



Verkehrsbetrieb Stadtwerke Potsdam



Tourist-Information
Besucherinformation
Stiftung preußische
Schlösser und Gärten

VIP-Kundenzentren
VIP-Information: (0331) 6 6142 75
VIP-potsdam.de
VBB App „Bus & Bahn“ und
twitter.com/VIP_potsdam

Umsteigehaltestelle

Das Heft „Potsdam entdecken
mit S-Bahn, Tram und Bus“ mit
genauerer Routendeskriptionen
gibt es in allen VIP-Kundenzentren

Stand 12/2022

Potsdam entdecken mit den touristischen Linien

Straßenbahnen und Busse fahren
Sie direkt und schnell vom Potsdamer
Hauptbahnhof zu den zahlreichen
Sehenswürdigkeiten:

677 Schloss Sanssouci Südflo (07.04. bis 05.11.2022)

695 Alt-Görlitz

Sanssouci-Linie

Park und Schloss Sanssouci, Orangerie, Drachenhaus,
Belvedere auf dem Klausberg, Weg zum Park Sanssouci

695 Sience Park West
Historisches Dampfmühlchenhaus, Park und Schloss
Charlottenhof, Neues Palais, Weg zum Park Sanssouci

695 Campus Jungfernsee

695 Volkspark-Linie

Historische Innstadt, Russische Kolonie Alexandrowka,
Volkspark Potsdam

695 Jannowitz, Kirchholz

Holländisches Viertel, Russische Kolonie Alexandrowka,
Belvedere auf dem Klausbberg, Ruinenberg, Volkspark
Potsdam, Königin Borissd

695 Glienicker Brücke

Entwurf, Schiffbauerpasse, Hans Otto Theater, Schloss
und Park Glienicke

Bei Platz der Einheit/West dort umsteigen in:

695 Höherstraße

695 Cecilienhof-Linie

Historische Innstadt, Russische Kolonie Alexandrowka,
Neuer Garten, Marmorpalais, Schloss Cecilienhof,
Belvedere auf dem Klausbberg
Südost ab Hauptbahnhof (07.04. bis 05.11.2022)

695 Johannes Kepler Platz

Friedenstadt Babelsberg im Filmpark

Filmpark-Linie

Märkisch-Brandenburg im Filmpark

Source: https://www.swp-potsdam.de/content/verkehr/bilder_6/liniennetz/touristischer_liniennetzplan_screenshot_1280_960.jpg

Temporal Graphs

Daniel Cermann

January 28, 2025



Hasso Plattner Institute

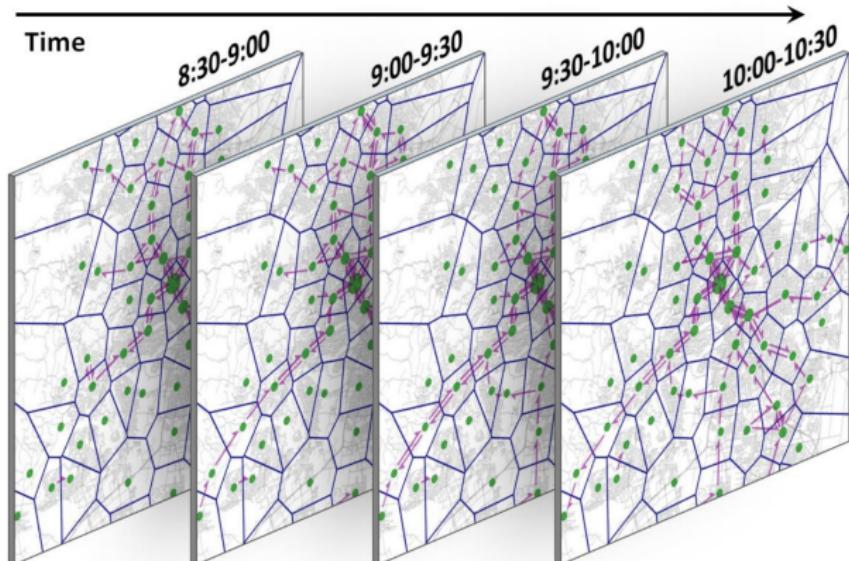
Motivation

Clip: School day

<https://youtu.be/BSNJSUkc5-Q?t=996>

Google Maps

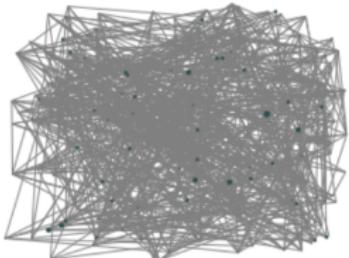
Figure 1: Illustration of a trajectory flow map, a dynamic graph of aggregated traffic flows constructed from trajectory data. The presented example is based on bus passenger trajectories obtained in Brisbane, Australia.



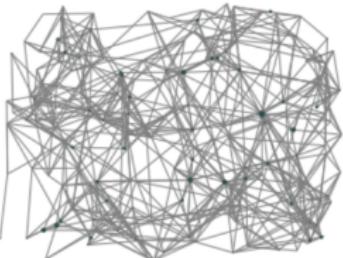
Source: https://australiantransportresearchforum.org.au/wp-content/uploads/2022/03/ATRF2016_paper_166.pdf

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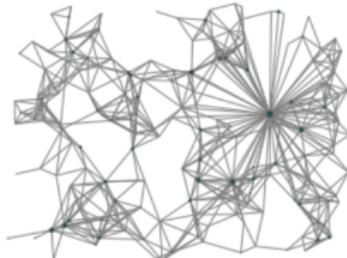
Distributed systems



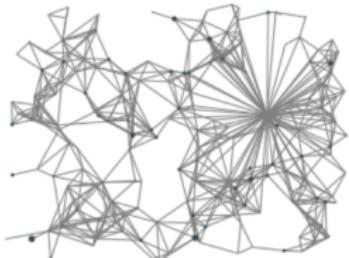
(a) Random initial network



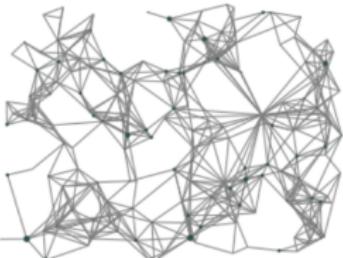
(b) Intermediate state



(c) Equilibrium network



(d) Change of node capacities



(e) Intermediate state



(f) Equilibrium network

Source: <https://www.sg.ethz.ch/publications/2012/scholtes2012organic-design-of/>

Temporal graphs for physical/chemical models

DATA SCIENCE | May 9, 2023

A Temporal Graph Model to Predict Chemical Transformations in Complex Dissolved Organic Matter

Philipp Plamper, Oliver J. Lechtenfeld*, Peter Herzsprung, and Anika Groß*

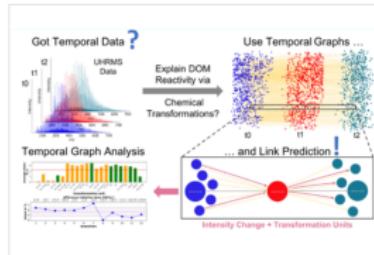
Open PDF

Supporting Information (1)

ACCESS

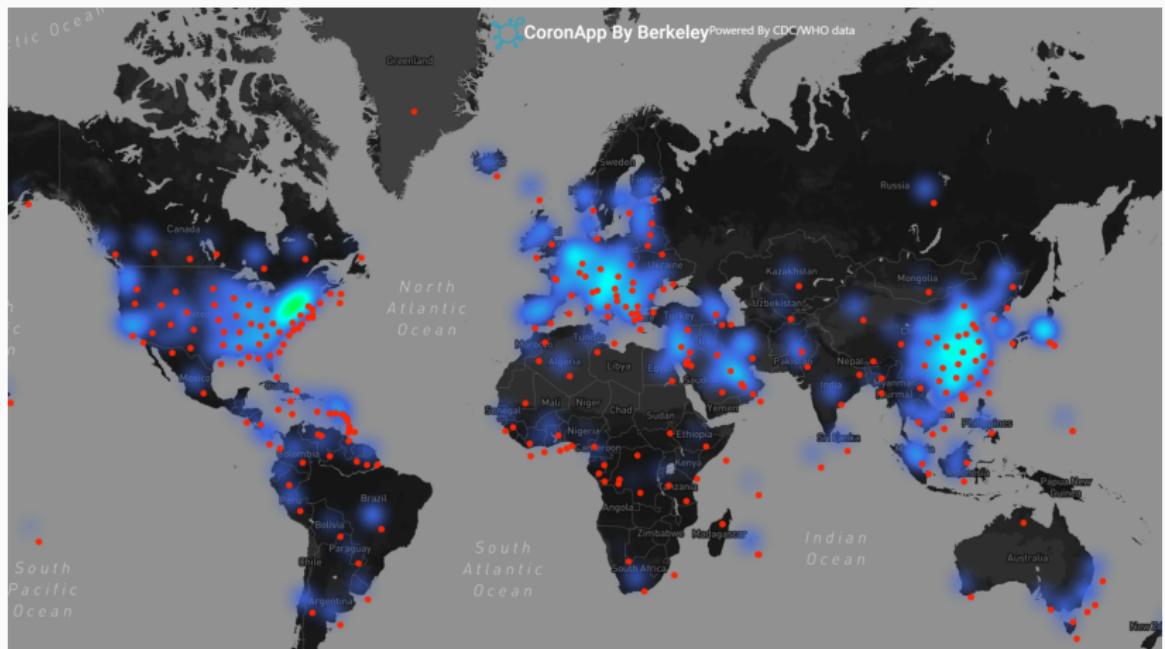
Abstract

Dissolved organic matter (DOM) is a complex mixture of thousands of natural molecules that undergo constant transformation in the environment, such as sunlight induced photochemical reactions. Despite molecular level resolution from ultrahigh resolution mass spectrometry (UHRMS), trends of mass peak intensities are currently the only way to follow photochemically induced molecular changes in DOM. Many real-world relationships and temporal processes can be intuitively modeled using graph data structures (networks). Graphs enhance the potential and value of AI applications by adding context and interconnections allowing the uncovering of hidden or unknown relationships in data sets. We use a temporal graph model and link prediction to identify transformations of DOM molecules in a photo-oxidation experiment. Our link prediction algorithm simultaneously considers educt removal and product formation for molecules linked by predefined transformation units (oxidation, decarboxylation, etc.). The transformations are further weighted by the extent of intensity change and clustered on the graph structure to identify groups of similar reactivity. The temporal graph is capable of identifying relevant molecules subject to similar reactions and enabling to study their time course. Our approach overcomes previous data evaluation limitations for mechanistic studies of DOM and leverages the potential of temporal graphs to study DOM reactivity by UHRMS.



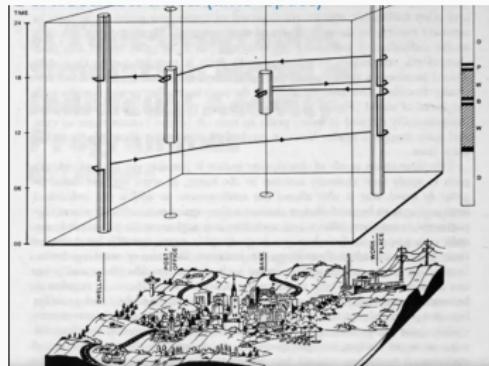
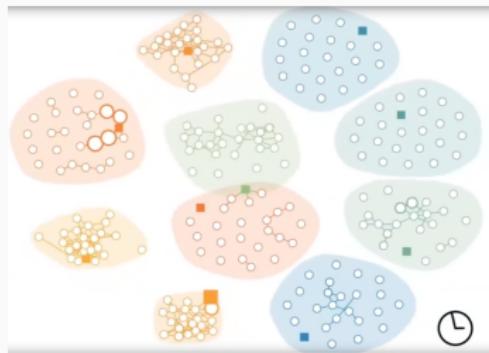
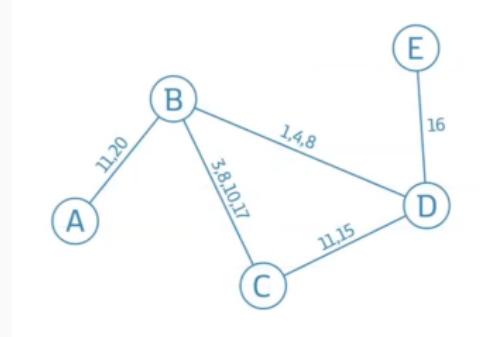
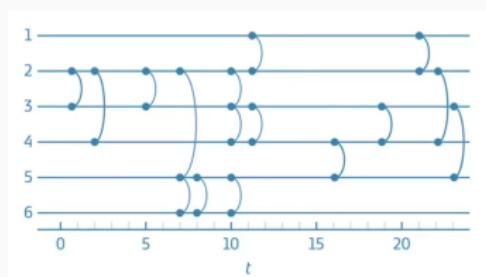
Source: <https://pubs.acs.org/doi/full/10.1021/acs.est.3c00351>

Dissemination processes



Source: <https://engineering.berkeley.edu/wp-content/uploads/2020/03/CoronApp.png>

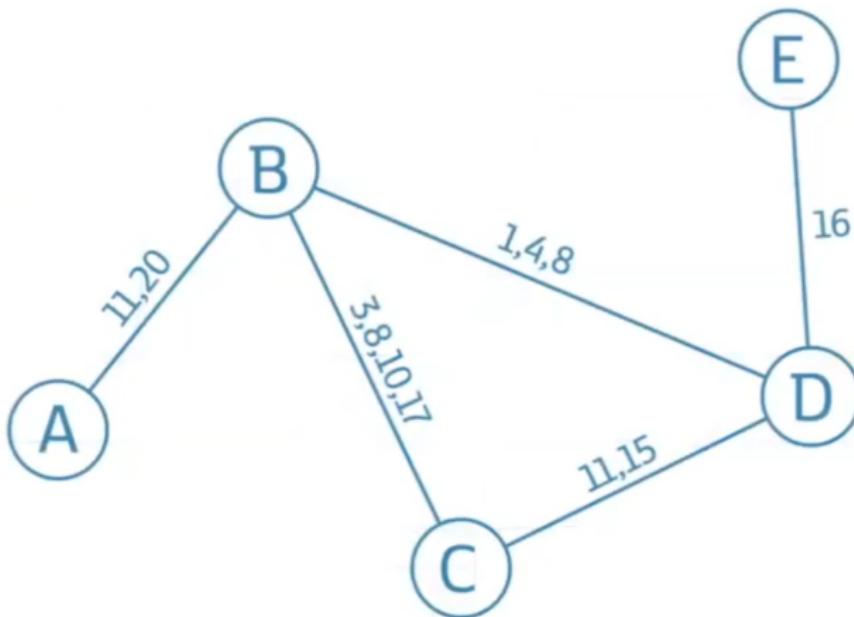
How to represent time in graphs?



Source: <https://www.youtube.com/watch?v=BSNJSUkc5-Q>

How to model temporal graphs

How to model temporal graphs



Source: <https://www.youtube.com/watch?v=BSNJSUkc5-Q>

Definition labeled and temporal graphs

Definition

A **labeled graph** [GHOSH201888] is a triple $G = (V, E, \lambda)$ where:

- V, E is a graph
- $\lambda : V \cup E \rightarrow Z$ is a mapping of nodes and edges to a set of labels Z

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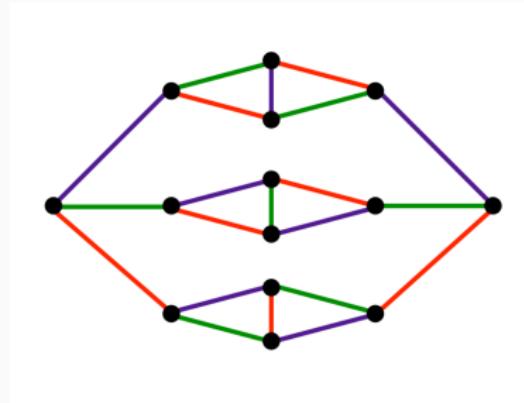
- V, E is a graph
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Definition

A **temporal graph** [Michail2015] is a triple $G = (V, E, \lambda)$ where:

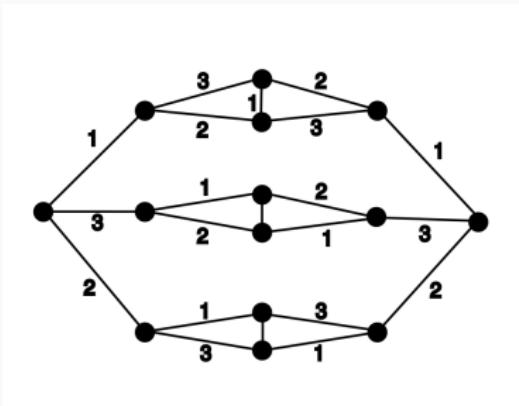
- V, E is a graph
- $\lambda : E \rightarrow 2^{\mathbb{N}}$ is a mapping edges to a set natural numbers (time steps when this edge is active)

Relationship labeled and temporal graphs



a

↔



a

^aSource: <https://www.algorist.com/images/figures/edge-coloring-R.png>

^aSource: me:)

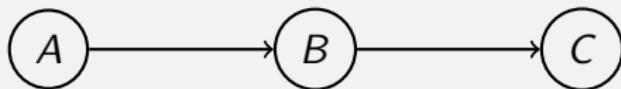
Notation for convenience → [Michail2015]

- $\lambda(G)$ - temporal graph with respect to G
- $\lambda(E)$ - multiset of all labels
- $|\lambda| = \sum_{e \in E} |\lambda(e)|$
- $\lambda_{min} = \min\{l \in \lambda(E)\}$
- $\lambda_{max} = \max\{l \in \lambda(E)\}$
- $\alpha(\lambda) = \lambda_{max} - \lambda_{min} + 1$ - lifetime of a temporal graph $\lambda(G)$

Transitivity of reachability in static graphs

Reachability in a static graph is transitive

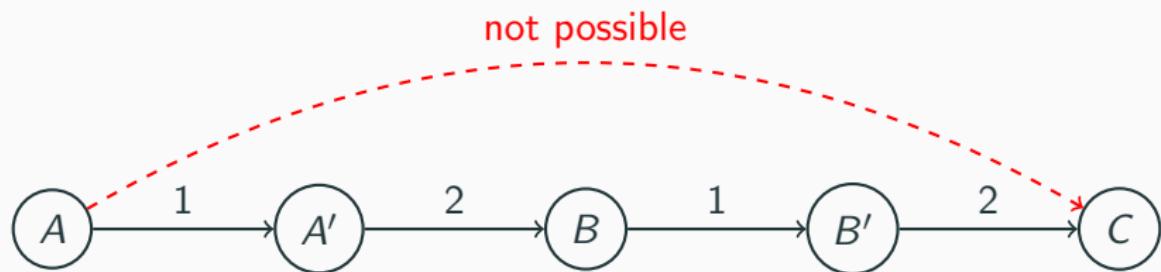
Given A static graph $G = (V, E)$, for all nodes $A, B, C \in V$ we have: If B is reachable by A and C is reachable by B, then C is reachable by A.



Transitivity of reachability in static graphs

Is reachability in a temporal graph transitive?

Time matters!

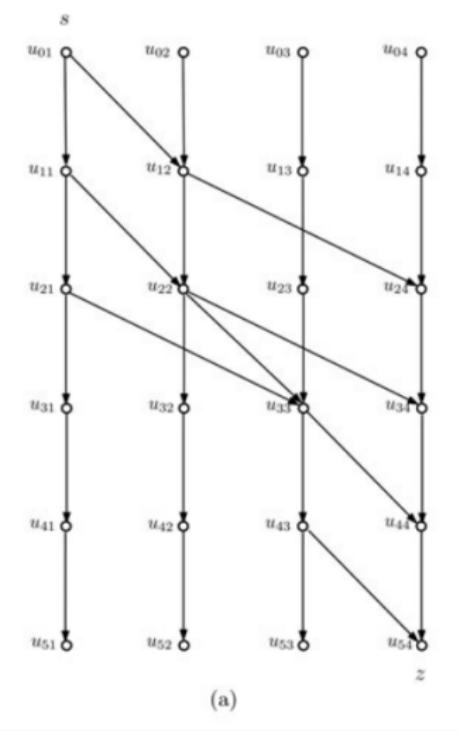


⇒ Deep implications for complexity of temporal graphs

Notation #2

- A temporal graph D is an ordered set of disjoint sets (V, A)
- $A \subseteq V^2 \times \mathbb{N}$ - 'time edges'
- $A(t) = \{e | (e, t) \in A\}$ - set of edges at time t
- $D(t) = (V, A(t))$ - snapshot of graph D at time t

Static expansion of a temporal graph



Static expansion of a temporal graph

Definition: static expansion of a graph

The static expansion of a temporal graph $D = (V, A)$ with $V = \{u_1, u_2, \dots, u_n\}$ is a DAG $H = (S, E)$ with:

$$S = \{u_{ij} \mid \lambda_{min} - 1 \leq i \leq \lambda_{max}, 1 \leq j \leq n\}$$

and

$$\begin{aligned} E = \{ & (u_{(i-1)j}, u_{ij'}) \mid \lambda_{min} \leq i \leq \lambda_{max} \wedge \\ & 1 \leq j, j' \leq n \wedge (j = j' \vee (u_j, u_{j'}) \in A(i)) \} \end{aligned}$$

Repetition - walks and paths in static graphs

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- A **walk** is a finite or infinite sequence of edges which joins a sequence of vertices.

Repetition - walks and paths in static graphs

- A **walk** is a finite or infinite sequence of edges which joins a sequence of vertices.
- A **path** is a walk where all vertices are distinct.

Definition: temporal/time respecting walk

A **temporal** or **time-respecting walk** W of a temporal graph $D = (V, A)$ is an alternating sequence of nodes and times $(u_1, t_1, u_2, t_2, \dots, u_{k-1}, t_{k-1}, u_k)$ where

- $\forall 1 \leq i \leq k - 1 : ((u_i, u_{i+1}), t_i) \in A$ and
- $1 \leq i \leq k - 2 : t_i < t_{i+1}$

- t_1 - departure time
- t_{k-1} arrival time
- $t_{k-1} - t_1 + 1$ - duration/temporal length

Definition: Journey

A **journey** is a temporal walk with pairwise distinct nodes
 \triangleq a journey of D is a path of the underlying static graph of D that uses strictly increasing edge-labels.

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 \triangleq a journey of D is a path of the underlying static graph of D that uses strictly increasing edge-labels.

Definition: Foremost Journey

A u - v journey J is called foremost from time $t \in \mathbb{N}$ if it departs after time t and its arrival time is minimized.

Definition: Temporal distance

The **temporal distance** from a node u to at time t to a node v is defined as the duration of a foremost journey from u to v that departs at time t .

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Definition: Temporal diameter d

The minimum integer d such that there exists a foremost journey from every node $(u, t) \in V \times \{0, 1, \dots, \alpha - d\}$ to every node $v \in V$ with duration at most d .

Computing foremost journeys - Problem formulation

Given a source node $s \in V$ and a start time t_{start} compute the foremost $s - w$ journey for all $w \in Vn\{s\}$

Sidenote - offline vs. online algorithms

offline algorithms

takes whole temporal graph D
as input

online algorithms

temporal graph is revealed to algorithm over time

Computing foremost journeys - Algorithm

Computing foremost journeys - Proof of correctness

Computing foremost journeys - Running time

The government has been lying to us

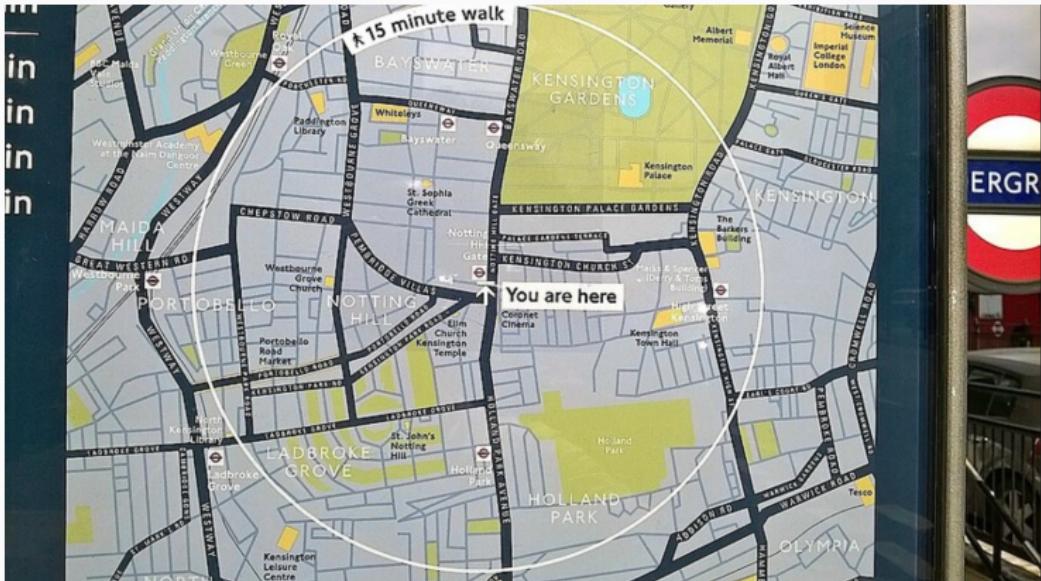
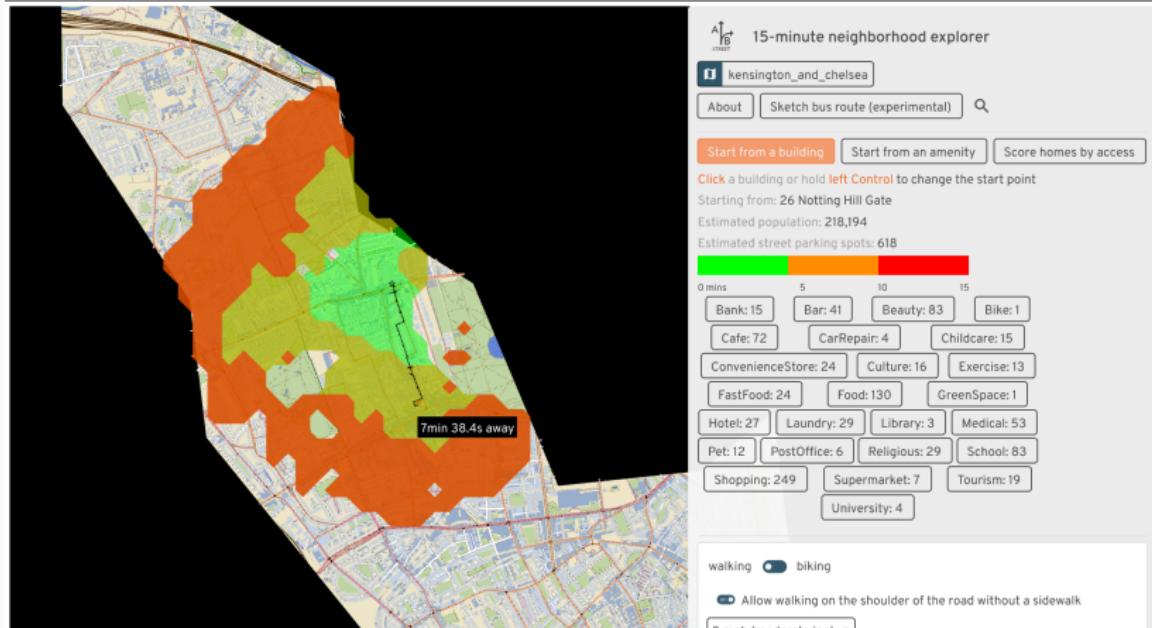


Figure 2: You-are-here-maps are wrong!

Source: https://commons.wikimedia.org/wiki/File:Notting_Hill_Royal_Borough_of_K%26C_Council_Map_Outlining_the_Official_Area_of_Notting_Hill_and_the_Surrounding_Areas_2018.jpg

15 min walk



Source: https://play.abstreet.org/0.3.49/fifteen_min.html

Reachability

Definition: Reachability

Temporal graphs for modeling dissemination processes

A natural application domain of temporal graphs is that of *gossiping*
~ [Michail2015]

What are dissemination processes?

- spread of rumors
- spread of fake news
- spread of diseases

Teasers

Temporal Graph Neural Networks

Sources