Comparison of logical binary step based and metric properties in flow network: Case Helsinki

Anssi Joutsiniemi, Lecturer, MArch

Tampere University of Technology
Department of Architecture
Institute of Urban Planning and Design
POB 600, FIN 33101 Tampere, Finland
e-mail: anssi.joutsiniemi@tut.fi

Abstract

Recent changes in the urban structure of Helsinki metropolitan area indicate that the agglomeration is going through a transformation process different from the one in modernist era. Theories for on-going change have been suggested in field of social sciences by authors like Manuel Castells and Saskia Sassen. Recently, the origin of this networking phenomenon has advanced, and is to be found in human mobility (Nigel Thrift) and in the way "unbundled" infrastructure networks are reassembled (Stephen Graham and Simon Marvin). Still, tools for predicting and analyzing this phenomenon of networking conurbations area are unavailable. Theories behind Space Syntax may be of a great help in making these ideas operational.

Previous work by this author (Joutsiniemi, 2002) suggests that with an application of the axial map analysis method some valuable information about functional clusters of metropolitan area may be derived. A simple change in the method concerns the underlying network. The Space Syntax method for evaluating the complex structure formed from lines of sights is used for movement-based division of a street network. Since the applied method seems to reveal different accessibility levels and neighborhoods some further comparison is needed.

Binary step methods used in Space Syntax have a strong connection to the recent theories of so called "small world" networks. These connections serve as a bridge between binary relations and metric world. The objective of this paper is to compare the results of binary step based method of accessibility with more time consuming calculations of different metric properties of a network. The aim is to find out whether findings in clustering formation are comparable with traditional network analysis based on the Dijkstra algorithm or whether they lean on different intellectual backgrounds.

Introduction

Networks have been used for ages as a metaphoric narration for urban development. Also traffic and transportation planners have successfully used networks for controlling and optimizing the flow of people and vehicles. Yet the implementations of network analysis into the formation of townscape have been rare. Among planners the axial analysis by Hillier and Hanson has long remained the only truly established method for measuring spatial properties of urban form. This sounds rather embarrassing especially, because recent development in field of social sciences as well as innovations in graph theory have proved to be very effective tools in understanding the complex world. The main argument in both science and scholarship is after all the phenomenon of networking. The most urgent need for planners is to find practical tools for operating in between.

The nature of axial map analysis

The understanding of the principle behind axial map analysis requires the definition of graph depth. The integration values used are in fact normalized derivatives of the mean total depth concept. (Hillier & Hanson 1984, p. 108) The total depth of a line in turn is gathered by the summing up of degrees of separation of all other lines. (ibid. 104) The flash of genius in method thus is twofold: the network structure and the concept of depth.

The calculation of depth is by its nature a calculation of logical distances within network under consideration. Since the summation of natural numbers is probably the most simple way of operationalizing the "widely agreed premise, sometimes called Tobler's First Law of Geography, that everything is related to everything else but near places are more related than far places." (Longley & Batty 1996, 150) The result of summations is dictated by standard deviation of operands; while the distance (i.e. the absolute value) increases, the stress of near and far places naturally generate asymmetry. This calculation works as an index value relative to the form of justified graph generated from a specific point (Hillier 1996, 102). The same principle of asymmetry analysis was used by Bavelas in analysis of patterns of social relations. (Bavelas, 1951)

In his book "Space is the Machine", Hillier makes a significant move towards the phenomena behind the axial analysis. The chapter "Cities as movement economies" describes in detail the formation process of the city in history. In metropolitan regions the diversity of movement, I believe, has moved beyond historical discourse and created a heterogenic structure that has become incomprehensible for vista based methods.

Analysis of accessibility

In its traditional meaning the concept of accessibility is defined as the degree of interconnection with all other points on the same surface. (Ingram 1971) This gives us a general form of integral accessibility A_i of a point as:

$$A_i = \sum a_{ij}$$

where a_{ij} is relative accessibility of point *j* at *i*. Ordinarily this relative accessibility is defined as the trip length between locations *j* and *i*. It wouldn't be very different to use some other metric property, the travel time e.g., instead of Cartesian distances, but it is most uncertain what kind of accessibility may be defined according to the degree of separation of logical linkages.

In previous work by this author it was proposed that accessibility may be defined with same kind of binary step method as spatial integration on axial map analysis and retrieve valuable information about structure underneath (Joutsiniemi, 2002). The trick was to use episodes of movement instead of the basic Space Syntax unit, the line of sight. This episode was further defined as segment of flow network formed between junctions. It was shown that defining relative accessibility as binary step based degree of separation on carries valuable information about properties of centre formations and functional clustering of metropolis.

Since the edge length tends to grow according to road standard, the time spent in a defined episode is most likely the property remaining constant and thus correlating with binary step analysis. By performing two sets of calculation it is possible to compare how well this hypothesis holds true. The pictures below show the integration of episode based network as compared to integral accessibility based on travel times. Pictures show different sizes of neighborhoods in similar manner than calculations of local integration levels on axial map analysis. (Hillier 1996, 170) Radii were chosen to match time based accessibility intervals of five minutes.

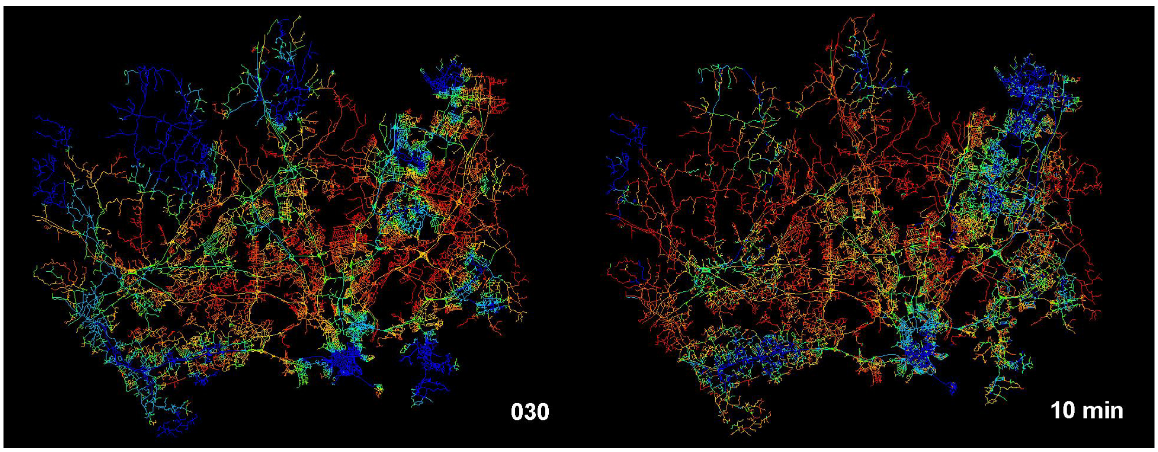

Figure 1.

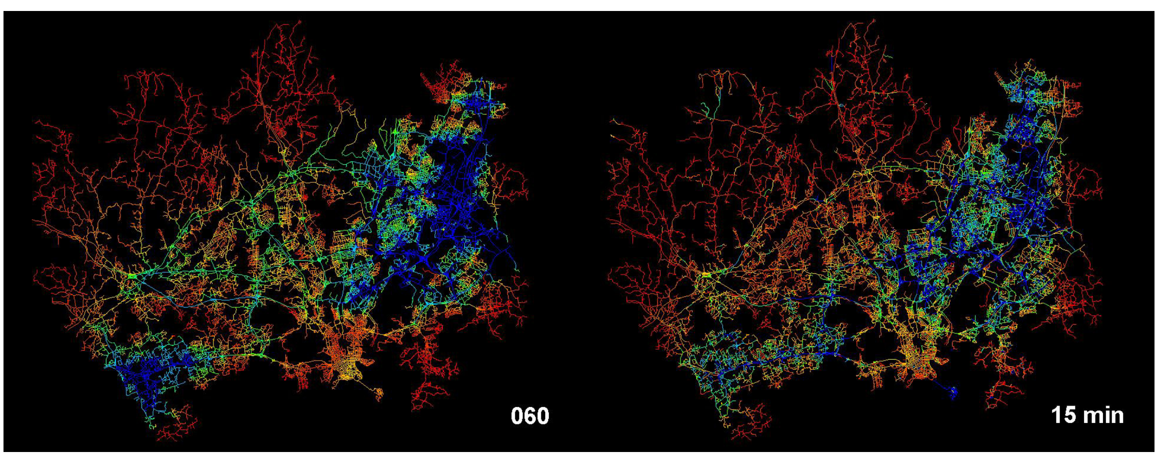

Figure 2.

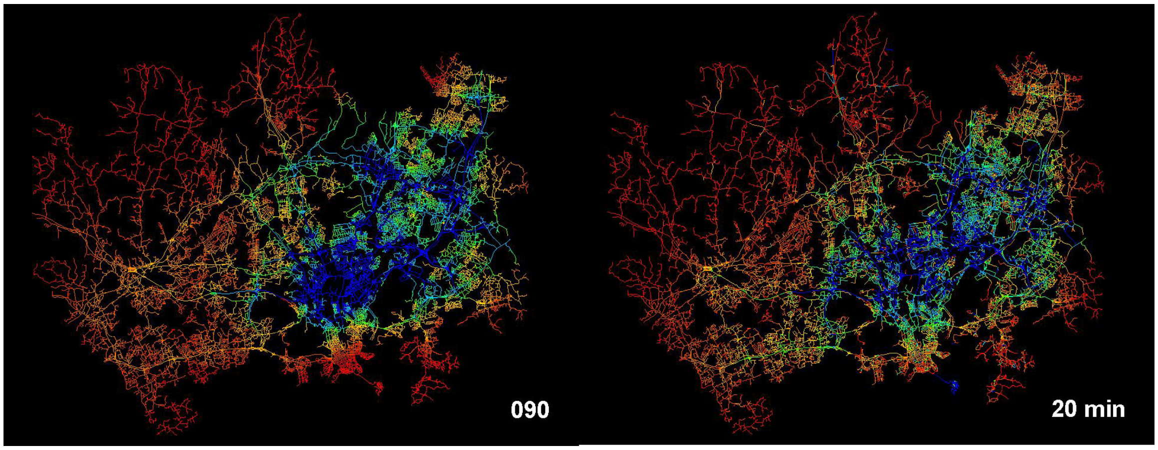

Figure 3.

Figures 1-3: Comparison of the binary step integration and the shortest travel time integration. 20 % most integrated links shown darker. Neighborhood sizes are shown on lower right corner of each picture. Radii marked with binary steps on left hand side and corresponding minute based neighborhoods on right hand side pictures.

In general the pictures are very much alike. Both of them are showing different integrated neighborhoods according to the maximum depth of calculation. The integrated areas that are left out from time based analysis are the ones that didn't fall into the pattern when areas were compared to functional clusters of real world.

The major differences in pictures are at the edges of network. In axial map analysis it is very common that edges of networks suffer from the lack of the other half of their natural neighbor. In these episode based analyses the average edge length is typically much shorter and the edge effect thus more local. Since the analysis was carried out for identical networks it is worth taking closer look at road types and speeds as well as graph edge lengths. The following graph shows the crucial relation differences between the length of edge and the speed of traffic flow.

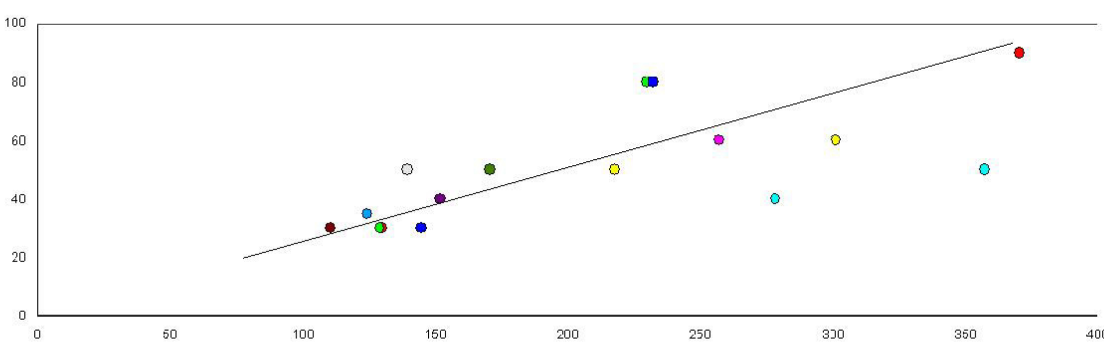

Figure 4: Graph showing the relation between average edge lengths of road classes and corresponding speed limits in real world road segments.

Even though there is great variety on lengths in every road class, it seems to have very little effect on the overall analysis. Figure 4 shows the average length of each road class and indicates clearly that correlation between speed (y-axis) and length of edge (x-axis) exists in different road classes pretty much as might be expected. What is not so obvious are the two separate road classes that are way below and the two clumped up ones above speed-length equilibrium line. The dots below the line are the ones that gain from binary calculation and dots above those that suffer from the method. The picture below shows the geographic locations of the suffering ones on left side and the ones that are benefiting on right side. These are also the areas where methodological shortcomings are to be found in the analysis of Helsinki metropolitan area.

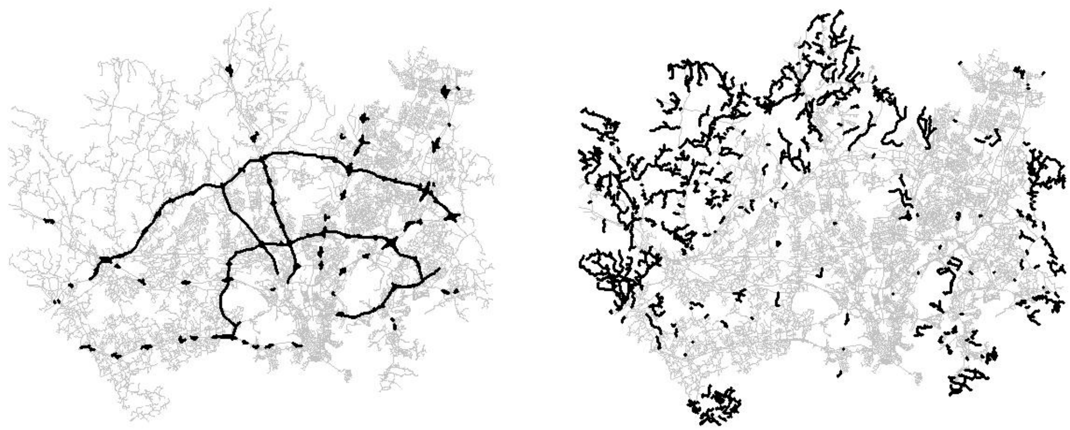

Figure 5: Road segments affected with methodological error of binary step calculation: Sections suffering from calculation shown on left and benefiting ones on right.

The biggest errors are located in areas that previously sited merely scattered small houses, but are nowadays more and more connected to the trends of metropolitan housing development. The old village roads are affected the most since the increasing density forces to lower the speed limits down to keep up with safety regulations, but the road structure remains traditional for much longer and differs logically from the rest of the network. Small errors may also be found on ring road sections that hold higher speed limits than their logical structure in the analyses would expect. This is a minor problem though since the roads containing more intersections also mostly have a lower speed limit, so the error is caused more by a classification of heterogenic road links within one and the same class, than the analysis method itself.

Taking a look at these two different methods of analysis, it is fair to say that (at least) in the Helsinki metropolitan area the binary step analysis serves as a very decent estimation of actual travel times. The excellence of the method is its speed of analysis. In very large networks, as the metropolitan flow networks usually are, the analysis performed from every connection to every connection is always on the edge of combinatoric explosion. With ordinary breadth first algorithm used for binary step analysis it is possible to reduce the time complexity for one link to n from n^2 of Dijkstra algorithm. Most analysis times can be cut down from several hours to a few minutes which is essential for any serious modelling purposes.

Connections to recent network theory

Recent research on networks has changed the way our world is made up. Our social behavior seems to form structures that have universal features similar to structure on Internet or protein network of cells. (Barabasi, Watts etc.). Probably the most significant finding was done by Watts & Strogatz in 1998 that revealed the “small world” properties of real life networks that differ from graph theoretical foundation laid by P. Erdös & A. Rényi at the end of 1950's.

One might ask why the most important macro level network around us has been left untouched by this new series of analysis. What I'm talking about is of course the traffic network formed of roads and streets, alleys, mews and crescents that forms an overall complex structure with its own centers of concentration of human actions. It is true that in Barabasi's book “Linked”, transportation networks have been taken into consideration. That is done as an example showing major difference between airplane and vehicle flow networks. In his example, airports and their connections seem to form a scale-free network that has a couple of hubs that are the main connectors of structure while vast proportion of airports contain only a couple of flights per day. It is also claimed by Barabasi that the national road network serves as an example of random distribution of links. It is argued in this paper that if the road network appeared random for him it was only because it depicted an ill-formed network based on administrative division of major roads, not one based on actual usage. Binary step based analysis shown in this paper indicates that there are strong clustering formations in true world street networks.

A quick look at road network convinces us that we are not dealing with a small world phenomenon but something different. The maximum depth graph, theoretically speaking a könig number of some 180 in Greater Helsinki (or 250 in Greater London), indicates that it is not likely that any hubs exist within the network. That holds with the intuition of physical limitations of road building; usually junctions contain no more than maximum six incoming road segments. That is not the situation with the axial analysis though. Taking a closer look at Hillier’s networks of Greater London (Hillier 1996, Plate 2), it is clear that the resemblance of radius n and radius 10 analyses is so great that the könig number for core lines is already reached. Without seeing other intermediate steps it is not possible to say how much earlier it is reached, but anyway the relation to the maximum degree of separation of the whole system is in our hands: it can not be bigger than twice the minimum könig number. Since we are dealing with a network containing hundreds, if not thousands, of rings, it is most likely that the maximum degree of separation is much lower. This means that systems formed by lines of sight are in themselves “small worlds” and thus the sky is the only limit for further analyses.

Conclusion

Comparison of analyses presented in this paper strengthens the evidence that the binary step based method for calculating the network depth in essence forms a special case of accessibility analysis. Since the inner logic of townscape formation is strongly related to movement speed, the metropolitan flow network structure forms into the movement episodes that area very likely to be stable enough for the most brutal but also the most cost efficient form of network analysis: the binary step analysis. The major task for further development of episode based analysis is to outline some advanced properties that make difference in clustering of the "large worlds".

Bibliography

Aura, S. (1989). *Episodi liikkumisen analyysiyksikkönä (Episode - analyzing unit of movement [finnish])*, Tampere University of Technology Publications.

Barabasi, A. (2002). *Linked*. Perseus Publishing.

Bavelas, A. (1951). "Communication Patterns in Task-Oriented Groups", in Lerner, D.;

Lasswell, H. D.: *The Policy Sciences*. Stanford.

Hillier, B. (1996). *Space is the Machine*, Cambridge University Press.

Hillier, B.; Hanson, J. (1984). *The Social Logic of Space*, Cambridge University Press.

Ingram, D.R. (1971). "The Concept of Accessibility: A Search for an Operational Form." *Regional Studies 5*, pp.101-107.

Joutsiniemi, A. (2002). *Accessibility in Helsinki Metropolitan Region*. Paper presented at AESOP conference at Volos. [http://www.tut.fi/~joutsini/aesop/atj_2002volos.pdf]

Longley, P.; Batty, M. (ed.)(1996) *Spatial Analysis: Modeling in a GIS Environment*, Pearson Professional Ltd.

Watts D. J.; Strogatz, S. H. (1998). "Collective dynamics of 'small-world' networks." *Nature*. Vol. 393.