VISUAL BALANCE:
The Tightrope of Computer Generated Layout

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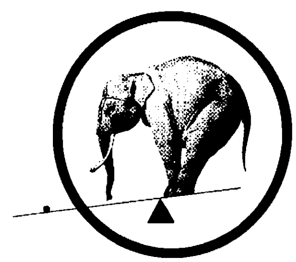
Like skating or walking the tightrope, the art of layout is an art of balance.

A. TOLMER
MISE EN PAGE, THE THEORY AND PRACTICE OF LAYOUT
1920 PARIS



Abstract

This thesis work proposes an theoretical framework for generative design systems based on the principle of visual balance in graphic design. It discusses a new metaphor for both the novice and professional designers to explores graphic layout variations, a new approach to machine understanding of visual balance and a new way to support automated layout of computer-based documents. Dynamic balancing systems have been implemented and tested through textual and imagery data.

Visual balance, or equilibrium, is a state of a visual composite, in which all factors such as size, location, orientation, color, shape and texture are mutually determined in a way in which no change seems needed. The concept of visual balance is present in both *symmetrical* and *asymmetrical* design. If a visual design lacks visual balance, it is unsettling and the information conveyed by the design is obscured. Designers strive for balance in order to make the conveyed meaning clear and the visual communication efficient [Arnheim, 1974]. Designers also use balance in different ways. Based on the analogy between physical balance and visual balance, I explored a computational model for visual balance and possible applications of using visual balance as a criterion to *evolve* and *alter* a computer generated layout so as to automate the presentation of information. This research also investigates the possibility of using various non-linear optimization algorithms such as *simulated annealing* and *Monte Carlo* to search for layout alternatives for designers.

This work was performed at the Visible Language Workshop, MIT Media Laboratory. Support for this work was provided, in part, by the JNIDS, News in the Future Consortium, Alenia, and Nynex. The views expressed within do not necessarily reflect the views of the supporting sponsors.

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The following people have served as readers for this thesis.

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MIT Media Laboratory
Th[illegible]

Rosalind W. Picard
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I would like to dedicate this thesis to my parents, and sisters for their love and care. I wish you all will come to Boston in some colorful season and I will sail with you on the sunshine-flickering Charles river.

CONTENT

INTRODUCTION

1

Introduction

For both the sender and the receiver of visual information the lack of balance and regularity is a disorienting factor.

DONIS. A. DONDIS
A PRIMER OF VISUAL LITERACY
1973 CAMBRIDGE

In this Chapter, I will briefly introduce the concept of visual balance, why it is important and how it is possible to build a computational model for the visual balance, and establish a possible framework to apply visual balance concept to the field of dynamic document layout. More details will be discussed in the following chapters.

CHAPTER 1 INTRODUCTION.

- This chapter.

CHAPTER 2 APPROACH

- The methodology used in this research.

CHAPTER 3 REPRESENTING VISUAL BALANCE

- Detail discussion about representation of visual balance and related visual parameters.

CHAPTER 4 SEARCHING AND OPTIMIZATION

- Detail discussion about grid systems, searching techniques and optimization methods.

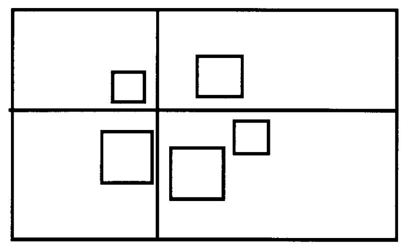
CHAPTER 5 CONCLUSION AND DISCUSSION

- Conclusion and discussion regard future research directions and vision of application scenario for use of visual balance in generating dynamic document layout.

Visual balance, clarity and order

The ultimate goal of visual design is to present the right information with the right form, at the right position and the right time. Information can be conveyed via various visual forms including type, image, patterns, or simply a stroke of color. In making various visual statements clear and meaningful, designers need to arrange, according to visual communication principles, visual objects such as types, pictures, dots, lines, shapes and colors into an ordered, cohesive and integrated layout. To achieve and maintain visual balance is one such essential principle in visual design [Arnheim, 1974; Kepes, 1957; Langer, 1957; Ruder, 1981; Dondis, 1973; Hurlburt, 1977; Gottschall, 1989; Gatta & et al., 1991; Conover, 1992; Siebert & Ballard, 1992; Carter & et al., 1993].

Figure 1.1. The visual intentions in this composite are unclear and ambiguous, and the effect created is an unsatisfying and frustating one for the audience. The balance cannot be established one way or the other; the element cannot be organized and related. The Gestalt law of perceptual simplicity is greatly frustrated by such an unclear state. (example from [Dondis, 1973].)



In making visual judgments, balance, or equilibrium, is man's firmest and strongest visual reference, and both conscious and unconscious basis [Dondis, 1973]. An off-balance design can be ambiguous, uneasy and frustrating to the receiver, and the intended visual message may not communicate (Figure 1.1). According to Arnheim, balance is the state of distribution in which all action has come to a standstill. In the book *Arts and Visual Perception,* he states, "In a balanced composition all such factors as shape, direction, and location are mutually determined in such a way that no change seems possible, and the whole assumes the character of 'necessity' in all its parts" [Arnheim, 1974].

To show how *visual balance* is embedded in visual design, contrast is made in Figure 1.1 and Figure 1.2 in which unbalanced and well balanced layout are compared. Also compared in Figure 1.3 and Figure 1.4 are *symmetrical* and *asymmetrical balance* used in page layout. As it will turn out, a *grid system*, although not apparently seen, is always involved in either *symmetrical* and *asymmetrical* design.

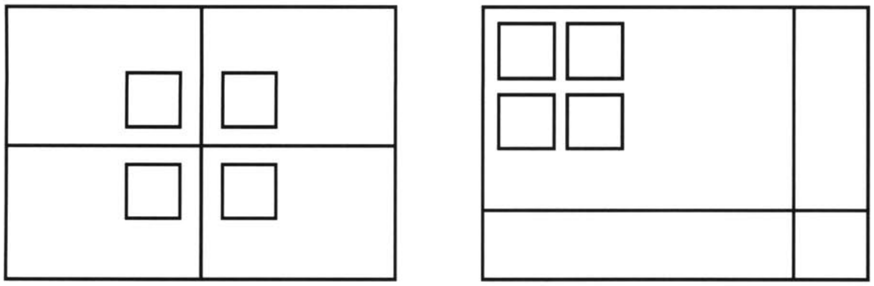


Figure 1.2. Balance is present in both symmetric and asymmetric design. Symmetric and asymmetric balance are also called, by some designers, formal and informal balance [Conover, 1990].

This notion of visual balance is analogous to the one for physics in which balance is defined as the state in which the forces acting upon a body compensate one another. This analogy serves as the basic assumption in the proposed research in deriving a computational model to describe and implement the concept of ***visual balance*** in the design process of document layout as well as other visual design.

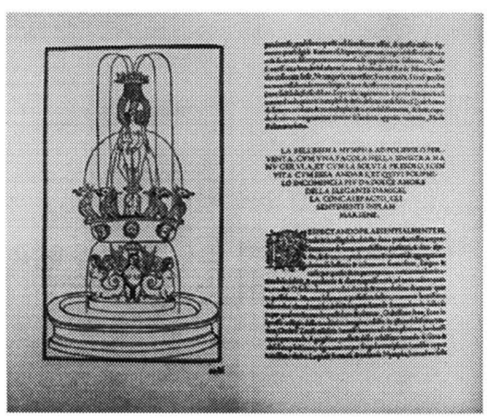


*Figure 1.3 Two Classic page layouts from the **Polihilus**, published by Aldus Manutius in Venice in 1499. The near perfect **symmetric balance** illustrates a feeling of formality, exactness, carefulness, and stiffness.*

A balanced pattern is so strongly established that it attempts to preserve its integrity by segregating any departure as an intruder.

RUDOLF ARNHEIM
ART AND VISUAL PERCEPTION
1974 BERKELEY CALIFORNIA

There are two ways to achieve visual balance: ***symmetrically*** and ***asymmetrically*** [Hurlburt, 1977; Gottschall, 1989; Gatta & et al., 1991; Siebert & Ballard, 1992; Conover, 1992; Carter & et al., 1993]. ***Symmetric balance***, or formal balance, involves equal size and weight that is above and below the fulcrum center of a page, and communicate strength and stability. The fulcrum center of a page is referred as optical center [Conover, 1992], which is discussed in broader details in Chapter 2. ***Asymmetrical balance***, or informal balance, on the other hand, bring contrast, variety, movement and tension. Initiated by Dutch ***de stijl*** and Russia ***Constructivism,*** and developed by Bauhaus, and other design movements, asymmetrical balance become dominating, although symmetrical balance still be widely used even within an asymmetrically balanced layout.

Although widely used and discussed, the concept of *visual balance* has been mysterious to both artists and researchers in that it is asserted that the sense of *visual balance* is only an unconscious sense, and is "*essentially a matter of feeling*" and cannot "*be expressed merely as a mathematical calculation*" (quote of *Mise en Page* by A. Tolmer, quoted in [Hurlburt, 1977]). This research is an attempt to respond to the challenge of exploring computational ways for representing *visual balance* and an attempt to investigate possible applications of utilizing *visual balance* in automated layout of computer-based documents. "Affective Computing" would be necessary to respond to the "matter of feeling" aspect of design [Picard, 1995], the focus in this work however is on a physics-based analysis method.

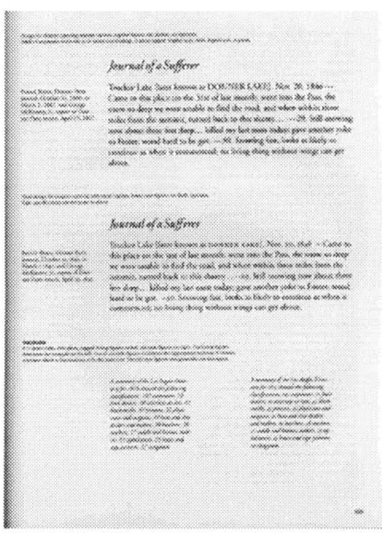


Figure 2.4 A modern page layout demonstrates the shift from the classic symmetric ideal to the ***dynamic, asymmetrical balance.***

Asymmetric balance *brings* ***contrast, variety, movement*** *and visual* ***tension*** *to a page.*

In other visual design domains, visual balance is also equally important and naturally embedded. Figure 1.5 through Figure 1.7 show layouts of a front page of a newspaper, a page in a newsletter and a page in a brochure, where visual balance is achieved asymmetrically in a modern fashion.

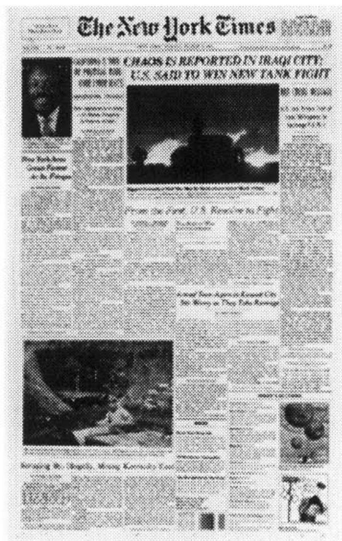

The New York Times
CHAOS IS REPORTED IN IRAQI CITY;
U.S. SAID TO WIN NEW TANK FIGHT

Figure 1.5 The front page of The ***New York Times****. Considering the text segments as a texture background, the design reflects an asymmetric balance of images, headlines, subheads and even white spaces. (From* *<u>The Best of Newspaper Design</u>* *[Jennings, 1992])*

Figure 1.6 Layout of a newsletter page. (from *<u>Making A Good Layout</u>* *[Siebert & Ballard, 1992]). Asymmetric balance is present to create dynamic eye movements.*

of human visual experience. In the years when the computer was still huge and practically inaccessible for designers, Kepes envisioned a *visual* world of *plastic organization* or *dynamic iconography* to be emerging as the mainstream of design [Kepes, 1944, 1961].

This thesis work started from another perspective but reached the similar conclusion that computer generated layout for electronic document must cope with the dynamic, elastic and temporal nature of visual experience and the constantly updating feature of computer-based document. This thesis argues that ***visual balance and dynamism is an appropriate concept and medium*** to make a layout elastic (or plastic, following Kepes), dynamic and responsive to user's change of intention and document updating. As will discussed in Chapter 3, this research argues that the approach taken by this thesis work provides a framework to build a generative design system. Such a generative design system can be built as a design agent for the novice user and an apprentice for the professional designer.

Compared to traditional communication, in which "the information is encapsulated into fixed forms" [Ishizaki, 1994], and flows one way to the reader, the new, computer-based electronic communication supports interaction between the reader and the information base and includes more temporal information. As the reader's intention may also be changing constantly as well as the information content, the design problems become even more dynamic. Thus, "a design solution must continuously adapt in response to the dynamic changes of the context" Ishizaki, 1994].

These situations lead to the concept and practice of automated layout systems that can determine parameters for a visual design based on given information content and readers' preferences. An automated generative layout system can well meet the dynamic, interactive needs of users and support dynamic change of information.

To build such a computational system that can automatically layout documents implies encoding visual design knowledge and the sense of *visual balance.* While encoding *general* visual design knowledge is a difficult task, there have been different approaches to encode the knowledge necessary to describe the presentation of information, such as the *grammar-based* system VIA [Weitzman, 1994] and a *grid-based* approach by Feiner [Feiner, 1988]. However, none of these attempts has encoded the sense of *visual balance,* and the systems have to rely on the user to judge the *visual balance* of a layout.

The challenge to automated layout is to develop a set of constraints and evaluation criteria for the generation of effective layouts [Feiner, 1988]. In VIA, the constraints are embedded in the *relational grammar* and the grammar takes as input the pre-annotated structural information and produces a layout. Feiner's approach uses a *grid system* and a *Prototype display grammar*, and has no concept of *visual balance* for simplicity. Feiner's approach also employs a set of rules that place constraints (such as location and color) on visual objects. Neither approach has a mechanism of evaluation for the evolution of the generated layouts.

This thesis research investigated nonlinear computational models for visual balance and dynamic, generative design system. The quantitative value of visual balance computed from the ***balance function*** (detailed in Chapter 2) have been used, together with a set of constraints and a grammar representing spatial relationships, as one of the *criteria* in evaluating and evolving a generated layout.

Scope and framework

The design process can be viewed as *interactive iterations* of ***seeing-moving-seeing*** [Schon and Wiggins,1992]. In the interaction of *doing and discovering*, the designer makes appreciative judgment based on many different *ways of seeing,* at the local (in group) and global (inter-groups) levels. ***Visual balance*** involves *global seeing, or holistic appreciation,* and the designer's sense of balance executes this *holistic seeing* during the entire designing process. In a typographic or visual design space, the designer arranges visual objects, makes holistic judgments or evaluations of the arrangement, alters the arrangement by controlling the size, tone, and position of all the visual objects, and makes judgment again. This cycle of ***seeing-moving-seeing*** continues until the layout reaches a state of visual equilibrium.

This interactive notion of the design process can be also viewed as a dialogue between *generation* and *evaluation* or *making and testing* of layout, which is an operative metaphor. During the dialogue, design alternatives are developed and visual properties are evaluated against design principles.

This thesis research reflected this strategy of *seeing-moving-seeing* and *generating-testing-generating* in implementing generative design system.

In order to realize the above mechanism of a generative design system, this thesis work takes *visual balance* as the key concept that is both operable and visible. It is argued that a computational model for visual balance can be integrated into a generative design system, given an appropriate set of constraints, either rule-based or situational (reactive to parameter changes), and a set of criteria to evaluate and evolve a generated design layout into a balanced yet dynamic, elastic and responsive one.

As an example of ***dynamic layout,*** a pioneering work by Muriel Cooper [Cooper, 1990] is shown in Figure 1.8. In the work a sequence of layouts was produced to show how computer generated layout can dynamically respond to the changes from the information environment or from the reader's navigational change of interests. Visual balance in this dynamic situation is complicated by the multi-tiered information and the asynchronous interactive exploration from the reader. The author argues that a layout system may be built to be able to respond to the dynamic changes from either the environment or the user by preserving *visual balance* in a dynamic way.

Figure 1.8 Muriel Cooper's pioneering work on dynamic layout. (caption taken from Design Quarterly No. 142 1990

Four image and three text segments are used to explore ways simultaneously to represent multi-tiered information using changes of size, placement, color, and translucency. Each frame will change as the "reader" browses in real time with text and image cues dependent on the linkages that have been designed for browsing. On one level this series is analogous to a book printed on transparent paper, but it takes advantage of the potential for change inherent in the computer. Priorities may be achieved in terms of color, size, leading, or copy width,. The tools for this series were developed at the Visible Language Workshop by Suguru Ishizaki; the series was designed by Muriel Cooper(1988).

This thesis work continues Cooper's pioneering exploration by building a computable model for visual balance, turning the balancing process into a search process within a multi-dimensional space spanned by visual parameters, and exploring non-linear algorithms to search for balanced states for a given page and a set of graphic objects. Generative systems have been built and tested using different sets of constraints and optimizing and searching algorithms. In Figure 1.9 in next page, a series of layout variations from one generative layout system are shown to sample one possible way of design.

Summary

In this chapter, I introduced the concept of ***Visual Balance*** that is related to the principle of visual balance in the graphic design practice. Design concept such as order and clarity have been briefed. Examples in which the visual balance concept has been incorporated into a cohesive holistic layout are provided. The correlated nature of dynamics of visual balance and generative layout system has been revealed. Resulted examples from the theoretical model used in this thesis work has be shown to demonstrate one way of systematically designing through a generative design system based on the dynamic scheme of visual balance.

Figure 1.9 Layout variations generated by this thesis work. One image of Muriel Cooper, her name as a title, and a paragraph from an memorandum article are used as objects. Theses layouts are considered as balanced ones but with different balance value computed based on a balance function (see chapter 2).

APPROACH

2

Introduction

This research explores a computational model for visual balance and investigates theories and techniques in searching for the states of visual equilibrium and for layout variations in designing computer-based documents.

In order to examine different ways of achieving visual balance in a 2D layout, an analogy is made between visual balance and physical balance. A balance function is defined as a function of the visual weight, location and other visual properties of each graphic object involved. Non-linear optimization methodology is employed in the search process for alternative, balanced layout solutions. Also explored are approximations that are used to guide the search process. It must be noted, however, that the goal is not to obtain a single 'optimum solution' for a layout problem. This is in accordance with graphic design practice [Ruder, 1981; Gottschall, 1989; Carter & et al, 1991; Siebert & Ballard, 1992] in which designers explore different solutions instead of looking for ***the optimum*** one. Besides, an optimal solution can be computationally intractable making it impossible to - a practical system.

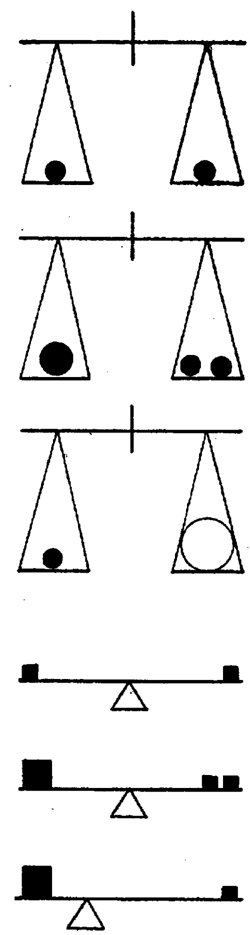


Figure 2.1 Kepes' [Kepes 1957] analogy between visual balance and physical balance

A ***generating and testing*** strategy is employed to find layout alternatives and variations. The criteria used in guiding the search direction include a set of constraints and the overall value of the balance function that is discussed later. A Graphic grid system is used for reducing the size of the ***search space*** in which any minimum valley on the multi-dimensional landscape (of the visual parameters of *all* graphic objects) is considered as a state of visual balance.

In this chapter, I will describe the schematic diagram of the methodology used in this thesis work. Then I will outline the methodology by briefing the representations of visual knowledge and visual balance; relating the graphic design process to layout generation; and turning the layout problem into a search problem. A detailed discussion about each of these three aspects will follow in the next chapters.

The scheme of this thesis research is shown in the diagram in Figure 2.2.

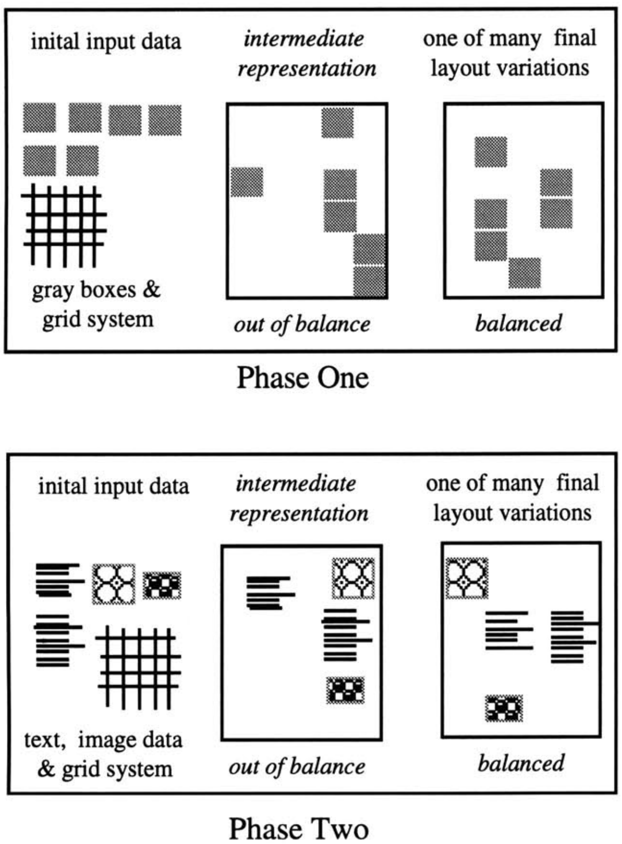


Figure 2.2 The scheme of the proposed research.

In the diagram, the objects on the left are input data and a grid system; the layout in the middle is the intermediate representation to be balanced; the one on the right is one of many variations that is considered in a state of balance by the system.

Phase One: at an abstract level, grey boxes are used to represent visual objects that are repository by the system to achieve balance.

Phase Two: real data including text and image will be used to demonstrate the concept of visual balance and its possible application in the automated layout system.

The two-phase scheme in exploring visual balance and other visual properties is drawn from visual designer's experiences [Dondis, 1973; Conover, 1990; Siebert & Ballard, 1992]. It should be noted that in the diagram in Figure 2.2 the balanced layout on the right side is only ***one of many*** possible layouts that are in the state of balance for a given set of visual objects and constraints. It is ***not*** the goal of this research to find a single optimal solution in searching for layout.

Representation of Visual Knowledge and Visual Balance

Balance in printed communications is a must. We must place elements on the page in a way that will make them look secure and nature--not top-heavy, not bottom-heavy.

THEODORE E. CONOVER
GRAPHIC COMMUNICATION TODAY
1985 ST. PAUL

In solving a graphic layout problem, one is concerned with two basic kinds of knowledge: *visual knowledge* and *content knowledge.* While *content knowledge* refers to such principles as to keep illustrations on the same page as the text that refers to them, *visual knowledge* is concerned with, on the other hand, principles of balance, rhythm and contrast [Arnheim, 1969; Greenlee, 1988]. Since many visual properties, such as size, shape or color, and many visual relationship such as left-to, above-of, or small-than, are independent of information content, it is reasonably argued that visual knowledge may be separated from the content [Weitzman, 1995; Feiner, 1988] and that visual knowledge can be computationally encoded and operated. In this thesis it is intended to *only* deal with visual properties and their relationships under ***the principle of balance***.

From the theories of visual arts and graphic design [Kepes, 1957; Arnheim, 1974; Dondis, 1973], the following visual properties are selected: ***visual weight, visual contrast, graphic attraction, felt graphic axis, graphic optical center, visual fulcrum center, and visual balance.*** The computability of each visual property is among other considerations that support the selection. Other visual properties, such as *visual emphasis, visual tension, visual activeness, visual rhythm and others,* are treated as "invisible" or "hidden" variables some of which are imbedded in the constraints. In a future study, these visual properties can be incorporated into a complex generative system with multiple representations of visual balance and with the capability of "Affective Computing" [Picard, 1995].

Visual weight *is* "the dynamic power inherent in an object by virtue of its correspicuousness, size shape, location, etc." [Arnheim, 1974], and is defined as a function of the size, the color value, and the location of the involved graphic object. ***Visual contrast*** is related to size relationship (such as small-than) and color value contrasted with the background (such as black against white has higher contrast than black against gray background). ***Graphic attraction,*** *or grouping,* is used to determine whether two or more graphic objects can be grouped together and is defined as a function of the distance between graphic objects.

Visual balance is defined as a compositional state in which visual weights are equally distributed over the page [Siebert & Ballard, 1992]. It must be noted here that *equal distribution* of visual weight does not necessarily mean a symmetric layout. On the contrary, as asymmetric composition has a higher probability of being produced than a symmetric one. Although it is recognized that the equal distribution of visual weight is a multi-dimensional phenomenon [Arnheim, 1974], in this thesis work, the system is tested on cases of two dimensions: equal distribution of visual weight over the horizontal and the vertical dimensions. The choice of horizontal and vertical dimensions is based on the following observations from human visual recognition process: a vertical ***felt axis*** [Dondis, 1973; Arnheim, 1974] and an ***optical center*** that is slightly above and left to the geometric center [Conover, 1992] are imposed to the concerned visual space, or the page, and the visual objects.

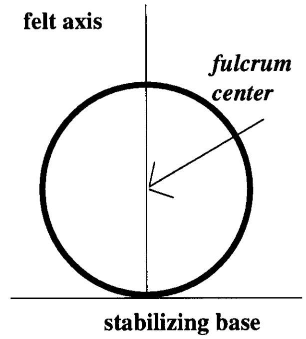


Figure 2.3 Felt axis, stabilizing base and fulcrum center for a circle.

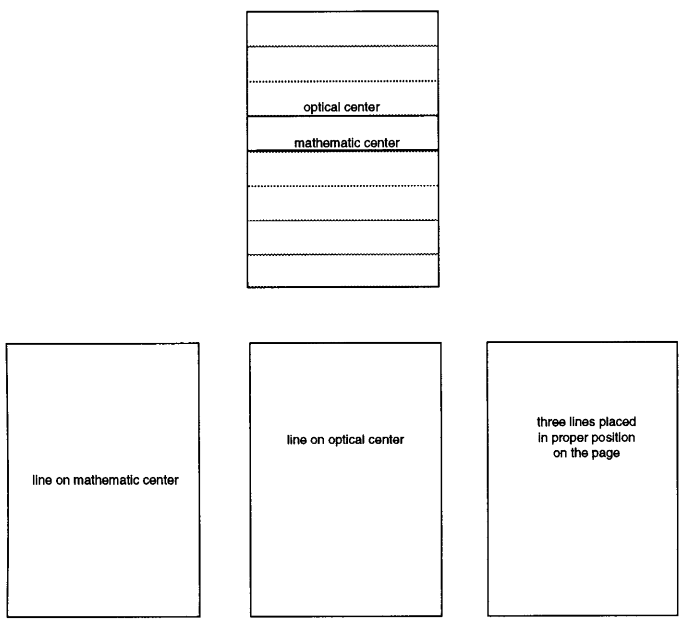


Figure 2.4 Diagrams showing the optical center on the surface of a page. The optical center is the focal point or fulcrum for placing elements on the layout.

In order to compute and manipulate the distribution of visual weights over a page, ***visual torque*** is introduced to each graphic object (e.g., a headline or a picture). It is defined as the multiplication of the object's visual weight and the distance from the ***fulcrum center*** of the object to the visual axis of the concerned page:

Visual torque ≡ ***Visual weight*** × ***Distance from visual axis*** (Eq. 21)

where

Visual weight ≡ ***Area of object*** × ***Visual contrast of object*** + ***Position factor of object*** (Eq. 2.2)

where ***Position factor*** is determined by ***the principle of visual preference favoring lower-left corner*** of a page [Arnheim, 1974; Dondis, 1973], which assesses that a visual object appears heavier in upper-right part of a page than the same object in lower-left part. A testing system is built to estimate this factor [Yang, 1994b].

A physical system is balanced when the torques and forces of all objects compensate each other and thus the total torque of the system is zero. Based on the analogous comparison to balance of a physical system, I argue that ***visual balance*** of a graphic system (that is, a layout) is said to be achieved *when* the ***total torque*** of all involved graphic objects is ***near zero***:

$$\textbf{Total torque} \equiv \sum \textbf{Torque of each object} \cong \mathbf{0} \qquad \text{(Eq. 2.3)}$$

This equation will be referred as ***balance equation*** or ***balance function*** throughout this thesis. This equation is used to evaluate the balance value of a generated graphic layout in a process of searching for the state of visual balance. Moreover, it is the function that is optimized against various visual parameters, such as the size of a text block or the position of a headline, in the process of searching for the states of visual balance for a graphic layout. A detailed discussion is followed in the next chapters.

Search in Multi-dimensional Space of Visual Parameters

Once we have a mathematical representation of visual balance, ***the balance function***, we can relate a graphic layout to a set of computationally controllable parameters that are associated with each graphic object. A layout can then be represented by such a set of

parameters that satisfy *the principle of balance* and other constraints. Now, the challenge is how to determine such a set of parameters.
From (Eq. 2.2) we understand that visual weight is a function of the size, the contrast value, and the position of an object (It may also be a function of other factors, but here are the only ones considered in this thesis). In other words, if an object's size, width and height is changed, or it is moved to another position, its ***visual weight*** will be changed accordingly. Thus, for a given set of graphic objects, together with a set of constraints, and a given page, a ***trial*** layout can always be evaluated by computing the value of (Eq. 2.3) to see if it is balanced. If the value of (Eq. 2.3) is not near zero, the **trial** layout is said to be not balanced. A new trial should be conducted, according to various searching schemes, and tested against (Eq. 2.3). This cycle of trial-evaluate-trial is referred as the ***generate and test*** strategy.

Thus the process of looking for a solution of a *balanced layout problem* is turned into a process of searching for a ***zero*** value of the *balance function* through varying the involved parameters. The layout problem is turned into a multi-dimensional **search problem**. In the search process, (Eq. 2.3) is the principle heuristic to guide the search direction, together with other constraints that the layout has to comply with.

It is a natural conclusion from (Eq. 2.3) that there are an infinite number of ways for the total torque to reach a ***near zero*** value since the equation can be tuned by any change in any parameters of any graphic object. This conforms to graphic design practice in which a single optimal solution is not desired.

From this perspective about the *visual balance* of a graphic layout, this research experimented with one way to build a generative design system. Such a system takes graphic data, such as text and images, with graphic constraints, and outputs graphic layouts that are considered as *visually balanced.* It is *not* claimed in this thesis work that a visually balanced graphic layout is *the* best layout. Rather, this work argues that a *'good'* graphic layout has to comply with *the principle of balance* if it is designated to *communicate clear visual information.* That is to say that to be visually balanced is a gateway into effective visual communication [Dondis, 1957].

As is pointed out earlier in Chapter 1, the design process involves designers' *interactive iterations* of ***seeing-moving-seeing***. In this design process, visual balance or equilibrium is constantly evaluated. Global seeing (system-wide or page-wide) or local seeing (group-wide or object-wide) are executed during designer's dynamic appreciation and holistic judgment of the layout space. It is a goal to reflect in a generative design system this process of *seeing-moving-seeing, generating-testing-generating.*

It is an essential task for a generative graphic design system to determine the sizes, positions and values for a set of graphic objects [Feiner, 1988; Ishizaki, 1995]. This task can be very costly, as indicated by Beach [Beach, 1985] that it is an NP-complete problem to fit an arbitrary set of non-overlapping objects into a limited 2D space.

One possible scenario of how a generative design system works is envisioned as follows. The system takes a set of input data and lays them out for a trial according to the given constraints. The system evaluates the layout to see if the layout is balanced, that is, if the visual weights are distributed equally over a page, or if the balance value of (Eq. 2.3) is near-zero. If the balance value of (Eq. 2.3) is not near-zero, the system changes some of the parameters of some objects, and re-evaluates the balance value of (Eq. 2.3). This process continues until the balance value of (Eq. 2.3) reaches near-zero.

In this scenario (Eq. 2.3) serves as a heuristic for the search process. The result of the search is *one of many possible balanced layouts*. For novice users, the system can make graphic layout decisions based on user's preference by searching for a balanced layout. For the professional graphic designer, the system suggests layout variations based on the balance value and other criteria such as alignment, grouping and grid system. In the latter case, it is up to the designer to make the decision whether a layout should be chosen as a solution.

Summary

In this chapter, I introduced my approach to solve ***the balanced layout problem.*** I argue that visual balance is analogous to physical balance and that visual weight, visual torque can be determined numerically for each graphic object. I further argue that a layout is said to be balanced when the sum of visual torque of each graphic object is near zero.

Based on the above arguments and observations of graphic design process, I suggested a ***generate and test*** strategy to search for possible balanced layout variations. From that I further assert that this research provides *a way of designing* [Ishizaki, 1995] for automatic, generative visual design systems that can be either a graphic design agent for novice user, or a graphic apprentice for professional designer.

Representing Visual Balance

3

Introduction

In this chapter, I will discuss the analogy between visual and physical balcend, used by this work. Visual properties that affect the visual balance of a graphical system will be addressed in details. Examples will be given to demonstrate the effectivity of this thesis approach.

An Analogy Between Visual and Physical Balance

Visual balance has puzzled both artists and researchers for a long time. Some experiments were carried out in the last three decades by psychologists and art theorists [Arnheim, 1974; Gombrich, 1950]. Progress has been made in neurology and vision studies in understanding the human visual cognitive process; however, few scientific conclusions have been drawn to explain why and how human eyes are delighted by certain (the balanced) visual designs while upset by others (the ill-balanced). Centuries-old myths still cloud this area.

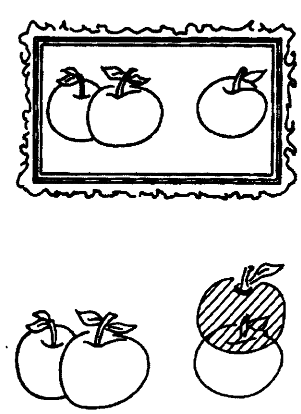


Figure 2.2 Examples to show the lower-left corner preference from [Dondis, 1974]. Two apples on the left side are balanced by one apple on the right. (upper). Balance breaks down if the one on the right is moved to the position above the original one.

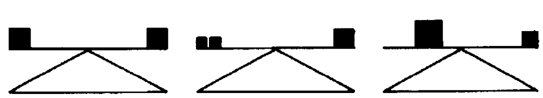


*Figure 3.1 Diagrams from [Dondis, 1973] showing examples of visual balance along the horizontal axis. The left and center diagrams demonstrate distribution of equal visual weight in horizontal axis. The right diagram shows balance of dissimilar weights via shifting their positions. In these examples the **felt axis** is retained at the horizontal center of the page layout.*

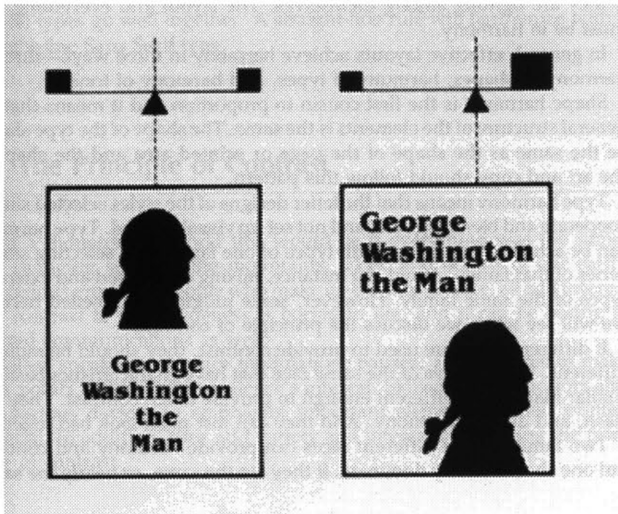


Figure 3.2 ***Horizontal; Balance***. *An example taken from Graphic Communications Today by T. E. Conover [Conover, 1992] illustrates in one way the* ***analogy*** *between the* ***physical balance*** *and the* ***visual balance***. *The page layout on the left has classic* ***symmetric*** *balance while the other one has* ***asymmetric*** *balance. The teeter-totter and the fulcrum show the principle of balance.*

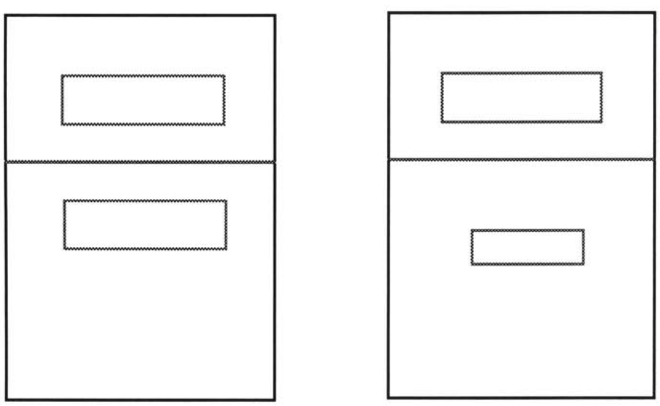


Figure 3.3 *Examples of* ***vertical distribution*** *of visual weight and* ***vertical balance***. *Two groups of equal size placed on a page* ***in balance*** *from the* ***optical center*** *of the page (left), and one group half the size of the other placed twice the distance from the* ***optical center*** *for proper balance (right).*

This research targets the problem of visual balance by using Newtonian classics methods. Analogous to concepts in Newtonian mechanics, such as *weight*, *torque*, *balance*, and *potential*, each visual object is given a '*visual weight*' and correspondingly, a *torque* relative to a visual axis. The *balance* is said to be achieved when the *total torque* of all objects in the layout is nearly zero. Since the *total torque* can reach zero in multiple ways, a visual design thus can be balanced in multiple ways. This is consistent with the fact that visual balance or equilibrium in graphic design can be achieved in a variety of ways.

Models and theories describing physical processes can be applicable to the process of searching for the states of visual balance, as represented by the minimum values of the balance function (Eq. 3.3), For example, a Hopfield network, a simulated a nnealing process, and the harmony theory [McClelland and Rumelhart, 1989] are a few.

Based on the above arguments, a system was built to test the ideas. Detail discussion follows in the section on **Visual Equilibrium.**

This testing system adopts a Hopfield network [Hopfield, 1982] to search for local minima. Hopfield network is a deterministic one in which an energy function over the whole network is defined and minimized by deterministic updating rules. A Hopfield network behaves very much as a thermodynamical system, which seeks minimum energy states [McClelland & Rumelhart, 1989]. This feature is considered analogous to the process of searching for balanced states for a given set of graphic objects, where only the 'local minimum' is of interest. The testing system takes advantage of a Hopfield network's feature of falling into energy minima, which is considered as a disadvantage when an optimal solution is desired. Finding local minima corresponds tofinding balanced layouts in the multi-dimensional space of visual parameters.

In the test environment rectangular was divided a (6 x 10) grid system into a finite number of rectangular areas. Each has two states: occupied or not. An upper bound is given to the total number of objects (occupied rectangles). The system starts with a random distribution of occupied rectangles, evaluates the 'energy function' or *balance function*, (Eq. 2.3), and reaches a local minimum (a balanced layout).

Visual Properties: Weight, Felt Axis, Torque and Balance

As introduced in Chapter 2, weight is a concept that is used to describe the strength of the gravitational force pulling an object downward. A similar downward pull can be observed in pictorial objects, seemingly acting at the fulcrum of a visual object, but ***visual weight*** also exerts itself in other directions. *Visual weight* can create tension among visual objects or between visual objects and the eye of the observer, and can be influenced by various factors. Location of a visual object, size, color, spatial depth, semantic meaning or intrinsic interest, shape, isolation, and even knowledge, can influence visual weight. For example, a visual object at the center can be counterbalanced by smaller ones placed off-center. The larger object will be heavier given other factors being equal. Bolder font is usually heavier than fine font. A dark image may be heavier than a lighter one. Weight of colors is more context dependent and sometime semantics dependent [Arnheim, 1954].

Just like the physical fulcrum can be determined by hanging at one's finger tip [Arnheim, 1954], the 'gravitational' center of a visual object can also be determined by trial and error. In simplest case where rectangular blocks of text or image are the only concern, the fulcrum center is set to its geometric center [Arnheim, 1974; Greenlee, 1988]. In order to determine the relative strength of visual weight, a test system was built to measure, informally, visual weights in terms of standard visual object. The results were applied to solve new design process. Figure 3.5. shows one image of the test system.

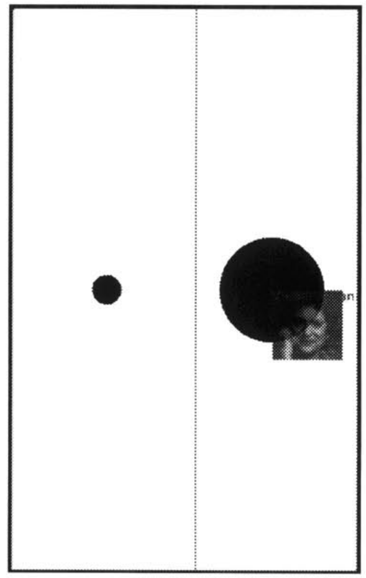


Figure 3.5 A test system is built to measure visual weight in terms of standard graphic object (such as the small solid circle). The informal results are used in this thesis work.

*In this testing system, each of the graphic objects are movable, re-sizable, and their color values can be altered. Designers were asked to move, change size or color value of the objects to find out the **balanced visual relationship** among a given set of visual objects.*

In this research, since our concern is focused on document layout, the weight of all objects will be considered as pulling in a downward direction. This assumption can be reinforced by the rectangular shapes for almost all visual objects that appear in a layout. To simplify the problem, among the factors that affect visual weight we exclude spatial depth and shape. Inclining orientation is not considered since all of the visual objects would be oriented vertically and horizontally in this study.

From the experience of graphic design and psychological studies [Dondis, 1973], there is a process of stabilization in visual expression, perception and interpretation. As breifly mentioned earlier in Chapter 2 this stabilizing process imposes on all things seen and planned a vertical "axis", often called the ***felt axis***, and a horizontal secondary referent, often called the ***stabilizing base***, which together establish an invisible structure affecting visual balance (Figure 3.3). The ***optical center***, as called by some theorist and designer, plays an equal important role balancing a layout. For example, ***visual torque,*** was defined in Chapter 2 as the product of *visual weight* and the distance from the *fulcrum center* of the visual object to the "*felt axis*". This is an analogical definition to the one in *Classic Mechanics*. The "felt axis" is not only seen as vertical (Figure 3.1 and 3.3), but also horizontal, as shown in Figure 2.4 and Figure 3.4 where graphical objects are balanced *vertically* with respect to the ***horizontal*** "felt axis". Axes of other orientations are also important in determine visual balance. Arnheim shows an experiments with a round plate and a square area in which the plate is placed and replaced, and the visual gravitational forces are indicated to show that the diagonal axes are also playing important role in visual balance [Arnheim, 1974]. In this thesis, since only rectangular objects are considered, axes that are other than vertical and horizontal ones are ignored. Thus, *visual balance* is argued to be the state of a composite in which the *sum of torques* for all visual objects relative to all vertical and horizontal axes reaches zero.

Object and Visual Grouping Hierarchy

Graphic objects can be grouped according to this content, context or visual context. For example, a headline should be spatially related to its news story and the picture associated with it. In this thesis, content context is separated from visual context, and the former is handled by rules that are incorporated into a set of constraints, such as a relational grammar [Weitzman, 1995]. Visual context is concerned with visual relationships among the objects. In relation to grouping, there are three types of visual relationships: ***proximity*** or ***nearness***, ***equality*** or ***similarity*** in size, shape, value, orientation and texture, and ***visual closure.*** This research takes into account only the ***nearness*** and ***similarity*** in size, value and texture.

Figure 3.6 and 3.7 show different types of grouping, and the sensitivity of each grouping mechanism.

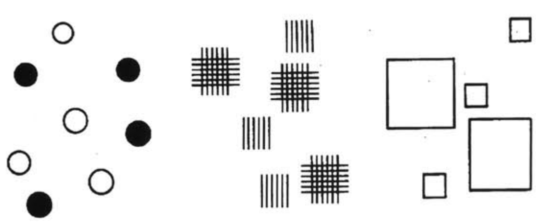


Figure 3.6 Dondis's [Dondis, 1973] grouping by similarity in value (left), texture (center) and size (right).

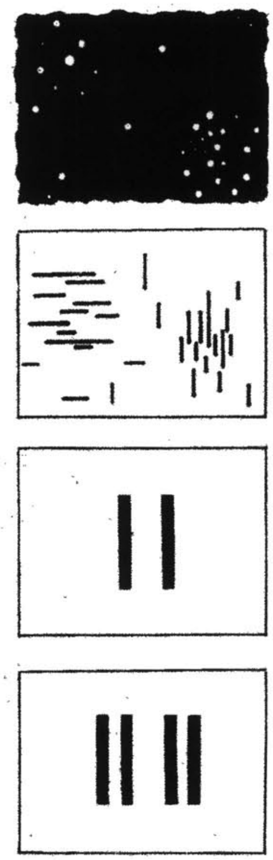


Figure 3.7 Kepes' [Kepes, 1957] grouping by proximity, and similarity in orientation.

In the camera/iterasion process of *generating-evaluating-generating* of layouts, it is necessary to maintain the group relationships among the objects. Previous research used a fixed structure or form to keep the groups from being dispersed [Weitzman, 1995; Feiner, 1988; Greenlee, 1988; Krishna, 1994]. In this thesis, both the content context (logical relationships) and the visual context (spatial proximity and visual similarity) are retained in a way in which no fixed structure or form is assumed to be associated with the given input data. The spatial arrangement of all objects is affected by the changes of visual properties of individual objects or groups. So is the spatial relationship within a group.

For example, when the system decides to change the size of a picture, this change will affect the gravitational center of the object group associated with the picture. The system will first attempt to change other group members' size, position or value to keep the gravitational center of the group from being moved. If successful, the spatial relationship of the group will be altered, but the visual context of the group is retained (they are still visually grouped). If the system fails to do so, it will try to accept the best result from the first attempt, and then try to move the group entirely so as to retain the overall balance of the layout (if there is no higher level group).

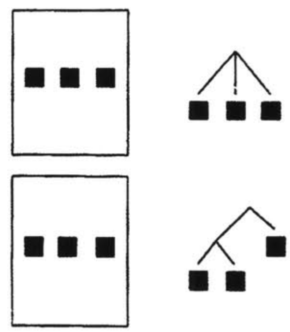


Figure 3.8 Greenlee's diagrams [Greenlee, 1988] showing grouping sensitivity in term of spatial proximity. Above: equal distances don't discriminate the three similar objects. Below: a slight change of the distance between the two objects on the left makes them a group. Hierarchy is then created.

In general, the system will always keep each group from being dispersed by retaining the visual relationships among the group. When there is no room for maintaining the visual context within the group, then the system will optimize the balance function at the global (page-wide) level.

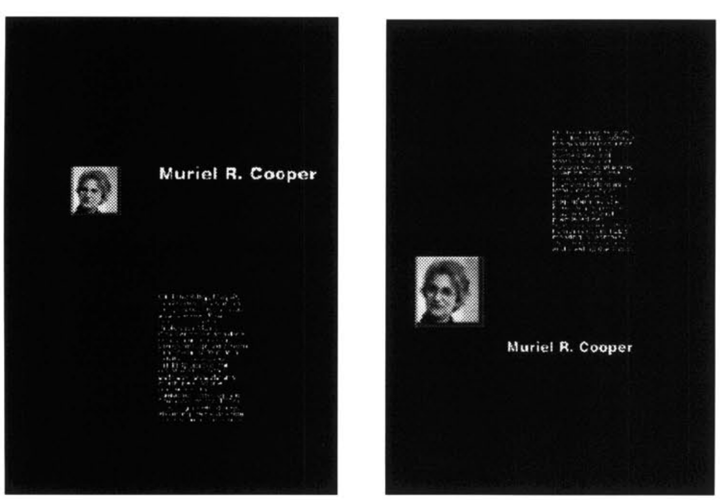


Figure 3.9 Examples of retaining visual context within a group of graphic objects while changing some of the visual attributes of some objects. The fulcrum center (center of gravitation) of the group is retained in the two layout variations, but the size, position of all objects are changed.

Figure 3.9 shows two layouts with their fulcrum center (center of gravitation) of the group retained after an optimization process in which the objects are altered by position or size. In this case, only one group is under investigation. Starting from the left layout, the system is asked to re-size the picture by 2 times, and then to find out what are the possible layouts under that condition. The layout on the right is one of the layout variations provided by the system.

Grouping and visual context have been a target for vision studies for decades. Visual similarity has also been extensively studied, as well as vision orientation sensitivity. By augmenting the optimization framework here with constrained optimization tools, such as Sherstingsky and Picard's "M-Lattice" [Shertingky and Picard, 1994], the above issues could addressed togother in a broader sense, but that will be beyond the scope of this thesis.

Visual Equilibrium

Visual equilibrium is defined as the state in which all visual forces compensate one another so that no change seems needed, or any change would have to unsettle the balanced layout arrangement.

A dynamic, balancing system was implemented to test the feasibility of the proposed model for visual balance or equilibrium, and the result is encouraging [Yang, 1994b]. In the system, a mathematical function is defined to represent the total torque of the system, which is a function of locations (X and Y coordinates) of each visual object. A *balance state* is argued to be reached when this total torque reaches zero. Since there are potentially an infinite number of possible points at which the total torque can reach zero (local minimum), optimization algorithms are employed to search for these local minima.

A typical situation would be that the system starts with a randomly distributed layout of objects, optimizes the torque function by adjusting the positions of some of the visual objects, and ends when the algorithm finds one local minimum. In this fashion, layout alternatives are naturally produced, since for a given set of visual objects, there are an infinite number of points on the surface of the torque function at which the layout is considered in a balance state by the algorithm. This approach also supports the idea that an optimal solution for layout is not necessary nor desired by the designer, and the user might desire for variations to be proposed vs. "one optimal variation".

Two programs have been developed to support this new approach. The first one applies the analogical concept, *visual torque* to a two dimensional *6 x 10* grid, and uses a Hopfield network [Hopfield, 1982] together with an embedded constraint system to optimize the process of searching for local minima. The results have shown that for a set of given input data and a random distribution of occupied grid units in the two dimensional *6 x 10* grid, the program is able to optimize a pre-defined 'energy function' and settle down at one of the local minimum [Yang, 1994b]. The author argues that at these local minima, the *visual balance* ***is*** achieved, although a detailed and extensive study may be extended to include changes of other parameters (for example, the change of font size) that are related to the input visual objects. At this stage, the system works primarily with layouts that have one color. In the multiple-color situation, techniques such as grouping or spatial constraints would be included. Besides, multiple representations of visual properties such as size and color should be considered and may be implemented to facilitate variations in the components of *visual balance*. In order to simplify the problem in the current testing system, only the distribution of *visual weights* is considered as a component in this program.

The results from the first testing program are shown in Figure 3.10. In these figures, each rectangle is a generated layout based on the *6 x 10* grid. The one on the top is an initial arbitrary distribution of gray boxes overlaid on the grid, with the balance value 8.75, while the bottom five ones are the balanced layouts with balance values displayed in an order of descreasingconsidered by the program as in a state of balance. The program starts from the initial layout randomly generated, follows an algorithm derived from the gradient descend method and a set of constraints, and then stops at one of the local minima, which is considered as the state of balance. A randomly selected *jump* in the multi-dimensional parameter space is incorporated in the algorithm so that multiple balanced layout variations could be reached interactively.

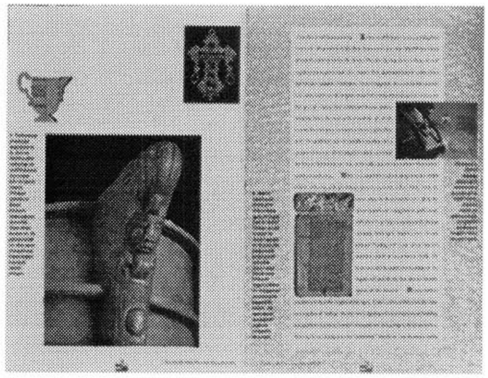


Figure 1.7 Layout of a brochure page. (from Making A Good Layout [Siebert & Ballard, 1992]).

Opportunity and related work

Throughout the history of visual design, people have searched for ways to give structure to ideas and concepts, to store knowledge in graphic form, and to bring order and clarity to information (Figure 2.2-2.3). Much has been achieved in the domain of graphic design since the mid-fifteenth century's printing revolution, however, there has been only limited success at encoding graphic design knowledge that has been used to support automatic and interactive design in computational environments [Arens, 1993; Bertin 1983; Senay, 1991]. Among the systems that have been developed in the last decade are *grammar-based system* [Weitzman, 1994], *procedural systems* [Ishizaki, 1989], *case-based system* [MacNeil, 1990; Colby, 1992], *cooperative design* [Kochhar & Friedell, 1990], *constraint systems* [Borning, 1981; Gross, 1985], and *programming by demonstration* [Lieberman, 1993; Myers, 1993]. All the pioneer attempts, however, more or less failed in encoding a designer's sense of ***visual balance***, which is an indispensable part of and naturally embedded in a design.

Graphic design theorists and practitioners have researched intensively to bring scientific methodology into the graphic design field. As early as in the beginning of this century, artists from ***de stijl*** and ***Bauhaus*** tried to bring *order* and *clarity* to design without losing the vitality and originality [Gottschall, 1989]. This line of pursuing order and vigor has been constantly carried on throughout this century. In particular, Gyorgy Kepes, in his book LANGUAGE OF VISION, proposed the concept of ***plastic organization*** in response to the ***dynamic, plastic*** nature

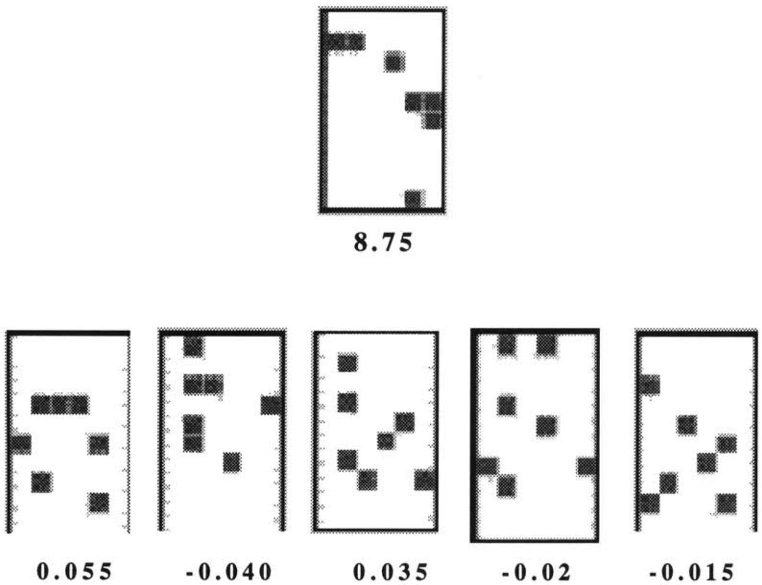


Figure 3.10 Comparison of before and after the program balancing is applied to the computer generated layout in an abstract fashion. Top: initial randomly generated layout, Lower: final layouts that are considered as ***balanced*** *by the system. The numbers below the layouts are their value of balance. A negative sign means that the left side is heavier than the right side, and vise versa for positive values. Note that assumptions are made to weigh an object more at the lower-left part.*

The second program uses a modified simulated annealing algorithm mixed with Monte Carlo method to optimize and search for local minima for the *balance function*. Figure 3.11 shows the results from it, in which 16 layout variations are generated.

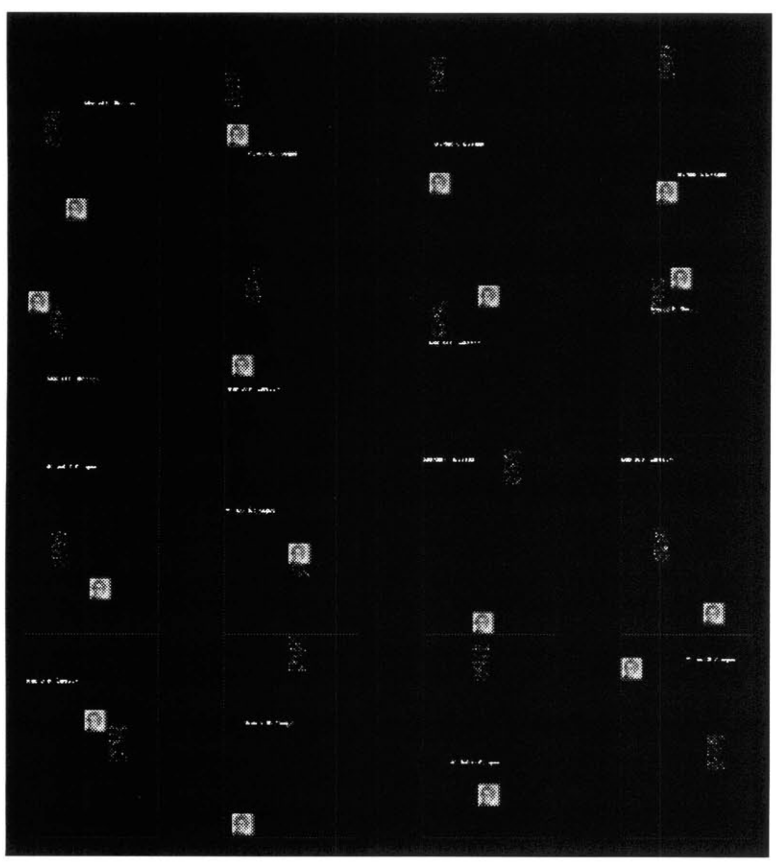


Figure 3.11 Sixteen variations have been produced using a non-linear optimization algorithm. Each layout has the same three objects: an image, a headline, and a paragraph.

Summary

In this chapter, I discussed the analogy between visual balance and physical balance (section ***Analogy between Physical and Visual Balance***). Examples are given to show horizontal and vertical balance in relation to the ***felt axis*** and ***optical center*** of a page, respectively. The related visual properties are also discussed in a greater details to support the approach taken by this thesis work (section ***Visual Properties: Weight, Felt Axis, Torque and Balance***). Visual grouping and its application in this approach is showed in section ***Graphic Object and Visual Grouping Hierarchy.*** Programs implemented to test the ideas of analogy of visual balance to physical balance are discussed. Results clearly demonstrate that visual balance of a page layout can be represented by an equal distribution of visual weight over a page.

In Chapter 4 I will discuss to a broader extent the algorithms used to search for balanced state.

SEARCHING AND OPTIMIZATION

4

Introduction

I will continue the discussion initiated in Chapter 2 to address the issue of searching and optimization in a greater detail. Emphasis is put on grid systems and optimization algorithms. Results from the generative layout systems implemented in this thesis work will be displayed and discussed.

The grid makes it possible to bring together all of the elements of design-typography, photography, and drawings-into harmony with each other. The grid process is a means of bringing order into design.
JOSEF MULLER-BROCKMANN
GRID SYSTEMS IN GRAPHIC DESIGN
1985 NIEDERTEUFEN, SWITZERLAND

In this thesis approach, a layout could be represented in different ways such as *a local minima on the global parameter landscape,* or *an equal distribution of visual weights.* In the discussion of visual properties and visual context, a layout is referred as an equal distribution of visual weights which is the sum of the visual weight of each graphic object. When search and optimization issue is being addressed, a layout is considered as one of the local minima of the balance function in the multi-dimensional space of visual parameters.

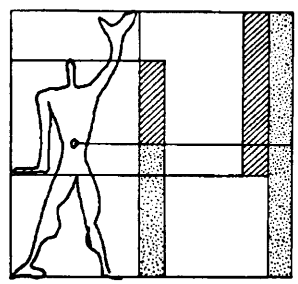


Figure 4.1 **Le Corbusier** is one of the pioneers who called for the use of grid systems in design. He created and patented ***Modular,*** the best known design system in which he developed a theory of space division and proportion. It has influenced graphic layout design, especially page layout, by inspiring designers to create asymmetrical layout out of a symmetrical mean, and to develop grids-based design systems [Hurlburt, 1977].

To bridge the pioneering exploration for dynamism in traditional design and the experiments on generative design systems that will be inevitably ubiquitous, a line is drawn from modern and contemporary design history to show that the pursuing of visual clarity and order has been always accompanied by striving for vitality and originality. This thesis argues that by applying the dynamics of visual balance, a generative design system could produce layouts that satisfy both clarity and vitality requirement.

Grid System to Narrow Down Search Space

In Chapter 2, it is mentioned that determining whether an arbitrary set of non-overlapping rectangular objects can fit on a display is NP-

Complete [Beach, 1985]. The same is true for finding the minimum size rectangle in which the objects can be packed [Feiner, 1988]. In this thesis work, the challenge is to determine the position and the size for a set of graphic objects in a given 2D space (page). A natural solution to this problem is to develop a set of constraints so as to restrict some of the possibilities. A typographic grid system is one such constraint system, in which a page space is divided into small pieces called ***modules*** [Carter, 1993] or ***grid fields*** [Gottschall, 1989]. Graphic elements are placed in these modules.

Initiated by *El Lissitzy* of ***Russia Constructivism***, developed by *Theo van Doesburg* and *Piet Mondrian* of ***de Stijl***, *Laszlo Moholy-Nagy* and *Herbert Bayer* of ***Bauhaus***, and later advanced by *Jan Tschihold* [Tschihold, 1967] and design schools of ***IIT***, ***Basel*** and ***Ulm,*** there has been a continuing movement striving for order and clarity in communication graphics. The contemporary concept of grid systems grew out this movement [Gottschall, 1989], though its roots can be traced back to ancient architectural designs in China and Japan [Hurlburt, 1977]. However, as the counterpoise direction of chasing order, clarity or readability in contemporary visual design, vitality, originality and dynamism have been an ultimate goal pursued by designers. Blending clarity and vitality, practitioners like Jan Tschihold, Karl Gerstner and Wolfgang Weingart have given the typographic grid systems vigor and life [Gottschall, 1989]. It is argued in this thesis that to maintain visual balance of layout is a way to achieve the goal.

A grid consists of rectangular modules defined in a *Cartesian*-like coordinate system of intersecting, perpendicular lines, shown in Figure 4.2. Figure 4.3 to 4.6 demonstrate the influence of pursuing order and clarity in communication design by pioneer designers.

It is interesting to note that the derivation of grid systems shown in Figure 4.2 at the bottom coincides the ***Haar basis sets*** which is a set of basic grid patterns that can be used to describe all possible grid systems by combining the basis set linearly. It would be an interesting research issue whether or not any grid system (such as ***Le Corbusier's Modular***) can be derived from a basic set of grid systems [Picard, 1995, private conversation].

Also interesting is that this thesis work makes it possible to build an interactive and dynamic design system to produce ***Modrian***-like designs (Figure 4.5 middle picture).

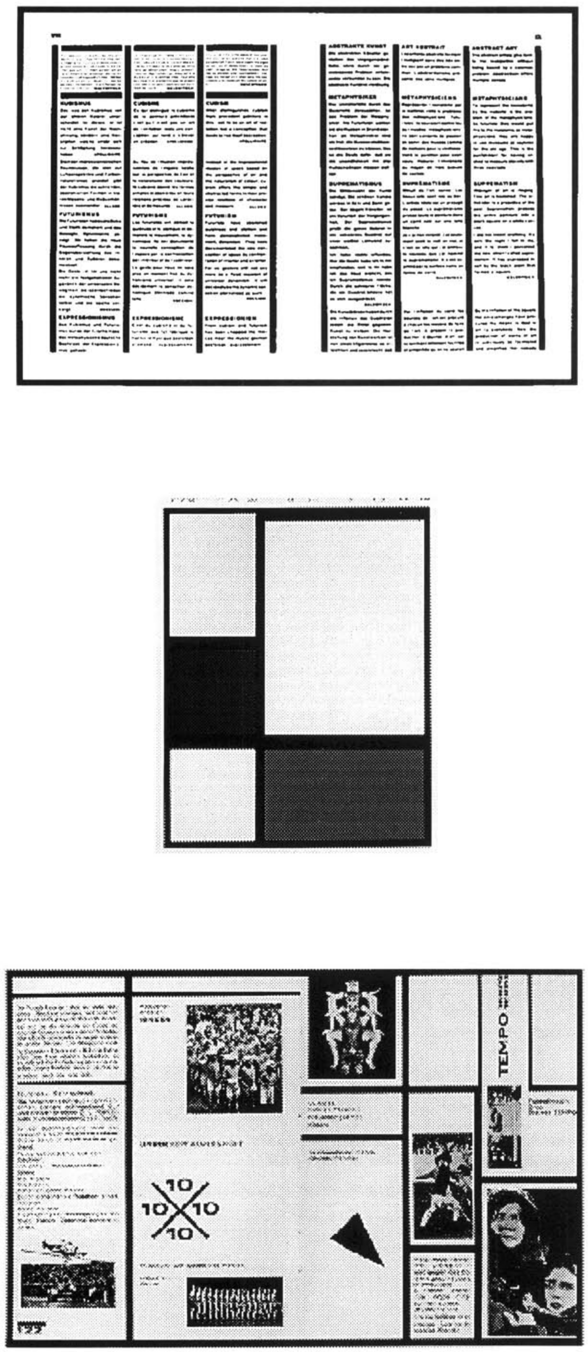


Figure 4.5 Pioneering grid based design by Russia Constructivist **Lissitzy** (top), **de Stijl** activist **Mondrian** (middle) and Bauhaus leader **Moholy-Nagy** (bottom).

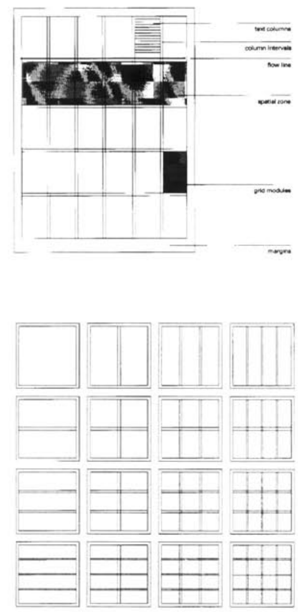


Figure 4.2 A typographic working grid (top). Progressed from simple to complex grid systems (above)

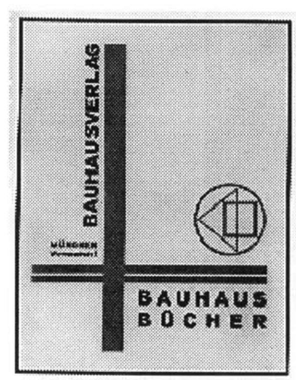


*Figure 4.3 A Bauhaus early example using grid, designed by **Laszlo Moholy-Nagy**. [Gottschall, 1989].*

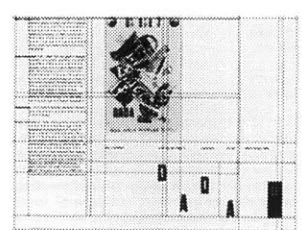
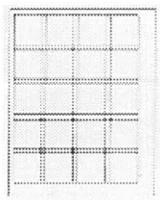
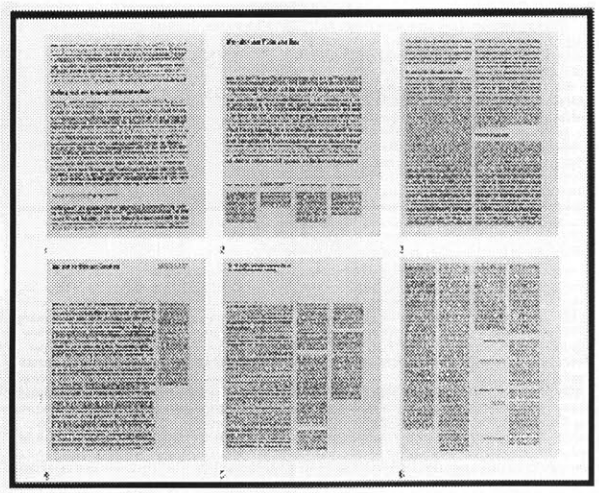
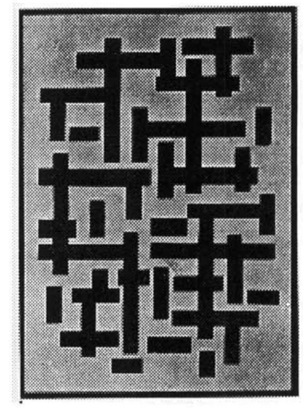


Figure 4.4 A page layout with a complex grid system designed by Rob Carter [Aldrich-Ruenzel, 1991].

Figure 4.7 A grid with 20 grid fields or modules (below) and six out of many typographic solutions possible with this grid for text data (mid-below) and for text and image data (bottom). Note only a few variations are shown here.







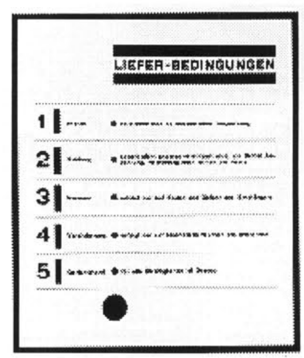


Figure 4.6 Above: ***Dynamic equilibrium*** *was established with this* ***Theo von Doesburg*** *experiment at* ***de stijl.*** *Middle and bottom:* ***Asymmetrical balance*** *was achieved by* ***Bayer*** *at* ***Bauhaus*** *and* ***Tschihold*** *at America.*

A grid system brings order and clarity to a void page space of two dimensions. It supports asymmetrically balanced design and It has been used extensively for magazine, newspaper and poster design. Recent research used grid systems to place a set of icons [Friedell, 1984] and for table layout [Beach, 1985]. Feiner [Feiner, 1988] used a grid system to generate page layout that is evaluated against a set of rules derived from graphic design practices. In his system, a grid is generated based on the size of the smallest picture or text block to be laid out. The pictures and text blocks are then placed into the grid to produce multiple layouts.

As I argued earlier, maintaining visual balance of a layout can bring vitality and originality to the order and clarity of a grid system, the graphic design practice of this century has demonstrated a history of ***blending clarity and vitality*** for a layout and ***striving for dynamic asymmetrical balance***. Shown in Figure 4.6 are dynamically balanced, asymmetric layout examples by **Theo von Doesburg** at **de stijl. Asymmetrical balance** by **Bayer** at **Bauhaus** and **Tschihold** at America.

In this thesis work, different grid systems are utilized to accommodate different problems. In the first testing system, at an abstract level, graphic objects are represented by rectangular blocks that have the same size of the grid field or module. A six by ten (6x10) grid is used to test the concept of visual balance and its possible applications. For the second system, in which layout variations of a poster design is produced by the system, a complex grid system is utilized to support a set of sophisticated graphic objects. A third system was built to re-design a page for FRAMES, an internal magazine of MIT Media Laboratory, based on a , two layered, over-lapping grid system.

The role of grid systems in graphic design is in fact an effective way of **narrowing down** the size of the ***search space*** in which a balanced state for a given set of graphic elements is at the bottom of the multi-dimensional landscape, with each dimension representing one visual property of some object. The problem of freely placing a set of visual objects in a page is turned into a problem of placing them onto a finite number of grid fields or modules.

Layout as a Local Minimum in Global Parameters Space

As discussed in previous chapters, in a typical situation, a layout generator will generate a layout variation, evaluate the ***balance function,*** then re-generate a new layout. And so on. The evaluation process is to test to see whether the value of balance is a near-zero value. If not, the system will alter some parameter(s) for the whole layout and every visual object; and see if this alteration of parameter(s) is reducing the value of balance, either in a steep descent or other means of long-term descent. This process is described as a ***search process*** for states of balanced layout. The process in which the system alters parameters so as to reduce the value of balance function is an ***optimization process.*** So a problem of layout is a problem of search and optimization [Yang, 1994b].

With the help of a grid system, the search space is reduced a lot from virtually infinite possibilities, however, an additional set of constraints is needed in order to determine ***where should the grid system to place what and at what size***. An obvious solution is to randomly place and size each of the objects over *the grid fields or modules.* Another solution is to place and size them according to a pre-designed layout that is possibly ***balanced***. In the latter situation, of course, the system is asked to make layout alternatives or variations, based on certain conditions such as that the size of a picture needs to be maintained. Then the system breaks the balance of the layout by varying the position of an object, and then complete the search and optimization cycle until a minimum point has been found for the balance function.

Search Techniques, Algorithms and Implementation

The search and optimization cycle is the primary dynamic mechanism for the layout problem this thesis deals with. After testing several search techniques, an algorithm was chosen based on ***simulated annealing***, ***Monte Carlo, gradient descent***, and a set of ***relationship rules*** that describe the spatial and logic relationships of the objects.

Four generative systems have been implemented based on the above arguments (and their variations). The first one is based on abstractive representation of graphic objects, the rectangular blocks and their distribution over a six by ten (6x10) grid.

In the first testing system, the algorithm is as follows for one round of generating-testing-generating until the balanced layout is found. Note that graphic objects are represented by rectangular blocks.

a generate a random distribution of blocks;
b check against the *relationship rules*, if not satisfied, satisfy them;
c evaluate ***the balance function*** of the layout.
if not a near-zero value:
1 randomly pick up one block;
2 make a toss to move one block;
3 if the tossed move reduces balance value,
and satisfies **step b**, move it; or
4 re-do **step 1-3.** until the near-zero value of balance reached.

In the balance function, the mathematical representation of visual weight for each object was tested to satisfy the graphical preferences such as ***the lower-left corner preference,*** which states that a graphic object will be less weighted at the lower-left part of the page than at the upper-right part (Figure 4.8).

The second is an exploratory system in which a headline, a block of textual paragraph, and an image are the graphic objects involved. A grid system is used. The generative algorithm is:

a generate a spatial arrangement of the three objects, either randomly or pre-designed;
b check against the *relationship rules*, if not satisfied, satisfy them;
c evaluate ***the balance function*** of the layout.
if not a near-zero value:
1 randomly pick up one object;
2 toss to enlarge / reduce the size of the object:
3 **if** the re-size reduces the balance value or increase sit by a controlled amount, proceed with the toss;
else toss to move the object;
3.1 **if** the tossed move reduces balance value,
and satisfies **step b**, move it; or
4 re-do **step 1-3.** until the near-zero value of balance reached.
else if it is a near-zero value: stop.

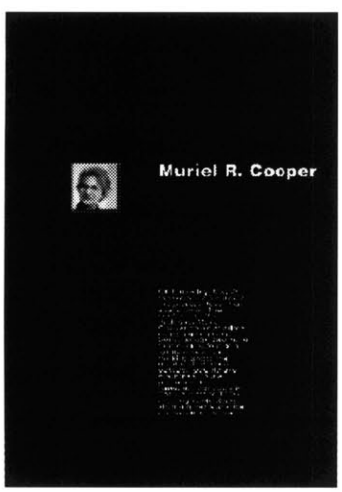
Note: the *relationship rules* include such requirements as to keep the fulcrum center of the object group unchanged

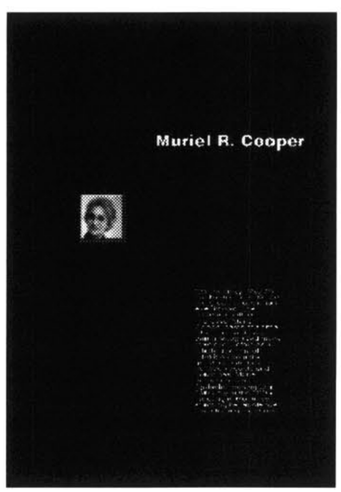
The algorithms used in the other two systems adopted the same strategy but utilized different sets of *relationship rules.*

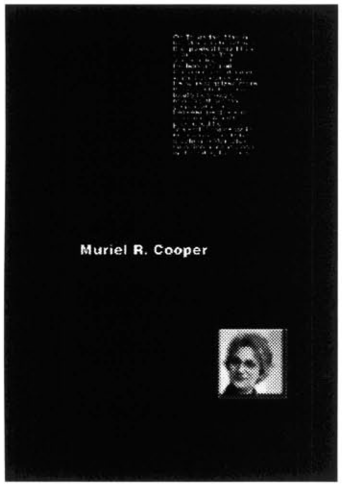
Variations of layout produced by each of the systems are shown in Figure 4.10-12. In Figure 4.10, twelve variations are displayed to show balanced layout under the search and optimization operations on the balance function. The original data includes a picture of Muriel Cooper, a title of Muriel Cooper, and a paragraph about Muriel Cooper's life, all which appeared on FRAMES, September, 1993. The algorithm used to do search and optimization is described above. The pre-defined relationship rul*es* include:

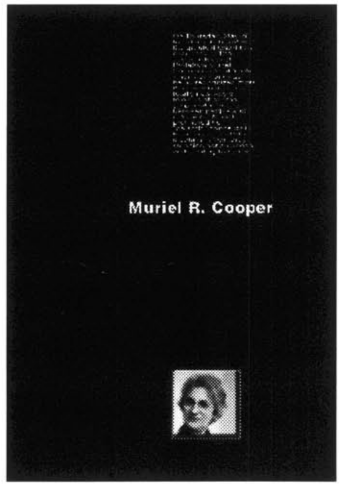
1. preserve the aspect ratios of a picture;
2. each grid field has the size of smallest picture;
3. overlapping is prohibited;
3. out of page is prohibited.

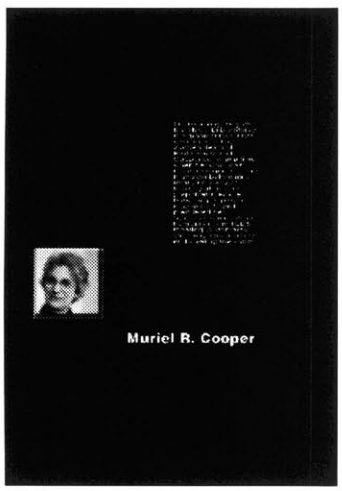
Figure 4.10 Twelve layouts have produced with the previous discussed algorithms.

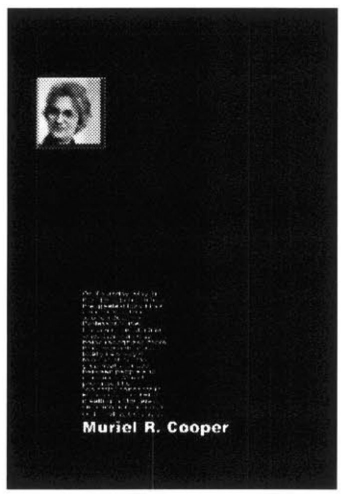


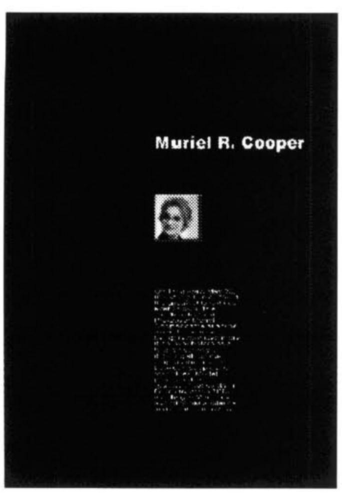


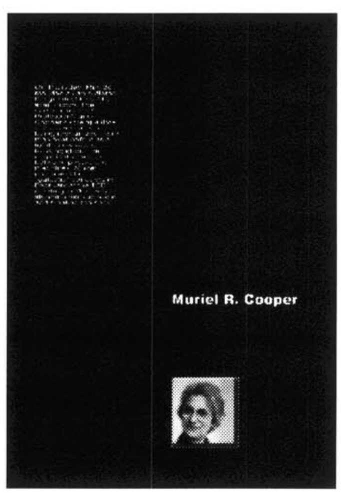

Muriel R. Cooper


Muriel R. Cooper


Muriel R. Cooper


Muriel R. Cooper


Muriel R. Cooper


Muriel R. Cooper

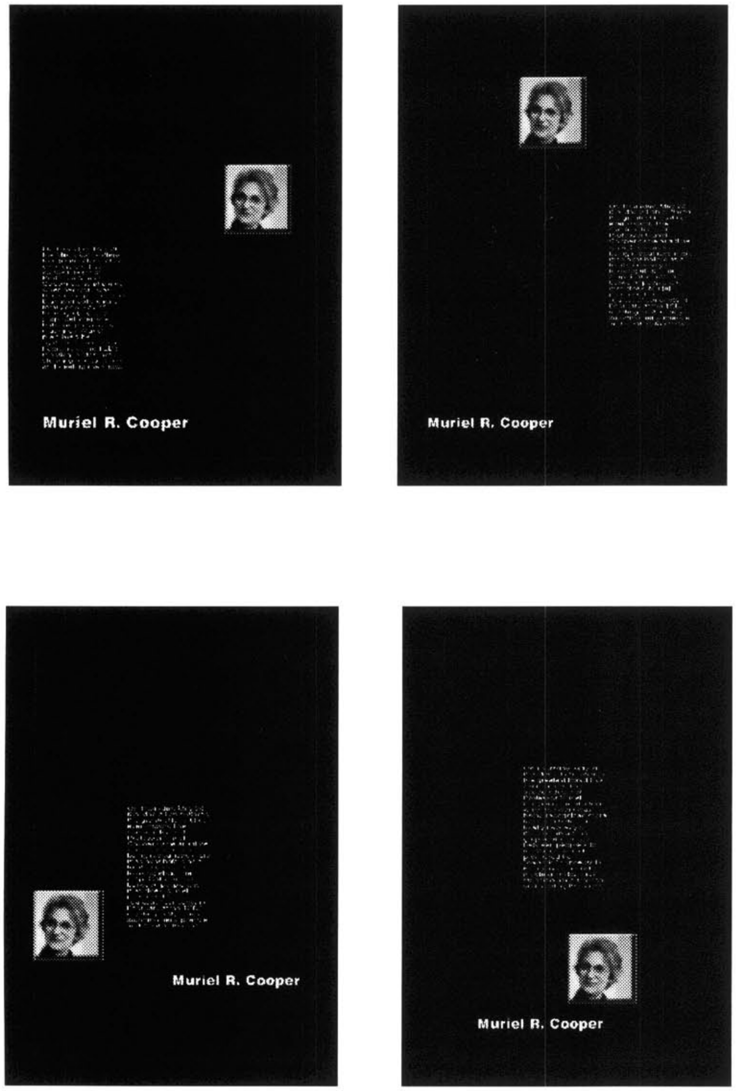


Figure 4.11 and Figure 4.12 show one balanced layout variation for large amount of data. They are intended to be able to provide interactivity to the users. Each of the graphic objects is able to interact with users and with each other graphic object. The user specifies an interest to one of the graphic items (for example by pointing to it, or through voice recognition interface). The graphic object knows how to react to this user's interaction by highlighting itself, moving itself to closer to the user, and triggering other objects to be de-highlighted. The user can also trace back to the list of objects which he or she has viewed or been interested by simply clicking. The ease of use characteristics is designed for a better interface for a generative, dynamic and elastic design system.

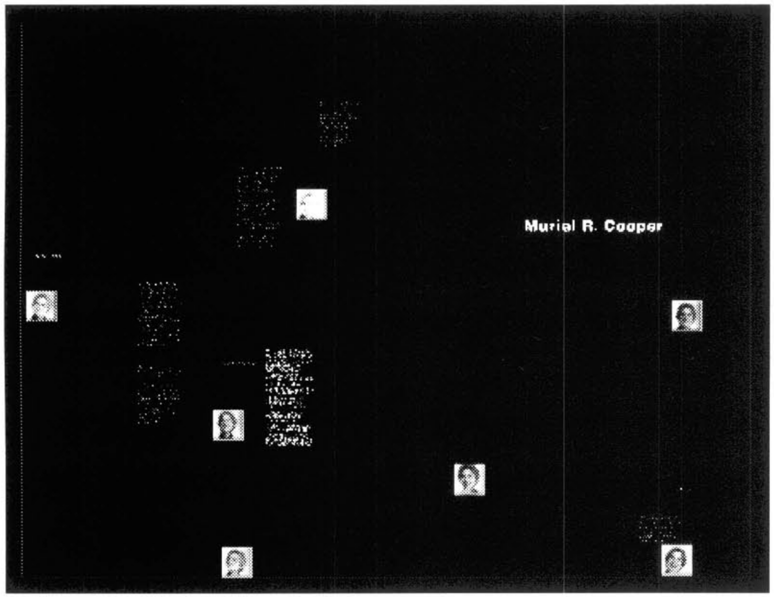


Figure 4.11 Balanced layout produced for FRAMES. Each of the object is clickable and approachable via mouse press. Once hit and pressed, the user is approaching the object he is interested in and be able to view it in a greater detail. The list of clicked objects is traceable.

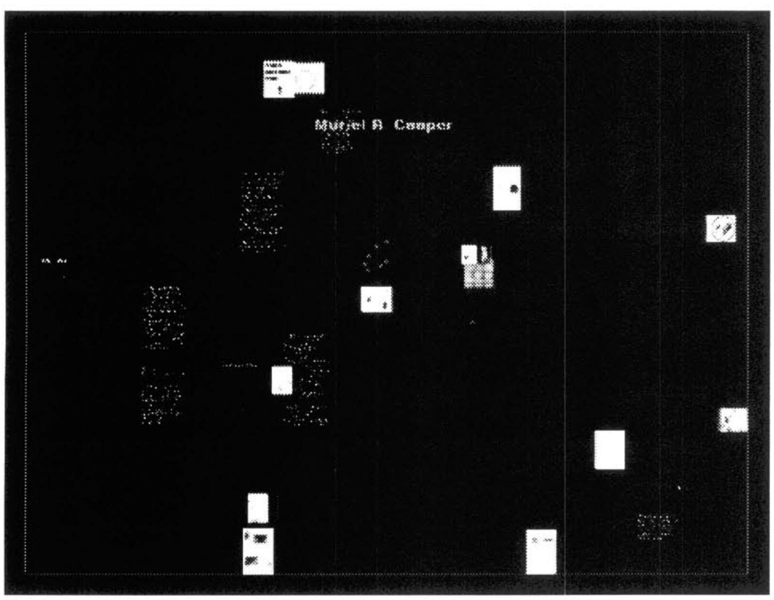


Figure 4.12 Balanced layout reproduced for a poster page that was displayed at the earlier occasion at MIT Media Laboratory. Clickable and approachable capability retains in this system. It also lets the user to trace the list of interested objects.

Interface for Generative Layout System

A good interface is self explanatory and intuitive. Since visual design involves a large amount of variables (size, weight, color and others), the design process is a complex, dynamic course in which a good designer can visualize the multi-dimensional space and play and replay the possible scenarios of producing each piece of layout work. While it beyond the scope of this thesis to design and implement a effective and intuitive interface for the proposed generative and elastic layout system, an interface to show how the system is producing layout variations is implemented to visualize partially the complex, multi-dimensional space of visual parameters.

Figure 4.13 shows the interface. The left side small layout variations are those produced by the system, the one on the right hand side is the current layout that is being explored. The dynamic process of searching is depicted through a smooth moving strategy and a gradual transition manner.

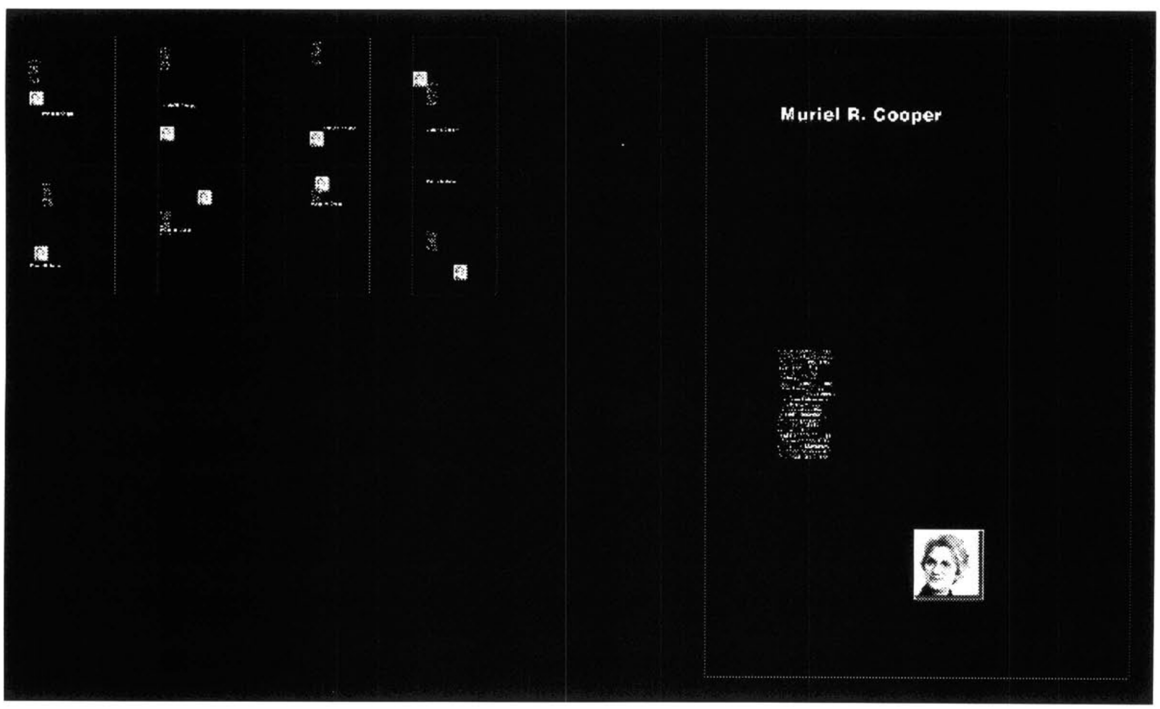


Figure 4.13 One of the interface of the implemented generative design systems with ten variations be laid out. The number of variations can be shown is variable. When the graphic objects are still in transitional and searching process, the counterpart will be showing the same dynamic animations.

Summary

In this Chapter, I discussed three aspects of the algorithms used to generate effective graphic layout. Firstly, in the section of ***Grid system to Narrow down the Search Space***, I discussed typographic grid systems, their brief history and their functionality in designing layout. Grid system brings order and clarity to a page. Visual balance that is manipulatible can serve as a dynamic mean to achieve a blending of order/clarity and vitality/originality, I argued. Then in the section of ***Layout as a Local Minimum in Global Parameters Space***, I related the grid systems to the approach taken by this thesis work, and I discussed the core of the layout problem is to determine where to place what at what size and to determine a set of constraints rules. Thirdly, in the section of ***Search Techniques, Algorithms and Implementation,*** I discussed the algorithms used in the four generative layout systems.

Interface issue is addressed briefly and an example of the interface for the implemented dynamic layout system is given (section **Interface for Generative Layout System**).

CONCLUSION AND FUTURE WORK

5

Introduction

In this Chapter, I conclude this thesis research by discussing the results from the implementation and foreseeing the future possibilities of use this thesis approach to build generative graphic design systems for computer based documents presentation.

Visual Balance as Search Heuritics

A theoretical model and implementation for ***visual balance*** has been discussed. This research has shown one way to model *visual balance*. This thesis work has provided a frame work for liberating layout for computer-based documents from fixed form and static structure. Implementation of four generative systems have proven to be able to lay out date to satisfy a broad range of constraints while retaining the flexibility in the layout structure. This flexibility leads to the concept of ***intelligent and responsive layout*** which, predicted by this research, will be the key feature of the next generation of the software for document processing.

In my approach of this thesis work, ***visual balance*** serves as (**a**) a primary criterion for evaluating generated layout; (**b**) a heuristics for searching for near-zero values of balance function; and (**c**) an 'energy function' (that is, the balance function defined in Chapter 3) for optimization.

It is not the goal of this research as well as not the goal of graphic designer to seek an or 'the' optimum solution for a layout problem.

Each local minimum, if satisfying the pre-defined relationship rules, is considered as a valid, balanced layout.

Visual balance is necessary for that it brings order and clarity to a page, and dynamically, it also brings vitality and originality to a grid.

Future Research Direction

There are several research issues related to ***visual balance*** need to be addressed in the future research.

1. The **ambiguity of determining visual weight** and **the ambiguity of determining visual balance.**

Formal psychological, cognitive and vision research are necessary to formulate the complex relationship between visual weight and size, orientation, color and other visual properties.

Designers need to be involved in formal experiments to determine how much personal experience affects the judgment of balanced layout.

2. **Search, optimization and other techniques**.

More techniques should be tested and combined with the current one to provided systematic way of making variations of a generative layout. Cluster theory [Johnson and Wichern, 1992] might be applicable to the grouping problem discussed in Chapter 4.

3. **Classification of design styles and retrieval**.

Classification algorithms should be tested to group design styles. Emphasis should be given to those commonly accepted concepts of design styles. Dondis [Dondis, 1974] and Hiebert [Hiebert, 1992] list a set of polarized design styles each in their own books. For example, Understatement vs. Exaggeration, Activeness vs Stasis, and Subtlety vs Boldness from Dondis [Dondis, 1974], and Random vs Patterned, Abstract vs Representational from Hiebert [Hiebert, 1992]. Professional graphic designers should be involved to define and determine styles.

Retrieval of design styles for novice and professional user should be distinguished and designated for different purposes. For example, professional designer might need to access the definition of styles and be able to modify it if necessary, while novice user might need to link his data to the retrieved style.

4. **Interfaces**.

Interfaces for exploring layout variations for different users groups should be designed accordingly. For a novice user, the interface should emphasize the ease of use, while for professionals, flexibility of the functionality.

Multilevel interfaces should be always considered as the basic structure. Depending on their activeness, the interfaces should be responsive to either the change of user's intention or the update of the data.

Toward Responsive, Intelligent and Dynamic Layout

In the following paragraphs, the vision of application scenarios for the theory established in this thesis will be presented. Three situations are envisioned to be applicable for the computational model of dynamic visual balance and for the scheme of generating balanced layout variations. User navigational interactions, the information sources, and the graphic representatives of layout objects are all assigned ***elastic, dynamic*** characteristics. Dynamically balanced layout can be made responsive to possible changes arising from any of these characteristics.

It is envisioned that the computer generated layout will be inevitable and ubiquitous, and a virtual society interconnected with computers, in which programmable agents are communicating with each other, is emerging [Mitchell, 1995]. Interface designing that is associated with the generative design system will become the central issue.

By combining with an auditory system, a design system could provide more channels for expresiveness, communication, and understanding. More complicated, an aestheiscally sound and emationally 'alive' system could be further built by apllying "Affective Computing" principles to cope with the dynamic nature of human congitive process [Picard, 1995].

Receptive layout as interface to documents

Traditional design use fix forms to store information. When information changes over time and space, static layouts cannot respond, or can only respond in a limited, inefficient way. For example, when a news story updates, newspaper can only reflect the change in the next day's paper.

You are reading news from your home computer. There are many interesting things happening and your news agent selected a set of news stories and displayed them in a ***one-screen, computer generated*** layout. While you are reading news about a bombing in Oklahoma city, there comes a new development to the whole story. Your system, which knows, based on your past reading pattern, that you are interested in knowing more about the event, decides to enlarge the area currently assigned to the news you are reading. so that you can read better and so that it may be able to put more news story in the area. The enlargement of this particular area of the layout breaks the visual balance established initially, and imposes a layout design problem in a dynamic way.

In order to keep your layout visually clear and stable, other graphic objects on screen must be either re-sized or repositioned so as to regain the order and clarity of the layout as a whole.

Fortunately, your layout system has a built-in ***sense of visual balance,*** and therefore alters several graphic objects according to the principle of balance and other constraints that are required. When the system finishes, you get a new, balanced layout.

Layout ***as interface to document*** will have to be responsive to any changes from the in-flowing information.

Reactive layout as interface to user

Now you are navigating your news browse. Your layout manager displays in an elastic structure your favorite news group discussion articles, based on their association with each other. While you are navigating through clusters of articles, some subject catches your attention. You express your willingness to read this item by pointing to it or other means.

Now your system responds with enlarging and highlighting the item and de-highlighting and down-sizing the other items that are not associated with that item, but leaving those associated with the item in between. Now your previously balanced layout has been destroyed by these changes.

Your experienced layout manager, the programmed agent inside your computer, re-arranges the graphic objects based on grouping relationships, sequentiality in the discussion, and associativeness with the item your were reading, and generates another layout that is structurally clear and balanced.

Elastic layout as interface among graphic objects

You are watching an on-line cross-firing by a number of people who are actively involved in the hottest discussion in days. Your screen seems very busy with the active input by each of the remote participants, some of whom are typing from Iceland.

You favored several netters' opinions and your system knows that. The typographic space, the screen, now serves as stage for those typographic characters to play their roles, whose appearance could be type with certain feature of personality [Wong, 1995]. These characters are considered as a group of graphic agents who know where and when to present themselves and what size, color, and form to assume [Ishizaki, 1995]. In the middle of the discussion, some netter raised a harsh question. The characteristic representation of that netter now assumes a harsh form, whatever it can be. Other characters who represent other participating netters now see this change, and will respond by changing their forms, color and size, of course, based on ***the principle of visual balance.***

What you are watching, always, is balanced layout or spatial arrangement of graphic objects, at some points in time. But it is also dynamic, evolving and performing in between those time slots when the 'layout', the space occupancy and arrangement for each graphic agent, is balanced, visually.

Summary

Scenarios of future computer generated layout systems are envisioned and the related issues discussed. The principle of visual balance in visual communication design is argued to be an applicable mechanism for building a responsive, intelligent and dynamic layout system.

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