Correlation Landscapes: A New Approach to Sub-area Definition in Low Intelligibility Spatial Systems

Noah Raford and Bill Hillier
University College London, UK
n-raford@spacesyntax.com, b.hillier@ucl.ac.uk

Abstract

This paper explores the influence of configuration on movement in fragmented, low intelligibility spatial systems. Traditional space syntax theory holds that correlation between space and movement breaks down in such situations, resulting in lower predictability and/or apparently chaotic behaviour. This paper suggests that a careful analysis of sub-area definition and overlapping neighbourhood boundaries can be used to disentangle the effects of low intelligibility environments and reveal clear influences on pedestrian movement. The case study of Boston, Massachusetts is used to explore this hypothesis through the use of multiple regression analysis and a new technique named “correlation contour mapping”, which outlines the boundaries of predictability within complex spatial systems. It is shown that space plays a significant role in pedestrian movement in the case of Boston ($r^2$ between 0.65 and 0.94), but that it correlates non-uniformly with different areas and users. An understanding of sub-area definitions and the effect of overlapping patterns of correlation is therefore necessary in order to fully comprehend the effects of fragmentary configuration. It is suggested that the use of correlation contouring may achieve this and is a useful diagnostic tool for exploring the interaction of different user groups in urban space.

1. Introduction

A wide variety of space syntax studies have examined the relationship between integration and pedestrian movement in cities across the world (Hillier and Hanson, 1984; Hillier, 1989; Penn et al, 1998; Hillier, et al, 1993; Hillier, 1996). It is not uncommon to achieve correlation co-efficients of 0.8 or higher between integration and observed movement where conditions approximate all-point to all-point movement. Hillier et al. (1993) refers to such movement as “natural movement”, or the percentage of movement resulting from the configuration of the urban grid itself.

Natural movement relies on an adequate level of intelligibility, or the ratio of connectivity to global integration measures (Hillier et al., 1987). Intelligibility measures the degree to which local spatial conditions correspond to global spatial structure. This condition has been found to encourage people’s wayfinding abilities and their ease of navigation. It has also been found that complex environments with difficult or confusing layouts result in conditions of “unintelligibility”, or low correlation between these two variables. Thus complex environments that involve many changes of direction can make navigation more difficult; weakening the relationship between space and movement (Peponis, 1990; Penn, 2001; Chang and Penn, 1998; Conroy-Dalton, 2001; Hillier 2003).

Several studies from both the space syntax and cognitive science literatures provide evidence to support this notion. Peponis et al. (1990) used space syntax to map the interiors
of hospitals, then gave study participants a tour of each hospital. Participants were then asked to conduct way-finding activities within each hospital and their performance was measured in a variety of ways. It was found that participants were able to more quickly find interior landmarks in higher intelligibility environments than lower intelligibility environments, suggesting that spatial layout strongly affects navigation in complex interior environments.

In his study of adjacent neighbourhoods in a north London suburb, Kim (2001) asked residents to draw sketch maps of their local environment and then conducted axial analysis of these maps. These were then compared to axial maps of the actual neighbourhoods under study. Kim found that the degree of intelligibility of each neighbourhood corresponded to the accuracy of the sketch maps drawn by its residents, suggesting that a higher degree of intelligibility resulted in better spatial understanding.

Conroy-Dalton’s (2001) work provides an interesting bridge between these two scales of study (the architectural and the urban). Using virtual reality technology, Conroy-Dalton (2001) analyzed the behaviour of real people navigating virtual environments with different degrees of intelligibility. In addition to finding that people tended to follow angle-minimizing pathways, she found that people tended to take longer to navigate less intelligible spatial systems and got lost more frequently in low-intelligibility virtual worlds than in high intelligibility ones. Based on this evidence she concludes that local visual cues that are well related to global structure helped subjects navigate more effectively, while local cues that are not well representative or even misleading of global structure can produce the opposite effect. All of these studies indicate that environmental intelligibility is an important variable in learning, understanding, and navigating complex spatial systems.

There are many studies from cognitive science that support these findings, but their measurement of space is often less precise than space syntax research. Haq and Girotto (2003) cite a study by Wiesman (1981) in which seventy-three self-reports regarding wayfinding in ten university buildings were analyzed relative to the “simplicity” of the floor plan of each building. It was found that simplicity related strongly to self-reported wayfinding performance. O’Neill (1991) also found that higher levels of configurational understanding in test subjects was frequently associated with better wayfinding performance. Golledge (1999) also reviews a variety of studies that suggest that errors in cognitive maps inhibit spatial problem solving, suggesting that global spatial cognition is a vital component of wayfinding and navigation behaviour.

Why is this the case? Penn (2001) suggests that the consistent correlation between configurational spatial properties and pedestrian movement can be explained by looking at the underlying mechanisms by which people perceive, understand, and then navigate their surroundings. He asserts that cognitive space is made sensible through the locomotive exploration of the environment, and that the more intelligible the environment, the better the spatial cognition.

Hillier and Iida (2005) expands upon this in more detail when they argue that human navigation in spatial systems is dominated by metric properties at the local level, but topological or angular properties at distances beyond which humans can visually approximate. They note that estimates of distance are influenced by the division of routes into discrete visual chunks (Golledge, 1992; Montello, 1997; Kim, 2001), tendencies to correct bends to straight lines and approximate turns as right angles (Allen, 1981), and the directions from which the estimate is made (Sadalla, 1980; Montello, 1992; Golledge, 1995).

These studies suggest an important relationship between the configurational properties of space and people’s ability to form topological understandings of their environment. A
Figure 240: Notional street grids display the effects of small changes in visual integration on intelligibility and simulated agent movement. The first two grids display visual integration, colour coded from dark to light with light representing the most integrated lines of sight. The second two grids (on the bottom) display the motion of simulated agents moving through the system. It can be seen that the grids on the left display higher integration and more logical through movement, while the grids to the right lose their strong spatial structure, resulting in a lower intelligibility and more random agent movement. This demonstrates the influence of physical configuration on visual intelligibility and natural movement.
close match between local and global spatial structure may influence people’s ability to form topological understandings of their environment, thus influencing their patterns of movement and navigation therein.

This paper argues that the layout of urban sub-areas strongly influences cognition of complete urban systems, and that additional understanding of how such sub-areas interact is necessary to understand the effects of natural movement in complex, fragmented urban structures.

2. The effects of sub-area definition

In “Cities as Movement Economies”, Hillier (1996) observed that sub-areas could be identified in an intelligibility scattergram of the Greater London area by their slope and degree of linearity within the larger system. Sub-areas displaying linear scattergrams suggest strong area definition and good intelligibility; their slope indicating the degree to which they operated as local areas. Sharply sloping linear clusters such as Leadenhall Market were taken to indicate distinct local areas within the larger grid, while more dispersed clusters with low slope appear to indicate sets of smaller spaces related to the grid but without strong local spatial identities to themselves.

This early research points to the role of sub-area definition in global intelligibility, but offers little specific guidance as to which urban forms produce tightly clustered scattergrams or intelligible sub-areas. Subsequent research using notional street grids and Visibility Graph Analysis (VGA) has shown a clear relationship between linear streets, longer lines of sight, and higher intelligibility. In Figure 240 Hillier (2005) demonstrates how slight shifts in the layout of two notional block systems can produce radically different spatial structures, with consequent impact on integration, intelligibility, and simulated movement. This suggests that linear lines of sight produce a well ordered spatial hierarchy which is more conducive to spatial cognition and urban navigation.

This can be seen in real urban systems as well. Figure 241 uses a simple analysis of street orientation to reveal a quick and powerful picture of sub-area formation. The structure of two urban systems, London and Denver, Colorado is illuminated by colouring up streets based on their compass orientation. The map of Denver reveals a strong linear grid, broken into clear sub-areas by rotated grids or diagonal streets, while the map of London reveals a more patchwork urban structure.

Although relatively simple, this method reveals sub-area formations as interruptions to the regular grid of the city, suggesting that perturbations in the linear structure of space can be used as a proxy for sub-area definition. It also suggests that such perturbations may form cognitive boundaries as well, which can influence spatial cognition and movement. The following section explores this hypothesis in more detail using the city of Boston, Massachusetts as a case study.

3. Methodology

The city of Boston, Massachusetts is a noteworthy case for the space syntax community because it is nearing the end of one of the largest redevelopment projects in American history, colloquially known as “The Big Dig”. This project will significantly altered the city’s spatial structure by burying an 8 lane motorway which cut through the heart of the central business district and replacing it with an integrated network of parks and streets.
Figure 241: Directional analysis of streets in Denver, Colorado and London, England reveal strong sub-area formation. By colouring the street grids based on their orientation, with north-south and east-west grids shown in lighter line thickness and diagonal grid systems shown with darker line thickness, sub-area formation can easily be picked out. It is suggested that changes in visual direction resulting from sub-area interaction contributes to the perception of a city's layout and can encourage or inhibit coherent movement patterns.
This transformation offers a unique opportunity to conduct a natural experiment testing the influence of intelligibility on spatial cognition and urban movement, using before and after quantitative data to evaluate the hypotheses of this paper.

An analysis of the city’s spatial structure, land use distribution, and current pedestrian circulation patterns was conducted. This included a detailed pedestrian movement survey which gathered pedestrian counts at 82 pedestrian locations in the city for 5 minute segments every hour between 8 AM to 8 PM. Both weekday and weekend data was recorded, analysing movement for three different demographic groups at each location. These groups were workers, residents, and tourists. Pedestrian movement was found to be non-normally distributed at all gates, and was therefore transformed using the square root of observed values to create a normal statistical distribution.

Axial line maps were then drawn using standard mapping techniques to quantify the spatial structure of the study area. Both before and after maps were drawn of the study area, reflecting conditions before and after completion of the Big Dig. Figure 242 displays this map, with Radius 4 integration coded by line thickness.

Multiple regression analysis (MRA) was then conducted to explore the statistical relationships between different variables to observed movement. MRA techniques allow the comparison of multiple variables simultaneously and can result in significantly stronger explanatory correlations. All variables were correlated individually and then step-wise in groups to determine the optimal correlation combinations, given adequate p-values and statistical validity.

4. Findings

Initial analysis produced relatively low correlations between these variables and the hourly average of all pedestrian movement \( r^2 = 0.42, p < 0.001 \). The addition of other explanatory variables such as topological step depth to major attractions increased this correlation only slightly \( r^2 = 0.51, p < 0.0001 \). Space was also found to correlate differently (and more poorly) with different user groups \( r^2 = 0.22 \) for Suits, 0.22 for Locals, and 0.41 for tourists) as opposed to the total average.

An analysis of the correlation of different pedestrian groups movement patterns to each other revealed a classic “perpetual night” syndrome similar to the L-shaped graphs found in many of London’s worst housing estates. Figure 243 reveals how little overlap was found between demographic groups, illustrating the point that different user groups use Boston’s spatial system in very different ways and over different areas.

The low intelligibility of central Boston was thought to contribute to these low correlations (Boston’s intelligibility before the Big Dig was found to be 0.36). To explore the effects of sub-areas on movement, the analysis was subdivided into four areas based on estimates of their spatial coherence. These estimates were tested through combinatorial experimentation, adding or removing observation gates in roughly contiguous convex areas and then evaluating the effect on the correlation of that sub-area. Stepwise regression analysis was then repeatedly re-run for all variables until stable islands of correlation were observed. These islands were then mapped, resulting in a map of varying correlation for all user groups, henceforth termed “correlation contours”.

Correlation contouring is a new technique based on the additive process of gate inclusion and exclusion for all gates and all variables. This process begins with clusters of gates that appeared to correlate well, starting with a small group of four to six gates per
Figure 242: Axial integration analysis of Boston, Massachusetts reveals a fragmented spatial structure with no strong integration core. Several smaller sub-areas can be seen, but there are no powerful lines of high integration accessibility which knit the system together into an urban whole. The result is low intelligibility, poor spatial cognition, and fractured movement systems with little overlapping interaction.
N. Raford and B. Hillier

Figure 243: Scatterplots of pedestrian movement reveal the extent of separation between different demographic groups. It can be seen that suits, tourists, and locals display an “L-shaped” movement graph when compared to each other, similar to the “perpetual night” syndrome found in some of London’s worst housing estates.

Cluster. Individual gates are then added and step-wise regression performed with all input variables until all gates have been included.

Gates added in this fashion thus create a “correlation landscape” which traces the extent of correlation between movement and explanatory variables such as integration and the number of topological steps to the nearest transit station. The resulting correlation contour maps allow discrete sub-areas of movement to be described and quantified in more detail than previously possible. This creates an overlapping map of correlations which allows for detailed exploration of the data and finer scale movement correlations.

By incorporating a finer understanding of sub-area definition this new technique resulted in higher correlation coefficients with observed movement, thus extracting the influence of spatial layout from a difficult and complex low-intelligibility system. Three separate correlation contour maps were created for each user group (suits, locals, and tourists), and one for the average all total movement. Figure 244 displays these maps, which were then used to forecast movement rates in central Boston after the completion of the Big Dig project.

5. Discussion

Aside from the methodological utility of correlation contours, what can they teach us about the part/whole problem and the effects of spatial fragmentation on the urban experience? Can they offer any specific insight towards the development of stronger, more vibrant places and better, more functional urban movement systems?

First, it can be said that strong correlation between sub-area definition and the movement of different user groups indicates that space is heterogeneous in influence and non-uniform in its experience. The observation that different user groups exhibit different correlation contour maps provides quantitative evidence towards this end. What this literally means is dependent on the individual goals and objectives of each urban inhabitant. But instead of an infinitely diverse interpretation of urban space, where each person lives in their own city with their own interpretation of neighbourhood boundaries and sociospatial relationships, correlation contouring suggests that even though such definitions may differ, they maintain an overall emergent continuity. This continuity suggests a shared commonality of spatial cognition, urban navigation, and social experience.
Figure 244: These maps show the “correlation contour” method described in this paper. Different contour maps can be seen for different user groups, detailing both sub-area formation and the extent of overlap between different demographics. The use of multiple regression analysis and correlation contouring allows for a more nuanced understanding of the effects of different variables on movement, proving to be a powerful diagnostic and analysis tool.
Second, to the extent that an urban spatial structure influences the formation of coherent cognitive maps and guides the formation of overlapping systems of movement, and to the extent that urban vitality requires a strong mixture of different scales of movement, users, and activities, such an analysis could be used as a tool to measure the likeliness of the creation of the “urban buzz” sought after by so many of today’s any architects and planners. Correlation contour mapping can thus be a useful diagnostic and design tool, as well.

An analysis of Boston’s street layout similar to that conducted above immediately reveals why Boston experiences low intelligibility and fragmented movement systems. Figure 245 reveals that contrary to the regular street grid of Denver or the lumpy yet still coherent structure of London, Boston has several distinct spatial subsystems which have poor global connectivity to each other. Systems of north-south and east-west streets are broken by separate systems of diagonal streets, resulting in several changes of direction, short sightlines, and little interaction between these two systems of street typology. There are no major lines linking sub-area to each other in a coherent global structure and the linkages that do exist are short, require several turns of direction, and are difficult to navigate.

Boston’s structure makes the formation of a coherent cognitive map of the city very difficult to construct, resulting in poor spatial cognition and segregated movement systems. A comparison between Figure 245 and the correlation contour maps in Figure 244 reveals striking similarities. Areas of high correlation tend to be found in topologically similar areas, while movement and correlation breaks down at their boundaries.

6. Conclusion

This paper began by asking, “how does street topology influence spatial cognition, and how does natural movement function in fractured, low-intelligibility spatial systems?” It used integration analysis and a new technique named “correlation contouring” to identify the localising effects of segregated spatial systems and to measure their impact on urban movement. It then extrapolated from these findings to suggest that low-intelligibility segregated spatial systems inhibit the formation of system-wide spatial cognition, resulting in fractured movement systems and segmented urban experience. It found that sub-areas could be identified using simple morphological techniques, and more precisely circumscribed using the correlation contouring method introduced herein. It is suggested that planners and architects can use such methods to diagnose and correct conditions of low intelligibility when they arise and prevent them from occurring, this contributing to the formation of vibrant, interactive social spaces which benefit from a mixture of movement, users, and activities.

Future research involved correlation contour methods to identify sub-areas should experiment with automatic methods of combinatorial gate correlations, perhaps combining brute force algorithms with step-wise interactive visualisation similar to those found in genetic algorithm programs or L-systems. This would allow for the relative weight of each variable to be explored and a variety of contour maps to be created, depending on the research objectives chosen and the dynamics of the particular spatial system in question.
Figure 245: A directional analysis of Boston’s streets reveals why the city experiences disconnected movement systems and a weak urban core. Systems of north-south and east-west streets are broken by separate systems of diagonal streets, resulting in several changes of direction, short sightlines, and little interaction between these two systems of street typology. These factors make a cognitive map of the city difficult to construct; resulting in poor spatial cognition and segregated movement systems.
Literature


Correlation Landscapes: A New Approach to Sub-area Definition in Low Intelligibility Spatial Systems


