Visually Analyzing Latent Accessibility Clusters of Urban POIs

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Abstract

Accessibility of urban POIs (Points of Interest) is a key topic in a variety of urban sciences and applications as it reflects inherent city design, transportation, and population flow features. Isochrone maps and other techniques have been used to identify and display reachable regions from given POIs. In addition, domain experts further want to study the distribution effects of accessibility in the urban space such as finding spatial regions that have different accessibility patterns. Such patterns can be manifested by clustering POIs based on their accessibility of different time periods under different traffic conditions. In this paper, we present a visualization system that helps users to find and visualize Latent Accessibility Clusters (LACs) of POIs. The LACs discover temporally changing urban sub-regions (including nearby POIs) with disparate accessibilities at different times. LACs are computed by a POIGraph which connects POIs into a graph structure by extending the dual road network of the corresponding city. The LAC computation is facilitated by graph traversal over the POIGraph. By visualizing the LAC regions on the map, users can visually study the hidden patterns of spatial accessibility. It can contribute to urban transportation, planning, business, and related social sciences.

1. Introduction

An emerging and critical topic in urban sciences is to discover and analyze urban objects (e.g., restaurants, hotels, schools, buildings, etc.) for their disparities in the access to essential facilities and services (e.g., hospitals, shops, public transits). The *accessibility* (or *reachability*) of urban regions and POIs (Points of Interest) is a key policy interest across the world so that people and products can reach certain destinations in necessary times. In [Van16], Van Wee reviewed existing domain research and practice in accessibility study, and suggested a set of future directions including an important challenge which is to discover and analyze the *distribution effects* of accessibility, such as "How to measure equity and distributions of accessibility over which population groups, areas, etc.?". In this paper, we present new visualization tools that help users discover and study urban sub-regions, which is temporally changing and have disparate accessiblities to specific POIs. Thus, the distributions of accessibility over areas (and their citizen) can be studied. The visual analysis contributes to evaluate the effects of transport system and population movement, so as to enhance urban and business planning.

Urban POIs can reach different sets of facilities and services depending on a variety of factors such as the real-time traffic on city transportation systems. For example, given a 5 minutes of driving, an apartment complex can access 20 restaurants in Saturday noon, but can only access 4 restaurants in Wednesday noon. These numbers of reachable facilities in given travel times indicate inherent characteristics of accessibility of a POI. They can be used to compute the *accessibility similarity* of a pair of POIs. Therefore, we propose *Latent Accessibility Clusters* (LACs) by applying graph-based spatial clustering on urban POIs based on their accessibility similarities. The clusters are "latent" because they are dynamically changing and often not relied on known urban regions. A LAC discovers *a neighborhood of POIs forming a local region with similar accessibility*. By visually studying the spatial patterns and temporal variations of multiple types of LAC regions, users can study the latent disparities of the capabilities that people and goods can travel to specific facilities from different types of POIs.

Our work is built up on the algorithms and visual tools of defining, computing, and analyzing LACs in the geo-context. It supports visual analysis of LACs regions for studying urban accessibility distribution. The new technical approaches include:

1. *Flexibly building accessibility similarity:* The similarities among POIs are computed by the number of accessible destinations, based on given travel times, transportation modes (e.g., walking, driving), at different time periods of different days. Meanwhile, users can build LACs based on specified categories of starting POIs (seeds) and destination POIs. Users are enabled to interactively define multiple combinations of these factors.

2. *Creating POIGraph and generating LACs using graph-based clustering:* We create a new data structure, POIGraph, to facilitate easy and quick computation of LACs. POIGraph extends a street network by connecting spatially neighboring POIs. It is further weighted on the graph edges (between POIs) by the accessibility similarities. Then, the graph is partitioned to generate a group of subgraphs (POI clusters), each of which leads to a

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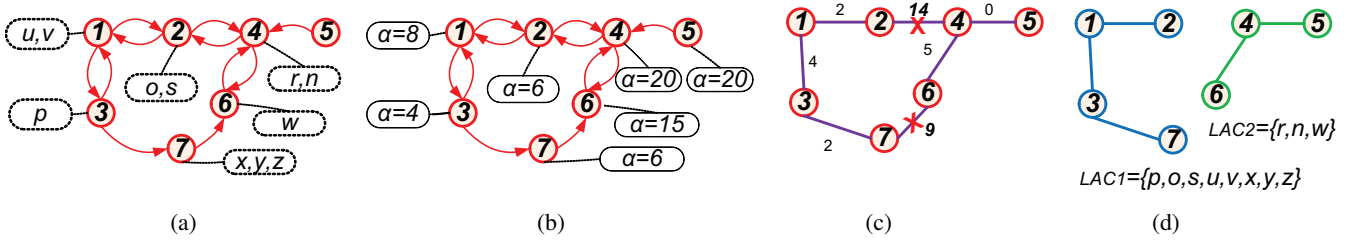
Figure 1: *Illustrating LAC generation. (a) Create POIGraph from road network and POIs; (b) Compute accessibility function; (c) Compute accessibility difference; (c) Form subgraphs that represent LACs.*

LAC consisting of a group of neighboring POIs sharing similar accessibilities.

3. *Visualizing and analyzing LACs:* We develop a Voronoi-based drawing method to compute and visualize the spatial regions of LACs. The characteristics of these regions are also extracted and visualized.

A visualization system is built up for users to combine analytical reasoning and interactive visualization of LACs. In summary, the contributions of this paper are: (1) we present a visual analytics system that studies temporal urban sub-regions of POIs with similar accessibilities; (2) we propose a POIGraph model and graph-based clustering to discover spatial LACs; (3) LACs are visualized and studied for their disparity and features by integrating visualizations and interactions with LAC definition, computing, and analysis.

2. Related Work

Studying the accessibility in geographical spaces is an important work [Van16, RFT*14] to understand and improve transportation and urban systems. A variety of research work in urban research has been conducted to study accessibility with a set of challenges and future directions (see [Van16] and papers therein).

To analyze and visualize accessible facilities of given urban objects, isochrone map defines the reachable region within a given travel time in traffic [BGL*08, EGL*13, HC01, KAZ*19]. Computing isochrones over transport networks is integrated in geospatial databases [BGL*08, GBCI11]. Isochronic regions are usually visualized together with geographical attributes [EGL*13, RFT*14]. Some APIs (e.g., Google, HERE) provide functions for computing and drawing the isochronic region. Isoscope [GKvLN14] utilizes these functions and optimizes them for better appearance. Isochrone map is used to visualize the accessible areas for passengers on public transportation system [ZFA*14]. Traffigram [HKYA14] designs an interactive cartographic visual system where isochronal map is combined with geospatial context and travel conditions. A variety of urban accessibility metrics are built into a framework to visualize how the accessibility can be affected by urban design of different public transit scenarios [Ste14]. USAVis helps users to study jointly-constrained accessible regions based on specially designed set operations [KAZ*19]. The authors of [TM09] use the traditional intersection set operation to find POIs that are reachable to one person or group of people. In this paper we focus on clustering the POIs based on their accessibility to other facilities to discover hidden sub-regions with various accessibility patterns. Weng et.al. [WZB*18] propose a visual analytics system that helps people finding ideal home based on multiple criteria in-

cluding reachability. Unlike these approaches which express accessibility by finding reachable objects and connectedness between objects, in this paper, we present a different visualization approach to study and evaluate the distribution of accessibility. [VG11].

Spatial clustering methods have been used in hotspot analysis [SSK17, SSB*17, GZH18] and regionalization [AA17, Guo08, CWF*13, GZJ*12, RSS17]. *More to add in visualization fields about region creation*, our method utilizes a new graph-based method to perform spatial clustering of POIs to discover salient regions based on accessibilities, and provide visual analytical capability for users to study their dynamics.

3. POI Accessibility and LACs

3.1. Accessibility Function

Assessments of accessibility gauge the attraction of an urban POI with respect to other places. For example, one important question about a hotel is "*how many restaurants can be reached in 5 minutes by driving in 6pm afternoon?*". The answer to this question reflects the accessibility feature of one POI p, which is the function of several factors (parameters):

- Origin POI category Ψ: a hotel
- Destination POI category Ω: restaurants
- Accessible time threshold η: 5 minutes
- Current time t: 6pm
- Transportation mode ζ: by car

Thus, we define the accessibility function α to compute the number of destination POIs accessible from p as

$$\alpha(p, \Omega, \eta, t, \zeta) = \Sigma_{\forall q \in \Omega}(T(p, q, t, \zeta) < \eta ? 1 : 0) \quad (1)$$

Here q is one destination POI in Ω. $T(p, q, t, \zeta)$ computes the travel time from p to q at t with the transportation mode ζ. If the travel time is in the threshold η then q is reachable from p given these constraints. Urban POIs have dynamical α values at different times and locations. The disparity of the accessibility over different POIs reflect the effects of urban structures, transportation, and population dynamics.

3.2. Spatial LAC Generation

Neighboring POIs with similar α values form a POI cluster, named as Latent Accessibility Cluster (LAC), which discovers a spatial region having similar accessibility behavior. LACs need to be computed by discovering spatially close POIs based on their α values, which includes two major algorithms: (1) the computation of the
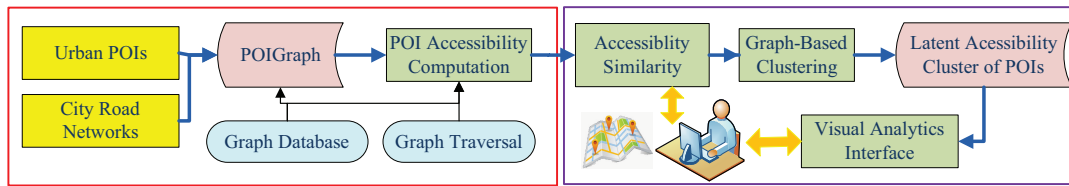
Figure 2: *System overview. Red box:Pre-processing of POI accessibility; Blue box:Interactive discovery and visualization of LACs.*

shortest path from one POI to others (similar to traditional route planning). (2) the spatial clustering of nearby POIs. We develop a POIGraph which can complete both of them. Fig. 1 illustrates LAC generation method in an example with several steps:

- **Build dual graph from road network:** We first acquire the road network of a city, which can be represented as a dual graph. Here each node represents one street segment. An edge from node i to node j is added if people can travel from a street i to its neighbor street j in a given transportation mode. Fig. 1a depicts a directed graph based on the car driving mode. It has seven street segments nodes. It shows people can drive between node 1 and node 3, and from node 3 to node 7. But people cannot drive from node 7 to node 3 and this is due to one way traffic limit.

- **Construct POIGraph:** We then add city POIs to the graph nodes. Each POI is geometrically projected to its closest street segment. Each graph node i thus stores a set of POIs. We call this graph with POIs as a *POIGraph*. As illustrated in Fig. 1a, node 3 stores one POI p and node 7 stores three POIs x,y,z, etc.

- **Compute accessibility functions:** Once the POIGraph is constructed, the accessibility functions can be computed. For example, we can compute $\alpha(p,\Omega,\eta,t,\zeta)$ of POI p after specifying the factors Ω,η,t,ζ, which is implemented by traversing the graph starting from node 3 with a breadth-first search algorithm. Fig. 1b shows that each graph node achieves its α value.

- **Define accessibility difference/similarity:** We then can compute the difference of the accessibility values between two neighboring graph nodes. Here the graph is converted to an undirected graph (since we no longer need the driving directions). The difference values define the edge weights between two neighboring nodes, which is depicted in Fig. 1c. For example, node 1 and node 3 has a difference of α values as 4, and so on. Indeed, in our system, each node can compute different α values with different factors (Ω,η,t,ζ). Two neighboring nodes can define their similarity (edge weight) by utilizing more than one α values. That is, users can choose to compute the similarity by a set of selected parameters, for example, by using accessibilities of both morning and afternoon times.

- **Cut graph into subgraph clusters:** A threshold β is defined so that the graph edge of Fig. 1c can be cut to form a set of subgraphs. As shown in Fig. 1c, we cut the two edges that has the difference values bigger than $\beta = 8$. Then two subgraphs (i.e. clusters) are generated in Fig. 1d.

- **Generate LACs:** Each subgraph cluster has a set of POIs leading to an LAC. Fig. 1d identifies two LACs where *LAC*1 includes POIs p,o,s,u,v,x,y,z and *LAC*2 consists of POIs r,n,w. These LACs also discover spatial regions having different accessibility patterns.

3.3. LAC Visualization

These LAC computation steps finally divide user selected original POIs (e.g., hotels) of the selected area of interest into a group of clusters each representing a sub-region. We find the boundaries of these regions and visualize them on the map within two steps:

- **Voronoi subdivision:** Given the original POIs in the city space, we apply a Voronoi subdivision method which partitions the 2D space into cells by using the locations of these POIs as Voronoi seeds. A Voronoi cell is a spatial region closer to one seed than to any other.

- **Voronoi cell merging:** We merge two neighboring Voronoi cells into one, if the two seed POIs belong to the same LAC. A recursive algorithm repeatedly merging such cells so that eventually, the remainder regions represent the LACs.

4. Visual System Framework

Fig. 2 illustrates our system framework of computing and visualizing LACs in an urban city. It consists of the following steps in pre-processing (red box) and interactive visual discovery (blue box):

- **Build POIGraphs:** We construct POIGraphs from urban road network and POI database, as well as the real-world traffic information over different times of different days. These graphs are stored and managed in a graph database.

- **Pre-Compute POI accessibilities:** The accessibility functions from each POI to a set of destination POI types with predefined factors (Ω,η,t,ζ) are pre-computed based on the POIGraphs by utilizing a graph traversal algorithm. These computations in the preprocessing stage can accelerate interactive visual study with fast response to users' choices of different accessibility factors.

- **Discover LACs:** When users select a city region and the preferred parameters (Ω,η,t,ζ) to find specific LACs. The graph-based clustering method is applied to partition the graph into multiple spatial LACs. Here users can adjust the threshold β for different LACs. The LACs are visualized by the Voronoi-based method to show the regions on map that can reflect hidden urban accessibility patterns.

- **Interactively visualize LACs:** The LACs are interactively manipulated by users for studying their preferred accessibilities of different categories in different time periods.

5. Case Study

Our visualization system is used to discover LACs in downtown of Hangzhou city, China. We collected 247,642 POIs grouped into 18 categories including real estate, shopping, education, etc. Traffic information were computed from one month taxi trajectory data in the city. In Fig. 3, hotels are selected as seeds and tourist attractions
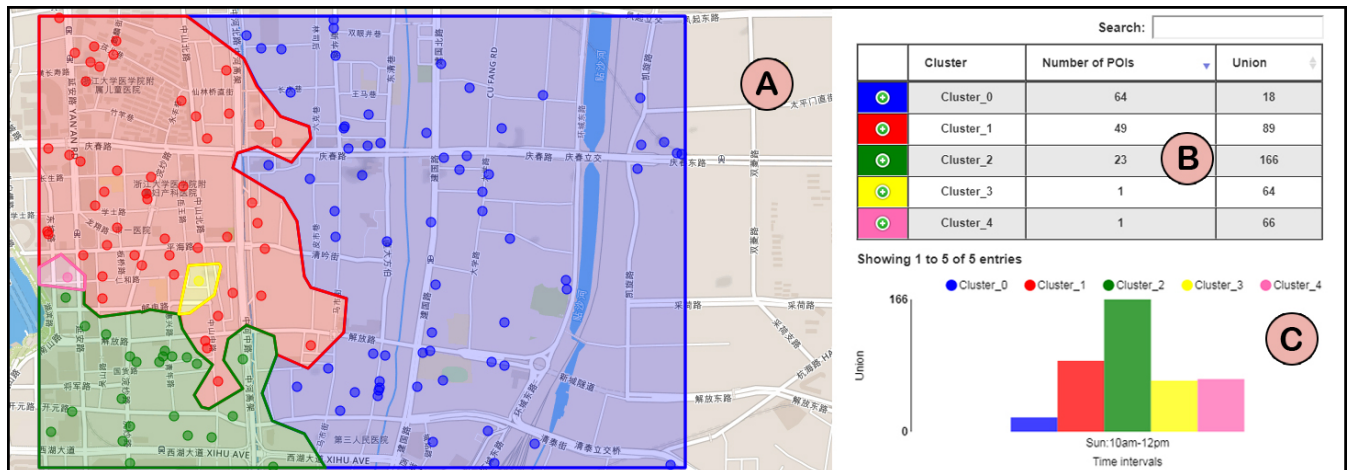
Figure 3: *Case study: Clustering hotels based on their accessibility to tourist attraction places. Five LACs are detected with different numbers of hotels as blue:64, red:49, green:23, and yellow:1, pink:1. They can reach different number of tourism attractions as blue:18, red:89, green:166, yellow: 64 and pink: 66. (A) Map view; (B) LAC details with the numbers of seed POIs and reachable POIs; (C) Chart of reachable POIs. Users can interact on the map to see POI details.*
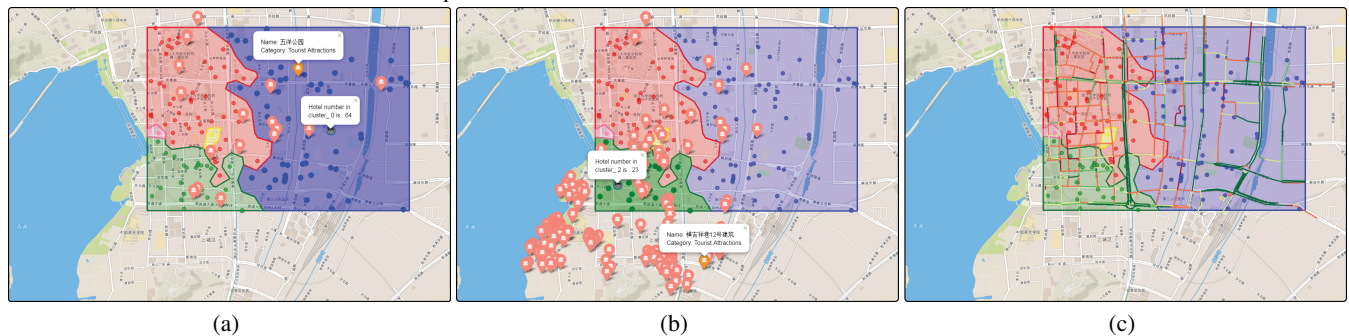

Figure 4: *(a) Reachable tourist attraction places from the blue LAC (cluster_0); (b) Reachable tourist attraction places from the green LAC (cluster_2) which are far more than the blue one; (b) Traffic speed on roads.*

as destination POIs. 5 minutes accessibility by driving is studied on Sundays at 10am-12pm. Fig. 3A reveals five LACs drawn on the map as five colored regions. As shown in Fig. 3B, they have different numbers of hotels as blue:64, red:49, green:23, and yellow:1, pink:1. They can reach different number of tourism attractions as blue:18, red:89, green:166, yellow: 64 and pink: 66. Fig. 3C shows a bar chart to indicate that the green area hotels can reach more attractions than others. Here for each cluster, union operation is applied to find out the number of all tourist attraction places that can be reached from either one of the hotels. Users can also show only those attractions can be reached by all of them. Analyzed by several local Hangzhou residents, the green area can reach more attractions because: First, there are more tourist attraction POIs near the lake and close to the green area, while the blue region is far away; Second, the fast traffic situation is in the green area, compared with the blue one as shown in Fig. 4C, where colors from red to green shows traffic speed of each road segment. Red means slow traffic speed and green represents fast speed. Moreover, Fig. 3A depicts two outlier LACs (yellow and pink regions). Each one has only one hotel. Though they are near the lake, they can reach fewer tourist attractions than the green and red LACs. By analyzing traffic around them, it can be found that the slow traffic situation hinders their accessibility to other POIs.

6. Experts Feedback, Limitation and Conclusion

We have interviewed with a group of 12 domain experts in the areas of geography, GIS, transportation, and urban study to evaluate our system. After using the system, they all agreed that the system is easy to use and useful for understanding the distribution of the regional accessibility. We will conduct a formal user study to evaluate the system. The experts also provide feedback on the system limitations and suggestions. The limitations are: (1) Some of the clustering parameters are complex to adjust. (2) The system relies on accurate traffic information which may not be available in small streets. (3) Mixed access mode integrating walking, public transit, and vehicle are not directly supported. (4) Multi-criteria assessment (e.g., in computing α) needs to be included. These limitations will be improved in future work. In summary, we have developed a new visualization tool for users to identify and study urban sub-regions of different accessibility patterns. It will be further improved by integrating domain users feedback and suggestions.

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