SIMULATION OF A DESIGN ENVIRONMENT
FOR USERS TO INCORPORATE
PROPORTIONING SYSTEMS INTO
SCREEN DESIGN

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SIMULATION OF A DESIGN ENVIRONMENT FOR USERS TO INCORPORATE PROPORTIONING SYSTEMS INTO SCREEN DESIGN

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DECLARATION

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___________________
Eugene Ch’ng
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DEDICATION

To my parents
ABSTRACT

Dynamic Symmetry has been around for a long time. But rarely do we hear any discussion about its use as a design tool. “(It) is now all but forgotten, but in its day, it produced a cult-like mass of followers in the art schools.” Dynamic symmetry was discovered by Jay Hambidge in the early 1920s and used as a means for art, design and architecture as an objective method of aesthetics design. The base of this proportioning system originated from the natural growth patterns of organisms. One of the very distinct properties of this system is the theme principle of sets of related dynamic rectangles in a plain composition. Designs utilizing the principles of this system yield very orderly and natural relationships between elements and the elements and the whole.

Survey in the literatures of screen design in the past and present did not see the use of this system. Research in aesthetics has grown in recent years and researchers in this area have come to realize that aesthetics is important to usability in many ways. However, the topic is still in its infancy and requires much study. This article aims to introduce dynamic symmetry as a proportioning system as well as an objective approach to laying out aesthetically pleasing screens.

Two computer-based tool has been developed for the study of this system as applied to screen design in general. The first application, a dynamic symmetry analysis tool was developed based on Hambidge’s analytical methods of dynamic symmetry. A study was conducted to see if dynamic symmetry has been applied to screen design in the past. One hundred fifty screens from a variety of multimedia and web screens were selected for the test and input to the tool using the built in screen editor. Dynamic rectangles show up everywhere in these screens. More than 40% of the screens use these proportions and a number of them conform to dynamic symmetry principles.

Another study examines viewer judgements about the aesthetics of real screens copied from existing multimedia and web screens compared to their reformatted versions using dynamic symmetry. The evaluation yielded an average of 74.5% selected
reformatted screens over original versions. The studies provided a positive view toward this system. The principles and methods of dynamic symmetry design were then implemented as a grid-based design tool and the screens designed using the systems were evaluated. The viewer judgements yielded an average of 67.85% preferring the system suggested layouts to user proposed layout. The results of this formal study have been very positive. Through this we see the desirability of adopting dynamic symmetry as an aesthetic guide on which screen design may hang upon.
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PREFACE

Developers have been designing screens since a cathode ray tube display was first attached to a computer. During the 1980s guidelines for text-based screen design were made available and many screens began to take on a much less cluttered look through concepts like grouping and alignments. Then, the advent of graphics yielded another milestone in the evolution of screen design, providing many alternative ways of interacting with a computer system through the screen. Graphics enabled considerable presentation enhancements, making screens easier to understand and use. While the concepts such as groupings and alignments did not cease to exist, other elements of the aesthetics belonging to the visual arts were introduced. A few examples are balance, symmetry, harmony, colour studies, etc. The bloom of multimedia and the World Wide Web during the 1990s made aesthetics even more crucial as this concept benefits usability and soft issues such as user motivation and long-term satisfaction toward a system of which its screen has been enhanced by aesthetics. However, the aesthetics spoken before was mainly subjective in nature with minimal scientific and objective basis.

The 1990s and the dawn of the millennium saw the emergence of scientific research in the aesthetics of screen design. These research targets a more objective approach to laying out a screen with visual design principles, enabling even non-designers, with the help of the integrated aesthetic elements in a screen design system, to design aesthetically pleasing screens. In the history of design, the experiences of designers tell us that a lack of orderliness in design reflects the lack of a structured approach. In a survey of the history of design, we also saw that there was not many identifiable approaches that are scientific in nature except for those found applicable to architecture during the classical period. As such, a study was conducted to test the integrity of these systems as a real aesthetic tool for screen design. One modular system was proved to be beneficial. This thesis conveys that classical modular system termed dynamic symmetry, its characteristics, properties, and techniques to assist the aesthetical layout of screen design.
Chapter 1: Introduction

1.1 Introduction

Research in Human-Computer Interaction (HCI) has advanced manifold since the mid-1980s when this term was adopted as a means of describing this new field of study. The characterization of the definition of HCI is given as follows, ‘human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them’ (ACM SIGCHI, 1992, p.6). During the technological explosion of the 1970s the notion of the User-Interface (UI), also known as the Man-Machine Interface (MMI), became a general concern to both system designers and researchers and is defined by Moran (1981, p.4) as ‘those aspects of the system that the user comes in contact with’.

User-interfaces have evolved since the Command Line Interface (CLI) the oldest of all Human computer interface still in use today, to Menu-driven interface, Form Fill-in Interface, and the Graphical User Interface (GUI) popularly in use in most computer systems today. As the field began to develop other aspects of areas involving especially the users are found to be necessary in the design and implementation of useful or ‘user-friendly’ interfaces that not only assist the efficiency and productivity of the use of a well-designed system user-interface, but also motivate users in the long-term interests in the system. Thus, human-computer interface depended heavily upon other areas of expertise for contribution to its framework (Faulkner, 1998). These areas may be defined as psychology, artificial intelligence, ergonomics, anthropology, physiology, sociology, philosophy, linguistics, computer science, engineering, visual arts, and graphic design. These areas have all contributed much to the development of HCI.

The user-interface design may be categorized as two parts, constructional domain and behavioural domain (Hix and Hartson, 1993):
Constructional domain (User Interface Software Design) includes:

- Algorithms
- Data Structures
- Calling structures of modules and widgets
- Toolkits and library routines

Behavioural Domain (User Interface Interaction Design) includes:

- User Actions
- Feedbacks
- Screen Appearance
- User Tasks
- Functionality
- Sequencing
- Content
- Information Access
- Designing Interface Objects
- Screen Layout
- Interaction Styles

Constructional domains are system-centred whereas behavioural domains are user-centred. Development in the behavioural domain involves human factors, guides and rules, human cognitive limitations, graphic design, interaction styles, scenarios, usability specifications, rapid prototyping, and evaluation with human users.

1.2 The Scope of Research

This research covers both constructional and behavioural domains and is motivated by the user-centred aspect of visual perception, graphic design and screen layout. In other words the study is centred upon the aesthetics of screen design.

Developers have been designing screens since a cathode ray tube display was first attached to a computer. In the 1970s when IBM introduced its 3270 cathode ray tube text-based terminal, screens looked visually cluttered, and the emergence of a more widespread interest in the application of good design principles to screen design began to surface. At the turn of the decade, guidelines for text-based screen design were finally
made widely available (Galitz, 1980, 1981) and many screens began to take on a much less cluttered look through concepts like grouping and alignments of elements. The advent of graphics yielded another milestone in the evolution of screen design. While certain design principles did not change such as groupings and alignments, other elements were made available to visually enhance the interface. Interaction styles and controls also began to develop that enabled simpler and more efficient interaction. Graphics has indeed revolutionized design and the user interfaces. The 1990s and the dawn of the millennium saw the emergence of research in aesthetics of graphical user interfaces (Kurosu and Kashimura, 1997; Tractinsky, 1997; Ngo et al 1994, 2000, 2001; Ch’ng and Ngo, 2001a, 2001b).

But why aesthetics in particular considering that mainstream human-computer interface research has been along the line of usability since the beginning? How would aesthetics enhance the usability of an interface? Two studies show that very high correlations were found between users’ perceptions of interface aesthetics and usability. Three experiments (Tractinsky, 1997) were conducted to validate and replicate, in a different cultural setting, the results of a study by Kurosu and Kashimura (1995) concerning relationships between users’ perceptions of interface aesthetics and usability. The results support the basic findings by Kurosu and Kashimura. Very high correlations were found between perceived aesthetics of the interface and priori perceived ease of use of the system. Although aesthetics may not be the only solution to an efficient user-interface, it certainly plays an important role in enhancing usability.

Attractiveness in a screen layout is not merely cosmetics. Zetie (1995) suggests that “The attractiveness of a layout is more than cosmetic, it has a balance and flow that supports the other two objectives [it works, it organizes].” However, a study (Tractinsky, 1997) showed that the HCI literature in general, and that on usability in particular, has mostly neglected the aesthetics issues completely. Though it is true that an attractive interface will not ensure that it will serve well as a user-interface, aesthetics is still needed for issues other than usability. According to Dix et al. (1998), “A pretty
interface is not necessarily a good interface. Ideally, as with any well-designed item, an interface should be aesthetically pleasing. Indeed, good graphic design and attractive displays can increase users’ satisfaction and thus improve productivity.” Zetie also agrees to this, “The attractiveness of an interface may have a strong influence on ‘soft’ issues such as the motivation and satisfaction of the user.” If a user is satisfied and motivated to use the system because of the attractiveness of the interface, a long-term interest is retained towards the system. This is also true in web interfaces, Wesley and Wesley (1997) suggests that if a website is not visually pleasing, users are not going to be motivated to spend time there.

Towards the ease of learning of an interface, Szabo and Kanuka (1998) indicates that if we are concerned with minimising learning time and maximising learner completion rates, as we design screens for computer-based instruction we should consider applying the principles of design used in the study. Aesthetically pleasing layouts can also affect the student’s motivation to learn (Toh, 1998).

Can a visually pleasing screen enhance communication? Heines (1984) claims that a poorly designed computer screen can hinder communication. Arlov (1997) directed that good visual design make our windows easier to understand. Aspillage (1991) assert that good graphic design and attractive displays aid the transfer of information. A study by Grabinger (1991) showed that organisation and visual interest are important criteria in judging the readability and studyability of the real screens. Careful application of aesthetic concepts can also aid comprehensibility (Dix et al., 1998).

The importance of screen aesthetics has been demonstrated in a variety of studies above, at a glance the studies can be summarized below:

Screen aesthetics promotes:

- Acceptability
- Learnability
It is important to ensure that the layout adopted for the screen is visually pleasing and effective (Faulkner, 1998). Two areas that contributed an abundance of benefits to screen design are the visual arts and graphic design. The visual arts have benefited screen aesthetics whereas graphic design contributed to the layout of user interfaces. According to Galitz (1997), graphics not only assist in presentation, representation, transfer, and simplification of information in screen design, “Graphics can also add appeal or charm to the interface and permit greater customization to create a unique corporate style.” Amidst the many topics of visual arts and graphic design is found the catalyst of organizing principles called modular systems. Modular systems originated from the classical era and have been developed through the use of certain systematic principles of proportion by mathematicians, artists, designers, and architects through the course of history in an attempt to create aesthetics in their masterpieces. Since it mainly uses natural proportions to create unity and harmony in design, it can also be called proportioning systems (Ching, 1979). In at least one study (Ngo, 1994) modular systems have shown to benefit screen design in aesthetics.

Screen design and layout principles are very important in an interface and require psychological understanding and graphic design (Dix et al., 1998). Traditionally, research in these areas of screen design has been relegated to the realm of art rather than science. Only recently did we see the advent of a purely objective and scientific research into aesthetics of interface design (Ngo et al. 1994, 2000, 2001).
1.3 Research Objective and Methodology

Aesthetics in screen design is still at its infancy and requires exploration into better objective models. In order to address the issues of providing an objective approach to aesthetics in screen design, a research project was formed to investigate new ways of accomplishing it. The goal of this project is to incorporate modular systems into a computer aided-tool for screen design assistance. This includes:

- Investigating suitable modular systems for use in screen layouts,
- a comprehensive study of the targeted modular system’s methodologies,
- defining how the methodologies of the modular system can be used in screen layouts,
- defining how the methodologies of the modular system can be integrated as an algorithms for grid-based computer-aided design tool, and
- integrating the modular system into a computer system to improve the aesthetical layout of a screen design.

This research aims to introduce a classical modular system to screen design. Many other systems were investigated beforehand to ascertain their credibility to screen layouts. One particular system termed dynamic symmetry enables designing screens in a structured and objective approach and has been popularly used in art, architecture, graphic design, and industrial design since its discovery by Jay Hambidge in the early 1920s (Hambidge, 1920, 1924, 1926, 1932). A survey of screen design literatures did not find the true use of dynamic symmetry. Dynamic symmetry is a proportioning system based on the law of natural design found in the growth of living organisms such as the logarithmic spiral curve of shells, pattern of plant growth, and even the proportions found on our human body. Because of a certain property, these patterns can be reduced to rectangular form to solve problems of composition and design.

By employing the principles of dynamic symmetry, a computer aided analysis tool was developed to assist faster analysis of interfaces. This study examines whether
dynamic symmetry has been applied to screen design in the past. By using the analysis tool multimedia and web screens were analysed and found to contain plan schemes of dynamic symmetry in at least 40% out of the 150 selected screens (Ngo and Ch’ng, 2001; Ch’ng and Ngo, 2001a). The principles of dynamic symmetry were then used for reformattting popular screens. The new screens reformatted with dynamic symmetry principles were then evaluated and viewer judgements on over 50 candidates yielded an average of 74.5% preferring reformatted screens over their original versions (Ch’ng and Ngo, 2001b). The positive results led to the development of a screen design tool that incorporates the grid-based design rules of dynamic symmetry. By using this tool, users were asked to propose screen object shapes and position and allow the system to reformat them with dynamic symmetry grids. The evaluation yielded an average of 67.86% selecting the prototype-reformatted screens over user proposed screens. The results from these empirical studies have been very positive in achieving aesthetic layouts.

The role of interface aesthetics and its relation to usability has been demonstrated in various studies. It is shown that screen design with aesthetic considerations promotes benefits for usability in a variety of ways. As such, a study of a more structured and objective approach to interface aesthetics is essential to its development. This research pioneers the use of a fully functional modular system for screen layout. The use of dynamic symmetry offered designers a formula for reproducing natural proportions in their works. Empirical study of this system in analysis and design showed prospects for the adoption of this system by Integrated Design Environments (IDE). By using this modular system for screen layout, we have an easy framework from which to work. That is the purpose of this research, to demonstrate the use of modular system as a mean of laying out screen elements in a dynamic and aesthetically pleasing way.

1.4 Overview of Thesis

Chapter two covers related research in aesthetics and how modular systems are used in the arts, architecture and design field and how these can be used in screen design. The
modular systems are: the Japanese Ken, Le Corbusier’s Modulor, Classical Orders, Renaissance Theories, Anthropomorphic Proportions, the Golden Section, and Dynamic Symmetry.

Chapter three introduce dynamic symmetry, its origin, principles and properties, dynamic rectangles, and its uses in the past.

Chapter four reveal the practical methods of analysis, types of analysis, arithmetic and geometric analytical methods, process of analysis with dynamic symmetry, the algorithms of the analysis tool, and the interface of the tool with empirical studies.

Chapter five introduces static and dynamic grids, the principles of designing with dynamic symmetry and its two techniques called harmonic subdivision and similarity of figure, the algorithms used for generating dynamic grids in the dynamic gridding design tool, grid matching algorithms, and the interface of the system with empirical studies.

Chapter six conclude the research with the goals achieved, issues of this approach, contributions and future work.
Chapter 2: Related Research

2.1 Introduction
The design of the dynamic symmetry analysis and design environment was influenced by a number of researches in the areas of aesthetics, screen design, proportioning systems, modular systems and grid systems. This chapter covers these areas.

2.2 The Importance of Aesthetics
What is aesthetics, and how important is it to art, architecture, and design? Throughout the ages, many an inquest has been made concerning the aesthetics of art, architecture, and design. Is design intuitive or is it consciously and methodically worked out? Does a system or systems exist that governs the creation of beauty, of which when adopted will facilitate the creative process? Artist, art historians, and art critics alike have inquired upon these questions.

In the philosophy of the aesthetics, the metaphysical theory of beauty places some things in the context of everything (Townsend, 1997). The theory gives an account not just of individual things, but also for what individual things are in relation to all of the kinds of things there are or even could be. The universe is one great whole, all of its parts are related and combined in a harmonious relation in what we call beautiful. But when that relation is disturbed, the whole becomes disorderly. This in a very real sense is true. In the context of a painting, take a landscape painting for example, viewers do not only view individual objects in the painting, but also view the painting as a whole. It is the harmonious composition of the trees, the hills, and the skies with the correct dab of colour and the orderly elements of form that makes a painting beautiful. When we comment that a face is beautiful, we not only say that the eyes or the nose as an individual unit is beautiful, but that all the features worked together to make what we call a pretty face. The more perfect each features are, the nearer a face is to the standard of beauty. This is also true of architecture in the Vitruvian statement about the
fundamental principles of architecture (Vitruvius, 1960). The metaphysics that makes beauty an intrinsic part of the order of the universe has its origins in the works of Plato (427-347 BCE). He considered beauty as one of the highest form of the universe next to goodness and truth, and are the reality in which all other things participate. Whatever there is in the universe are connected to its forms, and ultimately to the highest forms. Plato’s philosophy was expanded later by Plotinus (204-70 BCE), who philosophised that beauty is the product of oneness as the organizing principle of reality. Classical theories of art and beauty are developed from the basic principles of these two philosophers. One example of this development is the use of classical modular systems, which solves design problems by unifying the elements of design to create oneness. Presently, in different areas of research, a common theme exists that motivates the exploration of visual aesthetics. These are mainly from philosophy of arts, basic psychological research, human factors studies, experiences of designers and users, and graphic design experience. This large base of knowledge resources could assist in deciding a suitable and objective system for laying out screen design.

Aesthetics is defined by Webster as the theory or philosophy of taste; the science of the beautiful in nature and art; especially that which treats of the expression and embodiment of beauty by art. It is the branch of philosophy dealing with beauty. What then is beauty, and which element characterizes a screen to which we agree as having a good appearance? According to Oxford, beauty is the combination of qualities that delights the sight or other senses or the mind. By exploring areas that has a certain relationship with screen design, we may find solutions to these problems.

The characteristics of screen design in this particular research can be narrowed down to three main points. Firstly, a screen is visual. Secondly, it exist on a two dimensional plane. And finally, a screen possesses separate or articulate objects, which together form a unit as a whole. A few identifiable areas that relates to this study are art, architecture, and design. Architecture is three-dimensional when completed, however the design began from conceptual sketches that leads to a two-dimensional blue print of the plan.
and elevation, thus it should be included in the survey. It is observed that these three areas possess corresponding elements since they are all related. Architecture involves design, and architecture is in fact art in a functional form (Hill, 1999).

All seeing is in the realm of the psychologist, and nobody has ever discussed the processes of creating or experiencing art without talking psychology (Arnheim, 1954). Gestalt Psychologists (Wertheimer, 1939; Kohler, 1947; Koffka, 1935) have studied and discussed visual perception of the principles of the arts. These principles have been explained and established to a certain extent (Arnheim, 1954, 1974; Dondis, 1974), they include balance, shape, form, growth, space, light, colour, movement, tension, and expression. These principles have very much shaped the art, architecture and design industry as far as aesthetics is concerned. Their importance and relevance to interface design has also been emphasized. Especially in the graphic design of an interface some of these principles are often applied. For example, in presenting the layout of an interface, the most common or critical information should be at the top left of the window or dialog, and the flow of the window should move from top to bottom or left to right (Weinschenk, Jamar, Yeo, 1997). This conception has its source from cognitive psychology, with a common explanation by the empiricists that the reading of pictures from left to right is a habit taken over from the reading of books.

The study of art over the years has also contributed much to the structuring of the guiding principles in the discipline of the visual arts. In the book Art Fundamentals (Ocvirk, Stinson, Wigg, Bone, 1990) dealing with this discipline the ingredients of art is broken into three groups; the first is the components – subject matter, form and content. The Second group belonged to the principles of organization – harmony, variety, balance, movement, proportion, dominance, and economy. And finally, the raw materials or elements that are organized by the principles – the elements of line, shape, value, texture, and colour. All of these contribute collectively to produce a work of art. Architectural design (Ching, 1979; 1987) touches these items much in the same way, but extend them in another axis in space.
The mediums used for producing artworks have also advanced with scientific technologies within these two centuries. Compare the digital brushes we often use in any paint program with the primitive cavemen method of mixing minerals ground into powders and blended with animal fat, egg white, and plant juice to a more modern approach of colour pigments and airbrush, plus the recent development of three-dimensional virtual worlds as a form of art. Nevertheless, by comparing and observing these mediums primitive or advanced that are used, we shall see that they cannot depart entirely from the foundation laid by perceptual research such as the visual arts with its components, principles and elements, these three ingredients worked together to achieve aesthetics. Although mainstream human computer interface (HCI) research depended largely on usability studies, when it comes to graphical user interfaces, the elements of art are crucial as contributing factor to its success in presentation. This is very similar to architecture, which unify aesthetics and functionality in the dominant concept of form follows function.

Modular systems have also contributed to the development in design. Throughout the history of design, there has been a search for systems and formulas that would assist the designer in his search for solutions to his problems. The ancient Egyptians and Mayans applied mathematics to form in ways that have yet to be understood. The Hindus in the 5th or 8th century B.C. worked out in the “rules of the cord” certain form of rectangles in the sacrificial altars. The classic designers of the Acropolis in Athens made sophisticated use of the rectangles derived form the square in working out the proportions of their architectural designs, and the Japanese made use of modular grids in their painted screens as well as in their domestic architecture. Modular systems have been developed through the use of certain systematic principles of proportion by mathematicians, artists, designers, and architectures through the course of design history in an attempt to create aesthetics in their masterpieces.
HCI is a multi-disciplined field. It leans heavily upon other areas of expertise, which in turn, provide significant inputs to its operation and a framework of its practices (Faulkner, 1998). Faulkner also argued that the use of expertise in art and design could help with the design of screen displays since they would be accustomed to presenting information in an appropriate and eye catching way, in the context of aesthetic appeal. However, “The attractiveness of a layout is more than cosmetic,” suggests Zetie (1995) “...[it] has a balance and flow that supports the other two objectives [It works, it organizes]. The attractiveness of the interface may have a strong influence on ‘soft’ issues such as the motivation and satisfaction of the user.” The question now is, which particular topic in perceptual research can have an impact on the aesthetics of a user interface. Can this item or items be structured as an objective framework so that it can be integrated into an interface design environment to assist designers who have no graphics background in laying out a presentable screen?

Two of the visual components mentioned earlier, subject matter and contents may not directly related to the aesthetic aspects of a screen whereas form, the other component is the completed state of work inclusive of the principles and elements. During design time, the screen with its collection of objects may already have all of the elements such as line, shape, texture, value and colour. The only item left are the principles of organization with three items relating to the layout of an interface – harmony, balance and proportion. In laying out a screen, the final appearance depended largely on these principles. One of the elements, the shape, is also crucial to the overall layout of the screen. Modular systems deal with these principles of organization in a very objective way. These principles are covered in later sections.

Does good visual design require more artistic than scientific skills? Traditionally visual design has been relegated to the realm of art rather than science. There are, however, attempts to measure aesthetics in an objective way (Birkhoff, 1933; Stiny and Gips, 1978). Research in screen design has also seen a development in this area of aesthetics.
2.3 Screen Design and the Importance of Interface Aesthetics

Mainstream human-computer interface research has been along the line of usability since the beginning. Usability is related to the effectiveness and efficiency of the user interface and to the user’s reaction to that interface. It is a combination of user-oriented characteristics such as (Shneiderman, 1992):

- Ease of learning
- High speed of user task performance
- Low user error rate
- Subjective user satisfaction
- User retention over time

Human-computer interface depended heavily upon other areas of expertise for contribution to its framework. One of the areas involved in the contribution is from the visual arts and graphic design. For example, the visual arts have benefited interface aesthetics whereas graphic design expertise contributed to the layout of a user interface. Recent studies in screen design have shown an increasing interest in this respect. For example, two studies show that very high correlations were found between users’ perceptions of interface aesthetics and usability. Three experiments (Tractinsky, 1997) were conducted to validate and replicate, in a different cultural setting, the results of a study by Kurosu and Kashimura (1995) concerning the relationships between users’ perceptions of interface aesthetics and usability. The results support the basic findings by Kurosu and Kashimura. Very high correlations were found between perceived aesthetics of the interface and priori perceived ease of use of the system.

The result of various studies on the impact of aesthetics in screen design towards communication and learning has been positive so far. The study of Szabo and Kanuka (1998) indicates that if we are concerned with minimising learning time and maximising learner completion rates, as we design screens for computer-based instruction we should
consider applying the principles of design used in the study. Heines (1984) claims that poorly designed computer screen can hinder communication. Toh (1998) state that aesthetically pleasing layouts can affect the student’s motivation to learn; this study is based on the ARCS model (Keller and Suzuki, 1983). In particular it is discovered that:

- **A = Attention** (good layouts will attract the attention of the student).
- **R = Relevance** (good layouts will be relevant to the student).
- **C = Confidence** (good layouts will boost the student’s confidence).
- **S = Satisfaction** (the students will feel satisfied if the design is good and appealing).

A study by Grabinger (1991) showed that organisation and visual interest are important criteria in judging the readability and studyability of the real screens. Screens that are plain, simple, unbalanced, and bare are perceived as undesirable. Aspillage (1991) claims that good graphic design and attractive displays aid the transfer of information. Arlov (1997) directed that good visual design make our windows easier to understand and suggested visual design elements for that purpose.

Multimedia and web screen design has come a long way with different production companies competing against one another. It is observed that in motivating sales and the interests and satisfaction of users in these systems, aesthetics plays a major role. For example, all the multimedia interfaces featured in *In Your Face: The Best of Interactive Interface Design* (Donnelly, 1996) supports an aesthetically pleasing look on top of the interaction styles to motivate usability and long-term interest and satisfaction in the system. From a purely practical point of view, the attractiveness of a screen layout will have dramatic impact on your ability to sell the application, whether commercially to external buyers, or to internal users (Zetie, 1995).

Aesthetics affect people’s long-term attitude towards a system. For example, in designing web screens, Wesley and Wesley (1997) claim that “If visitors don’t find a site visually pleasing, they aren’t going to be motivated to spend time there.” They also
suggest the two levels involved in designing a web site, one is structural design (function), and the other is aesthetics (form), which is the visual appeal of the content (Wesley and Wesley, 1997).

Organization and layout of a screen can also have dramatic effect on user performance. Tullis (1981) in an empirical study using two different formats for the same user task found that users interpreted information in a cluttered narrative format on average in 8.3 seconds, while the information in the structured format making use of white space, grouping of information and a columnar presentation scored an average in 5.0 seconds. The task was to perform diagnostic tests on telephone circuits based on information presented on a screen.

The aesthetic appearance of screen layout will be a result of its visual impact. Because vision is a result of interpretation by the brain as well as information gathering by the eye, it is important to ensure that the layout adopted for the screen is visually pleasing and effective (Faulkner, 1998 p.23).

From the studies above, we see the importance of art and graphic design in its contribution to the aesthetics of screen design, which in turn, benefited the usability of screen design in general. The graphic design of an interface involves decisions about issues such as where to put things on the screen, what size and font if type to use, and what colours will work best (Lewis and Rieman, 1994). Traditionally visual design is relegated to the realm of art rather than science. However, as mentioned earlier, there are attempts to measure aesthetics in an objective way. Recent research in screen design has paved the way for a more scientific nature in aesthetical use of visual design elements. For example, graphic design guidelines have been formalized for screen design layouts (Ngo, Teo, Byrne, 2000). These guidelines have also been used to evaluate interface aesthetics (Ngo, Teo, Byrne, 2001). Recently, Ngo (2001) reviewed and synthesized literature related to visual design and derived thirteen scientific measures that can be used to describe the spatial properties of any multi-screen interface, they are: balance,
equilibrium, symmetry, sequence, cohesion, unity, proportion, simplicity, density, regularity, economy, homogeneity, and rhythm. Recent research base on Ngo’s measure is being tested in an automated user interface generation tool with constructive problem-solving approach (Law, Ngo, 2001).

In the interface development arena, aid for usability tools integrating certain design principles has been developed. These are well known systems such as DON (Kim and Foley, 1993), AIDE (Sears, 1995), APEX (Feiner, 1985), APT (Mackinlay, 1986), Designer (Weitzman, 1986; Hollan, Hutchins, McCandless, Rosenstein, Weitzman, 1987), VIDEO (Johnson, Hartson, Ehrich, Roach, Reilly, Siochi, Tatem, 1986), and VISIT (Ngo, 1994; Ngo, Samsudin, Abdullah, 2000).

Though a number of researches on interface aesthetics have been conducted, the subject is still in its infancy and required further exploration into better aesthetic models. A survey (Ngo et al., 2000) showed that HCI literature has either belittle or ignored aesthetics altogether. A review of aesthetics in interface design literature and design environments showed limited development or use of modular systems with a grid-based approach. There are, however attempts to employ modular systems to achieve aesthetics in screen design. Two prominent design environments that employ modular systems are Pretty Windows (Gait, 1985) and VISIT (Ngo, 1994).

Gait’s system transforms windows of arbitrary sizes to pretty windows using the Golden Section, a naturally beautiful ratio found in living organisms. Gait’s approach realizes aesthetics by having the window sizes converted to the ratio of the golden section. Screens designed in this way may have some relationships in terms of the shapes, however, as far as placement of windows is concerned, there appears to have no governing principles. Certain shape of windows may also require ratios other than the Golden Section thus, the concept is not applicable to multimedia or web screens.
VISIT is a more complete approach to modular systems in screen design; it is also the first system to incorporate modular systems, aesthetic systems, and shape grammars into screen layouts. VISIT uses three rule-based systems, which are based on some modular systems such as Le Corbusier’s Modulor (Le Corbusier, 1954), the Japanese Ken, shape grammars such as the Palladian grammar (Mitchell, 1990), and Hambidge’s dynamic symmetry (Hambidge, 1926). The Modulor system used in VISIT took the golden section one step further by linking it to the scale and proportion of the human anatomy, producing two independent series of numbers called the blue and red series formed as tiles for design patterns. The shapes used in the Modulor are squares, double squares, and the Golden Section. The Ken uses only the double square. The third modular system is termed dynamic symmetry, which is the main subject of this thesis. So far, through the study of modular systems, dynamic symmetry has been the most convincing technique so far produced from natural proportions that is applicable to screen layouts. The use of dynamic symmetry shapes covers rectangles such as $\sqrt{1}, \sqrt{2}, \sqrt{3}, \sqrt{4}, \sqrt{5}, \phi, \sqrt{\phi}, \phi^2$, the last three are the Golden Section rectangle and its derivatives. These are called dynamic rectangles. These rectangles formed themes such that certain ratios of these shapes can only be used with the same species of rectangles. One example of a theme conception for a rectangle is the $\sqrt{5}$, which can only be used with $\sqrt{1}, \sqrt{4}, \phi, \sqrt{\phi},$ and $\phi^2$. Dynamic symmetry is the only modular system that uses the theme conception. VISIT failed to address and use this principle; its use of dynamic symmetry necessarily covers only the shape conversion aspects, this is very much like Gait’s Pretty Windows. Layout produced through such a method will not guarantee relationships among screen objects. This project pioneers and extends the full use of dynamic symmetry concepts to screen design layouts, covering the use of dynamic rectangles, their themes, and dynamic symmetry grids. Dynamic symmetry provides the most convincing argument to aesthetic layouts because of its flexibility and extensibility.

The section below briefly covers the proportioning and modular systems that has been developed and used in the past and its weaknesses. Section 2.4.6 on the Golden
Section is more thoroughly explained because it has extensive relationship with dynamic symmetry. The following chapter talks about dynamic symmetry concepts and its uses.

2.4 Proportioning Systems and Modular Systems

What are proportioning systems? To fully understand this, the concept of proportion has to be explained. According to Ghyka (1952) “The concept of proportion is in composition the most important one.” As taught by Euclid, this concept is derived from the concept of ratio which has to be defined first. Ratio is the quantitative comparison between two similar things. In this case, we are dealing with two-dimensional plane. Given a rectangle with sides height and width, the ratio between these two will be symbolized by \( \frac{\text{height}}{\text{width}} \), this has also the properties of a fraction, and can be represented by a number, result of division of height by width. For example, \( \frac{8}{5} \) will equal 1.6. The concept of proportion then, is the equality of two ratios. In this case we may have two rectangles, \( \frac{\text{height}_a}{\text{width}_a} \) and \( \frac{\text{height}_b}{\text{width}_b} \). The equality \( \frac{\text{height}_a}{\text{width}_a} = \frac{\text{height}_b}{\text{width}_b} \) expresses that they are connected by a proportion. This concept, taught Ghyka, “Is the geometrical proportion, the kind generally used in composition and design... this concept of proportion introduces, besides the simple comparison or measurement, this idea of a permanent quality transmitted from one ratio to the other; it is this analogical invariant which brings out an ordering principle.”

The concept of proportion brings an orderly principle to any pictorial composition if it is applied. Thus, this idea fulfils the metaphysical theory of beauty originated from Plato, that every part are related and combined in a harmonious relation in what we call beautiful. Proportioning systems brings about an orderly principle in any subject that employs them as their foundation. Ching (1979) mentioned that the intent of all theories of proportion is to create a sense of order among the elements in a visual construction. Thus, a proportioning system in the context of architecture establishes a consistent set of
visual relationships between the parts of a building, as well as between the parts and their whole. Ching continues to say, “Proportioning systems go beyond the functional and technical determinants of architectural form and space to provide an aesthetic rationale for their dimensions. They can visually unify the multiplicity of elements in an architectural design by having all of its parts belong to the same family of proportions. They can provide a sense of order in, and heighten the continuity of, a sequence of spaces.”

Historically, proportioning systems originated and developed from architecture. Architecture is necessarily of a three-dimensional nature, but while in the design stage where the proportioning system is being employed, the nature of the architectural drawing is two-dimensional. Since screen design involves only two-dimensions during the design and completed stage, and will not extend in another axis in space, proportioning systems are very much a benefit to us. It can be a useful tool in promoting unity and harmony (Ching, 1987). “Classical systems of proportion codify relationships known to please the mind as well as the eye,” states Mullet and Sano (1995). According to them proportion is a powerful tool in the hands of an experienced designer; it sets the rhythm of the display. In the same chapter they taught that, “harmony describes the effect, seen at the level of the whole, of the pleasing interaction of the parts” In addition to creating harmony, proportions can also make a form more visually inviting, it also enhances functionality (Bowers, 1999).

2.4.1 Ken

The Ken is a traditional Japanese unit of measure introduced in the latter half of Japan’s middle ages. It was originally used to designate the interval between two columns, and varied in size, the Ken was soon standardized for residential architecture. It later evolved into an aesthetic module that ordered the structure, materials, and space of Japanese architecture. In designing with the Ken modular grid, the standard Tatami floor mat measures $\frac{1}{2} \times 1$ Ken. A $\frac{1}{2}$ Ken has the ratio of 1:1 or a square, whereas 1 Ken has the ratio of 1:2. Because of the flexibility of this ratio, the floor mats can be arranged in a
number of ways for any room size. The Ken is generally arranged within a 1 x 1 unit grid in Japanese architecture as in Figure 2.1:

![Diagram of a 1x1 grid for Ken design module](image)

**Figure 2.1: Tatami Floor Mat In The Ken Design Module.**

The Ken specifically uses the square and the double square rectangle. It has been used by Ngo’s VISIT (Ngo, 1994) as a modular system in screen design. The square and especially the double square is used throughout the history of design in most proportioning systems. Other aesthetic rectangles such as the Golden Section are derived from the square, however the Ken system did not develop other rectangles from these. The nature of these rectangles is generally static or lifeless and would not be of much benefit to screen layouts.

### 2.4.2 The Modulor

Le Corbusier’s modular was greatly influenced by the mathematics of nature, namely the Golden Section and the Fibonacci series and the proportions of the human body. During his early days, he observed and studied nature and found that “nature is order and law, unity and diversity without end, subtlety, harmony and strength.” He adopted and developed the measuring tools of the Egyptians, the Greeks and other civilizations which he saw as “infinitely rich and subtle because they form part of the mathematics of the human body, gracious, elegant, and firm, the source of that harmony which moves us,
beauty.” Le Corbusier saw the modulor as a system that could “maintain the human scale everywhere.” This system could also “lend itself to an infinity of combinations; it ensures unity with diversity.” The basic grid of this system consists of three measures that are proportioned according to the Golden Section: 113, 70, 43 (cm).

\[
\begin{align*}
43 + 70 &= 113 \\
113 + 70 &= 183 \\
113 + 70 + 40 &= 226 \times 113)
\end{align*}
\]

The series of the sum of the three measures: 113, 183, 226 define the space occupied by the human figure. From 113 and 226, was developed the Red and Blue series, diminishing scales of dimensions that were related to the stature of the human figure. This system was applied to his principle work, the Unite’ d’ habitation at Marseilles, (1946 – 1952). Two books were published on the Modulor (Le Corbusier, 1954; 1955).

![Figure 2.2: The Panel Exercise: A Square Divided In Accordance With The Measures Of The Modulor. Image Taken From Le Corbusier (1954).](image-url)
The Modulor was used by Ngo (1994) as a modular system implemented in VISIT for aesthetic screen layout. The shapes used in the Modulor are limited to the square, the double squares, and the Golden Section.

2.4.3 The Classical Orders

The Classical Orders represented in the Greek and Roman proportioning elements the perfect expression of beauty and harmony. The standard measure of proportion comes from the diameter of the column. This measurement then gave place to the dimensions of the other parts of the building like the shaft, the capital, the pedestal, the entablature and other details. The sizes of the columns may vary in different buildings and are not important. The importance lies in the proportions between the details of the parts in relation to the column in which their dimensions originated. This proportioning system was not used in any screen design systems mainly because there were no ordering principles such as the use of certain rectangles. Proportioning is mainly based on the details of the parts in relation to the columns.

Figure 2.3: A Comparison Of The Orders. (Image Taken From Vitruvius, 1960).
2.4.4 Renaissance Theories: Andrea Palladio

Andrea Palladio (1508-1580) in The Four Books on Architecture proposed seven “most beautiful and proportionable manners of rooms.” He also proposed several methods for determining the proper height of a room so its width and length would be in proper relationship with the height. For flat ceilings, the height from the floor to the ceiling must be equal to their breadth. For square rooms with vaulted ceilings, their height must be one-third greater than their width. In other rooms where the length is greater than the width, he used Pythagoras’ theory of means to determine their height that their proportion may have a relationship. Palladio noted that “Beauty will result from the form and correspondence of the whole, with respect to the several parts, of the parts with regards to each other, and of these again to the whole; that the structure may appear an entire and complete body, wherein each member agrees with the other, and all necessary to compose what you intend to form.” (Palladio, 1570)

![Figure 2.4: The Seven Most Beautiful And Proportionate Shapes Of Rooms.](image)

Three shapes proposed by Palladio have been used in screen design. They are the square, the root-two rectangle, and the double square. Bowers (1999) mentioned that the root-two rectangle is very popularly used through history and today and is considered

2.4.5 Anthropomorphic Proportions
Anthropomorphic proportioning systems are based on the natural dimensions and proportions of the human body. While Classical and Renaissance architects discovered and used the aesthetic ratios found on the human body, anthropomorphic proportioning systems seek the functional use of these proportions. They are predicated on the theory that forms and spaces in architecture are either containers or extensions of the human body and should, therefore, be determined by its dimensions (Ching, 1979). For example the dimensions and proportions of our hand affects the design of doorknobs and handles, while the average dimensions of our height and width affects the spaces around us. Anthropomorphic proportions have no direct benefit to aesthetics of screen design.

2.4.6 The Golden Section
The Golden Section (GS) is by far the most enduring of all proportioning systems and the most widely accepted and utilised aesthetic ratio. The GS is also termed “Golden Mean” or “Golden Proportion” or “Divine Proportion” or “Golden Rectangle” or $\phi$ depending on the context they are used. A Golden Rectangle has the ratio of $1.618 = \frac{\sqrt{5}}{2}$. The Golden Section Construction I & II and the Golden Section Rectangle Construction methods are in the appendix.

The GS has been applied both intentionally and unintentionally in two- and three-dimensional design. It occurs in a variety of natural forms and is considered visually pleasing to a variety of cultures (Bowers, 1999). Research has also shown this ratio to be the most inherently pleasing, when viewed as a simple rectangle, or many possible alternatives (Barratt, 1980, p.109-113). A survey of art, design, architecture, and industrial design literature and even screen design showed the theory and practical use of the GS rectangle (Dondis, 1974; Ghyka, 1952; Kielland, 1955; Le Corbusier, 1954;
Ching, 1979; Jute, 1996; Hambidge, 1924; Gait, 1985). The reason for its popularity comes from the fact that this ratio originated from nature itself. Numerous organisms in nature can be found that exhibits the pattern of this ratio in the sequence of the Fibonacci numbers. The Fibonacci series has long been recognized as the principle occurring in the structure of living organisms. Examples of the plant life are the growth patterns of leaves around a stem, and of the sunflower seeds and pinecones. This ratio can also be found abundantly in the animal life such as the growth patterns of rabbits and of shells. The logarithmic spiral of marine life forms, such as the nautilus shell is a perfect example (Fig. 2.5). The Golden Proportion can also be found on the proportions of the human body (Ghyka, 1952).

![Figure 2.5: The Logarithmic Spiral Of The Nautilus Shell And The Geometrical Version.](image)

Leonardo of Pisa or “Leonardo Pisano” in Italian discovered the Fibonacci numbers. He was born in Pisa (Italy), the city with the famous Leaning Tower in about 1175AD. He was addressed as the “greatest European mathematician of the middle ages”. He called himself Fibonacci (Smith, 1958), short for filius Bonacci which means son of Bonacci. In 1202, Fibonacci published “Liber Abaci” (Book of the Abacus). In this book he introduced a problem for his readers to use in practicing their arithmetic. “A pair of rabbits is put in a field and, if rabbits take a month to become mature and then produce a new pair every month after that, how many pairs will be in twelve months
time?" He assumes the rabbits do not escape and none died. The answer involves a series of numbers:

\[ 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, \ldots \]

The next number in this series is the sum of the two previous numbers. If the number of the latter is divided into the former i.e., \( \frac{55}{34} \), the answer is 1.618, which is the ratio of the GS Rectangle. Later, the French mathematician Edouard Lucas (1842-1891) gave the name Fibonacci numbers to this series and found many other important applications of them.

The history of the synthetic applications of the GS as a design principle originated from the Egyptian civilization (Kielland, 1955), probably as early as 2600BC. They developed it very early as an empiric or rule-of-thumb method of surveying. Possibly the date is as early as the first or second dynasty. Later it was taken over as a means of plan making in architecture and design in general. It is found that early Mycenaean and Cretan art (Edwards, 1967) dated 1600BC, in the Metropolitan Museum of Art, that these reversed spiral forms were already in use, in a free way. There is no doubt as to the origin of the spiral forms they adopted, natural shell forms were used to a great extent in their decoration. The Greeks, who would stop at nothing in their pursuit of perfection, obtained the knowledge of the Golden Proportion from the Egyptians some time during the 6th century BC. This canon of proportion supplanted, probably rapidly, a sophisticated type of symmetry then in general use. The Greeks, however, soon after acquiring the knowledge, apparently made the astounding discovery that this symmetry was the symmetry of the growth in man. It was the Greeks who called the irregular number, 1.618, “The Section” They demonstrate the absolute and logical pursuit of harmonious results in the design of such temples as the Parthenon. Utilizing the formula of the Golden Mean, the mathematically determined proportion.
Phidias, considered to be the greatest of Greek sculptors, frequently used the aesthetic ratio in his designs. He chose the Golden Proportion for its natural ability to draw the eye to the focal point of art. His urns were admired and used throughout the European region, and it was after him that the Golden Ratio was named Phi, the Greek letter φ. From among the Greeks, Euclid (365-300BC) wrote the Elements, which is a collection of 13 books on geometry. In the book he describe the method of finding the GS point on a given line in Book 6, Proposition 30.

The GS is a line segment that has been divided into two parts in such a way that the ratio of the longer part \(a\) to the shorter part \(b\) is equal to the ratio of the entire segment \((a + b)\) to the longer part \(a\). This can be indicated symbolically as \(\frac{a}{b} = \frac{(a + b)}{a} = \phi\), and this ratio \(\phi\), is called the Golden Ratio.

\[\frac{a}{b} = \frac{a + b}{a} = \phi,\]

Figure 2.6: The Golden Section.

The Golden Rectangle or \(\phi\) rectangle is a rectangle with proportions corresponding to the GS. It is a rectangle that has adjacent sides with lengths in the Golden Ratio. A Golden Rectangle has the property such that if a square with side equal to the rectangle's short side is marked off, the remaining figure will be another golden rectangle; this process can be repeated indefinitely (Fig.2.7a). This illustrates the property of continued similarity of form decreasing in a continued ratio to infinity. It is also called the rectangle of the whirling squares, on which the squares rotate at an axis to infinity (Fig.2.7b). It is very clearly seen that within the Golden Rectangle, there is a relationship of form and surface that is organized, primarily to one another, and, secondarily, to the whole.
In the past there has been studies related to the GS. Every person’s tastes may vary, but many who are asked to select a shape that is most pleasing to them would select the Golden Ratio – It is not too square and it is not too elongated. Many of these claims about people’s preference for the Golden Ratio seem to be based in large part on the experiments of Gustav Fechner performed in the 1860s. Fechner’s procedure consisted in placing 10 rectangles before a subject and asking him to select the most pleasing rectangle. The rectangles varied in the height/length ratios from 1.00 (square) to .40… the modal rectangle and a height/length ratio of .62 i.e., the Golden Section, with 76% of all choices centring on three rectangles having the ratio of .57, .62, and .67.

The use of GS has been widely accepted in the realm of the arts. Well known persons such as Leonardo Da Vinci, Piet Mondrian, Georges Seurat, Henri Matisse, etc, have used the GS ratio as their canvas.
In architecture, the Egyptian temples such as the temple of Osiris at Abydos, the temple of Luxor, and the Great Pyramid of Giza have used the same ratio. In the classical era, Iktinos, Kalikrates and Phidias used this ratio combined with other related ratios in the Parthenon. In more recent times Andrea Palladio, Le Corbusier, and Philip Johnson who designed the Famous Glass House in 1953 designed around a harmony of Golden Mean rectangles on both the side and front elevations, taking the width of the door as the organising measure.

The GS has also saturated the industrial market. A Norwegian designer named John Rohde produced a Graceful Pitcher in 1920. The entire pitcher fits into a golden rectangle. The 1921 Chanel No.5 perfume bottle approximates the Golden Ratio. The bottle has subtly changed 15 times in the subsequent years, but the elegant proportions have stayed the same. A classic design in aluminium and Bakelite is the Wear-Ever coffee pot from 1934. The Golden Section can be observed in the upper and lower division of the pot body. A well-known chair design by Charles and Ray Eames in 1946 has the Golden Proportion in its height and width ratio. In 1954, Fritz Eichler was hired by Autur Braun to modify the company’s product line by adopting a more functionalist approach. Described as a “rational” design in the book The Look of the Century, this radio has a very distinct shape and division of the Golden Section. Levin (1978) has also employed the Golden Section as grids for dental aesthetics.

2.4.7 Similarity Between Proportioning Systems

As we have seen in the previous sections, proportioning systems has been widely used throughout the ages to bring an orderly principle to any pictorial or three-dimensional composition. Some of it have also been used to a limited extent in screen design. These systems establish a consistent set of visual relationships between the parts and the parts with the whole. It is a useful tool to create unity and harmony. The proportioning systems that we have seen seemed to possess a fundamental similarity between them, that is, they commonly utilize certain shapes that are claimed or proven to be aesthetically pleasing, and that the shape when used promotes proportional relationships
among the entities of a piece of artwork or a solid structure. Thus far, dynamic symmetry has been the most convincing argument for application to screen layout when compared to other modular systems. It uses all of the rectangles mentioned and some other related rectangles in its design schemes. The concept of theme in a related set of rectangles is also a unique feature not found in other systems. On top of these its flexible use of combinations of rectangles and the grid-based approach is very suitable to screen layout design. This is the purpose of the thesis, to document the use of dynamic symmetry in screen design.

The next chapter is devoted entirely to dynamic symmetry, a marvellous concept originated from the classical Greek period that is flexible and extensive in its use of thematic dynamic rectangles of aesthetic value.
Chapter 3: Dynamic Symmetry

3.1 Introduction
Dynamic symmetry is a proportioning system originated from the classical Greek period. It uses proportions of the human figure, of the growing plant, and of the spiral curves of shells as its design principles. It is this principles of design found in the architecture of nature that have been given the name dynamic symmetry. This system uses a number of aesthetic or dynamic rectangles such as $\sqrt{1}=1$, $\sqrt{2}=1.4142$, $\sqrt{3}=1.732$, $\sqrt{4}=2$, $\sqrt{5}=2.236$, $\phi=1.618$, $\sqrt{\phi}=1.272$, $\phi^2=2.618$. A technique taught by Jay Hambidge, the discoverer and author of dynamic symmetry literatures, when applied to any dynamic rectangles form a pattern where only certain rectangles of the same theme are generated. This conception of thematic proportions in a composition is the unique aspect of dynamic symmetry not found in other systems.

3.2 Origins of Dynamic Symmetry
Dynamic symmetry, one of the most provocative and stimulating theories in art history was rediscovered in the early twentieth century by the late historian and theoretician Jay Hambidge, himself a practising artist. He was impelled to take up the study of symmetry because he could not entirely agree with the modern tendency to regard design as purely instinctive. He had studied many ancient artefacts across different cultures such as Saracenic, Mohamedan, Chinese, Japanese, Persian, Hindu, Assyrian, Coptic, Byzantine, Gothic, Egyptian, and Greek art and had observed the difference between the symmetry that was used in their artworks (Hambidge, 1926). His main discovery was that there were two types of symmetry – static and dynamic. His thorough study of Greek art convinced him that the secret of the beauty of Greek design was in the conscious utilisation of dynamic symmetry – the law of natural design based upon the symmetry of growth in man and in plants.
It has long been discovered that the summation series is connected with the orderly distribution of the leaves of plants. The series is 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, etc. This summation series of numbers, because of its character, represents a ratio, i.e., it is a geometrical progression. One term of this series divided into the other equals 1.618, such as 55 into 89, which is the ratio necessary to explain the symmetry of the plant design system. However, this series does not represent the phenomenon exactly but only so far as it is representable by whole numbers. A much closer representation would be obtained by a substitute series such as 118, 191, 309, 500, 809, 1309, 2118, 3427, 5545, 8972, 14517, etc. The substitute series are of much interest because they not only furnish the exact ratio of 1.6180, but each member of this series is an actual ratio of the dynamic commensurable area scheme and is found abundantly not only in the human skeleton, but throughout classic Greek design. From this series the entire structure of dynamic symmetry is obtained, which applies not only to the architecture of the plant but also to the architecture of man.

Jay Hambidge became convinced that the spiral curve found in plant growth and the law of leaf distribution, and that of the curve of the shell, were identical, and must be the equiangular or logarithmic spiral curve of mathematics. He also saw that because of a certain property which it possessed, the spiral could be reduced from a curve form to one composed of straight lines and thereby be used by the artist to solve certain problems of composition and connect design closely with nature.

Figure 3.1 is any rectangle and AB is a diagonal. The line CD, drawn from C intersects the line AB and ends at D. The lines AC, CB, BD, DE, EF is identical with the angular spiral derived from the shell and from the plant. It is well known at that time that any shape drawn within the area of a rectangle whose diagonal is common to the diagonal of the containing area is a similar shape to the whole (CD of Fig. 3.1). The line CD determines the reciprocal of a rectangular shape and is itself the diagonal of that shape. HD which is drawn parallel to CB fixes the area of the reciprocal of the shape AB. With this notion of a reciprocal in mind it is apparent that the fatter or squatter the
rectangle the larger will be the area of the reciprocal until both diagonals crossed on a square. The breadth of the reciprocal increases with the breadth of the parent form until it coincides with it as a square; or it decreases until both become a straight line. Obviously there must be rectangles such that the reciprocal is some even multiple of the parent form, such as 1/2, 1/3, 1/4, 1/5, etc. Perception of this fact led the author to discover the root rectangles. It was found that a rectangle whose reciprocal equalled one-half the whole was a $\sqrt{2}$ rectangle; 1/3 a $\sqrt{3}$, 1/4 a $\sqrt{4}$ and 1/5 a $\sqrt{5}$ rectangle and so on. When the $\sqrt{5}$ rectangle was defined and its commensurable area examined it was found that this shape was connected in a curious manner with the phenomena of leaf distribution.

![Figure 3.1: Reciprocal Of A Rectangle.](image)

The dynamic rectangles, which was obtained from the growth phenomena, are distinguished by this property of area measurableness. It is this characteristic which lies at the base of the rhythmic theme conception and gives the dynamic scheme its greatest design value. Through analysis of Greek art and architecture, and much experimentation with the dynamic rectangles he published a number of books that are very useful and practical for designing objectively. These books are *Dynamic Symmetry*, *The Greek Vase*, *The Parthenon and other Greek Temples: Their Dynamic Symmetry*, *Elements of*
**Dynamic Symmetry, Practical Applications of Dynamic Symmetry** (Hambidge, 1920; 1924; 1926; 1932).

### 3.3 The Symmetries

The concept of symmetry as understood generally today is defined by Webster as “similarity of form or arrangement on either side of a dividing line or plane; correspondence of opposite parts in size, shape and position”. There are also related concepts such as symmetrical balance which is defined by Ocvirk et al (1990) as “A form of balance achieve by using identical units placed in mirror like repetition on either side of a central axis”, and approximate symmetry “The use of similar imagery on either side of a central axis. The visual relationships may give a feeling of resembling each other, but are varied to prevent visual monotony”.

Several guidelines documents have proposed that the spatial relationships among the elements on a screen should provide some degree of symmetrical balance. For example, Mullet and Sano (1995) stated that “… heavy use of symmetrical layouts … is perfectly appropriate for a user interface.” Some GUI standards such as OSF/Motif strongly encourage symmetrical arrangement of windows and dialog boxes throughout the environment.

Galitz (1997) proposed that symmetry should be achieved by centring the display itself and maintaining an equal weighting of elements on each side of the vertical axis. Streveler and Wasserman’s (1984) symmetry was computed as the difference between the centre of mass of the displayed elements and the physical centre of the screen. In addition, Ngo et al. (2000) proposed a measure of symmetry as one of their objective techniques for assessing the spatial properties of screens.

These concepts gave the general idea that symmetry is of a mirror like repetition on either side of an axis or equal weighing of elements on each side of a vertical axis. The Greeks however, had a different understanding of symmetry. Each element of a building
must be related to every other element, and each element to the whole as in the human body. When every important part of a building is set in proportion by the right correlation between height and width, and between width and depth, dynamic symmetry is achieved. Or, as the Greeks called it, *analogia* (it achieves), consonance between the parts and the whole.

Hambidge’s study of artefacts showed two types of symmetry – static symmetry and dynamic symmetry. These two types of symmetry are found in nature and can be utilized in design. One of these types, because of its character, was termed “static”, the other “dynamic.” (Hambidge, 1926) Static symmetry is a symmetry which has a sort of fixed entity or state. Grids of an equal width and length of the whole and the divisions are considered static (Fig. 3.2a), they are lifeless and monotonous to the visual perception. The rectangles such as 3/2, 5/4, 8/5, 3, etc. of which the proportions show only rational numbers, are called static rectangles. Dynamic symmetry in nature is the type of orderly arrangement of members of an organism such as we find in a shell (Fig. 3.2b) or the adjustment of leaves on a plant. It is a symmetry suggestive of life and movement. Rectangles such as $\sqrt{2}$, $\sqrt{3}$, $\sqrt{5}$, $\phi = (\sqrt{5}+1)/2$, $\sqrt{\phi}$, $\phi^2$, showing irrational numbers in their proportions, are called dynamic rectangles. These latter are the ones used in dynamic symmetry. They allow much more flexibility and a much greater variety of choice than the static rectangles, especially when used in order to establish the commodulation by proportion of the elements and the whole of a composition. The rectangles $\sqrt{1}$, and $\sqrt{4}$ can be considered both static and dynamic and are used abundantly together with all the other dynamic rectangles (Hambidge, 1926).
3.4 Dynamic Rectangles and Their Themes

There were a number of relevant studies recommending the use of classical rectangles such as the root rectangles and the Golden Section rectangles. Bowers (1999) mentioned that the $\sqrt{2}$ and the golden section are very popularly used throughout history and today and is considered visually pleasing. Marcus' (1992) book on screen design describes these rectangles as aesthetically pleasing. Ken Blundell’s (Blundell) lecture notes on human computer interface states that, “A rectangle generated by such a rule (the Golden Rectangle) is inherently pleasing.” Galitz (1997) suggests that aesthetically pleasing proportions should be considered for major components of the screen, including windows and groups of data and text. Proportioning systems in the past have also used these rectangles abundantly. These studies have shown the acceptable use of individual aesthetic rectangles. But so far, through observation, none combines these shapes through the use of dynamic symmetry concepts.
Figure 3.3: Relationships Of Dynamic Symmetry Rectangles.

A unique feature found only in this proportioning system is the use of themes of dynamic rectangles as seen in the Venn diagram of Figure 3.3. The method introduced by Hambidge, “The tracing of diagonals and perpendiculatrs to diagonals” (Appendix 3.1) forms the principle or themes of dynamic symmetry of which certain classes of dynamic rectangles are related only to themselves and can be used as a group only in the same compositional layout. In ‘A’ of Figure 3.3 the rectangles $\sqrt{5}$, $\phi$, $\sqrt{\phi}$, $\phi^2$ are of the same theme, $\sqrt{2}$ in ‘B’ and $\sqrt{3}$ in ‘C’ will not unite with themselves except those composed of even squares, and $\sqrt{4}$ and 1 are the neutral types which can be employed with any of the other groups. In a paragraph about these rectangles, Hambidge (1932) commented, “We learn from this that the root-five base is the most flexible one that is probably one of the reasons why the Greek designers preferred this base.”

This is even true in screen design. In a study (Ch’ng and Ngo, 2001a) of multimedia screen layouts using Hambidge’s analytical methods, it was found that the $\phi$ theme, which also implies its derivatives and the $\sqrt{5}$ are dominant in most of the screens (Appendix: 3.2). This is again explained by Hambidge, “We must first understand that the $\sqrt{2}$, $\sqrt{3}$, and $\sqrt{4}$ rectangles represent, apparently, a symmetry type intermediate between the static and complete dynamic types.” In another paragraph he stated that “Of the many hundreds of examples of classic Greek design which have been examined in
both the American and the European museums, about 85 per cent show dynamic schemes based upon √5; about 10 per cent upon √2, 1 or 2 per cent upon √3, and the remainder are either uncertain or are clearly static”

The themes of dynamic symmetry are classes of rectangles that can be used together with one another to produce the commodulation of elements. The commodulation or linking of all the elements of the planned whole is through a certain proportion or a set of related proportions. This notion of relationship between rectangles, that is, between their proportions, derives its importance from a law of composition already mentioned by Leone Battista Alberti, a famous renaissance architect (Alberti, 1965), and rediscovered by Hambidge, the “law of the non-mixing of proportions or themes in a plane composition”; in such a composition, only “related” themes must be used, “antagonistic” themes must not be mixed (Ghyka, 1952).

Hambidge’s method takes into consideration the fact that the overall frame of a two-dimensional plan or composition is generally a rectangle or a complex of rectangles; in his method of harmonic subdivision or analysis, these rectangles are treated by the diagonal. That is, we draw a diagonal, and from one of the opposite summits a perpendicular to this diagonal; this can be repeated with the other diagonal, and from the points of intersection between diagonals, perpendiculare and sides, are drawn parallels to the sides. This process can be continued with many variations, and every diagram thus obtained is what Hambidge called a “harmonic subdivision”, that is, produces a perfect commodulation of surfaces, and obeys the “law of non-mixing themes”.
Figure 3.4: Harmonic Subdivision Of The Golden Section Rectangle.

Figure 3.4 is a harmonic subdivision of the Golden Section rectangle. The theme conception of this figure is consistent to that of figure 3.3. In order to obtain dynamic symmetry or commodulation with the diagonals method, we must use rectangles already introduced as dynamic (Hambidge, 1926). Figures 3.5-7 uses other dynamic base to produce their themes, notice that the rectangles obey the law of non-mixing themes.

Figure 3.5: Harmonic Subdivision Of The $\sqrt{2}$ Rectangle.
3.5 Compound Dynamic Rectangles

The use of dynamic rectangles as a base for design is not limited merely to the fundamental rectangles of this symmetry. These rectangles can also be compounded to form secondary dynamic rectangles to increase its flexibility. Compound dynamic rectangles are found abundantly throughout classic Greek design (Hambidge, 1924). In fact, within each elementary dynamic rectangle is an abundance of compounded elements when it is treated by the diagonals, this can be seen in figures 3.4-7.

The substitute of the summation series mentioned earlier with the numbers 118, 191, 309, 500, 809, 1309, 2118, 3427, 5545, 8972, 14517, etc, are actual ratios of compound dynamic rectangles. Take 191, 309, and 809 for example, if each of these numbers
represented by \( n \) are multiplied as \( m = n \times 10^{-3} \), the resultant \( m \) will be 0.191, 0.309, and 0.809. \( m \) should represent the reciprocal of a ratio greater than 1. If \( m \) is inversed as, \( 1 / m \), the ratio will be clearly seen:

\[
\frac{1}{0.191} = 5.236 = 3 + \sqrt{5}, \text{ the value 5.236 is a compound rectangle of 2 squares added to a } \sqrt{5} \text{ rectangle.}
\]

\[
\frac{1}{0.309} = 3.236 = 2 \times 1.618, \text{ the value 3.236 is a compound rectangle of 2 } \phi \text{ rectangles added together.}
\]

\[
\frac{1}{0.809} = 1.236 = 2 \times 0.618, \text{ the value 1.236 is a compound rectangle of 2 reciprocals of the } \phi \text{ rectangle added together.}
\]

Figure 3.8 is a diagram of the compound rectangle of the substitute series.

![Diagram](Figure 3.8: Compound Rectangles Of The Substitute Series.)
3.6 Properties of Dynamic Symmetry

Dynamic symmetry is a symmetry suggestive of life and movement. The great value of this symmetry lies in its power of transition or movement from one form to another in the system. Figure 3.9a is a natural form of a dynamic rectangle. Figures 3.9b and c are two other variations.

![Figure 3.9: Different Manifestations Of The Golden Rectangle.](image)

The curve patterns of an organism like the nautilus shell, when reduced to a rectangle forms a dynamic area. These rectangles are distinguished by the property of area measurableness, or the commensurability of area, meaning that the area or areas are proportionately related. It is this characteristic which lies at the base of the rhythmic theme conception and gives the dynamic scheme its greatest design value. Because of the persistence of the normal ratios of the dynamic rectangles, which has similar properties with the growth patterns of plants, the measurable area themes possess life and all the qualities that go with it, while areas which do not possess this peculiar property do not have life. They are “static” or dead areas at least as far as design is concerned. Many have noticed that one characteristic of Greek design is just this life-suggesting qualities.

From the earliest times the artist has been searching for co-ordinating principles, which will bring order out of chaos. Dynamic symmetry is capable of conducting such task by its systematic use of dynamic rectangles of similar themes and the
commodulation of surfaces (Ghyka, 1977). Dynamic symmetry is also unlimited in its manifestation of surfaces; many variations of surface structures can be generated in a dynamic rectangle or compounds of dynamic rectangles using the techniques of dynamic symmetry.

### 3.7 Dynamic Symmetry Uses

The classical Greeks first used this system especially in their architectures such as the Parthenon in Athens and many useful items such as vases and ornaments. Later, when Hambidge rediscovered dynamic symmetry his contemporaries found many uses for it such as tile and fabric patterns and designs (Edwards, 1967), layout of book pages, and paintings. Hambidge himself gave two very practical examples of dynamic symmetry design. They are the chair and the water sprout lion head (1932). To this day a number of artists, architects, sculptors, and photographers have used Hambidge’s system in their works.

Among those he influenced decisively are Maxfield Parrish (painting), Anne Carleton (painting), John Steuart Curry (painting), Paul Sample (painting), George Bellows (painting), Emil Bisttram (painting), Diego Rivera (painting), José Clemente Orozco (painting), Jeffrey Smart (painting), Mary Crovatt Hambidge (decorative art), Edward B. Edwards (decorative art), Gary Bernstein (photography), Ed Buffaloe (photography), Edward Steichen (photography), Walter Dorwin Teague (in architecture and product design), Tony Smith (in architecture, painting, and sculpture), William Buck Stratton (sculpture), etc.

The characteristics of dynamic symmetry made it very suitable for screen design. The use of themes of dynamic rectangles as surfaces within a dynamic base allows for consonance of parts and of the whole between screen objects and frame. Dynamic symmetry compound ratios are flexible enough to suit all shapes and sizes in a screen layout. On top of these benefits, the grid like structure of this system can be integrated with screen design environments to act as an assistant to screen designers. The next two
chapters cover the technical aspects of dynamic symmetry analysis and design and their algorithms.
4.1 Introduction

Jay Hambidge’s thorough study of Greek art and architecture yielded many methods of analysis. These methods both arithmetic and geometric can be converted into a series of algorithms for computer-assisted analysis.

During his time, Hambidge (1926) uses technical drawing tools to study the shapes of dynamic symmetry, among the items are: a scale divided into millimetres, or a foot-rule divided into tenths, a small drawing board, a T-square, a compass, and a lead pencil. These items are useful when used with precision. However, analysing composition information with manual tools can be time-consuming and tedious. In the introduction of The Elements of Dynamic Symmetry, Hambidge stated that “The synthetic use of dynamic symmetry design principles is simple, (but) the recovery of these design principles of analysis is difficult, requiring special talent and training, considerable mathematical ability, much patience and sound aesthetic judgement.” Analysing the plan of large building such as the Parthenon is not so difficult as the recovery of the plans of many minor design forms. Sometimes a simple vase required days of intensive inspection before the design theme becomes manifest.

In the earlier part of this research, I constantly use the technical drawing tools to construct as well as analyse many Greek artefacts as well as screen design in order to learn the methods of construction and analysis. As the number of diagrams increases, the thought of digitising them for storage and reproduction for later use began to manifest. AutoCAD 2000 then was the more suitable software to use as it provides the accuracy needed as well as easy measuring devices among many other tools in the package. As I began to master the methods, the research advances to a more mature stage of empirical studies of screen design. An abundance of screens were collected from multimedia and
internet systems. Many of these were digitised with AutoCAD and the need for a faster and more efficient tool was realized. Normally a screen would take a day or two to realize the thematic schemes, this can be very time consuming on top of the tediousness. Since the analysis is done in arithmetic, a further study of the analytical methods proves that simple algorithms of a computer system can assist in a quicker and more efficient study with Microsoft Excel. These algorithms were implemented as an application using Visual Basic, this is where version one of the analysis tool was developed. The system was then improved with automatic analysis in version two using Borland Delphi. Eventually when I became affluent in the experience of analysis, I designed a system (info. in appendix 6.1) that integrates the functionality of version two and a simple drawing interface as version three using Visual Basic 6.0 object oriented concepts.

The sections below provide a guide to analysing the composition information of screen design using Hambidge’s analytical methods of dynamic symmetry and also cover the automated system of analysis.

4.2 Application of Jay Hambidge’s Analytical Methods To The Parthenon

Hambidge’s theory conforms to early Greek mathematical thought. He has called attention to the fact that the Greeks recognised a geometrical, as well as an arithmetical, symmetry. Symmetry to the Greeks is most simply defined as commensurability. This means that two dimensions to be compared can be measured in multiples of a common unit. Two dimensions, though not commensurable in simple linear units, may be simply commensurable in square -- δυναμεὶ συµµετροι, to use the Greek term occurring in the earliest extant mathematical record; that is, “commensurable in power,” or, one might say, “dynamically symmetrical.” The name which Hambidge has given to his theory of proportions based on the “root rectangles” turns out to be a transliteration of a Greek term expressing the same idea.

There are facts supporting Hambidge’s theories. The Greeks of the fifth century are familiar with the root rectangles is clear from the well-known passage in the theaetetus
of Plato. Eudoxus, a contemporary of Plato, is said to have investigated “the section,” which is held to be the sectio aurea, i.e., the principle of extreme and mean proportion inherent in the root-five rectangle. These proportions also underlie much of the geometry of Euclid.

Critics argue that artists are not mathematicians, and that the construction of dynamic symmetry are too complex to have been comprehended at all by Greek artisans, or to have been put into practical use even by architects such as Iktinos. However, it is historically recorded that the sacrificial altars that were constructed in ancient India is in accordance with the proportions of the root rectangles. Thus, against critics’ argument, the Greek Architects and artisans were capable of comprehending and constructing dynamic symmetry.

The second argument to Hambidge’s theory is that the ratios, or rectangles, of his system are innumerable. Consequently any object under the sun could be analysed in accordance with it. What the critics have failed to explain is the constant recurrence in Greek works of art of a very limited number of proportions derived by simple construction from the square, namely the root rectangles. The properties of dynamic symmetry were found on the Parthenon from the huge structures of the Façade and elevations to the minute and more ornamental details of the architectural Frieze.

This section covers the logical divisions for analysis as applied to the Parthenon (Fig. 4.1). The logical divisions for analysis of the Parthenon can be divided into two categories:

A) The relation of the greatest height to the greatest width.
The Parthenon has a ευτυνερια, or levelling course. This is considered and decided that it should be included in the analysis since it is a normal feature in Greek temples and are included as part of the design process. (Hambidge, 1924, preface xviii).
B) Within the enclosed rectangle, the most important horizontal lines and vertical lines, the natural divisions (Hambidge, 1924 p.25). The Parthenon has prominent horizontal and vertical divisions:

Horizontal Divisions:
1) The line of the top of the entablature, the base of the pediment triangle
2) The line of the tops of the columns (most important line)
3) The line of the stylobate

Vertical Divisions:
1) The axes of the six intermediate columns
2) The axes of the angle columns

Figure 4.1: The Division Of The Parthenon, The Façade Divides Logically Into Gable, Entablature, Columns, And Base (From Hambidge, 1924).

There are two approach of analysing the proportions of the Parthenon as described by Jay Hambidge (1924 p.7). The first approach employs certain subdivisions of the
temple plan (Fig. 4.2), which were fixed by the architects, such as areas defined by column centres. The second approach consists of fixing the proportional relationships of the voids and solids in an enclosed rectangle of an elevation or plan of a building.

![Floor Plan of the Parthenon](image)

**Figure 4.2: Floor Plan of the Parthenon**

### 4.2.1 The Plans

This approach is necessarily limited to certain parts of the two dimensional plan. Figure 4.3 is the plan of the Parthenon. When lines are drawn across the temple floor from centre to centre of the flank columns, fixed in the same manner as are those of the front, the result is a series of area strips each of which is composed of .236 rectangles and squares. A .236 rectangle has two squares plus a $\sqrt{5}$ rectangle. $1/.236 = 4.237$, AD is a strip fixed by the column centres of the flanks, EF, FG are 2.36 rectangles (note the position of the decimal point), BE, GD are squares.
Figure 4.3: Lines Drawn Across Temple Floor from Centre of the Flank Columns
(From Hambidge, 1924).

Figure 4.4 is another variation of this method. There are six regularly spaced
columns on each front, consequently the area made by the six strips divides the major
part of the temple floor into a trellis of .618 rectangles. .618 is the reciprocal of a \( \phi \)
rectangle. A, B, C, D, E, F are centres of the six regularly spaced columns of the facade.
GH is composed of two .618 rectangles, HI is a .618 area. There are eleven of these
groups in each of the six strips.

Figure 4.4: Trellis Of .618 Rectangles Produced By The Six Regularly Spaced Columns
(From Hambidge, 1924).
4.2.2 Voids and Solids

The second approach consists of the fixing of the proportional character of voids and solids as made by the two or three-dimensional plans and elevations. This approach is sweeping in character and discloses every possible phase of proportional or non-proportional relationships. It is useful for every aspect of two or three-dimensional analysis. Figures 4.1-6 are examples. The method reduces outstanding proportions of the structure to rectangles and regards these as subdivided into other rectangles by architectural members. These again may be subdivided into smaller areas until each separate architectural unit is bounded by its own rectangle (Hambidge, 1924 p.9).

![Figure 4.5: A Three-Dimensional View Of The Proportional Relationships In The Parthenon (From Hambidge, 1924).](image)

There are some guidelines to follow while using this approach:

- The full height and width of the building furnish an end and side of a rectangle.
- The analysis is to begin with outstanding proportions.
- If the areas are unequal, they are considered separately first before relating them to each other. One example is the Metope and Triglyph on the Frieze (Fig. 4.6) (p.24). The Triglyph has a lesser height than the Metope, so they are considered separately in analysis.
The Metope in AB of Figure 4.6 is composed of two squares AH, and a $\sqrt{5}$ rectangle CB. The Triglyph in FG was probably intended to be a .618 rectangle, FE = 2.766 by EG = 4.484 feet, 2.771 = 1.618.

Voids and solids are present in the second approach of analysis but they are proportionally related. The process of analysis may be carried to any degree of refinement necessary of the void on solid projections. The voids as well as the solids have a proportional value. This is as it should be in a graphic proportioning scheme which fixes symmetry by area and volume rather than by line (Hambidge, 1924 p.4). This can be seen in the analysis of Figures 4.7 and 4.8.

HF of figure 4.7 are two $\sqrt{5}$ rectangle, CE and EF. AJ has two .618 rectangles on top of a larger horizontally positioned .618 rectangle.
AB of Figure 4.8 is a square fixed by the abacus width. CD is a .618 rectangle. AE and HF are squares. CE is composed of the square CJ and two .618 areas JF. DF is two .618 rectangles. AG, DI, and CH are each composed of a $\sqrt{5}$ rectangle and three squares. IE and BF are each composed of a $\sqrt{5}$ and two squares. The areas including the voids are exhausted.

As noticed there will be voids as well as solids represented within the rectangle, but the parts of the overall rectangle occupied by these voids must have the same proportional character as the rest. The analysis will therefore be an exhaustion of the major rectangle by the void and solid projections (p.9).
4.3 Analysis Technique: Arithmetic

It is in analysis that the great value of arithmetic is proven. The function of arithmetic in this connection is twofold, firstly it straightens out entanglements, secondly it furnishes positive prove of correctness of results. To recover themes of classic Greek design it is necessary to use arithmetical analysis (Hambidge, 1926).

The principle set forth in the analysis of a harmonic subdivision is that a square is always represented as one or unity, which is of the ratio \(1 / 1 = 1\). It may be 10. or 100. or 1000, but it will always be a square as an area of sides of equal length. In this context it will be apparent that the area of any rectangle may be composed of one or more squares plus some fractional part of a square.

4.3.1 The Notion of Ratio and Reciprocal

In arithmetic analysis the ratio and reciprocal of a rectangle are equally important (Hambidge, 1926, p30-32). The ratio of a rectangle is always greater than 1, this is obtained by dividing the greater into the lesser. If a \(\phi\) rectangle has its height as 250 and width as 404.5, we may divide 404.5 into 250, thus we obtain the ratio 1.618. A reciprocal of a rectangle is a figure similar in shape to the major rectangle but smaller in size.

To obtain the reciprocal of a rectangle, divide the smaller side of a rectangle into the greater, dividing 250 into 404.5 will give us the reciprocal value of 0.618. To obtain the reciprocal of any ratio, we divide that ratio into one: \(\sqrt{5}\) divided into 1 is .4472, \(\phi\) divided into one equals .618. Figure 4.9 is a geometric illustration of this. The diagonals CD and AB intersect each other at right angles at E to produce AB, a reciprocal to the shape CD. Except for the differences in sizes the ratio is similar between the two. Notice that the reciprocal of a rectangle has vertical orientation and a ratio has horizontal orientation. This observation is important when analysing the composition information of a screen design.
There are necessarily two types of arithmetic analysis where the ratio of the width and height are concerned:

1. The first type is where the whole number is the number of squares and the fraction is a dynamic rectangle in itself or a dynamic shape which may contain a square or squares plus the fraction of a square
2. The second type is where whole number plus the fraction is a dynamic rectangle plus compounds of dynamic rectangles

4.3.2 Dissecting Ratio and Reciprocal: Type One
Figure 4.10 is an example of the arithmetic analysis of the subdivision from the temple elevation of the Parthenon. There are four columns on each front of the *cella* and a cross section at either front is shown in (a). The line of the top step of the *cella*, that is, the *cella* floor, is produced to A and B, the outer lines of the stylobate, the area of the cross section of the temple elevation CD is divided to fix the rectangle CB. The area EF is composed of four $\sqrt{5}$ rectangles. Each of the areas AE and BG has the reciprocal value of .34164. In order to analyse this value the steps below are necessary:
1. Find the ratio of which it is the reciprocal:
   - If the value is smaller than one, it is a reciprocal of a rectangle. To find the ratio,
     we divide one with the reciprocal, \( \frac{1}{.34164} = 2.927 \).

2. Determine the number of squares with the whole number in the ratio:
   - With the ratio 2.927, the whole number is separated from the fraction, with the
     whole number representing the number of squares, in this case, a double square.

3. Dissect the fraction:
   - \(.927 - .618 = .309\). The area is now exhausted with dynamic rectangles which
     consist of 1 + 1 + .618 + .309. Figure 4.11b is a geometrical figure of this
     dissection. The ratio .309 is the reciprocal value of 3.236 which is a 2φ.

![Diagram](image)

**Figure 4.10:** An Analysis Of The Subdivision Of The Temple Elevation
(From Hambidge, 1924).

Let us consider the \( \sqrt{5} \) rectangle (Fig. 4.11a). The square root of five is 2.236; if one
or a square is subtracted from this number the result will be 1.236, a square plus the
fraction of .236. In the case of this particular rectangle, 1.236 represents the two small
rectangles on the side of the square, if 1.236 is divide by 2, the result is .618, this
number represents each of the two smaller rectangles. It is clear that the area of the \( \sqrt{5} \)
shape may be considered as 1 plus .618 plus .618; a square plus two .618 rectangles. .618 is the reciprocal of a 1.618 rectangle meaning that .618 is of the same shape as its parent form, therefore the $\sqrt{5}$ is composed of a square plus two $\phi$ rectangles.

![Diagram of the $\sqrt{5}$ rectangle](image1)

**Figure 4.11:** Analysing The $\sqrt{5}$ Rectangle.

In the case of the 1.618 rectangle (Fig. 4.11b), it is a composition of a square plus a 0.618 rectangle. In this type of arithmetic analysis, the whole number of the ratio is the number of squares whereas the fraction is the excess area which may be a dynamic rectangle in itself, or a dynamic shape which may contain a square or squares plus the fraction of a square. If the ratio of the rectangle is 2.618 (Fig. 4.12a), there are two squares before the decimal and a 0.618 as the fractional part; or a square plus a $\phi$ rectangle.

![Diagram of the $\phi^2$ and $\phi$ rectangle](image2)

**Figure 4.12:** Analysis Of The $\phi^2$ And The $\phi$ Rectangle.
With the simple arithmetic set in order, it is a simple task to analyse the dynamic subdivision of a dynamic rectangle. The method frequently used by Hambidge to analyse an unknown area is to convert a rectangle’s end (shorter side) to unity or 1 (Hambidge, 1926 p.43), and the side of the rectangle is made the same as the ratio of the rectangle. Figure 4.12b is a dynamic rectangle. AB is a square, BD has the ratio of $0.618 = 0.755 / 1.221$. We shall change the shorter side BC into unity and convert CD into 0.618, the ratio of BD. 1 / 0.618 = 1.618. BD is recognized as a $\varphi$ rectangle. Since the ratio determines the shape of a rectangle and the reciprocal is a similar shape to the ratio, this manoeuvre is necessary to simplify the steps in defining the area of a rectangle or its subdivisions. E.g., a rectangle with an end of unity and a side of 0.618 would clearly indicate a $\varphi$ rectangle. This procedure is recurrent until all the areas of the rectangle are exhausted.

### 4.3.3 Dissecting Ratio and Reciprocal: Type Two

The second type of analysis considers the whole number and the fraction of a ratio as a whole. Meaning that if the ratio is a dynamic area, it is composed of a dynamic rectangle or compounds of dynamic rectangles. Figure 4.13a has the ratio of $1.427 = 2.309 / 1.618$. In this analysis, it is necessary to use dynamic ratios to determine the hidden dynamic areas. If the reciprocal of the 1.618 rectangle 0.618 is subtracted from 1.427, the ratio 0.809 remains. The area 0.809 consists of two $\varphi$ rectangles placed on top of each other. Figure 4.13b has the ratio of $1.309 = 2.118 / 1.618$. 1.309 – 0.618 = 0.691, the number .691 represents the reciprocal of the ratio 1.4472, which is composed of a square and a $\sqrt{5}$ rectangle. The ratio 1.309 can also be dissected with type one analysis. 1.309 is a square plus a 0.309 area. 1 / .309 = 3.236. 3.236 / 2 = 1.618. The fraction consists of two vertical $\varphi$ placed end to end. Notice that it is also possible to yield results from ratios with both types of analysis; this is because dynamic symmetry is not fixed by only a single set of surfaces, it is this property that is most beneficial to design.
Figure 4.13: Analysis Of The 1.427 And 1.309 Rectangles.

Figure 4.14a, the geometrical representation of the Metope is an arithmetic example from the Parthenon. The Metope on the Entablature has the ratio of $1.0568 = 4.185 / 3.96$, $0.4472$ the reciprocal of $\sqrt{5}$ subtracted from $0.946$ the reciprocal of the ratio $1.0568$, leave us the fraction $.5$, a double square, $1 / 0.5 = 2$. AB of figure 4.14b is a double square while BC is a $\sqrt{5}$ area.

Figure 4.14: The Metope On The Parthenon Entablature.

From the examples above it is noted that the key to the analytical methods is the ratio between its longer and its shorter side. From the point of view of proportion, the most important figure in composition is the rectangle; the most important characteristic of a rectangle is its proportion or characteristic ratio (Ghyka, 1952). All the arithmetical operations such as the subtractions, additions, and divisions are executed on the
characteristic ratio to determine the hidden areas. The next section places these arithmetic analyses into formulas for practical geometrical analysis.

### 4.4 Analysis Technique: Geometric

The practical analysis using dynamic symmetry analytical methods over portions from the Parthenon and elementary dynamic rectangles is covered in this section. In analysis, Hambidge used the Greek method called “application of areas” over the areas to be analysed, and the resulting excess area is again analysed for the presence of elementary rectangles or compounds of these rectangles if it is not in itself a dynamic rectangle. Figure 4.15a-f are frequently found ratios in the Parthenon. These ratios together with the most frequently found ratios in nature and Greek design (Appendix 4.1) can be used to match with the excess areas to see if the areas of the rectangle are dynamically related. The algorithms to generate more dynamic ratios will be covered in section 4.6.

![Figure 4.15](image)

**Figure 4.15:** Frequently Found Ratios In The Parthenon.

The following proportions occur over and over again in the Parthenon (preface xvi-xvii):

1) The root-five rectangle. Ratio, 2.236. Reciprocal,.4472. Fig. 4.9a.

2) The extreme and mean proportion rectangle. Ratio, 1.618. Reciprocal,.618. Fig. 4.9b.
This, with its reciprocal added, equals the root-five rectangle, Fig. 10c.

3) The rectangle composed of a square and a root-five rectangle. Ratio, 1.4472. Reciprocal .691. Fig. 4.9d.

4) A combination of a .618 rectangle with half of a 1.618 rectangle. Ratio, .618 + .809 = 1.427. Fig. 4.9e.

5) The rectangle which remains when two squares are subtracted from a root-five rectangle. Ratio, 2.236 - 2.00- = .236. Fig. 4.9f.

In the following paragraph Hambidge (1926, p.101-102) explain the process of analysis:

“\textit{When we are confronted with the problem of determining the nature of unknown areas we may have recourse to several methods of analysis...If the unknown area is not recognizable as being composed of two or more familiar areas we may determine its reciprocal, or, if the ratio is less than unity, find the ratio of which it is the reciprocal; having fixed the reciprocal we may examine the excess or defect area: the logical position of a reciprocal is as an area, similar to the whole, applied to the end of a rectangle: we may turn the reciprocal sidewise and consider it as a subdivision of a square: we may apply it to the side of an overall area exactly as we should apply a square, and then analyze the excess area: we may apply a square or squares, or other known areas, and again examine the excess or defect.}”

Hambidge’s literature furnishes us with the methods, but he did not specifically set clear formulas for analysis. He gave the reason that, “\textit{... the average designer or the average layman is not sufficiently familiar with the processes of either algebra or geometry and to use mathematical formulae would result in placing design knowledge beyond the reach of those most interested in the subject.}” However, it is still necessary
to do so for clarity and for the purpose of the analysis tool. Equations transformed from Hambidge’s literatures after thoroughly studying the analytical methods are explained below.

### 4.4.1 Application of Areas

The Greeks for the purpose of dividing up the areas of a rectangle so that the divisions would be recognizable used a simple method called the “application of areas” (Hambidge, 1926 p.28-29). The areas to be applied to a rectangle may involve elementary dynamic rectangles with ratios of \( \sqrt{1}, \sqrt{2}, \sqrt{3}, \sqrt{4}, \sqrt{5}, \phi, \sqrt{\phi}, \phi^2 \) as well as compounds of these dynamic areas and is symbolised by \( dr \). The remaining area or excess area, symbolized by \( ea \) is again analysed for familiar dynamic ratios until the entire rectangle is exhausted. The most frequently found ratios in nature and Greek design may be used as a match for the excess area, or a more thorough analysis can be done with the dynamic ratio generator. It is necessary to first list down the universal set and its subsets that are related to this study.

\[
\begin{align*}
U &= \{ u \mid u \text{ is a rectangle within all dynamic rectangles} \} \\
G &= \{ g \mid g \text{ is rectangle within all generated dynamic rectangles} \} \\
E &= \{ e \mid e \text{ is an element of dynamic symmetry rectangles, } (\sqrt{1}, \sqrt{2}, \sqrt{3}, \sqrt{4}, \sqrt{5}, \phi, \sqrt{\phi}, \phi^2) \} \\
A &= \{ \sqrt{1}, \sqrt{4}, \sqrt{5}, \phi, \sqrt{\phi}, \phi^2 \} \\
B &= \{ \sqrt{1}, \sqrt{2}, \sqrt{4} \} \\
C &= \{ \sqrt{1}, \sqrt{3}, \sqrt{4} \} \\
R &= \{ r \mid r \text{ is any given rectangle of a screen object} \}
\end{align*}
\]

Through natural combinations of elements in the set \( E \), many variations of compound dynamic rectangles may exist as the Universal set \( U \). \( G \) contains algorithm
generated dynamic rectangles which will be covered in section 4.6. \( E \) contains the basic elements of dynamic symmetry rectangles. The sets \((A, B, C) \subset E\) and \(A \cap B \cap C = \{\sqrt{1}, \sqrt{4}\}\). We also know that \(E \subset G\) and \(G \subset U\). Within the set \(R, r \in U\) if the analysis is positive. Figure 3.3 in chapter 3 illustrates some of the relationships.

For a screen analysis given that \(dr \in G\). In a given rectangle of a screen object \(r\), when \(dr\) is applied to it, an excess area \(ea\) remained. Thus we know that \(r = dr + ea\). A simple decision for the analysis is given,

\[\text{Input rectangle’s height (h) and width (w) and get excess area (ea)}\]

\[\text{If } ea \in G \text{ Then}
\]

\[r \in U, \text{ since } r = dr + ea, \text{ so } r \text{ is dynamic}\]

\[\text{Else}
\]

\[r \notin U, \text{ so } r \text{ is not dynamic}\]

\[\text{End}\]

There are basically two application methods below on which we could examine a rectangle and its excess area. A rectangle positioned horizontally or vertically has its sides on the top and bottom and its end on the left and right hand side (Fig. 4.16a-e).

1. Application of areas to the end of a rectangle with ratio (a) and reciprocal (b). A vertically positioned rectangle can only have the reciprocal of a rectangle applied to its end, therefore it uses the same formula for (b).

2. Application of areas to the side of a rectangle with reciprocal (c) and to the side of a vertically positioned rectangle with ratio (d) and reciprocal (e). A horizontally positioned rectangle can only have the reciprocal of a rectangle applied to its side (e).
The formula to find the excess area $ea$ by applying the ratio of a dynamic rectangle $dr$ to an end of the rectangle (Fig. 4.17a) is given as,

$$ea = \begin{cases} \frac{h}{w-(h \times dr)} & \text{if } w-(h \times dr) \leq h \\ \frac{w-(h \times dr)}{h} & \text{otherwise} \end{cases}$$

where $h$ is the height of the rectangle, $w$ is the width, and $dr$ is the representation of the ratio of a dynamic rectangle or a compound area.

In certain cases, we may want to apply the reciprocal of a dynamic rectangle to the end of a rectangle (Fig. 4.17b). The formula is,
\[ ea = \begin{cases} 
  \frac{h}{w-(h/\text{dr})} & \text{if } w - (h/\text{dr}) \leq h \\
  \frac{w-(h/\text{dr})}{h} & \text{otherwise} 
\end{cases} \]

where \( h \) is the height of the rectangle, \( w \) is the width, and \( \text{dr} \) is the representation of the ratio of a dynamic rectangle or a compound area.

To find the excess area by applying the reciprocal of a dynamic rectangle to the side of a rectangle (Fig. 4.17c), the formula is given as,

\[ ea = \begin{cases} 
  \frac{w}{h - (w/\text{dr})} & \text{if } h - (w/\text{dr}) \leq w \\
  \frac{h - (w/\text{dr})}{w} & \text{otherwise} 
\end{cases} \]

**Figure 4.17:** Dynamic Rectangle Applied And Its Excess Area.
where $h$ is the height of the rectangle, $w$ is the width, and $dr$ is the representation of the ratio of a dynamic rectangle or a compound area.

There are conditions where dynamic rectangles are applied to vertically positioned rectangles. To find the excess area $ea$ by applying the ratio of a dynamic rectangle $dr$ to the side of a vertically positioned rectangle (Fig. 4.17d), we use the formula,

$$ea = \begin{cases} 
\frac{h - (w \times dr)}{w} & \text{if } h - (w \times dr) \geq w \\
\frac{w}{w} & \text{otherwise} \\
\frac{h - (w \times dr)}{w} & \text{otherwise}
\end{cases}$$

where $h$ is the height of the rectangle, $w$ is the width, and $dr$ is the representation of the ratio of a dynamic rectangle or a compound area.

To apply the reciprocal of a dynamic rectangle to the end of a vertically positioned rectangle (Fig. 4.17e), we use the formula,

$$ea = \begin{cases} 
\frac{h - (w / dr)}{w} & \text{if } h - (w / dr) \geq w \\
\frac{w}{w} & \text{otherwise} \\
\frac{h - (w / dr)}{w} & \text{otherwise}
\end{cases}$$

where $h$ is the height of the rectangle, $w$ is the width, and $dr$ is the representation of the ratio of a dynamic rectangle or a compound area.

In frequent cases, it is necessary to apply more than one dynamic rectangle to find the matching excess area. To apply multiples of dynamic rectangles, substitute the dynamic rectangle representation $dr$ in the previous formulas with $mdr$,

$$mdr = dr \times n$$
where \( mdr \) is the multiples of a dynamic rectangle, \( dr \) is the ratio of a dynamic rectangle, and \( n \) is the number of dynamic rectangles to be applied.

### 4.4.2 Division of Areas

Division of areas is used to determine an unknown ratio, usually the ratio of a rectangle that has great length. The input is the ratio of a rectangle \( r \) with the number of divisions \( n \), producing the result \( vda \) or \( hda \) for both vertical and horizontal division. If the result is an element of the generated dynamic ratio \( G \), then the rectangle is said to be dynamic. The algorithm is given as,

\[
\text{Input the ratio } r \text{ of a rectangle and the number of divisions } n \\
\text{Divide the ratio by the number of divisions} \\
\text{If } (vda \text{ or } hda) \in G \text{ Then} \\
\quad \text{Rectangle is dynamic} \\
\text{Else} \\
\quad \text{Rectangle is not dynamic} \\
\text{End}
\]

To vertically divide a rectangle the formula is,

\[
vda = \frac{r}{n}
\]

with

\[
r = \begin{cases} 
  r & \text{if } r \geq 1 \\
  \frac{1}{r} & \text{otherwise} 
\end{cases}
\]

where \( vda \) is the ratio of the divided area, \( r \) is the ratio of the parent rectangle, and \( n \) represents the number of divisions. Figure 4.18 has the ratio of \( 4.944 = \frac{3.3}{.667} \), when this
ratio cannot be explained by the previous analytical methods, division of areas is used.

\[
\frac{4.944}{8} = .618 \text{, the area has eight } .618(\phi) \text{ rectangles.}
\]

![Division Of Areas](image)

**Figure 4.18**: Division Of Areas.

To horizontally divide a rectangle, the formula is given as,

\[
hda = \frac{1}{\left(\frac{1/r}{n}\right)}
\]

with

\[
r = \begin{cases} 
  r & \text{if } r \geq 1 \\
  \frac{1}{r} & \text{otherwise}
\end{cases}
\]

where \(hda\) is the ratio of the divided area, \(r\) is the ratio of the parent rectangle, and \(n\) represents the number of divisions. Figure 4.19 is an analytical diagram of the Naos of the Parthenon, the room that contained the Phidian statue of Athena. The distance from the inner surface of the east to that of the west partition wall is 98.145. The distance from the inner surface of the north to that of the south wall is 62.953. The ratio of the Naos is \(1.559 = \frac{98.145}{62.953}\), this is a square AC plus a .559 area CD. .559 is the reciprocal of the ratio 1.789. If we apply the formula to this ratio, \(2.236 = \frac{1}{\left(\frac{1}{1.789}\right)}\), we obtain the ratio of a \(\sqrt{5}\) rectangle. Thus, the area CD is composed of four \(\sqrt{5}\) rectangles.
4.5 Analysis Technique: Similarity of Figure

To analyse similarity of figure or the relationship between the frame and the object, two inputs are given, the ratio of the object and the ratio of the frame. If the excess area $ea$ is an element of $G$ the generated dynamic rectangles, then the object is related to the frame. The algorithm is given as,

\[
\text{Input the ratio of object and the ratio of frame}
\]
\[
\text{If ratio of object equals to ratio of frame then}
\]
\[
\text{Perfect Similarity of Figure}
\]
\[
\text{Else if ratio of object is within the tolerance of ratio of frame then}
\]
\[
\text{Partial Similarity of Figure}
\]
\[
\text{Else}
\]
\[
\text{If the excess area } ea \in G \text{ Then}
\]
\[
\text{Object is related to frame in similarity of figure}
\]
\[
\text{Else}
\]
\[
\text{Object has no similarity of figure relationship with frame}
\]
\[
\text{End}
\]
\[
\text{End}
\]

The formula to determine the excess area $ea$ when the object is applied to the frame is given as,
If the object width divided by object height is smaller than the frame width divided by the frame height then apply the object to end of frame (Fig. 4.20a) and test the excess area, otherwise apply the object to side of frame (Fig. 4.20b). Figure 4.20 are all possible conditions in applying an object to end of frame or side of frame.

\[
e_a = \begin{cases} 
\frac{\text{frame}_{\text{width}} - \text{object}_{\text{height}}}{\text{object}_{\text{height}}} \cdot \frac{\text{object}_{\text{width}}}{\text{object}_{\text{height}}} & \text{if } \frac{\text{object}_{\text{width}}}{\text{object}_{\text{height}}} < \frac{\text{frame}_{\text{width}}}{\text{frame}_{\text{height}}} \\
\frac{\text{frame}_{\text{height}}}{\text{frame}_{\text{width}}} & \text{otherwise}
\end{cases}
\]

\( \text{Figure 4.20: Possible Conditions For Applying An Object To The Frame.} \)
4.6 Dynamic Ratio Generator

The dynamic ratio generator generates compound dynamic ratios for the analytical methods. The ratios are then stored in the set \( G \), and each element in the set is applied to each of the elements in \( R \), leaving an excess area \( ea \). If \( ea \in G \) then \( r \) is a rectangle of the dynamic type which belongs to an element within \( U \). The sets are shown below.

\[
U = \{ u \mid u \text{ is a rectangle within all dynamic rectangles} \}
\]

\[
G = \{ g \mid g \text{ is rectangle within all generated dynamic rectangles} \}
\]

\[
R = \{ r \mid r \text{ is any given rectangle of a screen object} \}
\]

The characteristic of Hambidge’s analysis of Greek artefacts is to look for patterns of dynamic rectangles or compound dynamic rectangles in a subject of analysis. Using the Metope of the Parthenon as an example (Figure 4.6), a double square (\( \sqrt{4} \)) is applied to the side of the rectangle AB, and CB is found to be a \( \sqrt{5} \) rectangle through an additional step of analysis or, it may also be said that the excess area CB is match with the elements of dynamic symmetry \( E = \{ \sqrt{1}, \sqrt{2}, \sqrt{3}, \sqrt{4}, \sqrt{5}, \phi, \sqrt{\phi}, \phi^2 \} \) until a similar figure \( \sqrt{5} \) is found. In another example (Figure 4.5) the compound rectangle with the ratio 1.4472, a square plus the reciprocal of a \( \sqrt{5} \) from the most frequently found ratios in nature and Greek design (Appendix 4.1) is applied to the plan of the Parthenon. A same figure with a different orientation is matched. In the analysis tool, compound dynamic rectangles other than those found in Greek artefacts are generated to provide a wider range of matches.

A series of algorithms is used for generating a set of compound dynamic rectangle for application of areas and excess area match. The operations are given in the table below (Table 4.1-2) with their diagrammatic descriptions (Fig. 4.21-22).

The theme and their elements are:
1. \( A = \{\sqrt{1}, \sqrt{4}, \sqrt{5}, \phi, \phi^2, \sqrt{\phi}\} \)
2. \( B = \{\sqrt{1}, \sqrt{2}, \sqrt{4}\} \)
3. \( C = \{\sqrt{1}, \sqrt{3}, \sqrt{4}\} \)

Each theme generates the compound dynamic ratios with a series of loop. The loops range from a double nested loop to triple nested loop. The general algorithm for all the operations is,

For each element(1) in the element set do
   For [each element(2) in the element set] or [number of squares to add] or [number of divisions to divide] or [number to multiply] do
      If necessary, for [the number of divisions to divide] or [squares to add starting from 1] do
         <Do operations for elements and store the ratio>
      If necessary, next
   Next
Next

**Addition of Elements**

<table>
<thead>
<tr>
<th>No</th>
<th>Operations ((n = 6))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Get ratio of the first element</td>
</tr>
<tr>
<td>2</td>
<td>Get ratio of the addition of the first and the second element</td>
</tr>
<tr>
<td>3</td>
<td>Get the reciprocal of the added element 1 and 2.</td>
</tr>
<tr>
<td>4</td>
<td>Get the addition of the reciprocal of two elements.</td>
</tr>
<tr>
<td>5</td>
<td>Divide the reciprocal of element 1 by each value from 1 to (n) and each division is added to element 2</td>
</tr>
<tr>
<td>6</td>
<td>Divide element 1 by each value from 1 to (n) and each division is added to element 2</td>
</tr>
<tr>
<td>7</td>
<td>Divide element 1 by each value from 1 to (n) and each division is added to the reciprocal of element 2</td>
</tr>
<tr>
<td>8</td>
<td>Divide the reciprocal of element 1 by each value from 1 to (n) and each division is added to the reciprocal of element 2</td>
</tr>
</tbody>
</table>

*Table 4.1: Addition Of Elements Reflecting Figure 4.21.*
Figure 4.21: Diagrammatic Description Of Addition Of Elements with the $\sqrt{5}$ theme as an example.

### Multiplication of Elements and Addition of Squares

<table>
<thead>
<tr>
<th>No.</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Multiply the element</td>
</tr>
<tr>
<td>2</td>
<td>Multiply the reciprocal of the element</td>
</tr>
<tr>
<td>3</td>
<td>Get the reciprocal of the element and add squares to it</td>
</tr>
<tr>
<td>4</td>
<td>Multiply the reciprocal of the element and get the multiplied element’s reciprocal</td>
</tr>
<tr>
<td>5</td>
<td>Multiply the reciprocal of the element and add squares to the multiplied element’s reciprocal</td>
</tr>
</tbody>
</table>

Table 4.2: Multiplication Of Elements And Addition Of Squares Reflecting Figure 4.22.
### Multiplication of Elements and Addition of Squares

<table>
<thead>
<tr>
<th>OPERATION 1</th>
<th>OPERATION 2</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element 1 (x \equiv n)</td>
<td>Add Reciprocates</td>
<td>0 0 0</td>
</tr>
<tr>
<td>Reciprocate Element</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reciprocate Element</td>
<td>Reciprocate + Squares</td>
<td>0 1 1 1</td>
</tr>
<tr>
<td>Reciprocate Element (x \equiv n)</td>
<td>Reciprocate Result</td>
<td>0 0 0</td>
</tr>
<tr>
<td>Reciprocate Element (x \equiv n)</td>
<td>Reciprocate plus Squares</td>
<td>0 1 1</td>
</tr>
</tbody>
</table>

**Figure 4.22:** Diagrammatic Description Of Multiplication Of Elements And Addition Of Squares with the \(\sqrt{5}\) theme as an example.

#### 4.7 Flowcharts from the Analysis Tool

In the last few sections the methods of analysis are sufficiently explained. This section covers the overall structure of the analysis tool. General analysis (Fig. 4.23) analyses the entire screen with its frame and objects. Three main themes are used for the analysis in sequence from \(\sqrt{5}\), then \(\sqrt{2}\) and finally \(\sqrt{3}\). The reason for this is stated in Hambidge’s text, “Of the many hundreds of examples of classic Greek design which have been examined in both the American and the European museums, about 85 per cent show dynamic schemes based upon \(\sqrt{5}\); about 10 per cent upon \(\sqrt{2}\), 1 or 2 per cent upon \(\sqrt{3}\), and the remainder are either uncertain or are clearly static.” In another paragraph Hambidge state that “the \(\sqrt{2}, \sqrt{3}, \text{and} \sqrt{4}\) rectangles represent, apparently, a symmetry
type intermediate between the static and complete dynamic types.” (Hambidge, 1932). If a $\sqrt{5}$ theme analysis yields a true value the next theme will not be continued, otherwise the analysis will use the next available theme until a conclusion is secured. The determinant for whether a screen is dynamic or static is based on a 75% decision. A screen designed consciously with Hambidge’s dynamic symmetry techniques would no doubt yield a 100% value. Because we have no way of knowing whether a target screen uses Hambidge’s techniques, but still would like to analyse for the conscious use of dynamic symmetry rectangles a 25% tolerance is given, meaning that if 75% of the screen objects are dynamic, then the screen is considered a dynamic symmetry screen based on our standard.

In object analysis flowchart (Fig. 4.24) before the analysis, the dynamic ratio generated by the ratio generator is tested to see if it is possible for applying to the object, if it is then the ratio is used for the analysis. Each object including the frame is applied a first set of dynamic ratios to its end; the excess area is then tested against a second set of dynamic ratio. The second set and the first set is generated from the same ratio generator and possesses similar sets of dynamic ratios. If a match is found the object will be recorded as dynamic and the applied area and excess area will also be recorded in a format called Dynamic Ratio Coding (DRC). DRC enables us to know the composition information in an object that is dynamic and will be covered later. Because dynamic symmetry rectangles possess multiple variations of surfaces, it is apparent that there may be more than one record in each object.
Get Height and Width of Frame and Objects

Finished analysis with √5, √2, √3 theme

Set next theme of analysis

Object Analysis (Flowchart 1)

Similarity of Figure Analysis (Flowchart 2)

Screen Dynamic

Display Result

Figure 4.23: General Analysis Flowchart.
1) Object Analysis Flowchart

Figure 4.24: Object Analysis Flowchart.
Figures 5.25 and 26 are two versions of analysis for similarity of figures. Both versions work in different ways by applying the objects to the frame. Version 1 applies all the objects first and tests the excess areas later whereas version 2 applies each object and immediately tests the excess area. It is apparent that version 1 analyses the relationships between all the objects with the frames whereas version 2 analyses the relationships of the each object with the frames only. Hambidge uses the former in his studies of Greek artefacts. The latter version was discovered when analysis was done manually on screen and was implemented as an automated algorithm; a prove (Appendix 4.2) is provided to show that if a dynamic rectangle is applied to a dynamic base or frame, the excess area is also dynamic in nature. Version 1 analysis is semi-automated using the system to indicate the applied area and the objects individually.

Figure 5.25 is version 1 of the flowchart on the analysis of similarity of figure. In this process, all the objects in the screen are applied to the frame according to their positions in the sequence of largest to smallest. The largest object would occupy the majority of the area leaving the rest of the area for the smaller objects to be applied to. Eventually an excess area remains. Since this area is not exhausted by any objects, it is analysed by having the generated dynamic ratios applied to it and the excess area tested again with another set of dynamic ratios until all the ratios have been tested. If the result of analysing the excess area is dynamic, then the frame and the objects have similarity of figure in their relationships.
2) Similarity of Figure Analysis: Object in Relation to Frame
Version 1

Figure 4.25: Similarity Of Figure Analysis Flowchart Version 1.

Figure 4.26 is version 2 of the flowchart on the analysis of similarity of figure. In this process, there are three levels of analysis. The first level test if the object is exactly the same ratio as the frame, if it is the object is recorded as perfect similarity of figure. The second level test if the object ratio is near the frame ratio in a given tolerance level, if this is tested positive, then the object is recorded as partial similarity of figure. The third level is more complex; each object in the analysis is tested for their relationship with the frame. If an object ratio is greater than the frame, it is applied to the side of the frame, otherwise the ratio is applied to the end of a frame (Fig. 4.20). An end of a frame is on the left and the right side whereas the side of a frame is on the top or the bottom. In both cases, the excess area is tested against a set of dynamic ratios, if the result of the
analysis is positive then the object is related to the frame and has a similar figure to a subdivision within the frame.

2) Similarity of Figure Analysis: Object in Relation to Frame
Version 2

Figure 4.26: Similarity Of Figure Analysis Flowchart Version 2.
4.8 Manual Analysis of a Multimedia Screen

In a related study (Ch’ng and Ngo, 2001a) screens are categorized into three major types in relation to Hambidge’s analytical methods. The first type (Fig. 4.27a) because of its properties is based on harmonic subdivision, screens with horizontal or vertical divisions, or both. These are multipane interfaces and web pages with frameset. The second type (Fig. 4.27b) is based on Similarity of Figure, these are screens with objects such as image or blocks of text. The third type (Fig. 4.27c) is a hybrid of the first and the second category, this type is found on most multimedia and web interfaces.

(a) Harmonic Subdivision  
(b) Similarity of Figure  
(c) Hybrid

**Figure 4.27:** Category Of Screens.

Below is a walkthrough of a manual analysis of a multimedia screen based on the analytical methods listed in the previous sections. The flowchart presented in the last section works in the same way. Similarity of figure analysis in this walkthrough uses version 1 of the flowchart (Fig. 4.25).

Figure 4.28 is an example of a screen design that was analysed and found to be in conformance to the $\phi^2$ and 1.4472 (i.e., $1+(1/\sqrt{5})$) theme of dynamic symmetry. Although the fit is not perfect, the plan scheme of dynamic symmetry is apparent. The screen is in accordance to the principle of similarity of figure, which means that instead of a screen solely with divisions like multipane interfaces, objects exists within the parent frame or within the divisions in the window (Figs. 4.27b-c). In this case, the screen has objects only.
The significant objects and the frame of the screen are captured (Figure 4.29a) using a screen editor. In Figure 4.29b, the ratio of the objects A and B are almost similar,

A: \[ \frac{3.049}{2.302} = 1.3245 \]
B: \[ \frac{5.402}{4.104} = 1.3163 \]

When the reciprocal of a $\phi^2$ is applied to A and to B, the excess area of each object is analysed and found to be another $\phi^2$, the application of areas for reciprocal of a dynamic rectangle is used,

For A, the excess area is 2.6807. The difference between 2.6807 and $\phi^2=2.618$ is minor at 0.06.

\[
2.6807 = \frac{3.049}{2.302 - (3.049 / 2.618)}
\]

For B, the excess area is 2.6472. The difference between 2.6472 and $\phi^2=2.618$ is minor at 0.02.
Both A and B has the area of a double $\phi^2$. $A\phi^2$ has the ratio of $1.618^2 = 2.618$. Figure 4.30a uses logical steps of similarity of figure and the diagonals to apply the two objects A and B to the frame in the sequence of larger to smaller.

![Fig 4.29: Representation Of Analysed Areas.](image)

The frame width measures 8.190 and the height 6.142. Beginning from the largest object, the ratio of B, 1.3163 is applied to the frame, leaving an excess area with the ratio of $1.743 = 6.142 / 3.524$,

$$1.743 = \frac{6.142}{8.190 - (6.142 / 1.3163)}$$

When the ratio of A, 1.3245 is applied to the previous excess area, an excess area C remained that has the ratio 2.39 with the width of 3.524 and height of 1.474,

$$2.39 = \frac{3.524}{6.142 - (3.524 \times 1.3245)}$$
A square subtracted from the ratio of $C=2.39$ leave a remainder of 1.39. When 1.39 is divided by 2, 0.695 remains. 0.695 is the reciprocal of a ratio larger than 1. $\frac{1}{0.695} = 1.44$. 1.4472 is a frequently found ratio in Greek design consisting of a square plus a reciprocal of $\sqrt{5}$ rectangle. Thus, $C$ is found to be a compound dynamic rectangle composed of a square, and two rectangles with a ratio of 1.4472 each (Figure 4.30b). The entire area is now exhausted with dynamic rectangles of the $\phi^2$ and $\sqrt{5}$ theme.

4.9 A Walkthrough of the Analysis Tool

The analysis tool, of which the information can be found in appendix 6.1, integrates the functionality of the analytical methods and a simple drawing interface (Fig. 4.31). The analysis of a complete screen is made possible by importing a screen capture and tracing a model screen with the trace interface. With these features it is possible to analyse the screen for harmonic subdivision and similarity of figure.
The user interface (Fig. 4.31) has three windows. The main window is where the analysis takes place, the other two windows shows the process of analysis and its result. The user begins by browsing and importing (Fig. 4.32a) the bitmap of a screen into the trace interface under the ‘Model Screen’ tab (Fig. 4.32b).
Within the screen object analysis interface, the cross-hair mouse icon is used for drawing the model of the screen frame and objects. Drawing of model screen objects with the built-in editor begin with the frame followed by the largest object to the smallest. The first object modelled will be recorded by the system as a frame object and the other objects are indexed as object(n) subsequently. A frame and two objects are modelled by tracing their boundaries (Fig. 4.33). Each time the frame and objects are drawn over, their ratios will be shown on the top left corner of the trace-line and also on the ‘Screen Object Ratios’ container on the left of the window. The width and height in units are also shown. The user is allowed to select the frame or objects with the radio button, selection is made by pressing the shift key with the mouse over the object or selecting from the object list directly.

![Model Screen Traced With A Frame And Two Objects.](image)

**Figure 4.33:** Model Screen Traced With A Frame And Two Objects.
When all the objects in the model screen are traced, the user proceeds to the analysis tab called ‘Analysis Results’ (Fig. 4.34). In this tab the user is given an option to analyse the entire screen at once or analyse each object separately. In this case the first object is analysed and found to be a rectangle with the dynamic type with five matches to generated dynamic ratios. The results are shown in Table 4.3. Note that 1, 2, and 4 in Table 4.3 are basically the same except for the coding. The different coding showed that the object is analysed with different object orientation (1 and 2), and multiples of a dynamic rectangle plus a single square (7). The system also checks for similarity of figure by applying the object to the frame and measures the relationship between the object and excess area with the frame. As shown on the screen, the object has an almost perfect similarity of figure to a hidden subdivision within the frame.

Figure 4.34: Analysing The Screen.
<table>
<thead>
<tr>
<th>No.</th>
<th>Dynamic Ratio Language</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4hs1.272+1</td>
<td>Four horizontally orientated $\sqrt{\phi}$ rectangle placed on top of each</td>
</tr>
<tr>
<td></td>
<td></td>
<td>other’s side + a square</td>
</tr>
<tr>
<td>2</td>
<td>4hs1.272+vs1</td>
<td>Four horizontally orientated $\sqrt{\phi}$ rectangle placed on top of each</td>
</tr>
<tr>
<td></td>
<td></td>
<td>other’s side + a square</td>
</tr>
<tr>
<td>3</td>
<td>3hs2.618+vs2.236</td>
<td>Three horizontally orientated $\sqrt[5]{\phi}$ rectangle placed on top of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>each other’s side + a vertically placed $\sqrt{5}$ rectangle</td>
</tr>
<tr>
<td>4</td>
<td>4hs1.272+1Squares</td>
<td>Four horizontally orientated $\sqrt{\phi}$ rectangle placed on top of each</td>
</tr>
<tr>
<td></td>
<td></td>
<td>other’s side + a square</td>
</tr>
<tr>
<td>5</td>
<td>7hs2.236+1Squares</td>
<td>Seven horizontally orientated $\sqrt{5}$ rectangle placed on top of each</td>
</tr>
<tr>
<td></td>
<td></td>
<td>other’s side + a square</td>
</tr>
</tbody>
</table>

**Table 4.3:** Description Of The Result Of Analysing The First Object In The Screen.

The output of the analysis tool is in the form of a simple code called the Dynamic Ratio Coding (DRC). This simple code enables the user to identify the dynamic area of an object after it has been analysed.

**Figure 4.35:** Dynamic Ratio Language Placement And Orientation.

Figure 4.35 is a description of the language. There are four types as shown, they are Horizontal Side (HS), Horizontal End (HE), Vertical Side (VS), and Vertical End (VE). Figure 4.16 showed that the side of a rectangle is on the top and the bottom and the end of a rectangle is on the left and on the right. The code is structured in the way below,
where \( n \) is the number of rectangles, \( po \) as placement and orientation which correspond to the four types (HS, HE, VS, VE), and \( dr \) as dynamic ratio is described by \( n \) and \( po \). This set may also be extended by another set,

\[
[n][po][dr] + [n][po][dr]
\]

Given an example from the analysis tool, an object is analysed as having this ratio,

\[
3hs2.618+vs2.236
\]

This DRC would be described as 3 horizontally positioned 2.618 (\( \phi^2 \)) rectangle placed on top of each other’s sides plus a vertically positioned 2.236 (\( \sqrt{5} \)) rectangle. Figure 4.36a describes this DRC in a diagrammatic way plus two other variations, b and c. In b, 1.272 is a \( \sqrt{\phi} \) rectangle.

![Figure 4.36: Diagrammatic Description Of An Example Of Dynamic Ratio Coding (DRC).](image-url)
By choosing the option to analyse the entire screen (Fig. 4.37) with the other two windows visible, the user is able to view the analysis process of the frame and the objects together with the final result. The result showed that the frame and the objects for this screen are all dynamic. Similarity of figure analysis showed the first object has relationship with the frame but not the second object. This screen is partly in the principle of dynamic symmetry. During the analysis the user can also change the settings particularly that of the tolerance for search matches with three levels of tolerance and a custom level. This enables the user to control how close to perfect dynamic symmetry the user wants the analysis to be.

The “Search Areas” tab allows the input of ratios to see if they correspond to the frequently found ratios in Greek art and architecture (Appendix 4.1); the dynamic ratio rectangle will be shown in the same tab.

![Figure 4.37: The Process And Result Of Screen Analysis.](image-url)
4.10 Empirical Results of Using the Analysis Tool

By using the analysis tool, 150 multimedia and web screens with apparent visual beauty were analysed (Ngo and Ch’ng, 2001). This study examines whether dynamic symmetry has been applied to screen design in the past. It began with the selection of 150 screens from a variety of multimedia systems. Screens were sampled that represented a wide variety of design characteristics, from simple to complex and from plain to sophisticated. Screens with many graphic features and a sophisticated design appearance were chosen, as well as ones with few text elements and little sophistication. Next the 150 screens were analysed for their composition information using the analysis tool covered in this chapter in which the analysis technique presented earlier has been implemented. The input to the tool is a model example of the screen to be analysed, drawn over original screen with the screen editor.

The root rectangles show up everywhere in these screens. More than 40% of the screens use these proportions. These results are quite surprising, given the fact that HCI literature mostly seem to neglect the proportion issue completely. The analyses show unmistakably the conscious use of the root rectangles in dynamic symmetry. However, it would seem that these designers did not consciously apply Hambidge’s technique of composition. Figure 4.38 and 39 are the good examples of the use of dynamic symmetry. But the fit is not perfect.
Figure 4.38: A screen from Boomerangs – Echoes of Australia
(MindVision Interactive, Australia).

Figure 4.38 shows the analysis of a screen from an award winning multimedia CD-ROM Boomerangs – Echoes of Australia. The overall area is a square plus a $\phi^2$ rectangle, the main area of the screen is a $\phi$ rectangle equal to the whole, the navigational bar is composed of five $\phi^2$ rectangles.

Figure 4.39: A screen from Boomerangs – Echoes of Australia
(MindVision Interactive, Australia).

Figure 4.39 shows the analysis of another screen from Boomerangs – Echoes of Australia. The overall area is a square plus three squares, the main area is divided into two parts: each composed of a square plus a $\phi^2$ rectangle, the navigational bar is
composed of eight $\phi^2$ rectangles. Appendix 4.3 has a few selected screens showing a clearer picture of the relational plan schemes in diagrams with the steps of analysis. Appendix 3.2 shows the screen analysis table.

These diagrams and the controlling diagrams of many other screens studied here show the conscious or unconscious use of dynamic rectangles, which produces, because of its characteristic properties, “the recurrence of the same proportion in the elements of a whole” (Ghyka, 1952). Although the fit between them and corresponding sets of proportions (which obey the rule of non-mixing themes) produced using Hambidge’s technique are not perfect, we see the desirability of using a system of proportions, rather than picking each dimension with no regards to the others in a composition. Without being taught, screen designers have gravitated to the basic technique of dynamic symmetry. Chapter 5 will cover the use of dynamic symmetry techniques implemented in a design tool for screen design.
Chapter 5: Design Algorithms

5.1 Introduction
Symmetry is the rhythm base of design, all design weakness is due to the poverty of symmetry and rhythm. If an artist does not understand these concepts, he can only design blindly and trust his feeling. The history of design shows us beyond question that artists, who are real masters of composition uses symmetry and rhythm consciously. The best of all methods in symmetry and rhythms flourished during the classical period of ancient Greek and the principles used by these masters have been recovered through Hambidge’s thorough study of static and dynamic symmetry in art and architecture (Hambidge, 1932).

Dynamic symmetry is not a substitute for design creativity nor is it for artistic expression. The actual process of studying and understanding the working of this natural design law opens up a realm of new ideas. The higher and more perfect the art, the richer is the remainder when the personal element is removed. Dynamic symmetry encourages originality and precludes imitation, it acts as a base for individual designers to build their design upon and yet retain the very personal elements in which all designers strive to achieve. It is a method of measuring, which fixes proportion and is a valuable instrument to design (Hambidge, 1932). It is the life-suggesting qualities of dynamic symmetry that influenced Hambidge’s contemporaries to adopt this system in many industrial applications.

This section covers the practical applications of dynamic symmetry as an objective method to aesthetic layout of screen design. The algorithms of the system used in this chapter lay a foundation for implementation in user interface development environment.
5.2 Static And Dynamic Grids

In all areas of design the grid format as a basis for design projects is absolutely necessary. Composing and designing spaces with a grid have become an essential tool for the practising designer (Swann, 1989). The first consideration in a web design project is to establish the basic layout grid for your pages (Lynch and Horton). Jute (1996) states that the primary purpose of the grid is to create order out of chaos, it is an aid to readability, recognition and understanding. A grid is the geometrical division of a space into precisely measured columns, spaces and margins, it is the backbone of screen design. Grids assist designers in creating good compositions, it helps to blend the linear formality of type with the flow of photography or illustration and it guide a viewer’s eye through a page (Waters, 1996). It also allows the use of space available to create an illusion of different depths of focus to the elements that are displayed.

In graphic design, the need for balance, structure and unity is achieved through the careful control of grids (Swann, 1989; Jute, 1996). Grids enable the designers to have greater control of visual elements while in the process of designing. In laying out a web page, the use of a grid was encouraged (Lynch & Horton; Weinschenk, 1997) so that similar types of pages have a similar look and feel, creating grids for page types during the planning phase of a project saves development time and helps ensure consistency throughout the site.

There are two types of symmetry (Hambidge, 1926) in nature that can be utilized in grid design. One of these types, because of its character, was termed “static”, the other “dynamic”. Static symmetry is a symmetry that has a sort of fixed entity or state. Grids of an equal height and width are considered static, they are lifeless and monotonous to our visual perception. The rectangles such as 3/2, 5/4, 6/5, 3, etc., of which the ratios show only rational numbers, are called static rectangles.

Dynamic symmetry in nature is the type of orderly arrangement of members of an organism such as we find in a shell or the adjustment of leaves on a plant. It is a
symmetry suggestive of life and movement. Because of a certain property the curves of these organisms possess, it can be reduced to rectangular shapes for artists and designers to solve problems of composition and design. The rectangles showing irrational numbers in their ratios such as \( \sqrt{2}, \sqrt{3}, \sqrt{5}, \phi=(\sqrt{5}+1)/2 \) (The Golden Section), are called dynamic rectangles [18]. Grids drawn on dynamic rectangle using Hambidge’s diagonal method are called dynamic grids.

As far as we know, the grid options found on all popular web page and multimedia design tools are categorized under the static type. Although it is true that designers can set up grids and guides to suit their needs none provided a structured option to automatically generate grids based on proportioning systems such as dynamic symmetry. Through the empirical studies here and observations of industrial areas that benefit from the use of proportioning systems, we see the desirability of adopting dynamic symmetry as a guide in which screen design may hang upon.

5.3 Hambidge’s Grid Design Techniques

For purposes of design the most important element of a rectangle is its diagonal. The element of a rectangle second in importance to the diagonal is the diagonal of a reciprocal (Hambidge, 1926 p.33). In Ghyka’s *Practical Handbook of Geometrical Composition and Design* (Ghyka, 1952) mentioned Hambidge’s use of a technique of harmonic sub-divisions of the square and of the dynamic rectangles by the tracing of diagonals and perpendiculrars to diagonals. Hambidge’s method takes into consideration the fact that the overall frame of a two-dimensional plan or composition, whether architectural, pictorial or decorative, is generally a rectangle or a complex of rectangles; in his method of harmonic subdivision, these rectangles are “treated” by the diagonal.
Figure 5.1a is an illustration of Hambidge’s technique. AC is a dynamic rectangle, from D draw a diagonal to the opposite angle at B. From C draw a diagonal perpendicular to DB passing through G at E. AC is the parent rectangle and FB is the reciprocal of AC, both are similar in shape. An important property of this method is that the perpendicular to the diagonal produces inside the original rectangle a smaller rectangle similar to it. If this process is continued with many variations (Fig. 5.1b), every diagram obtained is what Hambidge calls a “harmonic subdivision”, that is, produces a perfect commodulation of surfaces. If a rectangle is based on dynamic symmetry, the employment of this method however complicated the variations are, fulfils the requirements of the principle of this system. If the rectangle at Figure 5.1b is analysed with the arithmetic from the previous chapter, the areas are all exhausted and are found to be of the same theme as the parent rectangle, thus fulfilling the requirement of the principles of dynamic symmetry (Figure 5.1c). The paragraph below is an arithmetic explanation of Figure 5.1c.

A $\sqrt{\phi}$ rectangle is represented by the ratio 1.272; the reciprocal of this ratio is .786. AC of figure 7b has the ratio of 1.272, FC is a .786 area which is a similar figure to AC. 1.272 - .786 = .486, .486 is an area composed of two $\sqrt{\phi}$ placed side on end as in AG of figure 7c. The reciprocal .486 represents the ratio 2.0576. 2.0576 – 1.272 = .786, the
reciprocal of a $\sqrt{\phi}$ rectangle $EF$ of figure 5.1c. The area is now exhausted with the $\sqrt{\phi}$ rectangle.

In the sections below the design methods of dynamic symmetry will be covered. Since the characteristics of dynamic symmetry embody a grid-like structure, the design concepts can be inherited and solved by using a series of grids. There are necessarily two methods that fully encompass the pictorial composition of screen design. They are named as Harmonic Subdivision and Similarity of Figure.

5.3.1 Harmonic Subdivision
Jay Hambidge calls a dynamic rectangle that is treated by the diagonals the *Harmonic Subdivisions of the square and of the dynamic rectangles*. The majority of figures within this chapter that uses the diagonals and perpendiculars to diagonals are examples of Harmonic Subdivisions. To achieve Harmonic Subdivisions the Diagonals and Perpendiculars to Diagonals (DPD) method is used and every diagram thus produced is a complex of rectangles that are proportionately related to the parent rectangle and to each other. “*An analysis is not necessary when we have used a dynamic base for the development of a design, in this case we may be assured, if our procedure has been consistent, that the subdivisions of that area are dynamic whether or not we are able to define their composition.*” (Hambidge, 1926 p.102). The reason is that the surfaces within the subdivisions are either a reproduction of the parent or its derivatives, these fulfilled the principles of the non-mixing theme of dynamic symmetry. Harmonic Subdivisions on a dynamic base need not be analysed unless the area needs to be explained for design purposes. The diagrams in figure 5.2 are squares and $\phi$ rectangles with harmonic subdivisions in the $\phi$ theme.
Figure 5.2: Harmonic Subdivisions Of The Square And The $\phi$ Rectangles.

Figure 5.3a is a part of the subdivisions of the Naos and figure 5.3b is the façade rectangle of the Parthenon.

Figure 5.3: Examples Of Harmonic Subdivisions From The Parthenon.

5.3.2 Similarity of Figure

Similarity of Figure is used extensively in the reproductive arts to enlarge or reduce drawings. The average modern artist knows that rectangular shapes are enlarged or reduced by a diagonal and that any rectangular figure with a diagonal common to the diagonal of the whole is similar (fig. 5.4). As with all other methods of dynamic symmetry, the first priority is the presence of rectangles of dynamic symmetry. In order for a two-dimensional plane to achieve similarity of figure in dynamic symmetry, we are required to look for dynamic rectangles or compounds of dynamic rectangles in our
analysis because of their measurable properties. Unless rectangles are used which possess this dynamic property of modulation and measurableness it will be impossible to give design the vital qualities of life and growth. Design created within rectangles which do not possess this function of commensurable area are always flat and dead (Hambidge, 1926).

![Figure 5.4: Similarity Of Figure.](image)

The construction of similarity of figure can be:
1. In any position within a dynamic rectangle, where sides and ends are parallel to those of the parent figure 5.5(a)
2. A figure which is similar to any dynamic subdivision of the area that is within a dynamic rectangle 5.5 (b)

Based on the two points above, there are two possibilities for the construction of similarity of figure which we can begin with within the parent figure:

1. Select a dynamic point 5.6 (a)
2. Select a dynamic line 5.6 (b)

It is not necessary however, to construct with these elements (Hambidge, 1926), but since we want perfect dynamic symmetry these elements are a great help in the systematic approach of furnishing a complete dynamic symmetry figure.
Figure 5.5: Constructing Similarity Of Figure.

Figure AC of Figure 5.5a is a dynamic rectangle, suppose it is desired to construct a similar figure to the whole upon the line EF, which is a line in any position within the rectangle AC. From the corners AB extend the lines AI and BI through E and F until they cross each other at point I. Draw the lines DI and CI and complete the rectangle EG, which is now a similar figure to AC.

Figure 5.5b is a φ rectangle. CG is a dynamic area of the dynamic point of subdivision C. The line CD is a hidden line subdivided at the intersection K by the diagonals AB and the perpendicular JG. The line EH is drawn in any position within the area of subdivision CG. From the points C and B extend the line through E and H until they intersect at L, Draw the lines DL and GL and complete the rectangle EF. Figure 5.5c is the explanation of the dynamic area EF of figure 5.5b, EF is a similar figure to CG, EF can be defined as a $\sqrt{5}$ rectangle or two φ rectangle placed end to side as shown. It is now understood that the similarity of figure within a dynamic subdivision is a dynamic area itself.

The construction of similarity of figure in dynamic points (figure 5.6a) and dynamic lines (figure 5.6b) are in the figures below.
Figure 5.6: Dynamic Points And Lines.

A dynamic point is a point on the intersection of diagonals or right angles. AC of figure 5.6a is a dynamic rectangle, DB is a diagonal and AJ is its perpendicular. Point I is a dynamic point of intersection. Draw the line EF from any point of the line AJ, connect E to H and complete the rectangle with HG and FG. The rectangle EG is a similar figure to AC on a dynamic point.

A dynamic line is a line which is a dynamic subdivisional line of a dynamic rectangle. AC of figure 5.6b is a dynamic rectangle, DB AI and AC DJ are diagonals perpendicular to one another. From the point of intersection F extend the lines NM and KL, these are dynamic lines of subdivision. Complete the rectangle FGEH touching the dynamic line KL, the rectangle EG is a similar figure to the rectangle AC on a dynamic line. The similar figure also uses dynamic line NM.

A dynamic line may have a dynamic point as a basis. AC of figure 5.6c, DB and AJ are perpendicular diagonals. From point J construct the line JK parallel to AB and DC, and from point K draw the diagonal KM perpendicular to AJ. ML is a dynamic line and I is a dynamic point where the rectangle EG is constructed.

The two geometrical diagrams in figure 5.7 are examples of similarity of figure from the façade of the Parthenon. GM of the façade is a composition of four .618 rectangles,
NP is a similar figure. UT is composed of four 1.4472 rectangles, i.e. a square and a $\sqrt{5}$ area, which is similar to AD of the façade rectangle CD.

**Figure 5.7:** Similarity Of Figure As Seen On The Parthenon.

### 5.4 Interpreting Hambidge’s Design Process For Screens

Hambidge’s literatures provided us with practical constructions of various subjects from the industry as well as how the Greeks constructed their dynamic symmetry artworks. Two practical examples of dynamic symmetry design by Hambidge (1932) are the lion head architectural ornament and the chair (Figure 5.8a,b). The steps of Hambidge’s design of the lion head and the chair can be generalized in an algorithm as seen in Figure 5.9. The designer began by proposing a base that suits the subject, the base is then adjusted accordingly to the nearest ratio of dynamic symmetry. Base grid are drawn with Hambidge’s technique and the designer places elements of the design base on the divisions needed by the subject, i.e., the seat of the chair or the structure of the lion head, usually starting with the major structures. A set of secondary grids (for details refer to Hambidge’s book: Practical Applications of Dynamic Symmetry, 1932) is drawn for placement of the design details, usually there are repetitions of placing elements and drawing the grids, e.g., the designer proposes the placement of the back of chair and grids are drawn for the positioning, the arm of the chair is placed and grids are drawn
again to reposition the arm. Finally the elements are adjusted to fit the grids for an overall relationship between the elements.

Figure 5.8: Lion Head and Chair Designed With Dynamic Symmetry.
(Taken from Hambidge, 1932).
Figure 5.9: A General Algorithm Of Hambidge’s Design With Dynamic Symmetry.

Adopting Hambidge’s algorithm and construction techniques, figure 5.10 is a revised general algorithm for screen design. The process is straightforward and can be automated and implemented in a design tool.
Figure 5.10: A General Algorithm Of Designing Screens With Dynamic Symmetry (Version 1).
To develop an automated dynamic symmetry gridding system, it is necessary to understand the manual process of laying out a screen whether it is a graphical user interface, a multimedia system, or a web page. In designing an interface, there are three possible organizations of controls as advised by Dix et al (1998), functional controls and displays are organized so that those that are functionally related are placed together; sequential controls and displays are organized to reflect the order of their use in a typical interaction (this may be especially appropriate in domains where a particular task sequence is enforced, such as aviation); frequency controls and displays are organized according to how frequently they are used, with the most commonly used controls being the most easily accessible. According to Dix et al, the rule is that “Aesthetic placements of screen objects should not replace logical grouping of controls... Redesigning a screen with aesthetics must maintain the logical placements and usability of it.” Using the revised algorithm a web screen is designed manually with dynamic symmetry (Fig. 5.11a-d).
Figure 5.11: Manually Designing A Screen With Dynamic Symmetry Grids.

In Figure 5.11a, a dynamic frame is proposed and the base grid is drawn. Figure 5.11b places the screen elements in a functional layout. Object grid is drawn from the
base grid around the elements in Figure 5.11c; in the process screen elements are adjusted to fit the grids Figure 5.11d. Figures 5.11c and d are separated to show the difference. The final layout can be seen in Figure 5.12. The following paragraphs explain the design process in detail.

Figure 5.12: Dynamic Symmetry Design On Model Web Page.

As in analysis, the design using dynamic symmetry considers the most important structure of a subject before handling the details. To build the grid structures of this website, a $\phi$ dynamic rectangle was selected as the frame (refer to process: Fig. 5.10 A.). Dynamic shapes have in them the life impulse that causes design to grow, and any dynamic subdivision of a dynamic rectangle is like a seed endowed with the eternal principle of growth (Hambidge, 1926).

ABCD furnishes us with the $\phi$ dynamic shape of the frame. The lines EH FG IJ LK correspond to the dynamic “base grid” (process: Fig 5.10 B.) produced by Hambidge’s
method. The major diagonals are AC DB and their perpendicular diagonals are FC GB and AH DE. To create the banner of the circular logo situated on the top-left corner of the frame ABI, additional diagonals are drawn (here onwards process: Fig. 5.10 C. & D.) within the rectangle IE producing P1 and P2. From I is drawn a free curve to P1 and another free curve is connected to P2. A straight line that aligns with ST is extended to P3. P3 connects B as a closing curve that joins BAI to produce the banner shape. The logo is aligned at centre of A and M on line ST.

ABD is the bottom most feature of the banner. D connects to the inner joint which is perpendicular to P4. A diagonal line is drawn from the joint that connects to P5 and P5 to BAD to enclose the shape. The menu of five tabs has its top aligned and parallel to YZ and its bottom aligned with LK. A diagonal connects W to P6 to cut the slant of the menu.

The text box YZ is a similar figure to the frame constructed from the diagonal line AC and the eye of the two diagonals AC DE at Y. The bottom-right corner of the text box is the eye of the intersecting diagonal at Z. Z is produced within the sub-rectangle GK. The image within the text box begins from the eye of the diagonal DB CF at P7. Its bottom-right corner stopped at the line KL.

Details such as the two punch-holes at the top-right corner are added later to enhance the design further. The web page is now completed and “Every diagram thus obtained is what Hambidge calls a ‘Harmonic Subdivision’, that is, produces a perfect commodulation of surfaces.” (Ghyka, 1977) Many methods of subdividing the same dynamic rectangle are possible and that each method produces its own peculiar arrangement of form (Hambidge, 1926 p.98), this makes it very flexible to design any screens of interests. In a paragraph Hambidge stated, “If we have a dynamic base for the development of a design, we may be assured, if our procedure has been consistent, that the subdivisions of that area are dynamic whether or not we are able to define their composition.” (Hambidge, 1926 p.102) An analysis of the grids (Fig. 5.13) shows the
relationship of the proportions that proves Hambidge’s theory of proportional relationships.

Figure 5.13: An Analysis Of The Grid Structure For Proportional Relationships.

It is clear that rectangles within diagonals that are similar in angle such as AC and GB produce similar figures. The ratio of AC $1.618 / 1 = 1.618$, a $\phi$ rectangle. Therefore, AC GB DB AH AZ YZ are all $\phi$ rectangles. Within the subdivisions are many compound dynamic rectangles that form the structure of this model web page.

The ratio of compound shape AR is $4.236 = 1 / .2361$. 4.236 is a double square plus a $\sqrt{5}$ rectangle, $4.236 = 2 + \sqrt{5}$. AJ is a similar figure, $4.236 = 1.618 / .382$. NG is a square plus two $\phi$ rectangles placed side to side. $1.809 = 1 / .5527$. The ratio of NG is $1 + \left(\frac{1}{1.618 \times 2}\right)$. The text box YZ is a $\phi$ rectangle because of the diagonals AC. The picture within the text box is a double $\phi$ rectangle placed side by side, the ratio of the picture is
1.236 = .3416 / .2764, 1.236 / 2 = .618, the reciprocal of a $\phi$ rectangle. With simple construction of dynamic symmetry grids both harmonic subdivision and similarity of figure principles are fulfilled.

By applying the algorithm to designing screens, similar use of the process is possible with three different kinds of screens as shown in the studies below.

**5.4.1 Study 1: GUI Based Screen**

The user interface design begins with the frame and base grids (Figure 5.14a). A dynamic shape frame is selected that suits the structure of the interface. In this case a 1.309 rectangle, which is a square plus two $\phi$ rectangles placed end to end. In figure (b), the screen object shapes and positions are proposed. Object grids are drawn to accommodate the shape of the objects (c). Finally the objects are resized to fit the nearest grids. Figure 5.14e is the finished screen in dynamic symmetry.
5.4.2 Study 2: Multimedia Screen

A base grid is drawn (Fig. 5.15a) on a proposed frame with dynamic ratio. Screen objects are drawn based on the base grid (b). An object is drawn over the existing grid (c), and the screen objects are resized and repositioned to fit the secondary grid (d) and finally the screen is completed (e).

Figure 5.14: GUI Screen With Dynamic Symmetry Grids.
5.4.3 Study 3: Web Screen
The web screen begins with base grids on a dynamic rectangle (Fig. 5.16a). The web logo, banner, menu, and contents are placed in their respective positions (b). An object grid is drawn based on the size and position of the screen elements (c), and the elements
are resized and repositioned according to the dynamic grids (d). The web page in dynamic symmetry is completed (e).

Figure 5.16: Web Screen With Dynamic Symmetry Grids.
5.5 Implementing a Dynamic Gridding Design Tool

Through experimental studies in section 5.4 it is noted that the design process can be automated through a series of algorithms. These algorithms have much to do with generating dynamic grids and matching screen elements to the generated grids. Generation of grids and matching of elements to grids requires the input of values, processing of the values, and returning the output in a visible screen layout. These are covered in detail in this section.

5.5.1 Grid Generation: Horizontal And Vertical Orientated Frame Cell

Grid generation have different processes for horizontal and vertical frame cells. A frame cell is a division within a frame (Figure 5.17). Cell A of Figure 5.17 is a horizontally orientated cell; Cell B is a square cell, grids for square cell can be obtained by taking its sides, therefore whenever a cell has sides of the same length, grids are not generated. Cell C and D are vertically orientated. A given screen frame may be a cell by itself, or may contain numerous cells within the divisions.

![Frame And Frame Cells](image)

**Figure 5.17:** Frame And Frame Cells.
The algorithms below simulate the grid generation based on Hambidge’s method “The tracing of diagonals and perpendiculars to diagonals”. The target frame or frame cell must already be a dynamic rectangle for the surfaces of the generated grids to be dynamically linked through a rational proportion.

![Figure 5.18: Two Points Of A Cell.](image)

For any given cell, two points (Figure 5.18) must be fed to the grid generating method, beginning from the top left corner of the cell \(X_1, Y_1\) and the bottom right corner of the cell \(X_2, Y_2\) followed by how many number of grid sets to generate for a grid group, represented by \(G=4\) by default, with the method,

**Input values for grid generation** \((X_1, Y_1, X_2, Y_2, G)\)

The width \((WT)\) and height \((HT)\) of the cell is measured by,

\[
WT = X_2 - X_1 \\
HT = Y_2 - Y_1
\]

And the method processes the values and makes a decision by comparing the width and height.
If Width is greater than Height Then
Generate Horizontal Grids
Else
Generate Vertical Grids
End

Figure 5.19: Grid Generation In A Horizontal Orientated Cell.

For the horizontal grid generation (Figure 5.19), the perpendicular to the major
diagonal within the given cell produces a new length $N_n$ (for proof of how to obtain the
length, see appendix 5.1) that revolves around the “eye” or the intersection of the two
diagonals. The closer $N_n$ is to the “eye” the smaller is its length. $N_n$ is given as,

$$
N_1 = \frac{HT^2}{WT}, N_2 = \frac{N_1^2}{HT}, N_3 = \frac{N_2^2}{N_1}, N_4 = \frac{N_3^2}{N_2}, N_5 = \frac{N_4^2}{N_3}, ..., N_{n+1} = \frac{N_{n-1}^2}{N_{n-2}}, ...
$$
Or to simplify,

\[
N_n = \begin{cases} 
\frac{HT^2}{WT}, & n = 1 \\
\frac{N_1^2}{N_{n-1}}, & n = 2 \\
\frac{HT}{N_{n-1}^2}, & n \geq 3 
\end{cases}
\]

The new grid \( M_n \), which is the coordinates within the cell, is based on the subtraction and addition of the length \( N_n \) and is given as,

\[
M_1 = X_2 - N_1, M_2 = Y_2 - N_2, M_3 = M_1 + N_3, M_4 = M_2 + N_4, M_5 = M_3 - N_5, M_6 = M_4 - N_6, ...
\]

A grid group has many grid set, the first set of vertical and horizontal grids \((M_1, M_2)\) began from the right and bottom side of the given cell and requires two subtractions of the length \( N_n \) relative to the bottom and right side of the cell (Fig. 5.20a). The second set of grids \((M_3, M_4)\) is relative to the first set and requires additions of the length \( N_n \) from the first set of grids (Fig. 5.20b). Alternatively, the third set \((M_5, M_6)\) will be subtraction and the fourth is addition until a given number of grid sets is achieved.
Figure 5.20: First And Second Set Of Grids In A Horizontal Orientated Cell.

Figure 5.21 is a set of generated grids in a group of four grid sets within the given cell:
Figure 5.21: A Grid Generated According To The Horizontal Orientation Of Subdivision With Four Grid Sets. Mirror Grids Are Shown As Dashed Lines.

To mirror a grid in the grid set to the other side of the cell each time it is generated a reverse operation is necessary. The mirror grids uses the same values passed in to the grid generator, however, the first grid set will begin from the left coordinate $X_1$ and top coordinate $Y_1$ of the cell. While the grid coordinates $M_s$ for the normal grids begin with $M_1 = X_2 - N_1, M_2 = Y_2 - N_2$, the mirror grids begin with $M_1 = X_1 + N_1, M_2 = Y_1 + N_2$, and thus the sequence for the mirror grids is,

$$M_1 = X_1 + N_1, M_2 = Y_1 + N_2, M_3 = M_1 - N_3, M_4 = M_2 - N_4, M_5 = M_3 + N_5, M_6 = M_4 + N_6, \ldots$$
For the vertical grid generation (Figure 5.22), the perpendicular to the major diagonal within the given cell produces a new length $N_n$ (for proof of how to obtain the length see appendix 5.1) that revolves around the “eye” or the intersection of the two diagonals. The closer $N_n$ is to the “eye” the smaller is its length. $N_n$ is given as,

$$N_1 = \frac{WT^2}{HT}, N_2 = \frac{N_1^2}{WT}, N_3 = \frac{N_2^2}{N_1}, N_4 = \frac{N_3^2}{N_2}, N_5 = \frac{N_4^2}{N_3}, \ldots, N_{n+1} = \frac{N_{n-1}^2}{N_{n-2}}, \ldots$$

or to simplify,
\[
N_a = \begin{cases} 
\frac{WT^2}{HT}, & n = 1 \\
\frac{N_1^2}{N_2}, & n = 2 \\
\frac{WT}{N_2}, & n = 3 \\
\frac{N_2}{n-2}, & n \geq 3 
\end{cases}
\]

The new grid \( M_a \), which is the coordinates within the cell, is based on the subtraction and addition of the length \( N_a \) and is given as,

\[
M_1 = Y_2 - N_1, M_2 = X_2 - N_2, M_3 = M_1 + N_3, M_4 = M_2 + N_4, M_5 = M_3 - N_3, M_6 = M_4 - N_6, \ldots
\]

A grid group have many grid set, the first set of horizontal and vertical grids \( (M_1, M_2) \) began from the bottom and right side of the given cell and requires two subtractions of the length \( N_a \) relative to the bottom and right side of the cell (Fig. 5.23a). The second set of grids \( (M_3, M_4) \) is relative to the first set and requires additions of the length \( N_a \) from the first set of grids (Fig. 5.23b). Alternatively, the third set \( (M_5, M_6) \) will be subtraction and the fourth is addition until a given number of grid sets is achieved.
Figure 5.23: First And Second Set Of Grids In A Horizontal Orientated Cell.

Figure 5.24 is a set of generated grids in a group of four grid sets within the given cell:

Figure 5.24: A Grid Generated According To The Vertical Orientation Of Subdivision With Four Grid Sets. Mirror Grids Are Shown As Dashed Lines.
To mirror a grid in the grid set to the other side of the cell each time it is generated a reverse operation is necessary. The mirror grids use the same values passed in to the grid generator, however, the first grid set will begin from the top coordinate $Y_1$ and left coordinate $X_1$ of the cell. While the grid coordinates $M_n$ for the normal grids begin with $M_1 = Y_2 - N_1, M_2 = X_2 - N_2$ the mirror grids begin with $M_1 = Y_1 + N_1, M_2 = X_1 + N_2$, and thus the sequence for the mirror grids is,

$$M_1 = Y_1 + N_1, M_2 = X_1 + N_2, M_3 = M_1 - N_3, M_4 = M_2 - N_4, M_5 = M_3 + N_5, M_6 = M_4 + N_6,...$$

To fully understand the grid generation process a presentation of hierarchical rectangles is necessary. Figure 5.25 explains the hierarchy of rectangles. For a horizontally orientated cell, each layer of rectangle whirls alternatively between horizontal and a vertical orientation around the regulating lines shown as dashed diagonal lines. The characteristics of a vertically orientated rectangle are shown in Figure 5.26.

**Figure 5.25: A Hierarchy Of Rectangles.**
Figure 5.26: A Hierarchy Of Rectangles From A Vertical Orientated Rectangle.

Figure 5.27: A Hierarchy Of Rectangle In Separation.

Figure 5.27 shows the hierarchy of rectangles in separation. Hashed areas showed the position of the next hierarchy. Dashed lines show the grid line coordinates in the rectangle. As observed in the diagram, the lower the hierarchy the smaller the rectangle.
With this concept of hierarchy a grid-generating algorithm for horizontal and vertical orientated cells is presented below.

For a horizontal orientated cell,

While grid line is not completed do
    The 1st grid line coordinate of the current rectangle is equal to the width of the current rectangle (alternate minus/plus) the width of the next rectangle hierarchy

    The 2nd grid line coordinate of the current rectangle is equal to the height of the current rectangle (alternate minus/plus) the height of the next next rectangle hierarchy

    Mirror grid lines
Move to the next hierarchy of rectangle.

For a vertical orientated cell,

While grid line is not completed do
    The 2nd grid line coordinate of the current rectangle is equal to the height of the current rectangle (alternate minus/plus) the height of the next rectangle hierarchy

    The 1st grid line coordinate of the current rectangle is equal to the width of the current rectangle (alternate minus/plus) the width of the next next rectangle hierarchy

    Mirror grid lines
Move to the next hierarchy of rectangle.

The algorithm works in this way: For a horizontal orientated cell, the first grid line coordinate is vertical in the first hierarchy of rectangle. The grid line is obtained by subtracting the width of the next rectangle hierarchy as seen in the vertical dashed-line of Figure 5.27a. The second grid line coordinate is horizontal in the first hierarchy of rectangle as seen in the horizontal dashed-line of Figure 5.27a; this grid line is obtained
by subtracting the height of the rectangle after the next rectangle (the “next next rectangle” in the algorithm is Fig. 5.27c); note that this grid line is also the horizontal grid line of the second hierarchy (Fig. 5.27b). The operation to obtain the grid is alternated between addition and subtraction for the subsequent hierarchies. A vertical orientated cell works in the same way except that the first grid line coordinate began as a horizontal line instead of a vertical.

5.5.2 Base Grid and Object Grid
A base grid is generated by passing in the two points of a frame with the values $X1=0$, $Y1=0$, $X2=$ Screen Width, $Y2=$ Screen Height. An object grid is generated by passing in the cell coordinates of the extensions of the sides of a screen object that matches the nearest grids. This will be covered in the next section. Figure 5.28 is a flowchart of the process of grid generation and grid matching. The base grid generation begin at A. The following processes are covered in the subsequent sections.
Figure 5.28: The Design Steps Flowchart With Grid And Side Extension Added.
5.5.3 Grid Matching

For the four sides of a screen object to match the grid, a minimum and maximum tolerance level is required. Figure 5.29 is a 1.618 rectangle with base grid. The dashed-line is the tolerance level of the grid with a minimum and maximum tolerance of \( T \) units, \( T=10 \) pixel by default. Any object with sides that fall into the boundary of the tolerance line will have a relationship to the corresponding grid as shown in the enlarged diagram of the grid.

**Figure 5.29:** Tolerance Level For Grid Matching.

Because of the property of some rectangles, grids generated will be a certain measure inset from the boundary of that rectangle. As noticed in Figure 5.30, the closer a rectangle it is to a square, the nearer the grids to the rectangle centre, and the further away a rectangle from a square, the nearer the grids are to the boundary of the rectangle, notice that a square has its boundaries as the grid. For this reason decisions on the grid generation has to be based on the shape of the rectangle. To guarantee a thorough base grid for object grid generation, a secondary base grid is required. A perfect shape to set the threshold for a horizontally orientated rectangle is the ratio of 1.618, and a vertically orientated rectangle with the ratio of \( 1 / 1.618 \), since the grids are between the centre and
the boundary. Figure 5.28B is the process after the decision is made (process: Figure 5.28 B.).

**Figure 5.30:** Progression Of Dynamic Rectangles And Its Grids From A Square To A $\sqrt{5}$ Rectangle.

Figure 5.31 is a 1.4472 frame with base grids B1, B2, B3, B4 and the mirrored base grids B5, B6, B7, B8. The secondary base grids are generated within the bottom right quadrant BC with grid lines S1, S2, S3, S4, and top left quadrant AB of the frame with gridlines S5, S6, S7, S8. Four frame point values $X_1, Y_1, X_2, Y_2$ are sent to the grid-generating method to generate the grids. In this instance, two sets of points are sent in to describe the areas for grid generation. The top left quadrant AB receives the value of $X_1 = 0, Y_1 = 0, X_2 = \text{width} / 2, Y_2 = \text{height} / 2$ for its operation and the bottom left quadrant grids receives the values of $X_1 = \text{width} / 2, Y_1 = \text{height} / 2, X_2 = \text{width}, Y_2 = \text{height}$ for its operation.
During design time object boundaries (Fig. 5.32a), i.e., the top, bottom, left, and right are matched with the base grids within a tolerance margin before the object grids are generated (process: Figure 5.28 C.). In frequent cases, an object side may be “idle”, unable to find a matching grid relationship (Fig. 5.32b).
Figure 5.32: Grid Matching Of Object Sides.

To solve this issue, the “idle” side is passed to a program function (process: Figure 5.28 D.) that search for the next grid according to its direction (Fig 5.33). This function ensures the matching of all sides of the object, and receives the input of the side which may be in any direction of top, bottom, left, or right, represented by $S$ with the function,

\[
\text{Input value to search grid (} S \text{)}
\]
\[\text{For each grid in the relative direction of } S\]
\[\quad \text{If grid is found}\]
\[\quad \quad \text{Return grid and End Function}\]
\[\quad \text{End}\]
\[\text{End while}\]
\[\text{If no grid is found}\]
\[\quad \text{Return boundary of frame as the grid}\]
\[\text{End}\]
When all sides have relationships with the grid, the object grid is generated (Fig. 5.34). At this stage, another problem is encountered. The grids generated do not allow the object to conform to its shape because it is too far away from the sides.
To resolve this, instead of using the nearest matching grid as a generator for object grid, a better solution is to extend the matched grid (process: Figure 5.28 E.) in their respective directions to find the next possible grid boundary for generation (Fig. 5.35). Figure (a) is a diagram showing the matching grid and the extended grid. In figure (b), the extended grid generated object grids a, b, c, d, and e, f, g, h (process: Figure 5.28 F.). Each of these grids then produces its minimum and maximum tolerance for the object to conform its shape to the grid shape. The function receives the input of the four grids on four nearest sides of the object with top, bottom, left, and right represented by T, B, L, R with the function,

*Input values to extend grid (T,B,L,R)*

*For each grid in the relative direction of T, B, L, R do*

*If grid is found then*

*Return grid and end function*

*End if*

*Next grid*

*If no grid is found*

*Return boundary of frame as the grid*

*End*

*Figure 5.35: Extending Matched Grid For Grid Generation.*
When a user proposes the screen object shapes, sizes and positions, it is necessary to keep to minimal changes. Because dynamic grids are unevenly spaced, a grid compare function is added to compare the distances of the nearest grid to snap to between two existing ones (Fig. 5.36). The function (process: Figure 5.28 G.) receives two grids nearest to both sides of an object side represented by \(a\) and \(b\), with the function,

\[
\text{Input values to compare grid \((a, b)\)}
\]

\[
\text{If distance of } a \text{ is smaller than distance of } b \text{ Then}
\]

\[
\text{Use } a \text{ as the grid}
\]

\[
\text{Else}
\]

\[
\text{Use } b \text{ as the grid}
\]

\[
\text{End}
\]

**Figure 5.36:** Comparing Grid Distances.

Finally, each side of the object is extended to snap to any available grids.
The Dynamic Gridding System (DGS) is built in such a way that enables diversity of grids. Base on the extensibility of the grids over any frame shapes, screen objects within the frame can now be related to one another and to the whole in the naturally pleasing proportions of dynamic symmetry. The system provides dynamically generated grids that conform to the principles of themes base on screen frames, object shapes, and object positions. Therefore, the grids in this system are not limited to merely a few sets; instead the grids generated and its surfaces are dependent on object shapes and positions on the frame that contain them. Different object positions and shapes produce different sets of grids.

5.6 Designing Screens with Manually Drawn Dynamic Symmetry Grids

In a related study presenting empirical data to compare aesthetics between original screens and screens reformatted with dynamic symmetry grids (Ch’ng and Ngo, 2001b), popular multimedia and web screens were selected and reformatted with dynamic symmetry grids. The screen objects are reshaped and repositioned in accordance to the manually drawn grids using an image editor. Participants were 56 undergraduate students (23 males, 31 females, 2 unspecified sex) in a Malaysian university. Subjects were members of a variety of information technology classes and received credit for participating in the study. Although subjects were members of information technology courses, they were not familiar with screen design concepts. The four screens with their reformatted versions were transferred into grey scale transparencies and displayed using an overhead projector to a large audience. Each pair was displayed for about 20 seconds. During that time participants selected the most visually pleasing layout from each pair. The evaluation showed that viewer judgements on the participants yielded an average of 74.5% preferring reformatted screens using manual dynamic symmetry grids over original screens from popular multimedia and web interfaces. Figure 5.37 shows the results in individual percentages and the average of the four screens (screens 1-4 correspond in sequence with Figure 5.38-41). The four original and reformatted screens are shown in figure 5.38-41. The study materials were modified with minor changes to
the positions and sizes of the components. Trade-offs had sometimes to be made between ensuring compliance with the proportioning law on one hand, and preserving the original look-and-feel on other hand. In most cases, the former approach was preferred. Viewers clearly separated the aesthetically modified screens from their original versions. They seemed to notice “this symmetry or commodulation between the elements and between the elements and the whole”.

![Figure 5.37: Empirical Results Of Viewer Judgements On Reformatted Screens.](image)
The screen shown in Figure 5.38b was created by reformatting the screen shown in Figure 5.38a, which is from Microsoft Encarta Encyclopedia 1999, to adhere to the dynamic symmetry principle. Figure 5.38c shows the analysis of the reformatted screen. The object on the left is a $\sqrt{\phi}$ and the object on the right is a square. The navigation bar is composed of three 0.191 rectangles, each divided into three squares plus a $\sqrt{5}$ rectangle.

Figure 5.39b was the result of applying the dynamic symmetry principle to the format shown in Figure 5.39a, which is from IBM Worldbook 1999. Figure 5.39c shows the analysis of the reformatted screen. The object on the left is a...
square plus a $\phi^2$ rectangle, the object on the right is a square, the excess area in between is composed of six $\phi$ and two squares.

The reformatted web screen shown in Figure 5.40b obeys the principle of dynamic symmetry, while the original format shown in Figure 5.40a, which was developed by Virtual Realm Exchange, appears to violate the principle. Figure 5.40c shows the analysis of the reformatted version. The object on the left is a $\phi^2$ rectangle, the object in the middle is a $\phi$ rectangle, the object on the right is a square plus a $0.5528$ rectangle, which his is composed of a square plus two $\phi$ rectangles.

Figure 5.39: Two versions of a screen from IBM Worldbook 1999 (IBM Corporation).
(a) Original format. (b) Reformatted version. (c) Reformatted version, harmonic analysis.
The web screen shown in Figure 5.41a was developed by The Employment Agents Movement. Figure 5.41c shows the analysis of the reformatted version shown in Figure 5.41b. The object on the left is a $\phi$ rectangle with dynamic division into two parts: one at the top and the other at the bottom, the object on the right is a square, the object at the bottom is placed on the divisional lines created from the diagonals.

\[ \text{Figure 5.40: Two Versions Of A Web Screen By Virtual Realm Exchange. (a) Original Format. (b) Reformatted Version. (c) Reformatted Version, Harmonic Analysis.} \]
Figure 5.41: Two versions of a web screen by The Employment Agents Movement. (a) Original format. (b) Reformatted version. (c) Reformatted version, harmonic analysis.

5.7 Walkthrough of the Dynamic Gridding System (DGS)

The system is designed with Macromedia Director 8.5 and Lingo (info. in appendix 6.1) because of the flexibility of the language and its object-oriented technology. A simple user interface (Fig. 5.42) that caters to ease of use is designed for evaluation purposes. The system has a rollover pop-up menu on the lower left corner of the window which has four options in checkboxes. They are ‘Drag Snap’ which allows the user to drag the screen objects while the system suggests shapes based on the grids, ‘Alignment’ allows alignment of objects after the system suggests the new layout. The ‘Base Grid’ and ‘Object Grid’ options control the visibility of the grids. The quick buttons on the top right of the window gives the functions such as ‘Quit’, ‘Information’, ‘Screen Capture’, ‘Reset’, and ‘Suggest’. ‘Screen Capture’ captures the screen for disk storage and the ‘Suggest’ button generates secondary grids and allows the system to reposition and reshape the objects based on dynamic symmetry principles. When this button is clicked,
a new layout is proposed with the secondary grids turned on and all the objects aligned with the object grids (Fig. 5.43a). Figure 5.43b is the same layout without the grids.

**Figure 5.42:** The System User-Interface.

**Figure 5.43:** A Layout With And Without The Secondary Dynamic Symmetry Grids.
The grid in figure 5.43a looks very complex, but in actual fact if each of the enclosed grid surface, or compounds of the grid surfaces are analysed, dynamic ratios can be found that conforms to dynamic symmetry principles. During design time, the user interacts with the objects by scaling, repositioning, and reshaping. Scaling an object is with the command shift-Left Mouse Button, reshaping is with Alt-Left Mouse Button and repositioning, the Left Mouse Button. The aspect ratio of video, images or diagrams is an important element in visual information. A border is added to each of the visual objects so that while the user or the system is reshaping, the aspect ratio is preserved while the border is reshaped to conform to the grids.

5.8 Empirical Study of the System

The algorithms implemented in the Dynamic Gridding System (DGS) for suggesting dynamic symmetry grids for screen objects were tested in an evaluation. This system is designed to reformat a user-proposed layout to fit the principles of dynamic symmetry positions and shapes and yet retain minimal changes to the users’ personal preferences. Four users were asked to design a dummy screen within the system window (Fig. 5.44) by placing the default five objects in a position that the user deemed best, this is done without the assistance of dynamic symmetry grids. When the objects are positioned, the users allow the system to automatically reposition and reshape the objects according to the generated grids of dynamic symmetry.

The screens are then captured and stored as original screens and screens reformatted by the system (Fig. 5.45). The users are staff members of Information Technology Department of Multimedia University Malaysia. Even though the users possessed knowledge in information technology, none of them have experience in screen design or graphic design principles, however in the screens shown it can be observed that they possess some knowledge of functional placement of screen components.
Figure 5.44: The Dynamic Gridding System (DGS).
Figure 5.45: Original and Reformatted Screens by the Gridding System.
Each set of screens both original and system reformatted are placed side by side in a random order on an online voting system. Selection is done with radio buttons and submitted at the end of the 10 minutes session in a computer lab. 30 information technology students of Multimedia University participated in this evaluation where 18 are males and 12 females. The empirical study yielded an average of 67.86% selecting the system-reformatted screens over user proposed screens (Fig. 5.46). The percentage of selection of individual screen is shown in figure 5.47. The results suggest that screens reformatted by the system are generally better than a non-structured approach without dynamic symmetry grids. However, by comparing the percentages of the empirical studies between manually reformatted screens (Section 5.6) with the system suggested screens, the average of the latter is lower by a difference of 6.64%. This may suggest that the former approach has a better control of the layouts due to the fine ability of human perception in laying out screen elements in a balance and orderly way.
Nevertheless, the participants did not fail to notice the aesthetic shapes and positional relationships between “the elements and between the elements and the whole” that was suggested by the dynamic symmetry gridding system.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Symmetry Designed Screen</td>
<td>64.28571</td>
<td>78.57143</td>
<td>71.42857</td>
<td>57.14286</td>
</tr>
<tr>
<td>Original Screen by User</td>
<td>35.71429</td>
<td>21.42857</td>
<td>28.57143</td>
<td>42.85714</td>
</tr>
</tbody>
</table>

**Figure 5.47:** Evaluation Of Screens Designed By The System.

The screens generated by the Dynamic Gridding System (DGS) were analysed with the analysis tool covered in chapter 4. All of the screen objects were tested positive for dynamic symmetry ratios, proving the trustworthiness of the grid generating algorithms. Since the screen has the base of a $\phi$ rectangle, the objects should possess the same theme as seen in the figures below. Figures 5.48-51 are the screens with their analysis. The analyses of the screen object’s surfaces showed in the figures are a variation out of a number of other surfaces recorded by the analysis tool. The screen analyses were drawn with an image editor showing their dynamic symmetry relationships.
Figure 5.48: Analysis Of Reformatted Screen In Figure 5.45(a).

Figure 5.48a is the reformatted screen; the grids on the boundaries of the objects were drawn with an image editor and the surface relationships on the void areas were analysed (b) and showed in the analysis tool that they were of the same theme. (c) shows the analysis results of the objects with their themes: The largest object, the map, on the left hand side of the screen is composed of a $\sqrt{5}$ rectangle and a $\phi^2$ rectangle. The second largest object, the picture on the right is composed of a large square with a double square and a $\sqrt{\phi}$ on its side. The title of the screen is composed of three $\phi$ and four squares. The ‘Home’ button has two $\sqrt{\phi}$ and a square and the ‘Next’ button is composed of a double square plus three vertical $\phi$ placed on top of each other.
Figure 5.49: Analysis Of Reformatted Screen In Figure 5.45(b).

The reformatted screen is seen in Figure 5.49a; the grids on the boundaries of the objects can be seen in (b) these were drawn with an image editor and the surface relationships on the void areas were positively of the same theme when they were analysed. (c) shows the analysis results of the objects with their themes: The map on the left hand side of the screen is composed of two $\phi$ rectangles placed on top of one another and a $\phi^2$ rectangle on their sides. The picture at the centre is composed of a large square with five $\sqrt{5}$ rectangles. The title of the screen is composed of four squares a $\phi$, and two $\sqrt{5}$ rectangles. The ‘Home’ button has five squares vertically on three horizontal squares with a $\sqrt{5}$ at the end. The ‘Next’ button is composed of three squares.
Figure 5.50: Analysis Of Reformatted Screen In Figure 5.45(c).

Figure 5.50a is the reformatted screen; the object grids can be seen on the boundaries of the objects; these were drawn with an image editor and the surface relationships on the void areas were analysed (b) and showed in the analysis tool that they were of the same theme. (c) shows the analysis results of the objects with their themes: The largest object, the map, is composed of squares. The picture is composed of three $\sqrt{\phi}$ rectangles placed on top of each other with a larger $\sqrt{\phi}$ on their sides. The title of the screen is composed six squares. The ‘Home’ button has three $\sqrt{5}$ placed on top of one another with a $\phi^2$ on their sides, and the ‘Next’ button is composed of a double $\sqrt{\phi}$ plus three squares.
Figure 5.51: Analysis Of Reformatted Screen In Figure 5.45(d).

The reformatted screen from the original is seen in Figure 5.51a; the grids on the boundaries of the objects can be seen in (b) these were drawn with an image editor and the surface relationships on the void areas were tested positive with the same theme when they were analysed. (c) shows the analysis results of the objects with their themes: The map is composed of two $\sqrt{5}$ rectangles plus a larger $\sqrt{5}$ on their sides. The map object has three vertical $\sqrt{5}$ rectangles plus a double square. The title is composed of three horizontal double squares placed on top of one another, five squares, a $\sqrt{\phi}$, and a $\phi^2$. 
Chapter 6: Conclusion

6.1 Introduction
Dynamic symmetry, the proportioning system originated from the classical Greek period and rediscovered by Hambidge has been around for a long time. This system of proportion has also been used by a number of artists, architects, and sculptors since its discovery over eighty years ago. In this project dynamic symmetry is employed for analysis of popular screens using a computer-aided analysis tool implemented from Hambidge’s analytical methods. Due to the positive results from the analysis, dynamic symmetry design is studied and used as an aesthetic system for designing screen layouts. Thus far, the modular system has not been used as a grid-based format for designing screens. The use of grid format for screen layout is absolutely necessary. Grids facilitate screen designers in creating good composition, designing spaces, creating order, balance, structure, unity, and consistency. A survey of popular web page and multimedia design tools did not find a structured grid option integrated with modular systems, instead grids or guides are often set by users in a rather static way. Through empirical studies and observations of industrial areas that benefited from the use of proportioning systems, we see the desirability of adopting dynamic symmetry as a guide in which screen design may hang upon. This system offered designers a formula for reproducing natural proportions in their works. Using this system for screen layout will give us an easy framework from which to work. Information on both the analysis tool and the Dynamic Gridding System (DGS) are included in appendix 6.1.

6.2 Achievement of Research Objectives
This research successfully achieves the goals listed in section 1.3 of chapter 1. A number of proportioning systems were investigated and a suitable system was selected for a comprehensive study of its methodologies. The methodologies were defined for its suitability for use in screen layout and a series of algorithms were presented for integration into a computer-based tool with a grid design approach.
A study was done in chapter four to examine whether dynamic symmetry has been used in the past in screen design. Algorithms were defined after studying Hambidge’s analytical methods and were integrated into a computer-aided analysis tool. While using the tool, the study of the theory of proportions that underlies more than 150 screens from a variety of popular web page and multimedia systems showed an unmistakable use of plan schemes of dynamic symmetry in over 40% of them, few adhere absolutely to the system. The evidence based on the study supports the use of its root rectangles at least in those 40% cases. It is hard to say whether the use of dynamic symmetry was intentional because there was no written record verifying its use, however, the analysis show unmistakably the conscious use of the root rectangles in dynamic symmetry although these designers did not consciously apply Hambidge’s technique of composition.

The methodologies of dynamic symmetry design were defined and by employing these principles, screens from popular multimedia and web pages were reformatted and evaluated. Viewer judgements on over 50 candidates yielded an average of 74.5% preferring reformatted screens to their original versions. This result led to the development of the Dynamic Gridding System (DGS) that incorporates the grid-based design rules of dynamic symmetry in chapter 5. In an empirical study, users were asked to propose screen object shapes and position and allow the system to reformat them with dynamic symmetry grids. The evaluation yielded an average of 67.86% of viewers selecting the system-reformatted screen object shapes and layouts over user’s proposal. The results suggest that the system-reformatted layouts were more aesthetically pleasing than the original versions. The empirical study of the Dynamic Gridding System (DGS) showed positive results in achieving aesthetics in screen layouts.

6.3 The Position of Dynamic Gridding System in Development Environments
Current development environments do not provide options for grid-based integrated proportioning systems for screen layouts. In view of the empirical studies conducted on the use of dynamic symmetry in screen design, and particularly the algorithms for
generating dynamic symmetry grids, the algorithms of the system could be integrated with development environments to assist designers in screen layouts. Three areas may be listed as targets for this system; they are web page design tools, software development environments, and multimedia systems development platforms.

6.4 Contribution Of Dynamic Gridding System (DGS)
Dynamic symmetry is a formula for reproducing natural proportions, it allows for consonance of parts and of the whole in a composition. It also assists layouts in unity and harmony. The dynamic symmetry grid generating algorithms has provided an objective way for designing aesthetically pleasing screen layouts. Base on the multiplicity and extensibility of the grids over any frame shapes, screen objects within the frame can now be related to one another and to the whole in the naturally pleasing proportions of dynamic symmetry. Because of the nature of the grid the layout of screens can be made consistent throughout the entire project. Unlike the current grid and guide options found on development environments, the system provides dynamically generated grids that conform to the principles of themes base on screen frames, object shapes, and object positions. Therefore, the grids in this system are not limited to merely a few sets; instead the position of grids generated and its surfaces are dependant on object shapes and positions and on the frame shape which contain them. Dynamic symmetry is not a substitute for designer’s preference, rather it enables designers to utilise the aesthetically pleasing proportions of nature in their works.

6.5 Future Work
Although the results of evaluating screens designed by this system is fairly positive, more empirical testing is needed and much can be done to make both the analysis tool and the current gridding system better.

A few identifiable areas are needed for further development. Currently the algorithm of the dynamic ratio matching process in the analysis tool can be optimised. The object analysis flowchart (Fig 4.24) only applies the dynamic ratios to the end of an object;
applying the ratio to the side may produce a wider result for the matched areas. Artificial intelligence could be incorporated into the analysis process for intelligent matching. The Dynamic Ratio Coding (DRC) may be converted to graphical diagrams with added system function for easy reading of the results. Further development to the analysis tool such as those listed above may yield more accurate results in screen analyses.

The current dynamic symmetry grid design does not secure some fundamental graphic design elements, it purely provide for proportional relationships between the elements of a composition. For a more automated process in the system, a few examples that need to be included are the balance, alignment, and equilibrium of screen elements. Designing an interface with balance is surely a necessity; balance in the current gridding system is entirely based upon the user’s experience and knowledge of graphic design. Although placement of screen objects in the current system may enable a certain extent of alignment, it is entirely based on the nearness of the objects’ boundaries to one another; the grid snap function takes over the alignment for the same grids selected for the objects’ sides, grouping algorithms may be needed for aligning related screen elements. To provide for visual design of spatial properties, one solution is to integrate Ngo’s (2001) thirteen scientific measures into the same system. The DGS supports automated restructuring of shapes in their proportions when the user proposes the shape and layout of the screen. It also allows the user to interact with the grids while placing the objects; however, the system needed further improvement in terms of usability. Future work should integrate the graphic design principles mentioned above; after these principles are incorporated into the system, empirical studies should be conducted by having the algorithms implemented into web and multimedia development environments and letting users interact with the system for usability improvements.

Aesthetics in screen design applies to many other elements listed above. Colour experimentations for aesthetics is a major area for consideration. The visual arts possess a great source of wealth on aesthetic theories and experience that we can experiment with and perhaps made scientific for a more objective approach to screen design.
6.6 Application in Design Related Fields
Dynamic symmetry has been used in many areas aside from screen design. These areas, however do not automate the process of dynamic symmetry design with computer-aided tools. Logically, in such a situation designing is done manually whether in a two-dimensional form as in computer-aided tools for illustrations and graphic design, or three-dimensional form as in industrial design and architecture. The algorithms presented here can also be used for these areas that adopt computer tools for designing. The system can be implemented for any areas that present a need for grid-based design requiring aesthetic formulas.
Appendices

Appendix 2.1
Golden Section Construction I

The Golden Section and the Golden Ratio
A golden section is a line segment that has been divided into two parts in such a way that the ratio of the longer part $(a)$ to the shorter part $(b)$ is equal to the ratio of the entire segment $(a + b)$ to the longer part $(a)$. This can be indicated symbolically as $a/b = (a+b)/a = \phi$, and this ratio, $\phi$, is called the golden ratio.

1. Given the line with end-points A and B. We want to find the point which divides it at the Golden Section point using compasses for drawing circles and a set-square for drawing lines at right-angles to other lines.

2. Below is the construction method for finding a point $G$ between A and B so that $AG/AB = \phi (0.61803...)$ by which we mean that $G$ is $\phi$ of the way along the line. This will also mean that the smaller segment $GB$ is 0.61803... times the size of the longer segment $AG$.

3. Place the compass on end-point B, open them out to be somewhere near the other end of the line and draw a semicircle over the line AB. Repeat the process at the other end of the line without altering the compass size. The two points where the semicircles cross can then be joined and this new line will bisect line $AB$ at $C$.

4. Construct a line at right angles to $AB$ at end $B$.

5. Put the compass at B, expand to the mid-point of $AB$ and draw an arc to find the point on the vertical line. The new section $BD$ is the same length as $BC$.

6. Join point $D$ to $A$ to make a triangle. Compass point at $D$, construct an arc from $B$ and cut the line $AD$ at $E$.

7. Finally, compass at point $A$, draw an arc from point $D$ and cutting the line $AB$ at point $G$. Point G now divides the original line $AB$ into two parts, where the longer part $AG$ is $\phi (0.61803...)$ times as long as the original.
Appendix 2.2
Golden Section Construction II

1. This is a construction method of finding a point outside line segment AB so that the new point defines a line which is Phi (1.61803...) times as long as the original line.

2. Repeat steps 1 & 2 of the phi (0.61803...) construction method to bisect the line AB and also to have a line at right angles at B.

3. Place the compass at point B. Construct an arc to point E at the vertical line. BE is as long as the original line BA.

4. Compass at mid-point of line AB, construct another arc from point E to the extended original line AB to a new point G.

5. The line AG is now Phi times as long as the original line AB.
Appendix 2.3
Golden Section Rectangle Construction

1. Construct a 1 x 1 unit square.

2. Bisect the square at M.

3. Extend line D horizontally to point C. Compass at point M, draw and arc from point E to point C.

4. Close the rectangle at B. ABCD is now a Golden Rectangle.
Appendix 3.1
Hambidge’s Method: The Tracing of Diagonals and Perpendiculars to Diagonals.

Diagonals of the $\phi$ Rectangle

1. Construct a Golden Section rectangle and draw a diagonal from A to B.

2. From C draw a diagonal perpendicular to AB through O to D.

3. From D draw a line parallel with BC and another line from F to G passing through the intersections of AB and DE.

4. The diagonals AB and CD is mirrored and a similar line to DE is drawn.

5. The diagonals AB and CD is mirrored and a similar line to DE is drawn.

5. The rectangle is now a harmonic subdivision. More lines can be drawn through the intersections of the diagonals or the diagonals and the lines to create more complex subdivisions that conforms to the principle of themes of dynamic symmetry.
Appendix 3.2
Screen Analysis Table

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Appendix 4.1
Most Frequently Used Ratios in Nature and Greek Design
(From Hambidge, 1926)
Appendix 4.2
Prove of Similarity of Figure in Applied Objects

These diagrams proves the similarity of figure between the object and the applied area if the excess area is dynamic.

1. The object has the ratio of 1.236 a double vertical \( \phi \). The base is a \( \phi \). Both object and base are dynamic in ratio.

2. The object is applied to the base with the equation and also geometrically, leaving an excess area with the dynamic ratio of 1.236 a double vertical \( \phi \). This is also a similar figure to the object.

\[
\frac{1.236}{1.618 - (1/1.236)} = \frac{1.618}{1.618}
\]

3. This proves that if the excess area is dynamic, the object being applied is a similar figure to the applied area, which is a hidden subdivision of the dynamic rectangle.

\[a = b\]
Appendix 4.3a

Selected Screen Analysis Showing Plan Schemes of Dynamic Symmetry

**Theme:**

Square: \( \sqrt{5} \), \( \phi = 1.272 \), \( \phi^2 = 2.618 \)

**Screen Name:** Australian PAYE Tax Calculator 3.0.1 (Tax from Gross Calculator Screen)

**Screen Source:** http://www.ozemail.com.au/~ghardwic/screenshots.html

**Screen Description:**

The theme for this screen is based on the \( \phi \)

The overall area is a double square

The quick bar is composed of 12 squares and a \( \phi \)

The Options and Medicare Levy are both squares

The Enter Gross Pay Container is composed of a \( \phi \) + two areas, each composed of a \( \phi \) + two areas

This area is excess area two rectangles, each composed of a double square and four \( \sqrt{5} \)

Logical Procedure of Analysis

1. Divide the layout of the objects into its natural horizontal and vertical divisions. Get the ratio of the height and width.
   \( 9.432 / 4.635 = 2.03495 \)
   The difference from a double square is .03495, so the layout of the object is a double square.

2. Use analytical methods on the natural divisions A,B,C,D,E,F,G

**Application of 12 Squares**

The width of excess area is \( 1.116 = 9.432 / 8.332 = 2.254 \)

The ratio of excess area is \( 9.618 : 9.833 = 1.010 \)

The difference is .039

**Ratio Analysis:**

\( B \) is a Square: 1.1025 = 2.147 / 1.949

Difference is .1

\( C \) is a Square: 1.09929 = 2.147 / 1.921

Difference is .08929

**Application of Vertical Theme:**

The length of vertical \( \phi \) is: 3.082 = 3.921 X (1 / 1.272)

The length of excess area is: 2.101 = 1.116 / 0.693

The ratio of excess area is: 1.848 = 3.921 / 2.122

Division of excess area:

\( 0.924 = 1.848 / 2, 0.927 \) is a compound rectangle of a \( \phi \) + two areas

The difference is .003

**Vertical Division:**

The width after division into three parts: 0.084 = 2.682 / 3

The ratio of division area is a double square: 1.950 = 1.343 / .844

Difference is .045

The area of E, F, G are such an area of 9 squares (i) or a square + 2 square (ii)

The entire area (iii) can also be analysed below:

**Division of Areas:**

Height of EF after division into 4 parts: 0.471 = 3.825 / 3.121

Ratio of each division: 1.121 = 3.825 / 3.472

0.473 in a square + 2.15

Difference is .004

Screen Name:

Australian PAYE Tax Calculator 3.0.1 (Tax from Gross Calculator Screen)


Email: ghardwic@ozemail.com.au

Screen Description:

The theme for this screen is based on the \( \phi \)

The overall area is a double square

The quick bar is composed of 12 squares and a \( \phi \)

The Options and Medicare Levy are both squares

The Enter Gross Pay Container is composed of a \( \phi \) + two areas, each composed of a \( \phi \) + two areas

This area is excess area two rectangles, each composed of a double square and four \( \sqrt{5} \)
Appendix 4.3b
Selected Screen Analysis Showing Plan Schemes of Dynamic Symmetry

Theme:
Square = 1; √4 = 2; √5 = 2.236; √φ = 1.272; φ = 1.618; φ² = 2.618

Screen Name: Boomerangs - Echoes of Australia
Email: webmaster@mindvision.com.au

Screen Description:
The theme for this screen is based on the φ
The overall area is a square + φ²
The main area of the screen is an object that is a similar figure to the whole if it is a φ
The navigational bar is composed of five φ²

Logical Procedure of Analysis:
1. Divide the layout of the objects into its natural horizontal and vertical divisions.
2. Get the ratio of the height and width: 12.665 / 8.539 = 1.477
   If a vertical φ² is applied to this ratio, it leaves us an area close to the square:
   The length of the excess area after application of φ²: 12.665 / 8.539 = 1.3808
   Difference is 0.095

3. Use analytical methods on the natural divisions A,B,C

4. Similarity of Figure
   Since object A is significant and inside object B, we can use similarity of figure for this analysis
   Ratio of A is close to φ: 1.618: 1.618 = 1.616: 1.614 = 1.004
   Difference is 0.003

5. Division of Area
   The ratio of C is 13.072 = 12.665 / 0.923
   Ratio divided by 5 is close to φ²: 2.618: 2.614 = 1.003
   Difference is 0.003
Appendix 4.3c(1)
Selected Screen Analysis Showing Plan Schemes of Dynamic Symmetry

Theme:
Square = 1; √4 = 2; √5 = 2.236; √φ = 1.272; φ = 1.618; φ² = 2.618

Screen Name: Boomerangs - Echoes of Australia
Email: webmaster@mindvision.com.au

Screen Description:
The theme for this screen is based on the φ
The overall area is a square + three squares
The main area is divided into two parts, each composed of a square + a φ²
The navigational bar is composed of eight φ

Logical Procedure of Analysis
1. Divide the layout of the objects into its natural horizontal and vertical divisions.
Get the ratio of the height and width: 1.3334 = 12.549 / 9.411
1.3334 is the ratio of a square (1) + a triple square area (.3334)

Use analytical methods on the natural subdivisions A,B,C,D,E

Application of Square on A
Length of squares area after square applied: 6.499 / 6.274 / 1.235
Division of excess area [2] close to .809 (2φ side to side)
2.4378 = 6.274 / 2.618
Difference is .009

Application of theme [φ² = 2.618] on D
The height and width of D is similar to ABC, which is composed of a square + a φ²

Application of theme [φ² = 2.618] on A+B+C
The area A,B,C can also be compounded and analysed. Height of excess area after application of
φ/cuspopen is: 6.0465 = 8.443 - (6.274 / 2.618)
The ratio of excess area is close to square (1): 1.0376 = 6.274 / 6.0465
The difference is .04

The area is composed of a square + a φ²

Division of area [6]
Ratio of C is 4.144 = 6.274 / 1.514
Ratio after division is .691 = 4.144 / 6
.691 is the reciprocal of 1.4472 which is a square + a √5

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Ratio of C is 4.144 = 6.274 / 1.514
Ratio after division is .691 = 4.144 / 6
.691 is the reciprocal of 1.4472 which is a square + a √5
The Area may also be analysed as such according to the facade of the Parthenon using diagonals.
Appendix 4.3d  
Selected Screen Analysis Showing Plan Schemes of Dynamic Symmetry

Theme:
Square = 1; √2 = 2; V = 2.236; √φ = 1.272; φ = 1.618; φ² = 2.618

Screen Name: Bose Surround CAD Kiosk
Screen Source: http://www.traylormm.com/samples/kiosk/

Screen Description:
The theme for this screen is based on the φ²
The overall area is a √5 + two φ
The top menu is composed of six φ
The description panel on the left are two squares and a φ²
The layout screen is a square

Logical Procedure of Analysis

1. Divide the layout of the objects into its natural horizontal and vertical divisions.
   - Get the ratio of the height and width: 1.329 = 12.598 / 9.481
   - If a horizontal √5 is applied to this ratio, it leaves an area close to the double φ = .309:
   - Height of the excess area after application of √5: 3.847 = 9.481 - (12.598 / √5)
   - The ratio of the excess area is: .305 = 3.847 / 12.598
   - Difference is 0.003

2. Use analytical methods on the natural divisions A,B,C

3. Division of Area (B)
   - The ratio of A is 15.553 = 12.598 / .810
   - The ratio after division is close to φ² = 2.618
   - The difference is 0.026; therefore A is similar to B

4. Application of Horizontal Theme: φ² = 2.618
   - Height of excess area after application of φ²: 7.256 = 8.671 - (3.704 / √φ)
   - Ratio of excess area is close to double square = 2
   - 1.835 = 1.256 / √φ, the difference is 0.041

5. Ratio Analysis
   - The ratio is close to the square, 1.026 = 8.894 / 8.671
   - Difference is 0.026

ANALYSIS | Bose Surround CAD Kiosk

Logical Procedure of Analysis
Appendix 4.3e
Selected Screen Analysis Showing Plan Schemes of Dynamic Symmetry

Themes:
- Square: 1; \( \sqrt{2} = 1.414; \sqrt{3} = 1.732; \phi = 1.618; \phi^2 = 2.618 \)

Screen Name: Canadian Pacific Railway
Screen Source: http://www.amg1.com/sample_work_cpr.html
Email: contact@amg1.com

Screen Description:
The theme for the screen is based on the a
1.618 area + \( \phi \) area square.
The objects within the divisions are each composed of \( \phi^2 \) and 5 squares.

1. Divide the layout of the objects into its natural horizontal and vertical divisions.

   Get the ratio of the height and width: \( 0.745 = 12.643 / 9.482 \)
   If a horizontal \( \sqrt{5} \) is applied to this ratio, it leaves us an area close to the double \( \phi = 1.618 \):
   Height of the excess area after application of \( \sqrt{5} \):
   \( 3.847 = 9.481 - (12.598 / \sqrt{5}) \)
   The ratio of the excess area is: \( 0.305 = 3.847 / 12.598 \)
   Difference is 0.003; the entire rectangle is composed of a \( \sqrt{5} + \phi \)

2. Analysis of Divisions A, B
   A) \( 9.482 / 7.732 = 1.226 \)
   The division A is close to 1.236 two \( \phi \) placed side to side.
   The difference is 0.01
   B) \( 9.482 / 4.911 = 1.931 \)
   If a horizontal \( \phi \) is applied, the excess area is 1.313, close to 1.309 a square + two \( \phi \)
   The difference is 0.004; the division B is composed of \( \phi + 1.309 \)

3. Get ratio of objects A1, B1 within divisions:
   A1) \( 9.279 / 3.088 = 3.014 \)
   If a vertical \( \phi \) is applied to the side, the excess area is composed of 5 squares.
   5 Squares = height / (width - (height / \( \phi^2 \))
   1.399 = 3.279 / (3.088 - (9.279 / 2.618))
   B1) \( 7.216 / 4.199 = 1.719 \)
   Object B1 is similar to A1

4. Fitting Objects into their slots
   Generate slots based on position and relation of objects.
   Get ratio of excess areas after objects A1 & B1 have their slots.
   All excess areas are exhausted.
   Screen conforms to dynamic symmetry in harmonic subdivision and similarity of figure.
Since $AB \parallel CF \parallel DE$ we get that $\angle ABG = \angle FGH = \angle DEH$

Also, again by the fact that $CF \parallel DE$ we get that $\angle GFH = \angle EDH$

Hence,

$\angle GFH = \frac{\pi}{2} - \angle DEH = \frac{\pi}{2} - \angle ABG = \angle CBG$

Now, $\tan \angle GFH = \frac{Z}{X}$ and $\tan \angle CBG = \frac{X}{Y}$ and thus,

$\frac{Z}{X} = \frac{X}{Y} \quad$ or equivalently,

$Z = \frac{X^2}{Y}$ (1)

Note in particular that in (1) if $X=Y$ (i.e., ABDE is a square) then $Z=X$
Appendix 6.1  
Information on the Analysis Tool and the Dynamic Gridding System (DGS)

The Compact Disc included with the thesis has two directories named *Analysis Tool* and *Design Tool*. Each directory contains the programs, source code, and user manual. The tables below contains the file information and their directories:

### Analysis Tool Directory

<table>
<thead>
<tr>
<th>Directory</th>
<th>File Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>../Program/</td>
<td>analysis.exe</td>
<td>Analysis Tool Executable File. For usage, this directory should be copied to your local hard disk.</td>
</tr>
<tr>
<td>../Source Code/</td>
<td>prjDSAnalysis.vbp</td>
<td>Visual Basic 6.0 project file for analysis tool.</td>
</tr>
</tbody>
</table>

### Design Tool Directory

<table>
<thead>
<tr>
<th>Directory</th>
<th>File Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>../Program/</td>
<td>DGS.exe</td>
<td>Dynamic Gridding System executable file. For usage, this directory should be copied to your local hard disk.</td>
</tr>
<tr>
<td>../Source Code/</td>
<td>DGS.dir</td>
<td>Macromedia Director 8.5 project file for the design tool.</td>
</tr>
</tbody>
</table>
References


GLOSSARY

<table>
<thead>
<tr>
<th>Words</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commensurable</td>
<td>Proportionate; symmetrical; extending over the same space; balanced; equal; uniform.</td>
</tr>
<tr>
<td>Commodulation</td>
<td>Linking together of the elements in harmony.</td>
</tr>
<tr>
<td>Composition</td>
<td>Act of putting together; arrangement of parts of picture, etc.</td>
</tr>
<tr>
<td>Decomposition</td>
<td>Separate into elements.</td>
</tr>
<tr>
<td>Dynamic Rectangle</td>
<td>The rectangles such as $\sqrt{2}, \sqrt{3}, \sqrt{5}, \frac{\sqrt{5} + 1}{2}$ showing irrational numbers in their proportions, are called dynamic rectangles. Most used in geometrical composition, especially in the technique discovered by Jay Hambidge and called by him Dynamic Symmetry. These rectangles allow much more flexibility and a much greater variety of choice than the static rectangles, specially when used in order to establish the commodulation by proportion of the elements and the whole of an architectural, pictorial or decorative compositions.</td>
</tr>
<tr>
<td>Dynamic Symmetry</td>
<td>Dynamic Symmetry or symmetry “in the second power” means that although the linear elements (segments of straight lines) used in the composition are irrational (not commensurable “in the first power”), the surfaces built on them may be commensurable, linked through a rational proportion. In order to obtain Dynamic Symmetry or commodulation, we must use the rectangles already introduced as dynamic, that is the rectangles $\sqrt{2}, \sqrt{3}, \sqrt{5}, \phi, \phi$, and $\phi^2$ (that is rectangles such that the ratios between their longer and their shorter side are equal to these numbers). The rectangles 1 and 2 can be considered either as static or dynamic. Mr. Hambidge has convincingly demonstrated two things: first, that a great number of objects and arrangements in space, in which we recognise the quality of beauty, readily submit themselves to the particular order of mathematical analysis formulated in Dynamic Symmetry; and second, that the application of these formulae to new aesthetic problems, involving the element of design, operates as a unifying and organising force.</td>
</tr>
</tbody>
</table>
| Gnomon        | The Greek word gnomon means, “that by which something is
known.” Known as Carpenter’s square; It is that figure which, added to a figure, increases the size of the latter but maintains its original shape.

The reciprocal of a rectangle, when removed from the parent rectangle will leave an area called a gnomon. The gnomon of a 1.618 rectangle is 1.

Later, in classic Greek days, the name gnomon was given to the upright shadow caster of a sun-dial. There is a Theorem of the gnomon (Hambidge, 1926, p.103).

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>In Harmony; Harmonious.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic Analysis</td>
<td>Analysis of certain subjects for geometrical harmonies or commodulation of elements.</td>
</tr>
<tr>
<td>Harmonic Decomposition</td>
<td>Harmonious separation of elements of Geometry.</td>
</tr>
<tr>
<td>Harmonic subdivision</td>
<td>Hambidge introduced as the method probably used by the Greek architects his technique of harmonic sub-divisions of the square and of the dynamic rectangles by the tracing of diagonals and perpendiculars to diagonals. Hambidge’s method takes into consideration the fact that the overall frame of a two-dimensional plan or composition, whether architectural, pictorial or decorative, is generally a rectangle or a complex of rectangle. In his method of harmonic subdivisions or analysis, these rectangles are “treated” by the diagonal. That is we draw a diagonal, and from the points of intersection between diagonals, perpendiculars and sides, are drawn parallels to the sides. This process can be continued with many variations, and every diagram thus obtained is what Hambidge calls a “harmonic subdivisions”, that is, produces a perfect commodulation of surfaces, and obeys the “law of non-mixing themes” (look up Law of Composition). An important property of this method is that the perpendicular to the diagonal produces inside the original rectangle a smaller rectangle similar to it, obeying thus the general “Principle of Analogy”.</td>
</tr>
<tr>
<td>Harmony</td>
<td>Symmetry; concord</td>
</tr>
</tbody>
</table>

“Harmony results only from the repetition of the principle"
Proportion | The definition of proportion follows immediately that of ratio. Proportion is the equality of two ratios.
---|---
Ratio | Ratio is the quantitative comparison between two things, aggregates or magnitudes, belonging to the same kind or species. This comparison, of which ratio is the symbol and the result, is a particular case of judgment in general, of the most important operation performed by intelligence. This (judgment) consists of:
1. Perceiving a functional relationship or a hierarchy of values;
2. Discerning the relationship, making a comparison of values, qualitative or quantitative.

When this comparison produces a definite measuring, a quantitative “weighing”, the result is a ratio.
Reciprocal | The reciprocal of a rectangle is a figure similar in shape to the major rectangle but smaller in size. The end of the major rectangle becomes the side of the reciprocal.
Static Rectangle | The rectangles such as $\frac{3}{2}, \frac{5}{4}, \frac{8}{5}, 3$, etc., which the proportions show only rational numbers, are called static rectangles.
Surface | Geometry thing with length and breadth but no thickness; face; plane.
Symmetry | Correct proportion of parts; beauty resulting from this; structure allowing object to be divided into parts of equal shape and size; repetition of exactly similar parts facing each other or a center. Regularity; harmony; equilibrium; balance; uniformity.

Symmetry for Greek and Roman, and also Gothic Architects, meant the *commodulation* or linking of all the elements of the planned whole through a certain proportion or a set of related proportions.

“When this symmetry or *commodulation* between the elements and between the elements and the whole is achieved in the right way, we obtain *eurhythmy*.” - As Vitruvius states in what is the key sentence of his treatise on architecture.