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**THE CITY AS SURFACE:
INVESTIGATIONS IN FRACTAL THEORY AND SOCIAL SPACE
IN SAINT-LOUIS, SENEGAL**

by DAVID BROSCOE, B.A.

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of**

Master of Arts

Department of Geography

**Carleton University
Ottawa, Ontario**

August 10, 1993

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INVESTIGATIONS IN FRACTAL THEORY AND SOCIAL SPACE
IN SAINT-LOUIS, SENEGAL"**

submitted by David Broscoe, B. A.
in partial fulfillment of the requirements for
the degree of Master of Arts

Thesis Supervisor

pp. I.W.

Thesis Supervisor

Chair, Department of Geography

Carleton University
September 10, 1993

Abstract

This thesis explores the links between the texture of scanned aerial imagery of Saint-Louis, Senegal and that city's morphology. The texture of the imagery is analyzed using a fractal-based method, implemented by the author, which produces raster 'surfaces' indicating both the local fractal dimension (texture) and the fit of the imagery to the fractal-based method. As these derived surfaces can be viewed in a raster Geographic Information System (GIS), this approach offers a new way of visualizing the texture and morphology of human settlements.

This study explores to what extent the city may be considered fractal. The theoretical framework of this examination links Henri Lefebvre's concept of 'social space' to multidisciplinary discussions of the concept of texture and its links to order and disorder. Given that space is frozen time, this thesis also explores the processes which have formed the 'colonial city', in the generic sense as well as the specific history of Saint-Louis. The thesis finds that the fractal categorization of urban neighbourhoods augments rather than contradicts a visual interpretation of the imagery, while a nuanced classification of the city's morphology requires extensive knowledge of local and colonial history.

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1 INTRODUCTION

1.1 Research Directions

This thesis may be described on a simplistic level as a textural analysis of urban, aerial imagery using digital techniques, in order to examine urban morphology. Such an analysis attempts to emulate the use of texture in air photo interpretation by human interpreters, while using digital imagery and computerized procedures. There are many definitions of texture; a working definition might be the "variability of tone within a neighbourhood" (Mather 1987: 312), but texture has been related to morphological characteristics such as shape and pattern (Arnheim 1968). These extensions of the concept of texture are critical to this thesis, forming the link between image texture and urban morphology. The thesis attempts to go beyond this simplistic level, however, by examining the relationship between social theory and texture, as applied above. This chapter will introduce both levels of analysis.

While texture is one of the important clues traditionally used in manual air-photo interpretation (Lillesand and Kiefer 1979: 96; Jensen 1986: 169), its digital implementation has been problematic in comparison to such other diagnostics as tone. This thesis is one of many attempts at addressing the issue of textural measurement of digital imagery (see for example MacLennan 1988, Shih and Schowengerdt 1983).

The impetus for this analysis comes from several fronts. The first is technical, with the increasing resolution of digital aerial imagery, due to advances in airborne and spaceborne scanner technology. Increased image resolution implies increased image heterogeneity, and with it a reduced efficiency in image processing using traditional methods based on spectral response (Latty et al. 1985: 1459-1460; Marceau et al. 1990: 513). The importance of incorporating image texture in image classification is increasingly recognized within the remote sensing community (Shih and Schowengerdt 1983: 337; Wang and He 1990: 61). The emerging field of fractal geometry, described by Mandelbrot (1983: 310) as implicitly concerned with texture, would seem to provide a tool suitable for measuring and describing texture in a more elegant way than previous quantitative methods (Dellepiane et al. 1991). With explicit links between the micro realm (texture, tone) and the macro realm (form, pattern), in the fractal concepts of scaling and self-

similarity, fractal geometry would seem to provide a quantitative way of linking texture with morphology.

The second impetus is theoretical, involving an investigation of how theories of urban space, particularly Lefebvre's (1991) concept of social space, connect with application, specifically the use of texture to analyze urban imagery. Such a conjunction is an attempt at advancing Lefebvre's theoretical discourse about the nature of urban space, by grounding the theory within a quantitative analysis of a specific city. The merging of these two realms of questioning, the methodological and the theoretical, stems from an interest in the relationship between culture and spatial representation, in terms of both mathematical and textual description of urban morphology. There has been a tendency in Western textual descriptions of irregular, non-Western urban form towards the pejorative (Camara 1968, Morris 1972). At the same time, there has been a lack of research into the quantitative analysis of such urban form, mainly because it was considered as too difficult computationally (Batty 1991: 45; Longley and Batty 1989: 48). Perhaps there also exists a cultural bias in this realm towards research about regular, centrally planned, 'controlled' urban form. It is the author's hope that this research, by attempting to describe both irregular and regular urban form through textural measures, will lead to a description of urban form, both qualitative and quantitative, with less cultural bias.

The questions which must be asked, given such a project, include the following:

What exactly is being measured in such an analysis?

How does texture, as measured, relate to morphology, as interpreted?

How does an aerial image of an urban area relate to what people living in those spaces feel?

Are the theoretical frameworks which have been advanced to link social structure to physical form sufficient in the light of new methodological approaches to morphology?

Is it appropriate to use existing theoretical frameworks as a basis for the application of new techniques or do the implications of the use of new techniques suggest a reformulation of the theoretical framework?

These questions will be explored in the context of a case study, using aerial imagery of Saint-Louis, Senegal. As this thesis is, at its most basic level, a study in interpretation of aerial imagery, this introductory chapter will begin with a brief history and a simple interpretation of the study area, in order to begin to tie these general questions to a specific place. It will then examine a sample of qualitative descriptions of irregular morphology, then introduce fractal geometry as a potential quantitative tool to describe such morphology. With this background, the research questions will then be reframed in terms more specific to fractal theory. The chapter continues with a justification of the choice of Saint-Louis as a suitable study area.

1.2 Interpreting the City: The Example of Saint-Louis, Senegal

Saint-Louis was founded as a trading post in 1659 by the French (O'Brien 1972: 30). Between 1850 and 1900 it served as a base for the expansion of the French West African Empire (Crowder 1967: 9-15) and was developed by the French as a colonial capital (Camara 1968). On a contemporary (1983) aerial photo of Saint-Louis (Plate 1.1) three urban areas, separated by bodies of water, are easily distinguished using the visual cues of pattern and texture. One can identify the island itself (L'Île) as the colonial centre, as laid out in a near-perfect grid pattern in the mid-to-late nineteenth century to reflect the city's position as capital (Camara 1968: 50-62; Winters 1982: 140). A second area, the settlement of Guet N'Dar, is situated on a spit of land separating the Senegal River from the Atlantic (partially visible at the left edge of plate 1.1; see plate 1.2 for a detail of the area). A reference map, figure 1.1 is provided. Guet N'Dar is also laid out in a grid, but it is perhaps less regular than that of the colonial centre. In addition, it may be distinguished from the colonial centre by its smaller buildings. The third area, generally known as 'Sor', encompassing Leona, N'Diolofene and Senofobougou, is on the inland side of the Senegal River (the right side of the aerial photo). Settlement here is of more recent vintage than the other two areas (Camara 1968: 69), with different neighbourhoods exhibiting various

Plate 1.1
Overview of Saint-Louis

Plate 1.2

Saint-Louis: Detail. Scale 1:4000 approx.

The neighbourhood of Guet N'Dar is to the left, while 'la ville' is to the right

Figure 1.1

degrees of affluence and infrastructure, and in terms of morphology, 'regularity' and conformity to the grid. Suburban estates full of trees and bungalows, reflecting the 'garden city' aesthetic more commonly found in later colonial cities of francophone Africa (Winters 1982: 143) coexist with 'bidonville' or shantytown areas of very recent origin, whose 'irregular' form reflects planning predominantly at the local level.

A series of questions follow from this simple interpretation: what allows one to distinguish, through the process of photo-interpretation, one neighbourhood from another? That is, when one studies the image, what are the cues that indicate that one area is the colonial sector and one area is a bidonville? How different are the areas in terms of pattern and texture?

1.3 Neighbourhood Classification and Limitations of Language

The process of classification involves boundary identification, and the creation of dichotomies (Sibley 1988), the division of human settlements into discrete components. The above interpretation is a process of classification where grid-based urban form is contrasted to irregular, organic form. Saint-Louis is divided into sections according to a set of visible and interpretable criteria, some of which are not easily articulated. The literature on urban form is full of such dichotomies and division. One dichotomy is explicit in Fanon's

writing about the generic colonial city, the division between the "settler's town" and the "native town":

The settler's town is a strongly-built town, all made of stone and steel. It is a brightly-lit town; the streets are covered with asphalt, and the garbage-cans swallow all the leavings, unseen, unknown and hardly thought about...The settler's town is a well-fed town, an easy-going town; its belly is always full of good things...

...the native town, the negro village, the medina, the reservation, is a place of ill fame, peopled by men of evil repute. ...It is a world without spaciousness; men live on top of each other, and their huts are built one on top of the other. The native town is a hungry town, starved of bread, of meat, of shoes, of coal, of light. The native town is a crouching village, a town on its knees, a town wallowing in the mire. It is a town of niggers and dirty Arabs. The look that the native turns on the settler's town is a look of lust, a look of envy; it expresses his dreams of possession...

...This world divided into compartments, this world cut in two is inhabited by two different species (Fanon 1966: 32).

In many ways, Fanon paints a very clear, albeit ironic, picture of the two realms he wished to contrast. One gets a sense of how it feels to live in the 'native town'. Fanon's viewpoint is clearly subjective. His unblinking approach, his use of adjectives such as 'hungry' and 'crouching', and his description of envy serve to introduce the reader to Fanon's conception of the power relations between the settler's town and the native town. One begins to understand how those power relations, which were no doubt made more clear to Fanon because of his involvement with Algerian resistance against French colonialism, affect the 'feel' of the two areas, but the sense of the physical appearance of the two realms is not as clear. Fanon advances no formal description of urban morphology.

Amos Rapoport, discussing the various facets of third-world cities, presents a more formalistic, abstract approach. In the context of a discussion of order, specifically urban order, he questions the use of sharp dichotomies:

...it may be incorrect to contrast urban *order* with *chaos* or *disorder*; it is more valid to speak of *different orders*, some of which (called 'chaotic' or 'disordered'), may be imperceptible, incomprehensible or unacceptable because [they are] incongruent with a particular set of norms, preferences, cultural rules or schemata...(Rapoport 1984: 62, author's emphasis).

Rapoport's 'order' is Fanon's 'settler's town'; the 'native town' is 'chaotic' or 'disordered' but Rapoport rejects this dichotomy, offering instead 'different orders'. He understands that order versus disorder is a culturally determined split. The concept of 'different orders' in itself, however, tells us little about either the physical and socio-economic characteristics of the individual orders in the settlements to which Rapoport alludes. Fanon's subjectivity is more evocative; it gives us something to react against.

A. E. J. Morris attempts to explain Rapoport's 'disorder' in terms of spatial characteristics:

Houses are grouped together in layouts which have grown out of the conditions of the primitive village and *are not laid out in any system of town planning*. This natural *unplanned* evolution of a town...is termed 'organic growth'.

...Despite their meandering and seemingly illogical route structures, these town plans nevertheless clearly conform to some *indefinable* natural pattern (Morris 1972: 9, emphasis added).

Unlike Fanon, Morris's text has a veneer of neutrality and objectivity in his attempts to describe 'organic growth', Rapoport's 'disorder'. Instead, Morris comes across as both imprecise and condescending. Centralized urban planning is considered as implicitly desirable, hence organic growth is defined as 'absence of planning'. That organic pattern is 'indefinable' points to the limitations in the language of form, in the geometry used to describe pattern. Morris reveals his biases in spite of himself.

Similar limitations exist in the attempts at description of the non-colonial sectors of Saint-Louis itself. Camara characterizes the neighbourhood of Pikine, a *bidonville* on the south-eastern periphery of the city, as totally lacking in spatial organization (Camara 1968: 252). A city map of Saint-Louis in the *Atlas du Sénégal* portrays most of the southern part of Sor, including Pikine, as possessing what is termed "loose order" (Ba, N'Diaye and Soumah 1980: 44). The old colonial settlement on the island, with crumbling buildings and a stagnant population growth but perfectly gridded streets, is known as "la ville" (Camara 1968: 205), while Pikine, with a high population density and very rapid growth rate, is considered as one of "les villages Africaines" (Camara 1968: 251). Morris is not alone in "this prison-house of language" (Gregory 1982: 203). These attempts at neighbourhood description elicit further questions to those posed by the photo interpretation in section 1.2: how much is the interpretation based on prior knowledge or existing models of the

colonial city? Is one's interpretation of complex, irregular settlement patterns shaped by the limitations of spatial language? The fuzziness in the descriptions of complex urban form would indicate that this may be the case.

1.4 Theories of Space and Spatial Language

The calls for new spatial languages have been many (for example, Gould 1984; Mark and Frank 1989). Harvey described "social space" which seemed to

...demand a different metric (or non-metric) system for discussing spatial relationships and spatial pattern.

He continued:

In some cases an appropriate language already exists, in others it is clear that new spatial languages need to be developed... (Harvey 1969: 191).

Over the past two decades of geographical thought, the concept of space has been first neglected, in reaction to what some might term the "spatial fetishism" (Soja 1989: 77)¹ of works such as *Explanation in Geography*, then tentatively reincorporated into critical geographical analysis (Massey 1985) as

¹ Using the term 'spatial fetishism' to describe Harvey's pre-Marxist work takes Soja's comment slightly out of context. Soja was actually referring to a critique by Harvey (Harvey 1973: 306) of the central and autonomous position of space in the works of Lefebvre (Lefebvre 1976; 1970). Ironically, Harvey has made an about-face and his later work (1989, 1990) is heavily influenced by Lefebvre. I think it appropriate to apply the description to Harvey's own pre-Marxist work rather than Lefebvre's.

spatiality, socially constructed space (Soja 1985; 1989) or social space (Lefebvre 1991; 1976), where space is an integral part of social theory and involves space as perceived, as conceived and as lived (Lefebvre 1991: 38-40). In terms of social theory, such a development is encouraging, as the importance of space and place in shaping social structure is again recognized. This incorporation, however, remains at the theoretical level: there is not a set of tools for measuring social space, although social space is conceptualized as being both qualitative and quantitative (Lefebvre 1991: 191). How best may this quantitative aspect of social space be measured? It would seem that there are situations where it is appropriate that space is described and analyzed on its own, as a physical entity. We need a theory of space which allows for

...a descriptive autonomy, in the sense that spatial patterns must be described and analyzed in their own terms prior to any assumption of a deterministic subservience to other variables (Hillier and Hanson 1984: 5).

In such situations, there is a need for those new spatial languages which Harvey called for 20 years ago, as demonstrated by the ambiguous descriptions of complex urban form cited in section 1.3. A series of attempts at formulating alternative spatial languages have been made, incorporating such mathematical frameworks as fuzzy sets and Q-analysis (see Odland *et al.* 1989: 736; Gould 1982), and graph theory (Hillier and Hanson 1984; Steadman 1983). None of these mathematical frameworks have found widespread acceptance in geography. Over the past fifteen years, however, one spatial language has developed - fractal geometry - which has found application in diverse

disciplines, including geography. The following sections will introduce the concepts of fractal geometry, outline the use of fractals in geography, and present the research questions of this thesis in the context of a debate in the geographical literature regarding the application of fractal theory to urban data.

1.5 Fractal Geometry

The term *fractal* was coined by Benoit Mandelbrot from the Latin *fractus*, implying fragmentation or irregularity (Mandelbrot, 1983: 4). The domain of fractal geometry falls between the points, lines and planes of Euclidean geometry to describe the way that objects fill space in a new manner (figure 1.2). Descriptions of objects are no longer limited to integer dimensions (0 for a point, 1 for a line, 2 for a square and 3 for a cube) but irregular objects can be defined as filling space between the integer dimensions. Two fractal figures, 1.2b and 1.2c are portrayed between the one-dimensional line and the two-dimensional rectangle. The fractal dimension, D , is related to the jaggedness of the figure, to the degree in which the figure fills space, with a higher fractal dimension corresponding to a more jagged figure. A similar logic applies to surfaces, where the fractal dimension lies between two and three, depending on the roughness of the surface, that is, on the way in which the surface can be considered to fill volume (Goodchild and Mark 1987: 269).

Mandelbrot has defined a fractal simply but enigmatically as "a shape made of parts similar to the whole in some way" (Mandelbrot, cited in Feder 1988: 11). Such a definition implies self-similarity, pattern-within-pattern, so that at any level of resolution a fractal object resembles itself at any other level of resolution (Mandelbrot 1983: 18; Voss 1988: 71-73). Self-similarity may be obvious, as shown in figure 1.3. Figure 1.3a represents the generator of figure 1.3b, where, in this case, each filled square of the generator is replaced by the overall pattern of the generator. In order to create a scaling fractal, one that is self-similar at any scale, such a process would be repeated *ad infinitum*. Figure 1.3c represents another generator, which yields figure 1.3d after one iteration of the process of fractal creation.

Self-similarity, however, does not necessarily imply simplicity and symmetry. Figure 1.4 illustrates "cross-lumping" (Mandelbrot 1983: 125) which occurs when the fractal generator is asymmetrical. Figure 1.4a generates figure 1.4b, while figure 1.4c generates figure 1.4d. In both instances, the resultant patterns achieve a complexity not present in the generator, due to the merging of patterns. One may conceive of fractal phenomena where absolute self-similarity might apply (crystals for example), but with most real-world data self-similarity is *statistical*, in that the object or process in question is fractal only when considered in aggregate terms. Such objects may also be *scale-*

Figure 1.2 Euclidean Versus Fractal Dimension

Note that any closed regular geometric figure will have a D of 2. The fractal and the Euclidean dimensions are identical for regular figures.

Figure 1.3 Symmetrical Self-Similarity

a

b

c

d

Figure 1.4 Self-Similarity with 'Cross-Lumping'

a

b

c

d

-bound, such that the fractal model applies only over a limited range of scales (Mandelbrot 1983: 19).

A series of methods have been proposed for calculating the fractal dimension of an object. All methods involve iterative measurement and the calculation of the slope of a regression line on a log-log scale of the iterative measures, where one axis is defined as the unit of measurement and the other axis is the total value (for example, a distance on a linear feature).

1.6 Fractal Theory and Geographical Phenomena

The concept of fractal geometry has found application in many fields, ranging from botany (Prusinkiewicz and Hanan 1989) to particle physics (Kaye 1988), physiology, music, and economics (for a summary of applications in various fields, see West and Shlesinger 1990). In the estimation of some practitioners, fractal geometry has the makings of a new meta-narrative, as evidenced by titles such as *The Fractal Geometry of Nature* (Mandelbrot 1983) and *Fractals Everywhere* (Barnsley 1988). Within geography, there have been fractal applications in areas ranging from Central Place Theory, where Christaller's work is recast as a subset of fractal theory (Arlinghaus 1985; Arlinghaus and Arlinghaus 1989), to cartographic line simplification (Broscoe and Prashker 1991; Carstensen 1989; Longley and Batty 1989; Muller 1987;

1986). Much of the controversy regarding the application of fractals to geographic phenomena stems from the implications of the concept of self-similarity. For example, if one were to view an aerial photograph of a truly self-similar world, it would not be possible to determine the scale of the photograph, since at any scale, the world would resemble itself (Goodchild and Mark 1987: 268). With real-world geographical data, this condition is most often not the case; an indicator of scale, either natural or cultural, is present, rendering the fractal model inappropriate according to some researchers (Lam 1990: 189).

Such a rigid view of fractal application, however, seems to miss the point. Mandelbrot himself devotes considerable attention to scale-bound fractals and their application (Mandelbrot 1983: 146-154). Increasingly, the fractal model is being used as a guide, as a kind of null hypothesis against which one can compare geographical 'reality' (Goodchild and Mark 1987: 275; Lam 1990; Mandelbrot 1983: 18-19; Pentland 1986). This is the general context for a specialized debate regarding the application of fractals to urban phenomena.

1.7 Fractals and Urban Form: The Debate

This debate concerns the nature of urban form, and the relationship between urban form and fractal theory. Two camps may be identified: those who believe that fractal theory can legitimately be applied to urban phenomena and those who do not. Those who utilize fractal geometry in urban studies do not assert that the urban forms they are studying conform completely to the fractal model. Rather, they find that the degree of conformity is close enough to be useful; certainly the correspondence of urban form to fractal geometry would seem to be closer than in previous studies where urban form was described by Euclidean geometry (Batty 1991: 48). Those who question the association between urban form and fractal theory do so based on the circumstantial nature of the evidence linking the two fields and the apparently partial conformity of urban form to fractal theory. An incomplete correspondence is considered enough to invalidate such research (MacLennan 1988: 70-71).

Michael Batty and Paul Longley, two researchers who feel that the application of the fractal model to urban studies is valid, represent the pro side of the debate. They have based much of their work on the relationship between urban boundaries and fractal theory, working at generalized scales:

those of the city and the region. Mark MacLennan, responding to the work of Batty and Longley, questions the degree to which urban forms are self-similar:

The evidence presented by Batty and Longley is mostly circumstantial and not particularly convincing ... The assumption that urban forms exhibit fractal behaviour should be questioned ... Unlike fractal objects, magnification of an urban scene should tend to resolve these intrinsic features at their intrinsic scale and reduce, not increase, their degree of irregularity (MacLennan, 1988: 70-71).

Up to a point, Batty would seem to agree with MacLennan. He wrote:

self-similarity of form and function usually exist over a restricted number of scales. This is very clear in terms of urban form. At physical scales finer than the neighbourhood, the geometry of form becomes Euclidean in that the streets and dwellings and other physical structures are usually laid out following simple straight line geometry (Batty 1991: 48).

Both of the above statements, however, are speculative. In addition, in the case of the third-world city there are many situations where streets and buildings do not follow simple straight line geometry. Thus the methodological path chosen by Batty and Longley precludes an adequate response to MacLennan's question. They are not working at the scales to which MacLennan refers. The digitized urban boundaries upon which Batty and Longley base much of their work certainly do not indicate what one might consider a basic unit of urban physical structure, for example, a building or a city block on imagery of an urban area. The fractal dimension of lines which form urban boundaries can be measured and compared, one to another. Such measurements describe the boundary, but not necessarily the internal spatial structure, of the enclosed neighbourhood.

1.8 Research Questions: Methodological and Theoretical Issues

With the background provided in the previous sections, it is now possible to frame the research questions more succinctly than was possible in section 1.1. The first goal of this study is to determine if city form, at the scale of the neighbourhood, conforms to the fractal model, that is, to determine whether it is self-similar². The proposed method is to consider, for the chosen city, scanned monochrome aerial imagery as a surface, where the grey tones of the photograph represent the Z dimension of the surface. The fractal dimension of that surface is then determined, evaluating the texture of the image, where texture is defined as variability in tone over a given area (Mather 1987: 312). This follows a long, albeit empirical, tradition of the use of texture as an heuristic device in aerial photo interpretation (Adeniyi 1983: 547; Pentland 1983: 1). It also follows from the assertion that much of fractal theory could be considered an implicit study of texture (Mandelbrot 1983: 310). The selected method of calculation, the "blanket" method (Peleg et al. 1984; Vernazza 1987; Dellepiane et al. 1991), allows for the calculation of the fractal dimension of a small window of the image, so that fractal surfaces, arrays of

² Already the assumptions of the fractal model have been violated, by assuming an upper limit to the extent of the study (the neighbourhood). This upper limit is a compromise, based on the limitations of the resolution and file sizes of scanned areal imagery. This approach stems from the desire to increase the resolution (and the scope of the study) beyond the analysis of generalized urban boundaries, as per Batty and Longley.

local fractal dimension values which relate explicitly to locations on the original images, can be obtained. This is a deliberate departure from the work of Batty and Longley, in terms of both the methodology and the underlying theoretical framework. It is hoped that some of the perceived shortcomings in their approach may thus be addressed. This aspect of the thesis will be developed in chapter 3.

The second goal is to determine if the fractal model, regardless of its degree of conformity, can be used as a way of distinguishing between neighbourhoods which appear different to the interpreter, on the basis of visual inspection. The fractal model is to be used as a guide (Goodchild and Mark 1987: 270-271; Lam 1990: 194) against which the different city neighbourhoods may be compared. In so doing, the capabilities of fractal geometry as a way of measuring the morphological characteristics of each neighbourhood may be tested, perhaps offering an alternative to the fuzzy and ethnocentric descriptions of complex and irregular morphology presented as examples in section 1.4.

Such an analysis, however, implies a clear understanding of the concept of texture. Towards this end this thesis includes an exploration of the concept of texture in various contexts. Such contexts include Lefebvre's (1991) references to texture in his discussion of social space, more abstract discussions

of order and complexity (Kuntz 1968a; Livingstone 1984), drawn upon by Rapoport in the formulation of his "different orders", as well as the field of remote sensing, where many quantitative measures of the spatial variation of image tone (texture) have been developed (Haralick 1973: 396; Hord 1986: 130; Jensen 1986: 169). The use of a fractal method of measuring texture necessitates a discussion of the relationship between texture and fractals. These aspects will be discussed in chapter three.

1.9 The Study Area: Why Saint-Louis?

1.9.1 Racial and Ethnic Segregation

Saint-Louis, Senegal, was chosen as the study area for several reasons. First, the city presents very marked contrasts in morphology between neighbourhoods, with a distinct colonial sector and examples of 'organic' growth on the periphery. This contrast is due to many factors, including the colonial tendency towards racial segregation, which persisted in the post-colonial era as economic and class segregation³ (Winters 1982: 147). At the same time, there was a tendency for ethnic groups from within the indigenous

³ although Winters cites the old colonial cities of Senegal, of which Saint-Louis is a prime example, as partial exception to this rule. In Senegal "the presence of metis complicated matters" (Winters 1982: 140; see also O'Brien 1972 and Crowder 1967). I would argue nevertheless that a significant degree of ethnic segregation did exist during the colonial period, with a white and mixed blood elite, and a black working class.

same time, there was a tendency for ethnic groups from within the indigenous population to live in segregated communities and for the resultant settlement patterns to reflect this segregation. Historical evidence of such segregation is documented in Faidherbe (1899), where a Bambara community was established on Sor in 1852, separate from both the colonial realm of 'la ville' and the predominantly Wolof settlement Guet N'Dar (Camara 1968: 258). This indigenous segregation was rigidly maintained until the 1930s (Camara 1968: 262). This was not a 'natural' pattern: although there is evidence of ethnic segregation in some precolonial African settlements (Hull 1976: 76-77), in the case of Saint-Louis, it is clear that such segregation was encouraged by the Colonial government. Segregation has remained persistent, although not absolute⁴.

⁴ This segregation is not consistent throughout Africa, and would appear to depend on a host of factors, including the ethnic composition of the city, the urban growth rate, the religious mix, and the conditions of colonization. Separation appears to have been extreme in northern Nigeria (Paden 1982; Peil 1981: 114), but Peil, based on a sample of eight towns in Ghana, Nigeria, and the Gambia, concludes that "there is little ethnic clustering in West African urban housing" (Peil 1981: 118). Mitchell, however, cites strong evidence of clustering of accommodation for single men working in urban areas, based on their ethnicity and village of origin, in Northern Rhodesia and South Africa (Mitchell 1987: 225-231).

In precolonial Africa, where various ethnic groups inhabited one city, segregation appears to have been the norm. Hull states that "patterns of segregation clearly existed in many African towns and cities" (Hull 1976: 80). In some African cities, numerous wards existed, "each possessing a distinct ethnic identity" (Hull 1976: 76).

1.9.2 Segregation, Vernacular Housing and Urban Morphology

In the third-world city, housing in indigenous neighbourhoods tends to be vernacular, produced by the occupants or others within the neighbourhood, within the context of an indigenous culture (Rapoport 1988; 1980; 1969: 4-5). Thus the physical characteristics of the neighbourhoods reflect the character of its occupants. The planning is neighbourhood based; the planners are local. In the first-world city, although ethnic segregation exists, ethnic minorities tend to migrate from one existing neighbourhood to another (see Jackson and Smith 1981; Peach et al. 1981). Although local character of the neighbourhood is apparent in street-level details, the morphology, as seen from an aerial photo, for example, may not reflect the current ethnic composition. The planning process, and thus the morphology, does not necessarily reflect the ethnic composition of the neighbourhood. In the third-world city, then, we have a better example of Robert Park's assertion that the "moral order was inextricably linked to spatial patterning" (Goheen 1970: 23; see also Jackson and Smith 1984: 66; Park 1925) than in Park's own laboratory, the first-world city.

The urban ecologists saw a direct link between social and physical structure, unlike much urban social theory since. Here, there is a link between urban ecology and fractal theory. Mandelbrot asserts that "to see is to believe", in reply to Cantor's original aphorism "to see is not to believe" (Mandelbrot

1983: 21). Much current social theory, however, would disagree with Mandelbrot:

The visible order, with its permanent grid of distinctions, is now only a superficial glitter above the abyss (Foucault 1970: 251).

It has been argued that Saint Louis presents a more direct link between physical and social structure than many first-world cities. If an important test of a model is that it must look right (Batty 1989: 168; Batty and Longley 1986: 1144), and a model hypothesizes a link between social structure and urban morphology, such a model should fit a city such as Saint-Louis. Hence, Saint-Louis would seem to be a suitable choice for the exploration of the links between social theory and theories of space. Such links will be explored in chapter three.

The other two reasons for choosing Saint-Louis are more routine. Aerial imagery was available, a prosaic but critical factor. The third factor is that the city is relatively small. Therefore, the task of choosing imagery from appropriate examples of neighbourhoods was less problematic than with a larger centre. The fact that Saint-Louis has remained a small city, however, prompts further questioning. Since the transfer of political power from Saint Louis to Dakar around 1900 (O'Brien 1972: 47) Saint-Louis has in many ways stagnated, acting only as a regional centre. Thus the physical structure, at least of the former colonial realms of Saint-Louis, may be more an historical artifact than a current social reality. This suggests an investigation of the history *vis-a-*

vis the morphology of Saint-Louis, inspired in part by Lefebvre but informed as well by other histories of colonial cities (King 1990; 1984; 1976; Ross and Telkamp 1985). Such an exploration helps to answer the research question "What exactly is being measured in this analysis of image texture?" posed in section 1.2.

1.10 Thesis Structure

This thesis, then, proposes a fractal-based textural analysis of aerial imagery of Saint-Louis, Senegal, in order to examine the morphological characteristics of the city. The remaining chapters are structured as follows: chapter two will set the specific historical and geographical context for this work. Chapter three will introduce the concept of social space, and within that discussion, the concept of texture. This reading of texture will be compared to the definitions of texture within the discussion of order and complexity, and within the field of remote sensing, itself drawing on the realms of image analysis and pattern recognition. An exploration of the links between fractal theory, texture and social theory will complete this chapter. Chapter four is a more technical treatment of texture, reviewing existing approaches to textural analysis, both fractal and non-fractal, in order to choose an appropriate method. The implementation of the selected technique, the blanket method (Peleg et al. 1984), and the methodological approach to the measurement of

image texture will be described. The discussion of results follows in chapter five, first attempting to answer the question, "Is the city fractal"? It will then explore the way that fractal theory can be used as a measure of texture to describe the morphology of, and to differentiate between, neighbourhoods, using aerial imagery of the city. An interpretation of the results of the textural analysis will tie to the history of Saint-Louis outlined in chapter two and the discussion of social theory in chapter three. Finally, chapter six will include a discussion of the strengths and weaknesses of remote sensing methodology, both in terms of the way that cities reflect the past and present (see Duncan 1990), and in terms of the place-specific nature of remote-sensing methodology. The thesis will conclude with a summary and suggested directions for further research.

2 SAINT-LOUIS: GEOGRAPHICAL AND HISTORICAL SETTING

2.1 Introduction

The previous chapter proposed that the morphology of Saint-Louis, as determined by texture measurements of aerial imagery, could be linked to the history and social structure of the city. This chapter explores that history and social structure, in order to discover how specific historic and social conditions have been instrumental in creating the morphology of Saint-Louis, so as to support the interpretation of the textural analysis which follows in chapters four and five. In this way physical manifestations can be linked back to the social and historical conditions. This chapter, then, attempts to tie the colonial history of Saint-Louis and the colony of Senegal to the development of an urban morphology which is historically and geographically specific, but at the same time linked to more general international and global processes.

This examination begins with an historical summary, from the inception of Saint-Louis in the seventeenth century up until the late nineteenth century

when Saint-Louis was at its height in terms of political power and economic prosperity. This history is then retraced, with specific emphasis on urban morphology, by focusing on the deliberate creation of a "colonial city" (O'Connor 1983: 32-35; King 1976: 24-40; King 1990: 13-43; Ross and Telkamp 1985), one which was created

by Europeans for their own purposes of administration and trade, playing a critical role in the process of colonial political domination and in the extraction of profit by colonial business enterprise (O'Connor 1983: 32).

This involves the exploration of the creation and maintenance of a "European city", the result of specific commercial, military and administrative initiatives, as distinct from the "African city" (Winters 1982: 141) which grew up around it. Such a distinction, while useful in introducing the subject, is ultimately overly simplistic: the growth and form of the 'African city' is as much an outcome of the process of colonization as that of the 'European city'. The morphological retention of this colonial history is profound, but it is not surprising, given the tendency for architecture and urban planning to freeze time in space (Harvey 1989: 206). In many ways the urban morphology of Saint-Louis still reflects the social conditions of the late nineteenth century.

Two additional themes are then explored, both found to be related to the creation of a 'colonial city'. The first theme addresses the issue of segregation. Ethnic segregation has been conceptualized as a characteristic of indigenous, pre-colonial African settlement (Hull 1976 74-84). While such a

perception would seem to be borne out by certain aspects of the history of Saint-Louis, other aspects would indicate that the path of ethnic segregation among the indigenous groups has been influenced primarily by the colonial process. Segregation is not limited to indigenous groups; evidence points to economic segregation between the French, Lebanese, and Moroccan communities. Again, as with the examination of the deliberate creation of the 'colonial city', segregation must be viewed historically, as historical anachronisms may be visible in current urban morphology.

The exploration of demographic characteristics at the level of the neighbourhood constitutes the second theme . The growth rates of specific neighbourhoods would appear to be related to their morphology as per a visual interpretation of the aerial imagery. These growth rates can be linked to the creation of the 'colonial city' by tracing the degree of colonial control throughout the history of specific neighbourhoods. Slow growth would seem to be associated with grid-based morphology, whereas rapid growth relates to organic form. Exploration of these themes will investigate whether factors such as economic status, historical precedents, and ethnic and demographic composition can be related to given morphologies of urban settlement. Such investigations have a bearing on the way that the textural analysis may be interpreted and applied. If a specific texture is associated with a specific

morphology, which in turn is tied to demographic characteristics, the textural measure would be a way of deriving demographic characteristics.

2.2 Historical Summary

2.2.1 Early History: Mercantile Trading

Although Europeans first encountered the Senegal River in 1445 (Crowder 1967: 9), it was not until the early seventeenth century that a French trading presence was established in the area (Camara 1968: 34). In 1659 the trading fort of Saint-Louis was founded by Louis Caullier, an employee of the *Compagnie du Sénégal*, on a deserted and desert-like island at the mouth of the Sénégal River (O'Brien 1972: 30), some eight kilometres and two major rivers away from N'Da, the only indigenous settlement in the area (Camara 1968: 34). Over the next one hundred years, the fort became the focus of a prosperous trading town (Crowder 1967: 9), based on a monopoly in the gum trade. The *compagnie* provided "the first form of European local government in the area" (O'Brien 1972: 30). The town came under British control between 1758 and 1779, as a result of the Seven Years War, and again between 1808 and 1817 (Camara 1968: 37).

Until the early nineteenth century, the French government displayed minimal interest in Saint-Louis or Senegal. Initially, Saint-Louis was controlled by mercantile interests, and the settlement's neglect on the part of the French administration was no doubt a factor in the maintenance of gum-trade monopolies, with the exclusion of other French capital. By the latter part of the eighteenth century France was preoccupied over conflict with England, with little energy to spare on colonies (Camara 1968: 40; Crowder 1967: 34). During this period Saint-Louis was neglected by both the French and the British. Commerce was slack and the settlement deteriorated. By the end of the second period of British rule Saint-Louis had fallen into a "deep lethargy" (Camara 1968: 41).

2.2.2 New Forms of Colonial Enterprise

The return of Saint-Louis to France in 1817 marked the beginning of a more aggressive attitude towards colonization and new and more concentrated forms of colonial enterprise. These forms included a failed attempt at white plantation agriculture, and a return to the gum trade, but under different terms than the previous monopoly (Crowder 1967: 12; O'Brien 1972: 34-36). The change in economic climate meant a significant change in the social climate as well.

Beginning in the 1780s a campaign against the monopoly of the *Compagnie du Sénégal* was mounted by two groups. The first was a group of businessmen from Bordeaux wishing for a place in the gum trade:

Hoping to break the mercantile system of the monopoly companies, the group advocated the abolition of the slave trade, one of the main links in the system (O'Brien 1972: 34)

The second group were the *habitants*, free Africans living in St. Louis, largely *métis*, the offspring of white company employees and local women, deemed "sufficiently influenced by French culture" to be granted some legal rights under French law (O'Brien 1972: 31). In linking with the group from Bordeaux, the *habitants* were successful in removing the many of the original company charters and in formally abolishing the slave trade (Crowder 1967: 11). By 1800 the gum trade was opened to all (O'Brien 1972: 34), and it soon became dominated by Bordeaux trading companies, the employees of which were more committed to making a life in Senegal than those of the old monopoly companies, settling in Saint-Louis to become "notables of the colony" by the 1860s (O'Brien 1972: 36).

This reconstituted and expanded trading was tenuous, however, with local animosity directed towards the French administration's attempts at regulation. The prospect of the groundnut as a viable commercial crop, however, galvanized the French to formally establish Senegal as colony in 1848. A naval commission

... gave the first official recognition to the groundnut which it said 'grew almost naturally'. It was this trade which ultimately transformed Senegal into an active commercial centre. Yet, according to the traders, this could not proceed until the safety of their agents travelling through the interior could be assured or until an effective colonial administration was established (O'Brien 1972: 36).

By 1854 the conquest and control of the interior of Senegal had begun, under the direction of the newly appointed governor Faidherbe (Crowder 1967: 15). The groundnut trade boomed. Groundnut exports through the port of Saint-Louis increased from 1200 kilograms in 1840 to 25000 tonnes in 1867 (Camara 1968: 61). This economic vigour was "reflected at Saint-Louis which [Faiderbe] made an effective colonial capital" (O'Brien 1972: 37).

2.3 A History of Urban Morphology: The Creation of a Colonial City

2.3.1 The Early Years

The functional transformation of Saint Louis from a mercantile trading fort to an administrative capital was accompanied by extensive physical changes to the settlement. Although the island, with sand dunes at the south, scrub at the north, and no fresh water, was deserted prior to the founding of the fort, the fort soon attracted a local indigenous population, drawn from N'Da, the nearest indigenous settlement, by the prospect of commerce (Camara 1968: 34). Early illustrations show the fort surrounded by what appear to be 'traditional' circular African buildings with colonial thatched roofing (Faiderbe 1889: 72-73). The extent of such settlement increased throughout

the eighteenth century (as illustrated by figure 2.1, with plates from ca. 1720 and 1780 respectively). Such settlement, however, did not necessarily house indigenous people. LaCourbe's 1685 account describes "reed huts" which were inhabited by low ranking company employees and army personnel, while dwellings of officers were lean-tos built against the fort (cited in Camara 1968: 35). It was not until much later, with the demise of monopoly trading and the coming of a merchant class more amenable to extended settlement in Saint-Louis that 'permanent' housing became the norm for the European population. By the end of the eighteenth century some twenty 'permanent' houses had been built, two story buildings based on styles found in provincial towns of Southern France, in which the slaves occupied the ground floor and the owner the second (Camara 1968: 37). By 1828 there were 200 brick houses; ten years later the count was up to 320 (Camara 1968: 47). This does not mean that Saint-Louis was considered home: most of the profits from trading were invested in slaves and in constructing "magnificent buildings" back home in Bourdeaux and Nantes (Camara 1968: 38).

Meanwhile, the indigenous population of Saint-Louis grew rapidly. By 1800 the total population of the settlement was given as between 5000 and 7000, with some 660 whites, 2400 "personnes libres" (free blacks or *métis*), and 3000 slaves (Camara 1968: 65). At that time, the vast majority of blacks did live in huts (Camara 1968: 39). Here, as with other colonial cities, segregation

Figure 2.1

Historical Maps , showing Guet N'Dar and Bouetville before and after colonial rebuilding. Source: Faidherbe 1899

by race would appear to be much more prominent after the abolition of slavery¹, as many slaves were engaged in domestic work (Ross and Telkamp 1985: 4). The release of slaves translated, in terms of urban morphology, in a rapid increase in the number of huts. A census in 1838 found that out of a total of 3237 buildings on the island, 2933 of them were thatched huts (Camara 1968: 49), the southern half of the island being entirely covered by such dwellings (Camara 1968: 47).

2.3.2 Overcrowding

Beginning around 1800, with the rapid growth of the settlement and scarcity caused in part by neglect on the part of France, administrative concerns about overcrowding began to be voiced, with accompanying gestures of planning and contemplated expansion to land off the island. This began with a detailed census, ordered by Blanchot, the chief administrator of Senegal, in 1803. Finding the island too small for its population, Blanchot purchased three nearby small islands, with the hope that residents of Saint-Louis would relocate and ease the crowding on Saint-Louis itself. The response from the

¹ France had formally abolished slavery in 1794 declaring that "all men [sic], without distinction of colour, domiciled in the French colonies, are French citizens, and enjoy all the rights assured by the constitution" (Crowder 1967: 13). Nevertheless, up "until 1833 freed slaves had uncertain status in law, and domestic slaves still existed in large numbers". It was only in 1848 that the category of "*captif* or domestic slave" was abolished (Crowder 1967: 13).

population was overwhelmingly negative, even in the face of the implementation of *l'investissement humain*, a policy of extraction of building materials and labour (or imprisonment for those who could not provide the above) from citizens who refused to move from Saint-Louis². These resources were put towards improvements to the infrastructure of the island, ironically creating a city even more attractive to migrants (Camara 1968: 40). Responses to attempts at in-migration included a twenty-four hour watch along the shores of the island:

The rush towards the island [of Saint-Louis] had grown to such a degree that strict surveillance, day and night, had to be initiated to stop all the boats coming from the continent (Camara 1968: 64, author's translation).

Blanchot's death in 1807, and the subsequent British occupation, marked a period of neglect resulting in the physical and commercial decay of the city (Camara 1968: 40-41). After 1817 and the return of Saint-Louis to French control, the reconstruction and the 'westernization' of the city began anew. A new attitude towards the island outside of the fort had come into place, with a form of centralized planning being contemplated, and later applied. This meant building repairs and new construction, using building materials imported from as far as France and the Canary Islands. In 1829, the rigorous grid-based street so evident today was legislated, although it would appear to

² It is not clear whether this decree applied to all occupants of Saint-Louis or if it was targeted at specific groups.

have existed at that time largely on paper (Camara 1968: 44-45). Between 1830 and 1850 two large barracks, the *Palais de Justice*, a large hospital and the grand mosque were constructed (Camara 1968: 47).

2.3.3 The Battle Against the Huts

After 1854, with the arrival of Faidherbe and an expanded colonial mandate, the city's physical appearance began to reflect more fully the grid plan introduced twenty-five years earlier. Faidherbe began a determined battle against huts. At first, a bonus was offered for building 'permanent' houses. When that initiative failed, a decree was issued which called for the demolition of all straw buildings in an area extending three blocks north and south of the fort, and from shore to shore in an east-west direction. This initiative was followed by others of similar intent. By 1861 an area encompassing seventeen streets north-south had been cleared of 'temporary' buildings. There was considerable opposition to these measures. Rather than using straw only, huts were constructed from wooden planks, or half out of sheet metal and half out of straw. Such building practices were considered "underhanded resistance", and were punished by fines, imprisonment and demolition (Camara 1968: 56-57).

Ostensibly, these measures were initiated by Faidherbe in order to reduce the risk of fire, given that a gunpowder magazine was located within the fort at the centre of the island. Thus, in the reconstruction of the city

The narrow paths serving as fire escape routes were eliminated to allow for the contiguity of the new permanent buildings (Camara 1968: 57, author's translation).

These permanent buildings were constructed out of more fire-proof materials, allowing for contiguous development, but the new development was precisely aligned to the planned grid. Although major fires had broken out among the huts previously, the risk of fire appeared to become an important factor only after Saint-Louis became a centre of power for a larger region, the colony of Senegal, rather than an isolated trading fort. If a fire was to break out in Saint-Louis, the entire territory would be vulnerable to attack. Camara adds, however, that this 'order' created on the island as a result of these massive demolitions

...favoured the creation of a homogeneous zone, clean and healthy, where merchants and mulattos could raise their buildings, still forming today the vital core of the city, the urban part in the Western European sense (Camara 1968: 57, author's translation).

The implications of this statement will be explored in the light of developments in Paris and in other French colonial cities, as described in the following sections.

Figure 2.2
Views of 'La Ville' from 1720, 1780 and 1865
Source: Faidherbe 1899.

Vers 1720 (d'après le Père Lalat)

Vers 1780 (d'après le capitaine du génie Goltz)

En 1865 (d'après une photographie).

2.3.4 Paris as a Model for Saint-Louis: Behind the Aesthetics

The rebuilding of Saint-Louis may be considered in global context: concurrently Haussmann was remaking Paris, described then as "a foul hole where plants wither and perish and four out of seven children die in a year" (Victor Considérant 1848, cited in Rabinow 1989: 74). In Paris, narrow, irregular streets in the city core were widened. Street widths were standardized. Water and sewer services were implemented or improved.

Haussmann's roads were straighter, longer, and wider than ever before; sidewalks were greatly expanded and more gas lamps placed on them (Rabinow 1989: 77).

These changes were not just aesthetic; they were reflections of, among other things, new realizations of the relationship between environment and health, made more apparent by rapid population growth and overcrowding of the old, central quarters of the city, with outbreaks of cholera in 1847, 1848 and 1849 (Rabinow 1989: 74). Widened streets, in addition to increasing mobility, allowed for better circulation of air and more light, and consequent improvements in public health and sanitation. Such measures seem to have been undertaken in response to difficulties in controlling life behind the facade of the house front:

Officials were fully aware of the need to extend the state's control of public health beyond the street, but a combination of popular resistance and Liberal governments ensured that this was very slow in happening (Rabinow 1989: 74).

It was this aesthetic, as reflected in Paris at the time, that Faidherbe would appear to have been aiming at, albeit on a smaller scale, in the remaking of

Saint-Louis³. In both cases, this aesthetic was also a social instrument resulting in the disruption of a sector of the population: while the construction of Haussmann's boulevards in Paris was tied to the "expulsion of the working class from the central city" (Harvey 1990: 421), in Saint-Louis the island became the domain of the "merchants and the mulattos" (Camara 1968: 57) while other ethnic groups were encouraged to migrate off the island.

³ Saint-Louis was an early example of Francophone approaches to the creation of a 'European city' in Africa. Winters comments on such cities:

The early European-type cities in francophone black Africa were designed places. The military personnel and, later, the colonial administrators who were responsible for the urban layout had more control over urban form than did their contemporaries in Europe or the city planners who were active in African cities after World War II. There were two reasons for the unparalleled control of urban design. Firstly the cities were totally new, and preexisting buildings and patterns were not concerns. Second, as officials in authoritarian governments, the administrators could command local labour freely and cheaply. Whatever the evils of the system, it did allow the officials within their considerable budgetary constraints to create cities that reflected the [European] ideals of the period.

The model was usually Haussmann's Paris. The grid was the basic form of the design, often with squares and diagonals intersecting at elaborate traffic circles (Winters 1982: 141-143).

In the case of Saint-Louis, the city was not "totally new", and the remaking of Saint-Louis into a 'European city' meant considerable disruption. This disruption was possible because of the considerable authority of the colonial administrators.

While the street network of the island of Saint-Louis does not include the elaborations mentioned above, the grid is perfectly etched. The street network of Sor, realized later than the grid on the island, is more complex, but only partially realized, since with the transfer of power from Saint-Louis to Dakar at the turn of the century meant that economic resources were transferred to Dakar. It was no longer considered important that Saint-Louis reflect a certain colonial aesthetic, since the city was effectively decoupled from colonial power.

Although it was the risk of fire, not disease, that was the explicit justification for segregation in the case of Saint-Louis, health and the protection from disease have been cited as reasons for dislocation of indigenous populations, rebuilding, and segregation in a number of colonial cities (Betts 1985: 198; Guillaume 1985: 188; Winters 1982: 141). Little argues that:

whereas the original settlement found in all coastal towns of Senegal was not divided into racial sections, new and exclusively European residential zones now took shape, arguments about hygiene being used to justify separation. (Little 1974: 59).

Camara's description above of the creation of a "clean and healthy" zone (Camara 1968: 57), as cited in section 2.3.3 above, corresponds with Little's assertion, implicating health as part of the justification for the aesthetic in the case of Saint-Louis. Segregation of the European⁴ and indigenous populations was part of the result. Although the evidence of this justification of segregation is indirect for Saint-Louis, it is explicit in the case of Dakar.

2.3.5 Dakar as a Comparative Case Study

French colonial power was transferred from Saint-Louis to Dakar in 1902 (Vennetier 1976: 21). By 1914, rapid population growth had resulted in 'unplanned' settlement patterns outside the limits of a settlement laid out by engineers.

⁴ with the *métis* population considered in many ways as part of the European population.

In 1914 Dakar suffered from an outbreak of bubonic plague which generated immediate medical concern, hasty administrative action, and a strong African sentiment that political reprisal was being carried out. It appeared that under the guise of medical necessity political expediency was being followed. The plague had been declared an epidemic one day after the election...of Blaise Diagne, an African opposed to the politics of the municipal authorities, to the French Chamber of Deputies. As the French burned the Lebou [the dominant indigenous ethnic group] huts and then sought relocation of the population, these moves were interpreted by the Lebous as spiteful retaliation for an election that had, in European opinion, gone awry.

...social unrest grew in Dakar. It was such that the movement of the population to what would soon be called the Medina, a specially designated isolated area northwest of the city, had to be carried out with troop support... By two edicts of 1922 and 1931 the *de facto* racial segregation, precipitated by the plague and complicated by local politics, was further defined. Dakar was now divided into two residential zones: one in which all buildings were to be built of durable materials, the other one in which straw huts and wooden barracks would be temporarily allowed. Here then was a spatial arrangement where a 'native Dakar' would develop beside a 'European Dakar'... (Betts 1985: 198).

This scenario was repeated in so many French-African colonial cities that a new French-African term, *déguerpissement*, implying eviction followed by resettlement in new quarters further from the city centre, was coined to describe the process (Winters 1982: 145).

2.3.6 The 'European City' and the 'African City'

Reading the case history of Dakar would indicate that in the case of Saint-Louis all the factors and motivations behind this process of "purification

of space"⁵ (Sibley 1988) are not necessarily accessible on a surface reading of the literature, and that readings of the actions of the French administration depend upon the viewpoint taken. What does emerge from the histories of colonial cities, is a general form to the physical layout of the 'colonial city', connected to a process of development centered around a delineated city core, the "European city" or "*zone urbaine*" (Winters 1982: 141), with strong colonial control over the aesthetics, layout, and appearance of the settlement within that core, and a relative disregard for the nature of settlement outside the delineated area. Often there was a physical separation between the 'European city' and the 'African city', related to the physical attributes of the site (Winters 1982: 141). Periodic expansion of the colonial core, due to increases in commerce, or extended military and administrative functions, was problematic and led to conflicts with the indigenous population, living around the *zone urbaine* in the "African city" or pejoratively, the "*zone semi-urbaine*" (Winters 1982: 141). In the process of displacement of the old *zone semi-urbaine* and the

⁵ The purification of space is defined as "the desire to homogenize space and to erect boundaries which secure the integrity of purified spaces" (Sibley 1988: 417), where the concept of purification, taken from social anthropology, involves the exclusion or expulsion of elements which are perceived to pose a threat to a certain group (Sibley 1988: 411). What makes Sibley's conceptualization particularly relevant to this work is the linkage he makes between the perception of a tendency for groups to seek the purification of space and the tendency of social science research to search for such purification, given the "general failure of social science to handle ambiguity" (Sibley 1988: 417). The implications of such links will be explored in chapters five and six.

expansion of the *zone urbaine*, a new *zone semi-urbaine* developed around the larger *zone urbaine*.

This process is illustrated for Saint-Louis by two maps from 1854 and 1885 (figure 2.1), which show in 1854 a new periphery, made up of Guet N'Dar and Bouetville, following expansion of the *zone urbaine* core on the island of Saint-Louis. In both Guet N'Dar and Bouetville, the settlement patterns are characteristically irregular, serving as examples of the "organic edge" of the colonial city, as opposed to the "carefully platted, neat centre" (Winters 1982: 145). Guet N'Dar, situated on the Langue de Barbarie, termed as the *quartier des pecheurs* (Camara 1968: 161), is portrayed on a 1789 map as a small settlement, circular in shape (Camara 1968: 36), probably already tied to the fishing economy, although Guet N'Dar existed off the island of Saint Louis. The settlement of Bouetville, on the island of Sor, by freed Bambara slaves in 1852 marked the beginning of a successful effort by the colonial administration to relocate inhabitants away from the island of Saint-Louis itself (Faidherbe 1889: 69).

The 1885 map documents the considerable changes after 1854. By 1885 a rail link to Dakar had been completed, with the Saint-Louis terminus located in Sor, and a bridge between Sor and the island of Saint-Louis (known as L'Ile) was in place. Sor had become a commercial centre, subject to greater colonial

control than when it was founded, and reflected in the grid-based blocks and street layout which had largely replaced the 1854 settlement pattern in Bouetville. N'Dar Tout, to the north of Guet N'Dar, had been created as a *village de liberté* for freed slaves, but it did not begin to grow until around 1860 (Camara 1968: 49, 55). As a favoured area for the summer homes of the *métis* community, it became known as "Petit Saint-Louis", with its newly created, grid-bound morphology reflecting its moniker. The morphology of Guet N'Dar, judging from the map, was transformed as well. These were early examples of the colonial attempts to "impose geometric order of the European city on the African sectors" (Winters 1982: 145), although one might argue that in functional terms, the *métis* summer dwellings and the railroad terminus were very much a part of the 'European city', and that these areas were examples of growth of the core.

The process would appear to have continued into the present, with much of Sor reflecting a colonial imprint⁶, and Pikine, a neighbourhood established around 1960 (Camara 1968: 257), as an example of a current

⁶ Although it is a different type of imprint from that imposed on l'île. The road network is a modest replica of the diagonals and circles of Haussmann's Paris, whereas neighbourhoods such as N'Diolfène reflect the "garden city" aesthetic, characterized in the colonial context by neighbourhoods of detached bungalows (appropriated and adapted by the British from East Indian models, see King 1984), set along straight streets and surrounded by trees (Winters 1982: 143). Later colonial developments in Léona, started in the 1950s, include grids of multi-story apartments intended for civil service functionaries (Camara 1968: 249).

peripheral residential area. In Camara's words, Pikine is a "village Africain" (Camara 1968: 25), exhibiting a much more 'organic' appearance than the neighbourhoods closer to the centre of the city. Camara underlines the historical continuity in this process: "Pikine ... had its birth in Bouetville" (Camara 1968: 56, author's translation), implying linkages to Bouetville at its inception, not to its later, more 'European' manifestations. This link may be made in spite of the one hundred year gap between the founding of the two neighbourhoods.

This chapter has thus far traced the creation of a colonial city with an expanding 'European' core and an 'African' periphery. Winters summarizes the difference between the process of development of the European settlement and the African settlement:

While the European city grew by in-filling of the grid, the early African settlements probably started with a single, isolated structure and grew by accretion of additional buildings (Winters 1982: 144).

This may point to ways of differentiating between neighbourhoods of the colonial city, through the examination of segregation.

2.4 Segregation

Winters argues that segregation made be tied directly to morphology, especially in African settlements:

Initially there was a tendency for Africans to sort themselves by ethnic group but the practice became less marked with the passage of years. As long as the practice continued, there were often several separate spontaneous settlements, each with its own chief or headman, at the edge of the European city (Winters 1982: 144).

This segregation will be discussed in section 2.4.2. But segregation was not limited to the 'African City'. Evidence shows that the 'European city' was hierarchically organised and various forms of segregation existed. This segregation, like that cited above, could be tied to urban morphology.

Although by the 1860s, the L'Ile (the island of Saint-Louis, as distinct from settlement on the Langue de Barbarie or Sor) had taken on a distinct 'European' morphology, differences between neighbourhoods within this 'European city' have been shown to be tied to the ethnic composition of those neighbourhoods at given points in history. The following section examines segregation and uneven growth within the 'European city'.

2.4.1 Historical Segregation in the 'European City'⁷

The development of a section of L'Ile , characterized by wide streets and comfortable homes, situated just to the south of the fort, "seems to trace very closely the destiny of the *métis*" (Camara 1968: 275, author's translation). This neighbourhood is still known today as Kertian, the name derived from the word *chrétien* (Camara 1968: 275-276), reflecting the faith of the *métis*. The maintenance of the distinctive physical characteristics of this neighbourhood still exists despite the disappearance of the *métis* population: in 1873 they made up 13.33 percent of the population of Saint-Louis but by 1965 that proportion was only 0.05 percent (Camara 1968: 276). The *métis* population, so influential in the political and economic life of the colony up until the end of the nineteenth century, isolated themselves from the indigenous population, marrying within the group or to whites. With low birth rates, and an exodus to France in the early 1900s the *métis*, as a group, vanished (Camara 1968: 274-275). Table 2.1 shows population statistics disaggregated by race, indicating

⁷ The most current population data presented in this chapter date from the mid 1960s. The lack of more recent data is due to several factors. First, much of the most pertinent data, referring to specific neighbourhoods in Saint-Louis, was not part of a conventional census, but collected by Camara for the specific study on Saint-Louis. While it would have been desirable to collect similar information which corresponds more to the date of the aerial photography, it was considered beyond the scope of this thesis. The use of historical demographic data is justified further by the 'memory' of the city's morphology, in that its urban morphology would seem to reflect the past as much as the present. This condition is discussed throughout the main text.

the relative decline of the European and *métis* population *vis-a-vis* the Black population. The remainder of the southern half of the L'Ile, known as Sindoné, with narrower streets and less grand houses, reflects Camara's description that it was "abandoned" to the Africans who flocked to Saint-Louis from the continent (Camara 1968: 276). The implication of such a description is that there was a lack of control or a sense of disorder in the development and appearance of the neighbourhood, tied to the ethnicity of the inhabitants.

Table 2.1

Saint-Louis: Population Figures Disaggregated by Race 1800-1963

	1800	1869	1925	1955	1963
Blacks	5,400	12,480	20,000	51,000	60,000
Métis	—	2,000	366	—	30
Whites	660	1,000	807	1,925	1,023

Sources: Camara 1968: 65-72; Winters 1982: 148

Other examples of segregation and uneven development on L'Ile exist. Both the extreme north and south ends of the island are characterized as "villages" which do not conform to the norms of urban habitation (Camara 1968: 18), the implied norm being the centre of the island, as exemplified by Kertian and the commercial centre just to the north of the fort at the centre of the island. Segregation and hierarchy are also evident in the distribution of commercial concessions in the commercial quarter, the north half of L'Ile. Whereas European commerce located itself in the centre of town, increasingly

peripheral positions were occupied by the Moroccans, followed by the Lebanese and finally by the Mauritians, although Camara notes that the spatial distribution of these concessions is less rigid than it was before the transfer of the capital to Dakar (Camara 1968: 148-49).

2.4.2 Segregation Within the 'African City'

Segregation is also evident in the more 'indigenous' neighbourhoods. The Wolof, the ethnic group indigenous to the area, made up 78.1 percent of the indigenous population for Saint-Louis as a whole in the early 1960s. This distribution was uneven, however, with higher representation in older, well established neighbourhoods such as Guet N'Dar, where they made up 92.9 percent of the population (see table 2.2). N'Dar Tout, located on territory subject to invasions of Mauritians before it became the summer domain of the *métis* (Camara 1968: 52), was 56.7 percent Wolof in the 1960s, with Mauritians making up 19.8 percent and other ethnic groups completing the breakdown with 14.9 percent. In close proximity to the Mauritanian border, N'Dar Tout was previously populated more heavily by Mauritians, but since the transfer of capitals, the Mauritians have scattered throughout the city, the more prosperous merchants among them taking over the commercial establishments of departing Europeans (Camara 1968: 260).

Table 2.2
Saint-Louis: Ethnic Breakdown of Selected Neighbourhoods 1960-1963
(Percentage of total population within each reporting area)

	Dagana*	Saint-Louis	Sud	Guet N'Dar	N'Dar Tout	Pikine
Wolof	61.7	78.1	81.7	92.9	65.3	61.8
Other	38.3	21.9	18.3	7.1	34.7	38.2
Maures*	8.1	—	—	6.0	19.8	—
Peuls*	26.1	—	—	—	—	—
Toucouleurs*	—	—	—	—	—	12.0

*The District of Dagana is the administrative district in which Saint-Louis is situated.

*These ethnic groups represent a partial disaggregation of the 'other' category.

Source: Camara 1968: 31, 260-265

Sor has a very different character. Originally founded in 1852 by freed Bambara slaves (Faidherbe 1889: 69, Camara 1968: 49), it is more heterogeneous than l'Île or the settlements on the Langue de Barbarie. The Bambaras maintained strict ethnic segregation until 1933, when it was broken by a *métis* move to wrest away the Bambara land in favour of the dominant Wolof, resulting in the partial dispersal of the Bambara to other neighbourhoods within Saint-Louis. At the same time they showed a tendency to resettle as a group in Sénofobougou, a section of Sor. Camara states categorically, "The Bambara live in Sénofobougou" (Camara 1968: 262, author's translation), although an ethnic breakdown is not provided to substantiate this. The Toucouleurs can be found in all parts of Saint-Louis, but especially in Sor (Camara 1968: 83). Exact numbers are difficult to obtain, especially since many

Toucouleurs migrate back and forth between Saint-Louis and their rural communities (Camara 1968: 83).

This is not to imply that Sor is not predominantly Wolof, for it is, but it has a different, more diverse character than the older settlements on L'Île and the Langue de Barbarie. This diversity would seem especially evident in Pikine, a bidonville on the periphery of the city. Here the proportion of the population of Wolof descent was only 61.8 percent in the 1960s (Camara 1968: 261), compared to the Saint-Louis average of 78.1 percent. While conventional wisdom would say that bidonvilles act as a receptacle for migrant population (McTaggart 1988: 30-31), this has been found not to be the case in Pikine. A survey carried out in 1963 found that 88 percent of Pikine residents had moved from other areas of Saint-Louis, especially from Leona, a section of Sor directly to the north of Pikine. The remaining 12 percent had arrived from diverse parts of Senegal and Mauritania (Camara 1968: 270). The ethnic mix found in Pikine is thus largely drawn from Saint-Louis itself, but it would seem that the non-Wolof population is drawn (by economic necessity or choice) to Pikine more than the Wolof population. This argument will be continued after discussion of the final factor, the demographic characteristics of the neighbourhoods.

While historical or current ethnic compositions of neighbourhoods might help to explain their morphology on a case by case basis, it is difficult to generalize about the city as a whole. One might hypothesize, for example, that the degree to which the morphology of a neighbourhood is 'organic' is directly related to its ethnic diversity. In Saint-Louis, based on the limited data available, this would mean that Pikine should be the most organic and Guet N'Dar should be the most regular. While the morphology of Guet N'Dar is based on a grid, it would be difficult to argue that Guet N'Dar was more 'grid-like' than Sud, the southern half of L'Ile, the area which most visibly retains the plan imposed by Faidherbe in the nineteenth century. One could argue, of course, that the historical segregation of the *métis* population, and the degree to which L'Ile became the commercial centre of Saint-Louis must be considered, but reliance on such arguments underlines the difficulties in making generalizations.

In addition, it is clear from the above historical sketch that segregation has been directly related to the colonial process. Racial segregation was imposed when there was a desire to expand the colonial core, to allow for expanded European commerce, administration and residence. Ethnic segregation of the Bambara population, for example, was related to European

evangelistic practices⁸, and such segregation was disrupted by the desire of the *métis*, the indigenous group most intimidated in the process of colonization, for access to the land occupied by the Bambara. The dispersal of the Mauritanian community throughout Saint-Louis occurred only after the transfer of the capital from Saint-Louis to Dakar, when Saint-Louis was no longer such a strategic centre to the French.

There remains one factor left to investigate, the issue of how neighbourhood demographic characteristics, in particular growth rates and age-sex structures, may be related to neighbourhood morphology.

2.5 Demographic Characteristics

2.5.1 Neighbourhood Growth Rates

A glance at the growth rates of selected neighbourhoods over a hundred year period reveals some astonishing contrasts (table 2.3). The population of L'Île barely increased over the period between 1857 and 1960, although one might speculate that the island was more densely populated later in the 1800s

⁸ The Bambara were converted to Protestantism upon their arrival to Saint-Louis, creating, besides ethnicity, another layer of isolation from the indigenous community, which was predominantly Roman Catholic (Camara 1968: 262).

and its population declined with the transfer of the capital to Dakar at the turn of the century. In contrast, Sor, which had just begun to be settled in 1857, had grown to a population of 24,352. The population of the Langue de Barbarie experienced similar growth, with an 1857 figure of 1488 comparing to 1960 figure of 17,506. Between 1954 and 1960, the population of the L'Ile grew by a yearly average of 1.5 percent, while the average yearly growth for both Sor and the Langue de Barbarie was 7.25 percent. Pikine, with an embryonic population of 169 in 1954, had grown to 1,171 in 1960 and mushroomed to approximately 6,000 by 1963, with an average yearly growth rate for the period 1960 to 1963 of 141 percent. These figures would seem to correspond with the author's intuitive sense of the respective neighbourhood morphologies, where slow growth is tied to strict geometric order in the 'European city', very rapid growth is associated with the 'organic' form of the 'African city', and intermediate rates are associated with hybrid morphologies, where the grid is visible but not so dominant⁹.

⁹ A better analysis of growth rates would be possible with data from intermediate time periods between 1857 and 1954. It is likely that the growth rates for L'Ile ca. 1857 was higher than is indicated from the sporadic data available, but that it would still not be as high as that in the 'uncontrolled' periphery.

Table 2.3
Saint-Louis: Population Figures by Neighbourhood 1857-1963

	1857	1954	1960	1963
L'Ile	12,081	11,462	12,696	---
Langue de Barbarie	1,488	11,033	17,506	---
Sor	308	16,148	24,352	---
Pikine	---	---	1,061	6,000

Source: Camara 1968: 255-257

2.5.2 Age-Sex Ratio

As outlined in section 2.4.2 above, the extreme growth rates in the population of Pikine are not associated strongly with in-migration from rural areas, since most of the population of Pikine comes from other parts of Saint-Louis. Consequently the age-sex structure of Pikine differs from that of bidonvilles in other African cities, characterized by a preponderance of young males, recently arrived from rural areas, searching for employment (Camara 1968: 271). A survey in 1963 of approximately one sixth of the population of Pikine (Camara 1968: 266-270) yielded a sex ratio of 1035 females per 1000 males. An unusually large proportion of females between twenty and thirty-five years of age is explained by the practice of polygamy, and by the large numbers of single young women, often living in groups, selling water, especially in the dry season (Camara 1968: 269).

The southern part of L'Ile, Sud, possesses an even more skewed sex ratio, with 1262 females per 1000 males. Again, this may be explained by polygamy. The population is predominantly Wolof (81.7 percent), and the polygamy rates are higher for the Wolof than for any other ethnic group in the area. In this prestige area a Wolof man is not considered a proper bourgeois until he has three or four wives (Camara 1968: 265). In terms of age structure, Sud has a higher dependency ratio than Pikine (table 2.3): Sud has both a greater percentage of population over 50 (16 percent to 8 percent), and a greater percentage of its population under 15 (45.8 percent to 41 percent). Sud is "stable" and established whereas Pikine is "new" (Camara 1968: 265-267): the history and morphology of these two neighbourhoods is reflected in their demographic characteristics. Information on age-sex structure is limited to Sud and Pikine, but results for these neighbourhoods conform to the population growth statistics and to the notion that the 'European City' is generally more established, prosperous and stable than the 'African City'.

2.6 Conclusions

In terms of their morphology, all the neighbourhoods of Saint-Louis, 'European' or 'African', 'grid based' or 'organic', reflect the process of the deliberate construction of a 'colonial city'. The colonial process is strongly related to population growth. It is less easy to generalize about segregation,

although consideration of the history of segregation has been shown to aid in the interpretation of urban morphology. It should thus be possible to interpret the morphology of aerial imagery of these neighbourhoods in terms of both colonial history and population growth rates. Texture is related to morphology in a series of disciplines. Texture is also a part of the vocabulary of "social space" (Lefebvre 1991), tied closely to the discussion in this chapter. In the next chapter, this usage of 'texture' will be compared to other usages of the term from the literature on order and disorder, and from discussions within the context of remote sensing, in order to tease out the commonalities of meaning of the same term in different contexts.

3 THEORETICAL FRAMEWORK

3.1 Introduction

This chapter sets out to establish a theoretical framework for the textural analysis of aerial imagery of Saint-Louis which relates the social history of Saint-Louis to its contemporary morphology, while providing the tools for the examination of that morphology. The approach arises from a dissatisfaction with traditional morphological approaches, which have tended to be either purely descriptive (see, for example, O'Connor 1983), or functionalist. Functionalist approaches are exemplified by the Urban Ecology (see Berry and Kasarda 1977; Hawley 1971; Park 1925) and the Systems-Theory schools (see Allen 1982; Davis 1973; Schlossberg 1982; Wolman 1965)¹. Neither the

¹ Both the Urban Ecology and Systems Theory schools can be conceptualized as stemming from the same source, in that both rely heavily on concepts derived from plant and animal ecology. Urban ecology, as developed in the early decades of the twentieth century, borrowed ecological concepts then current, such as competition and dominance, invasion and succession. The concept of the ecosystem, as introduced to ecology by A. G. Tansley in 1935 (Worster 1977: 301-302), was a strong influence on the systems theory school. See Stoddart (1986: 230-270) for the influence of ecological models on geographical thought. Linkages between both 'phases' of physical ecology and

descriptive nor functionalist approach deals very well either with the complex and irregular forms of this case-study city, or with its political, social and economic history.

While morphological approaches to the analysis of first-world urban phenomena have been heavily criticized for a number of decades (see Entrikin 1980; Goheen 1970: 21-43; Gottdiener 1985: 25-69; Saunders 1986: 52-83), the morphological approach to third-world cities has retained a currency which has only recently been challenged (Bassett 1989: 480; Simon 1984). O'Connor, in his oft cited descriptive typology of African cities (1983), is unapologetic about his focus on morphological description, claiming that the diversity of African cities makes a more theoretical approach futile. Although Simon (1984) considers O'Connor's "authoritative" work an improvement over previous attempts at creating a typology of cities, he disagrees with O'Connor regarding the utility of venturing beyond description of morphology. Simon's exploration of a more encompassing conceptual framework thus serves as an inspiration to establish a framework which, while still allowing for the investigation of morphology, allows for the incorporation of other realms.

culture are explored by Csanyi (1989: 87-90, 156-158). Histories of ecological thought are found in Bramwell (1989) and Worster (1990; 1977).

One could perhaps make the case that more recent explorations of urban morphology (including this thesis) reflect the current state of ecology, with its focus on multiple equilibria states, and the incorporation of chaos theory (Holling 1986; Lovelock 1987).

In order to establish this framework, I chose to explore the concept of texture, as referenced in four separate bodies of literature. The first body of work is research on the critical theory of space, specifically the exploration of texture within Lefebvre's (1991) concept of social space. The second involves debates about texture within the field of order and complexity, both in the abstract sense (Kuntz 1968a; Livingstone 1984) and related more specifically to human settlement (Rapoport 1984; Clement-Charpentier 1989). The third realm is fractal geometry, conceptualized by Mandelbrot (1983: 310) as an implicit study of texture. Combining these three approaches allows the linkage between texture and morphology at the abstract level, and the linkage between the abstract and the cultural realms. Texture as used in all three realms is tied to the fourth realm, remote-sensing use of texture, usually defined as a method of measurement of an image or surface, rather than a characteristic of that image or surface. It is at this level of measurement that any theoretical discussion of texture must be applied, to examine textural phenomena.

Using remote-sensing images in this way is a 'snapshot' approach, with the analysis based largely on aerial imagery captured at one instant, but it is tied to time, since time and space are often conceptualized as linked (Harvey 1990, but see also Klein 1983). Consideration of the colonial history of the city, as outlined in the previous chapter, is essential in the interpretation of urban space. As Thompson has said, "form is a diagram of forces" (Thompson 1968

cited in Olson 1979: 574). Space is produced through time; properly read, space may function as a record of time.

3.2 Social Space

The body of research I have labelled as the 'critical theory of space', is based on the work of Henri Lefebvre. Its strength is its ability to integrate the social and political realms with those of the individual, in examining the contradictions inherent in the concept of socially produced space. It concerns itself with the question of "space for whom?" in considering the way that social and spatial relations interact. While this research is theoretically rigorous, it lacks an accompanying set of "gadgets" (Foucault 1980: 65) for applying the theory to practical problems. Perhaps this is the way it should be, in that there cannot be a simple set of techniques which accompany such a complex theoretical analysis, but this thesis is an attempt at creating and merging technique and theory.

The concentration in this thesis on the concept of space would seem to indicate the need for a working definition of the term space. I am not going to propose one at this point, however; this work, and much of the literature on the critical theory of space might be thought of as an exploration of the concept of space, leading towards the posing of a working definition. What I

would like to outline instead is the conceptual dichotomy which has dominated the discourse on space since the Enlightenment. This is exemplified by the Cartesian distinction between *res extensa*, space as an abstract, homogeneous, and isotropic object, tied to Euclidean geometry, and *res cognitans*, mental space, space as experienced (Lefebvre 1991: 1). Through this distinction and later work building on, and sometimes questioning Descartes (see Popper 1969), *res extensa*, the 'ideal' space of mathematicians and scientists, became separate from what Lefebvre terms 'real' space, "the space of social practice" (Lefebvre 1991: 14). Eventually, through social and political practice, *res extensa* became dominant:

In the commonsense world that we inherit from the Enlightenment, 'space' has little concreteness: unobservable as such, it is presumed not to exist (Shields 1991: 50).

The realization of how this process has affected the way in which space is viewed is critical to an understanding of Lefebvre and his attempts to dissolve the barriers between disciplines which have emerged since the Enlightenment (see Sack 1980: 177 and Lawlor 1982 for commentary on pre-Enlightenment approaches). This process of changing the way that space has been defined and used over time is elaborated in section 3.3, below.

In a world where *res extensa* is dominant, the use of the map to represent space is often seen as unproblematic (see Peuquet 1988: 377). Although Mark and Frank (1989), working within the cartographic discipline,

question the map as a valid representation of space, their critique stems from the experiential model of individual perception, to the exclusion of the social and political realms. Lefebvre's approach to space directly addresses these areas. He proposes a new term, social space, to describe space as socially produced (Lefebvre 1991: 36-39) and to distinguish it from the scientific space of philosophers and mathematicians. Lefebvre's influence on contemporary geographic thought has been considerable. Soja's concept of spatiality², "socially produced space" (Soja 1989: 80), and the concept of social spatialization, as proposed by Shields (1991: 57-65), can be traced to Lefebvre. Harvey's recent work (1989; 1990) refers to Lefebvre extensively.

Lefebvre describes the concept of social space as itself being made up of three concepts: spatial practice, representations of space, and representational spaces, respectively corresponding to the realms of the perceived, the conceived and the lived (table 3.1) (Lefebvre 1991: 38-40). Spatial practices are, for example, flows of money, labour, information and goods, uses of land and practices of property ownership and subdivision (Harvey 1989: 220-221). They may also be considered as the daily spatial routines of individuals, which over time are "sedimented in the landscape" (Shields 1991: 53). Representations of space are instances of

² Other conceptualizations of spatiality which have not been explicitly informed by Lefebvre include the phenomenological approach of Pickles (1985), and Sack's (1980: 181) nested degrees of spatiality.

conceptualized space, the space of scientists, planners, urbanists, technocratic subdividers and social engineers ... all of whom identify what is lived and what is perceived with what is conceived. (Lefebvre 1991: 38)

While representations of space tend to be "systems of verbal (and therefore intellectually worked out) signs", representational spaces are "systems of non-verbal symbols and signs" (Lefebvre 1991: 39). Representational spaces are spaces of the "inhabitants and users", spaces which are "dominated and hence passively experienced" but which "the imagination seeks to change and appropriate" (Lefebvre 1991: 39). There is a logical necessity that the three realms be interconnected (Lefebvre 1991: 40).

Table 3.1 (After Lefebvre 1991, Shields 1991)

Social Space is composed of:

Spatial Practice (the Perceived)

Daily spatial routines of individuals, flows of money, labour, and goods, uses of land and practices of property ownership

Representations of Space (the Conceived)

Conceptualized space, the space of scientists, planners [and] technocratic dividers ... all of whom identify what is lived with what is conceived (Lefebvre 1991: 39)

Systems of verbal signs

Representational Spaces (the Lived)

Spaces of the "inhabitants and users", spaces which are "dominated and hence passively experienced", but which "the imagination seeks to change and appropriate" (Lefebvre 1991: 39)

Systems of non-verbal signs

Clearly this conceptualization is complex. Social space is at once quantitative and qualitative (Lefebvre 1991: 191; see Schatzki 1991 for a commentary). It is both a "medium for social actions, because it structures them, and ... a product" of those actions (Shields 1991: 52). Various social spaces operating in different spatial reference frames are intertwined,

with a structure far more reminiscent of flaky *mille-feuille* pastry than of the homogeneous and isotropic space of classical mathematics (Lefebvre 1991: 86).

3.3 What to Do with Theory, Part I: The Spatial Periodization of History

One of the major questions arising from this interpretation is how it may be used in analysis. Lefebvre offers several paths: the first is to recast history into an explicitly spatial periodization, beginning with absolute space (the space of rites and ceremonies appropriated from those who produced it), through to historical space, where the concept of exchange value became more general (Lefebvre 1991: 48-49). This "space of accumulation", corresponding roughly to the late imperial and early medieval periods (Lefebvre 1991: 253) was superseded by abstract space, "the space of the bourgeoisie and capitalism" (Lefebvre 1991: 57). Abstract space, currently dominant, has fused with the concept of *res extensa* such that knowledge has rendered power transparent:

We find that abstract space so understood is hard to distinguish from space postulated by the philosophers, from Descartes to Hegel, in their

fusion of the intelligible (*res extensa*) with the political - their fusion, that is to say, of knowledge with power (Lefebvre 1991: 308).

Since Euclidean space serves as a reference for abstract space, and abstract space is often reduced conceptually to Euclidean space, it follows that

the initial reduction leads easily to another - namely, the reduction of three-dimensional realities to two dimensions (for example, a plan, ...a map, or any kind of graphic representation...) (Lefebvre 1991: 285; see also Harley 1989; Harvey 1989).

Lefebvre's recasting of history is very much based on European traditions, with occasional insights into other cultures. In the case of third-world cities, two different conceptions of space coexist in time, although there is considerable tension between them. Lefebvre describes the third-world city in terms of relations between city core and city periphery:

Differences endure or arise on the margins of the homogenized realm, either in the form of resistances or in the form of externalities ... What is different is, to begin with, what is excluded: the edges of the city, shanty towns ... Sooner or later, however, the existing centre and the forces of homogenization must seek to absorb all differences ... (Lefebvre 1991: 373)

Also described in comparison/contrast to the core are the links between social space and social life within the periphery of the city:

The vast shanty towns ... manifest a social life far more intense than the bourgeois districts of the cities. This social life is transposed onto the level of urban morphology, but it survives inasmuch as it fights in self-defense and goes on the attack in the course of class struggle in its modern forms. Their poverty notwithstanding, these districts sometimes so effectively order their space - houses, walls, public places - as to elicit a nervous admiration ... The spontaneous architecture and planning ('wild' forms, according to a would-be-elegant terminology) prove

greatly superior to the organization of space by specialists ... (Lefebvre 1991: 373-74)

This spatial recasting of history (both sequential and simultaneous) casts new light on the relationship between knowledge (in this case spatial knowledge) and power in a much more explicit way than does Foucault, a reluctant geographer at best (Foucault 1980; 1984), whose use of spatial metaphor cannot be interpreted as anything more than metaphor. Lefebvre's wedding of disciplines, his refusal to accept the categorization of knowledge, is part of the basis of the 'spatial history' of Saint-Louis sketched in Chapter Two above.

3.4 What to Do with Theory, Part 2: Texture in the Context of Social Space

The second path of analysis is provided by Lefebvre's references to texture. Lefebvre provides no formal definition of texture and his writings on the concept sometimes seem contradictory. One apparent confusion is in the size of the region which constitutes a texture. On one hand, "the town and its surrounds constitute a texture" (Lefebvre 1991: 235), but neighbourhood textures are also implied:

... it is helpful to think of architectures as 'archi-textures': to treat each monument or building, viewed in its surroundings or context, in the populated area and associated networks in which it is set down, as part of a particular production of space (Lefebvre 1991: 118)

This apparent confusion becomes clear in the realization of the correspondence of texture to the notion of overlapping social spaces, operating in different

hierarchies and different reference frames. Textures may also overlap each other, interacting with each other.

Textures may also incorporate forms and structures, features which are identifiable as individual entities at some resolution:

The theory of space describes and analyzes textures. As we shall see, the straight line, the curve ..., the check or draughtboard pattern ... and the radial-concentric (centre versus periphery) are forms and structures rather than textures. The production of space lays hold of such structures and integrates them into a great variety of wholes (textures). A texture implies a meaning -but a meaning for whom? For some 'reader'? No: rather for someone who lives and acts in the space under consideration, a 'subject' with a body - or, sometimes, a 'collective subject' (Lefebvre 1991: 132).

The implications of this passage are several. First, texture is tied to sense of place, for those who live in the space. Texture, then, helps tie space to place. Second, Lefebvre ties texture to other forms of organization; the integration of structures may form a texture. Lefebvre's notion of order is tied to society, but it may be considered in more abstract terms. This corresponds to conceptualizations of texture within the more abstract framework of order and complexity. Here we are faced with a problem of ensuring that there is a correspondence between literatures regarding the understanding of the concept of texture. Before examining this correspondence, however, I wish to introduce Amos Rapoport's approach to texture within the study of urban phenomena, an approach based less on social theory and more on architecture. Such an approach conceptualizes space as unproblematically physical and

measurable, but is also concerned with the relationship between the physical environment and those who live in it. As Rapoport draws explicitly on abstract discussions of order and complexity in his discussion of texture, as related to urban form, a summary of his work serves as an introduction to that body of literature.

3.5 Rapoport's Approach to Texture

In *Human Aspects of Urban Form*, Rapoport outlines thirteen "cues", by which urban areas may be subjectively defined and distinguished. These include cues which are apparent only to the observer *in situ*, such as noise levels, smells and activity levels, but three of these cues can be detected using remote sensing. They are:

1. Levels of complexity
2. Urban grain and texture
3. Scale and size, building height and density
(Rapoport 1977: 150)

Concepts of complexity and texture have been considered in more abstract terms, as part of the discourse on the notion of order (Arnheim 1968; Atlan 1984; Serres 1984). Complexity may be defined in terms of order. Rudolf Arnheim states that:

Order and complexity are antagonistic, in that order tends to reduce complexity while complexity tends to reduce order. (Arnheim 1968: 154)

If complexity is defined as "the multiplicity of relationships among the parts of an entity" (Arnheim 1968: 154), then it would seem that the degree of complexity would be related to the grain, or texture of the entity. Arnheim links complexity to texture by conceptualizing texture as a quality of order which contains a minimum of complexity, mainly because the resolution is such that the variation is not apparent. According to Arnheim, texture results

when the elements of pattern appear quite similar, or when their shapes and interrelations vary so irregularly that they cancel each other out instead of adding up to a distinct design. (Arnheim 1968: 160)

Texture, then, contrasts to more complex qualities of order, such as hierarchy, "in which the elements are distributed along a gradient of importance" (Arnheim 1968: 162). These ideas of hierarchy and complexity, arising from Rapoport's first cue, and the concept of scale, from Rapoport's third cue, will be related to the fractal concept of self-similarity in section 3.8.

Rapoport's second cue, grain or texture, is also related, at least in perceptual terms, to his third cue, scale or size. Rapoport defines urban grain or texture as "the number of elements per unit length or urban fabric" and considers that grain "may play a role in perceived density" (Rapoport 1977: 204), relating it, in perceptual terms, to scale and size. Texture relates to scale and size in more abstract terms as well. In terms of imagery, texture is defined with reference to the size of the tonal primitive, the homogeneous tonal building block which is considered to form the texture of an image (Haralick

1986: 255-257). The concept of texture will be further examined in section 3.7, following a brief discussion of the concept of order itself.

3.6 Order, Disorder and Complexity

An extensive discussion of the concept of order will not be attempted here. At least two interdisciplinary explorations of the concept have been published (Livingstone 1984; Kuntz 1968a), providing much of the source material for this summary. In some ways these discussions clarify issues, in other ways more questions are raised than answered. Rapoport, drawing on the Kuntz volume in his discussion of urban order, acknowledges this difficulty:

One interpretation [of order] is that it is anti-entropic, i.e. involves organization³, but that idea is equally difficult to define; replacing one

³ The ecologist Howard Odum, in the context of systems theory, relates order and entropy to the amount of energy required to maintain a system at a given level of complexity, citing an experiment involving

...the progression of fluid vortices that develop as one increases the temperature gradient through an oil that is located between two glass plates...As the energy applied increases, hexagonal cells develop; then forming row patterns that seem fairly regular; and with more energy developing, more complex hierarchies form that seem less regular (Odum 1983: 324).

Odum notes the multiple meanings in the word 'order':

On one hand, it refers to simple structure as in a low-entropy crystal. On the other hand, it refers to complex, high entropy structures maintained away from equilibrium...(Odum 1983: 315).

Odum does not hesitate to extend such thinking, based on experimentation with closed, physical systems, to open human systems, and sometimes extends

concept with another is not useful. Assuming, then, that order involves organization, we return to that elusive concept of order. (Rapoport 1977: 52)

Henri Atlan shows that the problems in dealing with the concepts surrounding the term 'order' stem from the fact that they are self-referential, since using language to discuss such concepts "is making use of the kind of order always implicit in the use of language" (Atlan 1984: 109).

We are thus cautioned about the utility of endless semantic arguments over the definitions of concepts which are nebulous at best. Before leaving this discussion, however, I wish to cover two points. The first stems from Paul Kuntz's (Kuntz 1968b) distinction between chaos and order, where chaos⁴ is considered to be the negation of order. Kuntz posits that in human

the analogy to absurd lengths, with his conceptualization of the world, including heaven and hell, as a series of systems (Odum 1971). If we extend the analogy only slightly, however, to examine urban morphology in terms of the experiment cited above, Rapoport's idea of "different orders" (Rapoport 1984: 62) is reinforced and enriched. Present are the notions that order may exist but not be comprehensible to some observers, and that such 'invisible' order may in fact be more complex than more regular forms of order. When applied to the study area such ideas would tend to contradict assertions such as that of Camara's, that Pikine is totally lacking in spatial organization (Camara 1968: 252).

⁴ Chaos, in this sense, is not to be confused with the *chaos* of chaos theory, where chaos implies a very definite order, an order with "a fantastic and delicate structure implying complexity" (Gleick 1987:4). Historically, it would seem that this order was difficult to perceive, although "now that science is looking chaos seems to be everywhere" (Gleick 1987:5). This definition of chaos ties more to Kuntz's notion of disorder than his notion of chaos.

experience, chaos is an hypothetical state, a state we never experience, unlike disorder, the lack of correlation of orders, a state which we often experience:

Disorder is the uncoordinated which we can coordinate, whereas chaos is the undifferentiated which we cannot differentiate. (Kuntz 1968b: xxxv)

Disorder thus implies a clash of orders. Second, as Atlan reminds us, our concept of order is rooted in and shaped by language. Kuntz would extend that to include culture:

...some define relations rationally, as geometric figures, others prefer the organic order of growth that cannot be easily defined. (Kuntz 1968b: xxix)

Both language and culture affect one's conception of order, and order is a normative concept (Kuntz 1968b: xxix). The origin of Morris's definition of organic growth as "unplanned" (Morris 1972: 9), and Camara's description of the neighbourhood of Pikine, in Saint-Louis as displaying no visible order (Camara 1968: 252; see also Rudofsky 1964: 53) may be traced to differences in linguistic and cultural background. Charles Hartshorne is less charitable in stating that the conception of disorder is in one way or another "wholly relative to ignorance" (Hartshorne 1968: 256). There is an order to organic growth but it may be complex and not apparent to some observers.

This discussion of order is intended to serve primarily as a means of relating the concepts of texture, scale, and complexity, mentioned by Rapoport as important cues for defining settlement in the context of a discussion of

urban order. The discussion will now shift to concentrate on the notion of texture itself.

3.7 Definitions of Texture

Texture, in the brief discussion in section 3.5, was considered as the least complex form of order, where one perceives "only the over-all similarity of the whole surface" rather than "particular relations between individual parts" (Arnheim 1968: 159,160). While such a definition is based on the character of the surface itself, many definitions of texture in the remote sensing literature focus on the way that surface character is measured. Haralick begins his definition as follows:

Texture is concerned with the spatial distribution of the grey shades and discrete tonal features. (Haralick 1973: 396)

Wang and He describe texture as a "term used to characterize the tonal or grey level variation in an image" (Wang and He 1990: 61). Such definitions imply nothing about the type of order present on the surface, only that the surface is composed of a number of tonal 'building blocks'. This is not to imply that Arnheim's level of theorization does not exist within the remote-sensing literature. Niemann, for example, comments on a set of images of natural textures, ranging from grass to beach pebbles:

Although the areas shown ... are inhomogeneous on the basis of pointwise gray values, it is apparent that on a larger basis they exhibit homogeneous properties. The predicate best suited for measuring this

kind of homogeneity is not as easy to find as, for example, that of a monochromatic area. But nevertheless, the homogeneity is obvious to a human observer. These more complicated properties of surface are referred to as *texture* or textural properties (Niemann 1990: 110).

Like Arnheim, he identifies texture as exhibiting homogeneity (and therefore, relative lack of complexity) at certain levels of observation.

Mather, also working within the remote sensing field, contends that the observation of texture depends on "the scale of variation that we are willing to call *texture*" (Mather 1987: 312). This scale of variation relates to the size and character of the tonal primitive, the homogeneous tonal unit which is considered to be the textural building block of the image. Haralick considers that it is "a fundamental characteristic of texture" that "it cannot be analyzed without a reference frame of tonal primitive being stated or implied" (Haralick 1986: 257). The identification of the tonal primitive may be problematic. Haralick cites results of tests which compared computer generated texture measurements to interpretations of twenty human photointerpreters, indicating that the same surface may be identified as displaying different textures depending on the photointerpreter's perception of the size of the tonal primitive (Haralick 1986: 256-257).

Implicit in Neimann's description of texture, above, and explicit in the work of Mather and Arnheim is the notion that texture is part of a continuum

of surface descriptions, applicable depending upon the resolution at which that surface is measured (Arnheim 1968: 160; Mather 1987: 313). Individual features which might be distinguishable on a high resolution image become components of texture at medium resolution and form areas of uniform tone at coarse resolution (Haralick 1986: 257). There would appear to be a parallel between this continuum and Lefebvre's notion of overlapping social spaces incorporating "forms and structures". It seems possible to integrate these views, but the question remains, what is being measured? Here again one may return to Lefebvre, and his contention that space is both qualitative and quantitative. There is a measurable physical space, which is not abstract and isotropic, and approaching it with the "gadget" of texture means that the 'sense of place' is integrated into the analysis. So, can it all be taken this literally?

One could speculate from this that there might be, for a given object or collection of objects, an optimum resolution at which to observe its texture, as opposed to the identification of discrete features or the measurement of tone. At that point the texture algorithm would be working at its most efficient level, if indeed that efficiency could be measured, and the surface at that resolution would conform most closely to the surface-character definition of texture, as advanced by Arnheim and Niemann. Part of the research agenda is to test this speculation, as well as the related contention that the texture (as defined in terms of measurement techniques) of a complex surface, with

hierarchical relationships between surface components, will be different than that of a surface which displays only homogeneous texture (Arnheim's definition of texture according to surface characteristics). This discussion will be expanded in section 3.8, in the exploration of fractal geometry as a device to measure texture.

3.8 Hierarchy, Texture, and Pre-Fractals

...much of fractal geometry could pass as an *implicit* study of texture (Mandelbrot 1983: 310, author's emphasis).

Fractal geometry has been used by a series of researchers within the remote-sensing community to obtain explicit textural measures of imagery (Dellepiane *et al.* 1991; Lam 1990; MacLennan 1988; Peleg *et al.* 1984; Pentland 1986). The fractal concept of self-similarity, however, implies that fractal geometry may reveal more than texture. Fractal geometry is, by definition, concerned with hierarchies of scale. Perfect fractals display the same characteristics at any scale. Thus, while texture may be implied by fractal measurement, the evaluation of hierarchical relationships, more complex than homogeneous texture, would seem appropriate to fractal geometry. An indication of the degree of hierarchy might be found in the fit of the fractal model to the data.

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Before exploring this issue further, I would like to outline the 'pre-history' of fractal theory (pre-1975 and the coining of the word) in order to indicate that the concepts are not new, in terms of mathematical theory or geographical applications. Fractal geometry itself, as a sub-discipline of mathematics, has emerged over the last fifteen years as a conceptual framework which can incorporate all those mathematical phenomena which do not 'fit' the Euclidean framework, extending back as far as Aristotle and Leibniz (Mandelbrot 1983: 405) and including ideas from the nineteenth and early twentieth century by Cantor, Peano and Sierpinski, all of whom gave their name to various fractal objects (Jones 1991).

Pre-fractal explorations of the notions of hierarchy and scaling appear in the literature on urban form and function. Christaller's Central Place Theory is perhaps the best known example of a hierarchical network of urban areas, recently reframed as part of fractal theory (Arlinghaus and Arlinghaus 1989: Arlinghaus 1985). Lionel March (1974: 177) proposed a very fractal-like model for diffuse urban growth on the urban fringe (figure 3.1). Bacon's standard work on urban design contains a series of iterative developments of the square as "a countermodel for the growth and extension of an entity, be it an institution or an idea" (Bacon 1976: 49) (figure 3.2). Bacon notes that "the length of the line bounding the entity can be increasing indefinitely while holding the diagram within bounds" (Bacon 1976: 49) corresponding to the

Figure 3.1
Fractal-Like Diagram of Regional Growth
Source: March 1974: 177

Figure 3.2
Fractal-Like diagram of the Growth and Extension of an Entity
Source: Bacon 1976: 50-52

relationship between area and circumference on regular fractal figures such as the Sierpinski gasket (Peterson 1988: 116-121). The point here is that there has been a search within this field for better models, presaging Scharfstein's comments:

Our thought has been too deeply affected by models too simple to help us much. These models depend on our inclination to see mathematics and theoretical physics as ideals. That is, we have been educated to feel that a relationship between a cultural generalization and its instances should be like that between a regular geometric figure and an approximation to it ... We need other, better models to help us deal with cultural density, vagueness, and unpredictability (Scharfstein 1989: 171).

Scharfstein discusses the analogies of turbulence and cloudiness as possible ways of viewing the world, noting that he happened on them before he

learned that they were studied by the new geometry of *fractals*, inspired ... by the chaotic behaviour in deterministic systems (Scharfstein 1989: 172, author's emphasis).

Scharfstein's discussion of the cloudiness analogy begins to imply textural properties.

Cloudiness has its own analogical uses. Cultures may well have characteristics that resemble clouds' geometrical irregularities, varying densities, holes, instabilities, and vague boundaries (Scharfstein 1989: 173).

It would seem that a series of researchers have independently explored new ways of thinking about cities, and even society as a whole, using pre-fractal and fractal-like analogies within the realm of cultural studies. Now that the sub-field of fractals has come into its own, it can perhaps be used explicitly as

a tool to answer some of the questions posed in chapter one of this thesis, which relate to those pre-fractal and fractal-like analogies discussed above.

3.9 Conclusions

What does this mean, how does it all tie together? What I want to emphasize is the fact that it is all related together. Tone becomes texture becomes pattern, depending upon the scale and resolution of the image we are observing. While this is obvious with imagery, due to factors such as grain on conventional photography and pixels on digital imagery, it is less obvious when dealing with the more abstract concepts of order and disorder, culture and social space. In the abstract, texture has been hypothesized as related to other forms of order including pattern and hierarchy. And within this field of study as well, we see that order, disorder and complexity are interrelated. Lefebvre relates texture to pattern as well, within the concept of social space. There would appear to be enough commonality between the literatures discussed above to pursue this thesis, and to allow for an interpretation of a texture and pattern in aerial imagery which refers to the social realm, to Lefebvre's use of texture within the context of social space. On this basis we can proceed with a textural analysis of aerial imagery to measure morphology.

Chapter four will outline the various approaches to the measurement of texture within the remote-sensing literature, with an emphasis on fractal-based methods.

4 METHODOLOGY: SELECTION AND IMPLEMENTATION OF A FRACTAL-BASED TEXTURE MEASUREMENT ALGORITHM

4.1 Introduction

This chapter first reviews the characteristics of aerial imagery which are used in visual interpretation, texture being a common attribute in the minds of many researchers (for example Jensen 1986; Lillesand and Kiefer 1979). It then outlines texture measurement methods to set a context for a more detailed description of fractal-based texture measurement methods. A critique of these methods is used to justify the selection of the 'blanket' method (Peleg *et al.* 1984) for this thesis. The implementation and testing of this method is then described, as is the selection of appropriate imagery from aerial photography of Saint-Louis. After establishing the need for a multi-resolution analysis, the methodology for implementing such an analysis is outlined. Finally, the use of spatial autocorrelation statistics, as an alternative method of analyzing texture and a check on the 'blanket' method, is outlined.

4.2 Texture Measurement Methods: A Review

Researchers differ as to which basic characteristics of aerial imagery are taken into account in the process of visual interpretation. Lillesand and Kiefer (1979: 96) consider seven attributes: shape, size, pattern, shadow, tone, texture and site. Jensen (1986: 169) cites only four characteristics: context, edges, texture, and tonal variation or colour. While most digital image interpretation or classification algorithms have used only per-point spectral or tonal information, considerable research has been undertaken to incorporate these other attributes. The impetus for such research has been, in part, the increased resolution of air- and space-borne sensors. With increased resolution comes increased image heterogeneity, and a reduction in the ability of per-point methods to classify such imagery into contiguous units (Latty *et al.* 1985). Access to contextual information (incorporating shape, pattern, shadow and size) has been attempted through shape recognition (for a summary see Richards 1986: 124) and artificial intelligence techniques (Nagao and Matsuyama 1980). There is a body of work on edge detection (reviewed in Kashyap 1986), sometimes related to textural analysis, since both areas are concerned with the identification of image intensity extrema within the image in question (Richards 1986: 116-124). The focus of this thesis, however, is on texture, because of its ties to both social space and fractal theory, and its links to morphological characteristics such as pattern and form.

This focus has dictated the choice of fractal-based texture measurement algorithms over those algorithms based on more conventional techniques. Fractal based methods, however, are not revolutionary; rather they are extensions of conventional texture measurement techniques. The following review of texture measurement methods is intended to set the fractal methods in this larger context.

4.2.1 Descriptive Texture Models

Texture models may be divided into two groups, those which are descriptive, and those which are generative. The descriptive model generates a statistical summary of the texture of an image, while the generative model can synthesize (and later regenerate) an image which conforms to that given model (Kashyap 1986: 283-284). Since this thesis is concerned with the evaluation, not the generation, of imagery, this review section will focus on descriptive models. Generative texture models are reviewed in Kashyap (1986).

Haralick (1986) provides a review and categorization of descriptive models (in Haralick's nomenclature, descriptive models are termed "statistical approaches to image texture analysis"). To summarize the article here would caricature an already terse and dense review, but I will comment briefly on his

categorizations of texture analysis methods. Relevant to this thesis are the following categories:

- a. **Autocorrelation:** methods which use spatial autocorrelation as a means of image description. Spatial autocorrelation occurs when
the relationship among values of a single variable ... is attributable to the geographic arrangement of areal units (Griffith and Amrhein 1991: 134).

Autocorrelation is prevalent in, and some would say, characteristic of geographic data (Goodchild 1986; Gould 1984). Autocorrelation has been found to be related to the size of the tonal primitives on the image (Haralick 1986: 255).

- b. **Orthogonal Transformations:** methods based on the Fourier transform. Such methods have been found to perform more poorly than second-order grey-occurrence statistics (category 3, below) or first-order statistics of grey level differences, such as means, variances, and standard deviations (Haralick 1986: 258).
- c. **Grey-level Spatial Co-occurrence:** such methods are widely used in remote-sensing (Hord 1986: 129; see Connors and Harlow 1981 for description of the method; see Haralick *et al.* 1973; Sun and Wee 1983 for remote sensing applications). The methods rely on calculating a second matrix derived from the original image, where
each matrix element...is the count of the number of times that a pixel *I* of a given grey level was adjacent to a pixel *J* of in the given scan direction at the given neighbour distance (Hord 1986: 131).

From this matrix, measures such as energy, entropy, contrast, correlation, and homogeneity may be calculated (Haralick 1986: 260).

- d. **Mathematical Morphology:** the study of the shapes of the tonal primitives which make up the texture of the image, where a relatively complex image may be considered as a composite of a group of simpler tonal primitives.
- e. **Gradient Analysis:** Measure of the amount of "edge" per unit area (Haralick 1986: 264-265).
- f. **Relative Extrema Density:** methods which measure the number of extrema per unit area, such as the MIN-MAX method (Mitchell *et al.* 1977; for a remote-sensing application see Shih and Schowengerdt 1983).

What is interesting to me is the way that such categories may be transcended. Pentland's use of the Fourier transform in deriving the fractal dimension of scanned urban imagery (Pentland 1986) is classed as a orthogonal transform, whereas the 'blanket' method of deriving the fractal dimension (Peleg *et al.* 1984) is considered as part of the body of Mathematical Morphology techniques. Fractal methods are not classed separately. The 'blanket' technique, with its sensitivity to tonal extrema, would appear to have more in common with the MIN-MAX technique (Mitchell *et al.* 1977; Hord 1986: 129-

139) than with other mathematical morphology techniques. The 'blanket' method, rather than using a simple regular geometrical shape as a tonal primitive, considers the tonal primitive to be the image itself, an extreme extension, in my estimation, of the concept of mathematical morphology.

4.3 Fractal-Based Texture Measurement Algorithms

4.3.1 The Contour Method

A variety of fractal-based texture measurement algorithms have been developed. Lam uses the "contour" method (Shelberg *et al.* 1983), originally conceptualized as a way of measuring the fractal dimension (D) of raster Digital Elevation Models, to measure the texture of Landsat TM imagery, using spectral values as the Z-dimension of the surface (Lam 1990). The method draws a series of contours on the surface, based on a given contour interval. For each contour line, the image is scanned and a count is made of the number of pixels which border a contour line. This process starts with individual pixels, then for a series of iterations, aggregates pixels into larger cells, each time counting boundary cells for a given cell size. The D value of the surface for each contour line is derived from the slope of the regression line of the log of the average number of boundary cells against the log of the cell size. The D values of all the contour lines are averaged to determine the fractal dimension of the surface. This method extends Goodchild's (1980) research into the

measurement of generated self-similar surfaces, so that the fractal dimension of non self-similar surfaces can be estimated (Shelberg *et al.* 1983: 322; see Roy *et al.* 1987 for an appraisal).

4.3.2 Transect Methods

Another approach involves the use of the semivariogram, essentially a transect across a surface, which measures the average semivariance S^2 of the Z-value as a function of the "lag", the sampling distance between points. S^2 is defined as:

$$1/2m \sum [z_{xi} - z_{xi+h}]^2$$

where m is the number of pairs of observations along the transect, and h is the lag (Curran 1988: 494). Curran uses the semivariogram to characterize remotely-sensed imagery (Curran 1988: 495-504) without the use of fractals, but the method may be extended to measure the D value of the transect line, by measuring the semivariance of the Z-values with iterative increases in lag values, and regressing the log of S^2 against the log of the lag. Such a measure will yield a slope, from which the D value of the transect (a value between one and two) may be derived. To find the D value of the surface, one must repeat the process for a series of transects covering the image, average the transect D values, and add one, so that the fractal dimension of the surface is between two and three. This fractal method is commonly used to measure the

roughness of Digital Elevation Models (DEMs) (Klinkenberg 1988; Roy *et al.* 1987; Xia *et al.* 1991), but has been used in remote sensing to measure texture of remotely-sensed imagery (Ramstein and Raffy 1989).

Clarke and Schweizer (1991) evaluate variogram methods and propose a related method, the 'robust fractal estimator', based on the now classic 'divider' method, first introduced by Richardson (1961) in his study of the length of coastlines, recast as a fractal concept by Mandelbrot (1967), and implemented in the context of analytical cartography by Shelberg *et al.* (1982). The method measures the local D of DEMs by measuring the fractal dimension of a series of transects, running both east-west and north-south, centred on a given point. A weighted average of the D value of the transects, with transects closer to the point in question weighing more heavily than those further away, is used to determine the local D of the surface, centered at the given point.

4.3.3 A 'Box Count' Method

Burl *et al.* (1989) propose a method which, for a series of iteratively larger boxes, counts the number of boxes required to include the tonal extrema of a given feature (see Barnsley 1988: 172-197 for theoretical explanation of the method). D is derived from the slope of the regression of the log of the number of boxes against the log of the box size. The method, however, relies

on the identification of isolated textural features digital imagery, and on the determination of appropriate values to be classed as extrema prior to execution.

4.3.4 Methods Based on the Fractal Brownian Function

Pentland (1983, 1986) outlines two methods of fractal-based texture measurement. Both methods involve the use of a fractal Brownian function, "a mathematical generalization of Brownian motion" (Pentland 1986: 231). Pentland shows that the fractal dimension may be measured directly from the Brownian motion equation, or it may be derived from Fourier power spectrum measurements, as the spectral density of the fractal Brownian function is related to the Fourier power spectrum (Pentland 1986: 232). Pentland tested the Fourier transform version of his method on digitized imagery ranging from aerial photography of a city to a photo of a coffee mug, finding that "good segmentation" (Pentland 1986: 243) of all imagery tested was achieved. As well, the calculated fractal dimension was found to be stable over wide variations (ranging from 4:1 to 8:1) in scale. This was determined by a process of pixel averaging (decimation) such that the tonal values of groups of pixels on the original 512x512 image were averaged to form 256x256, 128x128 and 64x64 pixel images. Histograms measuring the frequency of occurrence of the local fractal dimension values were used to determine the points at which the

images should be segmented. Within this range of scales the break-points on the histograms occurred at approximately the same point along the fractal dimension axis.

4.3.5 The Blanket Method

Peleg *et al.* (1984) proposed a method which considers an image as a surface, and iteratively lays a series of digital 'blankets' of a given thickness above and below the original surface. As the number of blanket layers increases, the blanket becomes smoother, and its surface area reduced relative to that of the original surface. The fractal dimension of the surface is derived from the regression of the log of the surface area of the current blanket layer against the log of the volume between the original surface and the current blanket layer, for a series of blanket layers. This approach was used in the textural analysis and classification of aerial radar imagery (Dellepiane *et al.* 1988).

The blanket surfaces are calculated as follows: individual values of the top surface $u_{\epsilon}(i,j)$, where i and j are x and y identifiers in a raster matrix and ϵ is the blanket layer, are defined as the maximum value of either:

1. The value of the pixel $u_{\epsilon-1}(i,j)$ (the pixel on the surface directly below the pixel presently being calculated) plus the blanket thickness, or
2. The maximum value of the four rook's-case pixels which surround $u_{\epsilon-1}(i,j)$ (Figure 4.1).

An analogous strategy is employed to calculate the values of the bottom surface, using the minimum value rather than the maximum value.

The method may be modified for other definitions of contiguity, the bishop's case to search for diagonal trends, or the queen's case for both (Kenkel 1989: 971). Figure 4.2 is a transect across a hypothetical surface, illustrating the formation of blanket layers. The volume between surfaces, v_{ϵ} , for a given iteration ϵ may then be calculated summing the results of by subtracting the top surface from the bottom surface, on a pixel by pixel basis. The surface area A_{ϵ} is equal to $(v_{\epsilon} - v_{\epsilon-1}) / 2$, the difference in the volumes being divided by two to account for both the top and bottom layers. The fractal dimension is derived from the slope of the line found by regressing the log of the surface areas against the log of the volumes, for all iterations (Fractal Dimension = 2- slope, where slope is negative).

Figure 4.1 Raster Definitions of Contiguity

Rook's Case

Bishop's Case

Queen's Case

Figure 4.2: The 'Blanket' Method of Fractal Dimension Calculation

4.4 Evaluation of Fractal-Based Texture Methods

For the purposes of this thesis, several of the methods described above were considered to be unsuitable. I wished to be able to create 'fractal surfaces', images which portrayed the local fractal dimension of a window of pixels on the original image, and 'correlation surfaces', images which indicated the statistical fit of the fractal model locally, as well as deriving summary fractal statistics of the image as a whole. This meant that any algorithm used must be capable of working with windows, small subsets of the image. The contour method was thus eliminated, since it scanned the entire image, and the use of the variogram method was limited, since it relied on linear transects over longer distances than the window sizes I was contemplating. Clarke and Schweizer (1991) attempted to overcome such limitations by taking weighted averages of fractal dimensions of transects, using the 'robust fractal estimator', so that transects nearer a given point exert greater influence on the local fractal dimension than those transects further away, given the assumption of gradual change in character of natural surfaces over distance. While such an assumption may be valid for many natural surfaces, 'cultural surfaces' such as urban imagery may exhibit sudden changes in character. In such a case, the method may run into the potential problem of transects measuring areas of a different textural character, away from the given point of interest, where the measurement given as the local fractal dimension is unduly influenced by substantially different character of the image far from that point. The 'box-

count' method was rejected on the basis of its pre-processing requirements: the identification of isolated textural features, and the loss of subtlety in the binary classification of the image into regions of extrema and non-extrema.

The remaining three methods, two proposed by Pentland and the 'blanket' method, were suitable for use with small windows of the original image. Vernazza (1987) evaluated these three methods, finding that the "frequential Pentland approach", using the Fourier power function, performed less well, and was less stable than either the 'blanket' method or the "spatial Pentland approach", based on the fractal brownian function. Such an evaluation conforms with previous observations of non-fractal texture evaluation techniques, that methods based on the Fourier transform perform less well than other approaches (Haralick 1986: 258; Jensen 1986: 172; see also Whalley and Orford 1988: 193 for a discussion of Fourier transform methods and fractals). Clarke and Schweizer noted as well the complex and time-consuming calculations for Fourier transform-based methods (Clarke and Schweizer 1991: 40). As the 'blanket' and the 'spatial Pentland' methods were comparable in their performance, the 'blanket' method was chosen to be implemented for this research, since it was conceptually and computationally more clear to this researcher.

4.5 Implementation of the 'Blanket' Method

The 'blanket' method was implemented following the algorithm as described in Peleg (Peleg *et al.* 1984), using Turbo Pascal 5.5. This language was used because it was compatible with a series of shell programs which accompany EPPL7 GIS software (Minnesota State Planning Agency 1990), in uncompiled Pascal code, largely for file input/output of EPPL7 format raster data files. Thus some of the more mundane and time-consuming coding relating to file input and output could be avoided, and the data files could be manipulated, analyzed, and displayed within a GIS environment.

One refinement incorporated in this implementation but not mentioned in the description of the algorithm in section 4.2 above, was the division of the surface area and volume measurements into two, the top measurements and the bottom measurements, to better measure "asymmetrical" surfaces, for example, "an image of light particles scattered over a dark background" (Peleg *et al.* 1984: 520). The definitions of the upper volume v^+ , the lower volume v^- , the upper surface area A^+ and the lower surface area A^- are as follows:

$$v_i^+ = \Sigma(u_i(i,j) - g(i,j))$$

$$v_i^- = \Sigma(g(i,j) - b_i(i,j))$$

$$A^+(\epsilon) = v_i^+ - v_{i-1}^+$$

$$A^-(\epsilon) = v_i^- - v_{i-1}^-$$

where $g(i,j)$ is the value of the pixel on the original surface ((Peleg *et al.* 1984: 520-521). Thus the capability exists within the code to examine the upper and lower surfaces separately.

The method of slope calculation was altered slightly from that suggested. The authors used a mean slope derived from a series of best fit lines through three points defined by the log of the volumes and the log of the surface areas, for three successive blanket layers (Peleg *et al.* 1984: 520). My implementation altered this so that a linear regression line was calculated for points representing log-log values of volumes and surface areas for all iterations. This allowed for the calculation of the r^2 value for the regression line, and the creation of 'correlation surfaces', displaying the local r^2 values. Using a log-log linear regression is in the tradition of many other fractal applications, for example, Mandelbrot's initial work on the fractal dimension of coastlines (Mandelbrot 1967). Recent cartographic extensions of Mandelbrot's pioneering work (Broscoe and Prashker 1991; Bittenfield 1989; Carstensen 1989; Longley and Batty 1989; Muller 1986, 1987; Shelberg *et al.* 1982) have used the r^2 statistic as a way of evaluating the fit of the fractal model to cartographic data. Clarke and Schwiezer (1991) use the r^2 statistic to assess the fit of three different fractal methods to DEM surfaces.

4.6 Case Study Methodology

4.6.1 Selection of Imagery

For each of seven areas in Saint-Louis, digital images, each approximately 480 by 512 pixels, were obtained from 1:4000 scale monochrome aerial photography of the city, through a process of scanning. The per-pixel aerial resolution of each image was identical, (pixel size approximately 0.5 metres by 0.5 metres) within the limits of the scale variation of the original photography. A process of histogram equalization was then applied to the images, so that in statistical terms, the spectral character of each image was standardized. The difference between images, in terms of the range and the frequency distribution of intensity values, was thus minimized. This process eliminated some of the potential for differences in the image characteristics, such as range of tonal values and the overall image contrast, to alter the results of textural analysis of the imagery. These differences might be attributable to variations in atmospheric conditions at the time of exposure and variations in film processing.

The images were chosen to represent the extremes in the variation of city morphology within the city. Three images were selected from the colonial sector, which was rebuilt in the 1860s to reflect the position of Saint-Louis as capital (Winters 1982: 140; Vennetier 1976: 20). The morphology of this sector

is characterized by regular geometrical patterning, where the streets are laid out in a grid pattern and the buildings are aligned to the street, with regular geometric subdivisions of buildings within blocks. One image was obtained from Guet N'Dar, an established 'indigenous' neighbourhood, also rebuilt to a grid about the same time as the colonial sector, but with smaller buildings (Faidherbe 1899: 78-79). Two images were obtained from the rapidly growing settlement of Pikine, a 'shantytown' or *bidonville* (Ba *et al.* 1980: 44) founded on the periphery of the city around 1960, which is characterized by an irregular transportation network, 'haphazard' building alignment, and a polyglot ethnic composition. Both Pikine and a section of Sor, from which the seventh image was obtained, are examples of 'organic growth', a concept which is intuitively simple to grasp but difficult to define. This seventh image, obtained from an older neighbourhood than Pikine, shows 'organic growth' within the confines of a grid-based road network. The scanned images were oriented to a grid of street networks, if such a grid existed. In the case of the sixth and seventh images, determination of the 'correct' alignment was difficult, as the grid was either difficult to perceive or bore little relationship to the alignment of the dwellings within the grid. More than one image was obtained from individual neighbourhoods if there were visible differences in settlement density (Pikine) or differences in building size and settlement history (L'Ile).

4.6.2 Testing the Method's Parameters

Optimum values for the three parameters (blanket thickness in terms of Z-values, number of blanket layers, and box size), which control the 'blanket' method, were determined using a series of test images, from both the Saint-Louis data set and SAR imagery of ocean waves, provided by Eric Storie (Storie 1991). Most critical was the number of blanket layers (or, in other words, iterations). Fewer iterations than twelve or thirteen, regardless of the values of the other two parameters, resulted in local D values falling outside the range of theoretically possible values, especially at the low end (2.0 for a perfectly smooth surface to 3.0 for an 'infinitely rough' surface). Increases in the number of iterations resulted in reduced r^2 values and increased processing time. The optimum number of blanket layers was thus set at thirteen.

The value of D was somewhat arbitrary, since the x and y values were pixel locations but the z values were measures of tone. Thus the actual D value was dependent upon the relationship between the units assigned to the three axes. The value assigned to the blanket thickness controlled this relationship. A linear relationship was found to exist between the range of the local fractal dimensions on the image and the blanket thickness. A value of nine units (relative to the range of possible image Z values of 0 to 255) was found to result in a range of local D values from 2.0 to approximately 2.70 on

the Saint-Louis test images. This value was held constant at nine for all further testing.

The last parameter to be considered was the window size. Here again, some judgement was required. It was found that the correlation coefficient increased with window size, but I wished to keep the window size relatively small, to give a truly local D value, and to minimize processing time. A nine-by-nine pixel window method was found to be a good balance between the two tendencies.

4.6.3 The Creation of 'Fractal' and 'Correlation' Surfaces

These parameters (number of iterations: 13, blanket thickness: 9, window size: 9) were held constant throughout the study so that comparisons between images could be made. This D value was placed at successive locations on a 'fractal surface' which corresponded to the centre pixel of the window on the original surface. Thus a matrix of fractal values was created. A similar process was used to obtain a 'correlation surface', which measured the fit of the fractal model within the window, expressed in terms of an r^2 coefficient. These derived surfaces could then be examined visually, and localized areas of poor or good fit could be pinpointed.

The generated fractal surfaces reflected the character of the original surface. The fractal analysis process acted as an edge detector on images with relatively large buildings (the colonial sector and Pikine) but detected cloudlike areas of dense settlement on images with smaller buildings (Guet N'Dar and Sor) (Figures 4.3, 4.4). The correlation surfaces indicated that in areas of high homogeneity, for example road surfaces, the fractal model performed least well. Aggregate statistics for each image indicated that the statistical fit of the fractal model was high, with r^2 values ranging from 0.85 to 0.90, and minimum values for D stabilizing at 2.0, as expected for smooth surfaces. Neither the mean r^2 nor the mean D , however, could be used to differentiate between neighbourhoods. In addition, the method had to be expanded in order to investigate the concept of self-similarity. What was needed was a fractal investigation of city imagery at various resolutions. There are a number of precursors for such an approach. Witkin (1986) explored the decomposition of complex wave forms at various scales. Burrough (1983a; 1985; 1986: 124-126) has explored the fractal behaviour of nested multi-scale soil maps. A number of researchers working within the framework of analytical cartography have explored the relationship between scale and fractal dimension (Buttenfield 1989; Carstensen 1989; Muller 1987). More closely related to this thesis is the work of Mark and Aronson (1984) on the fractal dimension of DEMs at various resolutions, and Pentland's (1986) comparisons of segmentation of imagery at multiple resolutions, based on fractal-derived texture measures. Rather than

Figure 4.3
Sample Digital Images at Full Resolution

Figure 4.4
Fractal Surfaces Derived from Images at Full Resolution

Local Fractal Dimension
 based on a 9x9 pixel window

- 2.00 to 2.04
- 2.05 to 2.14
- 2.15 to 2.24
- 2.25 to 2.34
- ▤ 2.35 to 2.44
- 2.45 to 2.54
- Greater than 2.55

searching for existing imagery at various resolutions, and attempting to compensate for differences in atmospheric conditions, sun angle, date, etc., imagery at a series of different resolutions was synthetically created, as described in section 4.6.4.

4.6.4 Multi-Resolution Fractal Analysis

Each image was decimated, such that the resolution of the new image was coarser than that of the original image, from which it was derived. Each decimated image covered the same ground area as the original image with fewer pixels. This decimation process was applied recursively, resulting in a series of six decimated images from each original full resolution image. The per pixel areal coverage of the decimated images was increased by factors of 2.25, 4, 9, 16, 64, and 256 respectively. These decimated images were produced using a process of bilinear interpolation, where the mean value of a centre pixel and its four surrounding pixels on the original image became the new value on the decimated image. This method of decimation was chosen over other methods, such as the 'nearest neighbour' method, which selected a subset of pixels at a given spacing from the old image to form the new image, as it best approximated the way in which features are resolved on remotely sensed imagery. Each of these newly created images was then analyzed using the fractal program, creating a fractal and a correlation surface.

Visual examination of the fractal surfaces revealed that the fractal process was capturing differences in the size of the 'minimum building block' of the imagery. The fractal surfaces of the decimated images of the colonial sector, characterized by large buildings, began to resemble the fractal surfaces of the original, undecimated imagery of Guet N'Dar and Sor, characterized by smaller buildings (Figure 4.5).

4.6.5 The Creation of 'Histogram Ribbons' and 'Histogram Surfaces'

For fractal surfaces at all resolutions, complete histogram information, not just summary statistics, was displayed visually. Figure 4.6 illustrates the process used in preparing these data, beginning with a hypothetical histogram of a fractal surface, which measures the percentage area of the fractal surface which represents a given fractal dimension of the original image. This histogram was classified into ranges of coverage, with darker values representing predominant D value values. To correspond with the final presentation of the information, this classified histogram was rotated ninety degrees, so that the y-axis represents the fractal dimension and the x-axis represents the percentage area. This representation was simplified by imagining that the percentage-area axis of the classified histogram was projecting out of the page and histogram bars were viewed from above,

Figure 4.5
Fractal Surfaces Derived from Pikinel Images at Various Resolutions

Figure 4.6
Method of Classification and Simplification of Information Derived from a Fractal Surface

showing only the class in which a particular value falls. Thus a classed histogram was represented by a shaded ribbon, where shading intensity represents the area covered by a given D value.

These 'histogram ribbons' may be compared by placing them side by side. Sets of fractal surfaces derived from images of one neighbourhood at different resolutions can be summarized in graphical terms by grouping the 'histogram ribbons' of each neighbourhood to form a 'histogram surface'. Such histogram surfaces, inspired in part by Tufte's "small multiples" (Tufte 1990; 1983) and the work of Bertin (1981), and in part by the advances in scientific visualization which summarize a complex data set so that it may be examined visually. The 'histogram surfaces' are displayed and analyzed in the next chapter.

4.6.6 Spatial Autocorrelation as an Alternative Measure of Texture

Another method of texture determination was made to provide a comparison and reference for the 'blanket' method. Summary measures of spatial autocorrelation, using Moran's 'I' statistic (Goodchild 1986; Moran 1948) were also made. The Moran Index (I) yields positive values where there is autocorrelation, values of approximately zero when attribute values are arranged in a random pattern, and negative values when there is greater

dissimilarity than expected between points (Goodchild 1986: 16). Perfect autocorrelation (uniform tone) would be indicated by a value of one. The 'Rook's Case' definition of contiguity (Figure 4.1) was used to be consistent with the implementation of the 'blanket' method. The interpretation of the I statistic, and a comparison between the fractal dimension as calculated using the 'blanket' method, and the 'I' statistic will be undertaken in the next chapter.

5 DISCUSSION

5.1 Introduction: Methodological Summary

In the last half of the previous chapter, a methodology for a textural analysis of aerial imagery of Saint-Louis, Senegal was developed. This chapter discusses the results of this analysis and offers interpretation of the results. This interpretation is based on the spatial history of Saint-Louis, as outlined in chapter two, and on the theoretical framework for urban morphological analysis, incorporating social space, texture and fractal theory, as outlined in chapter three.

Section 4.6.5 suggested the creation of 'histogram surfaces', portraying for each image, detailed information of fractal analyses at a series of image resolutions. This approach was advanced in order to provide a visualization of the spread of the entire data set, rather than a portrayal of summary statistics (means, modes), in a situation where no assumption was made about the nature of fractal measure distribution. This was not intended for use in for

significance testing, but rather, as a way to view a complex data set. For each of the seven images in this study, a 'histogram surface' was constructed by laying side-by-side a series of 'histogram ribbons', one ribbon for each image resolution used in the case study. These histogram ribbons are inverted histograms showing the percentage of pixels which were assigned a given fractal dimension on the fractal surface (see section 4.6.5). Individual ribbons were arranged according to the per-pixel areal coverage of the series of resolutions of each individual image (inversely related to the image decimation). An image at the greatest decimation (the coarsest resolution) would be made up of pixels covering 256 (16 by 16) times as much ground area as a pixel on the original, highest resolution image.

Figure 5.1 shows these seven histogram surfaces. The areal coverage of each histogram surface is indicated by the horizontal axis as labelled along the top of the figure, and indicated by the 1—256 designation. The vertical axis indicates the fractal dimension, as labelled along the left-hand side of the figure and referenced by the white horizontal lines running through the individual histogram surfaces. The fractal dimension ranges from 2.0 for a uniform surface (in this case uniform photographic tone on the imagery) to 2.7, indicating the most heterogeneous section of photographic imagery. The tonal values on the histogram surface indicate the percentage area of the fractal surface which possess a given local (window derived) fractal dimension, with

Figure 5.1
Histogram Surface Derived from Fractal Surfaces

Table 5.1 Summary Statistics of Fractal Surfaces

Neighbourhood	Per-Pixel Areal Coverage (Full resolution=1)							Statistic
	1	2.25	4	9	16	64	256	
Col1	2.31	2.34	2.41	2.43	2.45	2.41	2.33	Mean D
	2.30	2.39	2.49	2.49	2.48	2.40	2.30	Modal D
	0.87	0.90	0.92	0.93	0.93	0.92	0.91	r ²
	0.94	0.92	0.86	0.83	0.72	0.51	0.36	Moran's I
Col2	2.32	2.34	2.40	2.42	2.45	2.42	2.34	Mean D
	2.34	2.42	2.44	2.44	2.44	2.42	2.37	Modal D
	0.85	0.86	0.88	0.90	0.92	0.93	0.92	r ²
	0.92	0.92	0.87	0.86	0.77	0.61	0.49	Moran's I
Col3	2.34	2.37	2.42	2.43	2.44	2.39	2.34	Mean D
	2.41	2.44	2.46	2.45	2.44	2.38	2.31	Modal D
	0.90	0.90	0.92	0.93	0.92	0.92	0.92	r ²
	0.90	0.89	0.82	0.80	0.68	0.48	0.37	Moran's I
Pikine 1	2.34	2.38	2.43	2.45	2.46	2.44	2.32	Mean D
	2.39	2.43	2.46	2.44	2.46	2.42	2.29	Modal D
	0.90	0.91	0.93	0.93	0.93	0.93	0.91	r ²
	0.91	0.89	0.81	0.79	0.65	0.43	0.24	Moran's I
Pikine 2	2.30	2.34	2.40	2.42	2.46	2.47	2.35	Mean D
	2.38	2.37	2.44	2.45	2.47	2.48	2.35	Modal D
	0.89	0.90	0.92	0.94	0.94	0.94	0.92	r ²
	0.93	0.92	0.86	0.84	0.74	0.56	0.41	Moran's I
Guet N'Dar	2.31	2.33	2.37	2.37	2.37	2.34	2.25	Mean D
	2.49	2.46	2.44	2.44	2.40	2.35	2.24	Modal D
	0.89	0.91	0.91	0.91	0.91	0.92	0.91	r ²
	0.91	0.88	0.80	0.77	0.64	0.51	0.52	Moran's I
Sor	2.20	2.23	2.27	2.28	2.21	2.18	2.13	Mean D
	2.35	2.39	2.35	2.32	2.22	2.17	2.11	Modal D
	0.85	0.86	0.90	0.91	0.91	0.91	0.87	r ²
	0.92	0.89	0.81	0.78	0.63	0.45	0.34	Moran's I

Table 5.2
Summary of Neighbourhood Characteristics

	Building Size	Organiza- tion	Founding Date	Growth Rate	Ethnic Makeup
Col1 (Sindoné)	Large	Grid	ca. 1860	Stagnant	Wolof
Col2 Col3	Large	Grid	ca. 1860	Stagnant	Wolof
Pikine1 Pikine2	Medium	Organic	ca. 1960	Rapid	Mixed
Guet N'Dar	Small	Grid	ca. 1860	Medium	Wolof
Sor	Medium	Organic/ Grid	ca. 1880	Rapid	Mixed

darker tone indicating higher percentages. The heavy curved white line running through each histogram surface indicates the modal trend. In other words, for each of the seven image resolutions, the line indicates the fractal dimension covering the largest part of each fractal surface. This trend line was created by plotting the modal D value for each image decimation, then connecting the points. Some interpretation was involved in this process, especially when a break in the trend line was indicated. Below the histogram surfaces are representative samples of each image, to provide a visual reference. All images are shown at the same scale, to facilitate image-to-image comparisons of block and building sizes.

The modal trend is also indicated in Table 5.1 as the modal D values for each image across the seven resolutions. The mean D is also indicated, along with the r^2 value, indicating the fit of the fractal measurement of the image of each resolution. Moran's I statistic, a measure of spatial autocorrelation, is recorded as well, to provide a comparison with the fractal measures.

5.2 Visual Interpretation of Histogram Surfaces

The histogram surfaces may be interpreted visually: one may compare surfaces, searching for similarities and differences. The informal hypothesis in this case would be that images from 'like' neighbourhoods (for example, the three images from the colonial sector, Col1, Col2 and Col3) would show a similar histogram surface. Such an hypothesis is based on a judgement or interpretation of what constitutes one sector or neighbourhood, as opposed to another. In this case the grouping of images is based partly on a knowledge of the history of settlement in Saint-Louis.

The interpretation of the histogram surfaces, based on visual examination, is that the histogram surfaces for the three colonial sectors are more similar to each other than to any of the histogram surfaces¹, although

¹ although Col1, taken from Sindoné, a less prestigious section of L'Ile, shows on visual interpretation more similar characteristics to the two histogram surfaces from Pikine as well as the other two histogram surfaces

they appear closer to the Pikine 1 and 2 histogram surfaces than to the other two surfaces. This interpretation is based on the overall form of the histogram surface, as well as the shape of the modal trend line. This modal trend line follows the general form of the frequency distribution. The distributions are unimodal except at the highest decimations (the greatest per-pixel areal coverage)². The modal trend would thus seem to be indicative of an overall trend in the histogram surface.

The three colonial-sector histogram surfaces do not exhibit a strong break in the modal trend, unlike the histogram surfaces of Pikine or Sor. The modal trend of the histogram surface for Guet N'Dar is also continuous, although its shape is different from those of the colonial sector. The degree of continuity of the modal trend would seem to relate to the grid/organic dichotomy already identified in previous chapters. The colonial-sector and Guet N'Dar images, as examples of grid-based urban form laid out by the colonial administration, may be contrasted to the Pikine and Sor images, examples of organic form determined more by local, neighbourhood-based

from the colonial sector. This impression conforms with the economic and morphological characteristics of neighbourhood.

² Perhaps the multi-modal tendency of the histogram ribbons at the highest decimation is due to the reduced number of pixels in the fractal surfaces, and consequently, a tendency for the histogram to be more jagged as each pixel accounts for a larger percentage of the area covered on the fractal surface.

power structures³. A smooth modal curve thus corresponds to a grid-based urban growth and form, while a broken modal curve would seem to indicate 'organic' growth and form.

The modal trend, as an indicator of the character of the entire histogram surface, would also seem to show a second characteristic of the imagery, the mean building size. This characteristic corresponds to general shape of the modal trend, and the point (in terms of image decimation) at which the modal trend reverses. The modal trend for imagery which portrays smaller buildings (Guet N'Dar and Sor) tends to peak at a higher resolution than that for imagery which portrays larger buildings. For Guet N'Dar, the image with the smallest buildings of the seven, there is no peak at all, although a textural analysis of a second image of the same area, scanned at a higher resolution than the first, indicated that the differences in the modal D values for the two images was very small (2.50 for the higher resolution image, as opposed to 2.49 for the original image). If one could extrapolate from the behaviour of the other modal trend lines, it would seem that this second, higher resolution image of Guet N'Dar would possess a modal D value close to the maximum for a series of resolutions of that image, and that with greater increases in

³ The very existence, however, of such neighbourhoods as part of the colonial city, and the location of these neighbourhoods on the periphery of the city, is very much a part of regional and global processes. See Armstrong and McGee 1985; King 1990, 1976; Ross and Telkamp 1985.

image resolution, the modal D value would begin to drop, since the slope of the modal trend line at that point was virtually flat.

The behaviour of the modal trend lines may thus be generalized as showing an increase in modal D as image resolution decreases, up to a point. At that point there is then a leveling off of the modal trend line until an inflection point in the slope of the line is reached, after which the modal D values decrease. This tendency of the modal trend line may be explained in terms of data redundancy and autocorrelation. On imagery portraying areas where buildings are large and streets are wide, there is a greater degree of similarity in the values of adjacent pixels showing roofs or pavement areas than on imagery showing smaller buildings and narrower roads. In the latter case proportionally more of the pixels on an image are showing boundaries between road and buildings, or between buildings. These areas are relatively heterogeneous, with marked pixel-to-pixel variations in tone and texture. Following this logic, it would seem that in one sense the modal trend would indicate, for a given image, an optimum resolution representing a balance between maximum image detail and minimum image file size. For all images except Guet N'Dar, that resolution would correspond to the maximum modal D value. This optimum resolution would vary depending on the nature of the imagery and the size of the features which form the building blocks of the image, in this case, buildings.

Thus far the analysis has been confined to the intuitive level, where the histogram surfaces have been considered as aids in the visualization of complex data sets and have been interpreted visually. This interpretation has led to the identification of two tendencies in the data, the first being the degree of continuity of the modal trend line, related to the degree with which the settlement pattern conforms to the grid. The second tendency is found in the shape of the modal trend line, where the position of the inflection point relative to the image resolution may be related to building size and road width.

This second tendency must be examined carefully, however, for among the seven images in the study, one proves the exception to the rule. Pikine2, an image taken from the rural fringes of Pikine, the *bidonville* area, shows a modal trend increasing almost up to the coarsest image resolution. This may be interpreted as reflecting not large buildings and wide streets but a relative abundance of bare ground, reflecting a reduced population density in this area relative to the Pikine2 image. There is still a great deal of data redundancy, but it does not relate to the same settlement characteristics as do the more heavily settled areas of Col1, Col2, Col3 or Pikine1. While such an exception is problematic and discouraging in terms of applying this fractal texture measurement technique to settlement classification on a more general basis, it does indicate a possibility of relating these measures to settlement density (and

through settlement density to population density, see Adeniyi 1983) where relatively homogeneous settlements of varying density may be identified.

5.3 An Alternate Method of Histogram Surface Creation

In starting out this project each subsequent decimation was related to its previous image by an areal factor of four (linear factor of two). In areas where the modal trend was changing direction, however, I felt the need to create images of intermediate decimation (aerial decimation factors of 2.25 and 9) so as to clearly delineate the inflection point of the modal trend curve. This additional information, while confirming the presence of a smooth transition from negative to positive slopes along the modal trend for the Colonial-sector imagery, creates potential problems in the creation of the histogram surfaces. The histogram surfaces discussed above were created by simply placing histogram ribbons beside each other, ranked in terms of decimation but without regard to the magnitude of those decimations. In order to create histogram surfaces where decimation factors increased at a continuous rate along the Y-axis of the histogram surface, an alternative approach to histogram surface creation was undertaken. This approach involved creating a raster surface and placing the columns of fractal histogram information (histogram ribbons) at distances apart from each other relative to their areal resolution factor.

A linear decimation scale, not an areal scale, was used to determine distances between histogram distances since fractal relationships are generally logarithmic (Burrough 1985; Bittenfield 1989; Richardson 1961). Thus the histogram ribbon for the image at areal resolution factors of 1, 4, 16, 64 and 256 were placed four columns away from each other, while the histogram ribbon for the intermediate decimation 2.25 was placed two columns away from the full resolution histogram ribbon, halfway between it and the histogram ribbon for the areal resolution factor of 4. In a like fashion the histogram ribbon for the aerial resolution factor of 9 was placed midway between that for 4 and that for 16. In addition, histogram ribbons for the two images which were scanned at higher resolution, Pikine1 and Guet N'Dar, were placed to the left of the full resolution histogram ribbons, so that this information could be incorporated into the histogram surfaces. A bilinear interpolation routine in EPPL7 (Minnesota State Planning Agency 1990) was then used to create a continuous histogram surface for each of the seven images. The results of this approach appear in figure 5.2.

While this figure is similar to figure 5.1, several differences are worth noting. First is the visual confirmation that the additional information of the two high resolution images yields: a trend is continued in both case (the section of the histogram surface to the left of the vertical white line is created using this high resolution histogram ribbon). Second is the way in which the

Figure 5.2
Interpolated Histogram Surface Derived from Fractal Surfaces

interpolation procedure treats the images which have a broken modal trend line (Pikine1 and 2, Guet N'Dar). The interpolation creates a bifurcation, which is to some extent an artifact of method, since if one was to examine the fractal surfaces for the images at coarsest resolution, those fractal dimensions indicated by the lower bifurcation on the histogram surface would not be found. On this figure it is difficult to identify clearly the areas along the diagram which represent original data and those areas which have been derived using interpolation. The bifurcation is interesting nonetheless, since it bears a resemblance, superficially at least, to the bifurcations of chaos theory, referenced in many disciplines, where seemingly simple, stable systems may suddenly exhibit 'chaotic' behavior (Gleick 1987: 59-80). This interpretation lends weight to the notion that the point at which the break in the modal line on original histogram surfaces (figure 5.1) occurs corresponds to a change in the dominant characteristic of the image at that resolution. Note that no modal trend line has been superimposed on this figure, since the histogram surface has been interpolated. Unlike figure 5.1, it is not a classed representation of raw data.

The above discussion has focused on the visual interpretation of the histogram surfaces, without explicit reference to the conceptual model as informed by fractal theory. The discussion has concentrated on determining to what extent the histogram surfaces may be used as a way of classifying and

distinguishing between neighbourhoods, as well as examining the fit between the classifications as determined by the histogram surfaces and those based on visual interpretation of the imagery and prior knowledge of the city's history and geography. The interpretation of figure 5.2, with its bifurcations in the histogram surfaces associated with organic urban form, however, leads to the investigation of other research initiatives as outlined in chapter one, namely the links between urban morphology and fractal theory. This connection to fractal theory is through the references to bifurcation and chaos theory, often mentioned in the same breath as fractals, as evidenced by book titles such as *Fractals and Chaos* (Crilly et al. 1991).

5.4 Digital Interpretation of Histogram Surfaces

While the visual interpretation of the histogram surfaces appears to identify two critical tendencies of image behaviour over a series of resolutions which may be related to morphological characteristics of the settlements, the nature of the histogram surfaces, as digital images, allows for digital comparisons between histogram surfaces. In order to explore the possibilities of this approach, I chose to compare the histogram surfaces on a pixel-by-pixel basis, subtracting the value of one pixel on one histogram surface from the value of the pixel in the same relative position on another surface. This process was continued for all pixels on the surface and a total of the absolute

values of the pixel-to-pixel differences was tallied. This total difference is expressed in rather meaningless units, since the pixel values measure the percentage of the fractal surface which has been assigned a given fractal dimension, but the magnitudes of these total differences may be compared.

Table 5.3 shows a matrix of these figures, showing total differences for both types of histogram surfaces, those created by placing the histogram ribbons side-by-side (figure 5.1) and those created using bilinear interpolation (figure 5.2). The values for both types of histogram surfaces are relatively similar, affirming the use of the bilinear interpolation method. The matrix may be classified by grouping together cells with similar values. Similar cells are thus outlined using double lines (this is an informal clustering, not a digital cluster analysis).

This digital analysis confirms the visual analysis of the histogram surfaces. Comparisons between the Col1, Col2 and Col3 histogram surfaces yield the smallest differences, indicating that they are most closely related, one to another. The two Pikine histogram surfaces, Pikine1 and Pikine2 show greater differences in relation to the colonial-sector surfaces. When compared to each other, Pikine1 and Pikine2 are relatively dissimilar, a condition noted in the visual interpretation of the histogram surfaces, and explained above in terms of settlement density. Differences for the Guet N'Dar and Sor histogram

Table 5.3
Matrix Showing Differences Between Histogram Surfaces

Col2	Col3	Pikine1	Pikine2	Guet N'Dar	Sor	
371	355	497	496	972	1881	Col1
315	298	438	450	899	1838	
	398	496	414	980	1713	Col2
	353	462	447	975	1809	
		467	588	840	1897	Col3
		493	576	778	1838	
			656	1160	1918	Pikine1
			529	1040	1844	
				1136	1915	Pikine2
				1112	2016	
					1615	Guet N'Dar
					1871	

Top number in each box: difference between uninterpolated surfaces
Bottom number: difference between interpolated surfaces

surfaces are more extreme than other differences, indicating that these two histogram surfaces are distinct from each other as well as from the other five surfaces. These digital results confirm the visual interpretation of the histogram surfaces, although it is difficult to envision a situation where an

automated classification procedure using such a method could be used without extensive post-classification verification based on visual interpretation.

5.5 Is The City Fractal?

This next section will address another of the issues introduced in chapter one: the question of whether or not urban imagery, as measured using this fractal-based texture algorithm, may be considered as fractal. Does the imagery display any degree of self similarity, and can one image be more self-similar than another? If so, can this distinction be used as a way of comparing one image to another? A perfect fractal object would possess the same fractal dimension at any resolution (Peterson 1988: 119). This condition is clearly not met on either of the sets of histogram surfaces presented in this chapter (figures 5.1 and 5.2). The modal trend in the case of a fractal object exhibiting perfect self-similarity would be a straight horizontal line extending from the left side to the right side of the histogram surface, illustrating a constant D with changing image resolutions. None of the modal trend lines in figure 5.1 match this hypothetical situation. Of the seven images, Col1 and Col2 would seem to display behaviour closest to fractal, but only over a section of the histogram surface. This lack of conformity to the fractal model might be explained by the presence of different processes which shape urban morphology, acting at different scales, ranging from the household to the block

to the neighbourhood to the city as a whole, and extending up to more global scales (see King 1990: 24-27; Sack 1980: 181-182; Simon 1984: 506-508). These processes acting at different scales may or may not be acting in a coordinated way; this coordination (or lack thereof) may not be visible in the morphology of the city.

There is perhaps another consideration here, however. Section 4.6.4 outlined the bilinear interpolation procedure used to create imagery at the various resolutions, digitally emulating the photographic imaging process at different scales. The process of bilinear interpolation, however, results in the generation of an image with coarser resolution but also with reduced local contrast, since values of adjacent pixels on the original image are averaged in order to produce a coarser resolution image. This method is consistent with other fractal measurement methods, for example the "divider" method for the measurement of the fractal dimension of linear features (Longley and Batty 1989; Richardson 1961; Shelberg et al. 1982), where the length of a line is recursively measured using increasingly longer divider distances. In this thesis, however, with its use of photographic imagery, reduction in contrast with reduced image resolution is indicated by measurements of the Moran "I" statistic for each resolution of image, as indicated in table 5.1. Moran's "I" statistic is a summary measure of pixel to pixel autocorrelation for each image as a whole.

The use of the autocorrelation measure was intended partly as a check and comparison to the 'blanket' method. The results, however, are quite different than the 'blanket' method, in part, it would seem, because of the size of the field used in measurement. In the case of the 'blanket' method, a 9x9 pixel array was used to determine the local fractal dimension of any pixel on the fractal surface, while the I statistic was determined using only four pixels around a centre pixel. In comparison to the 'blanket' method, then, the pattern of the I statistic is relatively stable image to image, showing a general reduction in autocorrelation with reduction in image resolution, with the I statistic of all images at full resolution measuring above 0.9. If autocorrelation relates to reduced local contrast, then perhaps the interpolation method should be taken into account in determining whether the city is fractal.

Given this reduced image contrast as image resolution is degraded, rather than considering that no variation in the fractal dimension with changes in resolution indicates perfect conformity to the fractal model, we should be consider that continuous reduction in fractal dimension with reduction in image resolution is closest to perfect fractal behaviour. If this is the case then the Guet N'Dar image would conform most closely to the fractal model. Either way, whether one is searching for no variation in fractal dimension with image decimation, or continuous reduction in fractal dimension with image decimation, the grid based images (especially Col2 and Col3, and Guet N'Dar)

would appear to conform more closely to the fractal model than the organic images.

5.6 Conclusions

The 'blanket' method of image texture analysis would thus appear to be quite useful in differentiating between grid-based and organic urban morphologies, supporting the contention of this thesis that there is a link between morphological characteristics like pattern and texture. It would seem, as well that one image can be more or less fractal than another image. The degree of conformity to the fractal model, at least when used as a tool in visualization, is a useful way of distinguishing different morphologies, offering quantitative information to a qualitative interpretation. Clearly such a conclusion is preliminary, based on only one city and one set of parameters with the texture-measurement method. Chapter six discusses the implications of these limitations and discusses potential approaches to further research.

6 CONCLUSIONS

6.1 Summary of the Issues

One of the primary issues that has been examined in this thesis has been the relationship between texture, as measured from aerial imagery of urban areas, and city morphology. Fractal geometry has been used both as tool in the measurement of texture and as a conceptual framework for linking texture to morphology in this exploration (Mandelbrot 1983). The research questions have thus been framed in terms of a debates concerning the applications of fractal geometry within the discipline of geography (Goodchild and Mark 1987; Longley, Batty and Shepherd 1991, MacLennan 1988).

The question is this: Is the city fractal? The thesis research has found that the case-study city of Saint-Louis is not fractal, concurring with MacLennan's contention that urban growth cannot be perfectly self similar, but the research has also shown that the fractal model is more useful as an informal null hypothesis, and that individual neighbourhoods within Saint-

Louis can be seen as more or less fractal, adding weight to Batty and Longley's arguments. In the case of Saint-Louis, the degree of conformity to the fractal model can thus be used as a tool in the description and classification of neighbourhood morphology (see Lam 1990, for a similar approach using non-urban imagery). This mode of description would seem to offer an alternative to both the existing non-fractal mathematical descriptions of morphology, and ethnocentric textual descriptions, as exemplified in this thesis by Camara (1968) and Morris (1972).

Such an analysis begins to yield a more detailed, quantitative approach to Rapoport's (1984) concept of the "different orders" which exist in human settlement. Introducing Lefebvre's (1991) concept of "social space", and his discussions of texture within that framework, adds a richness to this discussion. A new framework is created which has the potential to link morphology, as measured, to morphology as experienced by inhabitants, and to explain morphology in terms of the conflicts between local and globally influenced urban settlement. Saint-Louis, along with a number of other colonial cities, is a good example of the coexistence of *representational space*, the space of inhabitants and users, with *representations of space*, the space of planners (Lefebvre 1991; Ross and Telkamp 1985). Can these two aspects of 'social space' be considered as 'different orders', in Rapoport's terms? While Lefebvre, focusing on European settlement, conceptualized urban social space

as being simultaneously composed of both elements, in a colonial city such as Saint-Louis, there is a case to be made that the 'planned', grid-based sector is dominated by representations of space, while the areas of 'organic' growth are dominated by representational space.

There are thus two different models of urban growth at play in Saint-Louis: the 'planned' model, where an organizational framework (i.e. the grid in the colonial centre of Saint-Louis) is used as a basis for development, and most or all of the urban development reflects the organizational framework itself; and the 'organic' model, where urban growth is based on one or more focal points, and buildings, at least traditionally, were sited based on kinship ties (Denyer 1978: 19). In the case of the organic model in Saint-Louis, the streets and paths appear to work themselves around compounds. There is more local influence on neighbourhood morphology: that is, the compound and its growth controls the accessibility network. Of course this is related to the lack of state control (and support) in these neighbourhoods. Pikine, for example, experienced very rapid growth, very little regulation, and very poor state support in terms of infrastructure over the study period in this thesis, and based on my observations in 1983 in Saint-Louis and the 1983 aerial photography, continued to grow more rapidly than the rest of the city. Therefore it grew based on the initiatives and needs of its inhabitants, and its morphology reflects that fact. There is relatively little evidence of

representations of space, the space of planners and technocrats, because such organization implies pre-planning, a surveyed cadastre, and zoning.

The historical survey in chapter two shows us that this situation is consistent with the process of building other colonial cities. Pikine is the latest in a series of peripheral settlements on the outskirts, the more central areas having been appropriated and transformed as part of the colonial city as the colonial city grew. With the appropriation came a transformation of the morphology of the existing neighbourhoods, from the organic to the colonial model. At the same time, there is a definite colonial influence in areas such as Pikine, evident in the building materials and building shapes which make up this organic growth. The building of rectangular buildings within non-grid organic growth makes for a clash of geometries, much as there is a clash of cultures, with the 'traditional', indigenous, extended family colliding with the 'European' colonial model. This is perhaps another interpretation of different orders, and is evident in the breaks on the histogram surfaces of Sor and Pikine, where at one level of resolution, organic irregularity is dominant, while at a higher resolution, the rectangular nature of the individual buildings making up the settlement becomes the dominant factor. At this break point we have, in fractal terms, a discontinuity, evidence of two different processes operating at different scales.

6.2 Directions for Further Research

6.2.1 Methodological Issues

Clearly the interpretations in the above section are speculative, informed by a combination of quantitative and qualitative reasoning. Perhaps it always will be speculative, because of the intangible factors that are involved. Based on this research, however, there are some obvious areas that warrant further exploration. The first path is methodological, based on the implementation of the blanket method undertaken for the fractal analysis in this thesis. While Moran's I statistic, a measure of spatial autocorrelation (Kendel 1989: Moran 1948), has been used as a check and comparison to the fractal methods, other, more complex and widely used texture measures might be compared, such as methods using spatial co-occurrence matrices (Haralick *et al.* 1973). This testing would provide evidence of the effectiveness of the 'blanket', relative to *de facto* standards of texture measurement. As well, the parameters used to control the 'blanket' method should be tested more fully.

More generally, there are unanswered questions about the processing of the sample images. Care was taken to ensure that the images were equalized, using the default equalization mode in Idrisi, so that the histograms of all the images would be as similar as possible to each other. There are, however, an

infinite number of ways to manipulate a digital image. It would be useful to test more thoroughly the relationships between various image stretching and equalization procedures and the results of running the fractal program. Such testing and comparison, however, would constitute a thesis in itself. This thesis was an preliminary exploration into the potential applications of such a method, taking what I considered the minimum steps required to test the method prior to exploration.

6.2.2 City-to-City Comparison

The question of equalization introduces the second area of potential future exploration, the issue of how much of a generalization may be made about urban morphology and texture based on one study area. How can the morphology of cities be compared? Considerations such as atmospheric conditions, sun angle, image orientation and image resolution have meant that within remote sensing methodology, it is considered difficult, if not inappropriate, to compare one site to another. Accuracy is measured in percentage terms by using a confusion matrix which compared classification results to ground truth (see for example Cushnie and Atkinson 1985; Latty *et al.* 1985). Training sites are selected for each individual area. In this case, however, it would be useful to be able to generalize, and to be able to describe

urban growth as containing certain morphological characteristics, regardless of the specific site.

The term 'organic' has been applied to a range of urban form, ranging from medieval Europe (Morris 1972: 9) to ancient Egypt (Kemp 1972: 673); it is clear that there must be some kind of commonality which allows the identification of organic growth on imagery, regardless of site. There would also appear to be consensus as to what the term 'organic' means, but the question remains whether it is possible to be more quantitative and less culturally blinkered when describing organic growth, so that we can progress beyond descriptions such as "totally lacking in organization" (Camara 1968). This is an extremely broad, difficult question to tackle, and would require a major research thrust. Perhaps this thesis is a start in that direction. Technical and methodological questions would warrant serious consideration, as the issue of comparability between sites using remote-sensing techniques is difficult. Perhaps a series of studies similar to this one, where cities are selected on the basis of the presence of both grid-based and organic growth, could be a start-point. If the same sorts of dichotomies emerged as in Saint-Louis, in that there was a distinction in the histogram surfaces between the two types of growth within other cities, one could be more confident about making generalizations. Although the ranges of fractal dimensions might vary

between cities because of factors such as sun angle and image contrast, one would expect a similar general appearance to the histogram surface.

To be consistent in this approach, the cities chosen would necessarily have to have a similar form of organic growth, where rectangular buildings are arranged to form irregular clusters of settlement. We would thus expect a discontinuity in the fractal surface, as in Pikine and Sor. This raises another question, however. What happens in the case of the 'traditional' African settlements based on geometric forms such as the circle (Archer 1971; Blier 1987; Dalby 1975, 208), where there would be more of a consistency in the organic growth, where the 'building blocks', the individual buildings, would more closely resemble the overall form of the settlement (figure 6.1)? Would the histogram surfaces more closely resemble those of the grid based growth, because there is a unity throughout, or the urban organic growth, in spite of the "different orders" implied in urban organic growth? Further, is a raster computer system based on square pixels capable of discerning the order of a circle based settlement? When setting up the thesis study, the images were scanned in an orientation that, as closely as possible, was in alignment with the grid. In this way, individual buildings might correspond to pixels fairly closely at certain image resolutions. Where there was no obvious grid, alignment was problematic, and this would be even more of a puzzle with a

circle-based settlement. Perhaps such a settlement would require a much finer resolution image than that required for imagery of grid-based settlement.

6.3 Conclusion

In a world where the possible existence of a satisfactory meta-narrative is being challenged on all fronts, both within geography (Dear 1988; Shields 1991) and without (Hedbidge 1988; Lyotard 1984), this thesis may seem somewhat anachronistic. Fractal geometry is not being offered as an alternative meta-narrative as some (Barnsley 1988) might wish, however, but simply as a tool, a way of understanding. If using this tool helps to cast new light on arrogant, ethnocentric textual descriptions of some types of urban form, then the thesis has succeeded in helping to dismantle a long unchallenged meta-narrative.

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