Easiest Paths and Fuzzy Accessibility

Combining syntactic and geographic analyses in studying walking and cycling mobility

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TU Delft Delft University of Technology

Faculty of Architecture and the Built Environment

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Way-Finding for pedestrian and cyclist

*How **feasible** and **easy** is it for people to walk or cycle to their destinations in a neighborhood?*

What is it all about?

*Getting more people walking and cycling… **but how exactly**?*

- Intervention, Infrastructure Development, Policy Recommendations…; but first
- Analysing ‘how things are’!
- Predicting how people would probably behave (commute by means of walking and cycling) in the built environment
- Testing planning/design/intervention scenarios as ‘what-if scenarios’
- Developing a *Spatial Decision Support* Methodology

EASIEST PATH

*A path that is as **flat**, **short** and **straightforward** as possible*

Way-Finding Essentials for Walking and Cycling

Physical Impedance, slope ➔ speed; speed & length ➔ travel time

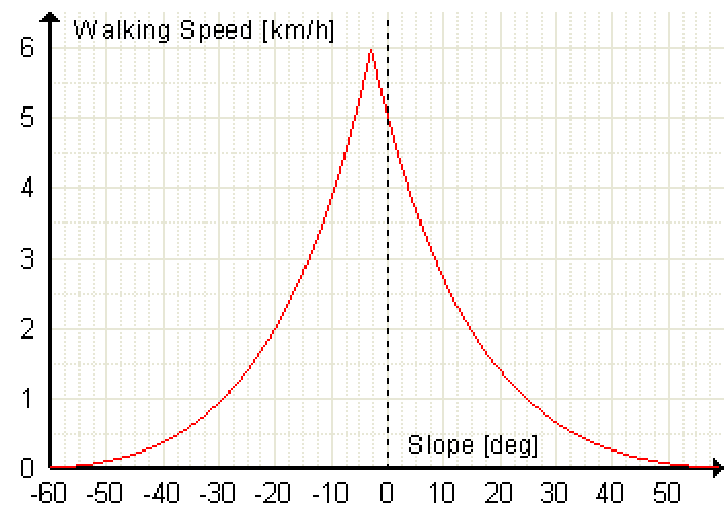
Physical Difficulty
Length Impedance
human power
Dimension: Time
Unit: Minute

- Slope
- Length
- Power

$$WLI_k := WLI_k(\alpha_k) = \frac{\delta}{WV_k} = \frac{3.6\delta}{6e^{-3.5|\tan\alpha_k + 0.05|}} = \frac{3.6\delta e^{3.5|\tan\alpha_k + 0.05|}}{6}$$

$$CLI_k := CLI_k(\alpha_k) = \frac{\delta}{CV_k} = \frac{\delta(mg\sin\alpha_k + F_f)}{P} = \frac{\delta(85 \times 9.81 \times \sin\alpha_k + 25)}{112}$$

Image courtesy of **Antonio Olmos** http://www.theagepage.co.uk/



The hiking speed function of Waldo Tobler, Wikipedia Images

Way-Finding Essentials for Walking and Cycling

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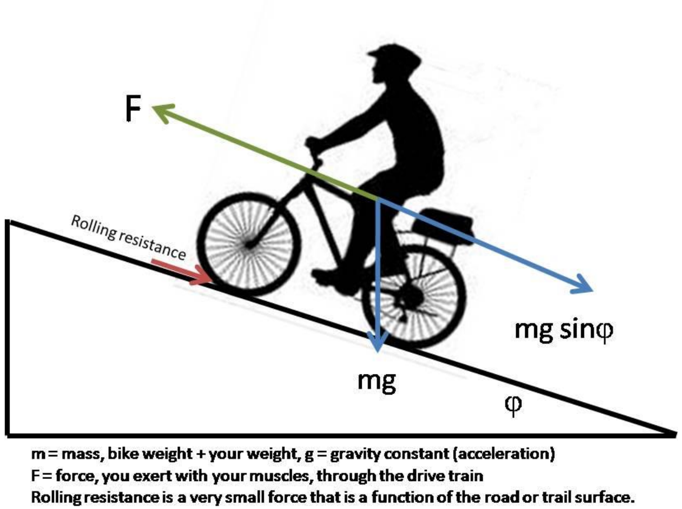
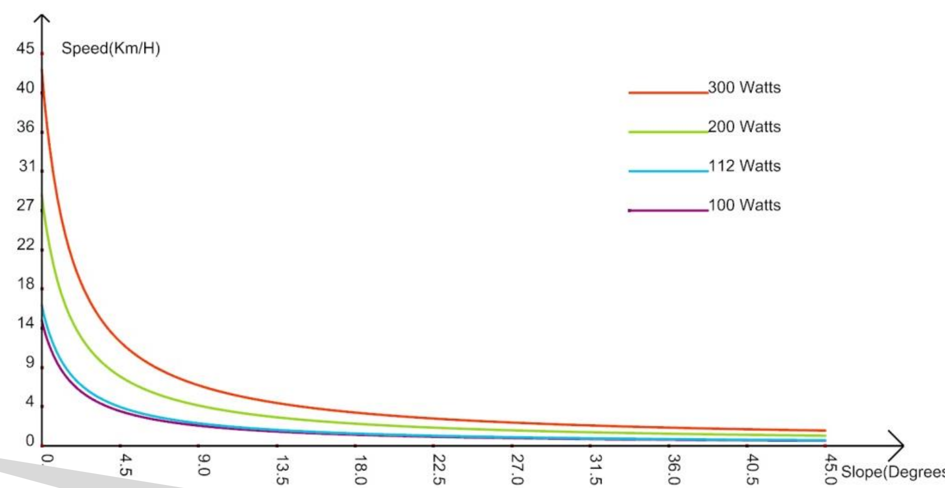


Image source:
http://www.lloydswellbeingcentre.co.uk/clives-cycling-blog-18/



Cycling mechanics model is done after the work of Allain, 2013

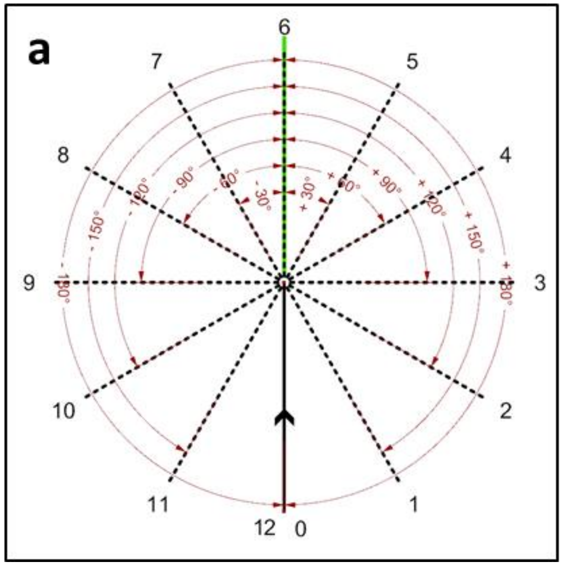
Way-Finding Essentials for Walking and Cycling

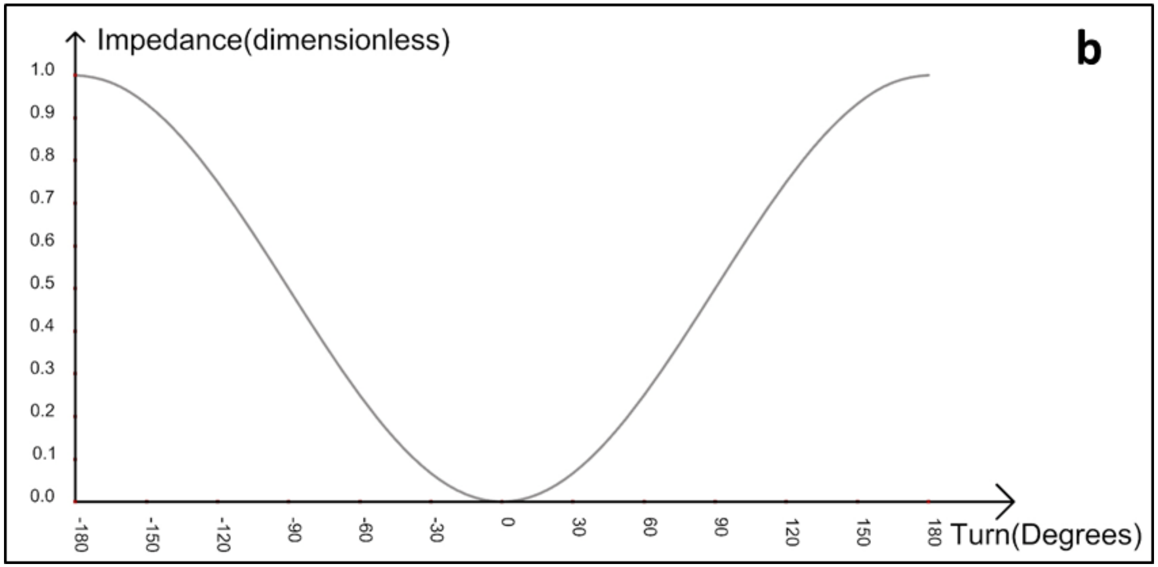
Cognitive Impedance, turn angle→ confusion → waste of travel time

Cognitive Difficulty ***Angular Impedance*** **intuitive navigation** Dimension: Time Unit: Minute	Change of direction or Turning at junctions

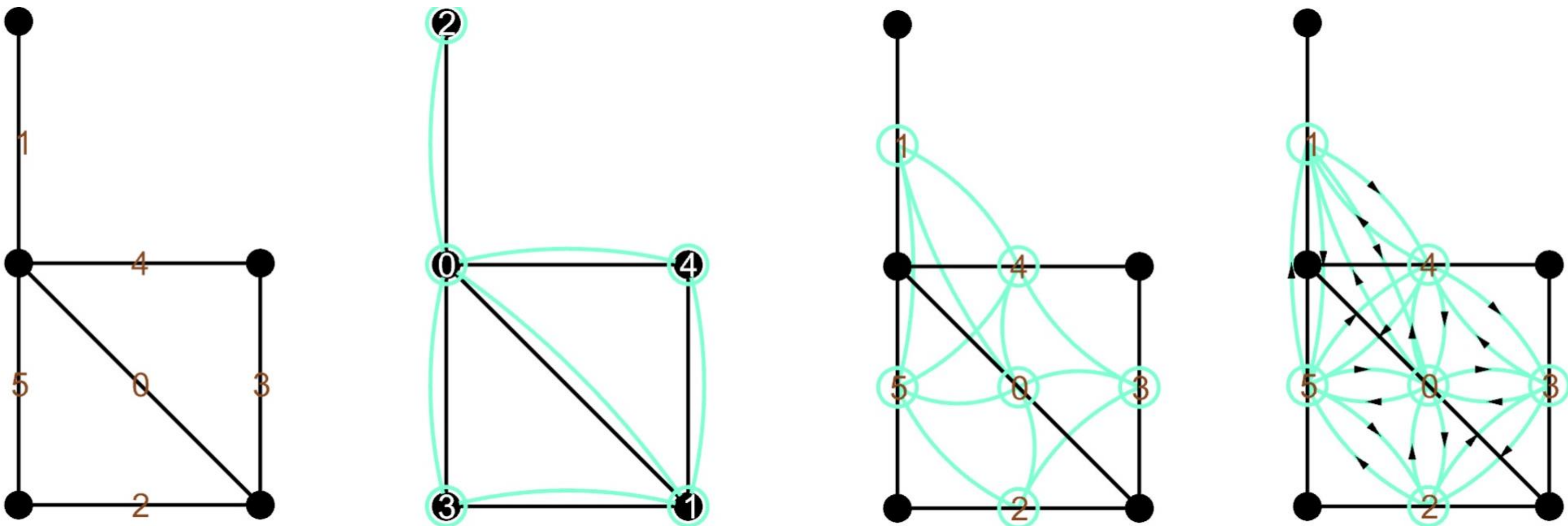
CETERIS PARIBUS

$$AI_k := AI_k(\theta_k) = \begin{cases} \tau \sin^2 \dfrac{\theta_k}{2} : \tau = 10 \text{ seconds, if } \mathrm{Deg}(l_k) > 2 \\ 0 \;\; otherwise \end{cases}$$





Constructing a topological model (a dual graph) from street centreline network



Conceptual Network

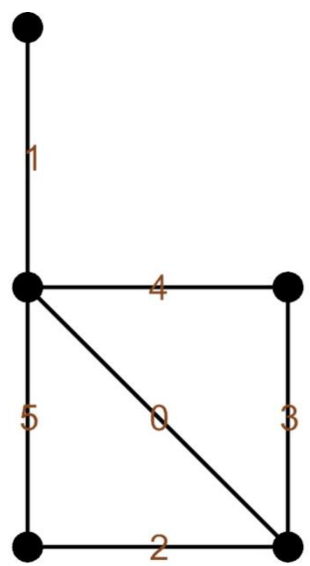
Primal Graph Links

Dual Graph Links

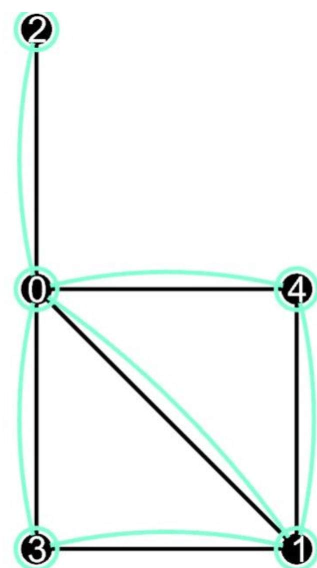
Dual Graph Links
Doubly Directed

Diagrams drawn after Batty, 2004

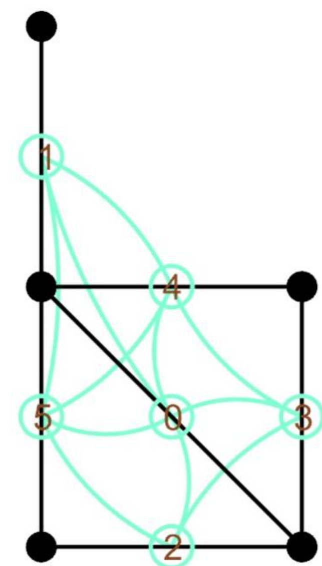
Constructing a topological model (a dual graph) from street centreline network



Conceptual Network



Primal Graph Links



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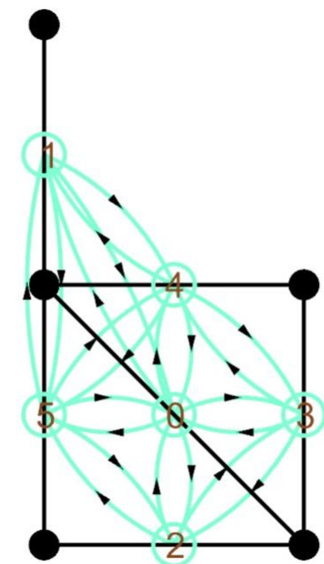
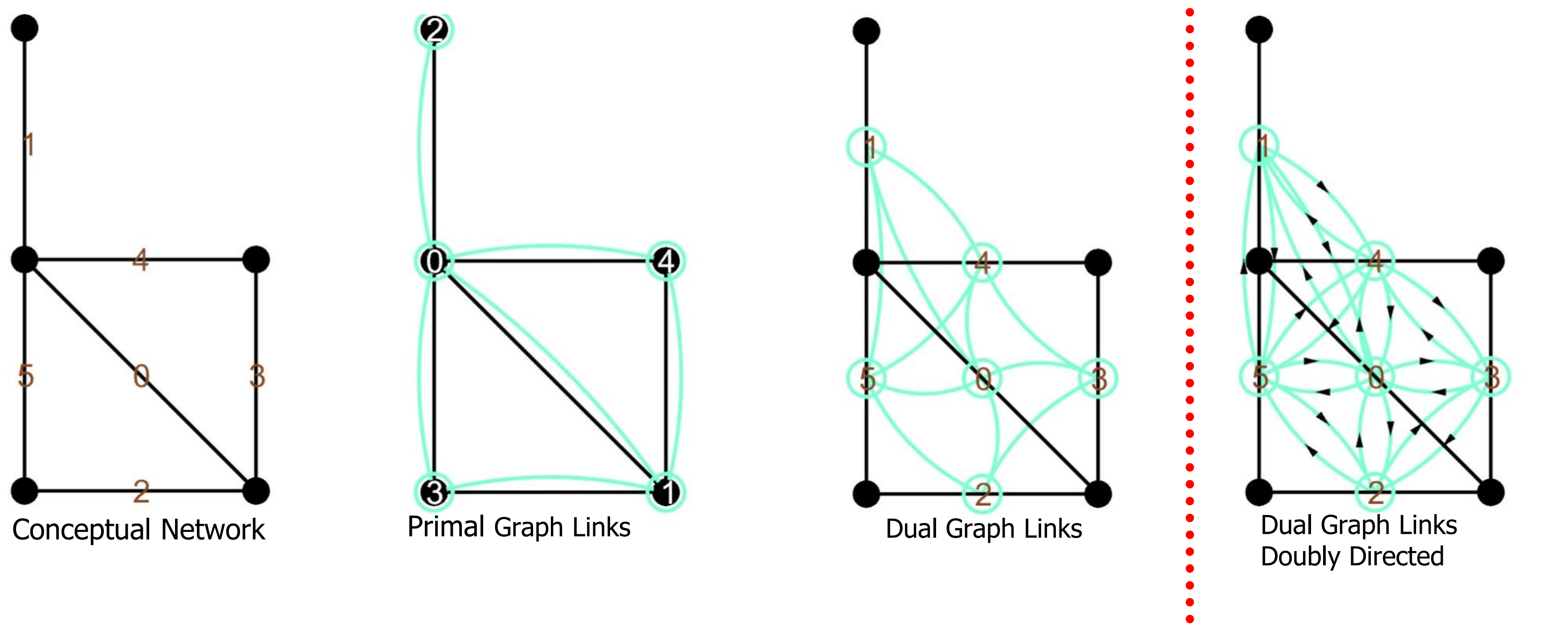


Dual Graph Links
Doubly Directed

The great work of late Alasdair Turner, the work of Duckham & Kulick and our earlier version of this work presented at Geodesign Summit Europe were based on this representation.

Constructing a topological model (a dual graph) from street centreline network

network size is doubled, adjacency matrix quadrupled:
this can exponentially lower the speed of further processing algorithms!!!



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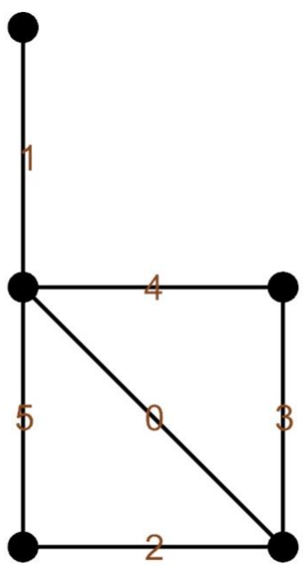
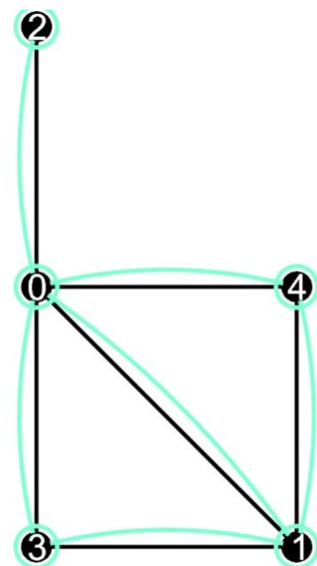
Constructing a topological model (a dual graph) from street centreline network

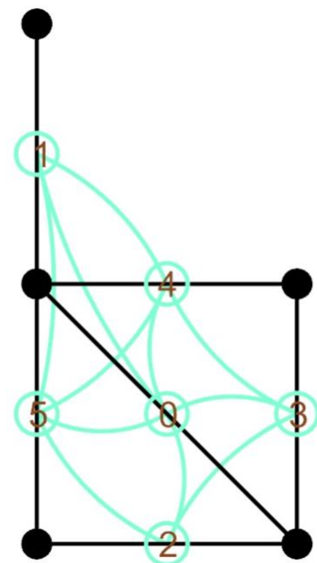
network size halved, matrix size quartered, almost the same effectiveness*, if looking at commutation trips only!



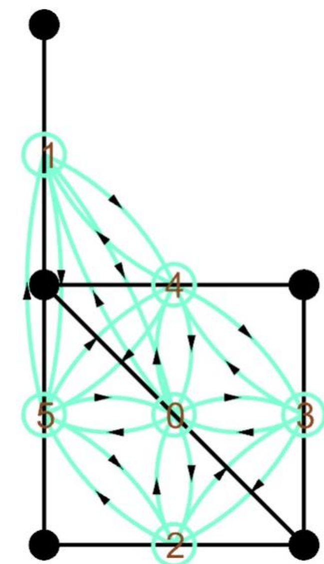
Conceptual Network



Primal Graph Links

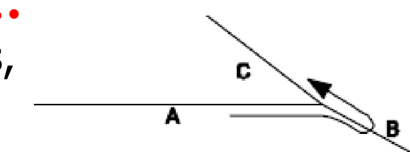


Dual Graph Links



Dual Graph Links
Doubly Directed

Using a different approach in graph construction and computation of angles, and we get around this problem pointed out by Turner (2005)…



Weighted Adjacency Matrix

$$WLI_k := WLI_k(\alpha_k) = \frac{\delta}{WV_k} = \frac{3.6\delta}{6e^{-3.5|\tan\alpha_k + 0.05|}} = \frac{3.6\delta e^{3.5|\tan\alpha_k+0.05|}}{6}$$

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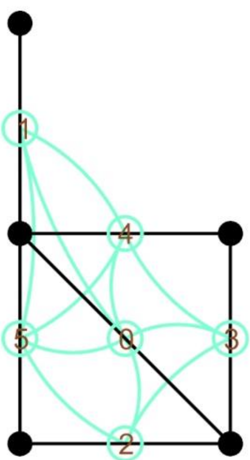
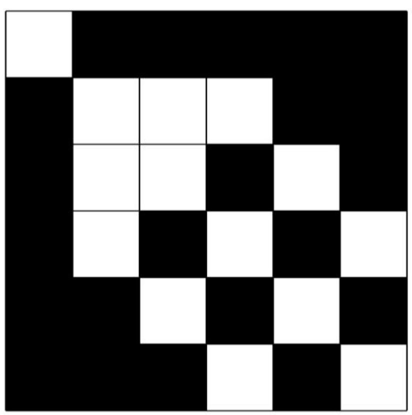
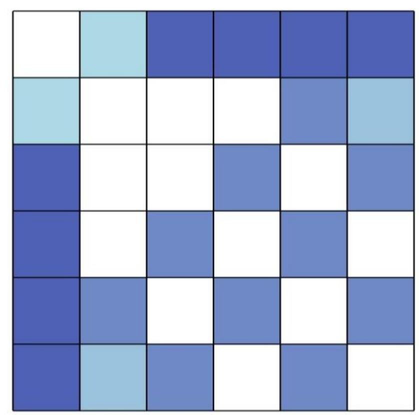
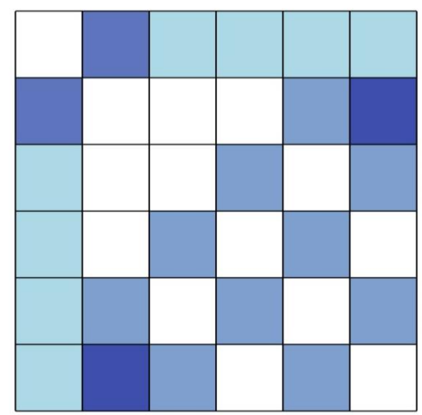




Connectivity Bitmap



Weighted Bitmap_ tau0



Weighted Bitmap_tau70

Weighted Adjacency Matrix

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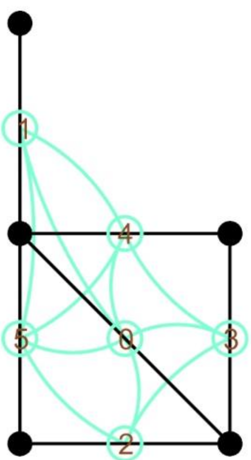
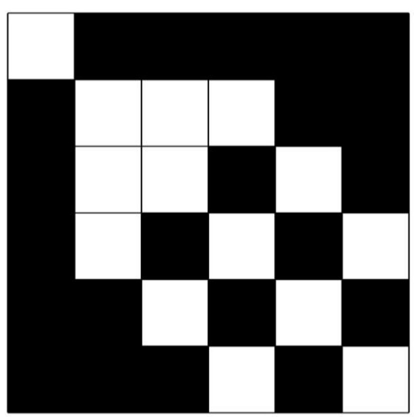
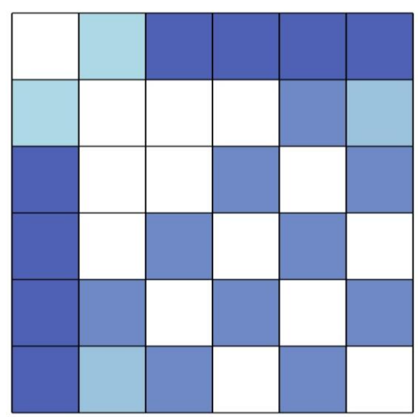
Not every value of tau would be acceptable, tau has a maximum corresponding to the smallest or average of the physical impedances!

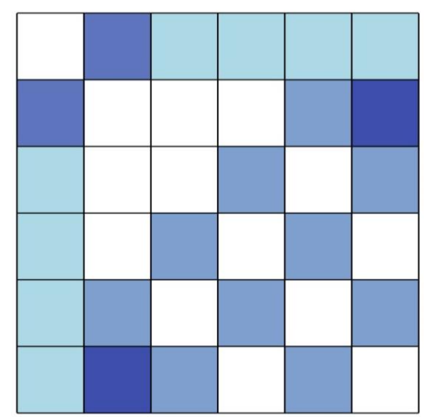




Connectivity Bitmap



Weighted Bitmap_ tau0



Weighted Bitmap_tau70

EASIEST PATH (Mathematical Formulation)

As Walking/Cycling ***Geodesics (a.k.a. optimal paths)***

Minimizing the impedance of travelling from an origin to a destination

we have defined both cognitive confusion and physical difficulty in terms of time, they are **commensurate** and therefore we can use a weighted sum model to model the total impedance of each link. The geodesics are then found using a graph search algorithm.

But how exactly?!

EASIEST PATH (Mathematical formulation)

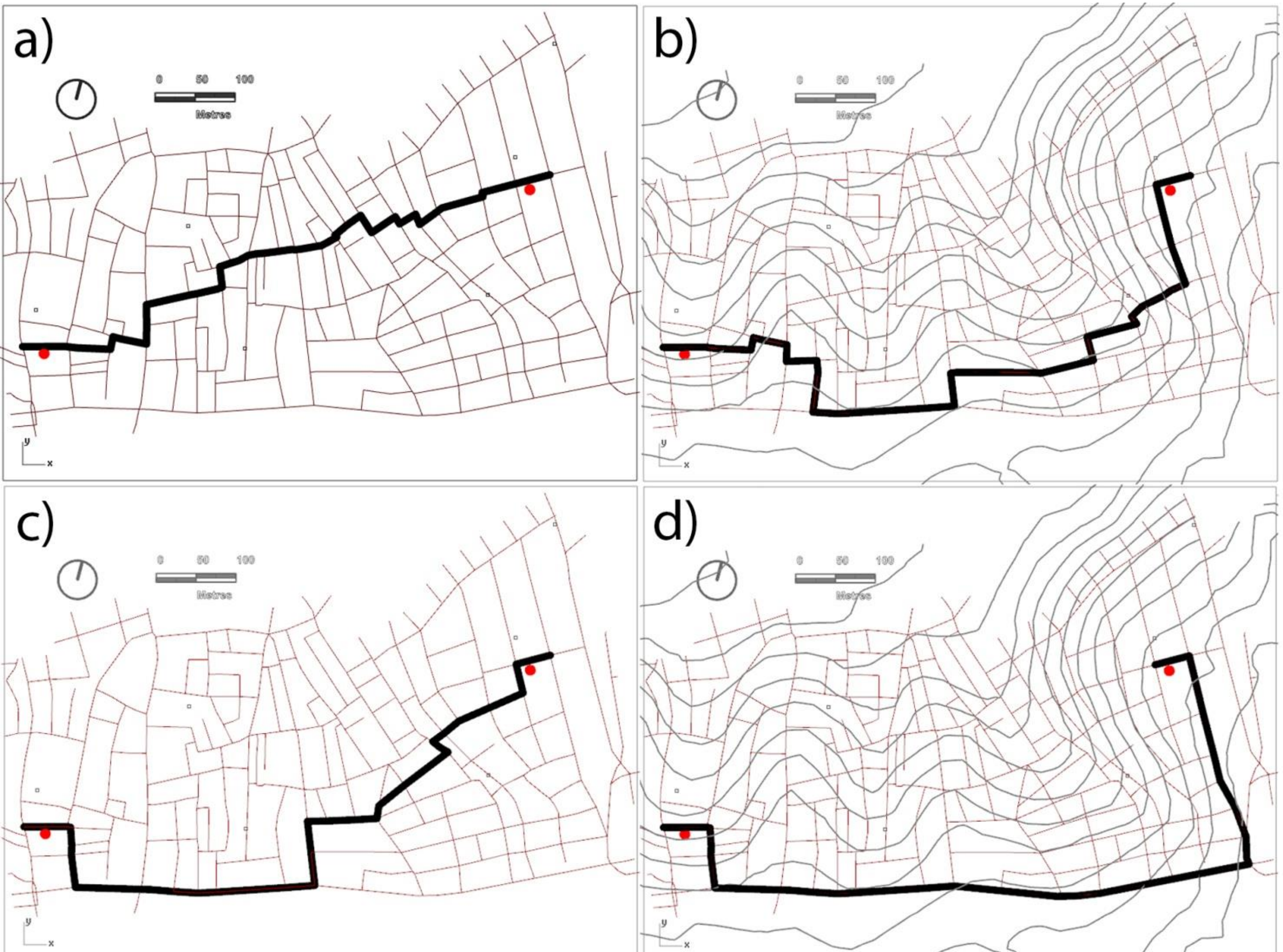
As Walking/Cycling ***Geodesics (a.k.a. optimal paths)***

Minimizing the impedance of travelling from an origin to a destination

A path π is defined as a sequence of nodes (i.e. street segments) $\pi = (n_1, n_2, \ldots, n_m) \in N \times N \times \cdots \times N$ such that n_j is adjacent to n_{j+1} for $1 \leq j < m$. The path π is said to be of length m from the first node (n_1) to the last node (n_m). Having defined a real-valued impedance/cost function $f: L \to \mathbb{R}$, which attributes an impedance or cost to each link of the graph $\Gamma_d(N, L)$, we need to find a path $\pi = (n_1, n_2, \ldots, n_m)$ that minimizes the total cost or impedance of going from an origin n_o to a destination n_d ($n_o = n_1, n_d = n_m$) over all possible paths between n_o & n_d. Let $L_{i,j}$ be the link in between n_i & n_j, then we need to minimize the following sum (with reference to our prior definitions of impedance): (note that we have denoted the cost function $f(L_k) = \zeta_k$) . Finding the link index (k) of for the link $\mathrm{L_{i,j}}$ we can get the cost of each link from the pre-calculated impedance set:

$$\sum_{j=1}^{m-1} f\left(L_{j,j+1}\right) = \sum_{k \in L \cap \pi} \zeta_k = \sum_{k \in L \cap \pi} LI(\alpha_k, L_k) + AI(\theta_k)$$

EASIEST PATH



a) Shortest Path without considering the terrain and difficulty of navigation on an example network from "Tarlabasi",Istanbul

b) Easiest Path geodesic considering the terrain and tau=0 for angular confusion (thereby no cognitive impedance)

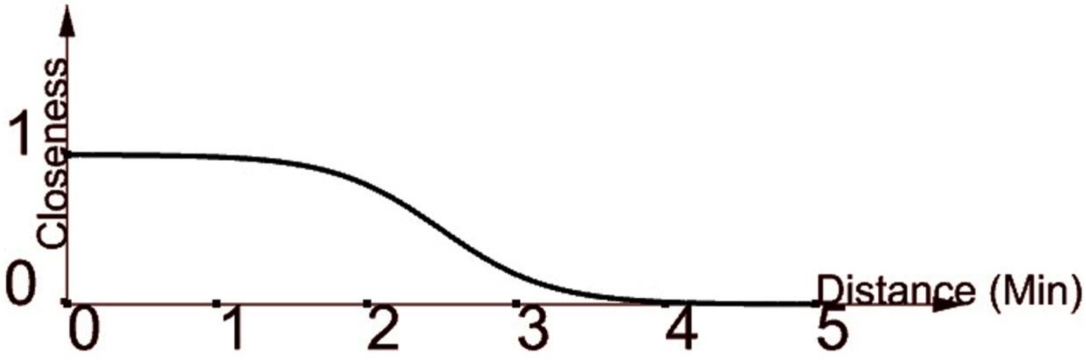
c) Easiest Path geodesic computed not considering the terrain and tau=15 seconds

d) Easiest Path geodesic Computed considering the terrain and tau=15 seconds

The Fuzzy Concept of Closeness

The Possibility of a Discrete Choice

Inspired by Logit models in discrete choice models of transportation forecasting models, we choose a **Logistic Function** as below, which represents the degree to which a statement such as 'destination D whose distance to origin O is x is close by' is regarded as true.

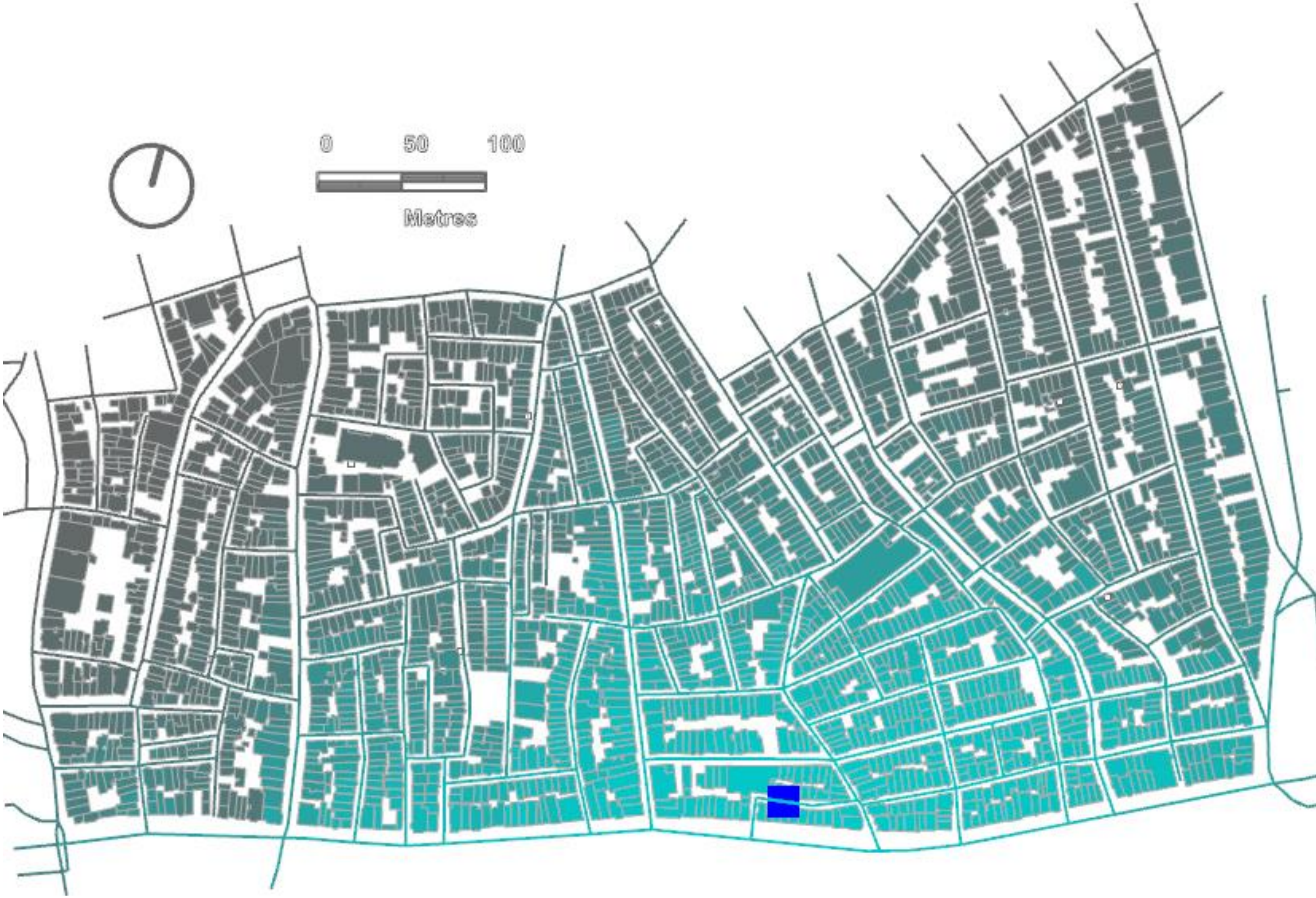


Fuzzy model of closeness given a 'how far' parameter equal to 5 minutes.

$$C(x) = \frac{1}{1 + e^{\lambda\left(x - \frac{F}{2}\right)}}$$

In this equation, C(x) denotes closeness of a destination at a distance x; and λ represents a coefficient whose role is to ensure the decline of the closeness value when distance x approaches F.

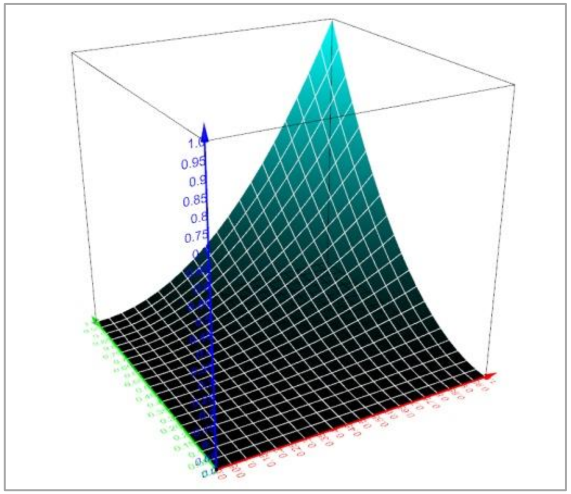
Fuzzy Closeness from a Single Origin



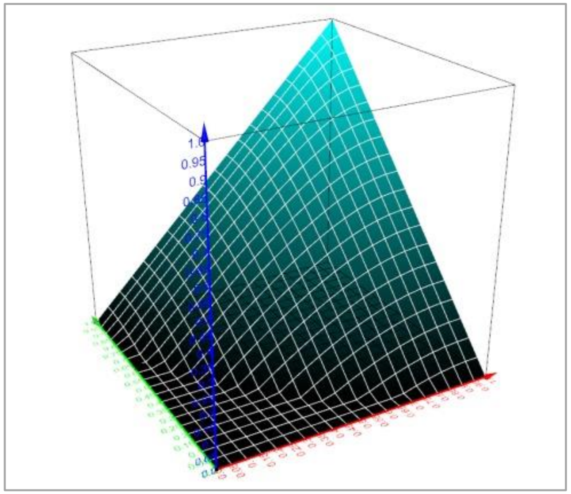
Fuzzy closeness for cycling from the origin marked (as blue dot) considering the terrain, tau=30 seconds. The sharper the colour the closer the destination

Fuzzy Aggregation Methods

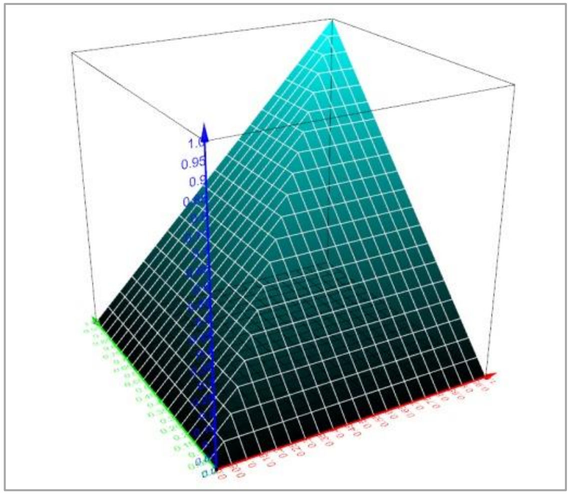
shown here for 2D inputs, actually done for ND inputs



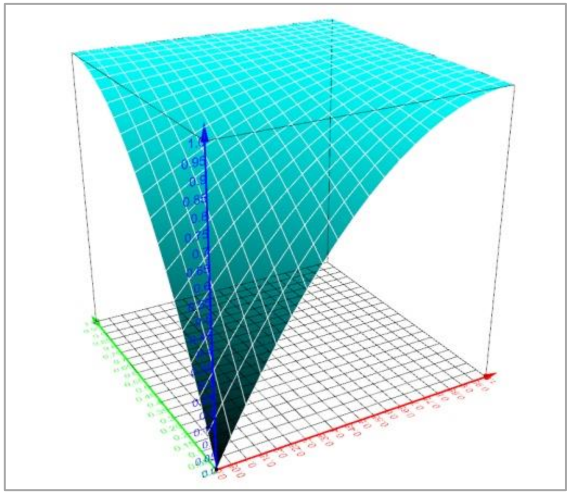
Fuzzy Aggregators_AND_PBL



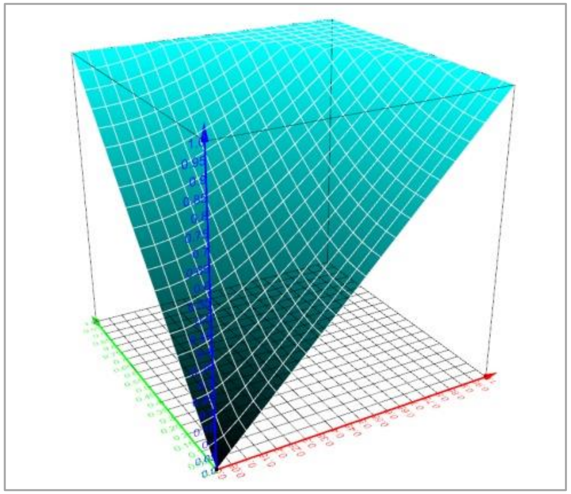
Fuzzy Aggregators_AND_YAGER



Fuzzy Aggregators_AND_ZADEH



Fuzzy Aggregators_OR_PBL



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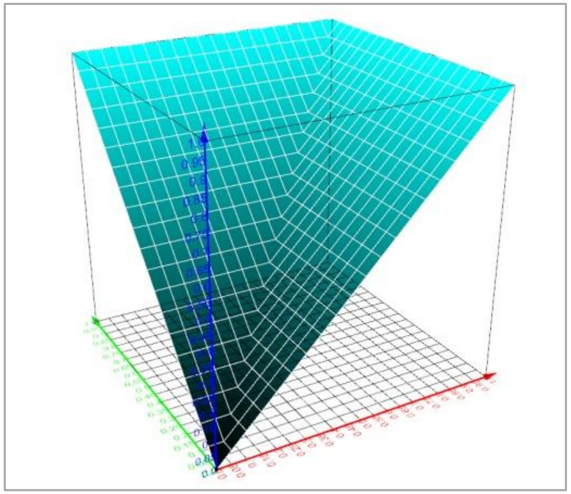


Fuzzy Aggregators_OR_ZADEH

Accessibility Indicators

Fuzzy Logics used to Aggregate Closeness Measures

Closeness to Any POI (Vicinity)

Tells how close a location to any destination of interest is. This measure is interesting as it can reveal the polycentric nature of a neighbourhood given a number of comparably interesting attraction places. More simply, a very straightforward application of this measure is to see whether for instance each location has a reasonable access to a grocery store by walking or cycling. This is important because then such daily routine trips can be made without using personal cars.

Closeness to All POI (Proximity)

The 'Proximity to All' (Proximity in short) tells how close a location to all destinations of interest is. It thus tells whether all interesting locations (attractions) are accessible given abovementioned willingness (how far) parameters.

Closeness to ANY POI (Vicinity)

vicinity of any POI, when the mode of transport is walking and people are prepared to go as far as 5 minute walking for each point but for attraction number 1 they are prepared to go as far as 2 minutes walking.

Closeness to ALL POI (Proximity)

proximity to all, supposing people would go as far as 15 minutes on foot from all POI but exceptionally 30 minutes to POI 3

Closeness to ALL Possible POI (Global Centrality)

shows proximity to all possible destinations, that is a measure comparable with local integration in space syntax, the colours are chosen to be relative in this case for aesthetic reasons

Catchment Areas: ALL POI or ANY POI using crisp logics

Catchment measure proposed here is different from conventional alternatives in that it is polycentric; can be computed to all or any of POI; and that it is based on preferred 'how far' parameters.

a) Proximity catchment (to all POI), walking, considering the terrain and tau=15

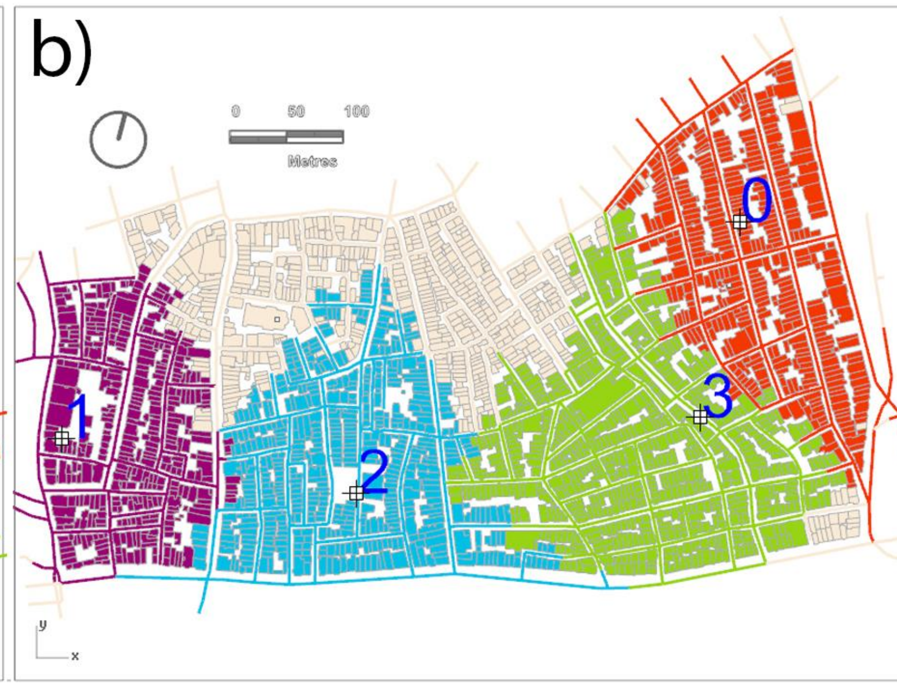
b) Vicinity catchment of POI(access to any POI), walking, considering the terrain when tau=15

Zoning for Preferred Access:

Generalized Voronoi Diagrams and Alpha-Shapes

Is it possible to tell to which POI each location has preferred access?
To answer this question we generalize alpha shapes and Voronoi diagrams.

a) Inclusive Zoning, walking, all acceptable ranges set to 5 minutes.



b) Exclusive Zoning for POI, given 'far' as 5 minutes when cycling

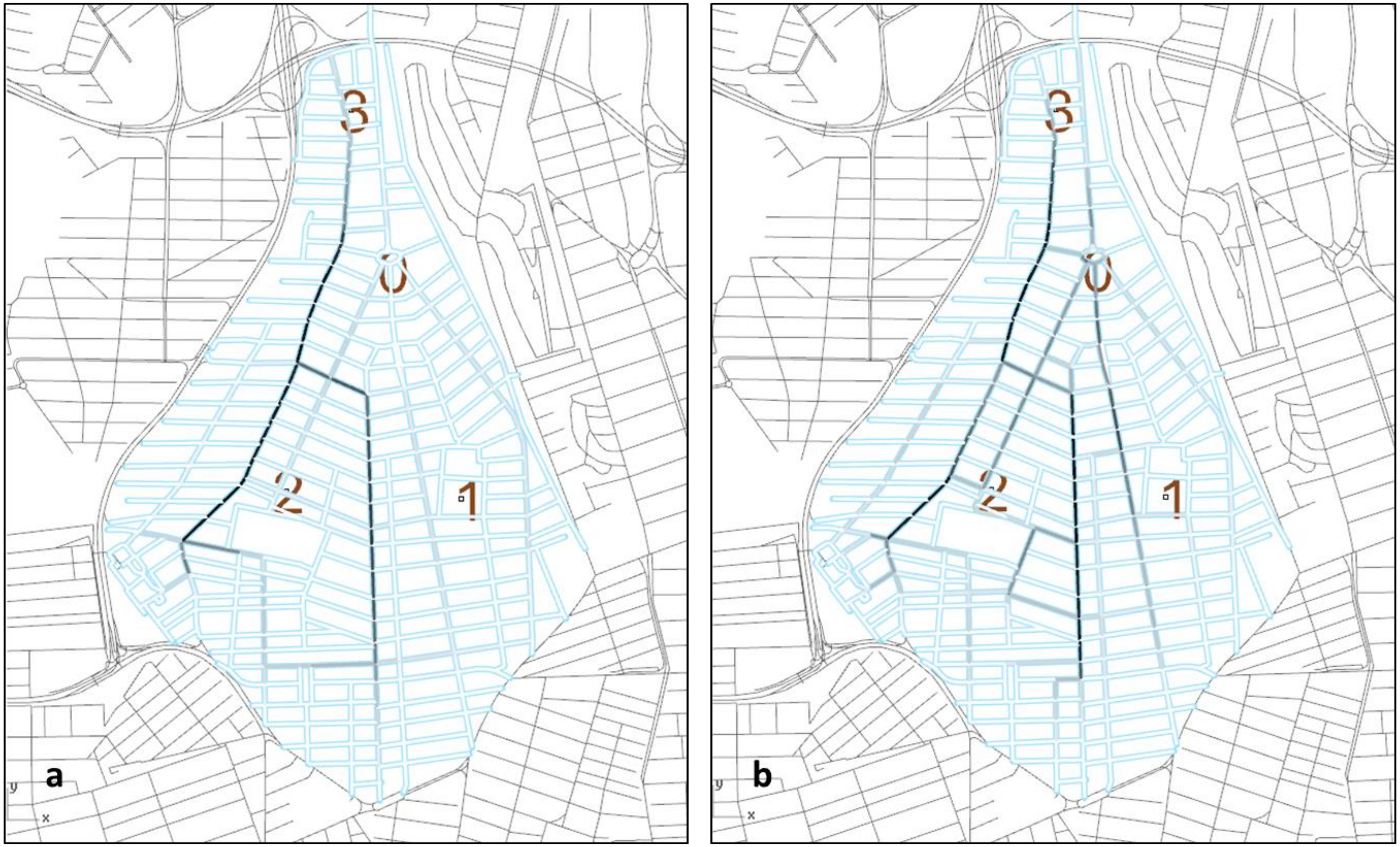
Betweenness Centrality Using Easiest Paths

Using the Easiest Path algorithm and its specific input graph, we can compute a number of centrality measures.
These measures are used in network analysis to rank network nodes as to their relative importance. In this case, the nodes are streets in our graph and the links are the junctions between them.

$$|\{(s,t)|s \in N, t \in N, s \neq i \neq t\}| = \binom{|N|-1}{2} = \frac{(|N|-2)\times(|N|-1)}{2}$$

$$B(n_i) = \frac{2 \times \sum_{s=1}^{|N|}\sum_{t=1}^{|N|}\sigma(s,n_i,t)}{(|N|-2)\times(|N|-1)} \mid s \neq i \neq t, \sigma(s,n_i,t) = \begin{cases} 1, if \;\; \gamma_{st} \ni n_i \\ 0, otherwise \end{cases}$$

the BIG difference of shortest and easiest paths!



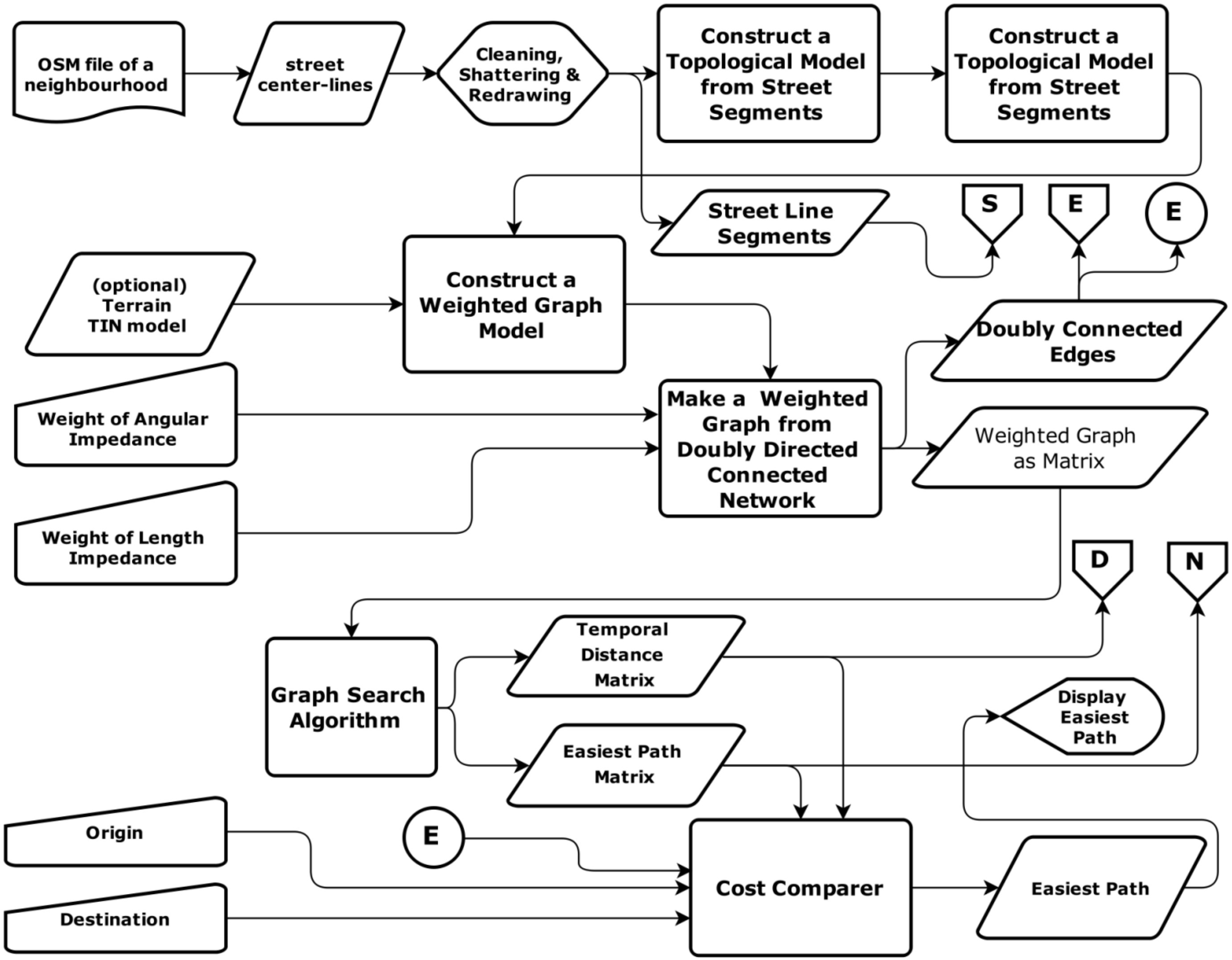
(a) shows the betweenness centrality when the geodesic is only angular and the weight of physical distance is zero; and (b) shows betweenness centrality when both angular and temporal impedances have been given equal weight. It is visible that the picture (b) takes better account of reality as to importance of main roads of the neighbourhood have been revealed better compared to the case (a) when the algorithms disregards the physical distance.

[Local] Betweenness Centrality [via Easiest Paths]

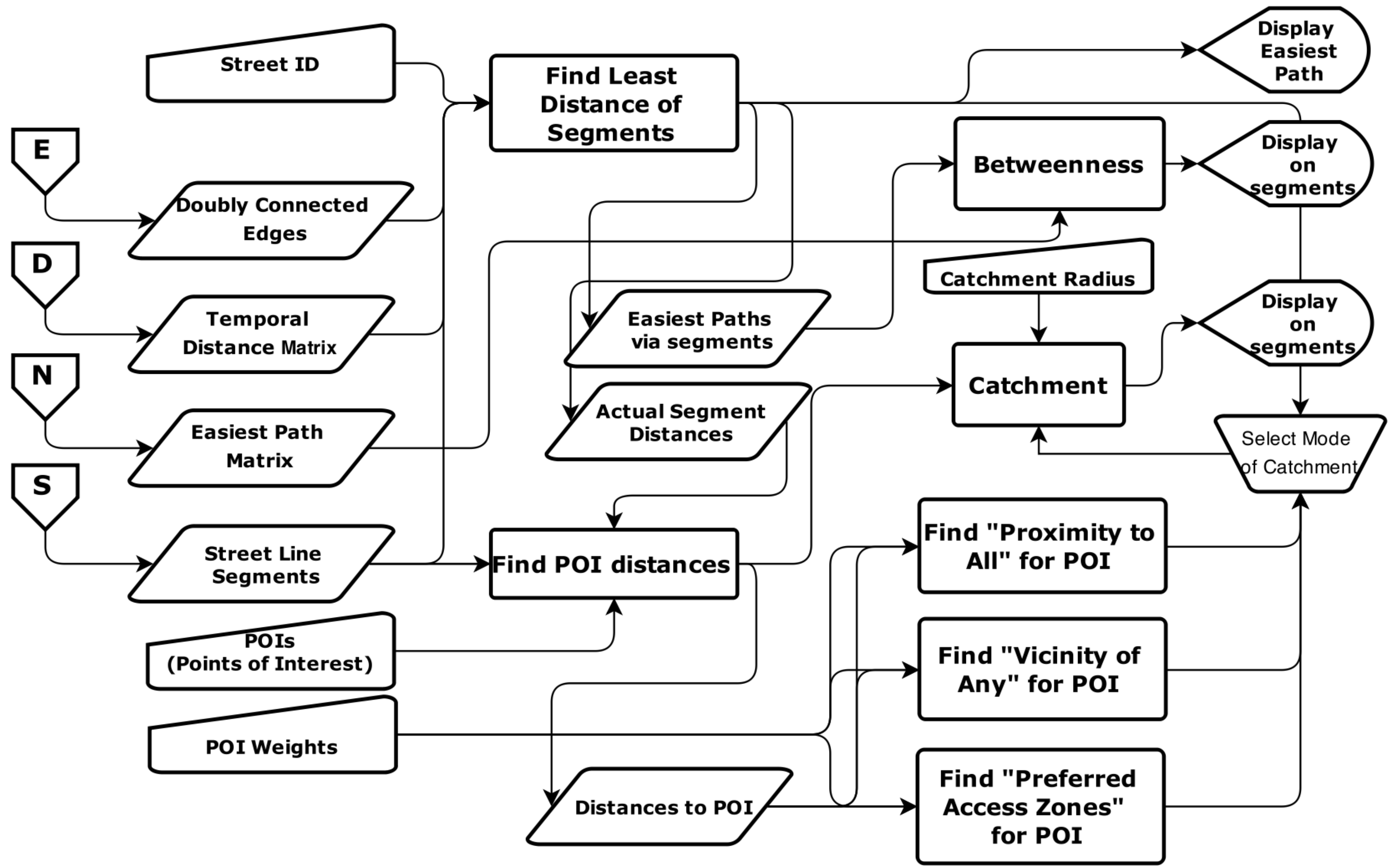
[Local] Betweenness Centrality [via Easiest Paths]

Tau=0, 5 10 15

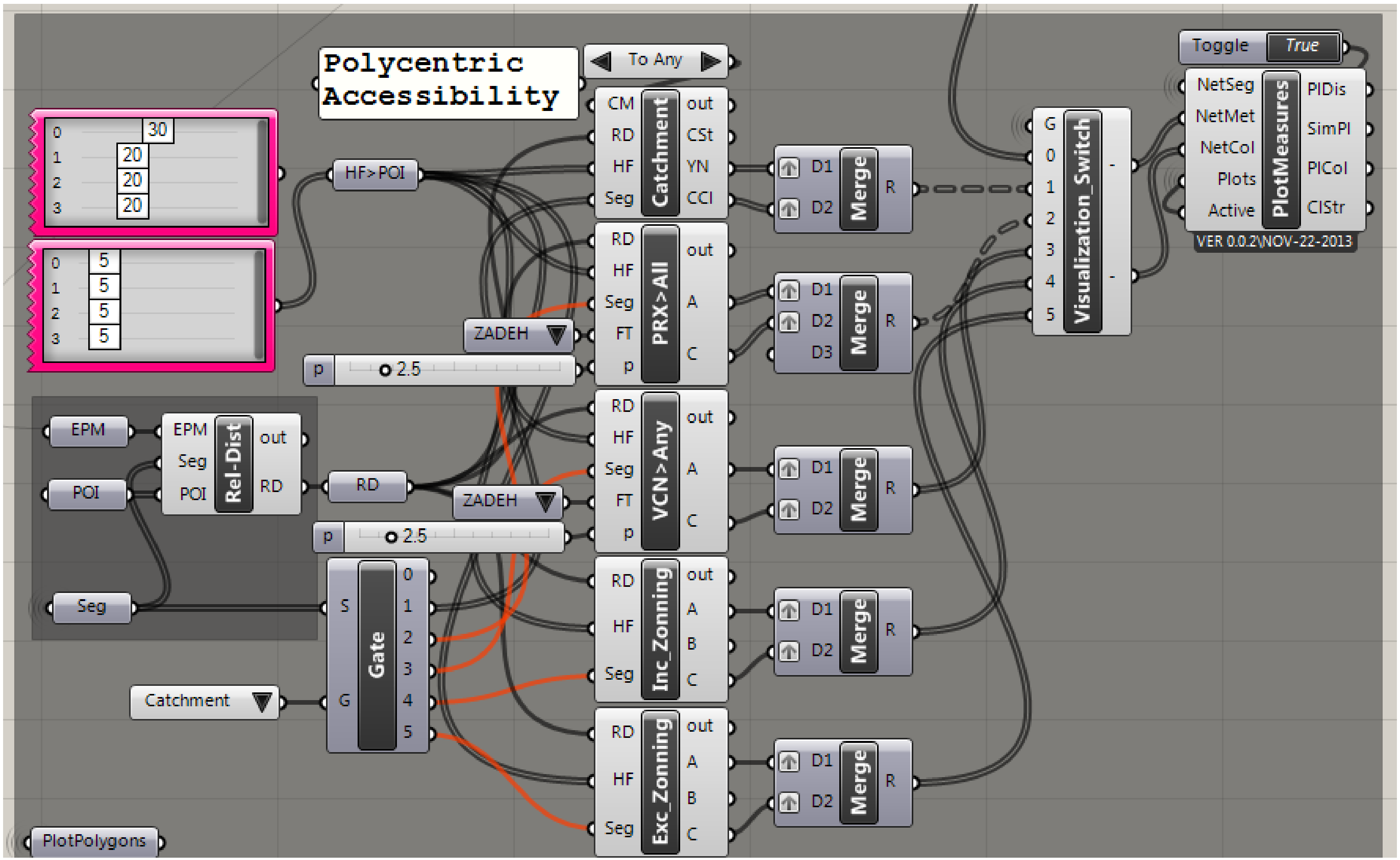
Flowchart of the Analytic Workflow, Page 1



Flowchart of the Analytic Workflow, Page 2



Accessibility modelling components implemented in C# for Grasshopper©



Work in Progress: A Markov Chain Model a.k.a. Random Walk, a variant of eigenvector centrality

- Model parameters (transition probabilities) based on angular impedance
- We solve it mathematically, very fast, without computing all eigenvectors

Highlights:

- Easiest Paths are paths that are as short, flat and straightforward as possible
- Any notion of distance corresponds to a geodesic (i.e. optimal path), we argue that actual temporal distance between locations can well be computed through easiest paths
- We allow for inter-subjectivity by means of modelling access to POI, located by expert users
- Computing distances and impedances in terms of time brings a number of advantages; namely the immediate intuitive comprehensibility of the measures and commensurability of impedance values
- We have revisited the notion of local accessibility using Fuzzy logics; which gives the whole idea of local closeness a solid mathematical basis
- We have generalized Voronoi diagrams and Alpha Shapes from 2D Euclidean space to the
- The freeware toolkit ensures repeatability of all experiments and allows for integrating accessibility analyses in urban 'design' workflows easily
- The Markov Chain model (a.k.a. Random Walk) simulated mathematically has a high potential for simulating walking and cycling flows statistically

Thank you for your attention!

A Selected Bibliography:

- Batty, M. “A New Theory of Space Syntax.” *CASA Working Paper Series*, March 2004.
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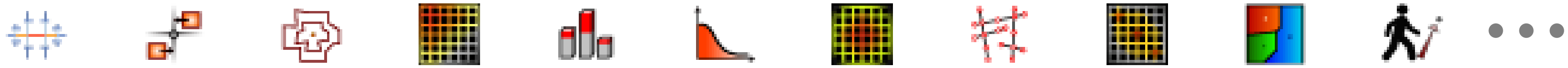
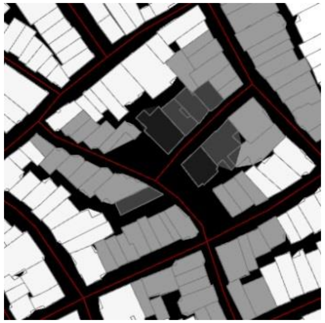
CONFIGURBANIST
(Cheetah)

- real-time accessibility analysis for walking and cycling modes, considering topography
- aggregate accessibility analysis of geographic attractions
- polycentric distributions
- metric between-ness analysis
- parametric zoning and cycling network design



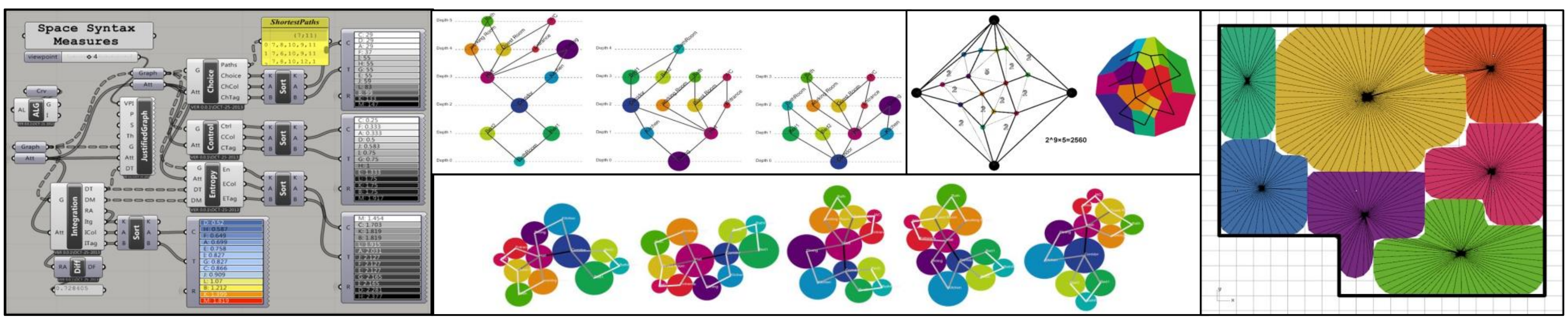


www.grasshopper3d.com/group/cheetah
https://sites.google.com/site/pirouznourian/configurbanist

SYNTACTIC

(Space Syntax for Generative Design)

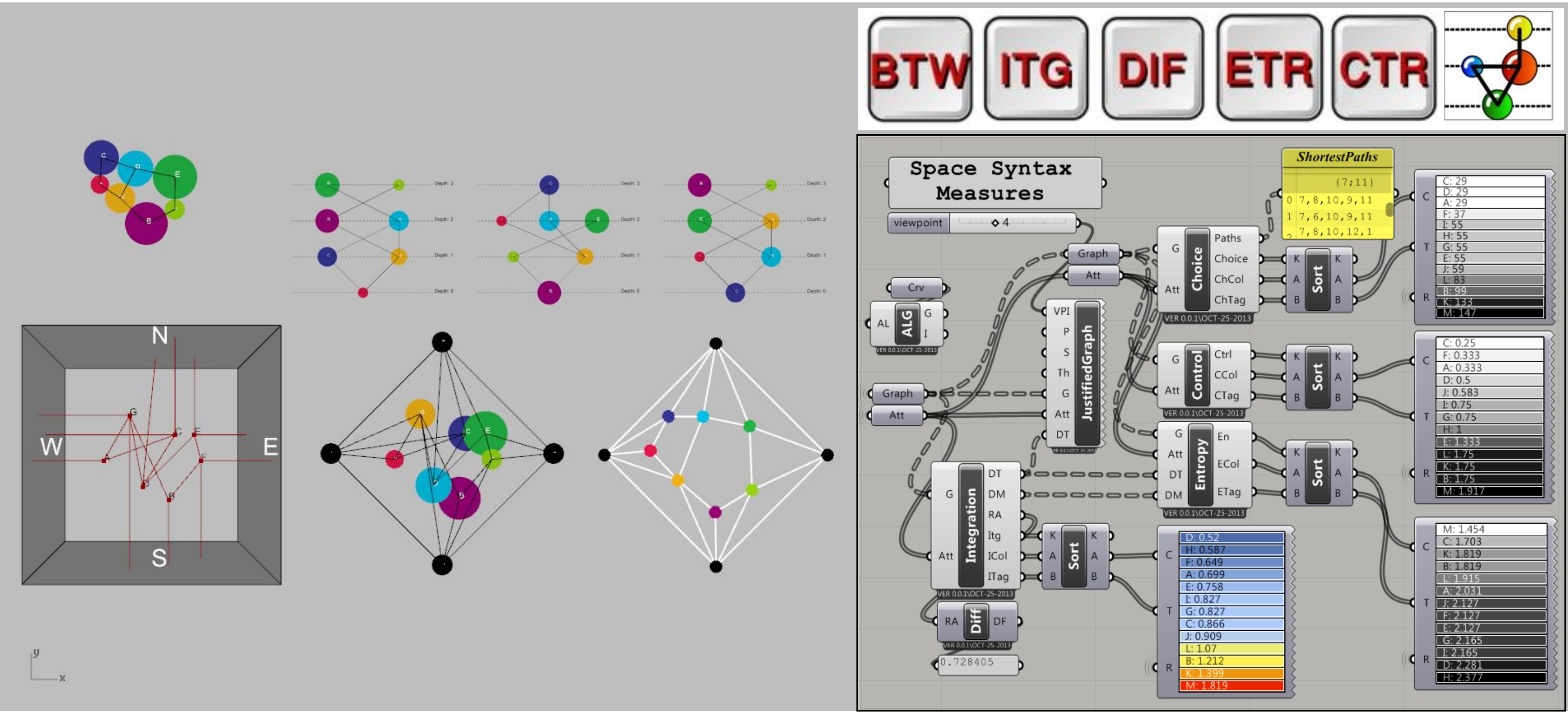
- real-time Space Syntax analyses for parametric design
- interactive bubble diagram
- automated graph drawing algorithms
- enumeration of plan configuration topologies
- measuring the socio-spatial performance



www.grasshopper3d.com/group/space-syntax

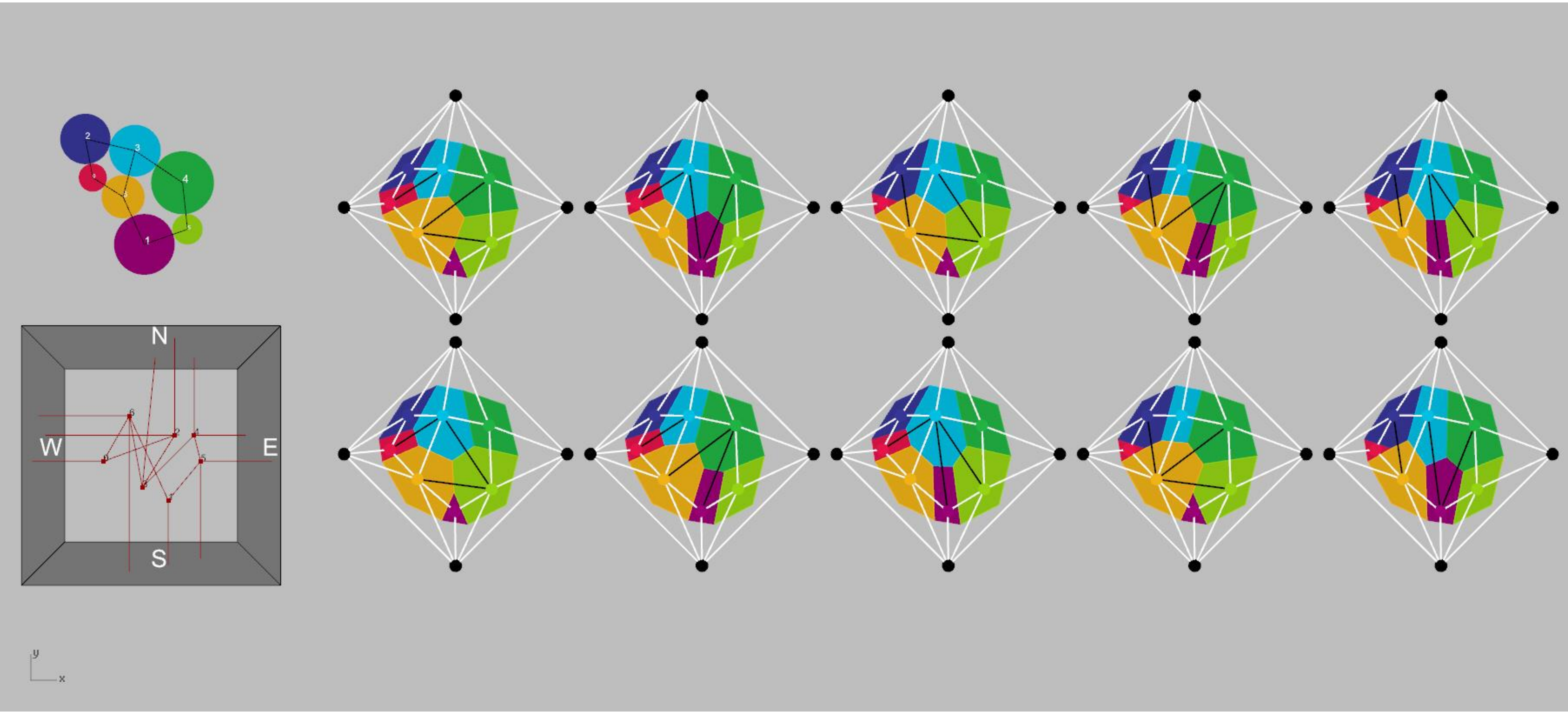
https://sites.google.com/site/pirouznourian/syntactic-design

Example Results from SYNTACTIC



- User specifies nodes and links, receives feedback on likely performance of the configuration
- User receives untangled graph drawings
- All computations run in real-time to allow for direct interaction

Example Results from SYNTACTIC



- **Each triangulation gives rise to a dual spatial configuration of rooms represented by nodes**