.91s, SD = 0.62). Table 19 shows pairs which were significantly different at p<.025.

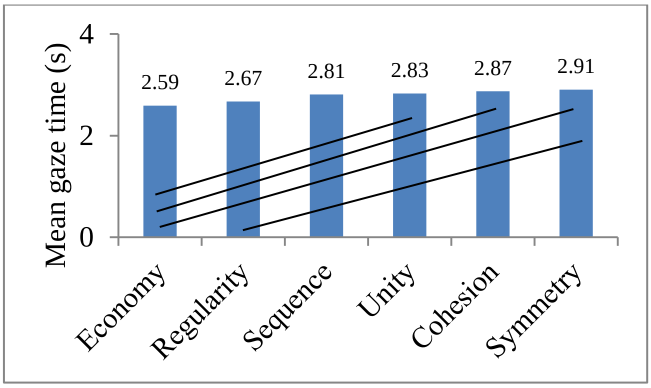


Figure 47. The mean of fixation duration/gaze time of the six layout metrics

	Cohesion	Economy	Regularity	Sequence	Symmetry	Unity
Cohesion	-	.006*	.04	.621	.682	.726
Economy		-	.251	.092	.001*	.009*
Regularity			-	.337	.005*	.079
Sequence				-	.507	.882
Symmetry					-	.454

Table 19. The pairs of the six layout metrics for the fixation duration/gaze time

6.6.3 Summary of results

HAL, MAL, and LAL

Table 20 shows the summary of results for the four metrics of visual effort for the three levels of aesthetics. Observe that the range of the following measures is between 1 (best) and 3 (worst).

Aesthetics level	Visual effort			
	Search efficiency		Processing efficiency	
	Scan path length	Scan path duration	The number of fixation	Fixation duration/gaze time
HAL	1	1	1	1
MAL	2	2	2	2
LAL	3	3	3	3

1-best 3-worst

Table 20. Summary of result of HAL, MAL, and LAL

Cohesion, economy, regularity, sequence, symmetry, unity

Table 21 shows a summary of the results obtained using the four metrics of visual effort for each of the six layout metrics. Observe that the range of the following measures is between 1 (best) and 6 (worst).

Layout metrics	Visual effort			
	Search efficiency		Processing efficiency	
	Scan path length	Scan path duration	The number of fixation	Fixation duration/gaze time
Cohesion	6	6	3	5
Economy	4	3	2	1
Regularity	2	2	1	2
Sequence	5	4	6	3
Symmetry	3	5	5	6
Unity	1	1	4	4

1-best 6-worst

Table 21. Summary of result of the six layout metrics

6.7 Analysis and discussion

6.7.1 HAL, MAL, LAL

Compared to interfaces with lower levels of aesthetics, interfaces with higher levels of aesthetics produced a smaller number of fixations, shorter gaze times, shorter scan path lengths and shorter scan path durations (Table 20). These results mean that visually searching an interface with a higher level of aesthetics requires less visual effort (and thus is more efficient) than visually searching an interface with lower levels of aesthetics.

This finding is important as it shows how to manipulate the aesthetics level of an interface to make it “easy on the eye”. This information can then be used as guidance for interface designers. This finding can also be used to help explain the findings in Chapter 4 which demonstrated better task performance at high aesthetics levels compared to low aesthetics levels, and provides justification for the incorporation of ideas about layout aesthetics in interface design.

The results of this experiment corroborate the finding of Goldberg and Kotval [49] who investigated interface quality by analysing eye-movement behaviour and found that visual search with a “good” layout is more efficient than an interface with “poor” layout. This study, however, was different from Goldberg and Kotval’s study in terms of how “good” and “poor” layouts were measured.

Why do high aesthetics interfaces require less visual effort than low aesthetics interfaces? In Chapter 4 it was revealed that the main difference between high and low aesthetics interfaces was their visual structure. High aesthetics interfaces have been described by participants as having a clear visual structure whereas low aesthetics interfaces have been described as having an unclear visual structure. But how is visual effort influenced by visual structure?

An interface with a clear visual structure contains screen elements which are arranged in an orderly manner. As the elements on screen are arranged in orderly manner, users can clearly see the location of each target on the screen. This leads to efficient information searching as it allows users to choose the shortest scan path length which in turn reduces scanning duration. It also leads to efficient information processing as it reduces the number of components to be processed by directing users to the appropriate location on the screen, thereby easily spotting the targets and keeping “wandering eyes” to a minimum.

Visual effort vs. actual performance

In Chapter 4 it was found that performance and preference increased with increasing aesthetics level. Based on the analysis of the layout structure of high aesthetics interfaces, it was speculated that the main reason for the good performance and high preference for high aesthetics interfaces compared to low aesthetics interfaces was the lower complexity which led to lower cognitive effort. Although this speculation seemed to be highly reasonable, concrete evidence to support this speculation was not provided in Chapter 4.

The finding of this experiment provides concrete evidence using data from the eye tracking to support the speculation made in Chapter 4. Tasks requiring less visual effort are likely judged as easier [43]. Thus, with the combinations of less demanding visual effort and positive perception of ease of use, users are more likely to perform efficiently and effectively.

While low levels of visual effort and perceived ease of use seem to relate to the good performance with high aesthetics interfaces, this does not necessarily result in the user preferring the appearance of the interface. This was revealed in Chapter 5, that investigated the relationship between layout aesthetics and preference where it was found that participants preferred a medium aesthetics layout rather than a high or low aesthetics layout. This showed that while performance was influenced by the effort required to perform the task, preferences were not necessarily related to visual effort measures.

6.7.2 Cohesion, economy, regularity, sequence, symmetry, unity

In order to find which of the six layout metrics required the least and the highest amount of visual effort, it is important to look at the efficiency of information searching and information processing with the six layout metrics.

- Search efficiency

  Unity produced significantly shorter scan path lengths compared to the other metrics (Figure 44, Table 16). It also produced significantly shortest scan path durations compared to all other metrics except *regularity* (Figure 45, Table 17). Thus, it could be suggested that *regularity* is the most suitable metric to support search efficiency.

  While *unity* can be easily identified as the most efficient metric for information searching, it is difficult to determine which of the remaining five layout metrics is the most inefficient. This is because, although *cohesion* produced the longest scan path length and longest scan path duration (Figure 44, Table 16), it was not significantly different from the other metrics such as *symmetry, sequence, and economy* (Figure 45, Table 17). Thus, it could be suggested that *cohesion*, *symmetry, sequence*, and *economy* should be avoided as they require the most visual effort for information search.

- Processing efficiency

  Regularity produced significantly lower numbers of fixations compared to all other metrics except *economy* (Figure 46, Table 18). In terms of fixation duration/gaze time, *economy* produced significantly shorter fixation duration/gaze times than all the metrics except for *regularity* and *sequence* (Figure 47, Table 19). Thus, it could be suggested that *regularity* and *economy* are the most efficient for information processing.

  Sequence produced the largest number of fixations but it was only significantly different from *regularity* and *economy*, but not other metrics (Figure 46, Table 18). In term of fixation duration/gaze time, *symmetry* produced the longest fixation duration/gaze time however, as with *sequence* it was significantly different only from *regularity* and *economy* (Figure 47, Table 19). Thus, it could be suggested that, except for *regularity* and *economy*, other metrics should be avoided as these metrics requires higher visual effort for information processing.

Based on the results of the search efficiency and processing efficiency of the six layout metrics (see Table 21), *regularity* seems to be the least demanding for visual effort, and *cohesion* and *sequence* are the most demanding for visual effort. *Regularity* can be considered as the least demanding metric for visual effort as it appeared to be highly efficient for both information searching and information processing. *Cohesion* and *sequence* are the most demanding metric for visual effort as these two metrics were not significantly different from one another and both were the least efficient for information searching and information processing. These findings are very important for a deeper understanding of the layout metrics, and to guide interface designers to choose the most beneficial layout metrics for users.

This finding was unexpected. It was expected that *symmetry* would require the least demanding visual effort over the other metrics. This expectation was made based on findings in the literature which claimed that symmetrical patterns contain less information and thus are much easier to process (Garner, 1974, as cited by [112]). A possible explanation for this difference might be that, what is considered as *symmetry* in this experiment was not consistent with the understanding of *symmetry* by the participants. Most people are used to reflection symmetry. In this experiment however, *symmetry* was measured with respect to three axes: vertical, horizontal, and diagonal. As a result, the layout of objects might not look like reflection symmetry as expected by the participants. As a result of not being reflection symmetry, the participants might have perceived the symmetry in this experiment to contain more information rather than less information thus requiring more visual effort.

The result of this experiment which showed *regularity* as the least demanding metric for visual effort, and *cohesion* and *economy* as the most demanding metrics for visual effort indicate that,

- An interface with high *regularity* (i.e. alignment points of elements on screen are kept to a minimum and are consistently spaced both horizontally and vertically) is “easy on the eyes”. One of the likely reasons why *regularity* is “easy on the eyes” is that it provides users with a relatively predictable event sequence thus users can easily prepare their next action.

- An interface with high *economy* (i.e. the variety of size of the elements on screen are kept to minimum) and *cohesion* (i.e. the aspect ratio of the elements on screen, the layout, and the frame size, are similar) is more difficult for the eyes. Despite being highly *economic* or *cohesive*, there was a possibility that the interface looked cluttered due to the lack of predictable patterns as these metrics do not control the locations of the elements on screen but the sizes and aspect ratios.

Thus, based on the results of this experiment it can be suggested that to create an interface that requires less visual effort or is "easy on the eyes", the alignment points of elements on screen must be kept to a minimum and consistently spaced both horizontally and vertically.

6.7.3 Limitations

Due to a technical problem with the program that ran the experiment, the stimuli were not fully randomized and unfortunately this problem was not detected until data collection was completed. 90 stimuli were used in this experiment, which means there were a total of 90 factorial possible sequences of the stimuli. In this experiment however, only two sequences were used for all participants. This means that many of the participants viewed the same sequence of stimuli. Ideally, each participant should view a different sequence of stimuli so as to counter sequential effects.

Although the randomization of stimuli in this experiment might not be adequate to counter the sequence effects, it is argued that the results were not significantly affected as sequence effects tend to be associated with users' performances (i.e. response time and errors), whereas in this experiment the focus was on investigating eye movement behaviours. The number of fixations, for example, depends on the complexity of the interface and is not influenced by previous exposure to the task [82].

Although in this experiment participants were asked to count the number of triangles carefully and as fast as possible, their performance in terms of response time and errors were not analysed as this experiment focused on the eye movement behaviour and not on the performance as such.

6.8 Conclusions

This chapter has described an experiment investigating the relationship between layout aesthetics and visual effort. The results from this experiment can be used to answer the research question posed earlier in this chapter.

1. What is the relationship between layout aesthetics and visual effort?

   In Chapter 4 the effect of layout aesthetics on performance and preference was investigated, and it was found that performance and preference increased with increasing aesthetics level. The research in this chapter investigated the reason behind the good performance and high preference for high aesthetics interfaces as compared to low aesthetics interfaces. The results suggest that the good performance and strong preference for high aesthetics interfaces is a result of the lower level of visual effort required to extract the information contained in the interface.

   In relation to Research Question 1, this experiment found that visual effort decreased with increasing aesthetics level. This was shown by the high efficiency of information searching (i.e. short scan path lengths and durations) and information processing (i.e. fewer fixations, shorter fixation/gaze time durations) with high aesthetics interfaces as compared to low aesthetics interfaces. Investigation of the six layout metrics revealed that, overall, the layout metric *regularity* required the least visual effort. The most demanding layout metrics for visual effort were *cohesion* and *sequence*.

   The experiment described here is the first study using an eye tracking method to investigate visual effort in interfaces where aesthetics was measured objectively in HCI. This experiment showed that high aesthetics interfaces require less visual effort than low aesthetics interfaces. This finding provides support for the findings of previous studies in the literature which have claimed that an aesthetic interface is perceived as easy to use and usable compared to low aesthetics interfaces, and is a good explanation for the good performance with high aesthetics interfaces found in Chapter 4.

The result of this research highlights the need to implement the principles of layout aesthetics in interface design. One concern with implementing aesthetic principles in interface design is that it might increase the complexity of the interface which then increases cognitive workload and results in deteriorating performance. However, the results of this experiment showed that high aesthetics layouts do not cause this. In fact, high aesthetics layouts decrease visual effort and as a result minimize cognitive workload.

These days with the advancement of technology, there is a demand for interfaces which are not only efficient to use but also aesthetically pleasing. This research has shown that this can be achieved by aesthetically designing the layout of the interface.

The next step of this research is to investigate the generality of the findings in Chapter 4 using more “ecologically valid” stimuli. In Chapter 4 the stimuli look rather “abstract and less informative”. Due to the design of the stimuli, however, it raises a question about its results’ generality to other types of interfaces. This is investigated in the next chapter, Chapter 7.

Chapter 7

Layout Aesthetics vs. Performance and preference II

In Chapter 4 the relationship between layout aesthetics, performance, and preference was discussed. The outcomes of this research indicated that performance and preference increased with increasing aesthetics level, and that performance and preference were highly correlated. These outcomes, however, were primarily found with “abstract” stimuli. Therefore, the next step of this research focuses on investigating the generality of these outcomes with more “ecologically valid” stimuli. The theoretical background outlined previously (see Chapters 2 – 4) is also applicable to this experiment.

The research questions of this thesis which have been addressed in Chapter 4 are readdressed in this chapter.

1. What is the relationship between the aesthetics of interface design and task performance?
2. What is the relationship between the aesthetics of interface design and preference?
3. What is the relationship between the aesthetics of interface design and search tool?
4. Is there any relationship between user preference and task performance?

7.1 Aims

In light of the questions mentioned above, the following aims are addressed:

1. to investigate the relationship between layout aesthetics and performance
2. to investigate the relationship between layout aesthetics and preference
3. to investigate the relationship between layout aesthetics and search tool
4. to investigate the relationship between preference and performance

7.2 Experimental design

This section outlines the experimental design. Section 7.2.1 discusses the component of the interface. Section 7.2.2 explains how the aesthetics of the interface was measured. Section7.2.3 discusses the programs that were used to create and present the stimuli used in this experiment.

7.2.1 Interface components

The interface consisted of images of animals and non-animals (Figure 48). These images were used to form the layout of the interface. These small images were obtained using Google™ search image. As all images were collected from publically-accessible webpages, their use does not violate copyright law, as non-commercial research and teaching use come under the category of "fair dealing".

The images were displayed at different scales (image dimension 50-100 width, 50-100 height) and positions on the screen to fit the specified aesthetics value.

Figure 48. An example of a stimulus with an aesthetics value of 0.8190

The task targets were pictures of an animal (Figure 49). There were 3 – 6 targets and the remaining images (of non-animal objects) were distractors (Figure 50). Animal pictures were chosen as a target because animals are more rapidly recognizable compared to other objects [135]. As the main aim of this experiment was to test task performance with respect to layout, it was important that the participants' time was spent on navigating the layout and not on interpreting the content of the picture. No picture of a human was included in the stimulus to avoid th```e participants mistakenly identifying the image of a human as a target.

Figure 49. Images of animals - the targets

Figure 50. Images of non-animals - the distractors

7.2.2 Measuring aesthetics

The layout aesthetics of the stimuli in this experiment was measured in exactly the same way as in Chapter 5.

7.2.3 The Java program

The program that created the stimuli

The stimuli were created using a custom written Java program (Figure 51). To create a stimulus, the experimenter set the aesthetics level (high, medium, or low) for each of the six layout metrics. The program then picked images from the database and adjusted the sizes and locations of the images (with no overlapping) within the dimension of 600 x 600 pixels, until they met the specified aesthetics level for each of the six layout metrics set by the experimenter. The experimenter had no direct control over the precise positions of the objects in the layout. The information on the stimuli sets (i.e. screen image library used, actual value of aesthetic parameters, Java pseudocode) can be found in Appendix 1 and Appendix 2.

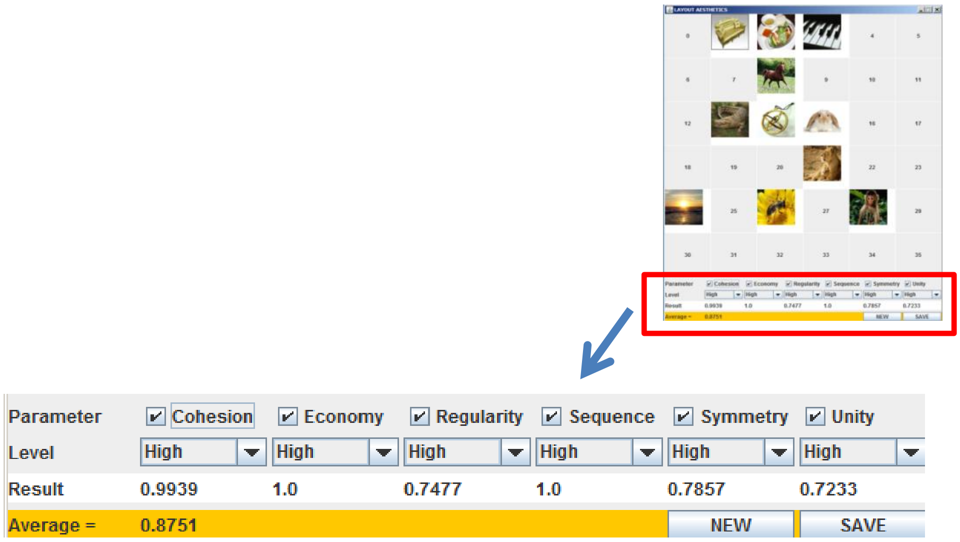


Figure 51. A screen shot of the Java program that created the stimuli

The program that presented the stimuli

Visual search task

The stimuli were presented to the participants using a program (Figure 52) that was different from the program that created the stimuli (see Figure 51). The program displayed the stimuli and recorded the response time and answers from the participants. Unlike Chapter 4 where answer buttons were provided to the participants (see Figure 22) in this experiment there was no answer button provided.

Figure 52. A screen shot of the program in this experiment

Preference task

The stimuli were presented to the participants using a Java program (Figure 53). The program displayed the stimuli one at a time for two seconds each before the participants made their choice. The participants were allowed to back-track the stimuli before they made their final choice. It was a forced-choice task: the participants were required to choose only one stimulus.

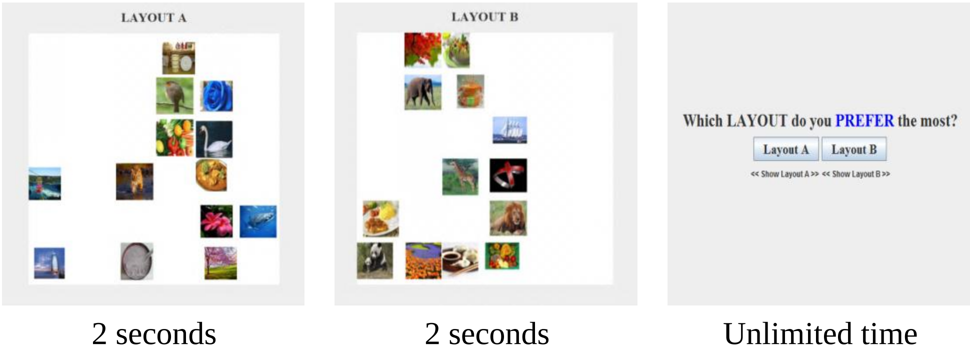


Figure 53. A screen shot of the program for the preference task (Note that each panel of the figure was presented separately in order from left to right)

7.3 Methodology

7.3.1 Tasks

The task in this experiment was similar to Chapter 4 where the participants were required to perform two tasks: a visual search task and preference task. The visual search task was always presented before the preference task.

- Visual search task – The participants were instructed to find and report the number of images that contained animals, and not count the number of animals inside the images.
- Preference task –The participants were asked to choose one stimulus from a pair of stimuli. It was a forced-choice task: the participants were required to choose only one stimulus.

7.3.2 Variables

- Dependent variables - Response time, errors, and preference
- Independent variables - Aesthetics level (high, medium, low), search tool (with mouse pointing, without mouse pointing) and six layout metrics (*cohesion, economy, regularity, sequence, symmetry,* and *unity*).

7.3.3 Participants

Participants were 28 undergraduate and postgraduate students enrolled in various courses at the University of Glasgow (13 Western, 14 Asian, 1 other) who received course credit for their participation or who volunteered to participate. All the participants were computer literate and used computers daily.

7.3.4 Stimuli

Each stimulus contained 10 – 14 small images containing animals and non-animals (Figure 49, Figure 50). There were 3 – 6 images of animals and the rest were images of non-animals. The total number of images including the number of animals and non-animals for each stimulus was randomly determined by the program. Notice that the number of images on the screen was larger than the number of triangles used in Chapter 4. The reason for this was to make the task more challenging.

Visual search task

There were 85 different stimuli used in the search task. 10 stimuli were treated as practice and 75 stimuli were treated as experimental stimuli. The data from the practice stimuli were not included in the analysis. These stimuli were presented to the participants in random order to minimize learning effects.

Table 7 shows the aesthetic properties of the 75 stimuli: 5 stimuli for each category. Some of the stimuli may have the same aesthetic properties but each stimulus was different, as each was created independently.

Unlike in Chapter 4, where 90 stimuli were used in the search task, in this experiment the number of stimuli used was 75. The difference in the number of stimuli was due to the differences in the number of categories and the number of stimuli allocated to each category in each experiment. In Chapter 4, as the main purpose of the experiment was to investigate the effect of the three levels of aesthetics (high, medium, low) on performance without being specific about particular layout metrics, the stimuli were categorized into three categories with 30 stimuli each.

In the current experiment however, the purpose of the experiment was not only to investigate the effects of the three levels of aesthetics but also to investigate the effect of specific layout metrics; thus, the stimuli were categorized into 15 categories with 5 stimuli each and 10 stimuli for the practice task.

Preference task

There were 15 different stimuli used in the preference task. These stimuli were taken from those stimuli used in the visual search task, one stimulus from each of the 15 categories.

7.3.5 Procedure

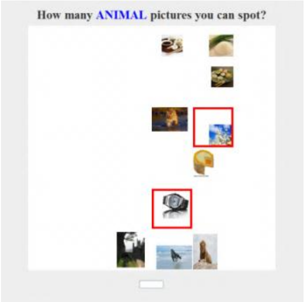
The procedure of this experiment was similar to the procedure in Chapter 4. First, the participants were asked to sign a consent form and filled in a demographics questionnaire. The participants were then briefed about the tasks, performed the visual search task, and finally the preference task.

Visual search task

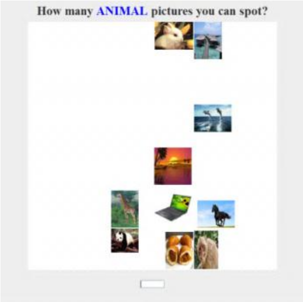
In this task, the participants were asked to count the number of images that contained animals carefully and as fast as possible and to type their answer using the number pad on the keyboard (Figure 52). To minimize learning effects, the program randomized the sequence of the stimuli for every participant.

The mouse cursor was automatically placed inside the answer textbox to prevent any time delay caused by moving the mouse pointer into the textbox. The next stimulus was automatically shown after the participants typed their answer. As there were 85 stimuli used in the search task, the display of the stimulus changed 85 times. A message box was shown after the 85th stimulus to inform the participants that the experiment was complete.

The search task was conducted under two conditions: “with mouse pointing” and “without mouse pointing”. Under the condition of “with mouse pointing” the participants were allowed to use the mouse pointer to assist them in the search task. There was a clicking effect of the mouse where a single click on the image surrounded it with a red border and double clicks made the border disappear (Figure 54a). Under the condition of “without mouse pointing” the participants did not use the mouse (Figure 54b).



(a) With mouse pointing



(b) Without mouse pointing

Figure 54. Examples of stimuli “with mouse pointing “and “without mouse pointing”

All participants were required to complete both conditions. Each condition took approximately 20 minutes to complete. Participants were randomly assigned to perform either condition 1 or condition 2 first. After finishing the first condition (1 or 2), the participants were given an opportunity to take a short break before continuing to perform the next condition (1 or 2, depending on which condition was completed first). Since the same stimuli were used in both conditions, there was a possibility that the participants would remember the answers while performing the task in the second condition. However, this possibility was minimized by the randomization of the sequences of the stimuli in the two conditions.

Preference task

This task was conducted exactly the same way as in Chapter 5 except that the participants were allowed to back track (Figure 53) before they made their final choice. The participants were allowed to back track in this experiment as a result of the experimenter's observation in the previous experiment (reported in Chapter 4), which showed that most of the participants indicated that they would have liked to be able to back track to revalidate their choice of stimulus.

7.4 Results

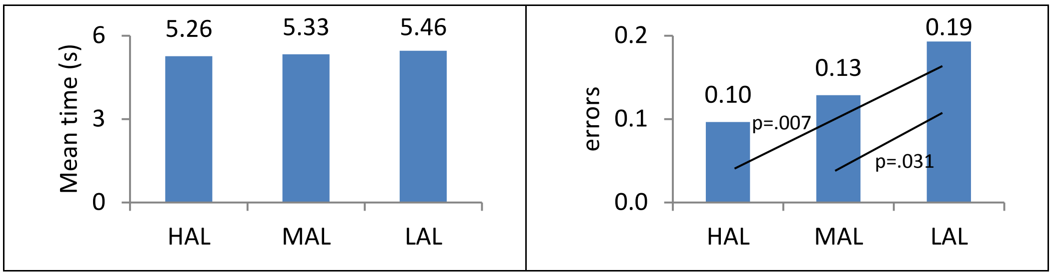
This section presents the results of the experiment in four sections. Section 7.4.1 presents the results of the visual search task in two parts. The first part presents the results relating to overall aesthetics level (high, medium, low) and the second part presents the results relating to the 15 layout metrics. The data from the visual search task were analysed exactly the same way as in Chapter 4. Section 7.4.2 presents the visual search results under two different conditions: "with mouse pointing", "without mouse pointing". Section 7.4.3 presents the preference results for the 15 layout metrics. The preference data were analysed exactly the same way as in Chapter 5. Section 7.4.4 presents the results relating to the interaction between preference and performance.

7.4.1 Layout aesthetics vs. performance

HAL, MAL, and LAL

There was no significant main effect of aesthetics level on response time $F_{2, 54} = 1.184$, $p=.314$ but there was a significant main effect of aesthetics level on errors $F_{2, 54} =$

4.765, p=.012 where higher levels of aesthetics produced fewer errors than lower levels of aesthetics (Figure 55).



*lines indicate where pair-wise significance is found

Figure 55. Mean response time and errors for HAL, MAL, and LAL

15 layout metrics: Response time

There was a significant main effect of aesthetics level on response time $F_{6.782,\ 183.107} = 9.480$, $p<.001$. Figure 56 shows the mean response time for all 15 layout metrics in ascending order. Table 22 shows the pairs of the 15 layout metrics for which the mean difference was significantly different at the .05 level. Other pairs which are not listed or are left blank in Table 22 were not significantly different.

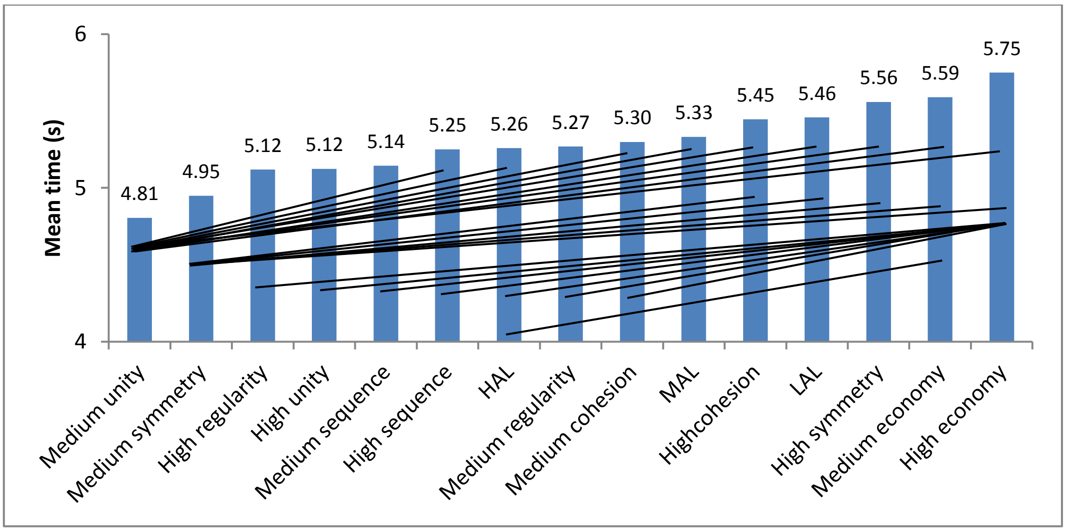


Figure 56. Mean response time for 15 layout metrics

	Medium unity	Medium symmetry	High regularity	High unity	Medium sequence	High sequence	Medium regularity	Medium economy	High economy
High sequence	.004								
HAL	.013							.023	.002

	Medium unity	Medium symmetry	High regularity	High unity	Medium sequence	High sequence	Medium regularity	Medium economy	High economy
Medium cohesion	.006								.001
MAL	.002								
High cohesion	.000	.010							
LAL	.000	.010							
High symmetry	.000	.000							
Medium economy	.000	.004							
High economy	.000	.000	.001	.009	.003	.018	.002		

Table 22. Pairs of the 15 layout metrics for response time

15 layout metrics: Errors

There was a significant main effect of aesthetics level on errors $F_{7.966,\ 215.085} = 4.899$, $p<.001$. Figure 57 shows the mean errors for all 15 layout metrics in ascending order. Table 23 shows the pairs of the 15 layout metrics for which the mean difference was significantly different at the .05 level. Other pairs which are not listed or are left blank at Table 23 were not significantly different.

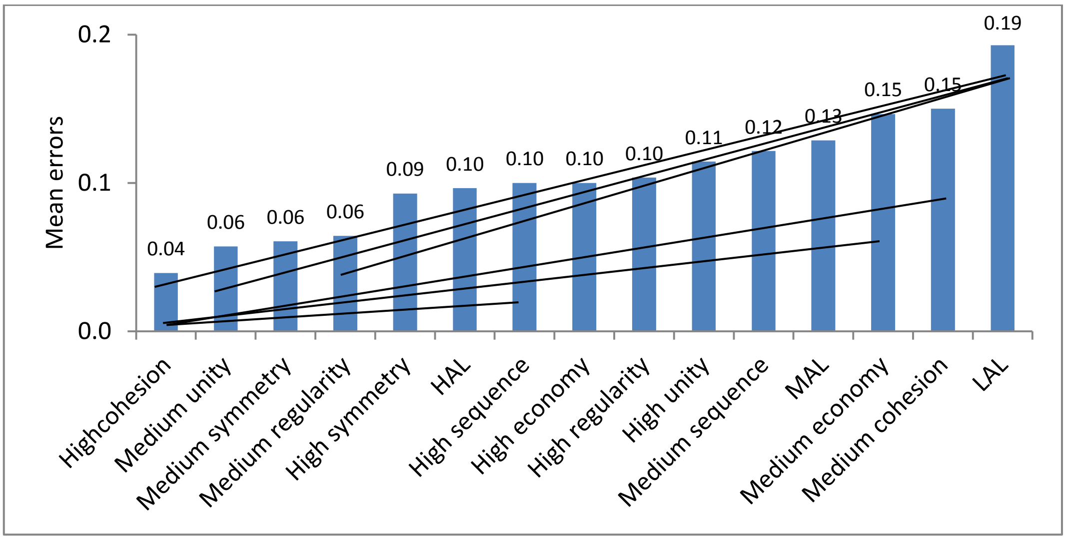


Figure 57. Mean errors for the 15 layout metrics

	High cohesion	Medium unity	Medium symmetry	High sequence	Medium economy	Medium cohesion
LAL	.005	.040	.026			
High cohesion				.037	.023	.034

Table 23. Pairs of the 15 layout metrics for errors

7.4.2 Layout aesthetics vs. search tool

HAL, MAL, and LAL: Response time

There was a significant main effect of search tool ($F_{1, 27}$ = 60.466, p<<.001) but not aesthetics level ($F_{2, 54}$ = 1.184, p=.314) on response time. As shown in Figure 58 "with mouse pointing" takes significantly longer than "without mouse pointing". There was no significant interaction between the effects of search tool and aesthetics level on response time ($F_{2, 54}$ = 2.440, p=.097).

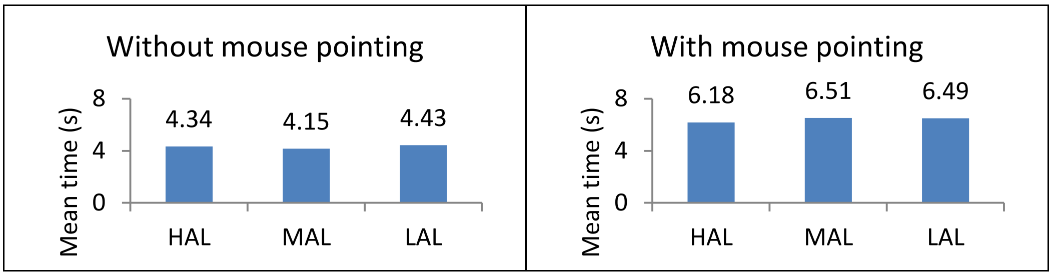


Figure 58. Mean response time for the two search tools

HAL, MAL, and LAL: Errors

There was no significant main effect of search tool ($F_{1, 27}$ = 1.259, p=.272) but there was a significant effect for aesthetics level ($F_{2, 54}$ = 4.765, p=.012) on errors. As shown in Figure 59, fewer errors were made with HAL than LAL. There was no significant interaction between the effects search tool and aesthetics level on errors ($F_{2, 54}$ = 580, p=.563).

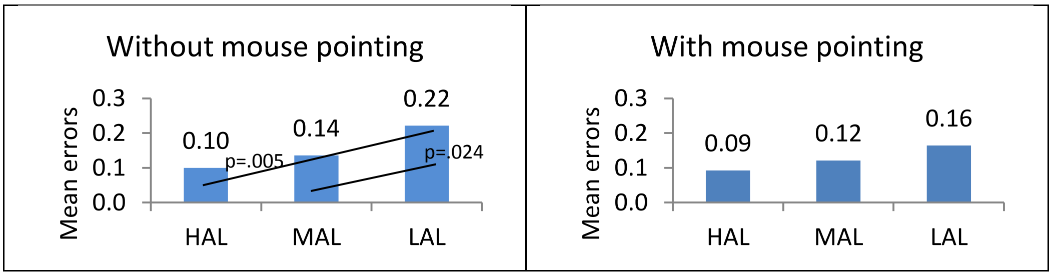


Figure 59. Mean errors obtained "without mouse pointing" and "with mouse pointing"

7.4.3 Layout aesthetics vs. preference

Kendall's coefficient of consistency (w)

Data from 6 of the 28 participants were discarded as the value of *w* was less than 0.50. The low value of *w* showed that the choices made by these participants included a large number of circular triads (see Chapter 5 for comparison). The remaining 23 participants were acceptably consistent with a mean *w* of 0.6826 and a standard deviation of 17.135. The number of circular triads for the 23 participants ranged from 7 to 69.

Kendall's coefficients of concordance (W)

The W for the 15 layout metrics was low (W = .2697 (of possible 1.0).)

Preference ranking of the 15 layout metrics

Figure 60 shows the preference rankings of the 15 layout metrics based on the number of votes by 23 participants. A large number of votes means that the layout was more preferred and a low number of votes means that it was less preferred. Table 24 shows pairs of the 15 layout metrics which were preferred significantly differently at the .05 level. Pairs which are not listed or are left blank in Table 24 were not significantly different.

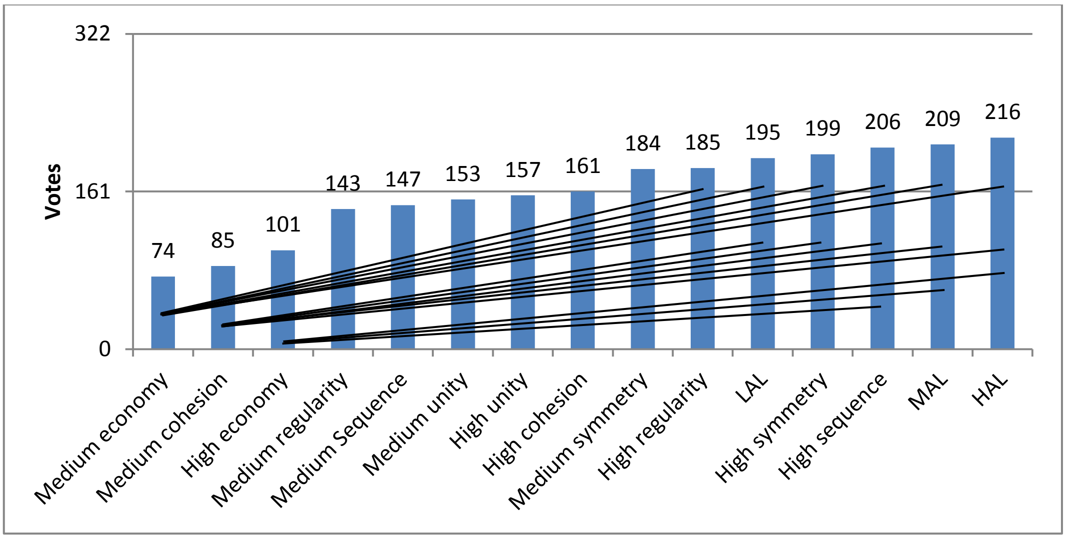


Figure 60. Preference ranking for the 15 layout metrics

	Medium economy	Medium cohesion	High economy
High regularity	110	-	-
Medium symmetry	111	-	-
LAL	121	110	-
High symmetry	125	114	-
High sequence	132	121	105
MAL	135	124	108
HAL	142	131	115

Table 24. Pairs significantly different at the .05 level (critical range = 103).

7.4.4 Preference vs. Performance

The performance (response time, errors) discussed here is limited to the performance relating to the 15 stimuli used in the preference task (not all 75 stimuli were used in the search task).

The correlation between preference and performance (response time, errors) was tested using the Spearman rank correlation coefficient (r_s). No significant ($p=0.7778$) Spearman rank order correlation coefficient was observed between preference and errors (r_s = -0.0796). There was also no significant ($p=0.3607$) Spearman rank order correlation coefficient observed between preference and response time (r_s = -0.2536). Table 25 shows the ranking of the 15 layout metrics in terms of preference and performance with the rank of 1 (worst) to 15 (best).

LAYOUT METRICS	**ACTUAL DATA**			**RANK**		
	Votes	Errors	Time	Votes	Errors	Time
Medium economy	74	0.04	4.81	1	12	13
Medium cohesion	85	0.05	5.08	2	8.5	10
High economy	101	0.04	6.08	3	12	2
Medium regularity	143	0.05	5.04	4	8.5	11
Medium sequence	147	0.13	5.73	5	4	4
Medium unity	153	0.05	4.49	6	8.5	14
High Unity	157	0.11	5.12	7	5	8
High cohesion	161	0.02	5.09	8	14.5	9
Medium symmetry	184	0.07	4.42	9	6	15
High regularity	185	0.23	5.55	10	1	5
LAL	195	0.18	5.81	11	3	3
High symmetry	199	0.2	6.29	12	2	1
High sequence	206	0.05	4.99	13	8.5	12
MAL	209	0.04	5.14	14	12	7
HAL	219	0.02	5.28	15	14.5	6

1 = worst, 15 = best

Table 25. Preference and performance ranks

7.5 Analysis and Discussion

This section analyses and discusses the results of this experiment based on the four aims of this chapter. Section 7.5.1 discusses the performance with the three levels of layout aesthetics and the performance with the 15 layout metrics, followed by Section 7.5.2 which discusses the performance with the three levels of layout aesthetics using two different search tools. Section 7.5.3 discusses the preference data for the 15 layout metrics, and finally Section 7.5.4 discusses the interaction between preference and performance.

7.5.1 Layout aesthetics vs. performance

HAL, MAL, and LAL

HAL produced significantly fewer errors than MAL and LAL. The mean response time for the three levels of aesthetics, however, was not significantly different. These results mean that, in this experiment, higher layout aesthetics supports improved task accuracy but not improved task efficiency.

These results are slightly different from the results described in Chapter 4 where it was found that higher layout aesthetics supported improved task speed but not improved task accuracy. A possible explanation for this discrepancy is that the task in this experiment is more difficult than the task in Chapter 4 for the following reasons:

- *Answer buttons vs. no answer buttons*

In Chapter 4, the layout was formed from 8 – 10 triangles and there were three labelled buttons that indicated the possible number of targets on each screen display (see Figure 22). Participants had to press the button that corresponded to their answer. The label on each button provided a clue to the participants that the possible number of targets on each screen display was either 4, 5, or 6. *How did this affect errors and response time?* With the clue provided, the participants made very few errors, regardless of the aesthetics level (over 90% correct, even at the lowest aesthetics level). For example, as the clue indicated that the answer was between 4 and 6, participants would only continue looking for more targets if they had already found only 3 targets and would discontinue looking for more targets as soon as they had found 6, although there were still more objects on the display. While the clue might affect the number of errors at the three levels of aesthetics, it would affect response time less, because although the maximum response time might be limited (search would terminate as soon as six targets were found), the minimum response time would not be affected. Thus, there was more scope for aesthetics level to affect response time than errors.

In this experiment however, there were no labelled buttons to indicate the possible number of targets on each screen display (Figure 52). Participants had to press the number key on the keyboard that corresponded to their answer. The lack of labelled buttons left the participants with no clue about how many targets they needed to find in each stimulus. This means that, even when the participants had found all the targets, because there was no indication that they had found all the targets, they had to continue searching all the images. With no clues provided and with the large number of objects (10 - 14) that formed the layout, the number of errors was potentially more affected by the layout aesthetics (performance never exceeded 90% correct). The unavailability of clues might also have encouraged the participants to apply some strategy to the task such as spending equal time or redoing the search on each stimulus just to make sure that they had found all the targets. In this case, response time between HAL, MAL, and LAL would not be different because the participants spent an equal amount of time on each stimulus.

- *Geometric shapes vs. real images*

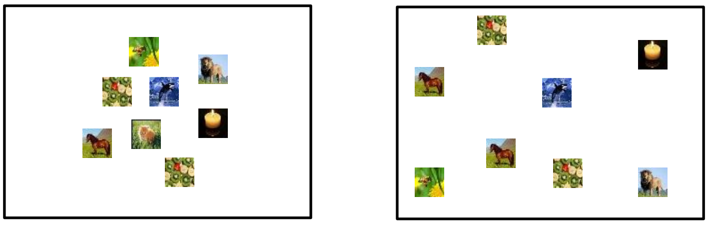
In Chapter 4, finding the target was easier than in this experiment, as the target and the distractor could be easily differentiated by shape direction. The target was an upright triangle and the distractor was an inverted triangle. Apart from the shape direction of the triangles on the display, no other attentional demands were required from the participants. This minimizes the possibility of the participants confusing the targets and distractors. This might explain the lack of significant effect of aesthetics level on the number of errors.

Unlike in Chapter 4, in this experiment the target and distractor differed by *content*. In this experiment the target was the image of an animal and the distractor was the image of a non-animal (Figure 49, Figure 50). A search task in which the target and distractor differ by content is potentially harder than a search task in which the target and distractor differ by shape direction, as the nature of the target stimulus is less predictable, and targets are less likely to group with one another, as they shared less low-level visual characteristics (e.g. colour, contour orientation). This suggests that it takes more effort to differentiate targets from distractors and there is more possibility of the participants making errors.

Although the type of performance affected by layout aesthetics in this experiment and in Chapter 4 is different, in general, the findings from both experiments show that increasing layout aesthetics level improves task performance.

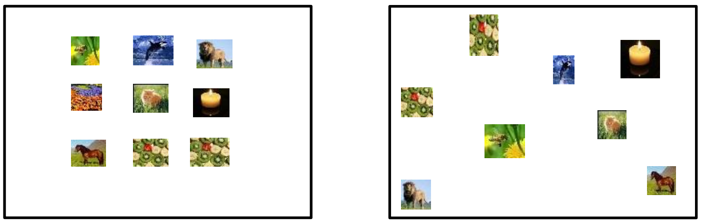
15 layout metrics

In terms of response time, performance was fastest with medium *unity* and slowest with high *economy* (Figure 61). In terms of errors, there were fewer errors with high *cohesion* and more with LAL (Figure 62).



Medium *unity* High *economy*

Figure 61. Examples of medium *unity* and high *economy*



High *cohesion* LAL

Figure 62. Examples of high *cohesion* and LAL

These results were unexpected. It was expected that among the 15 layout metrics, performance would be better with HAL and worst with LAL. It was also expected that performance would be better with a high level of aesthetics for each of the six layout metrics (e.g. performance with high *unity* should be better than performance with medium *unity*). These expectations were made based on the assumption that a high aesthetics layout is more structured than a low aesthetics layout, thus finding targets should be faster and easier with high aesthetics layouts.

There are several questions that arise from the interpretation of the results of the current experiment. One question might be that, considering that the distance between objects was much closer in high *unity* compared to medium *unity*, the results of the current experiment which show that response time of medium *unity* is shorter than high *unity* (although not significantly different – see Table 22) seems to be odd. A possible answer to this question could be that the distance between objects in high *unity* was so close that the screen looked unpleasantly cluttered, thus more time was needed to find the target as the structure was cluttered and confusing. In medium *unity* however, the separation between objects was not so tight which makes the interface less complex and thus makes the searching task easier. This indicates that although the distance between objects significantly affects search speed, the distance must not be so small that it causes discomfort to the eyes, and not so large that it takes longer. An ideal distance between objects must allow “breathing space” for the eyes to prevent discomfort.

What makes an interface with high *cohesion* support high search accuracy? A possible answer to this question could be that there is high “fluency” due to the similarity of the aspect ratio of the visual field and the aspect ratio of the layout of objects. Ngo et. al suggested that eye movement patterns were influenced by aspect ratio. The dissimilarity or changing of aspect ratio of the visual field and the layout of the objects can cause strain to the eyes.

It was surprising that HAL does not appear to be the best design when compared to the fourteen layout metrics although it is still the best design when compared to MAL and LAL (Figure 56, Figure 57). A possible reason for this might be that people get too comfortable with HAL which makes them less careful or there could be a possibility that the participants spent more time on stimuli which interested them and spent less time on stimuli in which the content did not interest them. If this happened, the performance data may be misleading. None of the participants, however, reported that they were distracted by the content of the stimuli.

The findings of this experiment are limited to stimuli on white backgrounds. There is a possibility that performance would be different if a range of different backgrounds were to be used. This issue is investigated in Chapter 8.

7.5.2 Layout aesthetics vs. Search tool

The participants took a significantly longer time to complete the task when using “mouse pointing” than “without using mouse pointing” (Figure 58). The performance pattern for both search tools was similar, in that aesthetics level had no significant effect on response time. In terms of the number of errors, the two search tools were not significantly different, but there was a significant effect of aesthetics level found in both search tools (although this appears to be stronger in the “without mouse pointing” condition). Even so, there was no significant interaction found between search tool and aesthetics level effects.

These results suggest that search tool and interface aesthetics are not related. Irrespective of search tool, an interface with high aesthetics level supports good performance. The use of mouse pointing is a drawback for performance as it slows down the searching process and does not significantly improves task accuracy.

These results confirm the findings from Chapter 4 which demonstrated that search tool and aesthetics were not related and that the aesthetics of the interface influences performance in the same way irrespective of search tool. The results of this experiment, however, are even more convincing because more "ecologically valid" stimuli were used and there was more user interactivity because of the effect of clicking the mouse during the "with mouse pointing" task (see Figure 54).

The drawbacks associated with mouse pointing in search task, have been reported earlier in a study by Cox and Silva [30] who investigated the role of mouse movements in an interactive search. The study by Cox and Silva, however, was limited to investigating the effect of eye movements in interactive search using a single-page web menu in which the aesthetic properties of the interface were not defined.

As in Chapter 4, the lack of significant difference in the number of errors between "with mouse pointing" and "without mouse pointing" task was not expected. It was expected that participants would make fewer errors when using mouse pointing than just relying on eye movements to navigate the layout. As with Chapter 4, this expectation was based on the findings of previous studies [54,4,30] which demonstrated that mouse pointing significantly aids a search by enabling the user to visually tag the object, while the eyes move elsewhere scanning for necessary information required for the tasks. The tagged object acts as a reference point and reduces the possibility of miscounts or recounts of previously identified objects, which in turn reduces the number of errors.

There are two possible reasons why the results of this experiment did not replicate the findings in the literature. First, perhaps the number of objects used to form the layout in this experiment was not large enough, which allows the participants to quickly find the targets even without the aid of mouse pointing. Previous studies [54,4,30] suggested that mouse pointing significantly aids visual search when there are large numbers of distractors competing with the target objects. Although the number of objects used in this experiment (10 – 14 images) was higher than the number of objects used in

Chapter 4 (8 – 10 triangles), it might still not be large enough. *Why not use more objects to form the layout*? This was not implemented in this experiment to minimize the risk of causing fatigue to the participants due to the large number of stimuli (180 stimuli). Secondly, it could be that the participants were very careful in finding the targets despite not using the mouse. This might not be evidence in real world usage when users are less focused on obtaining accurate results.

The most important and interesting finding of this experiment is that the pattern of performance between “with mouse pointing” and “without mouse pointing” is similar. This suggests that users’ performance is strongly influenced by the aesthetics level of the interfaces whatever assistive search tools are employed.

7.5.3 Layout aesthetics vs. preference

HAL is more preferred than MAL and LAL. The preference ranking of the 15 layout metrics shows highest preference for HAL and least preference for medium *economy*. The co-efficient of concordance of the 15 layout metrics was, however, very low (W=.2697 of possible 1.0). Analysis of preference for aesthetics level with the six layout metrics showed that high aesthetics tends to be more preferred than medium aesthetics (e.g. high *sequence* is more preferred than medium *sequence*). However, there is poor agreement in preferences between observers.

The finding of this experiment confirms the finding in Chapter 4 which demonstrated that there was a high preference for HAL compared to other layout metrics. The results of this experiment however, are even more convincing because it used more “ecologically valid” stimuli instead of “abstract” stimuli.

There are two possible factors that may have led to this preference. The first possibility relates to the “mode of use” of the participants. Since the preference task in this experiment was conducted after the visual search task, there was a strong possibility that preference was influenced by how effectively and efficiently the design of the layout assisted the participants in the search task. Compared to other metrics, HAL is highly effective and efficient for visual search due to its well-structured layout whereas medium *economy* is perceived as ineffective and inefficient due to its layout which focuses only on the size of objects.

A second possibility concerns the "content" of the image. There is a possibility that user preference was influenced by the content of the images that formed the layout and not by the layout of the images themselves. Although participants had been given clear instructions to make their preference judgements based on the layout of the small images on the screen, the experimenter was unable to prevent the participants making their preference judgements based on the images that they liked. No participants however reported that they were influenced by the content of the images.

In general, by considering the strong preference for HAL over MAL and LAL, and strong preference for the high aesthetics levels compared to medium aesthetics levels for each of the six layout metrics, it can be strongly suggested that an interface with high aesthetics is more preferred than one with low aesthetics.

The findings of this experiment, however, must be interpreted with caution due to a limitation of the stimuli. It should be noted that the backgrounds of the layout in this experiment were always plain white. This limits the generality of this finding on interfaces with many different backgrounds. This issue is investigated Chapter 8.

7.5.4 Preference vs. performance

There was no significant Spearman rank order correlation coefficient between preference and errors. There was also no significant Spearman rank order correlation coefficient between preference and response time. This finding means that there was no significant association between preference and response time performance. This result did not confirm the finding in Chapter 4 which demonstrated that preference and performance (as represented by response time) were highly correlated.

There are two possible reasons why preference and accuracy performance were not correlated in this experiment. First, the method used. The method used to conduct the preference task in this experiment was different from that used for the preference task in Chapter 4. In Chapter 4 the preference task was conducted by a direct ranking. That means all the stimuli were shown at once and the participants were asked to rank the stimuli from least preferred to the most preferred. As there were more than two stimuli shown to the participants at once, there was a possibility that the participants were less sensitive to the difference between the stimuli. In this experiment, the preference task was conducted using pairwise comparison. That means only two stimuli were compared at one time. As there were only two stimuli compared at one time, participants could have been more sensitive to differences between the stimuli.

Secondly, the content of the images. The preference judgements in this experiment might have been influenced by the content of the stimuli rather than the layout. Unlike in Chapter 4 where the interface was formed with simple black and white geometric shapes (i.e. upright and inverted triangles), in this experiment the interface was formed with small colourful images of animals and non-animals. Although the participants were asked to make their preference judgements based on the layout of the small images, it is possible that the participants made their judgements based on the content of the stimuli.

So, which experiment produced the more convincing results? Both experiments have their own strengths and weaknesses. Preferences in Chapter 4 were made based on the layout; however, the direct ranking might have made the participants less sensitive to the differences between the stimuli. Preference judgements in this experiment might be influenced by other factors such as content and not merely the layout. However, the pairwise comparisons may have made the participants more sensitive to the differences between the stimuli.

7.6 Conclusion

This chapter reported an experiment investigating the relationship between layout aesthetics, performance, and preference. This experiment was similar to that experiment reported in Chapter 4 but using more “ecologically valid” stimuli. The answers to each of the research questions posed at the beginning of this chapter are as follows:

1. What is the relationship between the aesthetics of interface design and task performance?

   The answer to this question is provided in Section 7.4.1 - 7.4.2 where it was found that among the three levels of aesthetics (high, medium, and low), accuracy performance was highest with high aesthetics and worst with low aesthetics. This result was slightly different with the result produced in Chapter 4, where it was found that there was no significant effect of aesthetics level on accuracy but on response time. Although the type of performance affected by aesthetics level was different in Chapter 4 and in this chapter, both show that high aesthetics is beneficial to performance.

As the result of this experiment was based on more "ecologically valid" stimuli and not "abstract" stimuli as in Chapter 4, it further highlights the importance of high aesthetics layouts in promoting good task performance irrespective of whether the interface has an abstract or a more 'realistic' design.

Whilst the accuracy performance with high aesthetics layouts was highest when compared to medium and low aesthetics layouts, when compared to the other 12 layout metrics, results showed that high aesthetics layouts were not necessarily the best. Instead, for search speed, performance was highest with medium *unity* and lowest with high *economy* and for search accuracy, performance was highest with high *cohesion* and lowest with low aesthetics layouts. These results show that some of the layout metrics are superior to others, thus there should more focus on particular metrics to achieve the highest performance. Note, however, although the high aesthetics layouts do not support the best performance, they are nowhere near the worst either, unlike low aesthetics layouts (at least for accuracy). Therefore, the use of high aesthetics layouts is definitely beneficial for performance.

The novel aspect of this study is that it provides an in-depth examination of the performance with each of the 15 layout metrics and shows the precise design of layout that supports better performance.

2. What is the relationship between the aesthetics of interface design and user preference?

   The answers to this question are provided in Section 7.4.3 where it was found that there was very little agreement in preferences for the 15 layout metrics. Nevertheless, the highest preferences were for high aesthetics layouts and the lowest preferences were for medium *economy*. The high preference for high aesthetics layouts confirms the findings of Chapter 4. Interestingly, an individual analysis of the six layout metrics showed that preferences for the three levels of aesthetics were not significantly different (except for *economy* and *cohesion*). This might indicate that it is hard to detect a change in preference data when only one metric is changed.

3. What is the relationship between aesthetics of interface design and search tools?

   An answer to this question is provided in Section 7.4.2 where it was found that on overall there was a similar pattern of performance between the two search tools. Therefore, it can be suggested that regardless of the search tools used, performance is better with high aesthetics interface.

4. Is there any relationship between user preference and task performance?

   An answer to this question is shown in Section 7.4.4 where it was found that there was no relationship between layout preference and performance. Therefore, a preferred interface does not necessarily support better performance, and an interface that is disliked will not necessarily impair performance when compared to a preferred one.

Since the stimuli in this experiment were designed with plain white background only, the next step of this research was to investigate if the expressivity of the background affects the performance of layout aesthetics. This is investigated in the next chapter, Chapter 8.

Chapter 8

Classical layout aesthetics and background image expressivity

The aesthetics of interfaces is thought to be expressible in terms of two dimensions: Classical aesthetics (CA) and Expressive aesthetics (EA) [67]. CA refers to the orderliness and clarity of the design and is closely related to many of the design rules advocated by usability experts (e.g. pleasant, clean, clear and symmetrical) whereas EA refers to the designer's creativity and originality and the ability to break design conventions (e.g. creative, using special effects, original, sophisticated and fascinating).

CA has been extensively investigated in the experiments reported in the previous four experiments (see Chapter 4, 5, 6, 7) in which CA was defined by the layout and which were presented on a plain white background. White backgrounds have a strong association with CA which emphasizes simplicity and orderliness [67]. Through Chapter 4 and Chapter 7, concrete evidence has been obtained showing that, for goal-oriented interfaces, CA has a strong effect on user performance and preference, with performance and preference increasing with increasing level of CA. Since this finding was obtained only from the perspective of CA, it raises a Question whether this result is specific to interfaces, which embody CA the most, or does it also applies to other interfaces with different levels of EA.

Therefore, the purpose of this chapter is to discuss the relationship between CA and EA. The research question in this chapter asks,

1. What is the relationship between Classical layout aesthetics and background image expressivity?

To investigate this question, the performance of participants using interfaces with varying CA and background image expressivity was investigated.

8.1 Theoretical background

As introduced earlier in this chapter interface aesthetics is considered to have two dimensions: CA and EA [67]. These two dimensions are similar to those proposed by Nasar (cited in [67]) as “visual clarity” and “visual richness” respectively. In a more recent study by Moshagen and Thielsch [91], they suggested that visual aesthetics also includes colourfulness and craftsmanship besides CA and EA. Figure 63is an example of high CA and Figure 64 is an example of high EA.

Figure 63. An example of high CA (taken from [3])

Figure 64. Figure 65. An example of high EA (taken from [3])

To date, there has been a limited number of studies investigating the relationship between CA and EA. Coursaris et al. [29] conducted an online survey of 328 participants to assess the perceived attractiveness of websites through assessments of CA and EA. They found that the perception of CA had a direct effect on the perception of EA, therefore they suggested that it is important to fulfil the fundamental design principles and guidelines of interface design before focusing on the creative side of the design.

Coursaris et al.'s view was not supported by Avery [5]. In her study, 8 participants were recruited to first rate three websites for overall impression and then a heuristic was employed (qualifier and statement) to rate each website on a scale from 1 to 7 in several categories. They found that web pages which were described as visually rich were not necessarily described as visually clear. They also found that webpages that embodied the most CA were reported to be the most usable and credible (r= .648).

Cai et al. [19] proposed a model that showed how CA and EA shape consumers' attitudes and behaviours. According to this model, the effect of CA and EA on consumer response is moderated by shopping task type: hedonic or utilitarian. Consumers seeking a hedonic shopping experience would expect EA as it provides an immersive and emotional experience, whereas consumers seeking a utilitarian shopping experience prefer CA as it helps them to complete the shopping task more efficiently.

Cai et al.'s claim was supported by Van Schaik and Ling [145]. While Cai et al. used the term utilitarian and hedonic, Van Schaik and Ling used the terms “goal mode” and “action mode” to represent the users' mode of use. Users in “goal mode” are more concerned about task efficiency and effectiveness whereas users in “action mode” are more concerned about their hedonic experience than merely task efficiency and effectiveness. Van Schaik and Ling suggest that for goal oriented products, the use of CA is more appropriate than EA because the characteristics of CA (such as order and familiarity) help users to complete the task with efficiency and effectiveness. For action-oriented products, Van Schaik and Ling suggest that EA is more appropriate because the characteristics of EA such as originality, fascinating, etc. provide users with a hedonic experience.

A slightly different view is expressed by De Angeli et al. [3] who suggested that the use of CA and EA depends on the target population and the intended context of use. . Their suggestion was based on their evaluation of two websites which had the same content but different interface styles: menu-based and metaphor-based. They found that the majority of participants agreed that a metaphor-based interface (embodying EA), is more suitable for children interacting with the website at home but not in a classroom; whereas a menu-based interface (embodying CA), is more suitable for mature and knowledgeable users.

One of the common similarities between the studies discussed above is that none of them have compared users' performance between interfaces with CA and EA. This is an interesting gap in the literature that needs further investigation.

8.2 Aims

In order to find the answers of the research question posed at the start of this chapter, the following aims are addressed:

a. To investigate the effect of CA on users' performance and preference. Although this has been addressed in Chapter 4 and Chapter 7, it was investigated only with plain white backgrounds, and not with backgrounds with different levels of expressivity.
b. To investigate the relationship between preference and performance, and between perceived usability and performance in the context of CA.
c. To investigate the effect of EA on users' performance.
d. To investigate the relationship between CA and EA

8.3 Experimental design

8.3.1 Interface components

The interface consisted of two components (Figure 66):

- Small images of animals and non-animals - These images were used to form the layout of the interface. These images were similar to the images which were used in Chapter 7. As mentioned earlier in Chapter 7, these images were collected from publically-accessible webpages, thus, their use does not violate copyright law, as non-commercial research and teaching use come under the category of "fair dealing".
- Image background - These images were taken from the wallpaper collections of Window XP and Window Vista (Microsof owns the copyright of the wallpaper collections) and Google™ search images. These images were selected because people often use these types of images as the backgrounds for their computer displays.

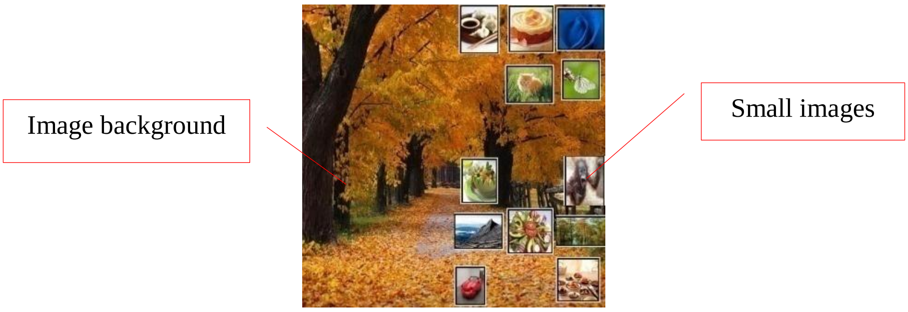


Figure 66. An example of stimuli

8.3.2 Aesthetic measures

The aesthetics of the interface was measured in terms of its CA and EA.

Classical aesthetics (CA)

CA was defined in terms of the layout of the interface and was measured objectively using the layout metrics proposed by Ngo et. al [98]. The interfaces were categorized into three levels of CA: HAL, MAL, and LAL (see Chapter 5 Table 7, Category 1 – 3 for the aesthetic properties of each category). Figure 67 shows an example of stimulus for each level of CA.

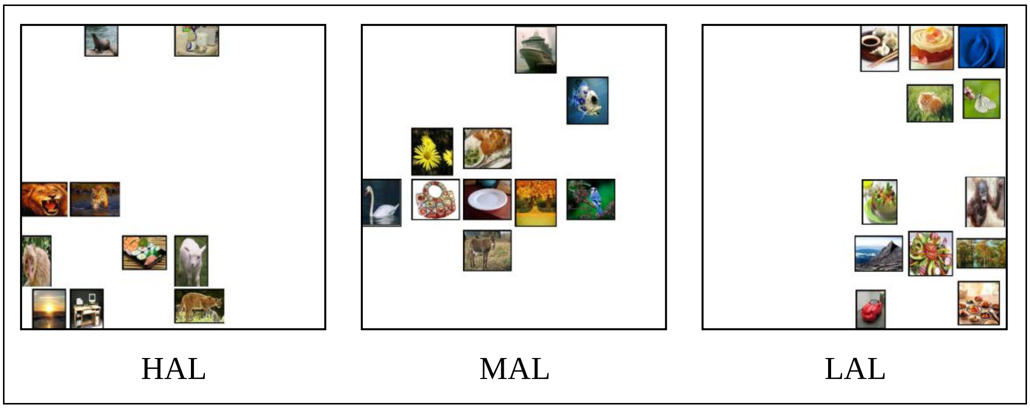
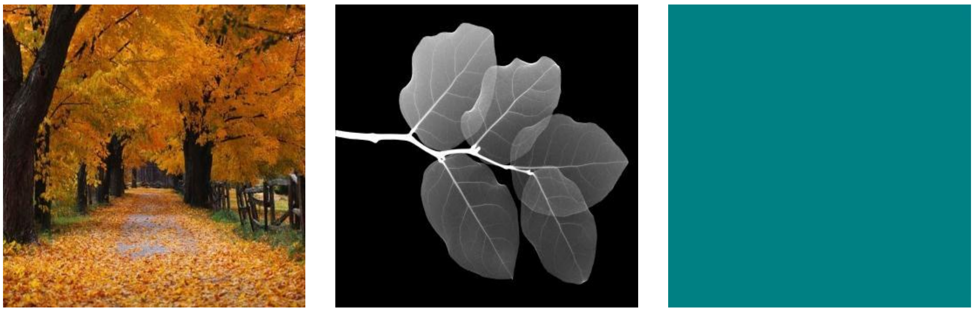


Figure 67. An example of HAL, MAL, and LAL

Expressive aesthetics

EA was defined by the background of the interface and was measured by subjective judgment. The interfaces were categorized into three levels of expressivity: high expressivity (HE), medium expressivity (ME), and low expressivity (LE) (Figure 68)



HE ME LE

Figure 68. An example of HE, ME, and LE[1]

Classical aesthetics vs. expressive aesthetics

Figure 69 shows the examples of the stimuli in this experiment.

MAL with LE HAL with ME LAL with HE

Figure 69. An example of the combination of CA and EA

8.3.3 The Java program

The program that created the stimuli

The stimuli were created using the same program used in Chapter 7 (Figure 51). The only difference was that, the program adds many different backgrounds to the stimuli.

The program that presented the stimuli

Visual search task

The stimuli were presented to the participants using the same program as in Chapter 7, except that in this experiment the background of the stimuli was not limited to plain white (Figure 70). The program recorded the participants' performance in terms of response time and the number of errors.

[1] Microsoft owns the copyright of these images

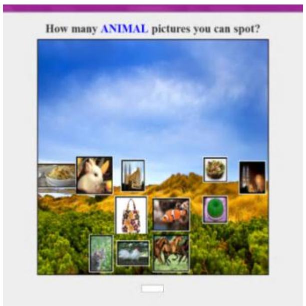
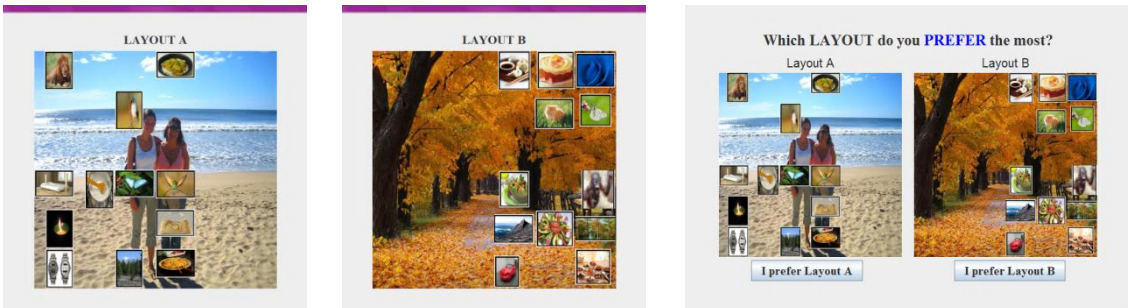


Figure 70. The screen shot of the program that was used to run the search task

Preference task

The stimuli were presented using the same program as in Chapter 7. The preference task was conducted twice. First, to see what kind of layout the participants preferred (Figure 71). Secondly, to see how the participants perceived the ease of use of the interfaces (Figure 72).



2 seconds | 2 seconds | Unlimited time

Figure 71. Screen shots from the program that ran the preference task (Note that each panel of the figure was presented separately in order from left to right)

2 seconds | 2 seconds | Unlimited time

Figure 72. Screen shots of the program that ran the ease of use task (Note that each panel of the figure was presented separately in order from left to right)

8.4 Pre-experiment

A pre-experiment was necessary in order to measure the EA of the images used as backgrounds in the main experiment. The EA was categorised into three categories: HE, ME, and LE.

The EA of the images could not be determined using the same method as with CA (i.e. objective measure) as the method used in CA was developed specifically for layouts and not images. Besides, subjective judgments are more suitable to measure EA which emphasizes the viewers' own perceptions.

8.4.1 Task

The participants were asked to arrange 30 images according to their perception of "image expressivity", beginning with the least expressive and ending with the most expressive. The instruction was "Please arrange the images from least expressive to most expressive".

8.4.2 Stimuli

There were 30 images used as stimuli in this pre-experiment (Figure 73). These stimuli were taken from wallpaper collections of Window XP and Window Vista and a few from Google search images. These images were selected because people often use these types of images as the backgrounds for their computer displays. Each image was colour printed on a piece of paper (10cm x 10cm) so that participants could physically rank them in order on a large table.

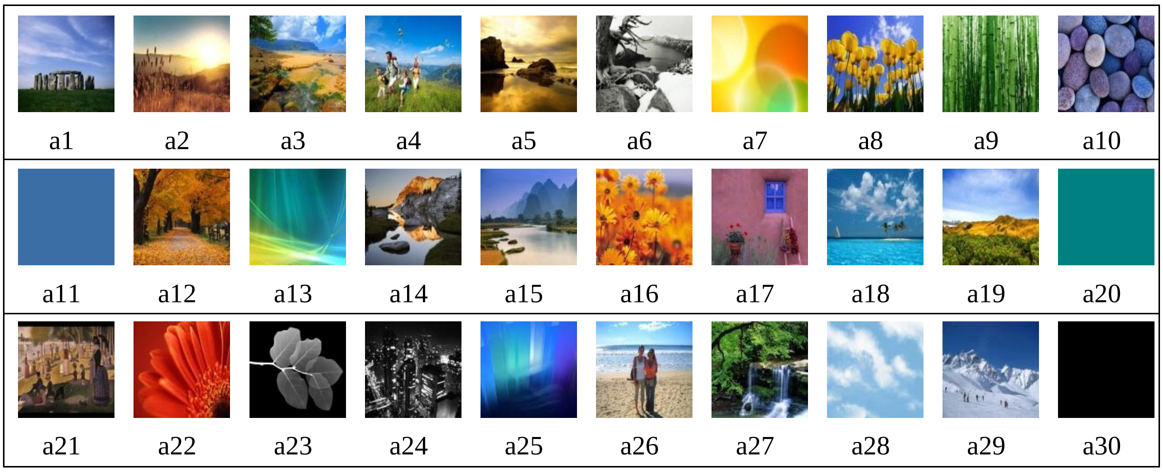


Figure 73. The 30 images used as stimuli in the pre-experiment[2]

8.4.3 Participants

Participants were 20 undergraduate and postgraduate students enrolled in various courses at the University of Glasgow. All participants were volunteers, computer literate and used computers daily.

8.4.4 Procedure

The participants were given 30 coloured images (10 cm x 10 cm) and were asked to arrange the images from least expressive to the most expressive ("Please arrange these images from least expressive to most expressive"). There was no time restriction on the task. Upon completion of the task, the participants informed the experimenter and the experimenter recorded the sequence of the images. The task took approximately 5-10 minutes to complete.

8.5 Results

Figure 74 shows the degree of variation between observers' ranking results for the 30 images. The 30 images are plotted along the *x* axis such that the leftmost images show the least variation of observers' ranking and the rightmost show the greatest variation of observers' ranking.

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[2] Microsoft owns the copyright of these images except for a4, a26, a27, a29

Figure 75 shows the rank of each of the 30 images in ascending order. The rank of each image was determined by taking the average rank given by the participants on each image. The 30 images were ordered from least expressive to the most expressive and were categorized into three categories: HE, ME, and LE. It was not trivial to classify these images into HE, ME and LE, as some of the images had similar mean ranks which meant that they might belong to one of two categories. To solve this problem, some images whose mean rankings were very close to one another were removed to ensure that there was a clear gap in rank between the images for each category (see Figure 76).

Figure 76 shows the selected and removed images. The images which were removed were a16, a15, a2, a14, and a4 (see Figure 73). The images a16, a15, a2 were removed to ensure that there was a proper gap of rank between the images in HE and ME whereas the images a14 and a4 were removed as their mean ranks were too different from the rank of other images in the HE category. No images were removed from the LE and ME boundary, because there was already a sizeable difference in rank between the highest rank image belonging to LE (a7) and the lowest rank image belonging to ME (a23). As shown in Figure 77, 9 images were selected for HE (mean rank: >18) and ME (mean rank: 13-18) and 7 images for LE (mean rank: 1 - 10).

The experimenter decided to add two more images to the LE category to ensure that it had the same number of images as the ME and HE categories. These two new images were images comprising a single colour (white, striking red). These two images were confidently allocated in the LE category as in a supplementary experiment where 6 new participants were asked to rank the first 10 least expressive images (a30, a20, a11, a25, a28, a13, a7, a23, a9, a29 – see Figure 73) together with these two new images (white, striking red); neither of these two new images were ranked as the least expressive or the most expressive. It was therefore inferred that an image with a single colour is more likely to be perceived as having low EA when compared with an image with multiple colours. Figure 77 shows the final images in each category (HE, ME, and LE) that were used in the main experiment.

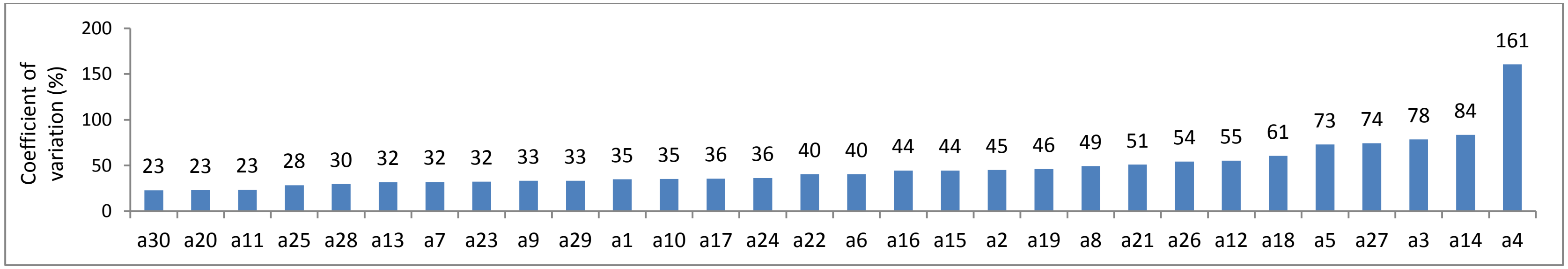


Figure 74. The Coefficient of variation of observers' ranking of the 30 images

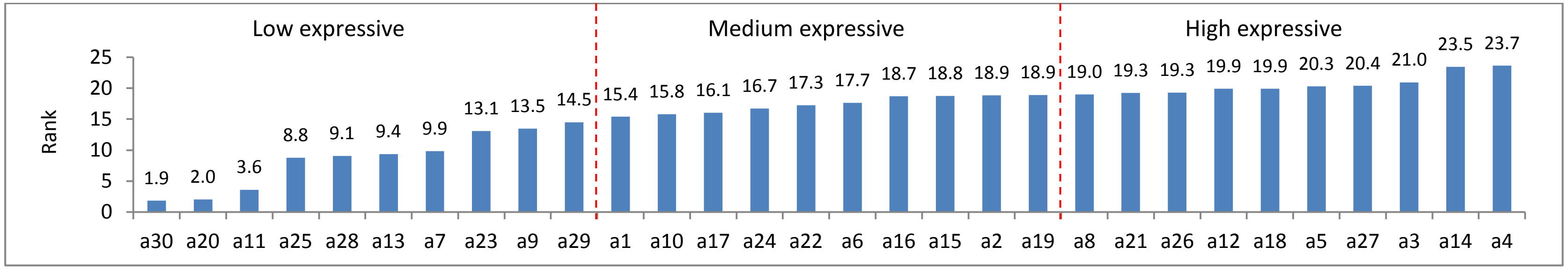


Figure 75. The rank of the 30 images in ascending order

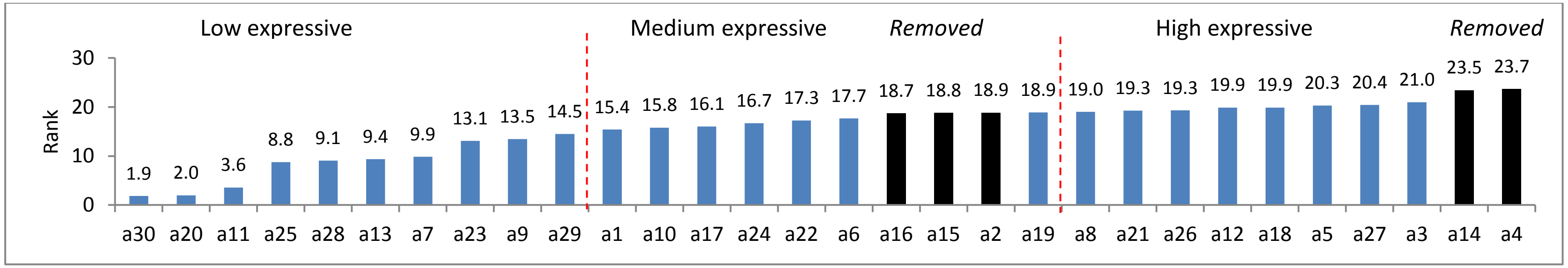


Figure 76. The selected and removed stimuli

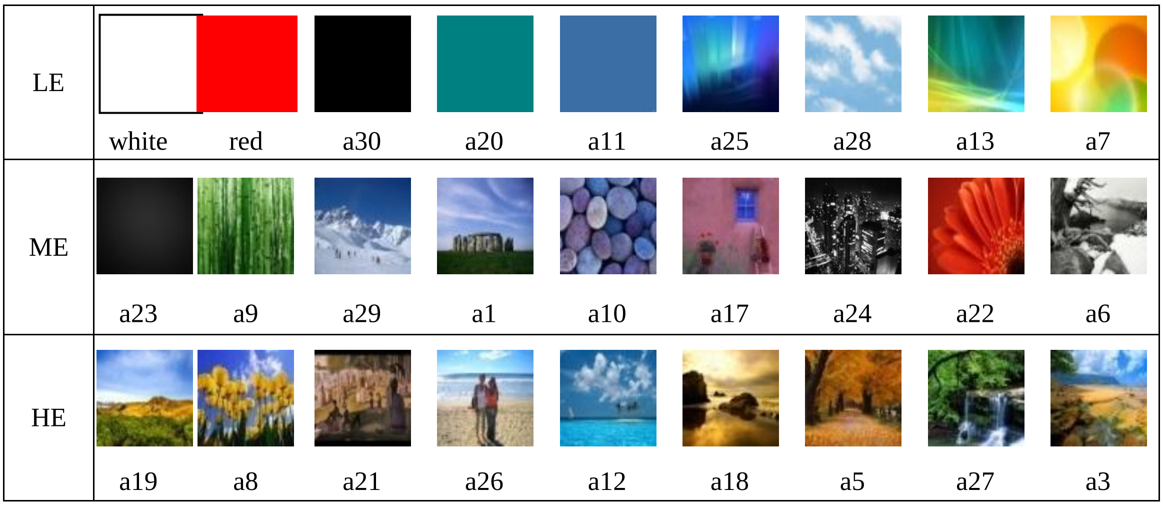


Figure 77. Images used in the main experiment

8.6 Methodology

8.6.1 Tasks

The task in this experiment was similar to Chapter 7 except that in this experiment the preference task was conducted twice. The search task was presented before the preference task.

- Visual search task – This task was similar to the visual search task in Chapter 7 (see Chapter 7 Section 7.3.1).
- Preference task – This task was conducted twice. First, the participants were asked to make their choice based on which layout they preferred the most (Figure 71). Second, the participants were asked to make their choice based on which layout their perceived as easier to use (Figure 72). It was a forced-choice task where the participants were required to choose only one stimulus.

8.6.2 Stimuli

The design of the stimuli in this experiment was similar to Chapter 7, except that in this experiment the aesthetics of the stimuli were measured by both CA and EA. The CA was measured as in Chapter 7 and the EA was determined by the categories defined in the pre-experiment. The information on the stimuli sets (i.e. screen image library used, actual value of aesthetic parameters, Java pseudocode) can be found in Appendix 1 and Appendix 2.

Visual search task

There were 59 stimuli used in the search task. 5 stimuli were treated as practice and discarded from the main analysis. Table 26 shows the aesthetic properties of the 54 stimuli and Figure 78 shows examples of stimuli used in the search task. The order of the 54 stimuli was randomized for every participant to minimize sequence effects.

Aesthetic properties	HE	ME	LE
HAL	6 stimuli	6 stimuli	6 stimuli
MAL	6 stimuli	6 stimuli	6 stimuli
LAL	6 stimuli	6 stimuli	6 stimuli
TOTAL =	18 stimuli	18 stimuli	18 stimuli

Table 26. The aesthetic properties of the 54 stimuli

Preference tasks

There were 9 stimuli used in each of the two preference tasks (Figure 78). These stimuli were previously used in the search task.

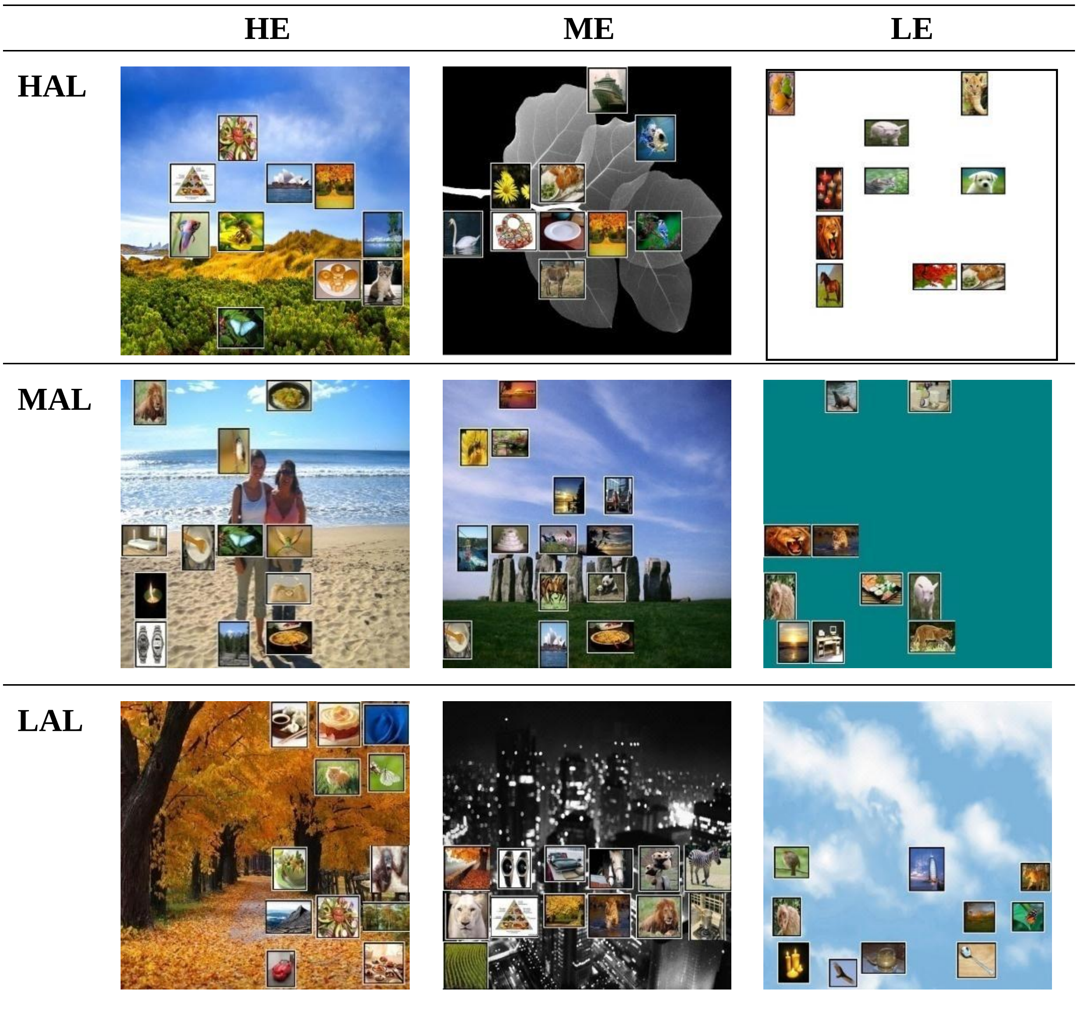


Figure 78. Examples of stimuli in preference tasks

8.6.3 Participants

Participants were 33 undergraduate and postgraduate students enrolled in various courses at the University of Glasgow (24 Western, 5 Asian, 2 African, and 2 others). All participants were volunteers or given a course credit and were computer literate and used computers daily. None of the participants had participated in the previous experiment.

8.6.4 Procedure

The procedure of this experiment was similar to Chapter 7.

8.7 Results

The results from the visual search task and the preference task were analysed using the same methods as in Chapter 7.

8.7.1 Classical aesthetics and performance

There was a significant main effect of CA $F_{2, 64}$= 16.565, p<.001 (Figure 79) on response time, where MAL produced a significantly longer response time than HAL (p<.001) and LAL (p=.002). HAL and LAL were not significantly different. There was no significant main effect of CA $F_{2, 64}$= 1.311, p=.277 (Figure 80) on errors.

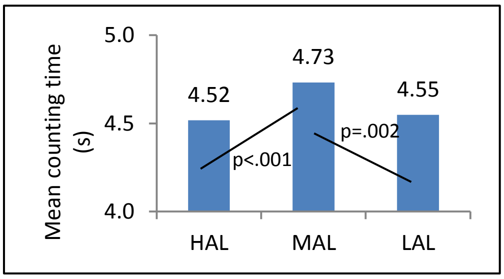


Figure 79. Mean response time for CA

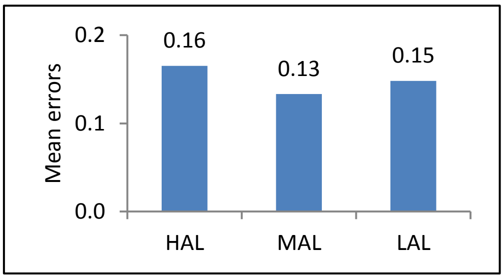


Figure 80. Mean errors for CA

8.7.2 Expressive aesthetics and performance

There was a significant main effect of EA $F_{2, 64}$=10.560, p<.001 (Figure 81) on response time where HE (p<.001) and ME (p<.001) produced significantly longer response times than LE. Response time with ME and HE interfaces were not significantly different (p=1.000).

There was a significant main effect of EA $F_{2, 64}=6.526$, $p=.003$ (Figure 82) on errors where HE ($p=.010$) and ME ($p=.011$) produced significantly more errors than LE. Errors with HE and ME interfaces were not significantly different ($p=1.000$).

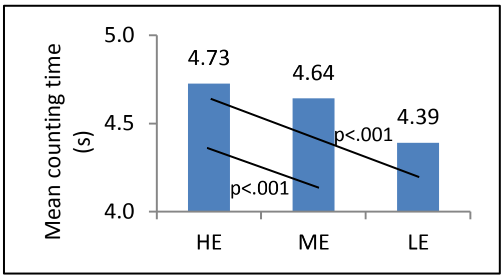


Figure 81. Mean response time forEA

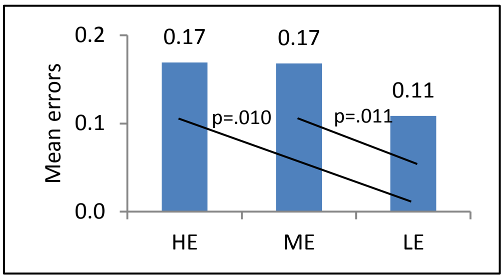


Figure 82. Mean errors forEA

8.7.3 Classical aesthetics vs. expressive aesthetics

Response time

There was a significant interaction between CA and EA, $F_{2.365, 75.688}=8.280$, $p<.001$ for response time (Figure 83). Table 27 shows all pairs of interactions between CA and EA. The three levels of CA were significantly different on ME and LE backgrounds but not on HE backgrounds.

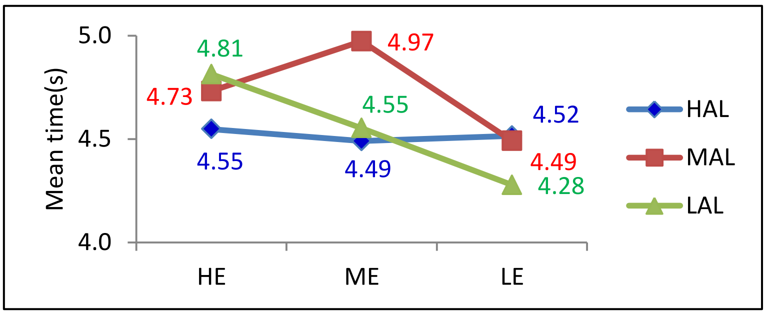


Figure 83. Mean response time for CA and EA

		MAL	LAL
HE	HAL	*p*=1.000	*p*=1.000
	MAL	-	*p*=1.000
ME	HAL	*P*<.001*	*p*=1.000
	MAL		*p*<.001*
LE	HAL	*p*=1.000	*p*=.004*
	MAL		*p*=.006*

Table 27. Pairwise of CA and EA for response time

Errors

There was a significant interaction between CA and EA $F_{4, 128}$=4.452, p=.002 for errors. The three different levels of CA were significantly different only under the condition of HE where the participants made fewer errors with MAL and more errors with HAL and LAL (Figure 84).

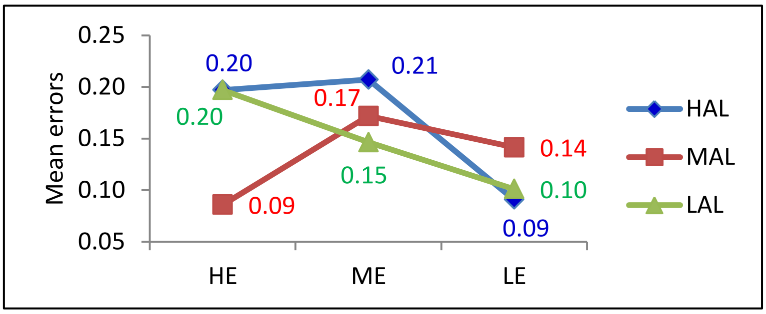


Figure 84. Mean errors for CA and EA

		MAL	LAL
HE	HAL	*p*=.008*	*p*=1.000
	MAL	-	*p*=.010*
ME	HAL	*p*=1.000	*p*=1.000
	MAL		*p*=1.000
LE	HAL	*p*=1.000	*p*=1.000
	MAL		*p*=1.000

Table 28. Pairwise comparisons of CA and EA for errors

8.7.4 Classical aesthetics and preference

None of the preference data from 33 participants were discarded from the analysis as the coefficient of consistency (W) of each participant was 0.50 or more. All 33 participants seemed to be highly consistent with their preference choice as the mean of W was 0.8141 (of a possible 1.0). The number of circular triads ranged from 0 to 15 with a mean of 5.576 and standard deviation of 4.131. Although the W was high, the coefficient of agreement (w) for the 9 layouts was very low (w=.1580, out of a possible 1.0) which means that there were large variations in interface preferences between participants.

Figure 85 shows the ranking of the 9 layouts in ascending order. The layout which received the lowest number of votes was the least preferred layout and the layout with the highest number of votes was the most preferred. The thumbnails of these layouts are shown in Figure 86. Table 29 shows the pairwise comparisons data for the 9 layouts. Pairs which were significantly different at $p<.05$ are indicated in bold (see Chapter 5 for details on how the tests of significance were done).

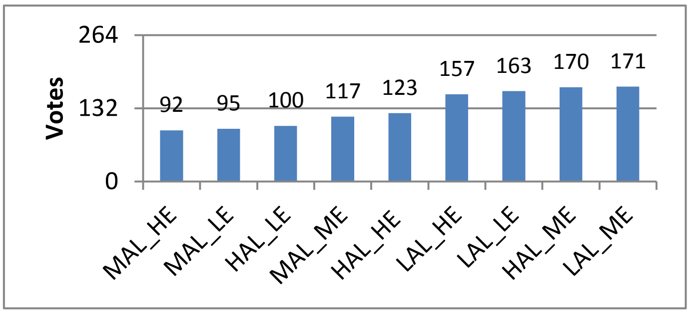


Figure 85. Preference ranking of the 9 layouts

		MAL_HE	MAL_LE	HAL_LE	MAL_ME	HAL_HE	LAL_HE	LAL_LE	HAL_ME	LAL_ME
	R_i	92	95	100	117	123	157	163	170	171
MAL_HE	92	-	-	-	-	-	-	-	-	-
MAL_LE	95	3	-	-	-	-	-	-	-	-
HAL_LE	100	8	5	-	-	-	-	-	-	-
MAL_ME	117	25	22	17	-	-	-	-	-	-
HAL_HE	123	31	28	23	6	-	-	-	-	-
LAL_LE	157	65	62	57	40	34	-	-	-	-
HAL_ME	163	**71**	68	63	46	40	6	-	-	-
HAL_ME	170	**78**	**75**	**70**	53	47	13	7	-	-
LAL_ME	171	**79**	**76**	**71**	54	48	14	8	1	-

Bold numbers are significant at the .05 level (critical range =69)

Table 29. Matrix of rank differences of the 9 stimuli for preference of layout

Figure 86. The sequence of stimuli based on the least preferred to most preferred

8.7.5 Classical aesthetics and perceived ease of use

Preference data from 2 of the 33 participants were discarded as the coefficient of consistency (W) was less than 0.50. The remaining 31 participants were highly consistent in their preferences with the mean coefficients of consistency of 0.8527 (of a possible 1.0). The number of circular triads ranged from 1 – 13 with a mean of 4.419

and standard deviation 3.529. Although the W was high, the coefficient of agreements (w) of the 9 layouts was very low (w=.2932, out of a possible 1.0), which indicates a large variation in perceived ease of use. Figure 87 shows the ranking of the 9 layouts in ascending order. The thumbnails of these layouts are shown on Figure 88. Table 30 shows the pairwise comparisons for the 9 layouts, with significantly different pairs indicated in **bold** ($p<0.05$).

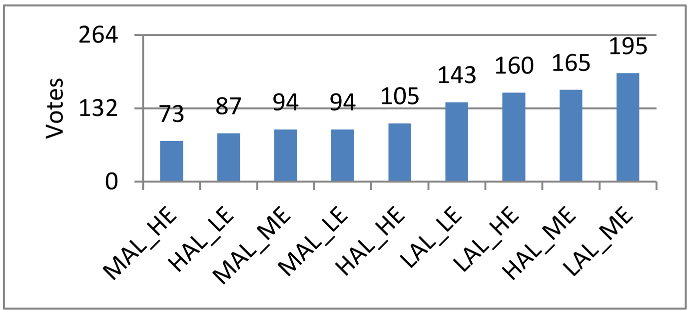


Figure 87. Preference ranking of the 9 layouts based on perceived ease of use

		MAL_HE	HAL_LE	MAL_ME_	MAL_LE	HAL_HE	LAL_LE	LAL_HE	HAL_ME	LAL_ME
	R_i	73	87	94	94	105	143	160	165	195
MAL_HE	73	-	-	-	-	-	-	-	-	-
HA_LE	87	14	-	-	-	-	-	-	-	-
MAL_ME	94	21	7	-	-	-	-	-	-	-
MAL_LE	94	21	7	0	-	-	-	-	-	-
HAL_HE	105	32	18	11	11	-	-	-	-	-
LAL_LE	143	**70**	56	49	49	38	-	-	-	-
LAL_HE	160	**87**	**73**	**66**	**66**	55	17	-	-	-
HAL_ME	165	**92**	**78**	**71**	**71**	60	22	5	-	-
LAL_ME	195	**122**	**108**	**101**	**101**	**90**	52	35	30	-

Bold numbers are significant at the .05 level (critical range =66.75)

Table 30. Pairwise comparisons of the 9 layouts for perceived ease of use

Figure 88. The sequence of stimuli based on perceived ease of use

8.7.6 Preference, perceived ease of use, and performance

It is important to note that, when discussing performance and preference, the performance of only those 9 stimuli used in the preference task are considered. The correlation between preference and performance (response time, errors), perceived ease of use and performance, and preference and perceived ease of use were tested using the Spearman rank correlation coefficient (r_s).

Preference vs. performance

There was no significant spearman rank correlation between preference and response time (r_s =0.20, p=.6059), or between preference and errors. (r_s =-0.20, p=.5368).

Perceived ease of use vs. performance

There was no significant spearman rank correlation between perceived ease of use and response time (r_s =0.25, p=.5165), or between perceived ease of use and errors. (r_s =-0.25, p=.5219).

Preference and perceived ease of use

There was a significant (p<.0001) spearman rank correlation (r_s=0.97) between preference and perceived ease of use.

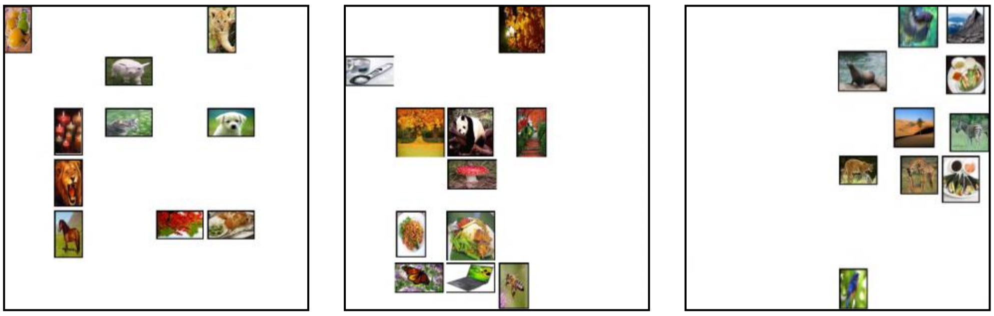
8.8 Analysis and discussion

8.8.1 Classical aesthetics vs. performance

The participants took a significantly longer time to count the number of animal images with MAL, as compared to HAL and LAL. There was no significant effect of aesthetics level on the number of errors. These results mean that CA does not necessarily support good task performance. These results did not confirm the finding from Chapter 7 which demonstrated that higher aesthetics layouts supported better task performance.

A possible reason for this apparently contradictory finding is the use of a background image instead of a plain white background. This reason seems relevant, given that previous experiments (see Chapters 4 and 7) which used plain white backgrounds consistently maintained that higher aesthetics layouts support better performance.

To investigate this speculation, participants' performances in this experiment using only stimuli with white backgrounds were analysed to see if the results of the previous experiments could be replicated. There were three stimuli with a white background which each represented HAL, MAL, or LAL (Figure 89). Performances (response time, errors) with these stimuli, however, failed to replicate the results obtained in Chapters 4 and 7. This maybe because of the smaller number of stimuli (i.e. only one stimulus for each aesthetics level). Using only one layout is problematic for generalization of the results.



HAL MAL LAL

Figure 89. The three stimuli with white backgrounds from this experiment

Thus, it can be suggested that the benefit of classical layout aesthetics may not be obvious when the background includes irrelevant objects that interfere with the perception of the objects of interest in the layout.

8.8.2 Expressive aesthetics vs. performance

The participants took a longer time to complete the search task with HE interfaces as compared to ME and LE. The results also showed that the number of errors the participants committed with HE and ME interfaces was significantly fewer than with LE. These results suggest that performance improves with a decrease in EA.

In the context of EA, it seems that interfaces with high aesthetics are detrimental to performance and interfaces with low aesthetics are beneficial to performance. This result seems to corroborate earlier suggestion about aesthetics in HCI that higher aesthetics interfaces can be detrimental to performance (as mentioned in [137]) but contradicts the findings of many of the recent studies (e.g. [65,137,133,90,129]). *Why does this experiment indicate that high EA does not support better performance?*

In seeking an answer to this question it is important to identify which aspect of an interface contributes to task performance. One of the most important aspects of interface design that affects performance is usability (e.g. ease of use). An interface with high usability allows users to effectively and efficiently accomplish the tasks for which it was designed [155]. As usability is the key for performance, *could it be that low performance relating to interfaces with a high level of EA is due to low usability?*

To investigate this theory, let us look at the characteristics of EA. EA is a manifestation of the designer's creativity and originality and the ability to break design conventions [79]. Clearly, usability is not the main concern. Put simply, EA is about designing an interface regardless of whether a usability problem might occur due to the design. An interface with low usability is not good as it hinders or prevents users from efficiently performing the task [107]. Thus, it can be suggested that the lack of usability of interfaces with EA could be the main reason why they do not support performance.

As EA can contribute to a deterioration of performance, *why is it used*? In seeking an answer to this question let us look at the design priority for interfaces with EA. The priority of EA is to provide a hedonic experience rather than to complete a task efficiently and effectively. Thus, it is more likely that EA is only suitable for users that are seeking fun and enjoyment or are in their leisure mode rather than for users who are motivated to complete the task with high effectiveness and efficiency.

One of the limitations of this experiment is that the participants were not tested with colour blindness. Colour blindness is the inability to distinguish differences between certain colours [63]. It is an incurable, genetic condition. There are three most common types of colour blindness [134]: protanopia, deuteranopia, and tritanopia:

1. Protanopia is red colour deficiency. People suffer from protanopia are unable to distinguish between colours in the green-yellow-red section of the spectrum, thus, they see all hues of red, orange, yellow, and green as hues of ochre or yellow [134].
2. Deuteranopia is green colour deficiency. Similar with people with protanopia, people affected by deuteranopia are also unable to distinguish between colours in the green-yellow-red section of the spectrum [134]. This leads them to perceive all hues of green, yellow, orange, and red as hues of ochre or yellow, and the hues of magenta, violet, and blue as the hues of blue.

3. Tritanopia is the rarest type of colour blindness. Tritanopia is blue colour deficiency. People with tritanopia are unable to distinguish between colours in the blue-green section of the spectrum [134]. Therefore, they see all hues of yellow, orange, red, and magenta as hues of red, and white and all hues of blue, green, and violet are perceived as hues of blue-green.

Figure 90 shows the comparison between people with normal colour vision and those with colour blindness.

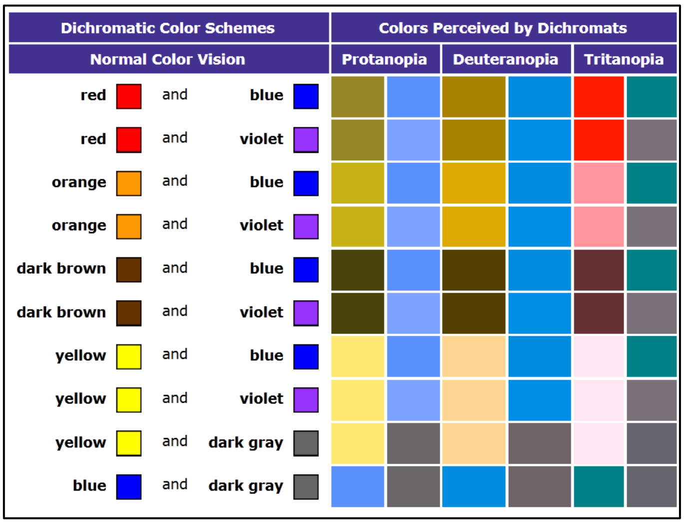


Figure 90. Normal colour vision vs. colour blindness (taken from [45])

As the stimuli in this experiment were presented with rich colours, there could be a possibility that some of the stimuli may cause misunderstanding to people with anomalous colour vision; therefore, affect the participants' performance. None of the participants, however, reported that they had colour-blindness problems.

8.8.3 Classical aesthetics vs. expressive aesthetics

There was a significant interaction between CA and EA for both response time and errors. This means that performance was affected by both aesthetic dimensions. The pattern of performance with varying CA and EA indicates that EA has a stronger influence than CA. This was shown by the increase in performance with decreasing EA. This is, however, not evident with CA, where performance did not necessarily decrease/increase with the increase/decrease of CA.

Response time

With the HE background, the response time for the three levels of CA was not significantly different which implies that under the HE background, the aesthetics level of the layout is not important. The main reason for the lack of significant difference between the three levels of CA was most likely because of interference from the background. The background might contain objects which are intended as decoration but instead interfere with the location of the objects that form the layout, which in turn creates a "new layout" which has a different *effective* aesthetics level.

With ME backgrounds, the participants took a significantly longer time with MAL than HAL and LAL, which indicates that MAL is detrimental to performance, whereas HAL and LAL are beneficial to performance. This is quite a strange result. A possible explanation is that, with the ME backgrounds, the performance is high with HAL because it is easy to find the targets. The high performance with LAL could be because participants found the layout difficult, and thus they worked harder. In MAL however, the participants might not have been so careful as they predicted it would be neither too easy nor too difficult. In other words, the perceived difficulty of the interface might be affecting participants' motivations to complete the task accurately.

With LE backgrounds, the participants took significantly shorter times with LAL than with HAL and MAL. This suggests that higher layout aesthetics does not support better performance. Again, a possible explanation for this apparently incongruous result could be that the participants found the LAL so difficult that they worked harder to complete the task.

Although there was no evidence for higher CA layouts to be superior to lower CA layouts for each of the three levels of EA, from a wider perspective, higher CA layouts are still a better choice than low CA layouts. It was shown from the interaction between CA and EA that participants' response times with HAL were found to be unaffected by the changing expressivity of the background, unlike MAL and LAL (see Figure 83, Table 27), which suggests that with a higher aesthetics layout the designer has more freedom to design the background of the interface without the need to worry whether it will affect task completion time. While the response time with HAL seems to be unaffected by the changing expressivity of the background, LAL was found to benefit from a decreasing level of background expressivity. This suggests that an interface with an unstructured layout should be designed with a low expressivity background to support performance.

Errors

In the HE background condition, participants produced significantly fewer errors with MAL than HAL and LAL. This suggests that MAL is the most suitable layout design for the HE background. While it is understandable that MAL produced fewer errors than LAL, it's quite difficult to understand why MAL produced fewer errors than HAL. It could be speculated that the participants might have found the task with HAL too easy, thus they were not very careful while performing the search task, and thus they made more errors. With LAL however, the participants might have found the task too difficult thus making more errors. In MAL, perhaps the participants are aware of the layout which is only slightly difficult, and thus worked harder resulting in fewer errors.

In the ME and LE condition, the number of errors with the three levels of CA were not significantly different which suggests that, under a ME background, the level of aesthetics of the layout is not so important.

Although there was no evidence that a high CA layout was better than a low CA layout in each of the three conditions of EA, the results showed that the performance with LAL improved with decreasing EA (see Figure 84, Table 28).

8.8.4 Preference

The most preferred layout was LAL with an ME background and the least preferred layout was MAL with a HE background. This result suggests that users prefer an interface with an unstructured layout with an ME background and least prefer an interface with slightly structured/unstructured layout with a HE background. This result is quite surprising since previous experiments (see chapter 4 and chapter 7) consistently maintained that preference was higher for HAL when compared to MAL and LAL.

A possible reason for this result is that user preference in the current experiment was influenced by the background. The stimuli used in previous experiments (see Chapters 4 and 7) were designed with a plain white background. The use of a white background instead of an image background makes the layout stand out from the background and avoids any distraction from the background that could alter the appearance of the layout. Thus, it can be confidently suggested that preference in previous experiments was based solely on the design of the layout and not on the background as there was "nothing" in the background.

Does this mean that layout aesthetics is only relevant with a plain white background? The answer is no. What this result means is that designers should make sure that the interface feature which they wish to be more noticeable should not be overshadowed by other features of the interface. Perhaps the most interesting finding of the current experiment is that EA has a stronger influence on preference than CA.

One of the main limitations of the finding of this experiment as well as in Chapter 4, 5, and 7 is that, in the preference task, only few examples were used to illustrate each layout metric. As all of the participants were presented with the same stimuli, it limits the number of examples to illustrate each layout metric. In the future, this experiment can be improved by using more examples for each layout metric. One way to do this is to create a program that generates real time stimuli, thus each participant would have different stimuli but still with the same layout properties.

8.8.5 Perceived ease of use

LAL with an ME background was perceived as the most easy to use and MAL with a HE background was perceived as the most difficult to use. This result means that users perceived an interface with an unstructured layout and an ME background as easy to use and an interface with a slightly structured/unstructured layout with a HE background as difficult to use.

This result was unexpected. It had been expected that participants would perceive HAL as the easiest and LAL as the most difficult. This expectation was made based on the result from previous studies (e.g. [65,137,144]) which demonstrated that an aesthetic interface is perceived as easier to use when compared to a less aesthetic interface.

How could an unstructured layout with an ME background be perceived as easy to use and a slightly unstructured/structured layout with an HE background be perceived as difficult to use? It could because of interference from the background. The background may have altered the perception of the interface so that the original "layout" is perceived as structured rather than unstructured (or vice versa). .

8.8.6 Preference vs. performance

The correlation between preference and performance (response time, errors) was not significant; this means that there was no association between layout preference and performance. This result confirms the result of Chapter 7.

This result also indicates that what is preferred by users does not reflect their actual performance; thus, should performance be the main concern, designers should focus on an interface design that improves task efficiency and effectiveness and not on what on users seem to like.

8.8.7 Perceived ease of use vs. performance

The correlation between perceived ease of use and performance (response time, errors) was not significant; this means that there was no association between perceived ease of use and performance.

This result indicates that what users perceive as easy to use does not predict that they will perform better; thus, again, should performance be the main concern, designers should focus on an interface design that improves task efficiency and effectiveness and not on what users perceive as easy to use.

8.8.8 Preference vs. perceived ease of use

The correlation between preference and perceived ease of use was highly significant; this means that there was a strong association between preference and perceived ease of use. This result indicates that preference judgments are essentially the same as perceived ease of use judgments (and vice versa).

8.9 Conclusions

The main purpose of this chapter was to investigate the relationship between CA and EA. CA was defined by the layout design and EA was defined by the expressivity of the background. The following research question was addressed:

1. What is the relationship between Classical layout aesthetics and background image expressivity?

   The aesthetics level of CA has a significant effect on search efficiency on ME and LE backgrounds, but not on HE backgrounds. Even so, the result failed to confirm the finding in Chapter 4 which demonstrated that performance (represented by response time) increases with increasing levels of CA, as the result showed that both high and low levels of CA supported good search efficiency. Based on the stability of the users' search efficiency at the three different levels of CA (HAL, MAL, and LAL) across three levels of EA (HE, ME, LE), it can be suggested that search speed is best supported by HAL as it is not affected by the change of expressivity of the background. For interfaces with poor layout design, the expressivity of the background should be kept to a minimum as high expressivity of the background definitely impairs search efficiency.

The way CA and EA affect search accuracy was different from search speed. The aesthetics level of CA had a significant effect on search accuracy only on HE backgrounds. There was no evidence found to support the claim in Chapter 7 that search accuracy increases with increasing levels of CA, as the result showed that search accuracy was highest with a medium level of CA.

The findings of this experiment are obviously inconsistent with the findings of Chapter 4 and Chapter 7, which demonstrated that performance and preference increased with increasing levels of CA. The different results demonstrate the huge impact of EA on performance and preference as well as the perception of ease of use of the interface. Contrary to what is reported in the literature, that a high aesthetics interface is more preferred and perceived as easier to use than a low aesthetics interface, this experiment found otherwise (Section 8.7.4 - 8.7.5). User preference and perception of the ease of use of the interface did not predict user performance. Nevertheless, user interface preference could be predicted by user ease-of-use judgments where the easier the interface is perceived to use, the more preferred the interface (Section 8.7.6).

The novel aspect of the findings of this experiment is that it has demonstrated the relationship between classical layout aesthetics and background image expressivity. To the best knowledge of the author, no studies have investigated performance with interfaces with respect to both CA and EA.

Chapter 9

Discussion and conclusion

This thesis has investigated the relationship between layout aesthetics, task performance, and preference. In Chapter 1, the thesis statement was as follows:

An empirically validated framework for the aesthetic design of visual interfaces is helpful to understand the relationships between layout aesthetics, task performance, and user preference in Human Computer Interaction.

The thesis statement and the following three research questions have been addressed throughout the thesis:

> **RQ1**: What is the relationship between the aesthetics of interface design and task performance?
>
> **RQ2**: What is the relationship between the aesthetics of interface design and user preference?
>
> **RQ3**: Is there any relationship between user preference and task performance?

These three questions have been addressed through a series of empirical experiments.

This chapter summarises the work reported in this thesis and discusses how the findings answer the three research questions above. It then describes a conceptual framework derived from this research, which could be referred to by interface designers or researchers who wish to design interfaces that are both aesthetically pleasing and support task performance and preference. The possibilities for future work in this research area are described. Finally, general conclusions are drawn from this research, with a focus on the main contributions of this thesis.

9.1 Thesis summary

Chapter 2 reviewed related research in visual aesthetics in HCI.

Chapter 3 discussed the rationale of this research as a whole and the rationale of each of the five experiments conducted in this research.

Chapter 4 reported an experiment investigating the effect of layout aesthetics on performance and preference, as well as the relationship between preference and performance. The effect of layout aesthetics was also compared between two search tools: with mouse pointing and without mouse pointing. Results showed that, regardless of search tool used performance (as represented by response time) increased with higher aesthetics levels, and decreased with lower aesthetics levels. Similarly, preference was highest for the higher aesthetics levels and lowest for the lower aesthetics levels. Preference and performance were found to be highly correlated. The results indicate that the aesthetic design of a computer interface supports both performance (as represented by response time) and preference, and that preference reflects actual performance (where response performance time was better when users liked the design of the interface and worse when users disliked the design of the interface). Figure 91 shows summary of results of an experiment reported in Chapter 4.

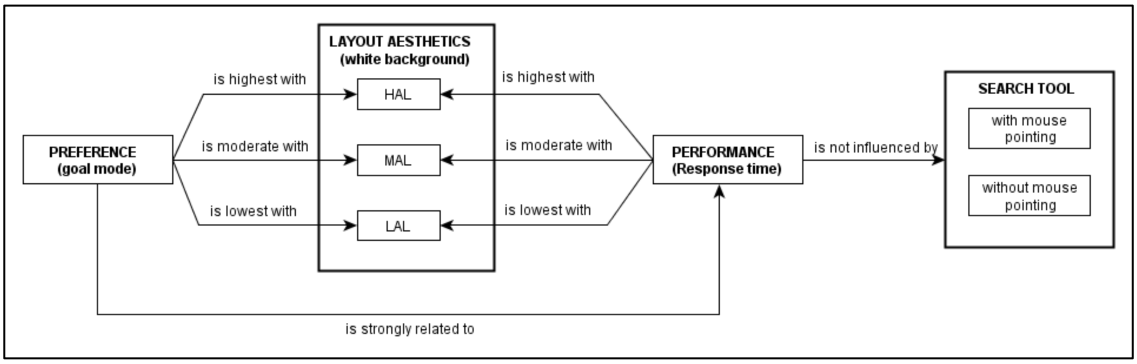


Figure 91. Summary of results of an experiment reported in Chapter 4

Chapter 5 reported an experiment investigating participants' preferences with fifteen layout metrics. This experiment was different to the preference task conducted in Chapter 4 as participants were not involved in a performance-based task before doing the preference task. This experiment aimed to investigate 1) participants' preferences at three main levels of aesthetics: high, medium, and low, 2) their preferences for fifteen layout metrics, and 3) the layout preferences of Asians and Westerners. Results showed that there was a large variation in preferences, which indicated that it is difficult to predict interface preference precisely. Among the three levels of aesthetics, preference was highest for the *medium* level of aesthetics and lowest for the low and high levels of aesthetics. The preference results with the 15 layout metrics showed highest preference for medium *symmetry* and lowest preference for the highest level of overall aesthetics. Whilst both cultural groups, Asians and Westerners, did not prefer the highest level of aesthetics, only the Asian participants showed any significant preferences for other layouts, with medium *symmetry* being ranked as the highest. These results indicate that people tend to prefer an interface with a moderate level of aesthetics and dislike an interface that has an extremely low or extremely high level of aesthetics. The preference variations between Westerners and Asians are relatively modest, thus design should be focused on creating interfaces with a medium level of aesthetics and not be overly concern with cultural differences. Figure 92 shows summary of results of an experiment reported in Chapter 5.

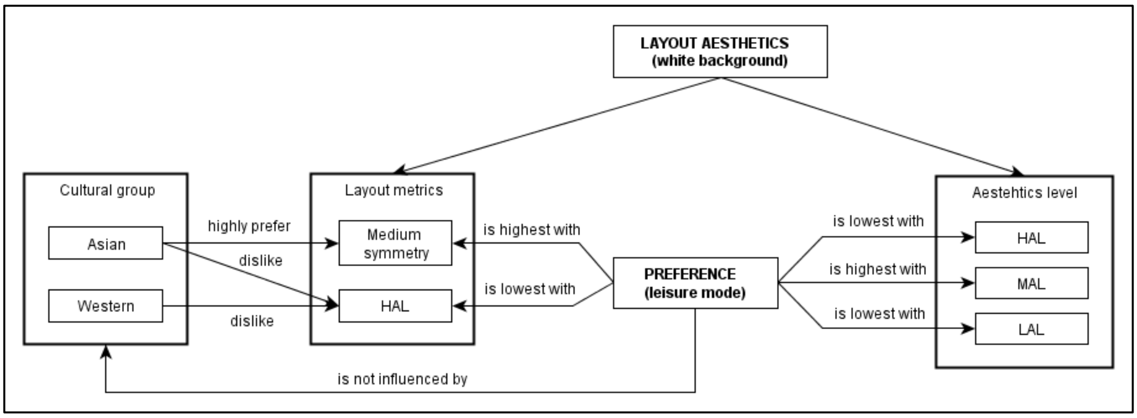


Figure 92. Summary of results of an experiment reported in Chapter 5

Chapter 6 reported an experiment investigating visual effort with respect to layout aesthetics. Visual effort was measured in terms of the number of fixations, gaze times, scan path length, and scan path duration. Visual effort was investigated with respect to the three main levels of aesthetics: high, medium and low, and six individual metrics. The results associated with the three levels of aesthetics showed that visual effort increased with at lower aesthetics level and decreased at higher aesthetics level. The result with the six layout metrics showed that overall *regularity* required less visual effort compared to the other five layout metrics. It was not clear, however, which layout metrics required the greatest amount of visual effort due to the lack of significant differences between the layout metrics. These results indicate the importance of designing interfaces with a high level of aesthetics or *regularity*, in order to reduce visual effort. Figure 93 shows summary of results of an experiment reported in Chapter 6.

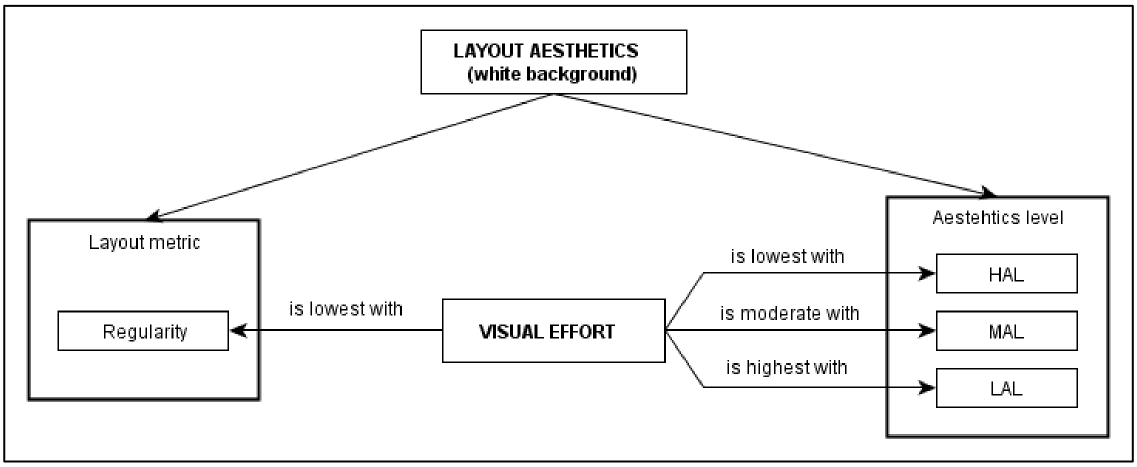


Figure 93. Summary of results of an experiment reported in Chapter 6

Chapter 7 reported an experiment investigating the effect of layout aesthetics on task performance and preference. This experiment was an extension of Chapter 4. The design of the experiment was similar to that in Chapter 4, except that the stimuli were more “ecologically valid”. The results support the conclusions made in Chapter 4, that aesthetics support accuracy performance and preference thereby increasing confidence in the earlier results (Figure 94).

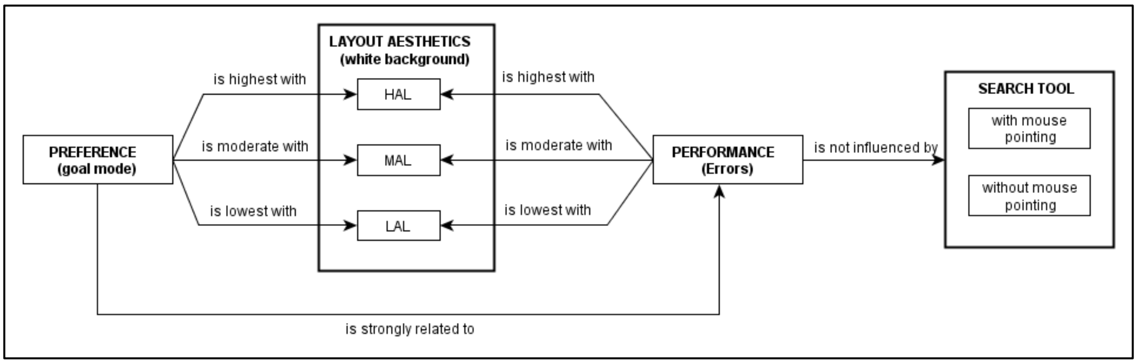


Figure 94. Summary of results of an experiment reported in Chapter 7

Chapter 8 reported an experiment investigating the relationship between classical layout aesthetics and background image expressivity. The results showed that in the context of classical aesthetics, performance was highest at high and low levels of aesthetics and worse at medium levels of aesthetics. In the context of expressive aesthetics, performance increased with a lower level of aesthetics, and performance decreased with a higher level of aesthetics. Preference and perceived ease of use were highest with low expressive aesthetics and lowest on medium expressive aesthetics. No correlation was found between either preference or perceived ease of use and performance, although, preference and perceived ease of use *were* strongly correlated. Figure 95 shows summary of results of an experiment reported in Chapter 8.

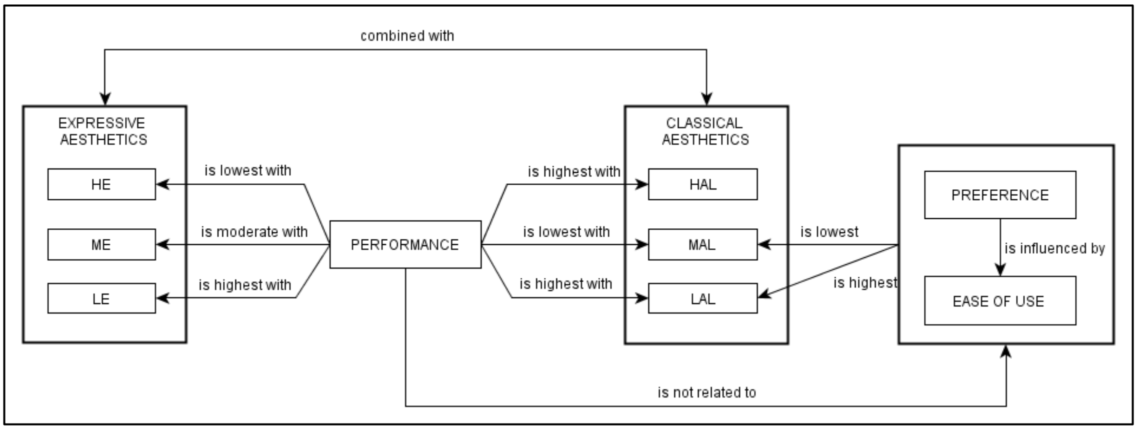


Figure 95. Summary of results of an experiment reported in Chapter 8

9.2 Research question 1

What is the relationship between the aesthetics of interface design and task performance?

Research Question 1 is answered in Chapters 4, 6, 7 and 8. The experiment reported in Chapter 4 revealed that there was a strong relationship between aesthetics and task performance where it was found that performance increased with increasing aesthetics level. Users' performance was shown to be genuinely affected by the aesthetics of the layout and not the search tool has a similar pattern of performance was observed when the participants were allowed to freely use the mouse during the search task and also when they were prohibited from using the mouse. This indicates that when the layout of an interface is aesthetically designed, regardless of search tool used (that is, whether users rely on eye movements alone or the aid of mouse pointing), performance is better with interfaces with higher aesthetics layouts than with those with lower aesthetics layouts.

The result of the experiment reported in Chapter 6 revealed that layout aesthetics has a strong relationship with visual effort, where visual effort decreased with increasing aesthetics level. This provides a good explanation for the performance with high aesthetics layouts, as compared to low aesthetics layouts reported in Chapter 4. In terms of visual effort with the six layout metrics, it was found that high *regularity* required the smallest amount of visual effort and high *cohesion* required the largest amount of visual effort. This ranking helps interface designers to choose the layout design that is most likely to support good search performance.

As the results in Chapter 4 were produced with “abstract” stimuli, its applicability to more “ecologically valid” stimuli was further investigated in Chapter 7. The findings in Chapter 4 were confirmed in Chapter 7 thus ensuring that regardless of the type of interface, performance is higher with interfaces with an aesthetic layout than with those with a less aesthetic layout. The performance with the 15 other layout metrics further showed that response time performance was best with medium *unity* and worst with high *economy*. Search accuracy was best with high *cohesion* and worst with low overall aesthetics levels.

The consistent results obtained in Chapters 4 and 7 suggest a strong influence of layout aesthetics on task performance. However, since both Chapter 4 and Chapter 7 used only plain white backgrounds, applicability to interfaces with more “visually rich” backgrounds was further investigated in Chapter 8. Chapter 8 provided no support for the claim made in Chapters 4 and 7 as the results of the experiment showed that performance was equally high with high and low levels of layout aesthetics. This indicates that the layout structure is less easily noticeable with “visually rich” backgrounds, as compared to “plain” backgrounds, such as white backgrounds. In order to guarantee that higher layout aesthetics support better performance, the “richness” of the background should be kept to a minimum.

Chapter 8 also investigated the relationship between the two dimensions of aesthetics: classical aesthetics and expressive aesthetics. The result showed that in the context of classical aesthetics, there was no concrete evidence that high classical aesthetics supported better performance or that low classical aesthetics degraded performance. This was, however, different with expressive aesthetics where there was very clear evidence which showed that high expressive aesthetics does not support good performance but low aesthetics does, which means that too much expressivity in an interface is not good for performance. Although there was no clear evidence that high classical aesthetics supported better performance than low classical aesthetics, overall, high classical aesthetics can still be considered as the most ideal choice as its response time performance was hardly affected by the changing of the expressivity of the background compared to medium and low levels of aesthetics.

The findings of this research indicate that interface aesthetics can be both supportive and detrimental to performance. Based on the consistent results between Chapters 4 and 7 which demonstrated better performance with high aesthetics layout, and the result in Chapter 8 which showed better performance with low expressivity backgrounds, it can be concluded that the main criterion of an interface that support good performance are “orderliness and clarity”. Thus, to ensure that the interface support good performance, the aesthetics of the interface should embody more “orderliness and clarity” or, in other words, following more the suggestion of usability experts rather than individualistic designers.

9.3 Research question 2

What is the relationship between the aesthetics of interface design and user preference?

Research Question 2 is answered in Chapters 4, 5, 7, and 8 through experiments investigating participants’ preferences for interface layouts. The results demonstrated users’ preferences for three main levels of aesthetics (high, medium, low) and for each of six layout metrics based on those of Ngo et. al.

The result in Chapter 4 showed that preference with the three levels of aesthetics was increase monotonically with aesthetics level, such that preference was higher with a higher level of aesthetics than with a layout lower level of aesthetics. Among the six layout metrics, preference was highest for *symmetry* and lowest for *economy*. To verify that this result was applicable to more “ecologically valid” stimuli, an experiment was conducted in Chapter 7. This experiment indicated that this result was applicable to more “ecologically valid” stimuli where the result of the 15 layout metrics showed that preference was highest for high aesthetics layouts and lowest for medium *economy*.

An experiment conducted in Chapter 8 investigated users’ preferences for layout in which the backgrounds were varied in expressivity level and not just limited to plain white. The result showed no replication of the result from Chapters 4 and 7 as preference was highest for the low aesthetics level and lowest for the medium aesthetics level. Does this means that layout aesthetics is not important for interfaces that do not use plain white backgrounds?

White backgrounds are arguably the "cleanest", and make the structure of the layout clearly visible. As shown in Chapters 4 and 7, with such a "clean" background the possibility of liking the high aesthetics layout is high. However, stating that the high aesthetics layout is more preferred than the low aesthetics layout when the background is "clean" is not true. It certainly increases the possibility of being preferred but not always. This was shown in Chapter 5, which showed preference results following an inverted-U-shaped pattern (i.e. preference was highest with medium levels of aesthetics, and lowest with high and low levels of aesthetics) instead of the monotonically increasing pattern of Chapters 4 and 7, even though the background of the stimuli was plain white. This difference was attributed to the different context of use in Chapter 5 compared to Chapters 4 and 7. In Chapters 4 and 7, the experiments were conducted in "goal mode" as the participants were involved with a performance-based task before the preference task. In Chapter 5, however, the preference task was conducted under "leisure mode" as there was no performance task before the preference task.

In "goal mode", preference is thought to be highly influenced by how the design of the interface helps users to perform the task with high efficiency and effectiveness. High aesthetics layouts with plain white backgrounds certainly helped users to perform better compared to low aesthetics layouts with expressive background. In "leisure mode" preference was highly influenced by the ability of the design to provide users with an enjoyable or exciting interaction with the system. Medium aesthetics layouts are arguably more enjoyable than high or low aesthetics layouts because they are less common than high aesthetics layouts but not as random as low aesthetics layouts. This combination of novelty with interpretability may make the medium aesthetics layouts more intriguing and interesting.

The findings of this research therefore indicate that preferences depend on the context of use: goal mode or leisure mode.

9.4 Research question 3

Is there any relationship between user preference and task performance?

Research Question 3 is answered in Chapters 4, 7, and 8 through experiments investigating performances and preferences in relation to aesthetics judgments.

In Chapter 4, the results showed that preference and performance were highly correlated. These results, however, were not replicated in Chapters 7 and 8 which used more "ecologically valid" stimuli. Due to the differing results between Chapters 4, 7 and 8 it is difficult to reach a definite conclusion as to whether there is a correlation between preference and performance in relation to aesthetics. Before drawing any conclusions, it is important to find the reasons why these experiments produced different results. There are two possible reasons. The first reason is the different methods used in the preference tasks. The second reason is the different number of stimuli used in the preference task in each experiment.

1. Direct ranking vs. pairwise comparisons

In the Chapter 4, the preference task was conducted by a direct ranking method. That means all stimuli were shown at once and the participants ranked the stimuli from least preferred to most preferred. Since all stimuli were shown at once, there was a possibility that the participants become less sensitive to the small differences between the stimuli. Insensitivity may have led participants to rank the stimuli without careful attention.

In Chapter 7, the preference task was conducted using pairwise comparisons. That means each stimulus was compared to other stimuli in pairs and the participants chose one stimulus from each pair. Since the stimuli were shown in pairs and not shown all at once, the participants could have become more sensitive even when there were small differences between the stimuli. Thus, it is possible that the preference decisions were made with more care.

Thus, the difference in the results of these experiments might be due to the extent of care with which participants ranked the stimuli.

2. Small number of stimuli vs. large number of stimuli

In Chapter 4, 9 stimuli used in the preference task. These stimuli were divided into two parts. In the first part, three stimuli were used and in the second part, 6 stimuli were used. Correlation between preference and performance was found with the stimuli used in the first part of the preference task but not with those used in the second part of the preference task.

In Chapter 7, 15 stimuli were used in the preference task. There was no correlation found between preference and performance.

The number of stimuli used in the preference task in Chapter 4 was obviously less (3 and 6 stimuli) than the stimuli used in the preference task in Chapter 7 (15 stimuli). A small number of stimuli means that the choice of the participants is limited whereas a larger number of stimuli means wider choice. It could be that the large number of stimuli made participants more careful with their choice than with a small number.

So, are preference and performance correlated? The answer to this question could be "yes" or "no". In the Chapter 4 it was clearly shown that there was a correlation between preference and performance. However, this result was based on a direct ranking method which makes participants less sensitive especially to small differences between stimuli. In Chapter 7, it was clearly shown that there was no correlation between preference and performance. However, this finding was based on a pairwise comparison method which means that participants were more aware of the small differences between stimuli. Thus, whether there is a correlation between preference and performance or not depends on how the experiment is conducted.

9.5 The framework

In addition to answering the three research questions posed in the introduction, another significant contribution of this thesis is the production of a conceptual framework for aesthetic design of computer interfaces which can be used by computer interface designers as a guideline to design interface that supports visual search and preference. This framework has been derived from the experimental results and mapped in Figure 96. Note that these guidelines apply irrespective of search tool (i.e. with or without the use of a mouse).

Guidelines for designing an aesthetic interface that support visual search performance

1. An aesthetic interface can be designed by focusing on the design of the interface layout.
2. The layout of the interface can be aesthetically designed using objective measures such as those proposed by Ngo et. al [94,97,98].
3. Seven out of the fourteen layout metrics proposed by Ngo et. al are sufficient to measure the aesthetics of layouts: *cohesion*, *economy*, *regularity*, *sequence*, *symmetry*, *unity*, and *order and complexity*.
4. The aesthetics of layouts is best represented by the composite measure of the six layout metrics than any individual metric.
5. For goal-oriented interfaces, in order to support both task performance and preference, the layout of the interface should be designed with high aesthetics and the background should be plain white.
6. For interfaces which use many different backgrounds, in order to increase the possibility of the interface supporting good performance, the background should be kept to the lowest expressivity possible.
7. For leisure-oriented interfaces, in order to support preference, the layout of the interface should be designed with medium aesthetics.
8. Preference of interfaces should not be taken as seriously as task performance because there is very little agreement as to which interface is the most preferred or least preferred.
9. There is only a modest difference in terms of Asian and Western cultures (at least for layout preference), thus when designing the interface, the difference between these two cultures needs not be taken into consideration.

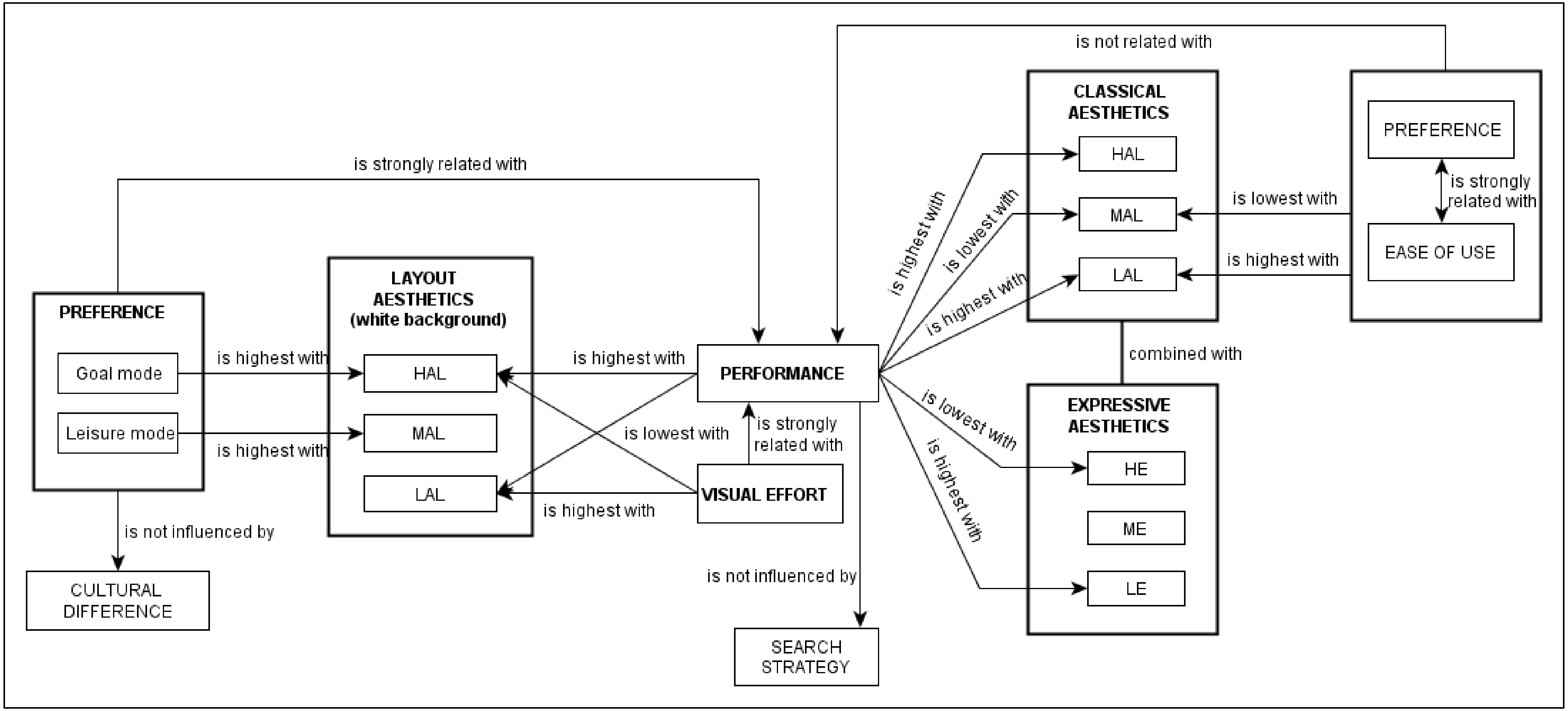


Figure 96. The conceptual framework for aesthetic design of computer interface

9.6 Conclusions

This thesis has investigated the relationship between aesthetic design, task performance, and preference. This thesis has provided the first detailed review of the fourteen layout metrics of graphic composition defined by Ngo et. al [98]. These can be reduced to just six yet still sufficiently measure the layout aesthetics of an interface. This is the first time that these six metrics have been applied to the design of layout interfaces in experiments that investigate performance and preference. The results from this research therefore provide a benchmark for future research in aesthetics, performance, and preference.

While a range of studies on visual aesthetics exist in the domain of human computer interaction, there has been little work done on investigating the applicability of objective measures of interface aesthetics in predicting task performance and preference. This thesis addresses the following question: *How do objective measures of interface aesthetics relate to performance and preference*? The results of this research have shown that objective measures are highly applicable in measuring layout interface aesthetics, as an interface that has a high aesthetics level produces good performance. Furthermore, by measuring the layout aesthetics of an interface using objective measures, there is no need to verify it with subjective judgment as it has already been verified in previous studies.

Objective measures have been used to measure layout aesthetics for stimuli used in a series of five experiments in this research. Studying task performance and preference for each level of layout aesthetics has enabled a deeper understanding of how aesthetics affects task performance and preference. These results provide information as to how and when layout aesthetics is most influential on performance and preference. Furthermore, a framework for aesthetic design has been derived from the experimental results to aid other researchers or interface designers in creating aesthetic interface designs that support performance and preference.

This thesis has successfully shown 1) the applicability of objective measures to measure the aesthetics of the layout of a computer interface, and 2) that the aesthetic design of a computer interface is beneficial for performance and preference. Therefore, objective measures can be used without hesitation, thus supporting design decisions. This is especially useful when collecting subjective judgment data is not possible.

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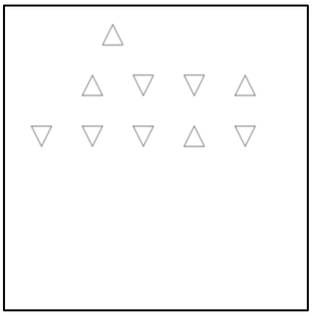
Appendix 1

The following are the set of stimuli used in Chapter 4, Chapter 5,Chapter 6, Chapter 7, and Chapter 8.

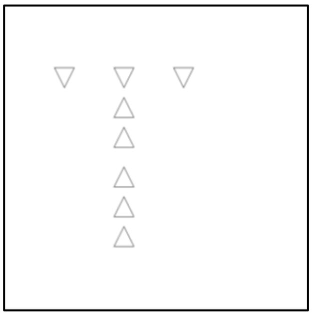
1. Chapter 4

a. HAL



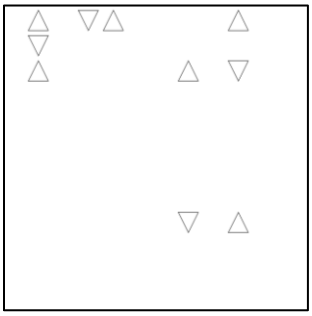
H1

CM	: 0.5455
EM	: 1.0000
RM	: 0.6139
SQM	: 1.0000
SYM	: 0.2905
UM	: 0.8614



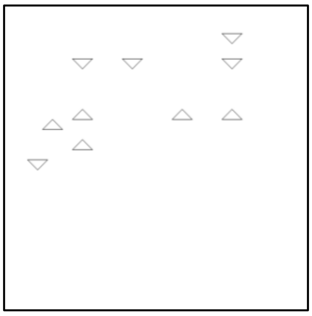
H2

CM	: 0.7778
EM	: 1.0000
RM	: 0.6116
SQM	: 0.7500
SYM	: 0.3067
UM	: 0.8665



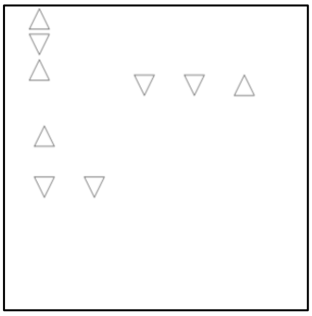
H3

CM	: 1.0000
EM	: 1.0000
RM	: 0.5333
SQM	: 0.7500
SYM	: 0.3128
UM	: 0.7364



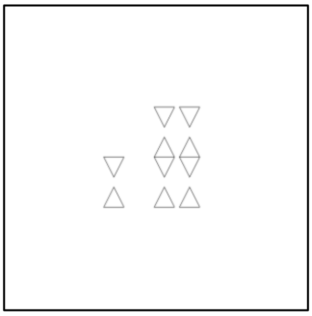
H4

CM	: 0.7121
EM	: 1.0000
RM	: 0.5333
SQM	: 1.0000
SYM	: 0.2462
UM	: 0.8426



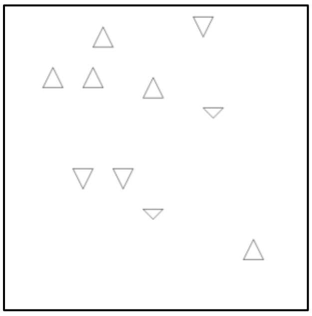
H5

CM	: 0.8222
EM	: 1.0000
RM	: 0.4514
SQM	: 1.0000
SYM	: 0.2871
UM	: 0.7742



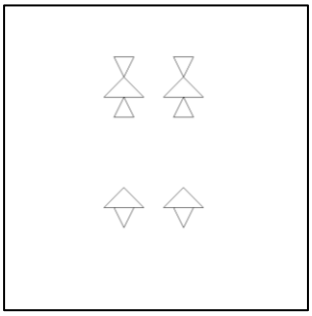
H6

CM	: 0.9500
EM	: 1.0000
RM	: 0.7944
SQM	: 0.2500
SYM	: 0.3929
UM	: 0.9574



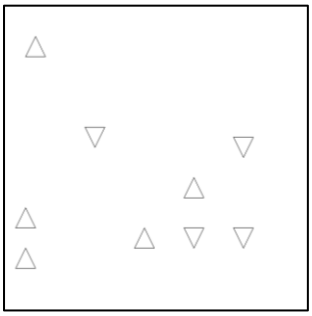
H7

CM	: 0.8708
EM	: 0.5000
RM	: 0.3250
SQM	: 1.0000
SYM	: 1.0000
UM	: 0.6609



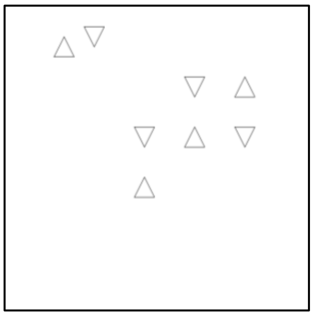
H8

CM	: 0.5294
EM	: 0.5000
RM	: 0.6889
SQM	: 1.0000
SYM	: 0.8248
UM	: 0.8686



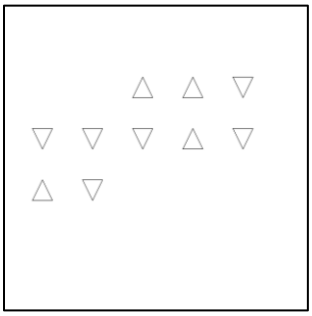
H9

CM : 0.9583
EM : 1.0000
RM : 0.4201
SQM : 0.7500
SYM : 0.5877
UM : 0.6973



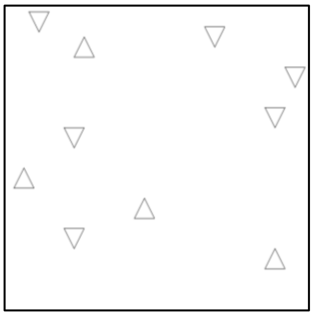
H10

CM : 0.8500
EM : 1.0000
RM : 0.4821
SQM : 1.0000
SYM : 0.2660
UM : 0.8167



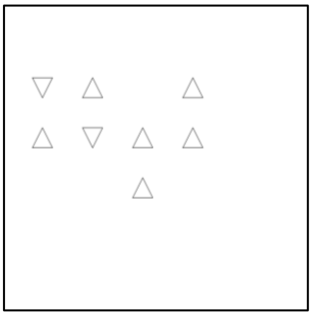
H11

CM : 0.5455
EM : 1.0000
RM : 0.6694
SQM : 1.0000
SYM : 0.3519
UM : 0.8614



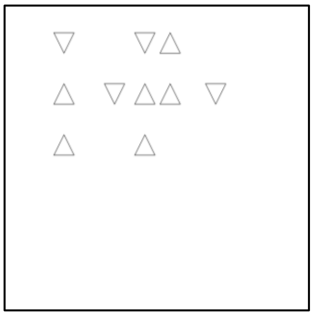
H12

CM : 0.8793
EM : 1.0000
RM : 0.2444
SQM : 1.0000
SYM : 0.7148
UM : 0.5912



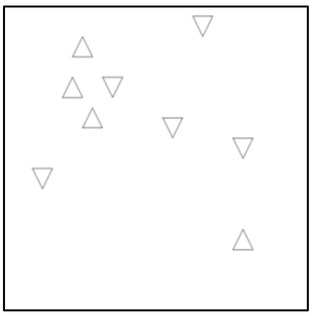
H13

CM : 0.7059
EM : 1.0000
RM : 0.6116
SQM : 1.0000
SYM : 0.2372
UM : 0.8937



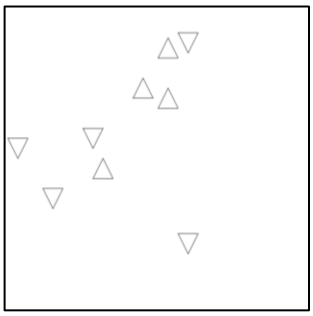
H14

CM : 0.7059
EM : 1.0000
RM : 0.5833
SQM : 1.0000
SYM : 0.2683
UM : 0.8955



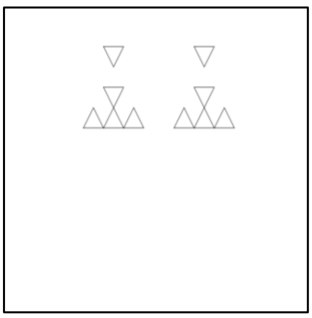
H15

CM : 0.9565
EM : 1.0000
RM : 0.2465
SQM : 1.0000
SYM : 0.5614
UM : 0.7234



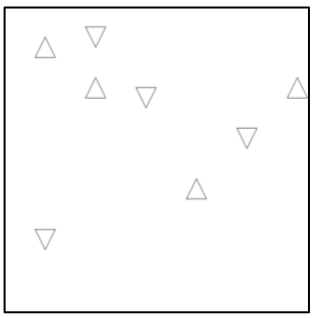
H16

CM : 0.8636
EM : 1.0000
RM : 0.2743
SQM : 1.0000
SYM : 0.6010
UM : 0.7732



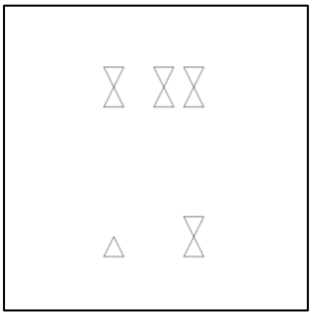
H17

CM : 0.5333
EM : 1.0000
RM : 0.7194
SQM : 1.0000
SYM : 0.3255
UM : 0.9432



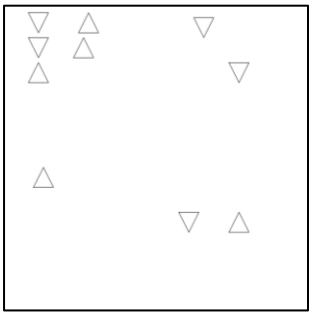
H18

CM : 0.8148
EM : 1.0000
RM : 0.4866
SQM : 1.0000
SYM : 0.5614
UM : 0.6731



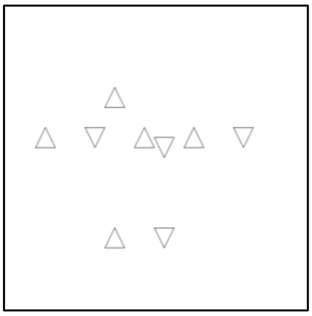
H19

CM : 0.5263
EM : 1.0000
RM : 0.7118
SQM : 0.7500
SYM : 0.6902
UM : 0.9025



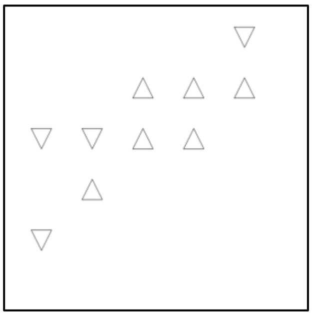
H20

CM : 1.0000
EM : 1.0000
RM : 0.3250
SQM : 1.0000
SYM : 0.5429
UM : 0.7364



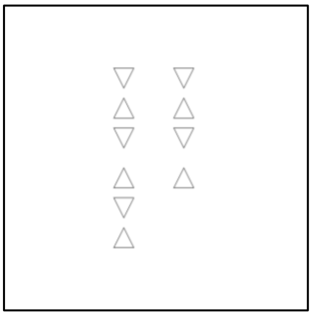
H21

CM : 0.7273
EM : 1.0000
RM : 0.4826
SQM : 1.0000
SYM : 0.6075
UM : 0.8107



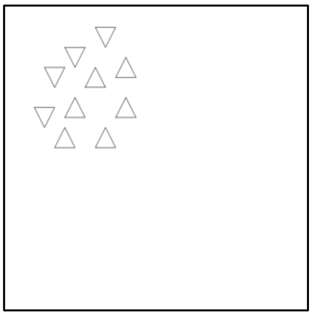
H22

CM : 1.0000
EM : 1.0000
RM : 0.6139
SQM : 1.0000
SYM : 0.3617
UM : 0.7364



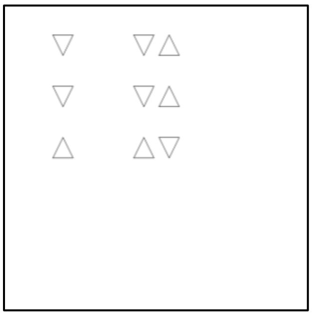
H23

CM : 0.4444
EM : 1.0000
RM : 0.7167
SQM : 1.0000
SYM : 0.6921
UM : 0.9295



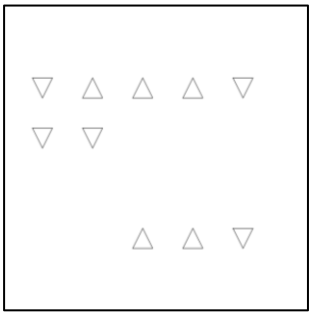
H24

CM : 0.8333
EM : 1.0000
RM : 0.5139
SQM : 1.0000
SYM : 0.5000
UM : 0.9432



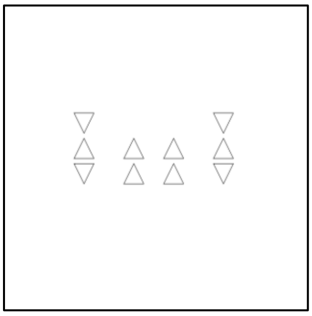
H25

CM : 0.9600
EM : 1.0000
RM : 0.6563
SQM : 1.0000
SYM : 0.2651
UM : 0.9252



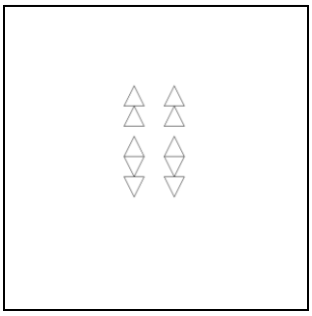
H26

CM : 1.0000
EM : 0.7727
RM : 0.6667
SQM : 1.0000
SYM : 0.6035
UM : 0.7989



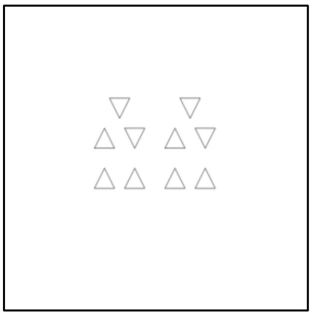
H27

CM : 0.4375
EM : 1.0000
RM : 0.6889
SQM : 1.0000
SYM : 0.8514
UM : 0.9477



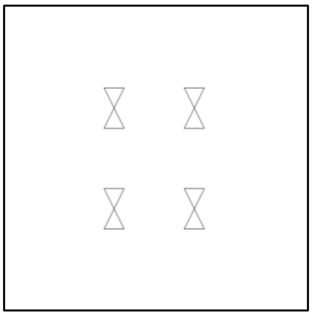
H28

CM : 0.5455
EM : 1.0000
RM : 0.7944
SQM : 1.0000
SYM : 0.7873
UM : 0.9739



H29

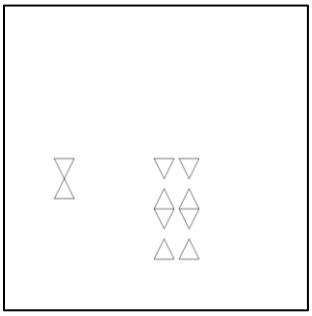
CM : 0.7500
EM : 1.0000
RM : 0.6389
SQM : 1.0000
SYM : 0.8230
UM : 0.9500



H30

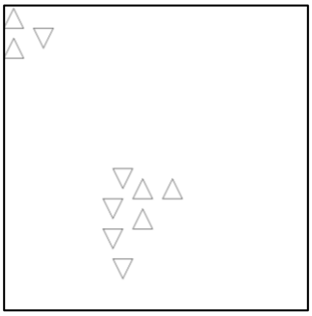
CM : 0.7143
EM : 1.0000
RM : 0.7411
SQM : 1.0000
SYM : 1.0000
UM : 0.9299

b. MAL



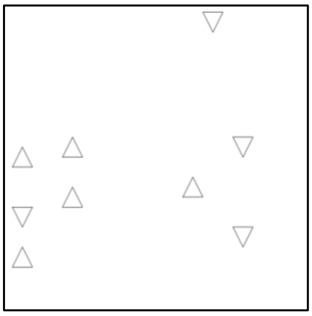
M1

CM : 0.5000
EM : 1.0000
RM : 0.7988
SQM : 0.0000
SYM : 0.3934
UM : 0.8789



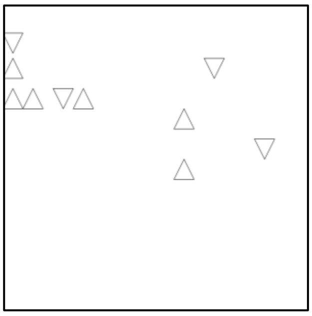
M2

CM : 0.6667
EM : 1.0000
RM : 0.5611
SQM : 0.5000
SYM : 0.2048
UM : 0.7352



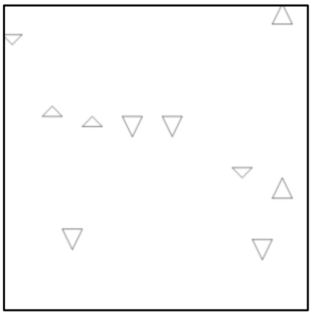
M3

CM : 0.9412
EM : 1.0000
RM : 0.3889
SQM : 0.2500
SYM : 0.4372
UM : 0.6633



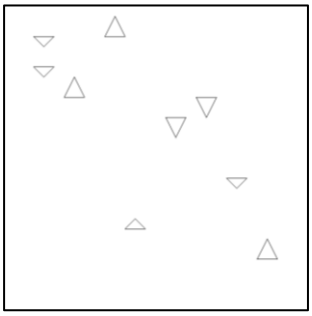
M4

CM : 0.5370
EM : 1.0000
RM : 0.4306
SQM : 0.7500
SYM : 0.1760
UM : 0.7889



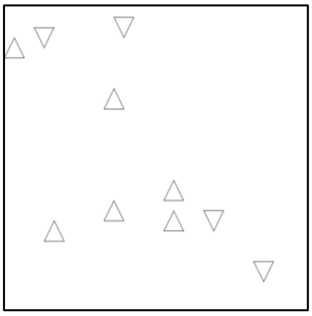
M5

CM : 0.8057
EM : 0.5000
RM : 0.4083
SQM : 0.7500
SYM : 0.6837
UM : 0.5490



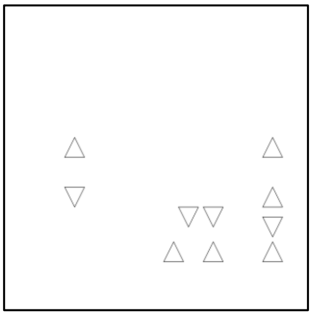
M6

CM : 0.8889
EM : 0.5000
RM : 0.3958
SQM : 0.7500
SYM : 0.5575
UM : 0.6273



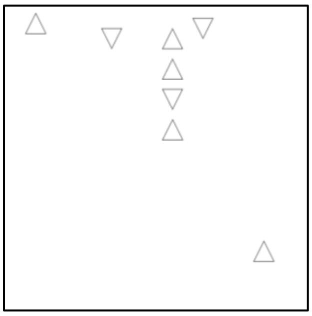
M7

CM : 0.9630
EM : 1.0000
RM : 0.3000
SQM : 0.5000
SYM : 0.3464
UM : 0.6125



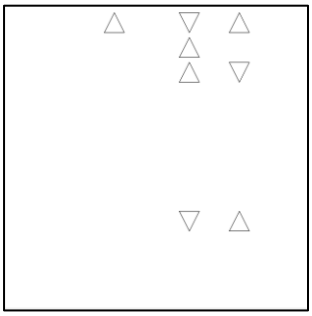
M8

CM : 0.5682
EM : 1.0000
RM : 0.5556
SQM : 0.2500
SYM : 0.4967
UM : 0.8551



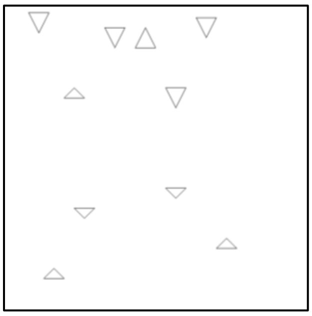
M9

CM : 1.0000
EM : 1.0000
RM : 0.3080
SQM : 0.5000
SYM : 0.2815
UM : 0.6695



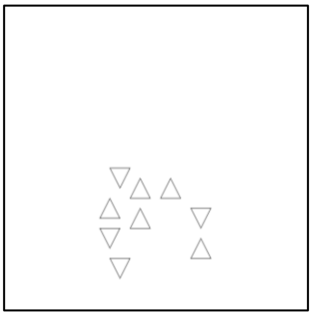
M10

CM : 0.6591
EM : 1.0000
RM : 0.5089
SQM : 0.5000
SYM : 0.2673
UM : 0.8286



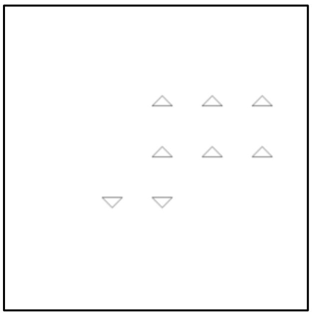
M11

CM : 0.6769
EM : 0.5000
RM : 0.2750
SQM : 1.0000
SYM : 0.6719
UM : 0.6516



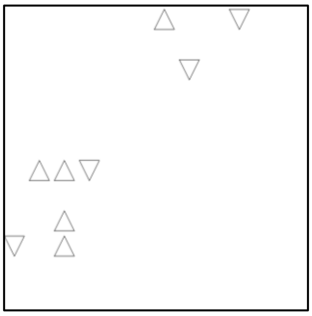
M12

CM : 1.0000
EM : 1.0000
RM : 0.5694
SQM : 0.0000
SYM : 0.2779
UM : 0.9416



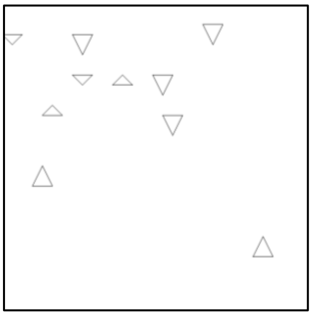
M13

CM : 0.7099
EM : 1.0000
RM : 0.7098
SQM : 0.2500
SYM : 0.2305
UM : 0.8997



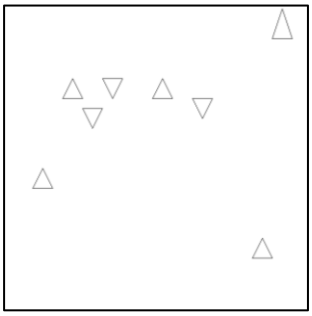
M14

CM : 1.0000
EM : 1.0000
RM : 0.3646
SQM : 0.5000
SYM : 0.2668
UM : 0.6699



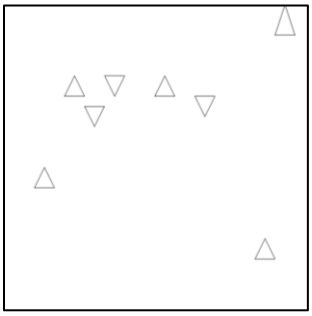
M15

CM : 0.7989
EM : 0.5000
RM : 0.4056
SQM : 1.0000
SYM : 0.5213
UM : 0.6078



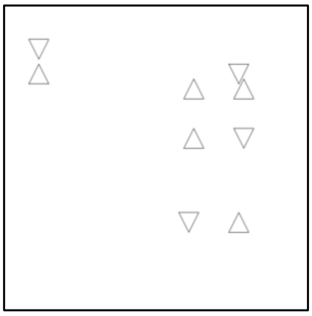
M16

CM : 0.9415
EM : 0.5000
RM : 0.2411
SQM : 1.0000
SYM : 0.5912
UM : 0.5791



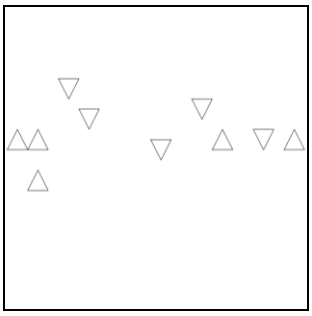
M17

CM : 0.9415
EM : 0.5000
RM : 0.2411
SQM : 1.0000
SYM : 0.5912
UM : 0.5791



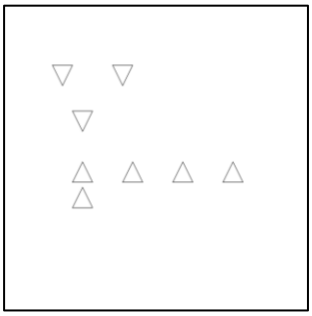
M18

CM : 0.8667
EM : 1.0000
RM : 0.4201
SQM : 0.5000
SYM : 0.3565
UM : 0.7615



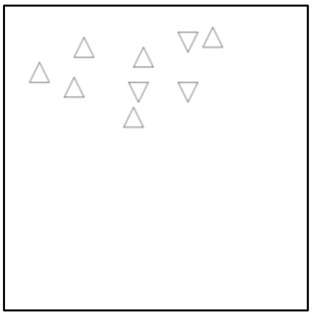
M19

CM	: 0.3793
EM	: 1.0000
RM	: 0.4333
SQM	: 1.0000
SYM	: 0.2647
UM	: 0.8301



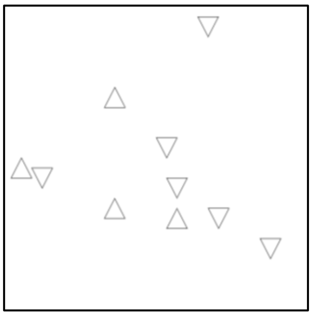
M20

CM	: 0.7368
EM	: 1.0000
RM	: 0.4732
SQM	: 0.5000
SYM	: 0.3513
UM	: 0.8586



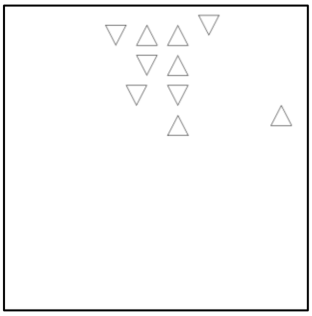
M21

CM	: 0.5128
EM	: 1.0000
RM	: 0.3333
SQM	: 1.0000
SYM	: 0.2765
UM	: 0.8997



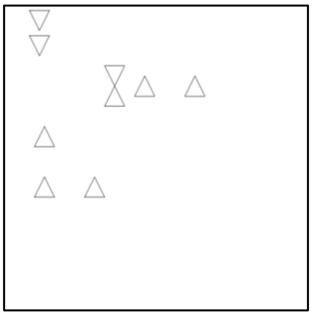
M22

CM	: 0.9231
EM	: 1.0000
RM	: 0.3806
SQM	: 0.5000
SYM	: 0.6099
UM	: 0.6568



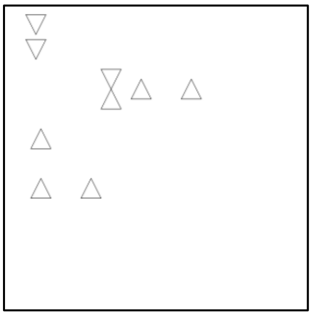
M23

CM	: 0.6667
EM	: 1.0000
RM	: 0.4833
SQM	: 0.7500
SYM	: 0.2947
UM	: 0.8886



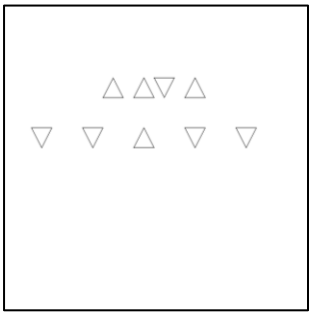
M24

CM	: 0.9459
EM	: 1.0000
RM	: 0.3889
SQM	: 0.7500
SYM	: 0.2123
UM	: 0.8267



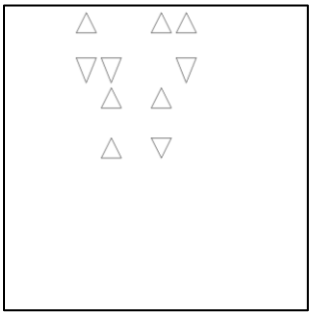
M25

CM	: 0.9459
EM	: 1.0000
RM	: 0.3889
SQM	: 0.7500
SYM	: 0.2123
UM	: 0.8267



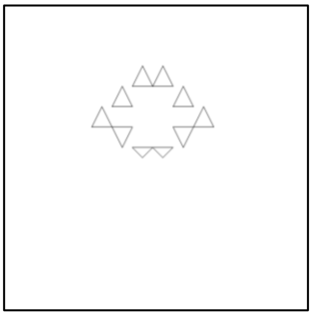
M26

CM	: 0.3182
EM	: 1.0000
RM	: 0.5694
SQM	: 1.0000
SYM	: 0.3173
UM	: 0.9229



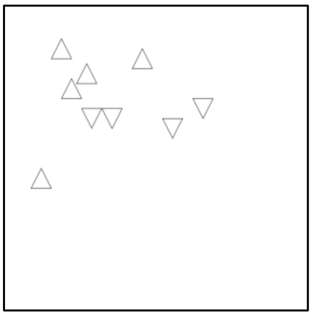
M27

CM	: 0.8484
EM	: 0.5000
RM	: 0.6361
SQM	: 1.0000
SYM	: 0.3026
UM	: 0.8632



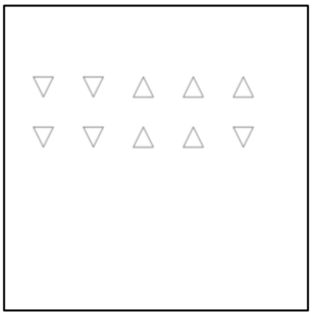
M28

CM	: 0.7417
EM	: 0.5000
RM	: 0.7222
SQM	: 1.0000
SYM	: 0.3333
UM	: 0.8990



M29

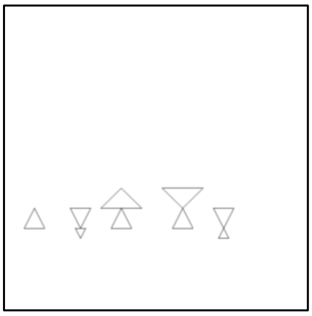
CM : 0.8333
EM : 1.0000
RM : 0.3118
SQM : 1.0000
SYM : 0.2030
UM : 0.7771



M30

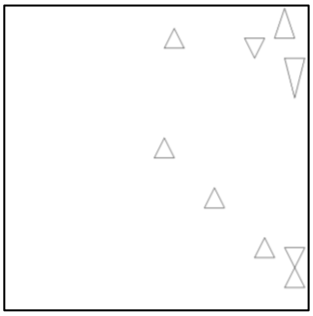
CM : 0.2282
EM : 1.0000
RM : 0.7194
SQM : 1.0000
SYM : 0.2874
UM : 0.9119

c. LAL



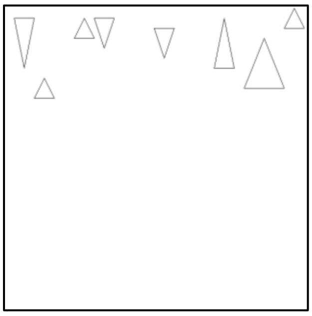
L1

CM : 0.2710
EM : 0.3333
RM : 0.4201
SQM : 0.0000
SYM : 0.3116
UM : 0.8415



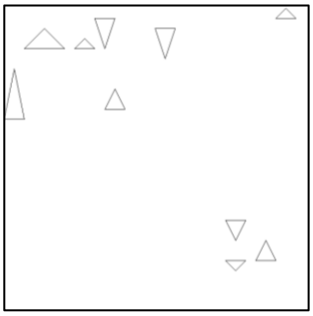
L2

CM : 0.5727
EM : 0.3333
RM : 0.3646
SQM : 0.2500
SYM : 0.3025
UM : 0.6619



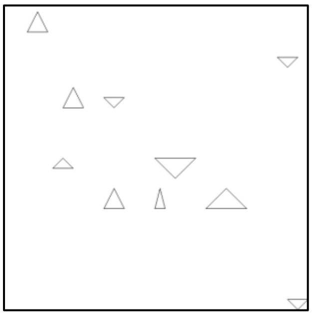
L3

CM : 0.2703
EM : 0.2500
RM : 0.3482
SQM : 0.7500
SYM : 0.3129
UM : 0.6806



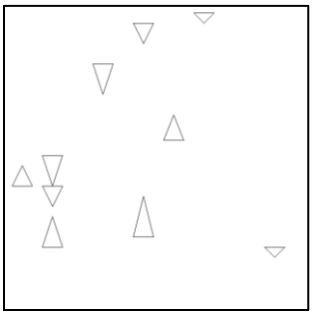
L4

CM : 0.7720
EM : 0.2000
RM : 0.3500
SQM : 0.7500
SYM : 0.3398
UM : 0.3833



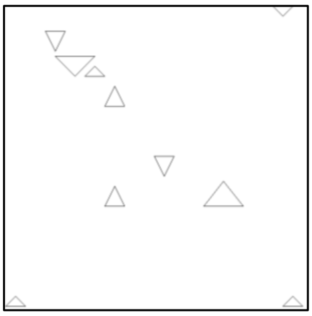
L5

CM : 0.7726
EM : 0.2500
RM : 0.3500
SQM : 0.5000
SYM : 0.6082
UM : 0.4004



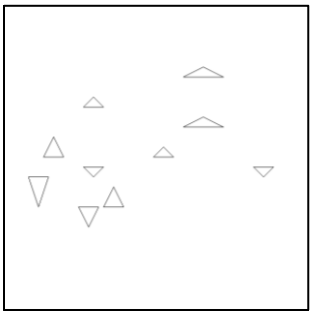
L6

CM : 0.7807
EM : 0.2000
RM : 0.3750
SQM : 0.5000
SYM : 0.5895
UM : 0.4438



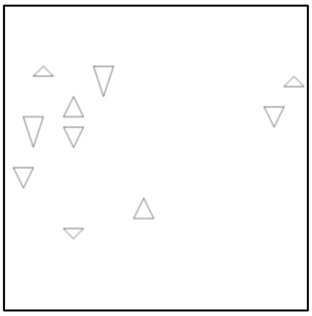
L7

CM : 0.8542
EM : 0.2500
RM : 0.2970
SQM : 0.5000
SYM : 0.6800
UM : 0.3600



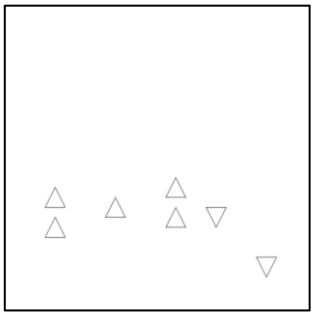
L8

CM : 0.6377
EM : 0.2500
RM : 0.3750
SQM : 0.5000
SYM : 0.5880
UM : 0.6377



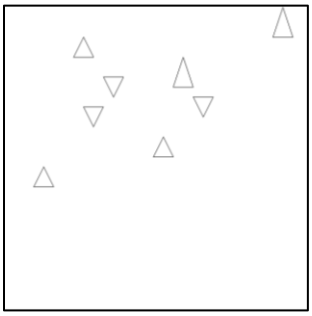
L9

CM : 0.4067
EM : 0.3333
RM : 0.2222
SQM : 0.7500
SYM : 0.3404
UM : 0.6310



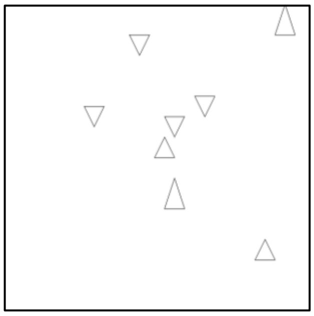
L10

CM : 0.3348
EM : 1.0000
RM : 0.4405
SQM : 0.0000
SYM : 0.3019
UM : 0.8781



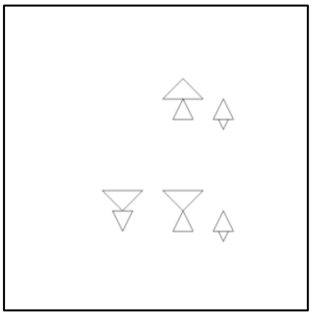
L11

CM : 0.5635
EM : 0.5000
RM : 0.2143
SQM : 0.7500
SYM : 0.2699
UM : 0.6824



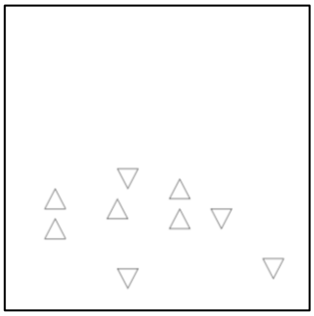
L12

CM : 0.6342
EM : 0.5000
RM : 0.2411
SQM : 0.5000
SYM : 0.3727
UM : 0.6501



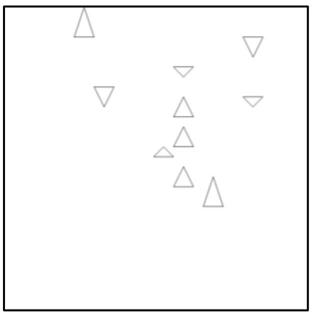
L13

CM : 0.7516
EM : 0.3333
RM : 0.4861
SQM : 0.2500
SYM : 0.3834
UM : 0.7945



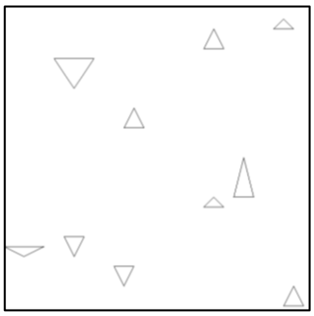
L14

CM : 0.4007
EM : 1.0000
RM : 0.4236
SQM : 0.0000
SYM : 0.3152
UM : 0.8537



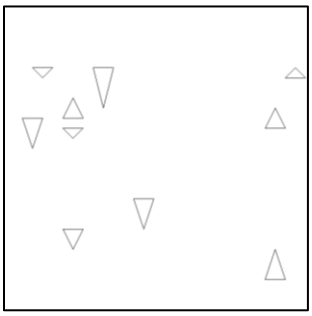
L15

CM : 0.8539
EM : 0.3333
RM : 0.4583
SQM : 0.4000
SYM : 0.3036
UM : 0.5951



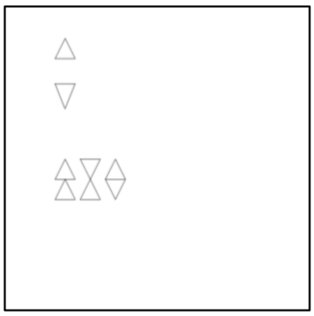
L16

CM : 0.8526
EM : 0.2000
RM : 0.2750
SQM : 0.6500
SYM : 0.6718
UM : 0.2171



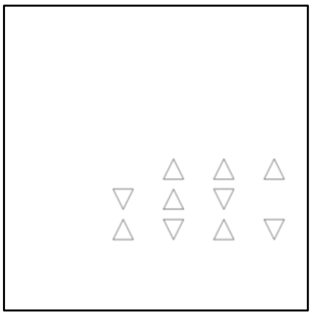
L17

CM : 0.5813
EM : 0.2500
RM : 0.4000
SQM : 0.6500
SYM : 0.5405
UM : 0.5277



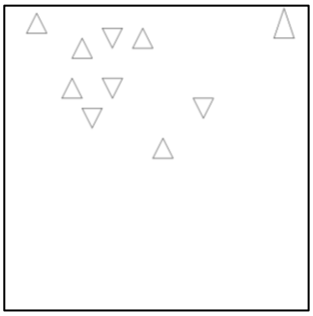
L18

CM : 0.3443
EM : 0.5000
RM : 0.5429
SQM : 0.5000
SYM : 0.2838
UM : 0.7835



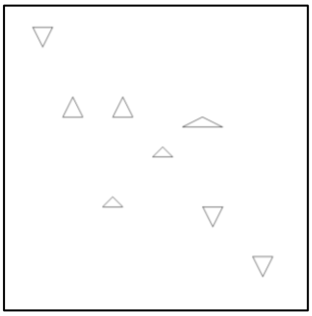
L19

CM : 0.3706
EM : 1.0000
RM : 0.3875
SQM : 0.0000
SYM : 0.2100
UM : 0.9331



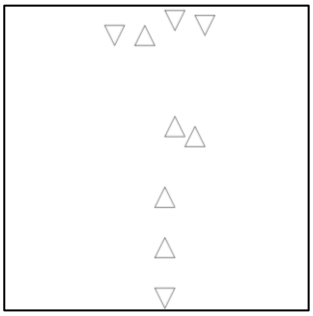
L20

CM : 0.3566
EM : 0.5000
RM : 0.3000
SQM : 1.0000
SYM : 0.1528
UM : 0.6358



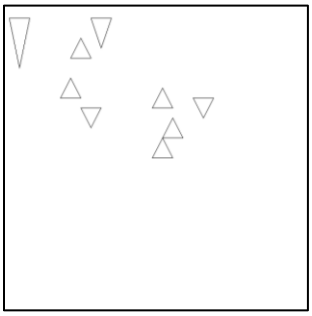
L21

CM : 0.7550
EM : 0.3333
RM : 0.2768
SQM : 0.7500
SYM : 0.4025
UM : 0.4443



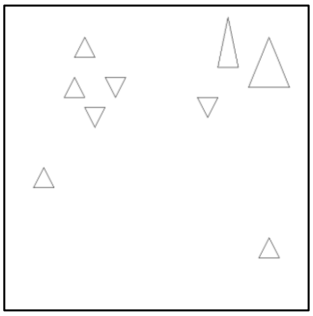
L22

CM : 0.2339
EM : 1.0000
RM : 0.2021
SQM : 0.5000
SYM : 0.3750
UM : 0.6262



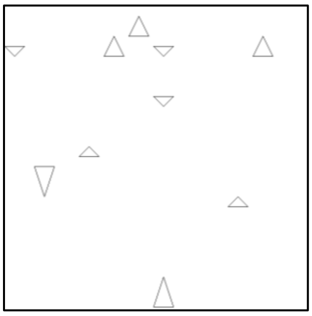
L23

CM : 0.4447
EM : 0.3333
RM : 0.2924
SQM : 1.0000
SYM : 0.2708
UM : 0.6420



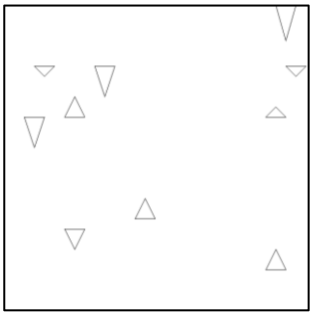
L24

CM : 0.8900
EM : 0.3333
RM : 0.1003
SQM : 0.7500
SYM : 0.4001
UM : 0.5001



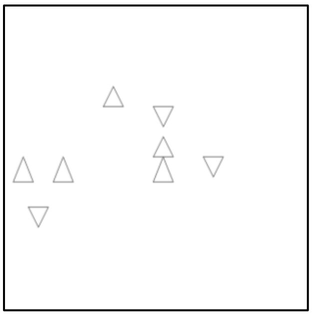
L25

CM : 0.7932
EM : 0.3333
RM : 0.4056
SQM : 1.0000
SYM : 0.6348
UM : 0.4663



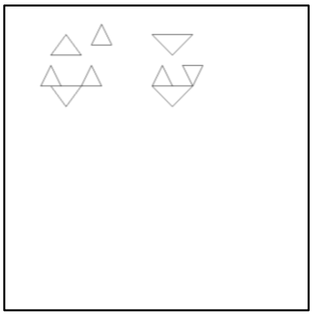
L26

CM : 0.7011
EM : 0.2500
RM : 0.3008
SQM : 1.0000
SYM : 0.4002
UM : 0.3201



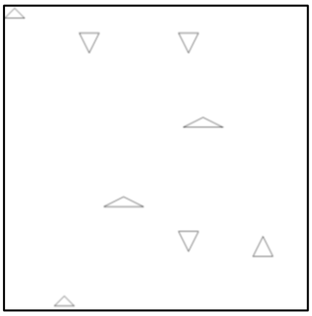
L27

CM : 0.4117
EM : 0.5000
RM : 0.4446
SQM : 0.5000
SYM : 0.4204
UM : 0.6008



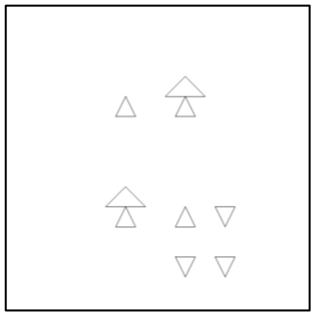
L28

CM : 0.3333
EM : 0.3333
RM : 0.3110
SQM : 1.0000
SYM : 0.2110
UM : 0.7795



L29

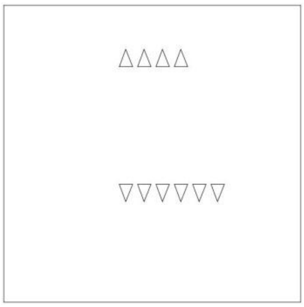
CM : 0.6034
EM : 0.3333
RM : 0.1111
SQM : 1.0000
SYM : 0.5401
UM : 0.3258



L30

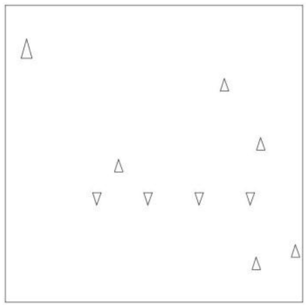
CM : 0.4412
EM : 0.5000
RM : 0.4230
SQM : 0.5000
SYM : 0.4123
UM : 0.6100

2. Chapter 5



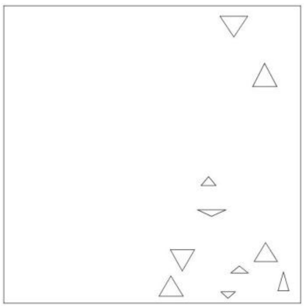
High

CM : 0.8121
EM : 1.0000
RM : 1.0000
SQM : 1.0000
SYM : 0.8277
UM : 0.9211



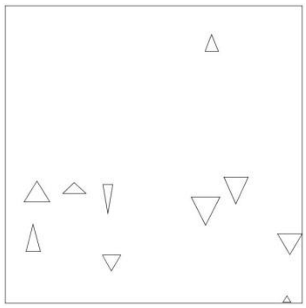
Medium

CM : 0.7451
EM : 0.5000
RM : 0.6744
SQM : 0.5000
SYM : 0.7561
UM : 0.6241



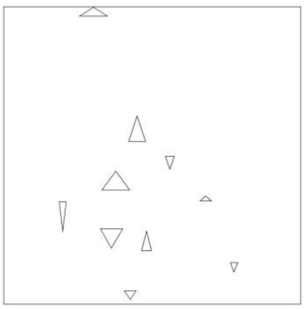
Low

CM : 0.4121
EM : 0.1000
RM : 0.0012
SQM : 0.2114
SYM : 0.2144
UM : 0.3333



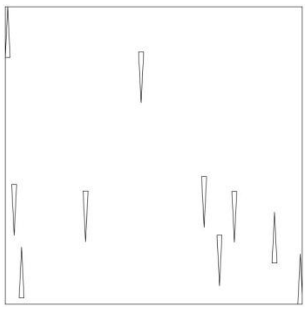
High_Cohesion

CM : 0.9144
EM : 0.1
RM : 0.0
SQM : 0.0274
SYM : 0.3177
UM : 0.1



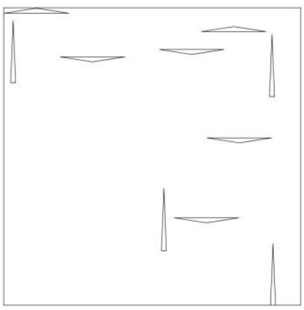
Medium_Cohesion

CM : 0.5884
EM : 0.1
RM : 0.0278
SQM : 0.25
SYM : 0.3191
UM : 0.2588



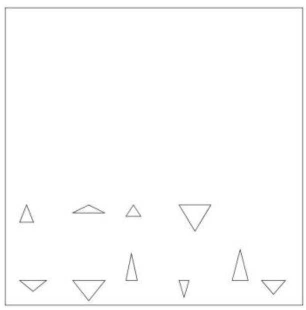
High_Economy

CM : 0.5
EM : 1.0
RM : 0.0
SQM : 0.0
SYM : 0.4
UM : 0.5



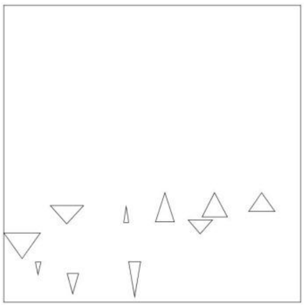
Medium_Economy

CM : 0.4952
EM : 0.5
RM : 0.0278
SQM : 0.25
SYM : 0.4003
UM :0.4957



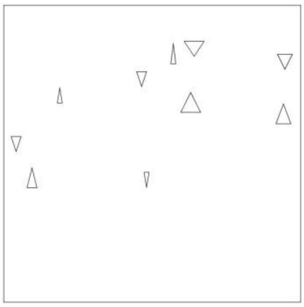
High_Regularity

CM : 0.4062
EM : 0.1
RM : 0.8889
SQM : 0.0
SYM : 0.3078
UM : 0.4143



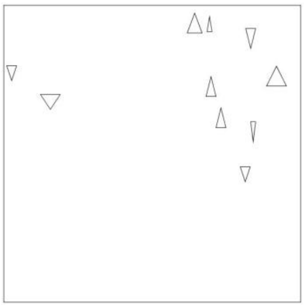
Medium Regularity

CM : 0.3784
EM : 0.1
RM : 0.6111
SQM : 0.0
SYM :0.2861
UM :0.399



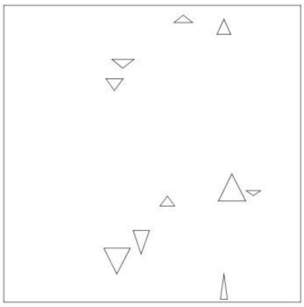
High Sequence

CM : 0.4121
EM : 0.1
RM : 0.1112
SQM : 0.8114
SYM : 0.3142
UM : 0.4211



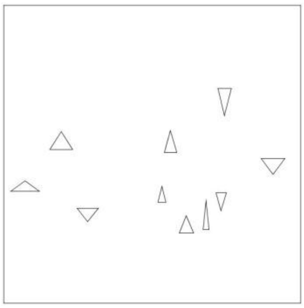
Medium Sequence

CM : 0.4973
EM : 0.1429
RM : 0.0278
SQM : 0.5
SYM : 0.1805
UM : 0.4364



High Symmetry

CM : 0.4946
EM : 0.1
RM : 0.0556
SQM : 0.25
SYM :0.7527
UM :0.3027

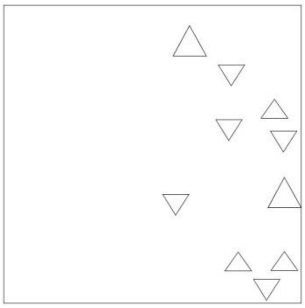


Medium Symmetry

CM : 0.4961
EM : 0.1
RM : 0.0556
SQM : 0.25
SYM : 0.5524
UM :0.3308

High Unity

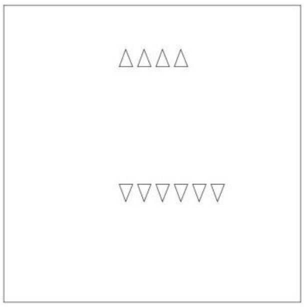
CM : 0.4132
EM : 0.3333
RM : 0.0
SQM : 0.2142
SYM : 0.3147
UM : 0.8767



Medium Unity

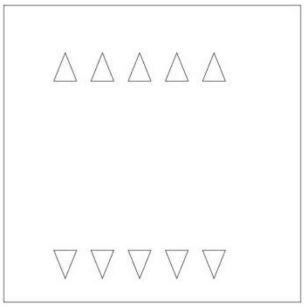
CM : 0.4522
EM : 0.3333
RM : 0.556
SQM : 0.25
SYM : 0.3211
UM : 0.6966

3. Chapter 6



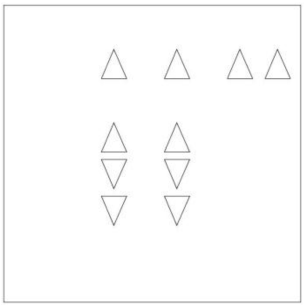
HAL1

CM : 0.8
EM : 1.0
RM : 1.0
SQM : 1.0
SYM : 0.8
UM : 0.9



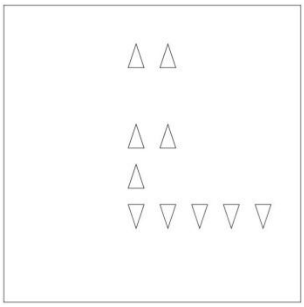
HAL2

CM : 0.9
EM : 1.0
RM : 1.0
SQM : 0.8
SYM : 0.8
UM : 0.8



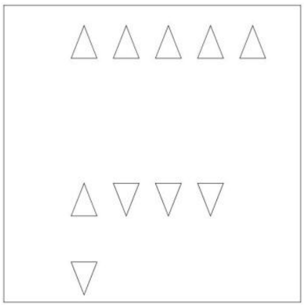
HAL2

CM : 0.8686
EM : 1.0
RM : 0.9167
SQM : 0.75
SYM : 0.7238
UM : 0.8258



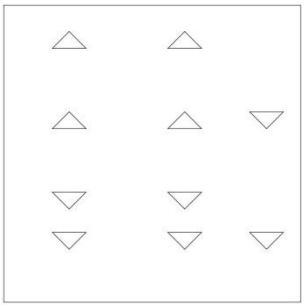
HAL4

CM : 0.8
EM : 1.0
RM : 0.9
SQM : 1.0
SYM : 0.8
UM : 0.9



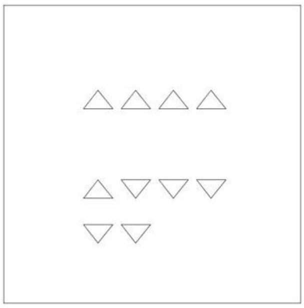
HAL5

CM : 0.8191
EM : 1.0
RM : 0.9444
SQM : 0.75
SYM : 0.7709
UM : 0.7146



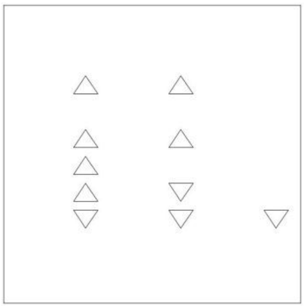
HAL6

CM : 0.7364
EM : 1.0
RM : 0.9167
SQM : 0.75
SYM : 0.8572
UM : 0.723



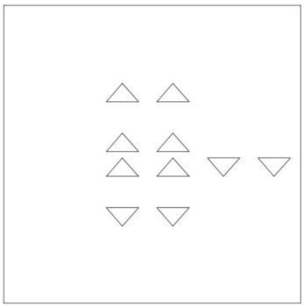
HAL7

CM : 0.8
EM : 1.0
RM : 0.9
SQM : 1.0
SYM : 0.8
UM : 0.9



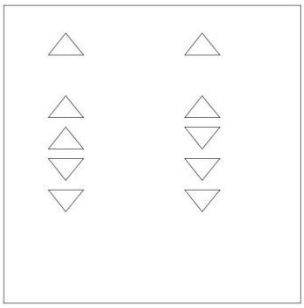
HAL8

CM : 0.8
EM : 1.0
RM : 0.9
SQM : 1.0
SYM : 0.8
UM : 0.8



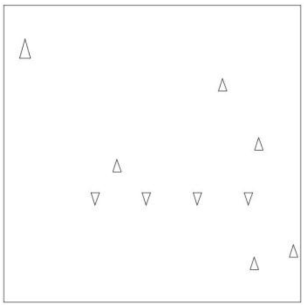
HAL9

CM : 0.7547
EM : 1.0
RM : 0.9444
SQM : 1.0
SYM : 0.8004
UM : 0.8643



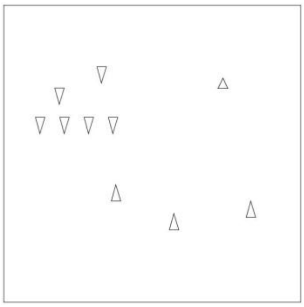
HAL10

CM : 0.7805
EM : 1.0
RM : 0.9444
SQM : 1.0
SYM : 0.7504
UM : 0.8423



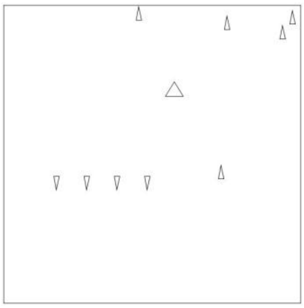
MAL1

CM : 0.7
EM : 0.5
RM : 0.6
SQM : 0.5
SYM : 0.7
UM : 0.6



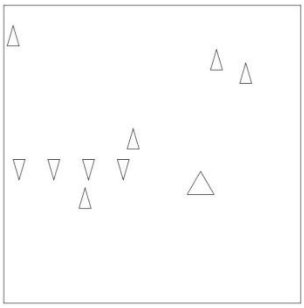
MAL2

CM : 0.6
EM : 0.5
RM : 0.6
SQM : 0.5
SYM : 0.5
UM : 0.7



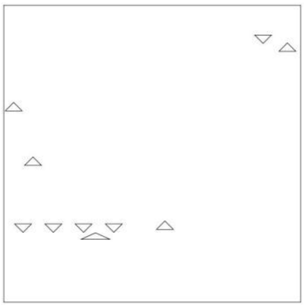
MAL3

CM : 0.6
EM : 0.5
RM : 0.6
SQM : 0.5
SYM : 0.5
UM : 0.7



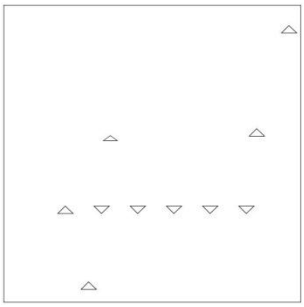
MAL4

CM : 0.6
EM : 0.5
RM : 0.6
SQM : 0.5
SYM : 0.6
UM : 0.7



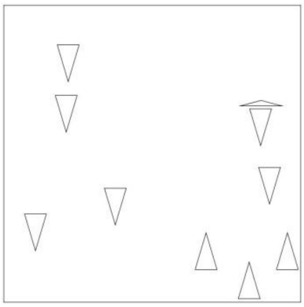
MAL5

CM : 0.7
EM : 0.5
RM : 0.6
SQM : 0.5
SYM : 0.5
UM : 0.6



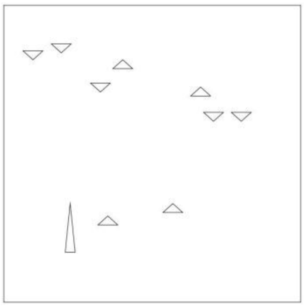
MAL6

CM : 0.7
EM : 0.5
RM : 0.7
SQM : 0.5
SYM : 0.5
UM : 0.6



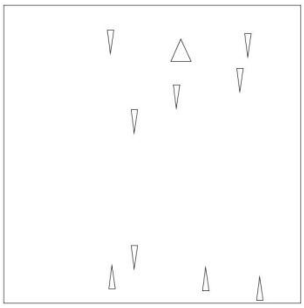
MAL7

CM : 0.7
EM : 0.5
RM : 0.6
SQM : 0.5
SYM : 0.7
UM : 0.6



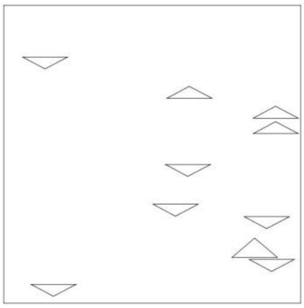
MAL8

CM : 0.7
EM : 0.5
RM : 0.6
SQM : 0.5
SYM : 0.6
UM : 0.7



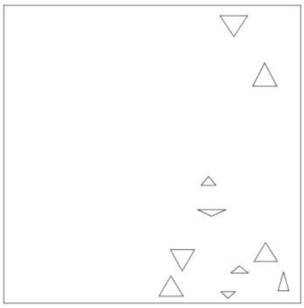
MAL9

CM : 0.5
EM : 0.5
RM : 0.6
SQM : 0.5
SYM : 0.7
UM : 0.7



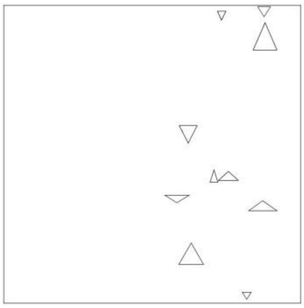
MAL10

CM : 0.6
EM : 0.5
RM : 0.6
SQM : 0.5
SYM : 0.6
UM : 0.6



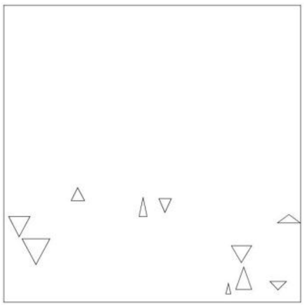
LAL1

CM : 0.4
EM : 0.1
RM : 0.0
SQM : 0.2
SYM : 0.2
UM : 0.3



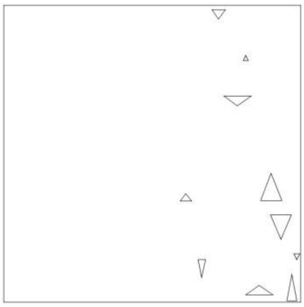
LAL2

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.2
SYM : 0.3
UM : 0.4



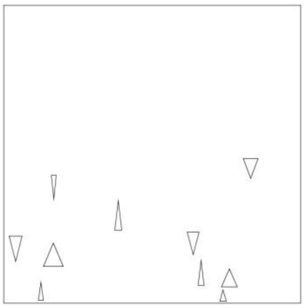
LAL3

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.0
SYM : 0.3
UM : 0.4



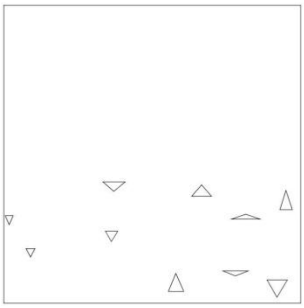
LAL4

CM : 0.4
EM : 0.1
RM : 0.0
SQM : 0.2
SYM : 0.3
UM : 0.4



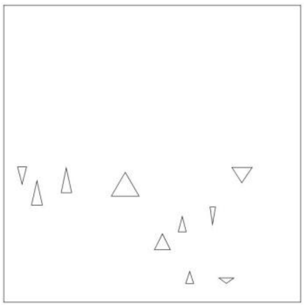
LAL5

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.0
SYM : 0.3
UM : 0.4



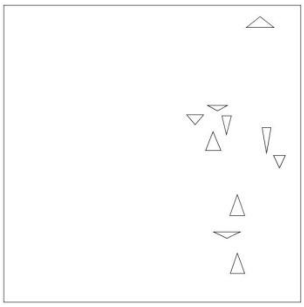
LAL6

CM : 0.4
EM : 0.1
RM : 0.0
SQM : 0.0
SYM : 0.3
UM : 0.4



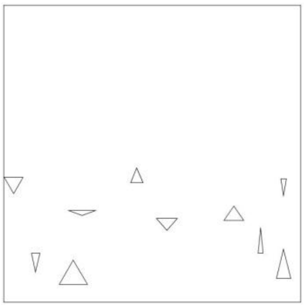
LAL7

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.0
SYM : 0.3
UM : 0.4



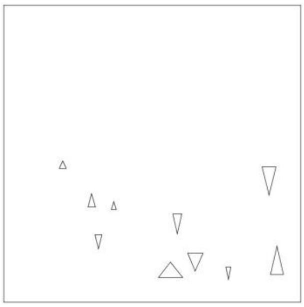
LAL8

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.2
SYM : 0.3
UM : 0.4



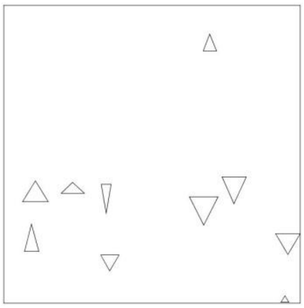
LAL9

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.0
SYM : 0.3
UM : 0.4



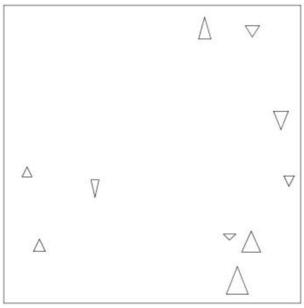
LAL10

CM : 0.4
EM : 0.1
RM : 0.0
SQM : 0.0
SYM : 0.3
UM : 0.4



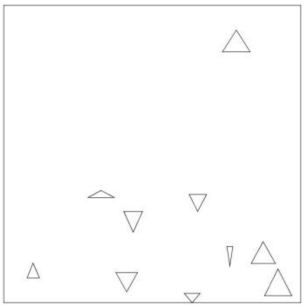
HighCohesion1

CM : 0.9
EM : 0.1
RM : 0.0
SQM : 0.0
SYM : 0.3
UM : 0.1



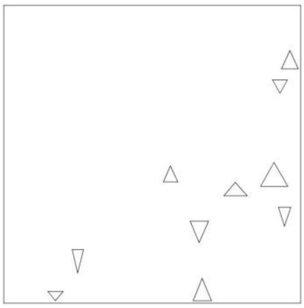
HighCohesion2

CM : 0.9
EM : 0.1
RM : 0.0
SQM : 0.2
SYM : 0.4
UM : 0.1



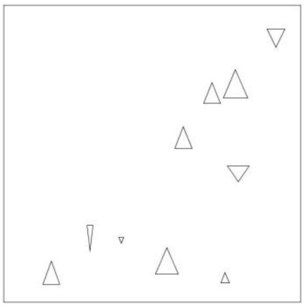
HighCohesion3

CM : 0.9
EM : 0.1
RM : 0.0
SQM : 0.0
SYM : 0.3
UM : 0.1



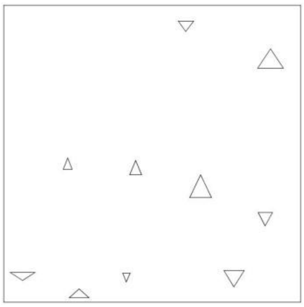
HighCohesion4

CM : 0.9
EM : 0.1
RM : 0.1
SQM : 0.2
SYM : 0.3
UM : 0.2



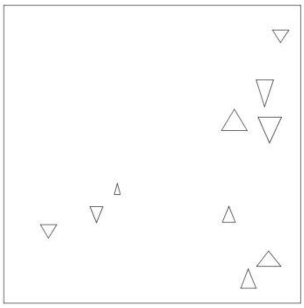
HighCohesion5

CM : 0.9
EM : 0.1
RM : 0.0
SQM : 0.2
SYM : 0.4
UM : 0.2



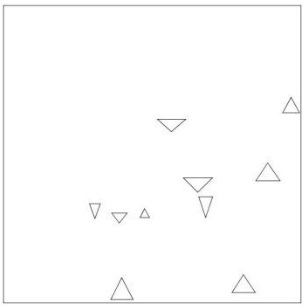
HighCohesion6

CM : 0.9
EM : 0.1
RM : 0.0
SQM : 0.2
SYM : 0.4
UM : 0.1



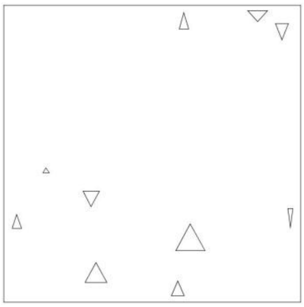
HighCohesion7

CM : 0.9
EM : 0.1
RM : 0.1
SQM : 0.2
SYM : 0.4
UM : 0.2



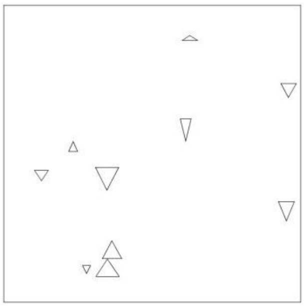
HighCohesion8

CM : 0.9
EM : 0.1
RM : 0.0
SQM : 0.2
SYM : 0.3
UM : 0.3



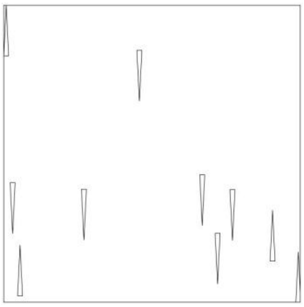
HighCohesion9

CM : 0.9
EM : 0.1
RM : 0.0
SQM : 0.2
SYM : 0.4
UM : 0.1



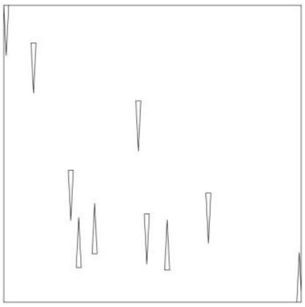
HighCohesion10

CM : 0.9
EM : 0.1
RM : 0.0
SQM : 0.2
SYM : 0.4
UM : 0.2



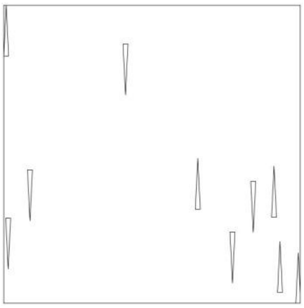
HighEconomy1

CM : 0.5
EM : 1.0
RM :0.0
SQM : 0.0
SYM : 0.4
UM : 0.5



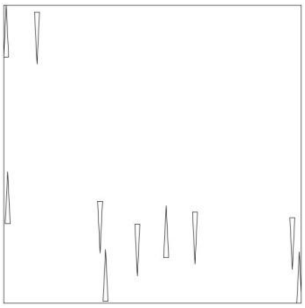
HighEconomy2

CM : 0.5
EM : 1.0
RM : 0.1
SQM : 0.0
SYM : 0.4
UM : 0.5



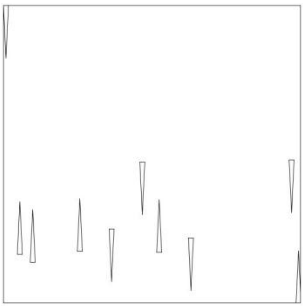
HighEconomy3

CM :0.5
EM :1.0
RM :0.1
SQM :0.0
SYM :0.3
UM :0.5



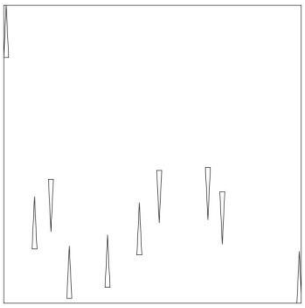
HighEconomy4

CM :0.5
EM :1.0
RM :0.1
SQM :0.0
SYM : 0.4
UM : 0.5



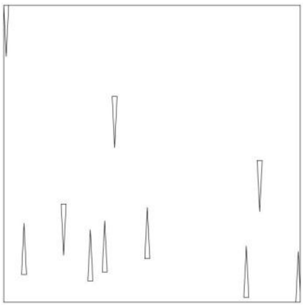
HighEconomy5

CM :0.5
EM :1.0
RM :0.1
SQM :0.0
SYM :0.3
UM :0.5



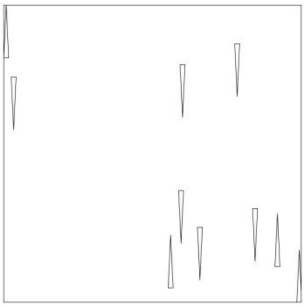
HighEconomy6

CM :0.5
EM :1.0
RM :0.0
SQM :0.0
SYM :0.3
UM : 0.5



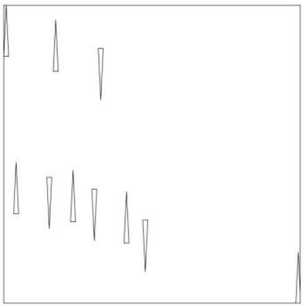
HighEconomy7

CM : 0.5
EM :1.0
RM :0.0
SQM :0.0
SYM :0.3
UM :0.5



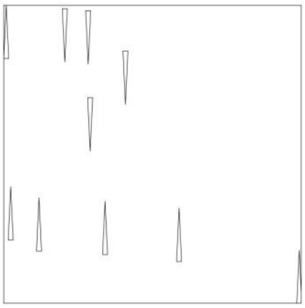
HighEconomy8

CM :0.5
EM :1.0
RM :0.0
SQM :0.2
SYM :0.3
UM :0.5



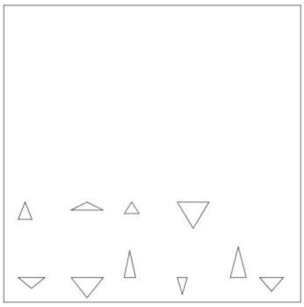
HighEconomy9

CM :0.5
EM :1.0
RM :0.1
SQM :0.2
SYM :0.3
UM :0.5



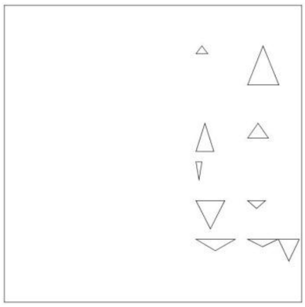
HighEconomy10

CM :0.5
EM :1.0
RM :0.1
SQM :0.0
SYM :0.4
UM :0.5



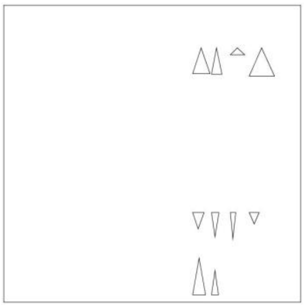
HighRegularity1

CM :0.4062
EM :0.1
RM :0.8889
SQM :0.0
SYM :0.3078
UM :0.4143



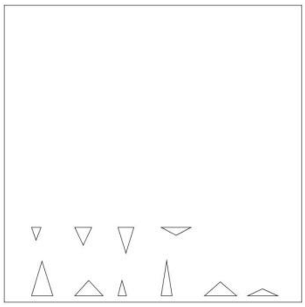
HighRegularity2

CM :0.4477
EM :0.1
RM :0.9167
SQM :0.25
SYM :0.3001
UM :0.434



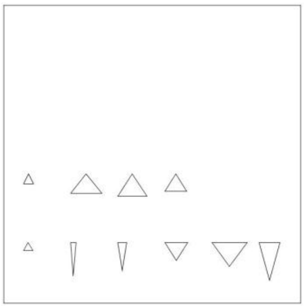
HighRegularity3

CM :0.4692
EM :0.1
RM :0.9167
SQM :0.25
SYM :0.305
UM :0.4421



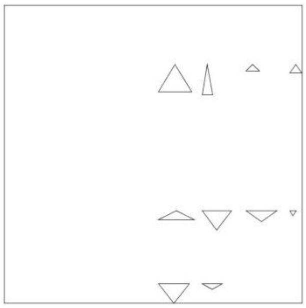
HighRegularity4

CM :0.3385
EM :0.1
RM :0.8611
SQM :0.0
SYM :0.3021
UM :0.4629



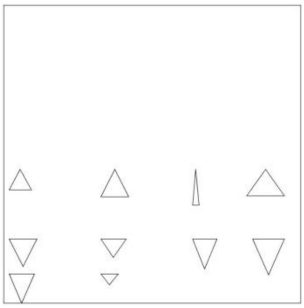
HighRegularity5

CM :0.4174
EM :0.1
RM :0.9722
SQM :0.0
SYM :0.3136
UM :0.4049



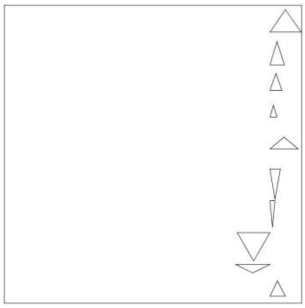
HighRegularity6

CM :0.4772
EM :0.1
RM :0.9444
SQM :0.25
SYM :0.2964
UM :0.364



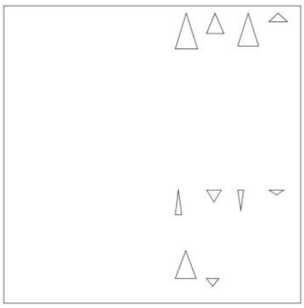
HighRegularity7

CM :0.4917
EM :0.1111
RM :0.8889
SQM :0.0
SYM :0.2951
UM :0.4037



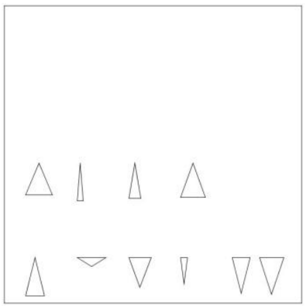
HighRegularity8

CM : 0.2807
EM : 0.1
RM : 0.9167
SQM : 0.25
SYM : 0.3211
UM : 0.4525



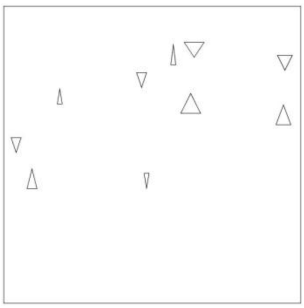
HighRegularity9

CM : 0.4352
EM : 0.1
RM : 0.9167
SQM : 0.25
SYM : 0.3254
UM : 0.3834



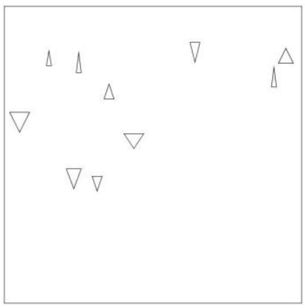
HighRegularity10

CM : 0.4085
EM : 0.1
RM : 0.9444
SQM : 0.0
SYM : 0.3036
UM : 0.3674



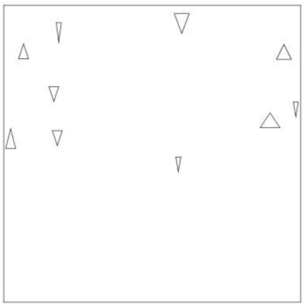
HighSequence1

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.8
SYM : 0.3
UM : 0.4



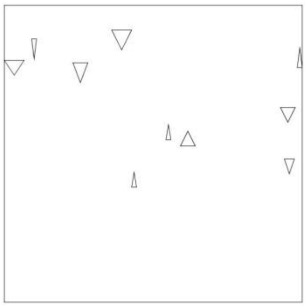
HighSequence2

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 1.0
SYM : 0.3
UM : 0.4



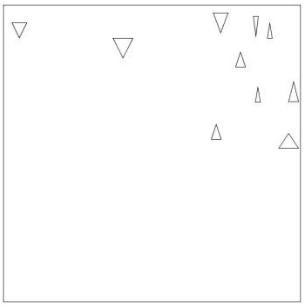
HighSequence3

CM : 0.4
EM : 0.1
RM : 0.0
SQM : 0.8
SYM : 0.2
UM : 0.4



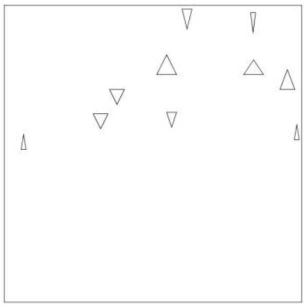
HighSequence4

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 1.0
SYM : 0.4
UM : 0.4



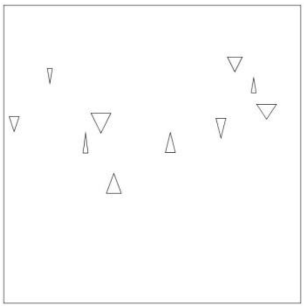
HighSequence5

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.8
SYM : 0.3
UM : 0.4



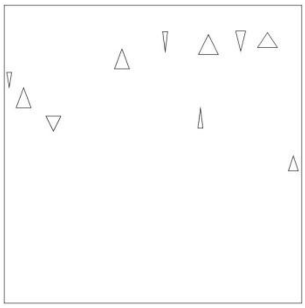
HighSequence6

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.8
SYM : 0.2
UM : 0.4



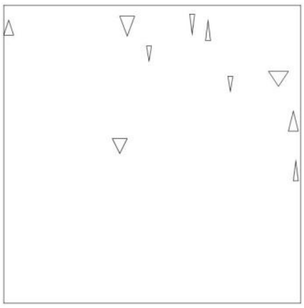
HighSequence7

CM : 0.4
EM : 0.1
RM : 0.0
SQM : 0.8
SYM : 0.3
UM : 0.4



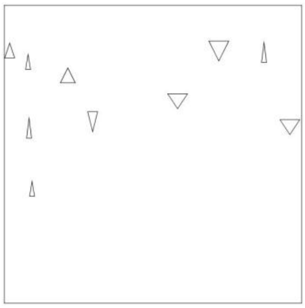
HighSequence8

CM : 0.4
EM : 0.1
RM : 0.0
SQM : 0.8
SYM : 0.2
UM : 0.4



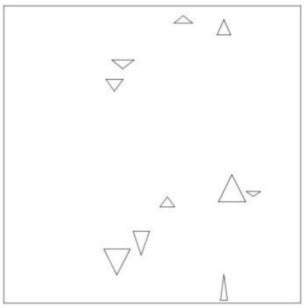
HighSequence9

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.8
SYM : 0.2
UM : 0.4



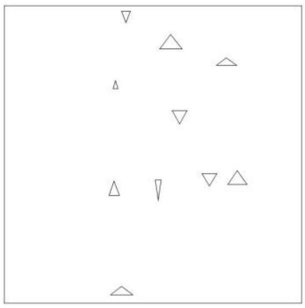
HighSequence10

CM : 0.4
EM : 0.1
RM : 0.1
SQM : 0.8
SYM : 0.2
UM : 0.4



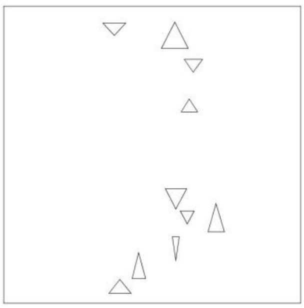
HighSymmetry1

CM : 0.4946
EM : 0.1
RM : 0.0556
SQM : 0.25
SYM : 0.7527
UM : 0.3027



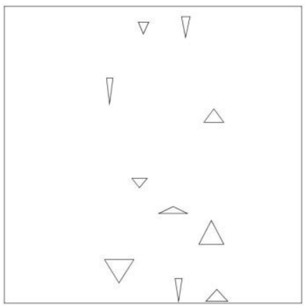
HighSymmetry2

CM : 0.4714
EM : 0.1
RM : 0.0556
SQM : 0.25
SYM : 0.7727
UM : 0.3323



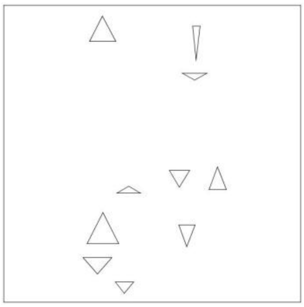
HighSymmetry3

CM : 0.4626
EM : 0.1
RM : 0.0278
SQM : 0.25
SYM : 0.7047
UM : 0.3699



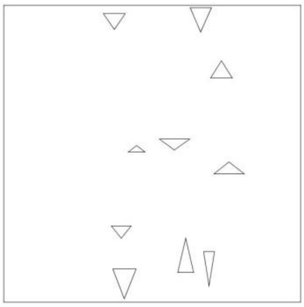
HighSymmetry4

CM : 0.4345
EM : 0.1
RM : 0.0833
SQM : 0.25
SYM : 0.7103
UM : 0.3571



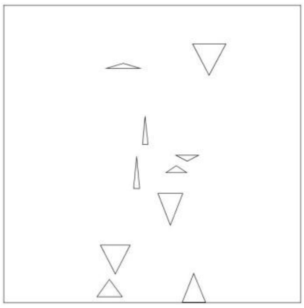
HighSymmetry5

CM : 0.4656
EM : 0.1
RM : 0.0278
SQM : 0.25
SYM : 0.7036
UM : 0.332



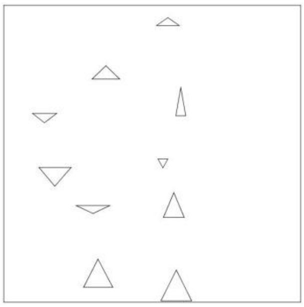
HighSymmetry6

CM : 0.4607
EM : 0.1
RM : 0.0278
SQM : 0.25
SYM : 0.7809
UM : 0.3245



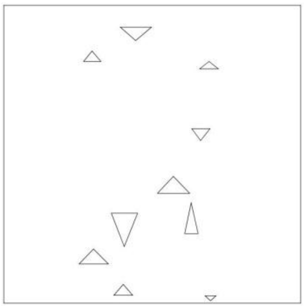
HighSymmetry7

CM : 0.4346
EM : 0.1
RM : 0.0278
SQM : 0.25
SYM : 0.7066
UM : 0.3705



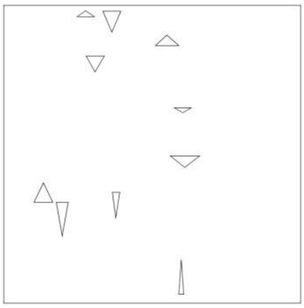
HighSymmetry8

CM : 0.4836
EM : 0.1
RM : 0.0278
SQM : 0.25
SYM : 0.7246
UM : 0.3016



HighSymmetry9

CM : 0.436
EM : 0.1
RM : 0.0556
SQM : 0.25
SYM : 0.7609
UM : 0.3411

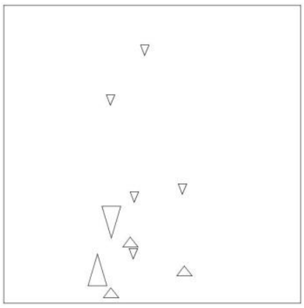


HighSymmetry10

CM : 0.4933
EM : 0.1
RM : 0.0278
SQM : 0.25
SYM : 0.7022
UM : 0.289

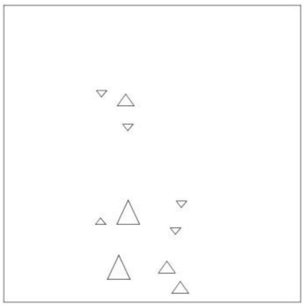
HighUnity1

CM : 0.4
EM : 0.3
RM : 0.0
SQM : 0.2
SYM : 0.3
UM : 0.8



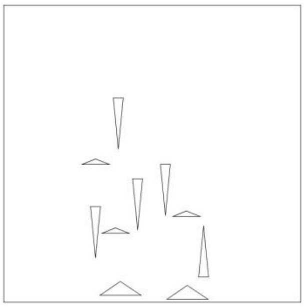
HighUnity2

CM : 0.4
EM : 0.3
RM : 0.1
SQM : 0.2
SYM : 0.3
UM : 0.8



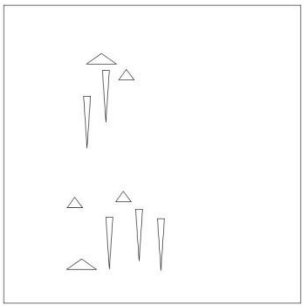
HighUnity3

CM : 0.4
EM : 0.3
RM : 0.0
SQM : 0.2
SYM : 0.4
UM : 0.8



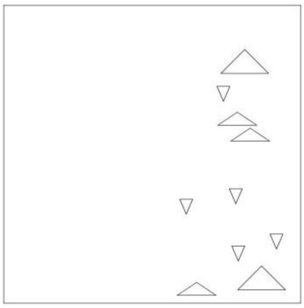
HighUnity4

CM : 0.4
EM : 0.3
RM : 0.0
SQM : 0.0
SYM : 0.2
UM : 0.8



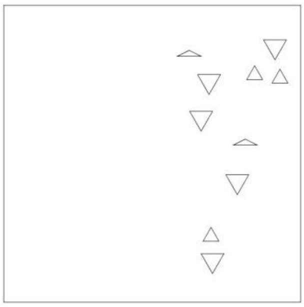
HighUnity5

CM : 0.4
EM : 0.3
RM : 0.1
SQM : 0.2
SYM : 0.3
UM : 0.8



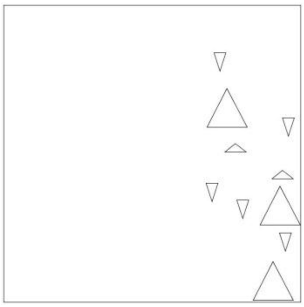
HighUnity6

CM : 0.4
EM : 0.3
RM : 0.1
SQM : 0.2
SYM : 0.3
UM : 0.8



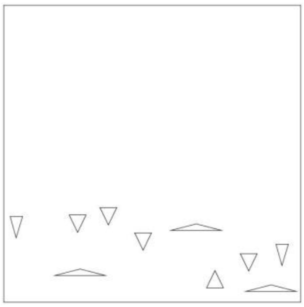
HighUnity7

CM : 0.4
EM : 0.3
RM : 0.0
SQM : 0.2
SYM : 0.3
UM : 0.8



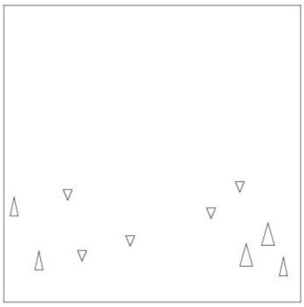
HighUnity8

CM : 0.4
EM : 0.3
RM : 0.1
SQM : 0.2
SYM : 0.3
UM : 0.8



HighUnity9

CM : 0.3
EM : 0.3
RM : 0.1
SQM : 0.0
SYM : 0.3
UM : 0.8



HighUnity10

CM : 0.3
EM : 0.3
RM : 0.1
SQM : 0.0
SYM : 0.3
UM : 0.8

4. Chapter 7

HAL1

CM : 0.7856
EM : 1.0
RM : 0.7477
SQM : 1.0
SYM : 0.9
UM : 0.7472

HAL2

CM : 0.8968
EM : 1.0
RM : 0.7477
SQM : 0.75
SYM : 0.7984
UM : 0.7216

HAL3

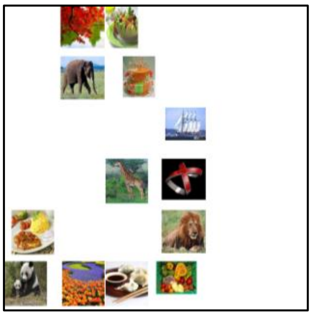
CM : 0.8956
EM : 1.0
RM : 0.7477
SQM : 1.0
SYM : 0.7984
UM : 0.7208

HAL 4

CM : 0.8892
EM : 1.0
RM : 0.7689
SQM : 0.75
SYM : 0.7778
UM : 0.7282

HAL5

CM : 0.7155
EM : 1.0
RM : 0.7222
SQM : 0.75
SYM : 0.8333
UM : 0.7421



MAL1

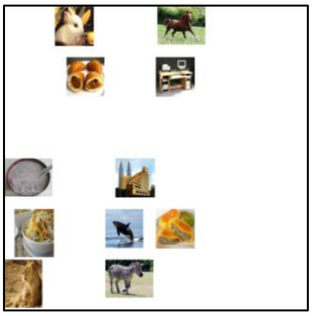
CM : 0.629
EM : 0.5
RM : 0.5545
SQM : 0.5
SYM : 0.5459
UM : 0.6805

MAL2

CM : 0.6981
EM : 0.5
RM : 0.5639
SQM : 0.5
SYM : 0.6348
UM : 0.6661

MAL3

CM : 0.673
EM : 0.5
RM : 0.5545
SQM : 0.5
SYM : 0.5985
UM : 0.6865



MAL4

CM : 0.6559
EM : 0.5
RM : 0.5361
SQM : 0.5
SYM : 0.6191
UM : 0.6725

MAL5

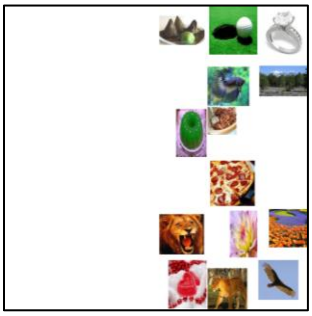
CM : 0.6071
EM : 0.5
RM : 0.5318
SQM : 0.5
SYM : 0.6103
UM : 0.6632

LAL1

CM : 0.4981
EM : 0.0909
RM : 0.1227
SQM : 0.25
SYM : 0.2857
UM : 0.3586

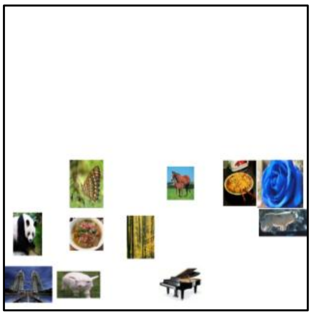
LAL2

CM : 0.469
EM : 0.0909
RM : 0.0977
SQM : 0.0
SYM : 0.3193
UM : 0.3498



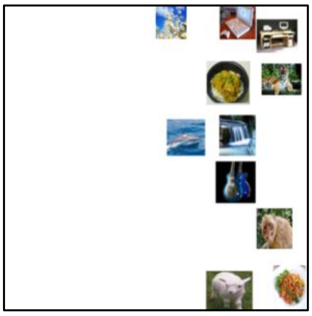
LAL3

CM : 0.4661
EM : 0.0833
RM : 0.1345
SQM : 0.0
SYM : 0.332
UM : 0.3409



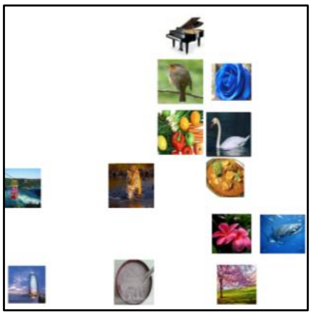
LAL4

CM : 0.4809
EM : 0.0833
RM : 0.1761
SQM : 0.0
SYM : 0.3291
UM : 0.353



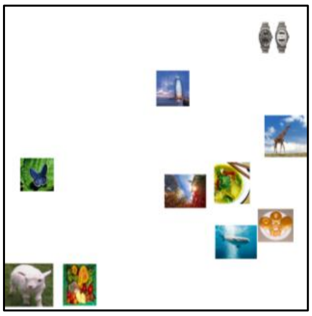
LAL5

CM : 0.4922
EM : 0.0833
RM : 0.2841
SQM : 0.25
SYM : 0.3323
UM : 0.3675



HighCohesion1

CM : 0.8949
EM : 0.1
RM : 0.1611
SQM : 0.25
SYM : 0.452
UM : 0.0558

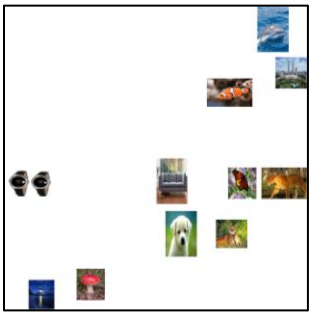


HighCohesion2

CM : 0.9056
EM : 0.0769
RM : 0.1218
SQM : 0.25
SYM : 0.4647
UM : 0.0859

HighCohesion3

CM : 0.8844
EM : 0.0769
RM : 0.1811
SQM : 0.25
SYM : 0.3326
UM : 0.057



HighCohesion4

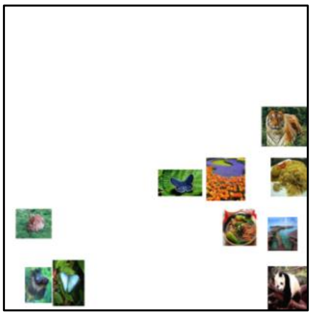
CM : 0.889
EM : 0.1
RM : 0.1333
SQM : 0.25
SYM : 0.2734
UM : 0.0824

HighCohesion5

CM : 0.8391
EM : 0.0909
RM : 0.0727
SQM : 0.25
SYM : 0.4436
UM : 0.1446

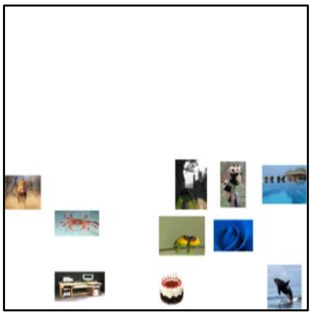
MediumCohesion1

CM : 0.6979
EM : 0.0909
RM : 0.1205
SQM : 0.25
SYM : 0.4045
UM : 0.2694



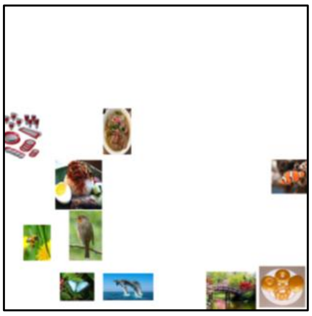
MediumCohesion2

CM : 0.6772
EM : 0.1
RM : 0.1889
SQM : 0.25
SYM : 0.3258
UM : 0.2577



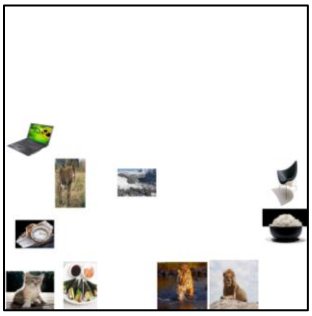
MediumCohesion3

CM : 0.6783
EM : 0.0909
RM : 0.0727
SQM : 0.25
SYM : 0.2336
UM : 0.2543



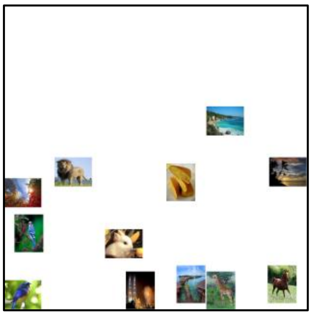
MediumCohesion4

CM : 0.6941
EM : 0.1
RM : 0.1083
SQM : 0.25
SYM : 0.344
UM : 0.2551



MediumCohesion5

CM : 0.6454
EM : 0.0769
RM : 0.1426
SQM : 0.25
SYM : 0.2919
UM : 0.2507



HighEconomy1

CM : N/A
EM : 1.0
RM : 0.4186
SQM : 0.25
SYM : 0.3074
UM : N/A

HighEconomy2

CM : N/A
EM : 1.0
RM : 0.3722
SQM : 0.25
SYM : 0.3333
UM : N/A

HighEconomy3

CM : N/A
EM : 1.0
RM : 0.4364
SQM : 0.25
SYM : 0.3278
UM : N/A

HighEconomy4

CM : N/A
EM : 1.0
RM : 0.3444
SQM : 0.25
SYM : 0.3889
UM : N/A

HighEconomy5

CM : N/A
EM : 1.0
RM : 0.4856
SQM : 0.25
SYM : 0.3873
UM : N/A

MediumEconomy1

CM : N/A
EM : 0.5
RM : 0.3106
SQM : 0.25
SYM : 0.2525
UM : N/A

MediumEconomy2

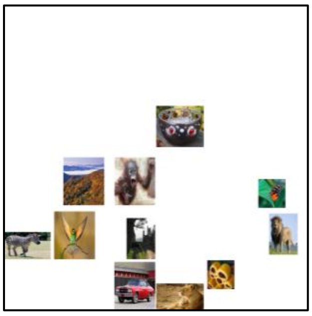
CM : N/A
EM : 0.5
RM : 0.2886
SQM : 0.25
SYM : 0.4121
UM : N/A

MediumEconomy3

CM : N/A
EM : 0.5
RM : 0.2139
SQM : 0.25
SYM : 0.351
UM : N/A

MediumEconomy4

CM : N/A
EM : 0.5
RM : 0.2898
SQM : 0.25
SYM : 0.4157
UM : N/A



MediumEconomy5

CM : N/A
EM : 0.5
RM : 0.2452
SQM : 0.25
SYM : 0.4546
UM : N/A

HighRegularity1

CM : 0.4833
EM : 0.1
RM : 0.7444
SQM : 0.0
SYM : 0.3003
UM : 0.3622

HighRegularity2

CM : 0.449
EM : 0.0714
RM : 0.8201
SQM : 0.25
SYM : 0.329
UM : 0.397

HighRegularity3

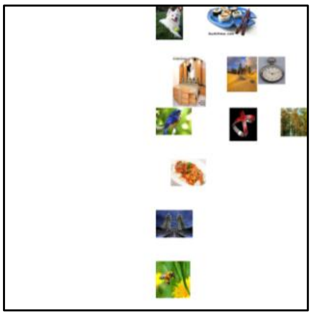
CM : 0.4945
EM : 0.0833
RM : 0.7898
SQM : 0.0
SYM : 0.3028
UM : 0.3779

HighRegularity4

CM : 0.478
EM : 0.1
RM : 0.7444
SQM : 0.0
SYM : 0.3314
UM : 0.3825

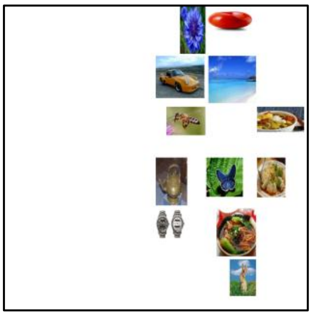
HighRegularity5

CM : 0.4821
EM : 0.0714
RM : 0.8201
SQM : 0.0
SYM : 0.3086
UM : 0.3765



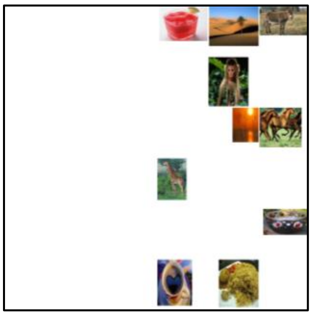
MediumRegularity1

CM : 0.496
EM : 0.0833
RM : 0.5909
SQM : 0.0
SYM : 0.3058
UM : 0.3617



MediumRegularity2

CM : 0.4927
EM : 0.0769
RM : 0.6651
SQM : 0.25
SYM : 0.2953
UM : 0.38



MediumRegularity3

CM : 0.3479
EM : 0.0833
RM : 0.5019
SQM : 0.0
SYM : 0.3282
UM : 0.4655

MediumRegularity4

CM : 0.4635
EM : 0.1
RM : 0.5306
SQM : 0.0
SYM : 0.302
UM : 0.3775

MediumRegularity5

CM : 0.4945
EM : 0.0833
RM : 0.5492
SQM : 0.25
SYM : 0.3311
UM : 0.3532

HighSequence1

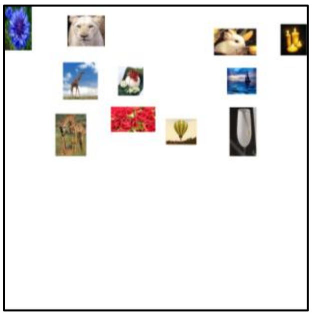
CM : 0.4983
EM : 0.1
RM : 0.0833
SQM : 1.0
SYM : 0.2679
UM : 0.346

HighSequence2

CM : 0.4935
EM : 0.0833
RM : 0.2436
SQM : 1.0
SYM : 0.3233
UM : 0.412

HighSequence3

CM : 0.4833
EM : 0.0714
RM : 0.1703
SQM : 1.0
SYM : 0.31
UM : 0.3602

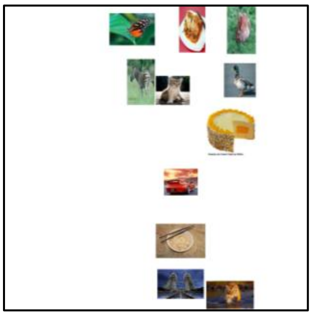


HighSequence4

CM : 0.4926
EM : 0.1
RM : 0.1861
SQM : 1.0
SYM : 0.3001
UM : 0.3472

HighSequence5

CM : 0.4877
EM : 0.1
RM : 0.1083
SQM : 1.0
SYM : 0.3301
UM : 0.3509



MediumSequence1

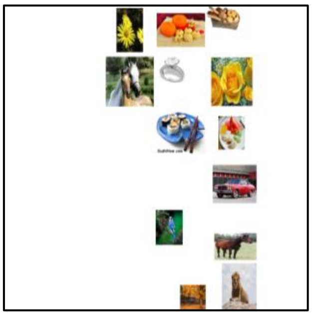
CM : 0.4686
EM : 0.0909
RM : 0.2159
SQM : 0.5
SYM : 0.3579
UM : 0.367

MediumSequence2

CM : 0.4898
EM : 0.1
RM : 0.1611
SQM : 0.5
SYM : 0.2738
UM : 0.3534

MediumSequence3

CM : 0.4681
EM : 0.1
RM : 0.1611
SQM : 0.5
SYM : 0.3518
UM : 0.3589



MediumSequence4

CM : 0.4981
EM : 0.1
RM : 0.1611
SQM : 0.5
SYM : 0.2452
UM : 0.3622

MediumSequence5

CM : 0.4555
EM : 0.0909
RM : 0.3114
SQM : 0.5
SYM : 0.3448
UM : 0.3959

HighSymmetry1

CM : 0.4833
EM : 0.0714
RM : 0.0948
SQM : 0.25
SYM : 0.7247
UM : 0.3648

HighSymmetry2

CM : 0.489
EM : 0.0769
RM : 0.1426
SQM : 0.25
SYM : 0.7219
UM : 0.371

HighSymmetry3

CM : 0.4746
EM : 0.0833
RM : 0.1553
SQM : 0.25
SYM : 0.7332
UM : 0.3579

HighSymmetry4

CM : 0.4993
EM : 0.0769
RM : 0.1218
SQM : 0.25
SYM : 0.7582
UM : 0.349

HighSymmetry5

CM : 0.4985
EM : 0.1
RM : 0.0833
SQM : 0.25
SYM : 0.7217
UM : 0.3685

MediumSymmetry1

CM : 0.4895
EM : 0.0833
RM : 0.1989
SQM : 0.25
SYM : 0.6516
UM : 0.3615

MediumSymmetry2

CM : 0.4919
EM : 0.0909
RM : 0.3864
SQM : 0.25
SYM : 0.5976
UM : 0.3766

MediumSymmetry3

CM : 0.4801
EM : 0.0714
RM : 0.2995
SQM : 0.25
SYM : 0.6001
UM : 0.3668

MediumSymmetry4

CM : 0.4782
EM : 0.0714
RM : 0.2047
SQM : 0.25
SYM : 0.5456
UM : 0.3497

MediumSymmetry5

CM : 0.4914
EM : 0.0833
RM : 0.1326
SQM : 0.0
SYM : 0.5353
UM : 0.3605

HighUnity1

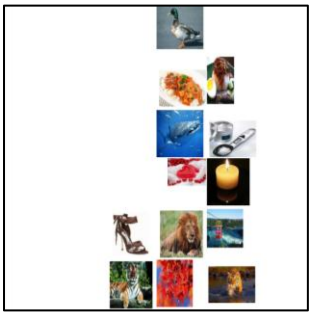
CM : 0.4806
EM : 0.3333
RM : 0.3365
SQM : 0.25
SYM : 0.332
UM : 0.7531

HighUnity2

CM : 0.4964
EM : 0.3333
RM : 0.4
SQM : 0.25
SYM : 0.3301
UM : 0.7374

HighUnity3

CM : 0.4718
EM : 0.3333
RM : 0.2886
SQM : 0.25
SYM : 0.3148
UM : 0.7174



HighUnity4

CM : 0.4482
EM : 0.3333
RM : 0.3173
SQM : 0.0
SYM : 0.3321
UM : 0.7467

HighUnity5

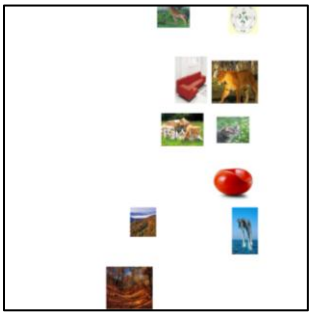
CM : 0.4874
EM : 0.3333
RM : 0.2667
SQM : 0.0
SYM : 0.3276
UM : 0.7173

MediumUnity1

CM : 0.4801
EM : 0.3333
RM : 0.3136
SQM : 0.0
SYM : 0.3167
UM : 0.6951

MediumUnity2

CM : 0.4893
EM : 0.3333
RM : 0.2917
SQM : 0.0
SYM : 0.3318
UM : 0.6834

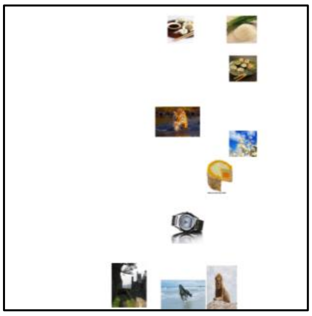


MediumUnity3

CM : 0.4677
EM : 0.3333
RM : 0.3222
SQM : 0.0
SYM : 0.3317
UM : 0.6882

MediumUnity4

CM : 0.4555
EM : 0.3333
RM : 0.1389
SQM : 0.25
SYM : 0.3319
UM : 0.6899



MediumUnity5

CM : 0.4648
EM : 0.3333
RM : 0.2139
SQM : 0.25
SYM : 0.3316
UM : 0.6957

5. Chapter 8

a. LAL with HE, ME, and LE backgrounds

LAL_HE1

CM	: 0.4925
EM	: 0.0769
RM	: 0.2837
SQM	: 0.0000
SYM	: 0.3211
UM	: 0.3614

LAL_HE2

CM	: 0.4875
EM	: 0.0769
RM	: 0.3029
SQM	: 0.0000
SYM	: 0.3192
UM	: 0.3627

LAL_HE3

CM	: 0.4948
EM	: 0.0714
RM	: 0.1525
SQM	: 0.0000
SYM	: 0.3306
UM	: 0.3680

LAL_HE4

CM	: 0.4942
EM	: 0.1000
RM	: 0.1639
SQM	: 0.0000
SYM	: 0.2957
UM	: 0.3525

LAL_HE5

CM	: 0.4668
EM	: 0.0833
RM	: 0.2197
SQM	: 0.0000
SYM	: 0.3019
UM	: 0.3655

LAL_HE6

CM	: 0.4889
EM	: 0.0714
RM	: 0.2431
SQM	: 0.0000
SYM	: 0.3315
UM	: 0.3505

LAL_ME1

CM	: 0.4717
EM	: 0.0909
RM	: 0.0750
SQM	: 0.0000
SYM	: 0.3221
UM	: 0.3775

LAL_ME2

CM	: 0.4949
EM	: 0.0769
RM	: 0.1426
SQM	: 0.0000
SYM	: 0.3222
UM	: 0.3563

LAL_ME3

CM	: 0.4990
EM	: 0.0833
RM	: 0.1117
SQM	: 0.0000
SYM	: 0.3316
UM	: 0.3523

LAL_ME4

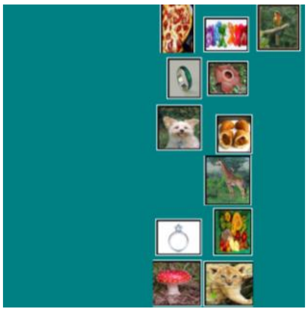
CM	: 0.4754
EM	: 0.0833
RM	: 0.1635
SQM	: 0.0000
SYM	: 0.2941
UM	: 0.3896

LAL_ME5

CM : 0.4632
EM : 0.0909
RM : 0.2636
SQM : 0.2500
SYM : 0.3188
UM : 0.3718

LAL_ME6

CM : 0.4863
EM : 0.0833
RM : 0.2860
SQM : 0.2500
SYM : 0.3058
UM : 0.3567



LAL_LE1

CM :0.477
EM : 0.0769
RM : 0.1827
SQM : 0.25
SYM : 0.2946
UM : 0.3809

LAL_LE2

CM : 0.4860
EM : 0.0714
RM : 0.2802
SQM : 0.0000
SYM : 0.3078
UM : 0.3717

LAL_LE3

CM : 0.4851
EM : 0.0769
RM : 0.3269
SQM : 0.0000
SYM : 0.3212
UM : 0.3613

LAL_LE4

CM : 0.4660
EM : 0.0909
RM : 0.1682
SQM : 0.0000
SYM : 0.3157
UM : 0.3541

LAL_LE5

CM : 0.4557
EM : 0.0909
RM : 0.1705
SQM : 0.0000
SYM : 0.3206
UM : 0.3861

LAL_LE6

CM :0.4773
EM :0.0714
RM :0.1497
SQM :0.0000
SYM :0.3290
UM :0.3506

b. MAL with HE, ME, and LE backgrounds

MAL_HE1

CM : 0.6470
EM : 0.5000
RM : 0.5611
SQM : 0.5000
SYM : 0.6534
UM : 0.6463

MAL_HE2

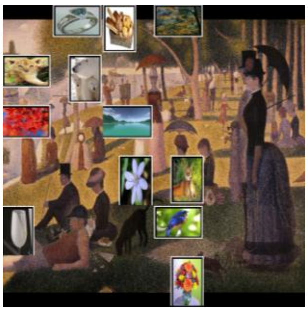
CM : 0.5952
EM : 0.5000
RM : 0.6727
SQM : 0.5000
SYM : 0.5918
UM : 0.6764

MAL_HE3

CM	: 0.6768
EM	: 0.5000
RM	: 0.5795
SQM	: 0.5000
SYM	: 0.6748
UM	: 0.6600

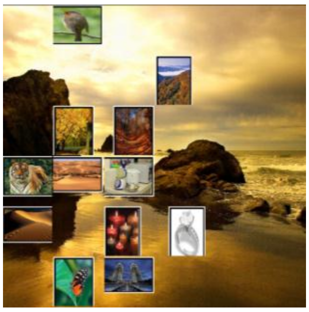
MAL_HE4

CM	: 0.6744
EM	: 0.5000
RM	: 0.5361
SQM	: 0.5000
SYM	: 0.6357
UM	: 0.6893



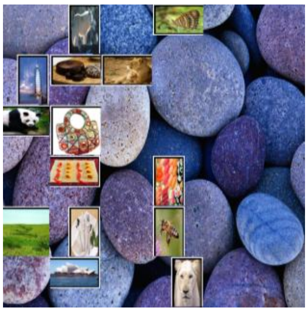
MAL_HE5

CM	: 0.6606
EM	: 0.5000
RM	: 0.6717
SQM	: 0.5000
SYM	: 0.5286
UM	: 0.6964



MAL_HE6

CM	: 0.6362
EM	: 0.5000
RM	: 0.6250
SQM	: 0.5000
SYM	: 0.5575
UM	: 0.6873



MAL_ME1

CM	: 0.6922
EM	: 0.5000
RM	: 0.5545
SQM	: 0.5000
SYM	: 0.5992
UM	: 0.6843

MAL_ME2

CM	: 0.5608
EM	: 0.5000
RM	: 0.6651
SQM	: 0.5000
SYM	: 0.5445
UM	: 0.6987

MAL_ME3

CM	: 0.6656
EM	: 0.5000
RM	: 0.6364
SQM	: 0.5000
SYM	: 0.5832
UM	: 0.6814

MAL_ME4

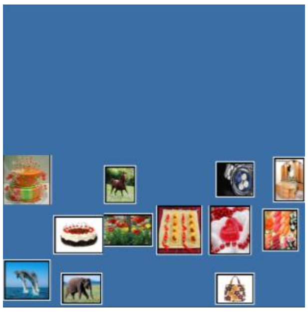
CM	: 0.6614
EM	: 0.5000
RM	: 0.6552
SQM	: 0.5000
SYM	: 0.5180
UM	: 0.6970

MAL_ME5

CM	: 0.6917
EM	: 0.5000
RM	: 0.5739
SQM	: 0.5000
SYM	: 0.6352
UM	: 0.6690

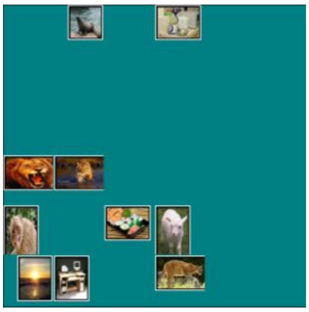
MAL_ME6

CM	: 0.6804
EM	: 0.5000
RM	: 0.5611
SQM	: 0.5000
SYM	: 0.5753
UM	: 0.6785



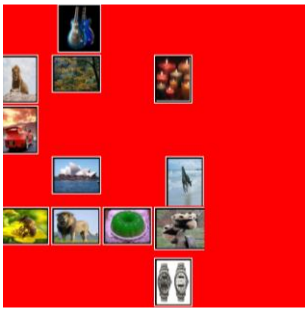
MAL_LE1

CM	: 0.6670
EM	: 0.5000
RM	: 0.6266
SQM	: 0.5000
SYM	: 0.6179
UM	: 0.6951



MAL_LE2

CM	: 0.6083
EM	: 0.5000
RM	: 0.6045
SQM	: 0.5000
SYM	: 0.5403
UM	: 0.6892



MAL_LE3

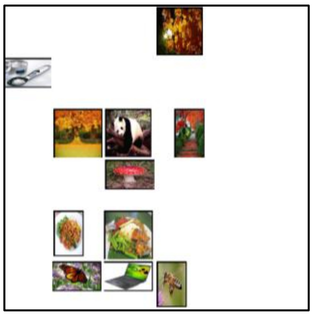
CM	: 0.6607
EM	: 0.5000
RM	: 0.5720
SQM	: 0.5000
SYM	: 0.5231
UM	: 0.6781

MAL_LE4

CM	: 0.6294
EM	: 0.5000
RM	: 0.6074
SQM	: 0.5000
SYM	: 0.6037
UM	: 0.6999

MAL_LE5

CM	: 0.6388
EM	: 0.5000
RM	: 0.6474
SQM	: 0.5000
SYM	: 0.5920
UM	: 0.6881



MAL_LE6

CM	: 0.6263
EM	: 0.5000
RM	: 0.5333
SQM	: 0.5000
SYM	: 0.6346
UM	: 0.6897

c. HAL with HE, ME, and LE backgrounds

HAL_HE1

CM	: 0.9527
EM	: 1.0000
RM	: 0.7477
SQM	: 1.0000
SYM	: 0.9000
UM	: 0.7266

HAL_HE2

CM	: 0.9811
EM	: 1.0000
RM	: 0.7689
SQM	: 0.7500
SYM	: 0.8302
UM	: 0.7377

HAL_HE3

CM	: 0.9017
EM	: 1.0000
RM	: 0.7455
SQM	: 1.0000
SYM	: 0.7984
UM	: 0.7231

HAL_HE4

CM	: 0.9700
EM	: 1.0000
RM	: 0.7689
SQM	: 0.7500
SYM	: 0.8302
UM	: 0.7286

HAL_HE5

CM	: 0.7007
EM	: 1.0000
RM	: 0.7444
SQM	: 0.7500
SYM	: 0.8667
UM	: 0.7962

HAL_HE6

CM	: 0.8220
EM	: 1.0000
RM	: 0.7689
SQM	: 1.0000
SYM	: 0.8302
UM	: 0.7265

HAL_ME1

CM	: 0.8499
EM	: 1.0000
RM	: 0.7477
SQM	: 1.0000
SYM	: 0.9000
UM	: 0.7245

HAL_ME2

CM	: 0.8830
EM	: 1.0000
RM	: 0.7194
SQM	: 1.0000
SYM	: 0.8667
UM	: 0.7172

HAL_ME3

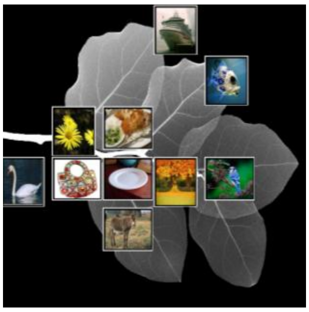
CM	: 0.7856
EM	: 1.0000
RM	: 0.7194
SQM	: 1.0000
SYM	: 0.8333
UM	: 0.7200

HAL_ME4

CM	: 0.9179
EM	: 1.0000
RM	: 0.7455
SQM	: 1.0000
SYM	: 0.7984
UM	: 0.7253

HAL_ME5

CM	: 0.8700
EM	: 1.0000
RM	: 0.7477
SQM	: 0.7500
SYM	: 0.7984
UM	: 0.7227



HAL_ME6

CM	: 0.8912
EM	: 1.0000
RM	: 0.7222
SQM	: 0.7500
SYM	: 0.8667
UM	: 0.7162

HAL_LE1

CM	: 0.7536
EM	: 1.0000
RM	: 0.7222
SQM	: 1.0000
SYM	: 0.8667
UM	: 0.7198

HAL_LE2

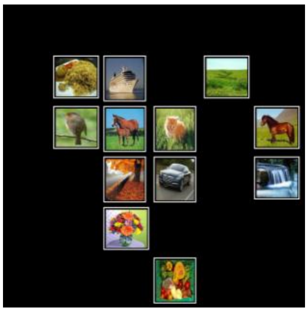
CM	: 0.9410
EM	: 1.0000
RM	: 0.7477
SQM	: 1.0000
SYM	: 0.7984
UM	: 0.7212

HAL_LE3

CM	: 0.9204
EM	: 1.0000
RM	: 0.7194
SQM	: 1.0000
SYM	: 0.8667
UM	: 0.7229

HAL_LE4

CM	: 0.9915
EM	: 1.0000
RM	: 0.7477
SQM	: 1.0000
SYM	: 0.9000
UM	: 0.7323



HAL_LE5

CM	: 0.7468
EM	: 1.0000
RM	: 0.7869
SQM	: 0.7500
SYM	: 0.7275
UM	: 0.7300

HAL_LE6

CM	: 0.9342
EM	: 1.0000
RM	: 0.7477
SQM	: 0.7500
SYM	: 0.9000
UM	: 0.7217

Appendix 2

The following are the pseudo codes of the Java program which created the stimuli in this study.

1. Pseudo codes of the Java program in Chapters 4, 5, and 6.

```
public class mainPage {
    public static void main(String[]args){
        CALL createLayout
    }
}

public class createLayout extends JFrame implements ActionListener {
    INITIALIZE totalTriangles to 10
    CREATE linked list <Polygon> triangles
    This method setups the GUI properties
    public createLayout (){
        SETUP GUI properties
        CALL drawingBoard (triangles)
        CALL aestheticProperties (triangles)
    }

public class drawingBoard extends JPanel {

    public drawingBoard (){
        CALL overlappAndAxisControl
    }

    This method checks if the triangles touch the axis or overlap
    public void overlappAndAxisControl() {
        boolean overlap = true, axis = true
        WHILE (the triangles are overlapped or touch the axis) DO
            FOR (Polygon p: triangles)
                DELETE existing objects in the arraylist triangles
            ENDFOR
            CALL createTriangles
            axis = testAxis()
            overlap = testBoundingBox()
```

```
    ENDWHILE
}
```

This method adjusts the number of inverted and upright triangles on the screen

```
public void createTriangles () {
      INITIALIZE inverted and upright to zero
```

This loop chooses the x, y coordinates of a triangle

```
      FOR (i =0 to totalTriangles)
          SELECT random number for x, y coordinates of a triangle
          ADD x, y coordinates of a triangle into linked list triangles
      ENDFOR
```

These conditions check the total number of upright triangles on the screen

```
      IF (the total number of upright triangles is less than 4) THEN
          FOR (Polygon p: triangles)
                CHANGE the coordinates of an inverted triangle into an upright
                triangle
                INCREASE upright by one
                IF (upright is more than 4) THEN
                      BREAK
          ENDFOR
      IF (the total number of upright triangle is more than 6) THEN
          FOR (Polygon p: triangles)
                CHANGE the coordinates of an upright triangle into an inverted
                triangle
                DECREASE upright by one
                INCREASE inverted by one
                IF (upright is less than 6) THEN
                      BREAK
          ENDFOR
 ENDIF
}
```

This method draws triangles

```
public void paintComponent(Graphics g) {
    CALL overlappingAndAxisControl
    FOR (Polygon p: triangles)
          DRAW a triangle
```

```
        ENDFOR
    }

    This method checks if the triangles touch the axis
    public boolean testAxis()
        boolean axis = false
        FOR (Polygon p: triangles)
            IF (the triangle touches the axis) THEN
                axis = true
                BREAK
            ELSE
                axis = false
            ENDIF
        ENDFOR
        RETURN axis
    }

    This method checks if the triangles are overlapped
    public boolean testBoundingBox (List<Polygon> triangles){
        boolean overlap = false
        FOR (Polygon p: triangles)
            IF (the triangle is overlapped with other triangles) THEN
                overlap = true
                BREAK
            ELSE
                overlap = false
            ENDIF
        RETURN overlap
    }

    This method writes layout properties to file
    public void writeStimuliCoordinateToFile (List<Polygon> triangles) {
        WRITE layout properties to file
    }
}
```

This class calculates the aesthetics value of each of the six metics

```
public class aestheticProperties {

    public aestheticProperties (List<Polygon> triangles) {
        CALL cohesion, economy, regularity, sequence, symmetry, and unity
        overall = (cohesion + economy + regularity + sequence + symmetry + unity) /
        6
        RETURN overall
    }

    This method calculates the aesthetics value of cohesion
    public double cohesion (List<Polygon> triangles){

            This loop gets the starting and ending points of each triangle
            FOR (Polygon p: triangles)
                GET the starting point of x, y coordinates of a triangle
                ADD the starting point of x and y coordinates into X1, Y1 respectively
                GET the ending points of x, y coordinates of a triangle
                ADD the ending points of x and y coordinates into X2, Y2 respectively
            ENDFOR
            SORT X1, X2, Y1, Y2
            widthOfLayout = last object of X2 – first object of X1
            heightOf Layout = last object of Y2 – first object of Y1
            cfl = (height of layout / width of layout) / (height of frame / width of frame)
            IF (cfl less or equal to 1) THEN
                CMfl = cfl
            ELSEIF (cfl more than 1) THEN
                CMfl = 1/cfl
            ENDIF
            FOR (i = 0 to the total number a triangle)
                GET width and height of a triangle
                ci = (triangle height / triangle width) / (layout height/ layout width)
                IF (ci is less or equal to 1) THEN
                    ti=ci
                ELSEIF (ci is more than 1)
                    ti=1/ci
                ENDIF
                T = T + ti
            ENDFOR
```

```
    CMlo = T/the total number of images on screen
    CM = {formulae of cohesion}
    RETURN CM
}
```

This method compares the sizes of triangles

```
public double numberOfTriangleSizes (List<Polygon> triangles){

   INITIALIZE nSizes to zero
```

   This loop gets the width and height of triangles

```
   FOR (Polygon p: triangles)
      GET the height and width of a triangle
      ADD height and width into sizes
   ENDFOR
```

   This loop compares the width and height of each triangle

```
   FOR (i=0 to the size of sizes)
      COMPARE the height and width of each triangle
      IF there is a variation in height and width of triangles THEN
         nSizes++
   ENDFOR
   RETURN nSizes
}
```

This method calculates the aesthetics value of symmetry

```
public double symmetry(List <Polygon> triangles) {

   GET the centre of frame
```

   This loop gets the x, y coordinates, width, height, angle, and total distance of triangles of each of the four quadrants

```
   FOR (Polygon p: triangles)
      GET the x, y coordinates of the centre of a triangle
      GET the height and width of a triangle
      x = x coordinates of the centre of triangle– x coordinates of the centre of frame
      y = y coordinates of the centre of triangle– y coordinates of the centre of frame
      angle = y / x
      distance = square root of (x^2 – y^2)
```

```
        GET the total of x, y, height, width, angle, and distance in the upper left quadrant

        GET the total of x, y, height, width, angle, and distance in the upper right quadrant

        GET the total of x, y, height, width, angle, and distance in the lower left quadrant

        GET the total of x, y, height, width, angle, and distance in the lower right quadrant

    ENDFOR

    CALL radial (summation of x, y, height, width, angle, and distance of each of the four quadrants)

    CALL vertical (summation of x, y, height, width, angle, and distance of each of the four quadrants)

    CALL horizontal (summation of x, y, height, width, angle, and distance of each of the four quadrants)

    SYM = {formula of symmetry}

    RETURN SYM

}
```

This method calculates the aesthetics value of radial symmetry

```
public double SYMradial (x, y, height, width, angle, and distance) {

    GET the total value of x, y, height, width, angle, and distance of each of the four quadrants

    NORMALIZE the total value of x, y, height, width, angle, and distance of each quadrant

    SYMradial =  {formulae of radial symmetry}

    RETURN SYMradial

}
```

This method calculates the aesthetics value of horizontal symmetry

```
public double SYMhorizontal (x, y, height, width, angle, and distance) {

    GET the total value of x, y, height, width, angle, and distance of each quadrant

    NORMALIZE the total value of x, y, height, width, angle, and distance of each quadrant

    SYMhorizontal = {formula of horizontal symmetry}

    RETURN SYMhorizontal

}
```

This method calculates the aesthetics value of vertical symmetry

```
public double SYMvertical (x, y, height, width, angle, and distance) {
    GET the total value of x, y, height, width, angle, and distance of each
    quadrant
    NORMALIZE total value of x, y, height, width, angle, and distance of each
    quadrant
    SYMvertical = {formula of vertical symmetry}
    RETURN SYMvertical
}
```

This method calculates the aesthetics value of regularity.

```
public double regularity(Component[] components) {
    GET the total number of triangles
    IF (the total number of triangle is 1) THEN
        RM = 1
    ELSE
        This loop gets the number of column and row starting point of triangles
        WHILE (there is a triangle) DO
            GET the starting x and y coordinate of each triangle
            ADD x coordinate into X1 and y coordinate into Y1
        ENDWHILE
        COPY X1 into X2 and Y1 into Y2
        REMOVE duplicate keys in X2 and Y2
        GET the size of X2 and Y2
        RMalignment = {formula of RMalignment}
        This loop finds the distinct distance between column and row starting
        points
        FOR (i  = 0 to the size of X2)
            xDistance = X2.get(i+1) - X2.get(i)
            yDistance = Y2.get(i+1) - Y2.get(i)
            ADD xDistance into X3
            ADD yDistance into Y3
        ENDFOR
        REMOVE duplicate key in X3 and Y3
        nSpacing = size of X3 + size of Y3
        RMspacing = {formulae of RMspacing}
        RM = {formula of regularity}
    ENDIF
```

```
    RETURN RM
}
```

This method calculates the aesthetics value of sequence.

```
public double sequence(List<Polygon> triangles) {
```

This loop calculates the total area of each of the four quadrants

```
    FOR (Polygon p: triangles)
        IF triangle belong to upperLeft quadrant THEN
            upperLeft area = upperLeft area + (height x width of a triangle)
        ELSEIF image belong to upperRight quadrant THEN
            upperRight area = upperRight area + (height x width of a triangle)
        ELSEIF image belong to lowerRight quadrant THEN
            lowerLeft area = lowerLeft area + (height x width of a triangle)
        ELSEIF
            lowerRight area = lowerRight area + (height x width of a triangle)
        ENDIF
    ENDFOR
```

These conditions assign weighting for each quadrant of the four quadrants

```
    IF the area of quadrant is the largest among the four quadrants THEN
        Weighting value of quadrant = 4
    IF the area of quadrant is the 3rd largest among the four quadrants THEN
        Weighting value of quadrant = 3
    IF the area of quadrant is the 2nd largest among the four quadrants THEN
        Weighting value of quadrant = 2
    IF the area of quadrant is the smallest among the four quadrants THEN
            Weighting value of quadrant = 1
    ENDIF
    upperLeft = 4 – weighting value of upperLeft quadrant
    upperRight = 3 – weighting value of upperRight quadrant
    lowerLeft = 2 – weighting value of lowerLeft quadrant
    lowerRight = 1 – weighting value of lowerRight quadrant
    SQM = (formulae of sequence)
    RETURN SQM
}
```

This method calculates the aesthetics value of unity

```
public double unity(List<Polygon> triangles){
    IF number of object is 1 THEN
        UM = 1
    ELSE
        CALL UMform
        CALL UMspace (components)
        UM = {formula of unity}
    ENDIF
    RETURN UM
}
```

This method calculates the relative measure of the space between triangles and that of the margins

```
public double unitySpace (List<Polygon> triangles){
```

This loop finds x, y coordinates, height, and width of triangles

```
    FOR (Polygon p: triangles)
        GET the height and width of a triangle
        area = area + (height * width of a triangle)
        GET the first coordinate of x and y of a triangle
        ADD the first x, y coordinate into X1 and Y1 respectively
        GET the last coordinates of x and y of a triangle
        ADD the last x, y coordinate into array list X2 and Y2 respectively
     ENDFOR
     SORT X1, X2, Y1, and Y2
     xWidthLayout  = last object of X2 – first object of X1
     yHeightLayout = last object of Y2 – first object of Y1
     layout = yHeightLayout * xWidthLayout
     UMspace = {formulae of UMspace}
     RETURN UMspace
}
```

This method finds the extent to which the objects are related in size

```
public double unityForm(List<Polygon> triangles, int n) {
     CALL numberOfImagesSizes (triangles, n)
     UMform = {formulae of UMform}
     RETURN UMform
}
```

2. Pseudo codes of the Java program in Chapters 7 and 8

```
public class createLayout extends JFrame implements ActionListener{

    CREATE arraylist called locationInTheGrid, alignmentInTheGrid,
    pictureInTheGrid, nonAnimalPictureFiles, animalPictureFiles, and choice
    aestheticLevels = {"High","Medium","Low"}

    animalPictureFiles = {filenames of animal picture}

    nonAnimalPictureFiles = {filenames of animal picture}

    choice ={aesthetic level of six metrics}

    public createLayout() {
        SETUP GUI components
        CALL checkAestheticsValue (choice)
    }

    public static void main(String[] args) {
          SwingUtilities.invokeLater(new Runnable() {
             public void run() {
              new createLayout ();
             }});
    }
```

This method controls the number of attempt to create a layout based on user's specification

```
    public void checkAestheticsValue (ArrayList<String>choice) {
        INITIALIZE attempt to zero
        WHILE (layout properties by the program does not match with the layout
        properties by user) DO
            IF (attempt is less or equal to100000) THEN
                CALL arrangePicturesInTheGrid (choice)
                CALL programOutputVsUserOutput (layout properties, choice)
                IF (the layout properties produced by the program match with the layout
                properties by user) THEN
                    CALL displayAestheticsValue
                ELSE
                    CALL arrangePicturesInTheGrid (choice)
```

```
        ELSE
            DISPLAY message to inform user that it takes too long to create the
            layout
        ENDIF
    ENDWHILE
}
```

This method creates the properties of layout

```
private void arrangePicturesInTheGrid (ArrayList<String>choice) {
    REMOVE all pictures in the grid
    CLEAR locationInTheGrid, alignmentInTheGrid, and picturesInTheGrid
    totalPictures = random number between 10 and 14
```

This loop selects the locations of pictures in the grid

```
    FOR (i = 0 to totalPictures)
        WHILE (locationInTheGrid does not contains cellInGrid) DO
            cellInGrid = random number between 0 and 35
            IF (locationInTheGrid  does not contains cellInGrid) THEN
                ADD cellInGrid into locationInTheGrid
        ENDWHILE
    ENDFOR
    width1 = random number between 50 and 100
    height1 = random number between 50 to 100
    totalAnimalPictures = random number between 3 and 6
    INITIALIZE counter to zero
```

This loop fills the selected cells with pictures

```
    FOR (i = 0 to the size of locationInTheGrid )
```

This condition selects non-animal pictures

```
        IF (counter is less than totalAnimalPictures) THEN
            WHILE (counter is less than totalAnimalPictures) DO
                selectedPicture = SELECT random file from animalPictureFiles
                IF (picturesInTheGrid  does not contain selectedPicture) THEN
                    ADD selectedPicture into picturesInTheGrid
                    INCREASE counter by 1
                ENDIF
            ENDWHILE
```

```
        This condition selects non-animal pictures
        ELSE
            WHILE (picturesInTheGrid  does not contain the selectedPicture)
                selectedPicture = SELECT random file from nonAnimalPictureFiles
                IF (picturesInTheGrid  does not contains selectedPicture) THEN
                    ADD selectedPicture into picturesInTheGrid
            ENDWHILE
        ENDIF
        CHANGE picture into an icon
        CALL createImageIcon (selectedPicture) to check if the file is exist
        These conditions ensure that for "high economy" all pictures have the
        same size whereas other layout metrics have many different sizes
        IF (the aesthetic level of economy is "high") THEN
            RESCALE icon based on width1 and height1
        ELSE
            width2 = random number between 50 and 100
            height2 = random number between 50 and 100
            RESCALE icon based on width2 and height2
        ENDIF
        SELECT alignment of icon in the grid
        ADD alignment into alignmentInTheGrid
        ADD icon in the grid
    ENDFOR
}
```

This method checks whether the layout properties by the program match with the layout properties by user

```
public Boolean programOutputVsUserOutput (Component[] components, choice){
    Boolean result = true
    CLEAR valueOfLayoutMetrics
    FOR (i = 0 to the size of choice) {
        IF (choice(i) is not null)
            IF (i==0)
                valueOfCohesion  = cohesion (components)
                ADD valueOfCohesion  into valueOfLayoutMetrics
            IF (i==1)
```

```
            valueOfEconomy  = economy (components)
            ADD valueOfEconomy into valueOfLayoutMetrics
        IF (i==2)
            valueOfRegularity  = regularity (components)
            ADD valueOfRegularity  into valueOfLayoutMetrics
        IF (i==3)
            valueOfSequence  = sequence (components)
            ADD valueOfSequence  into valueOfLayoutMetrics
        IF (i==4)
            valueOfSymmetry  = symmetry (components)
            ADD valueOfSymmetry  into valueOfLayoutMetrics
        IF (i==0)
            valueOfUnity = unity (components)
            ADD valueOfUnity into valueOfLayoutMetrics
    ELSE
        ADD null into valueOfLayoutMetrics
    ENDIF
ENDFOR

CREATE arraylist called aesLevelOfMetrics
```

This loop assigns aesthetic level to metric

```
FOR (i = 0 to the size of valueOfLayoutMetrics)
    IF (valueOfLayoutMetrics (i) is not null) THEN
        IF (valueOfLayoutMetrics (i) is equal or more than 0.7) THEN
            ADD "High" into aesLevelOfMetrics
        ELSE IF (valueOfLayoutMetrics (i) is within the range of 0.5 and 0.69)
        THEN
            ADD "Medium" into aesLevelOfMetrics
        ELSE IF (valueOfLayoutMetrics (i) is less than 0.5) THEN
            ADD "Low" into aesLevelOfMetrics
        ENDIF
    ELSE
        ADD null into aesLevelOfMetrics
    ENDIF
ENDFOR
```

This loop checks the layout properties by the program with the layout properties by user

```
    FOR (i = 0 to the size of aesLevelOfMetrics)
        IF ((aesLevelOfMetrics(i) == null && choice(i) != null) OR
        (aesLevelOfMetrics(i) != null and choice(i) == null))
            result = false
        ELSE IF (!(aesLevelOfMetrics(i)==choice.get(i)))
            result= false
        IF (!result)
            BREAK
     ENDFOR
    RETURN result
}
```

This method displays the aesthetics value of each of the six metrics

```
private void displayAestheticsValue (ArrayList<String> choice) {
    INITIALIZE counter as zero
    FOR (i=0 to the size of choice)
        IF(choice(i) is not null) THEN
            INCREASE counter by one
            IF (i=0) THEN
                CALL cohesion
            IF (i=1) THEN
                CALL economy
            IF (i=2) THEN
                CALL regularity
            IF (i=3) THEN
                CALL sequence
            IF (i=4) THEN
                CALL symmetry
            IF (i=5) THEN
                CALL unity
        ENDIF
    ENDFOR
    average = (cohesion + economy + regularity + sequence + symmetry +
    unity)/counter
    DISPLAY the individual and average aesthetics value of the layout metrics
    on JPanel
}
```

This method calculates the aesthetics value of cohesion

```
public double cohesion(Component[] components) {
    CALL layoutFrame (components)
    CALL layoutObject (components)
    CM = (layoutFrame / layoutObject) /2
    RETURN CM
}
```

This method measures the ratios of the layout and the screen

```
public double layoutFrame (Component [] components) {
    CREATE arraylist X1, X2, Y1, Y2
    FOR (Component component: components)
        GET the starting and ending point of x coordinates of a picture
        GET the starting and ending point of y coordinates of a picture
        ADD the starting and ending points of x coordinate into X1 and X2 respectively
        ADD the starting and ending points of y coordinate into Y1 and Y2 respectively
    ENDFOR

    SORT arraylist X1, X2, Y1, Y2
    Width of layout = last object of X2 – first object of X1
    Height of the layout = last object of Y2 – last object of Y1
    cfl = (height * width of layout)/ (height * width of the frame)

    IF (cfl <= 1) THEN
        Cfl = cfl
    IF (cfl >1) THEN
        Cfl = 1/cfl
    ENDIF
    RETURN Cfl
}
```

This method measures the ratios of the object and the layout

```
public double layoutObject (Component[] components) {
    INITIALIZE all variables to zero
    CALL layoutFrame (components)
    FOR (Component component: components)
```

```
        IF (cell in the grid contains an icon) THEN
            GET the width and height of icon
            ci = (height / width of icon) / layoutFrame
            IF (ci<=1) THEN
                t=ci
            ELSE IF (ci > 1) THEN
                t=1/ci
            ENDIF
            totalT += t
        ENDIF
    ENDFOR
    CMlo = totalT / total number of icons
    RETURN CMlo
}
```

This method calculates the aesthetics value of economy

```
public double economy(Component[] components) {
    CALL totalNumberOfIconInTheGrid (components)
    IF (totalNumberOfIconInTheGrid is one) THEN
        ECM = 1
    ELSE
        CALL numberOfDifferentSizes (components)
        ECM = 1 / numberOfIconWithDifferentSizes
    ENDIF
    RETURN ECM
}
```

This method calculates the number of icons on the grid

```
public int totalNumberOfIconInTheGrid (Component[] components){
    INITIALIZE totalNumberOfIconInGrid  to zero
    FOR (Component component: components)
        IF (cell in the grid contains an icon) THEN
            INCREAE totalNumberOfIconInGrid  by one
        ENDIF
    ENDFOR
    RETURN totalNumberOfIconInGrid
```

```
}
```

This method calculates the number of different size of icon

```
public double numberOfIconWithDifferentSizes (Component[] components) {
    INITIALIZE all variables to zero
    CREATE arraylist heightWidthOfIcon
    CALL totalNumberOfIconInTheGrid

    IF (totalNumberOfIconInTheGrid is one) THEN
        numberOfIconWithDifferentSizes =1
    ELSEIF
        FOR (Component component : components)
            IF (cell in the grid contains an icon) THEN
                GET width and height of the icon
                ADD width and height of icon into heightWidthOfIcon
        ENDFOR
    ENDIF
```

This loop compares the size of icons

```
    FOR (i = 0 to the size of heightWidthOfIcon)
        COMPARE objects in heightWidthOfIcon
        IF (there is a difference between objects) THEN
            INCREASE numberOfIconWithDifferentSizes by one
    ENDFOR

    RETURN numberOfIconWithDifferentSizes
}
```

This method calculates the aesthetics value of regularity

```
public double regularity(Component[] components) {
    CALL totalNumberOfIconInTheGrid (components)
    IF (totalNumberOfIconInTheGrid is one) THEN
        RM = 1
    ELSE
        FOR (Component component: components)
            IF (cell in the grid contains an icon) THEN
                GET the starting x point of the icon
                GET the starting y point of the icon
```

```
            ADD x and y into X and Y respectively
        ENDIF
    ENDFOR

    REMOVE duplicate keys in X and Y
    SORT X and Y
    GETS distance between x starting points of icon
    GETS distance between y starting points of icons

    FOR (i = 0 to the size of X minus 1) THEN
        distanceX = Object of X at position(i+1) - Object of X1 at position(i)
        Add distanceX into X2 at position(i)
    ENDFOR

    FOR (i = 0 to the size of Y minus 1) THEN
        distanceY = Object of Y at position(i+1) - Object of Y1 at position(i)
        Add distanceY into Y2 at position(i)
    ENDFOR

    REMOVE duplicate objects in X2 and Y2
    nSpacing = size of X2 + size of Y2
    CALL totalNumberOfIconInTheGrid
    IF (totalNumberOfIconInTheGrid  is one) THEN
        RMalignment = 1
        RMspacing = 1
    ELSE
        RMalignment = 1 – ((size of X2 + size of Y2) / (2 * totalNumberOfIconInTheGrid))
        RMspacing  = 1 - ((nSpacing -1)/(2*(n-1)))
    ENDIF
    RM =  (RMalignment + RMspacing) / 2
  ENDIF
  RETURN RM
}
```

This method calculates the aesthetics value of sequence

```
public double sequence(Component[] components) {
  FOR (Component component: components) {
    IF (cell in the grid contains an icon) THEN
```

```
            IDENTIFY where the icon belong to in the four quadrants
            On each of the four quadrants, sum up the area of all icons
            COMPARE the area of the four quadrants
            ASSIGN weighting to each quadrant: 4 for the largest area, 3 for the 2nd
            largest area, 2 for the 3rd largest area, and 1 for the smallest area
            upperLeftArea = 4 – weighting of upperLeft
            upperRightArea = 3 – weighting of upperRight
            lowerLeftArea = 2 – weighting of lowerLeft
            lowerRightArea = 1 – weighting of lowerRight
            SQM = 1 - ((UpperLeftArea + UpperRightArea + LowerLeftArea +
            LowerRightArea) / 8)
        ENDIF
    ENDFOR
    RETURN SQM
}
```

This method calculates the aesthetics value of symmetry

```
public double symmetry(Component[] components) {
    CALL radialSymmetry (components)
    CALL horizontalSymmetry (components)
    CALL verticalSymmetry (components)
    SYM = 1-((radialSymmetry + horizontalSymmetry + verticalSymmetry) / 3)
    RETURN SYM
}
```

This method calculates the aesthetics value of radial symmetry

```
public double SYMradial(Component[] components) {
    FOR (Component component: components) {
        IF (cell of the grid contains an icon) THEN
            GET x coordinate of the centre of the icon
            GET y coordinate of the centre of the icon
            GET the height of the icon
            GET the width of the icon
            x-distance = | x coordinate of the centre of the icon - x coordinate of the
            centre of the frame |
            y-distance = | y coordinate of the centre of the icon - y coordinate of the
            centre of the frame |
```

angleOfIcon = *y*Distance / *x*Distance

distanceOfIcon = square root (*x*Distance power by 2 + *y*Distance power by 2)

CHECK where the icon belong to at the four quadrants

On each of the quadrant get the summation of *x*-distance, *y*-distance, height of icon, width of icon, angleOfIcon, and distanceOfIcon

ENDIF

ENDFOR

NORMALIZE the summation of *x*-distance, *y*-distance, height of icon, width of icon, angleOfIcon, and distanceOfIcon on each quadrant

SYMradial = (formulae of radial symmetry)

RETURN SYMradial

}

This method calculates the aesthetics value of horizontal symmetry

public double SYMhorizontal (Component[] components) {

DECLARE all variables to zero

FOR (Component component: components) {

IF (cell of the grid contains an icon) THEN

GET *x* coordinate of the centre of the icon

GET *y* coordinate of the centre of the icon

GET the height of the icon

GET the width of the icon

x-distance = | *x* coordinate of the centre of the icon - *x* coordinate of the centre of the frame |

y-distance = | *y* coordinate of the centre of the icon - *y* coordinate of the centre of the frame |

angleOfIcon = *y*Distance / *x*Distance

distanceOfIcon = square root (*x*Distance power by 2 + *y*Distance power by 2)

CHECK where the icon belong to at the four quadrants

On each of the quadrant get the summation of *x*-distance, *y*-distance, height of icon, width of icon, angleOfIcon, and distanceOfIcon

ENDIF

ENDFOR

NORMALIZE the summation of *x*-distance, *y*-distance, height of icon, width of icon, angleOfIcon, and distanceOfIcon on each quadrant

SYMhorizontal = (formulae of horizontal symmetry)

```
    RETURN SYMhorizontal
}
```

This method calculates the aesthetics value of vertical symmetry

```
public double SYMvertical (Component[] components) {
    FOR (Component component: components) {
        IF (cell of the grid contains an icon) THEN
            GET x coordinate of the centre of the icon
            GET y coordinate of the centre of the icon
            GET the height of the icon
            GET the width of the icon
            x-distance = | x coordinate of the centre of the icon - x coordinate of the
            centre of the frame |
            y-distance = | y coordinate of the centre of the icon - y coordinate of the
            centre of the frame |
            angleOfIcon = yDistance / xDistance
            distanceOfIcon = square root (xDistance power by 2 + yDistance power
            by 2)
            CHECK where the icon belong to at the four quadrants
            On each of the quadrant get the summation of x-distance, y-distance,
            height of icon, width of icon, angleOfIcon, and distanceOfIcon
        ENDIF
    ENDFOR
    NORMALIZE the summation of x-distance, y-distance, height of icon, width
    of icon, angleOfIcon, and distanceOfIcon on each quadrant
    SYMvertical = (formulae of vertical symmetry)
    RETURN SYMvertical
}
```

This method calculates the aesthetics value of unity

```
public double unity(Component[] components){
    CALL totalNumberOfIconInTheGrid
    IF (totalNumberOfIconInTheGrid is one) THEN
        UM = 1
    ELSE
        CALL unitySpace (components)
        CALL unityForm (components)
        UM = (unityForm + unitySpace) / 2
```

```
    ENDIF
    RETURN UM
}
```

This method calculates the aesthetics value of unitySpace

```
public double UnitySpace(Component[] components){
    FOR(Component component: components) {
        IF (cell in the grid contains an icon) THEN
            GET the area of the icon
            SUM UP the area of all icons
            GET the starting and ending x coordinates of icon
            GET the starting and ending y coordinates of icon
            ADD the starting and ending x coordinates of icon into X1 andX2 respectively
            ADD the starting and ending y coordinates of icon into Y1 and Y2 respectively
        ENDIF
    ENDFOR

    SORT X1, X2, Y1, Y2
    widthOfLayout = last object of X2 – first object of X1
    heightOfLayout = last object of Y2 – first object of Y1
    xyLayout = widthOfLayout * heightOfLayout
    frame = 600 * 600
    UMspace = 1 - ((xyLayout - area) / (frame - area))
    RETURN UMspace
}
```

This method calculates the aesthetics value of unitySpace

```
public double UnityForm(Component[] components) {
    CALL totalNumberOfIconInTheGrid
    CALL numberOfIconWithDifferentSizes
    UMform = 1 - ((numberOfIconWithDifferentSizes - 1) / totalNumberOfIconInTheGrid)


    RETURN UMform
}
```

This method checks the existence of picture file

```
protected ImageIcon createImageIcon(String path) {
    java.net.URL imgURL = getClass().getResource(path)
    IF (imgURL != null) {
        RETURN new ImageIcon(imgURL);
    }
    ELSE {
        DISPLAY warning “Couldn't find file"
        RETURN null
    }
}
```

This method assigns action to JPanel components

```
public void actionPerformed(ActionEvent e) {
    This condition assigns action to “NEW” button
    IF (“NEW” button is selected) THEN
        This condition checks which checkbox is ticked and assign value to
        aestheticlevel
        IF (checkbox is ticked)
            ENABLE combobox
            aestheticlevel = GET the selected item of combobox
        ELSE
            DISABLE combobox
            aestheticlevel = null
        ENDIF

        ADD aestheticlevel into choice
        Boolean noSelection = false

        This loop checks the objects in arraylist choice
        FOR (i = 0 to the size of choice)
            IF (choice(i) is not null) THEN
                noSelection = true
                BREAK
        ENDFOR

        This condition displays warning when no checkbox is ticked or create a
        new layout when one or more checkboxes are ticked
        IF (!noSelection) THEN
```

```
        DISPLAY message "No metrics selected"
    ELSE
        CALL arrangePicturesInTheGrid (choice)
    ENDIF
```

This condition assigns action to "SAVE" button

```
IF ("SAVE" button is selected) THEN
    WRITE layout properties to file
ENDIF
}
```