Scale Unbound Analyses

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Abstract
This paper presents a new algorithm designed to provide a single description of urban centrality and remove the dependence on multiple/varying scale contexts in the deconstruction of local spatial structures. The proposed algorithm works by including scale as a variable rather than a context of spatial analysis. It assumes that destinations that are shallow in terms of angular differentiation and also metrically close to an origin have a greater influence over that origin's value than angularly shallow spaces that are metrically distant.

This extra consideration in the assessment of a spaces' accessibility has been included to account for the physical cost of larger scaled movement over shorter trips and presumes an inherent preference for destinations that are metrically close (all other things being equal). The results of analysis show extremely intuitive similarity to the distributions of central function activities in urban environments. A single global analysis is able to accurately describe complex centre hierarchies, identify over-permeability, sub centrality of all forms including urban typologies such as shopping malls and office parks and reveal how spaces of widely different spatial character complete in an overall market for accessible space.

Introduction

This paper outlines a new spatial measure based on the inclusion of metric distance in the cost calculation of individual geodesics. The proposed measure is predicated by the apparent preference of individuals to value destinations (not routes) according to the metric length of trip that has to be undertaken to access them.

The work stems from a far more extensive body of research that investigates the spatial similarities between different centre typologies (Ferguson, P 2008) (Ferguson, P 2007). This paper wishes to draw on some of this work to question the nature of certain space syntax measures and tentatively propose a solution to a specific problem.

At the core of the argument for a new measure is the fact that currently, each individual scale of analysis includes trips between origins and destinations of every preceding scale and as such the current global analysis should provide a holistic valuation of individual spaces across all possible scales of movement within a given system. Curiously however, current global descriptions reflect the largest scale structures of urban systems but do not provide an overall description of spatial centrality. It is argued here that an undervaluation of shorter scaled trips leads to this inability to deconstruct certain socio-spatial structures.

The visual relation between spatial descriptions based on the proposed algorithm and the location of central functions across multiple urban systems is extremely clear and intuitive. At this stage however, the lack of extensive empirical testing using the new algorithm means that this paper is one of proposition for discussion rather than one of acclamation.

To initiate discussion, the paper will argue that the current use of local and global analyses is restrictive, that a new form of global analysis is required to overcome these restrictions and why a single global analysis must theoretically exist that can identify multiple centre hierarchies of all types over a vast scale. Secondly, the paper will break the current centrality measure down into individual components to show how metric cost is heavily engrained in its common use but because it is not isolated as a separate variable is not perceived as being so engrained.

Finally the paper will show how a minor alteration to the existing algorithm which introduces metric trip length has a profound effect on resulting spatial analyses and concurrent urban descriptions; the ability to identify centre hierarchies across multiple urban systems with a single analysis being just one major implication.

Space Syntax analyses have been able to identify and explain the existence of a myriad of different centre formations from minor clusters of independent shops to regional commercial districts and their environs. The process by which centres are identified and decoded is one of an iterative process of investigation to find the particular spatial qualities that are impacting upon a given social behaviour such as the distribution and intensity of pedestrian movement. Often this requires the right spatial quality to be identified and in particular, the correct scale of analysis. It is the use of varying scale contexts that this paper questions for while the flexibility of using individual and varying scales of analysis has proven useful in understanding the character and functioning of many centres and sub centres, this same flexibility poses a major barrier to understanding centre distribution, formation and hierarchical distribution at a larger scale. The reason being that if different centres must be deconstructed using different scales of analysis, no one analysis can identify the locations and explain the relations between multiple centres. This is a major limitation for as long as no overall valuation exists of individual spaces across multiple centres, we cannot evaluate their respective centrality entirely objectively.

The logic of a single market for accessibility

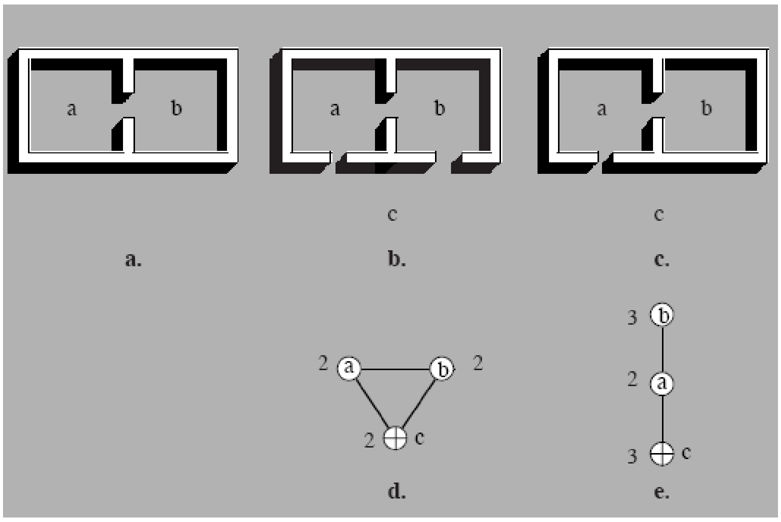


Figure 1
Basic configurative diagram demonstrating the difference between symmetric and asymmetric spatial relations. From Hillier 1996.

The practical limitations of using individual radii are mirrored by a fundamental theoretical problem. The logic of configurative spatial relations are based on an understanding that the nature of any one space is dependent on all indirect relations with those around it, not just direct relations. For example in Figure 1 above, space B on the far right of Figure 1c retrieves value description from relations with space C even though a direct relationship between the two spaces cannot be made. One core advantage of configurative spatial relations is therefore that regardless of the size of context, descriptions are retrieved based on relations between all spaces. However, the very existence of a local analysis questions this configurative logic as it automatically discounts specific indirect relations when the system size is constrained. It is in effect arguing both for and against the influence of indirect relations in spatial description at the same time.

Such a paradox can be explained away if we can argue that spatial change beyond a certain depth or metric distance from an origin has no influence on the character of that origin. Certainly the influence of each individual space further away from an origin will diminish, but can we say that there will be no influence at all? If the two spaces are part of the same spatial network, if they are connected in any meaningful way then change in one location represents reconfiguration and must impact on all other spaces in a network. Further to this, what distant spaces lack in individual impact they make up for in collective weight. More distant spaces are likely to be small fractions of a large catchment and proximate spaces large fractions of a small catchment. The collective influence of distant or deep spaces can therefore be as profound as that of an origin's immediate neighbours. Let us imagine that the abstract diagrams in Figure 1c represent trade relations between businesses rather than spatial relations. Business A trades directly with B and C but B and C only trade directly with A. Despite this, the location decisions of B and C will be heavily influenced by each other as they must both position in relation to A. In other words, business B and C are indirectly linked through their mutual association with a third party.

The implication of this simple configurative rule is that location advantage for any individual or organisation must emerge from a global market for space that is itself based on all direct and indirect socio-economic trade relations. Even the most locally focused of businesses, cannot separate their fortunes from influences on the other side of the planet simply because all business and all individuals can eventually be linked in some way indirectly. This is the basis of a single trade market and a single market for accessible space; the single market is just that because it is constructed on the basis of a single interconnected system.

If current space syntax global analyses over emphasise the large scale structures of urban systems, subsuming local centres into a single linear structure, then the question remains; why do global analyses subsume local description? Equally, if local analyses are merely inferior versions of their global equivalent, why has the practical use of global analyses in commercial applications been so limited?

This paper argues that the answer to both of these questions is the same, that global analyses subsume the value of local trips and emphasise the larger scale structure of networks as they fail to account for the physical cost of larger scaled movements or conversely, the proximity benefits of spatial agglomeration. This is what causes global analyses to have limited practical application; it is why local analyses have to be used to identify a finer detail of variation in spatial accessibility and it is the reason that Space Syntax has not been able to identify multiple centres and centre hierarchies with a single variable.

Finding the metric component in Space Syntax

Much has been written about the influence of metric distance costs in Space Syntax, from the linking of configuration and attraction in "Centrality as Process" (Hillier 1999) through the initial experimentations with segmental analysis by Hiller and Iida in 2005, to the 2007 symposium paper, "Metric and topo-geometric properties of urban street networks" which revealed the descriptive power of metric mean depth measures in identifying distinct character areas within urban networks (Hillier, Turner, Yang, Park). This paper wishes to add to this debate by proposing a new way of engraining metric properties in configurative analysis. The paper is only concerned with a deconstruction of the depth measure and is not conclusive about the equivalent weighting of choice.

The common construction of segment angular depth is based on two core spatial components, total depth and node count. In a global model node count is uniform for all spaces but locally both total depth and node count vary from segment to segment. To construct a useable form of depth that is commonly used to correlate with various social indicators, the total depth is divided by the node count to normalise the depth value against the size of the system. At a local level this will have a major impact as without this normalisation, a greater concentration of space within a given radius context will inevitably lead to higher depth values simply as a result of the larger number of origin destination trips available to generate depth. After normalisation however the resulting mean depth remains counter intuitive with high depth receiving the highest numerical value and concurrent hot colouring. It is therefore divided into one to retrieve the reciprocal value. At this point, mean depth is an accurate reflection of "depth per space". It is clear however that this description bares no resemblance to our intuitive understanding of centrality. In figure 2, an 800 metre radius angular mean depth analysis of Oxford, the city centre is considered far deeper than the rural tracks surrounding the city. In fact the sparser the urban fabric, the lower the depth appears to be. To counter this problem, mean depth is divided by node count again, or by equivalent, the reciprocal is multiplied by the node count. The impact of this further division by node count is highly significant. Oxford city centre immediately appears as the accessibility core of the settlement with a near inverse distribution of values when compared to the pure mean depth distribution. When compared to a pure node count measure however we can see a very strong positive relationship.

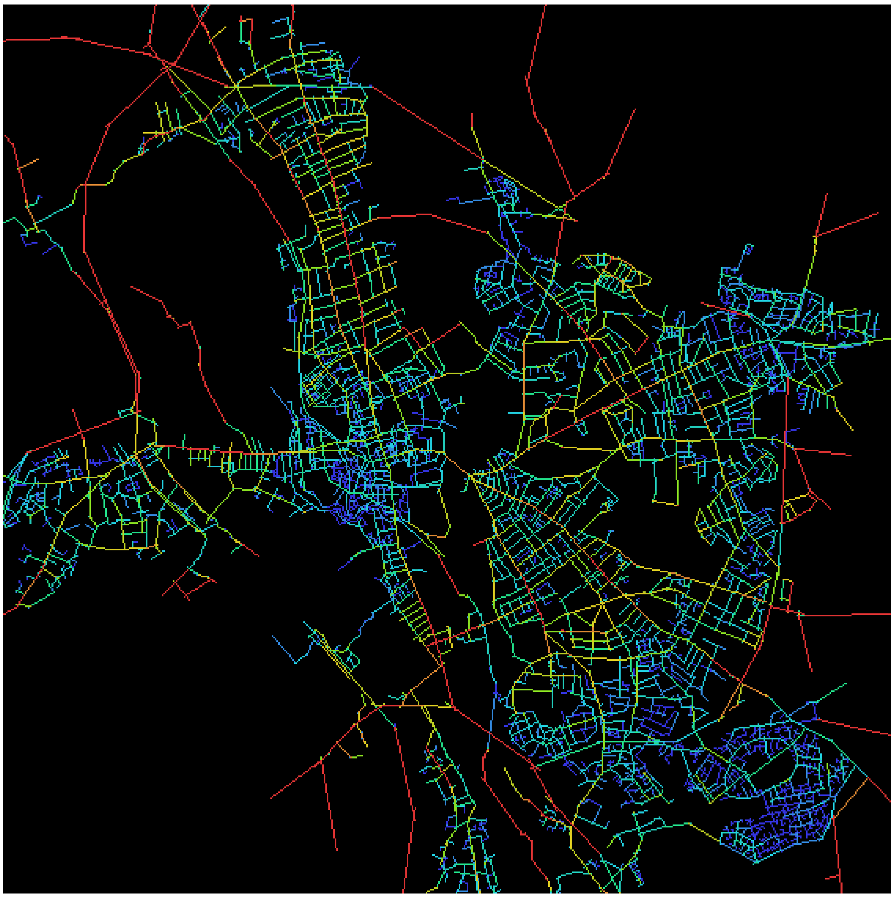


Figure 2
Radius 800m angular mean depth analysis showing the angular depth generated from grid intensification.

This current depth description raises a number of questions. Firstly, if the pure mean depth measure does not describe centrality then what does it describe? Secondly, why is there a need to "normalise" for node count twice? Thirdly, what does this tell us abut the role of metric qualities in the generation of centrality in urban networks?

Taking each one of these in turn, the pure mean depth (TD/NC) shown in Figure 2 describes the angular depth of all spaces from all others within a restricted context of 800m from every origin segment. The value has by this point already been normalised for system size so it is a true reflection of the angular depth between all spaces at this radius. One thing we can immediately conclude then is that the more grid intensified parts of the city generate greater angular depth, where as the most sparse areas seem to minimise it. The reason for this is that as the system becomes more convex, as the multiplicity of spatial relations increases, the proliferation of right angle or near right angle changes in direction must increase in order to accommodate the larger surface area of public realm. Interestingly then, the impact of grid intensification on mean trip length reduction as noted by Hillier in centrality as process runs counter to that of angle change minimisation.

"Mean trip lengths in shapes will always be minimised in compact and convex shapes and maximised in linear, jagged and otherwise non-convex shapes, following the logic of area perimeter ratios." (Hillier, B 1999)

The reason behind the depth distribution in Figure 2 is therefore obvious; the spaces on the outskirts are in almost complete angular alignment within the given context and therefore represent a minimum of angular depth. Spaces in the centre however are concentrated and contorted into near right angle relations generating high angular depth. Mean depth is therefore not an incomplete measure, it is a true measure of angular depth within urban systems and the further division by node count must be representing a separate influence on system centrality.

To answer the second and third question, we must first recognise that node count at a local radius is not a pure spatial property either but is itself made of two subcomponents – system size and system radius. It is the interplay between the two that provides node count with any meaning (The same number of spaces can signify sparse or dense environments if the radius context of analysis is not known).

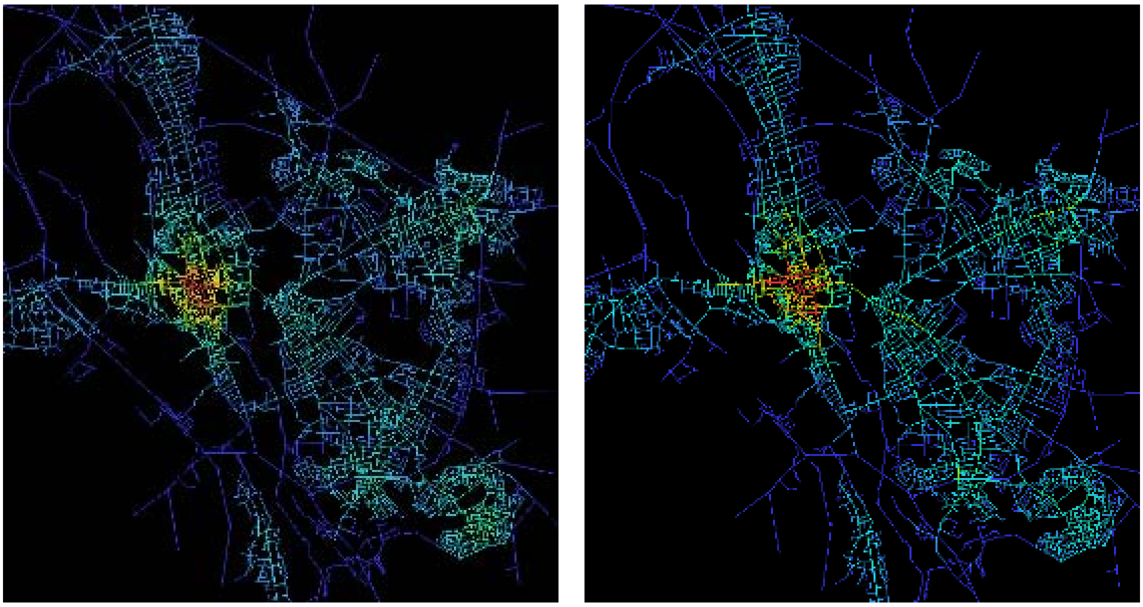


Figure 3
The 800m node count of Oxford (left) and the complete depth measure (nc/md) for the same radius on the right.

A local node count measure therefore provides a description of the number of spaces that can be accessed within a given distance, or in other words, describes spatial density. Dividing depth by node count again engrains this quality of spatial density in the resulting valuation. The obvious result being that within a restricted radius, clusters and concentrations of space receive higher values. If the restricted context is defined, as it most commonly is, by a metric radius, then we can argue that it is a metric density that is being applied. If so, there is a highly influential metric property engrained within our depth analyses even before weightings by segment length, or variables such as total segment length or metric mean depth are considered.

To summarise, the argument for the proposed measure is based on a deconstruction of the existing depth measure which states:

- That a mean depth analysis that considers only angle minimisation is insufficient to describe the distribution of centres within urban systems.
- That local analyses are compound measures by default, dependent on the interplay between a given configurative property and radius size.
- That a local node count measure can be conceptualised as spatial density and if the context for analysis is metric then it is a marker of metric density.
- That the current form of depth analysis that can identify local centrality requires this property of metric density to be engrained within a local analysis.
- That a metric cost is therefore an automatically implied component of most local Space Syntax depth measures.

The proposed measure

A metric radius is a fixed context for analysis that is needed to provide meaning to local measures of pure depth and system size but because it is a context and not a variable, its inclusion in spatial analysis is implied rather than explicit. Further to this, providing a single radius value masks variation in spatial density within each analysis. For example, all local trips within a 400m radius are assigned a metric context of 400m even though the majority of spaces within that context could be accessed over a smaller distance. Within any 400m analysis there are a number of trips that are just 100m long or 200 or 300. The reality is that the single metric context implied by the radius size is a very blunt aggregation of the varying densities and concurrent trip lengths within the given radius and the only way to overcome this would be to relate each spatial relation to the radius context within which they can be made. It is exactly this that the proposed measure seeks to do as it enables a far more fluid calculation of metric density in space and removes the need for any scale/radius distinction in analysis as scale has shifted from context to variable.

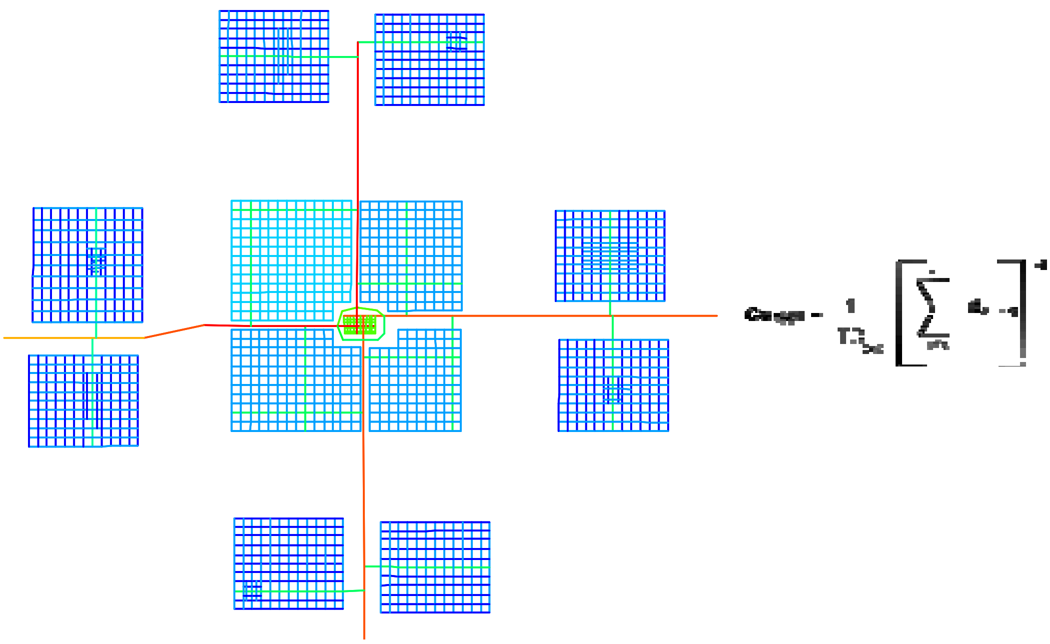
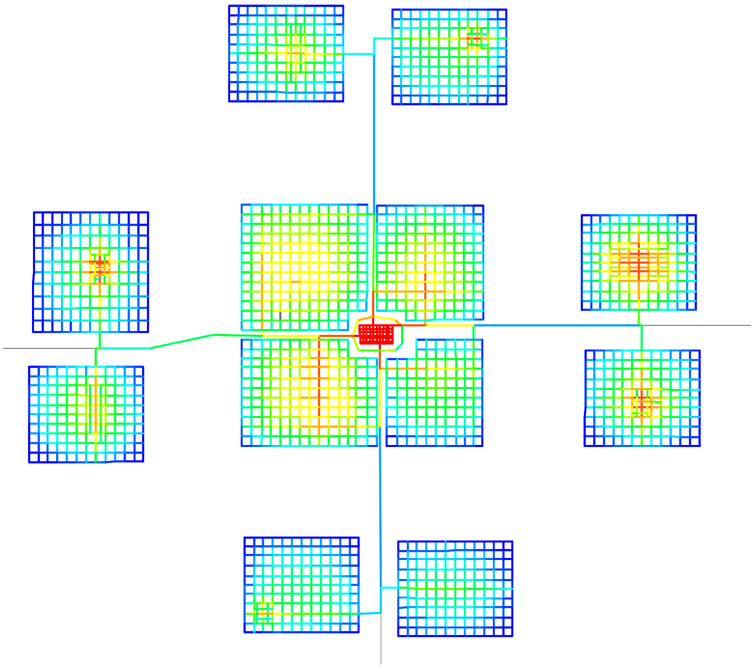


Figure 4
A description of global centrality within an abstract urban grid system offered by the existing depth measure and its concurrent algorithm.

The simplest way of doing this is then to calculate the "radius distance", scale or trip length of every single possible spatial relation. Instead of using a fixed radius cost to assess the varying number of spaces that can be accessed in a local measure (node count), the proposed measure assesses the varying radius cost (trip length) of accessing the uniform node count of a global measure.



$$Ac_{(\mu p)} = \sum_{q \neq p}^{n} \frac{1}{Rd}_{p \rightarrow q}$$

Figure 5

A description of global centrality within an abstract urban grid system offered by the proposed depth measure and its concurrent algorithm.

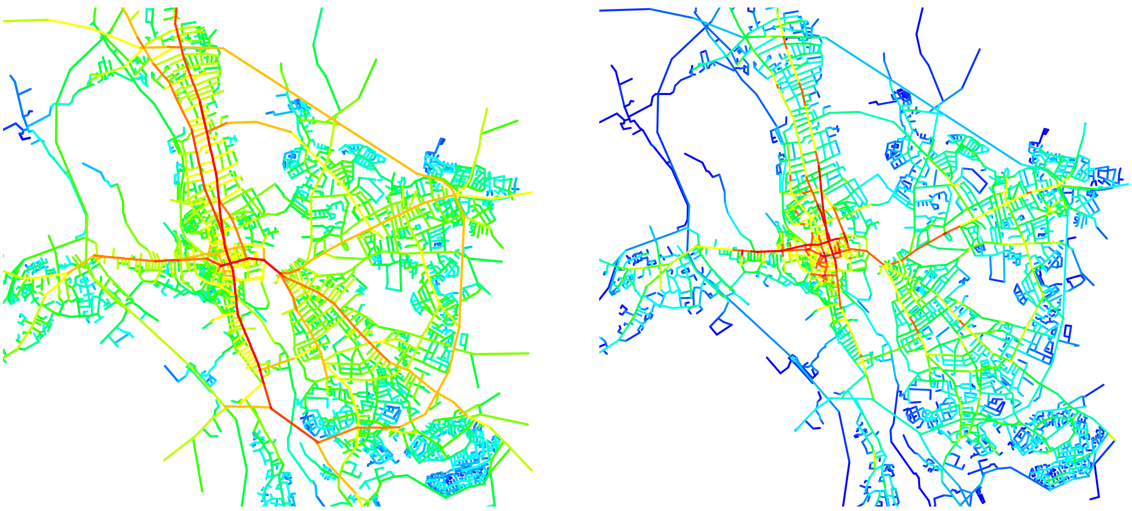


Figure 6

The existing global depth description of Oxford (left) and the proposed equivalent depth measure (right).

Figures 4 and 5 show the result of running the existing global depth (left) and proposed (right) measures on an abstract urban grid with their respective algorithms next to them. Figure four shows very clearly how the current global measure identifies the largest scale structures of an urban system with the "highways" of the system highlighted as the most central locations. We now that this does not make intuitive sense, the measure appears to be identifying important large scale routes rather than key locations. The proposed global measure however appears as a far more intuitive reflection of urban centrality. The central grid structure that might be considered a C.B.D appears as an intense concentration of accessibility with a hierarchy of local centres emerging in a multiplicity of forms and intensities, dependent on their respective relations with the rest of the system over all scales of movement. The change in nature of the global analysis is so significant that the proposed measure appears as closer to what we understand to be a local analysis. Certain aspects of Figure Five show that this is clearly not the case however. For example number critical points of high accessibility emerge without a local grid intensification (marker 1 in Figure 5), forming as a result of reasonably high levels of angular continuity and metric trip length reduction over all scales but with no discernable emphasis at any particular scale, something that no local or global analysis could describe.

If we return to Oxford, we can see from Figure 6 how the difference between the existing and proposed global measures is once again stark with the proposed measure highlighting multiple urban centres as well as the city centre accessibility core. More complex still, Figure 7 and 8 describe a system with multiple major commercial centres, in this case, Sough, Windsor and

Figure 7
The existing global depth measure of Slough, Windsor and Maidenhead

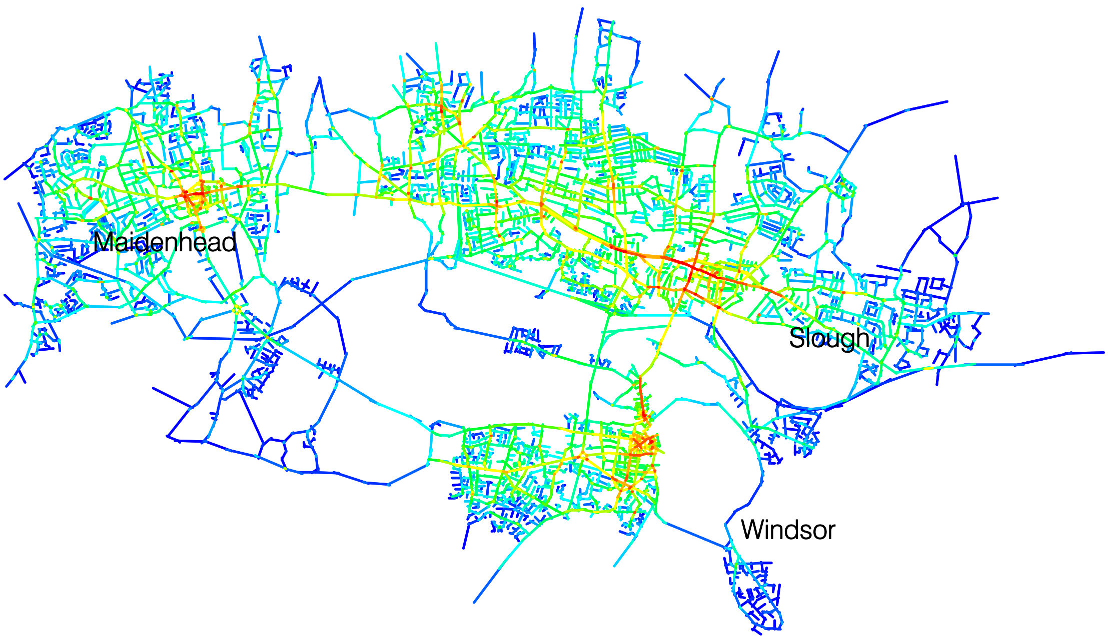


Figure 8
The proposed global depth measure of Slough, Windsor and Maidenhead

Maidenhead just west of metropolitan London. Despite the existence of three discernable commercial centres in the area, the existing global depth measure (Figure 7) describes one central focus between all three settlements with major communication links highlighted and none of the major commercial centres being identified. The proposed depth measure by comparison (Figure 8) identifies all three centres with great accuracy, specific parts of the network clearly emerging from the more homogenous values of surrounding residential areas.

Summary

This paper has argued that a simple modification to the current depth calculation is sufficient to radically change the character of description generated by global measures. By engraining the metric length of individual trips in the cost calculation of geodesics, the proposed depth algorithm is capturing the role of radius in the construction of local spatial properties and using it to counter the subjugation of smaller scaled trips in global analyses. The result is a global analysis in the true sense of the word; a holistic appreciation of centrality that is able to encapsulate every possible scale of analysis in one measure because it contextualises every spatial relation with its own individual scale.

At the point of writing the measure has not been tested empirically beyond the casual relationships found between the distribution of central function land uses and the distribution of spatial accessibility using the new measure. It is hoped that the new measure can be extensively tested on a range of datasets, particularly against indicators of market centrality such as land and property value, the distribution of commercial office space and rents and the overall distribution of residential property values across the largest possible market contexts.

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