Urban Perception Extraction from Texts Shared on Social Media: Framework and Applications

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ABSTRACT

In this Ph.D. thesis, we proposed an automatic and generic framework composed of 5 major layers (Data Collection, Preprocessing and Embeddings, Models Training, Knowledge Extraction, and Applications) to extract the user's urban perception from Location-Based Social Network (LBSN) data. The framework employs advanced deep learning algorithms, including sentence embeddings, to capture lexical and semantic relationships in textual data and, thus, effectively extract content related to urban perceptions from LBSNs. Moreover, this framework circumvents the need for labor-intensive field surveys or manual extraction processes, enabling scalable and real-time analysis of urban perception. Studying some urban areas from Chicago, New York City, and London, we demonstrate the framework's effectiveness in extracting valuable insights related to urban perceptions from LBSN data. Furthermore, we conducted a comparative evaluation using a public dataset derived from volunteers' perceptions in a controlled experiment, where it was possible to observe that both results yielded a very similar level of agreement. Finally, we introduce a novel tool called Real-Estate Urban Perceptions (REAL-UP), which aims to enhance the real-estate marketplace as a proof-of-concept for our work. REAL-UP provides rich knowledge regarding urban areas in the form of interactive 2D maps, more specifically, the emotion and sentiment perceived, and a short review generated by a Large Language Model (LLM) based on LBSN messages, for every city's neighborhood, in addition to information commonly provided by such applications, as rent price, property type, and so on.

KEYWORDS

Sentence Embeddings, NLP, LBSN, Real-Estate Marketplace

1 INTRODUCTION

1.1 Problem Description and Motivation

Cities are not merely collections of buildings, streets, and residents but are also places where individuals have diverse experiences. The visual quality of urban areas, crime rates, and noise levels influence people's perceptions of these areas. Touristic spots, for example, might be valued by tourists but avoided by residents during daily routines. Human perception is a complex process influenced by various factors, including culture and age, and involves interpreting sensory impressions to give meaning to environments. This study focuses on "urban perception," particularly regarding outdoor areas like parks, streets, and plazas. These areas can evoke different responses and behaviors, impacting health and crime. Capturing urban perception, however, poses challenges, particularly in gathering extensive data.

Traditional methods like field surveys and sensory walks are time-consuming and labor-intensive. Consequently, some researchers use crowdsourcing systems to gather urban perception data, though maintaining volunteer participation is challenging. Location-Based Social Networks (LBSNs) provide valuable urban perception data due to their extensive user base, offering insights into various urban aspects such as safety, traffic, and aesthetics. However, extracting useful information from the vast and varied content on LBSNs is complex. Most studies focus on one format of urban perception data from LBSNs, predominantly text. Methods range from simple keyword extraction, which can result in false positives, to more sophisticated approaches like topic modeling. These methods face challenges due to the brevity and density of social media texts.

This study introduces a framework combining Deep Learning algorithms to extract urban perceptions from LBSN data, utilizing sentence embeddings for powerful text representations. This framework captures multiple perceptions, such as sentiments and emotions, without requiring extensive field surveys. To demonstrate the practical applications of understanding urban perceptions, the study presents Real-Estate Urban Perceptions (REAL-UP), a novel tool enhancing the real-estate marketplace by incorporating urban perceptions. To the best of our knowledge, REAL-UP is the first tool to utilize users' urban perceptions to improve real estate market tools.

1.2 Adherence to Webmedia

This thesis focused on urban perception extraction from natural language texts, which combines two broad research areas: *Urban Computing*: helps the understanding of the intrinsic characteristics of urban areas in a scalable way and helps to leverage new services; and, *Natural Language Processing (NLP)*: among the possible types of media present in social media data (text, audio, image, etc), texts written in natural language stand out in social media data, once they are widely available in most of them. Such areas are very related to many topics of interest in Webmedia: (i) Crowdsourcing and Crowdsensing; (ii) AI, Machine Learning, and Deep Learning; (iii) Natural Language Processing; and (iv) Social Networks and Social Media. Evidence of the strong adherence to Webmeda, as described in the by-products of the work, a part of this thesis was presented as a short course in Webmedia 2022.

In: VI Concurso de Teses e Dissertações (CTD 2024). Anais Estendidos do XXX Simpósio Brasileiro de Sistemas Multimídia e Web (CTD'2024). Juiz de Fora/MG, Brazil. Porto Alegre: Brazilian Computer Society, 2024.

ISSN 2596-1683

2 METHODOLOGY

2.1 Objective

The main objective of this thesis is to extract useful urban perceptions using public social media content to help better understand urban areas and leverage new services and applications. With this, some key questions arise: **Research Question 1:** How can we extract urban perceptions from natural language texts shared by people on social media? **Research Question 2:** What is the level of agreement among extracted perceptions with respect to a "ground truth"? **Research Question 3:** How can we combine multiple layers of perception to obtain unified knowledge regarding urban areas? **Research Question 4:** How can urban perception be exploited to leverage new services and applications?

2.2 Framework

Our framework consists of five major layers and takes advantage of multiple online data sources to uncover people's perception of latent aspects of urban areas, giving interesting insights about the intrinsic characteristics of these areas to leverage or improve smart services and applications. An essential step of our framework is to construct a dictionary, namely UOP-dictionary, which organizes the main descriptive words (i.e., adjectives) used by people to qualify their experiences in urban outdoor areas of cities. For that, our approach to giving a tag from UOP-dictionary to text messages has a great advantage compared to others, as it does not require that the text messages have the same adjectives that form the UOP-dictionary, which is a clear disadvantage of previous works. Instead, we compare the similarity between embeddings to define the proper tag. In this way, our approach is more robust since people might choose words that do not belong to UOP-dictionary vocabulary, but our approach will still return relevant results. Another crucial part of our framework is the *Semantic Filtering and Tagging*, responsible for performing the subject classification and attributing a semantic tag for each tweet, which informs the sentiment, emotion, the existing entities, and the category from UOP-dictionary, which can be used to enrich our knowledge about the urban areas.

2.3 Experiments and Evaluation

A set of experiments to evaluate the extracted perceptions of different urban outdoor areas. We have used a Twitter dataset to demonstrate the potential of our framework to uncover the urban perceptions of outdoor spaces that emerge from LBSNs. Studying some urban areas from Chicago, New York City, and London, we demonstrate the framework's effectiveness in extracting valuable insights related to urban perceptions from LBSN data. We contrasted our results with Place Pulse 2.0, a controlled experiment expressing volunteers' perceptions in different urban outdoor areas [1] (experiment authorized, using Amazon Mechanical Turk). We observe that our approach yields results very similar to those shown by Place Pulse 2.0.

2.4 Application

The real estate marketplace has been providing websites and apps for people to consult detailed property information, such as price, parking spaces, description of rooms, photos, etc. However, this market still does not explore other relevant information about the property's surrounding area. To address this gap, we propose REAL-UP, an interactive tool designed to enrich real-estate marketplaces. In addition to information commonly provided by such applications, e.g., rent price, REAL-UP also provides subjective neighborhood information based on Location-Based Social Networks (LBSNs) messages. This novel tool helps to represent complex users' subjective perceptions of urban areas, which could ease the process of finding the best accommodation.

3 MAIN RESULTS

In this thesis, we presented a novel framework to support the learning and mapping of the perception of urban outdoor areas from an extensive collection of noisy data expressing users' opinions in LBSNs. Our results suggest that it is possible to identify perceptions reflected in urban areas in a scalable way. This is useful for supporting mechanisms to help people better understand the semantics in different city regions. Initially, we explored a vast amount of social media data to discover which subjects we could find on it. Based on the well-known unsupervised clustering algorithm K-means, we could find 17 main subjects in the Twitter data, among them the "Urban Perception" subject. Then, our framework combines sentiment and emotion analyses with the UOP-dictionary, enabling us to extract multiple aspects of perceptions of urban areas.

4 MAIN CONTRIBUTIONS

In total, **nine** peer-reviewed publications were produced to share the results obtained from this work over the doctorate program in relevant conferences and a prestigious journal in the Computer Science field, in particular, on tracks such as social network analysis and mining. In specific, one journal article (SNAM - A2), six conference papers (WWW - A1; two works in ICC - A1; WI-IAT - A3; SBRC - A4; WGRS-SBRC – Best Paper Award – B4), and two book chapters (WebMedia - A4; SBRC - A4). Other **two** works were developed in collaboration with our research group (VTC - A1; ICSC - A3). Besides the publications, parts of this thesis were conducted in collaboration with Prof. Dr. Azzedine Boukerche at SITE (School of Information Technology and Engineering), University of Ottawa, Canada, as part of the Sandwich Doctorate Program (PDSE/CAPES), and with Prof. Dr. Richard Pazzi at Ontario Tech University, Canada, as visiting research financial supported by Global Affairs Canada, via Emerging Leader in the Americas Program (ELAP).

Acknowledgment. This thesis was partly supported by the project SocialNet (grant 2023/00148-0 from Sao Paulo Research Foundation - FAPESP), CNPq (process 314603/2023-9 and 441444/2023-7), CAPES (process 88881.132016/2016-01), and by the Ministry of Science, Technology, and Innovation of Brazil, with resources granted by the Federal Law 8.248 of October 23, 1991, under the PPI-Softex. The project was coordinated by Softex and published as Intelligent agents for mobile platforms based on Cognitive Architecture technology [01245.013778/2020-21].

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