Getting Computers to Read
the architectural semantics of drawings

by

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Abstract

This paper presents an approach to the reading of the architectural semantics of drawings. Topological constraints on objects are used to represent various types of groups where the groups produce repeating patterns. A process model of visual rhythm discovery is developed. Discovery of visual rhythms in an architectural facade is demonstrated.

1. Introduction

Drawn shapes play a critical role in various design domains and particularly in architectural design not only in representing a design concept but also in allowing the designer to reinterpret them to develop new ideas. In the conceptual and creative aspects of designing this reinterpretation of what has been drawn appears to play an important role. Working in a visual medium - drawing - the designer sees what is there, draws in relation to it, and interprets what has been drawn, thereby informing further designing. In all this seeing, the designer not only visually registers information but also constructs and discovers visual patterns in it [Schön and Wiggins, 1992].

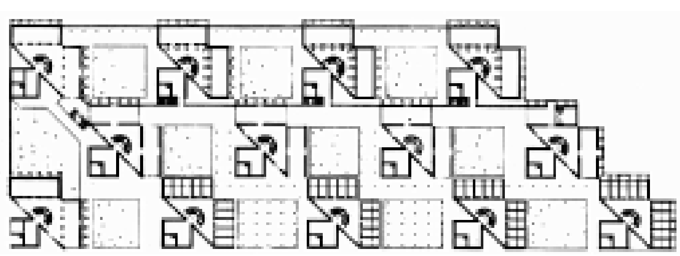


Figure 1: The plan of the Indian Institute of Management of Ahmedabad in India from which many architectural semantics can be discovered (Louis I. Kahn, 1963-) (from Giurgola, R. and Mehta, J. (1975), *Louis I. Kahn*, A.D.A. EDITA Tokyo, Tokyo, p.77)

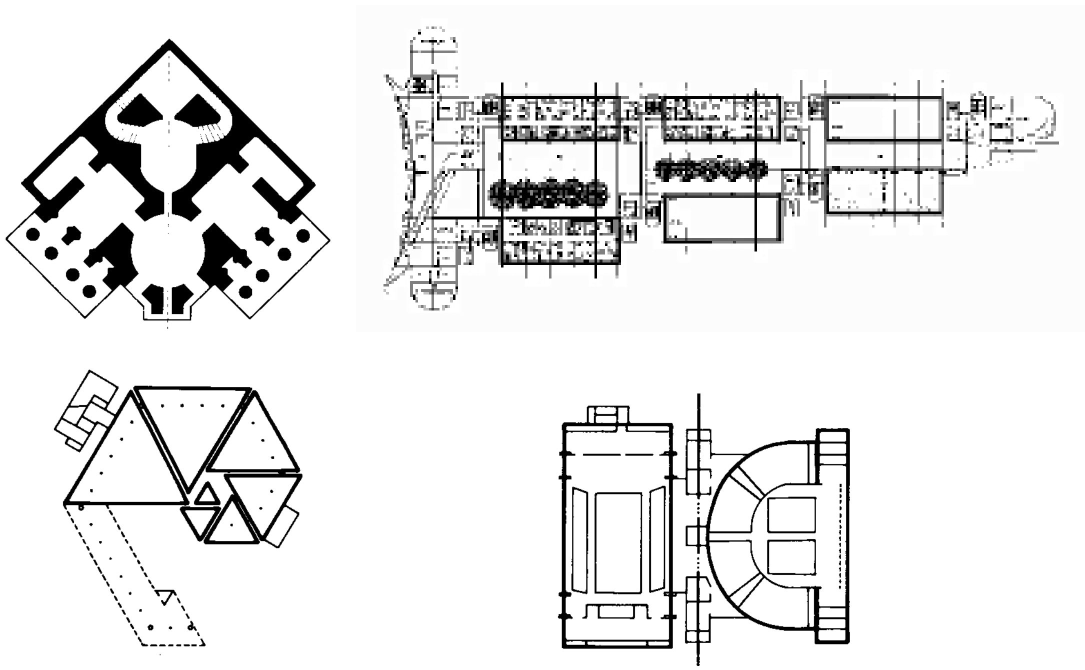


Figure 2: Emergence of architectural semantics from plans:
(a) reflective symmetry: Montmorency (Claude-Nicolas Ledoux) (from Mitchell, W., Liggett, R. and Kvan, T. (1987) *The Art of Computer Graphics Programming*, Van Nostrand Reinhold , New York, p.443);
(b) visual rhythm: Master Plan & Headquarters Office Development for the Langley Court Site (Richard Rogers, 1986) (from Anonymous (1988) *Richard Rogers*, Yoshio Yoshida, Tokyo.);
(c) visual movement: Holy Trinity Ukrainian Church (Radoslav Zuk, 1977) (from Clark, R. H. and Pause, M. (1985) *Precedents in Architecture*, Van Nostrand Reinhold, New York, p.207);
(d) visual balance: Annex to Oita Medical Hall (Arata Isozaki, 1970-1972) (from Clark, R. H. and Pause, M. (1985) *Precedents in Architecture*, Van Nostrand Reinhold, New York, p.180)

From seeing what was intended to be drawn, intentional and/or unintentional patterns of shapes are identified. The patterns can be grouped into dominant themes or formative ideas which can conceivably be used in the generation of designs. A formative idea is understood to be a concept which a designer uses to influence or give form to a design. Formative ideas from shapes are considered as *shape semantics.* Emergent shape semantics in architectural design from plans and/or facades include visual symmetry, visual rhythm, visual movement and visual balance.

Shape semantics play an important role in organising decisions, providing order, and generating a final form in visually-oriented design. They appear to have a special role in architectural design in particular. Architecture reflects its main design concept through the structure of visual organization. Visual organization can be treated as the visual semantics of the design and is perceivable by designers. However, current computer-aided drawing, computer-aided drafting and computer-aided design systems prevent the discovery and use of visual shape semantics because most computer-aided design systems treat shapes as sets of primitives, such as line segments and their endpoints [Mitchell et al, 1987]. Inadvertently such systems have enforced fixation so that it is not surprising that they are not used in the early stages of architectural design. This is one obstacle in using computers to provide significant assistance to human creativity. Symbolic models related to shapes and, to a lesser extent, to shape emergence have been studied [Stiny, 1994]. However there has been very little work on emergence of shape semantics at a symbolic level or on the development of a computational process model of it. Thus, the major aim of this paper is to describe a computational model for the emergence of shape semantics and to discuss their potential to improve the capability of CAAD systems to support a designer's creativity at the conceptual design stage in architectural design.

2. Shape Semantics in Architecture

2.1. Definitions

Shape semantics provide ways to interpret shapes. A *primary shape semantic* is a visual pattern of relationships of shapes which is represented explicitly and intentionally. An *emergent shape semantic* is a visual pattern of shapes that exists only implicitly in the relationships of shapes, and that was not explicitly input and was not represented at input time. Many such patterns have predefined labels. Figure 1 shows a plan from which examples of primary shapes, primary shape semantics and emergent semantics can be inferred. *Shape semantics emergence* is the process of recognizing both emergent and primary shape semantics from primary and /or emergent shapes.

2.2. Visual Rhythm

There is a vast array of possible architectural shape semantics which could be emerged. Four types of shape semantics of architectural design are of interest through interpretations of the visual patterns from plans and facades as shown in Figure 2: visual symmetry, visual rhythm, visual movement and visual balance. The representation of visual symmetry and a process model to discover it have been developed [Gero and Jun, 1994]. In this paper we will describe the representation of visual rhythm and a process model for its discovery. The term 'rhythm' has been used widely. Nature around us is throbbing with complex rhythms and these rhythms serve the purpose of life [Gombrich, 1984]. Even though rhythm reminds most of people of its musical sense, there is no concrete definition of rhythm itself in music because of the complexity of relations with other elements [Cooper and Weyer, 1960; Porter, 1986]. The concept of rhythm in architecture, sculpture and painting has played an important role in accomplishing and judging designers' works. The principle of composition in the works of the great masters has been investigated at a mathematical level [Richter, 1932]. Other research into rhythm has been in the area of psychology. The laws of perceptual grouping in Gestalt psychology could be used to explain visual rhythm as visual phenomena [Arnheim, 1966; Palmer, 1983]. Some principles in the laws of perception can be applied to architectural design [Meiss, 1986].

However, there appears to be no adequate representation of visual rhythm at a symbolic level. Therefore, in this paper we present two contributions which assist in the discovery of visual rhythm. The first is concerned with a representation of visual rhythm at the symbolic level. The second is concerned with a process model of visual rhythm discovery.

We define visual rhythm as the perception of patterns of relationships of equivalent objects or groups of objects such that the patterns contain repetition along one or more axes. Emergence of visual rhythm in architectural designs may be discovered when repetitions of visual patterns of shapes exist.

3. REPRESENTATION

3.1 Introduction

The general representation of forms constructed of objects is [Gero and Jun, 1994]:

$$F = \{N_0;\ \ \text{constraints}\}$$

> where N_0 is the number of objects constituting form F and the constraints, which constrain behaviours or properties resulting from the objects, based upon which particular forms are defined.

When the constraints on forms are constraints on visual rhythm, visual rhythm exists. Therefore the symbolic representation of visual rhythm R is:

$$R = \{N_o;\ \ \text{constraints}\}.$$

Objects are treated as units of visual rhythm. When the units are grouped into identical patterns, the pattern is regarded as the unit in visual rhythm.

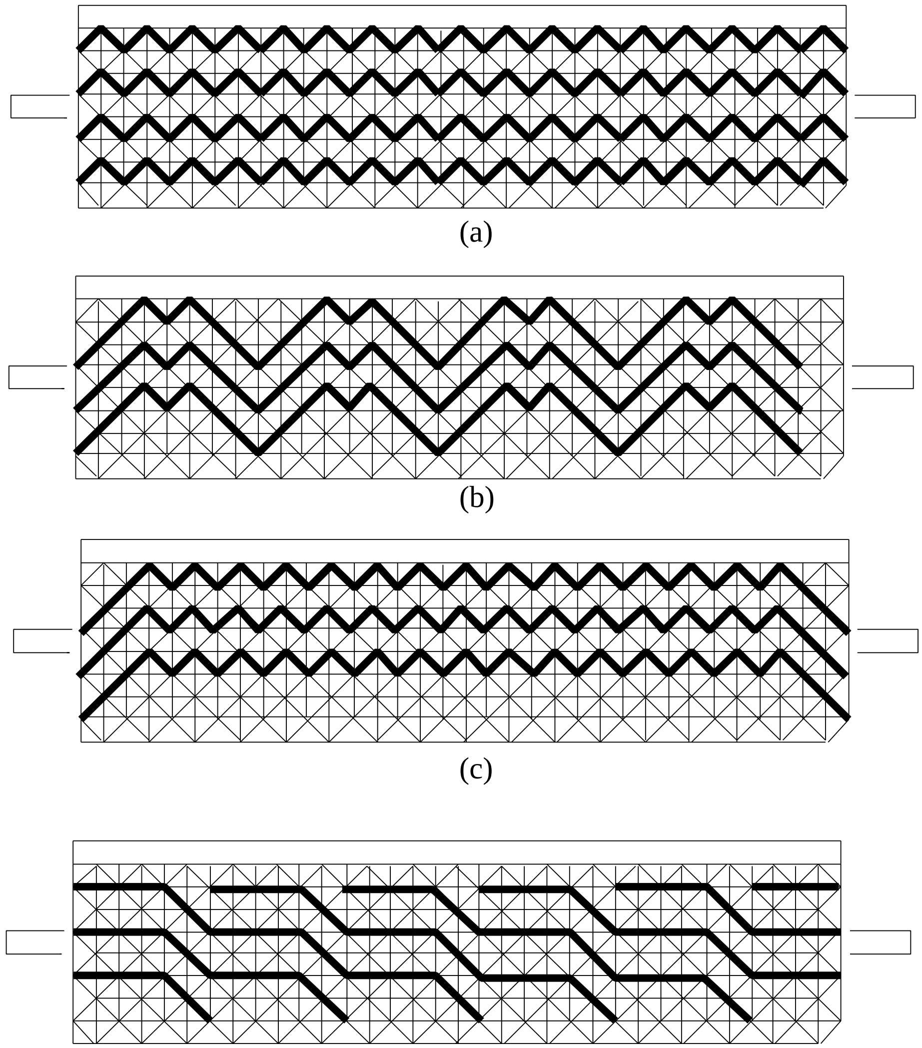
The group G is represented by the number of objects (n) and constraints on units:

$$G = n \text{ (constraints on units).}$$

Therefore, the representation of visual rhythm becomes:

$$R = n_g \text{ (constraints on groups).}$$

where n_g is the number of groups which produce the repeating patterns.



(a)

(b)

(c)

(d)

Figure 3: Examples of various types of visual rhythm as repeating groups of line segments in the Filigree Warehouse elevation (from Blaser W. (1980). *Filigree Architecture*, Wepf, Basel, p.131)

For generality a group may contain a single line segment, a single enclosed shape, a group of line segments or a group of enclosed shapes.

3.2 Constraints

Eight symbols, ` ^ a _ e b d c , for representing topological constraints on objects in visual rhythm are introduced. These define the topological constraints on objects.

O_2 is right of O_1 and $\tau(O_2) = O_1$ => O_1 ` O_2.
O_1 is left of O_2 and $\tau(O_1) = O_2$ => O_1 ^ O_2.
O_1 is below O_2 and $\tau(O_1) = O_2$ => O_1 a O_2.
O_1 is above O_2 and $\tau(O_1) = O_2$ => O_1 _ O_2.
O_2 is below right of O_1 and $\tau(O_2) = O_1$ => O_1 e O_2.
O_1 is below left of O_2 and $\tau(O_1) = O_2$ => O_1 e O_2.
O_2 is above right of O_1 and $\tau(O_2) = O_1$ => O_1 d O_2.
O_1 is above left of O_2 and $\tau(O_1) = O_2$ => O_1 c O_2.
Where O_i denotes objects and $\tau(O_i) = O_j$ means O_i is translated into O_j.

For example, $R = n_g$ {G(^)} represents identical groups, G, translated from left to right. The group may contain various types of objects or groups of objects such as: a single segment, denoted by L; a group of line segments, denoted L_g; a single enclosed shape, S; or a group of enclosed shapes, S_g. When a group is a group of enclosed shapes, the same symbols are used for topological constraints on shapes.

For example,

G = (^, c)
=> S_1 ^ S_2 c S_3
=> $t_1(S_1) = S_2$ and S_1 is left of S_2 ^ $t_2(S_2) = S_3$ and S_2 is above left of S_3

Various types of visual rhythm as repeating units of a group of line segments are shown in Figure 3. Representation of each type of visual rhythm shown in Figure 3 is as follows:

Figure 3(a):

Group of units: G = (L_{g1}),
Representation of visual rhythm: R = 4[17{G^)} _],
where L_{g1} =  ;

Figure 3(b):

Group of units: G = (L_{g2}),

Representation of visual rhythm: R = 3[4{G(^)} _],

where L_{g2} = ;

Figure 3(c):

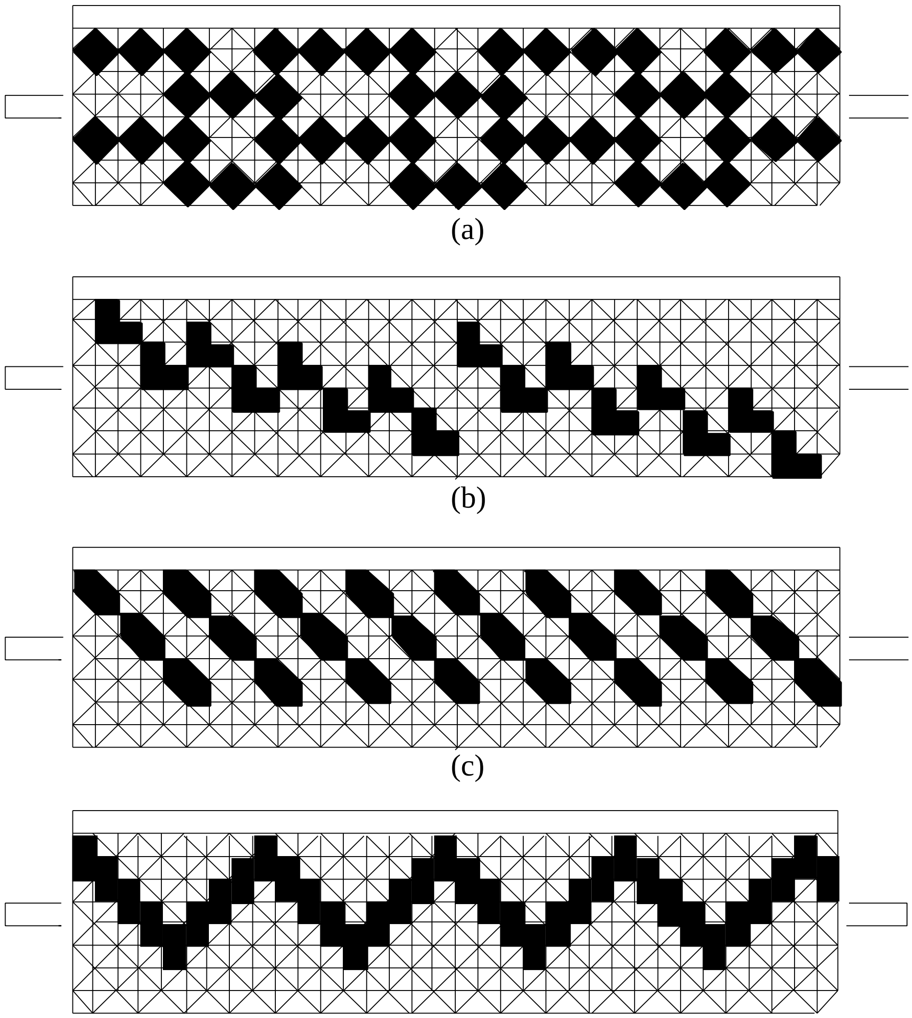


Figure 4: Examples of various types of visual rhythm as repeating groups of shapes

Group of units: G = (L_{g3}),

Representation of visual rhythm: R = 3[C_i, 14{G(^)} C_t_)},],

where L_{g3} = , C_i denotes initial condition ( )

and C_t is terminal condition ( );

Figure 3(d):

Group of units: G = (L_{g4}),

Representation of visual rhythm: *R* = n[3{G(c)} ^],

where L_{g4} = ⌐ .

Various types of visual rhythm as repeating units of group of enclosed shapes are shown in Figure 4. Representation of each type of visual rhythm shown in Figure 4 is as follows:

Figure 4(a):

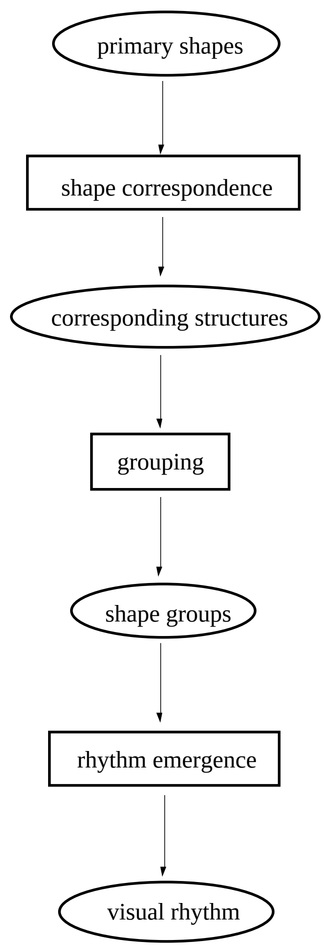


Figure 5: A process model of visual rhythm emergence

Unit = ◆,

Group of units: G = (3^,_, 2^, a),

Representation of visual rhythm: *R* = 2[n{G(^)} _];

Figure 4(b):

Unit = ,

Group of units: G = (c),

Representation of visual rhythm: *R* = 2[4{G(c)} c];

Figure 4(c):

Unit = ,

Group of units: G = (2c)

Representation of visual rhythm: *R* = 8{G(^)};

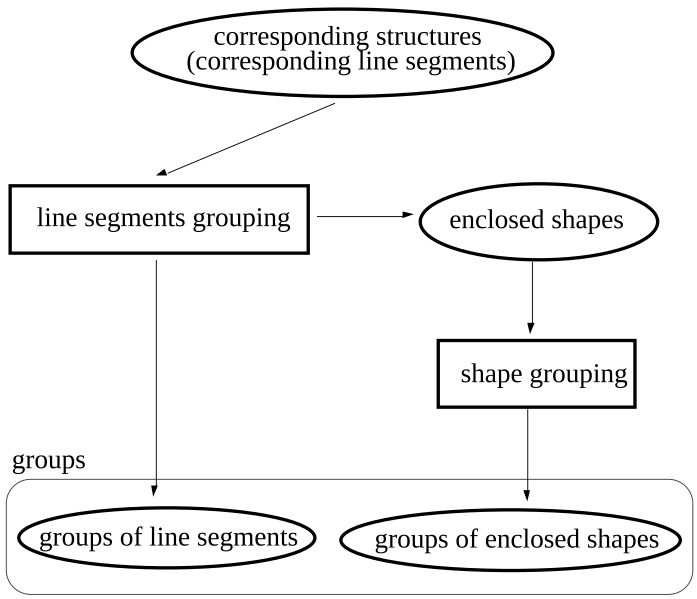


Figure 6: Process of grouping

Figure 4(d):

Unit =  ,

Group of units: G = (4c, 4b),

Representation of visual rhythm: *R* = 4{G(^)}

4. Process Model for Visual Rhythm Discovery

Visual rhythm is discovered when groups of identical units repeat in a uniform sequence. Equivalent properties of elements in primary objects are searched by a process called object correspondence. Corresponding structures of objects are inferred by constraints on structures of objects resulting from behaviours of the structures. Through the process of object correspondence, corresponding structures are found. After corresponding structures are found, groups from various objects are searched in the grouping process. Consequently visual rhythms are discovered by the process of rhythm emergence, as shown in Figure 5. Various types of visual rhythm based on their repetition sequence are discovered through the process.

Thus, visual rhythm discovery involves three steps: (1) searching for corresponding structures of objects, so called object correspondence; (2) searching for groups, so called grouping; and (3) discovering repetitions of groups, so called visual rhythm emergence.

4.1 OBJECT CORRESPONDENCE

Object correspondence confirms corresponding structures of elements in primary objects. Line segments are regarded as basic structural units for groups in visual rhythm. Corresponding line segments as units are searched for when line segments lie in parallel infinite maximal lines and dimensional constraints on the line segments are equal [Gero and Jun, 1994]. Given two infinite maximal lines and segments in lines respectively:

l_p and l_j and (i_{ap}, i_{bp}) l_p and (i_{jc}, i_{jd}), (i_{je}, i_{jf}) and (i_{jg}, i_{jk}) l_j.

Line segment correspondence exists when

$$l_p \,//\, l_j \;\wedge\; d(i_{ap}, i_{bp}) = d(i_{jc}, i_{jd}) = d(i_{je}, i_{jf}) = d(i_{jg}, i_{jk}) \;\Rightarrow$$
$$(i_{ap}, i_{bp}) \leftrightarrow (i_{jc}, i_{jd}) \leftrightarrow (i_{je}, i_{jf}) \leftrightarrow d(i_{jg}, i_{jk}).$$

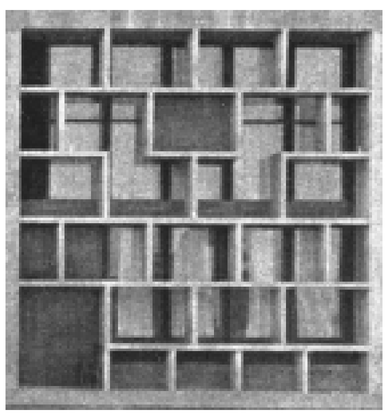
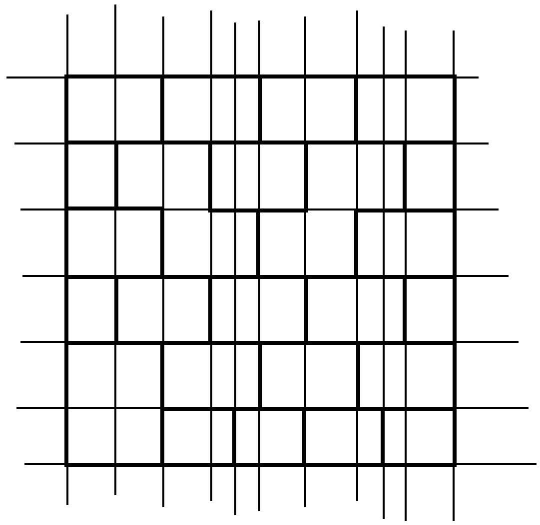


Figure 7: Example of facade design from the Palace of Justice designed by Le Corbusier, 1956 (from Boesiger, W. and Girsberger, H. (1967), *Le Corbusier 1910-1965*, Thames and Hudson, London, p.201).

Where $l_p \,//\, l_j$ means two infinite maximal lines, l_p and l_j, are parallel to each other, i_{ap} represents the intersections of two lines, l_a and l_p, (i_{ap}, i_{bp}) represents segment of a line, l_p and the dimension of the segment is represented as $d(i_{ap}, i_{bp})$.

Figure 8: Primary object representation (shown as heavy lines) of Figure 7 using infinite maximal lines (shown as light lines).



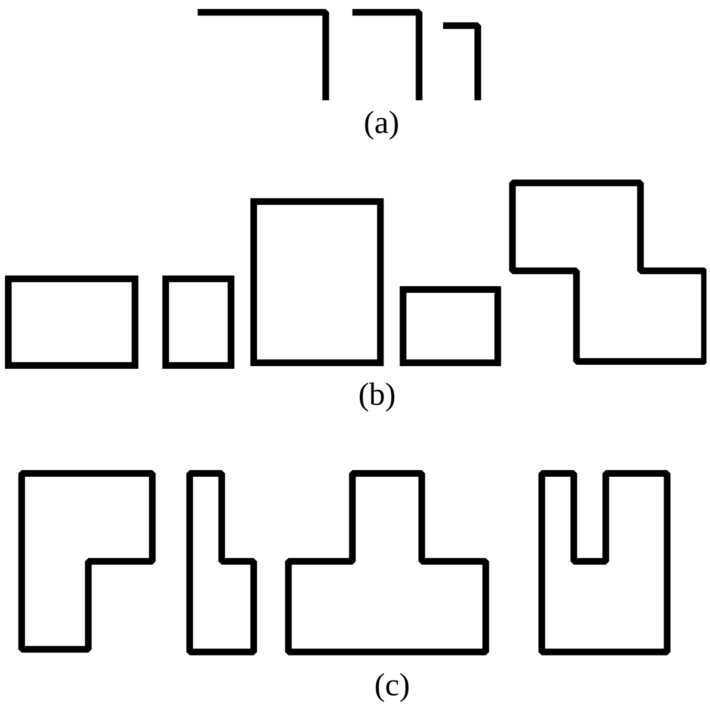


Figure 9: (a) Primary groups of line segments; (b) primary groups of enclosed shapes; and (c) some emergent groups of enclosed shapes.

4.2 Grouping

Grouping is the process of searching various types groups of line segments, enclosed shapes and groups of enclosed shapes resulting from grouping line segments. Grouping involves two steps as shown in Figure 6:

(i) searching groups of line segments, called line segment grouping; and
(ii) searching groups of enclosed shapes after searching enclosed shapes, called shape grouping.

In line segment grouping, a group of line segments as continuous patterns and enclosed shapes are searched by grouping adjacent intersections. Enclosed shapes are found by enclosed groups of intersections [Gero and Yan, 1994]. Otherwise various groups of continuous line segments are emerged.

4.3 Visual rhythm emergence

Visual rhythm emergence is the process of discovering possible visual rhythm from the shapes. Through processes of object correspondence and grouping, various groups of line patterns and groups of enclosed shapes are discovered. When identical groups are repeated, the pattern from repeating identical groups is searched by examining topological constraints on groups.

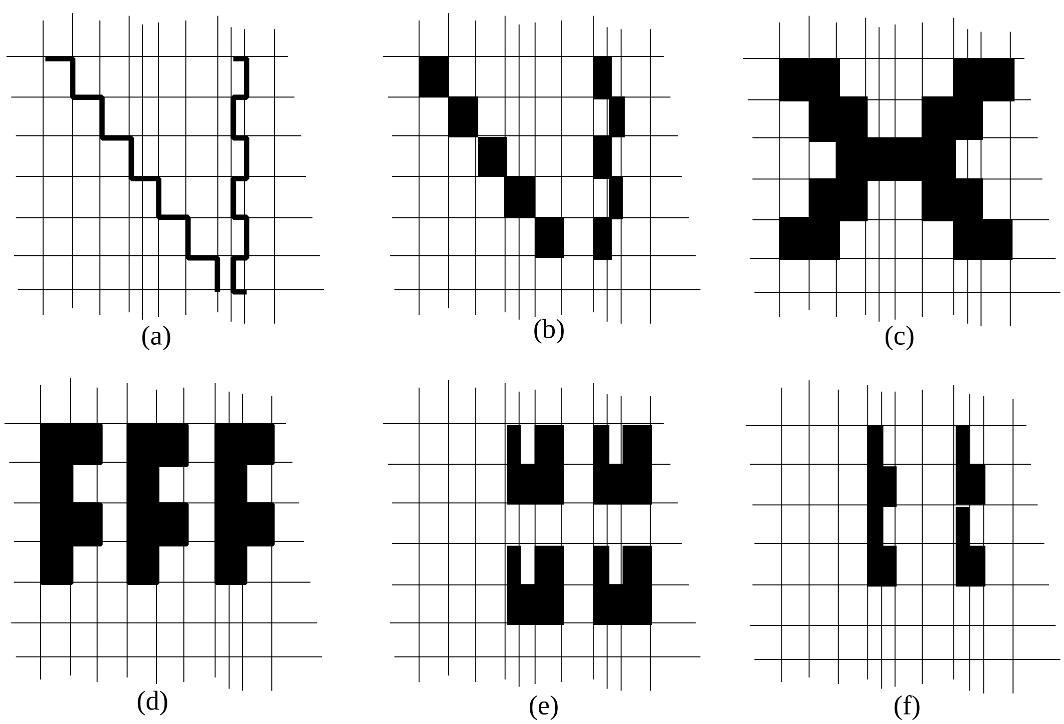


Figure 10: Examples of various types of emergent visual rhythms of Figure 7

Visual rhythms are discovered as repetitions of identical groups of objects. In other words, they are discovered when equivalent translational constraints exist for all groups. A visual rhythm is discovered, for example, when the following rule is satisfied.

Discovered: $G_1 = (2\wedge, c)$, $G_2 = (2\wedge, c)$, $G_3 = (2\wedge, c)$,

Find: visual rhythm

$$\tau(G_1) = G_2,\ \tau(G_2) = G_3,$$
$$G_1 \ c\ G_2 \ c\ G_3$$
$$\Rightarrow \quad \boldsymbol{R} = 3\{G(c)\}$$

5. Visual Rhythm in Architectural Design

The architectural facade of the Palace of Justice designed by Le Corbusier is analysed to discover various types of visual rhythms. Only some emergent visual rhythms could be presented. The facade of the building is shown in Figure 7.

5.1 Object correspondence

Grids of facades are one way for determining facade design for a building. Here, the grids are taken as infinite maximal lines for inferring corresponding line segments through this process. Four different types of primary corresponding line segments and numbers of emergent corresponding line segments are searched for in primary object representation using infinite maximal lines in Figure 8.

5.2 Grouping

Using the process outlined in Section 4.2 groups are discovered. Some examples of groups of line segments and enclosed groups are shown in Figure 9.

5.3 Visual rhythm emergence

Various emergent visual rhythms are discovered from the repeating identical groups through this process. The units are groups of line segments or groups of enclosed shapes. Some emergent visual rhythms from groups of line segments are shown in Figure 10 (a) and some emergent visual rhythms from groups of enclosed shapes are shown in Figure 10 (b), (c), (d), (e) and (f).

6. Discussion

The ability to discover architectural semantics from drawings readily offers opportunities to develop design-oriented graphics system which may be more amenable to augment designers during the early conceptual stage of design than current systems. We have developed a symbolic representation of shape semantics, in particular visual rhythm, from two dimensional shapes in this work.

We can conceive of a variety of visual semantics from architectural drawings such as visual movement and visual balance. These shape semantics can be symbolically represented at different levels of abstraction, where the symbolic representation can be characterised to allow it to be mapped onto the various semantics. So far we have been only concerned with discovering architectural semantics from existing drawings. An appropriate question to raise is how can the various architectural semantics be introduced into a design. It appears that there are two distinct situations to examine. The first is when the architectural semantics have been discovered in an existing drawing and the second is when the designer wishes to enforce a particular semantic in a design. Both these cases can be treated a constraint satisfaction problems using constraint-based graphics languages.

Acknowledgments

Valuable discussions were had with Dr. Routley of the Department of Music and Associate Professor Purcell of the Department of Architectural and Design Science both in the University of Sydney. Part of this work is supported by a grant from the Australian Research Council.

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