CONFIGURBANIST ☛

Easiest Paths, Fuzzy Accessibility, and Network Centrality for Walking and Cycling in Cities

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Cheetah ☛ (Cheetah, the CONFIGURBANIST), by Pirouz Nourian & Samaneh Rezvani since 2013

a computational methodology for urban configuration analysis
CONFIGURBANIST
(Cheetah)

- Easiest Paths for walking and cycling (flat, short, and straightforward)
- Fuzzy accessibility analysis of geographic attractions
- Polycentric distributions
- Geodesic, structural, and probabilistic Network Centrality analyses
- Voronoi and Alpha Shapes zoning and cycling network design

www.grasshopper3d.com/group/cheetah
https://sites.google.com/site/pirouznourian/configurbanist
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
Way-Finding for pedestrians and cyclists

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

A path that is as flat, short and straightforward as possible
Way-Finding Essentials for Walking and Cycling

Physical Impedance, slope $\Rightarrow$ speed; speed & length $\Rightarrow$ travel time

Physical Difficulty

**Length Impedance**

- Slope
- Length
- Power

**Dimension:** Time

**Unit:** Minute

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Image courtesy of [Antonio Olmos](http://www.theagepage.co.uk/)

The hiking speed function of Waldo Tobler, Wikipedia Images

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Way-Finding Essentials for Walking and Cycling

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

Physical Difficulty

**Length Impedance**

- Slope
- Length
- Power

Dimension: Time

Unit: Minute

\[
\begin{align*}
WLI_k & := \frac{WLI_k(\alpha_k)}{WV_k} = \frac{\delta}{6e^{-3.5|\tan \alpha_k+0.05|}} = \frac{3.6\delta e^{3.5|\tan \alpha_k+0.05|}}{6} \\
CLI_k & := \frac{CLI_k(\alpha_k)}{CV_k} = \frac{\delta (mg \sin \alpha_k + F_f)}{p} = \frac{\delta (85 \times 9.81 \times \sin \alpha_k + 25)}{112}
\end{align*}
\]

**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

\[ A_{I_k} := A_{I_k}(\theta_k) = \begin{cases} \frac{\tau \sin^2 \frac{\theta_k}{2}}{2}, & \tau = 10 \text{ seconds, if } \text{Deg}(l_k) > 2 \\ 0, & \text{otherwise} \end{cases} \]
Constructing a topological model (a dual graph) from street centreline network

Diagrams drawn after Batty, 2004
Weighted Adjacency Matrix

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

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

\[ AI_k := AI_k(\theta_k) = \begin{cases} \tau \sin^2 \frac{\theta_k}{2} : & \tau = 10 \text{ seconds, if } \text{Deg}(l_k) > 2 \\ 0 & \text{otherwise} \end{cases} \]

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 $\pi$ is defined as a sequence of nodes (i.e. street segments) $\pi = (n_1, n_2, ..., n_m) \in N \times N \times \cdots \times N$ such that $n_j$ is adjacent to $n_{j+1}$ for $1 \leq j < m$. The path $\pi$ 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 $f: L \rightarrow \mathbb{R}$, which attributes an impedance or cost to each link of the graph $\Gamma_d(N, L)$, we need to find a path $\pi = (n_1, n_2, ..., n_m)$ 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 $L_{i,j}$ we can get the cost of each link from the pre-calculated impedance set:

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

\[
C(x) = \frac{1}{1 + e^{\lambda(x-F/2)}}
\]

In this equation, \(C(x)\) denotes closeness of a destination at a distance \(x\); and \(\lambda\) 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.
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.

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

\[
B(n_i) = \frac{2 \times \sum_{s=1}^{\left|\mathcal{N}\right|} \sum_{t=1}^{\left|\mathcal{N}\right|} \sigma(s, n_i, t)}{(|N| - 2) \times (|N| - 1)} | s \neq i \neq t, \sigma(s, n_i, t) = \begin{cases} 1, & \text{if } \gamma_{st} \ni n_i \\ 0, & \text{otherwise} \end{cases}
\]
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.
[Global] Betweenness Centrality [via Easiest Paths]
[Local] Betweenness Centrality [via Easiest Paths]
[Global] Betweenness Centrality [via Easiest Paths]

Movement Through

Morwell, Victoria, Australia, Radius, 10 Minutes Cycling
[Local] Betweenness Centrality [via Easiest Paths]

Movement Through

Morwell, Victoria, Australia, Radius, 4 Minutes Cycling
Closeness 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.

\[
C(n_i) = \frac{1}{\sum_{i \sim j} \frac{1}{D(n_i, n_j)}}
\]

\[
|D(n_i, n_j)| = \sum_{k \in \gamma_{s,t}} \zeta_k
\]
[Local] Closeness Centrality [via Easiest Paths]

Walking, HowFar=5 Minutes
[Local] Closeness Centrality [via Easiest Paths]

Cycling, HowFar=5 Minutes
[Local] Closeness Centrality [via Easiest Paths]

HowFar=4,

6

8

10
[Global] Closeness Centrality [via Easiest Paths]

Movement To

Morwell, Victoria, Australia, Radius, 10 Minutes Cycling
[Local] Closeness Centrality [via Easiest Paths]

Movement To

Morwell, Victoria, Australia, Radius, 4 Minutes Cycling
A Fuzzy 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
A Fuzzy 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

**Probability of Presence**
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.
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Thank you for your attention!

A Selected Bibliography:

Pirouz Nourian

Education:
- BSc in Electrical Engineering, specialization in Systems/Control Engineering 2004
- MSc in Architecture & Urban Planning 2009
- PhD researcher (Computational Urban Design & Planning) since 2010

Appointment:
- Researcher (3D Raster GIS, directed by Dr. Sisi Zlatanova) at OTB, GISt (0.5 FTE) since 2014
- Instructor of Computational Design in TU Delft, BK, Design Informatics (0.4 FTE) since 2011
- 0.1 FTE as guest PhD since 2010

Experience:
- Released Design and Planning Support Tools and Systems
  - SYNTACTIC: Space Syntax for Generative Architectural Design
  - CONFIGURBANIST: Urban Configuration Analysis and Synthesis for Walking and Cycling
  - RasterWorks.DLL: Raster3D tools for computational urban analysis
  - TOIDAR: Computational tools for automated 3D reconstruction of city models out of point clouds
- Configurative Spatial Analysis (Graph Theory applied to built environment analysis)
- Computational Geometry, Analysis, Simulation and Optimization Algorithms
- Procedural/Parametric/Computational 3D Modelling

Computer Programming:
- VB.NET (Writer, Reader, Speaker)
- C#.NET (Reader, Writer)
- Python (Reader)

Courses:
GEO1004 directed by Dr. Sisi Zlatanova, AR0025 XXL Design Studio and AR0026 High-rise Design Studio 12 ECTS each directed by Dr. Michela Turrin (Responsible instructor of computational design), AR1AE015 BuckyLab Design CAD, AR4AC010 Computational Architecture, etc.