

UNIVERSITY OF LIVERPOOL

DOCTORAL THESIS

Exploring Place from the Perspective of Informal Social Media Text

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*A thesis submitted in fulfillment of the requirements
for the degree of Doctor of Philosophy*

in the

Geographic Data Science Lab
Department of Geography and Planning

Declaration of Authorship

I, Cillian Berragan, declare that this thesis titled, Exploring Place from the Perspective of Informal Social Media Text and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
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UNIVERSITY OF LIVERPOOL

Abstract

Geographic Data Science Lab

Department of Geography and Planning

Doctor of Philosophy

Exploring Place from the Perspective of Informal Social Media Text

by Cillian Berragan

The proliferation of social media platforms has given rise to a new form of geographic knowledge, where places are no longer only physically grounded, but also digitally manifested through informal communication. The way locations are described on these platforms embeds the informal geographic knowledge that individuals use to form their notion of place, which has been traditionally constrained within the subconscious of individuals, conceptualised through active participation methods through surveys, mapping exercises, or volunteered geographic information. Instead, communication between users on these platforms generates this place-based knowledge in a more comprehensive and larger volume than previously possible, generating insights into how broader populations experience, interpret and construct the notion of ‘place’.

Despite the abundance of natural language text on these social media platforms, much emphasis has been placed on the explicit geographic markers in these data, that primarily exist as geotags. Place-based research that considers social media data therefore typically focusses on the generation of vague semantic regions, where geotagged locations often do not directly correlate with formal administrative definitions. While these works give insight into the place-based knowledge that social media users contribute, there is a greater depth of knowledge that may be directly harvested through the informal text that is abundant on these platforms. In this thesis, I acknowledge that this textual content also possesses an inherent geographic dimension that can be harnessed, by attributing geographic coordinate information to embedded place names. This approach not only enables a substantially larger volume of place-related knowledge to be captured but also facilitates the extraction of embedded semantic information relating to geographic locations, contributed through the informal vernacular geography of social media users.

Moving beyond methods to only consider the geographic component of geotags associated with informal social media communications, this thesis first proposes improvements to geoparsing methods, that enable geographic information to be attributed with place names

embedded within natural language text. Geoparsing allows for specific geographic coordinate information to be attributed with this unstructured social media text, capturing informal vernacular geographic information through the associated semantic context of identified locations. With this established, this thesis considers how a large source of UK-specific informal text from the social media website Reddit may be analysed geographically to directly capture this knowledge. Comments are first explored from the perspective of mental maps, where the perceived cognitive associations between locations within the UK demonstrate varying levels of distance decay. Following this, this thesis explores how semantic associations with locational mentions may be captured through embeddings generated through a large language model; referred to as their semantic footprints. These footprints are demonstrated to exhibit geographically cohesive variation, and spatial autocorrelation which is broadly associated with formal national boundaries of the UK.

This thesis aims to explore how place-based geographic knowledge can be captured from informal social media text. The methodologies developed allow for place to be represented from a perspective not considered previously, utilising the depth of semantic information that accompanies place names embedded within informal communication. Results generated demonstrate that geographic information extracted from text does broadly conform with established geographic concepts, but with deviations that would be expected with informal place-based knowledge. The overall strength of cognitive associations between locations identified in our corpus was found to be inversely proportional to the distance between them, a distance decay effect that is commonly observed in real-world geographic environments. However, this effect was highly regional, weaker between cities where cultural associations are stronger and where perceived distance may be shorter compared with reality. Similarly, semantic information associated with locational mentions in this corpus exhibits spatial heterogeneity, but with distinct geographically cohesive clusters, particularly within Wales, Scotland and London.

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Publications

This thesis comprises three empirical chapters, which have been published or submitted for publication as regular research papers in reputable journals. A number of additional projects have taken place during this PhD, resulting in additional research outcomes listed below.

Thesis Publications

- Chapter 3: Berragan, C., Singleton, A., Calafiore, A. & Morley, J. (2022) 'Transformer based named entity recognition for place name extraction from unstructured text', *International Journal of Geographical Information Science*, 37(4), pp.747-766. doi:10.1080/13658816.2022.2133125.
- Chapter 4: Berragan, C., Singleton, A., Calafiore, A. & Morley, J. 'Mapping Cognitive Place Associations within the United Kingdom through Online Discussion on Reddit', *Transactions of the Institute of British Geographers*, **Under Review**.
- Chapter 5: Berragan, C., Singleton, A., Calafiore, A. & Morley, J. 'Mapping Great Britain's Semantic Footprints through a Large Language Model Analysis of Reddit Comments', *Computers, Environment and Urban Systems*, **Under Review**.

Appendix Publications

- Ballantyne, P. and Berragan, C. (2023) 'Overture POI data for the United Kingdom: a comprehensive, queryable open data product', *arXiv preprint arXiv:2310.18415*. **Under review** at *Environment and Planning B: Urban Analytics and City Science*.

Talks

The following talks were delivered during the PhD supporting the direction of the project and providing peer feedback.

- Berragan, C., Singleton, A., Calafiore, A. and Morley, J. (2022) 'Geoparsing comments from Reddit to extract mental place connectivity within the United Kingdom', *Spatial Data Science Symposium 2022 Short Paper Proceedings*. doi:10.25436/E28C7R.

- Berragan, C., Singleton, A., Calafiore, A. and Morley, J. (2023) 'Evaluating the Similarity of Location-based Corpora Identified in Reddit Comments', *GeoExt 2023: First International Workshop on Geographic Information Extraction from Texts at ECIR 2023*. Available at: <https://ceur-ws.org/Vol-3385/paper1.pdf>.
- Berragan, C., Calafiore, A. (2022) 'Comparing rule-based methods and pre-trained language models to classify flood related Tweets', *30th GISRUK Conference 2022*. doi:10.5281/zenodo.6411499.

Code Repositories

The following code repositories contain the code and models used for the analysis in each empirical chapter.

- GitHub repository for Chapter 3. Available at <https://github.com/cjber/ger-wiki>.
- GitHub repository for Chapter 4. Available at <https://github.com/cjber/reddit-connectivity>.
- GitHub repository for Chapter 5. Available at <https://github.com/cjber/reddit-footprint>.
- Reddit NER for place name identification hosted on the Hugging Face model Hub. Available at https://huggingface.co/cjber/reddit-ner-place_names.
- GitHub repository for the Reddit NER model. Available at <https://github.com/cjber/reddit-model>.

List of Abbreviations

(bi)LSTM	(bidirectional) Long Short Term Memory
GIR	Geographic Information Retrieval
GISc	Geographic Information Science
GIS	Geographic Information System
LAD	Local Authority District
LLM	Large Language Model
NER	Named Entity Recognition
NLP	Natural Language Processing
OSM	Open Street Map
POI	Point Of Interest
RGN	Region (England)
RNN	Recurrent Neural Networks
SpRL	Spatial Role Labelling
VGI	Volunteered Geographic Information

Chapter 1

Introduction

The proliferation of social media platforms has given rise to a new form of geographic knowledge, where places are no longer only physically grounded, but also digitally manifested through informal communication. The way locations are described on these platforms embeds informal geographic knowledge that individuals use to form their notion of geographic ‘place’, which has been traditionally constrained within the subconscious of individuals, conceptualised through active participation methods through surveys, mapping exercises, or volunteered geographic information. Instead, communication between users on these platforms generates this place-based knowledge in a more comprehensive and larger volume than previously possible, generating insights into how broader populations experience, interpret and construct a sense of place.

While most research has primarily focussed on explicit geographic markers on these platforms through geotags, an alternative source of geographic knowledge resides within the accompanying informal natural language text, which exists in a much greater volume and complexity. This thesis proposes how the notion of place is captured through social media text, generating insights into a collective understanding of informal geography, built from an aggregate perspective, and generated through communication between a multitude of individuals.

1.1 Background

The concept of ‘place’ is fundamental in geography, allowing for the study of the relationship between people and their geographic environment. Place encompasses the cultural and social aspects that relate people with geographic locations, and the ways they interact and shape their environment (Cresswell, 2014). Unlike structured administrative datasets, place-focussed geographic information represents informal geographic knowledge, which more closely aligns with the way people perceive geography (Goodchild, 2011).

Foundational work conceptualised this knowledge through mental maps (Lynch, 1964), suggesting that people construct their cognitive representations of their geographic environment. These mental maps incorporate specific features like landmarks or borders and are

generated through physical interactions, perceptions, and interpretations of geographic environments. Importantly, these mental maps incorporate a variety of biases that often do not correlate with formal administrative definitions. For example, they may emphasise features that are considered important or the perceived distance between locations can be influenced by their transport connections.

Early attempts at the physical generation of these maps primarily relied on participatory mapping methodologies, where individuals were asked to sketch geographic features from memory (Lynch, 1964; Lee, 1973; Goodey, 1974; Pocock, 1976; Canter, 1977; Haney and Knowles, 1978; Murray and Spencer, 1979; Gould and White, 1986; Montello *et al.*, 2003). These however are limited in scope, given the reliance on individuals who are willing to actively participate, and the time taken to manually generate these maps. Additionally, it is difficult for individuals to conceptualise certain features of mental maps, meaning their scope was traditionally constrained to the formalisation of pre-existing geographic concepts, like the borders of vague regions. More abstract concepts like quantifying cultural similarities or the perceived distance between cities are more complex for individuals to externalise, despite many likely having subconscious opinions regarding these geographically related concepts.

More recently, works have made use of the abundance of informal communication through social media platforms, where grounded geographic information exists as a by-product of digital social interactions. Popular social media platforms like Twitter embed geographic information alongside microblog messages through geotags, which represent the location of a user at the time of communication. Many works theorise that, unlike geographic information obtained through pre-existing and structured administrative data sources, geotags present a view of geography that more directly aligns with the concept of ‘place’ (Sui, 2009; Hollenstein and Purves, 2010; Sui and Goodchild, 2011; Goodchild, 2011; Purves, Edwardes and Wood, 2011; Cresswell, 2014; Quesnot and Roche, 2015; Wolter and Yousaf, 2018). While traditional formalisations of space are built ‘top-down’, meaning boundaries and names are generated primarily by government organisations (Agnew, 2005), these works note that place may be more accurately captured through a ‘bottom-up’ approach, built from the collective knowledge of individuals whose geographic knowledge is developed through experience, rather than formal definitions (Sui and Goodchild, 2011).

1.2 Research Gaps

While many works have considered the ability to capture informal and experiential geographic knowledge from social media, they typically only consider geotags as a geographic component. Few therefore have considered the ability to capture geographic knowledge from the natural language text associated with these social media platforms. This place-based knowledge is generated through ‘vernacular geography’, which describes the natural language used when informally describing geographic locations (Waters and Evans, 2003;

Hollenstein, 2008; Goodchild and Li, 2011; Gao, Janowicz, *et al.*, 2017). The ability to consider the vernacular geography of text in social media presents several benefits over geotags. First, geotags are not always a feature of social media platforms, and for platforms like Twitter, they are only present in a very low volume (Leetaru *et al.*, 2013). Text instead is a primary feature of social media, present in a much more abundant volume and passively generated through informal communication between users. Additionally, text itself arguably can more appropriately generate place-based knowledge; while geotags only provide single-coordinate information, the depth of semantic information available through text in theory presents a deeper connection with informal geographic knowledge.

Geographic information in text primarily exists as place names. These place names are often attributable to geographic locations in space and contribute informal geographic information when associated with informal communications between individuals on social media platforms. The task of attributing coordinate information with place names identified in unstructured text is typically known as geoparsing. Such methods are most frequently associated with information retrieval literature, where search results frequently need to consider whether a natural language query incorporates geographic information (Purves *et al.*, 2018). There has however been little focus on this task from the perspective of geographic research, despite there being a clear motivation to expand the volume of informal geographic information available for place-based research, to move beyond solely focussing on geotags.

Existing geoparsing systems are typically built with the consideration that querying is unrestricted in geographic scope, meaning all known place names on Earth are usually resolved, using a global gazetteer like GeoNames. Due to this, geoparsing models tend to primarily resolve place names no smaller than city level, meaning fine-grained locations like street names that frequently appear in natural language are ignored. When identifying place names, these models tend to build on existing natural language processing (NLP) research relating to Named Entity Recognition (NER), where place names are not the primary focus, meaning performance is limited. Finally, the corpora used to train NER models are built with more structured language in mind, meaning they struggle with more informal text like social media.

Place names embedded within informal social media posts contribute informal geographic knowledge from individuals, which may be harvested to contribute to a place-based view of geography. First improvements to geoparsing methodologies are considered in Chapter 3, where a methodology is developed to ensure that a more accurate and comprehensive recall of place names may be extracted from informal social media. Once achieved, this task and data specific geoparsing system presents the opportunity to explore place-based geographic knowledge from an alternative form of social media data that few works have previously considered in detail, with empirical work undertaken in Chapter 4 and Chapter 5.

1.3 Aims

To address the research gaps outlined above, this thesis outlines three key aims, which form three empirical chapters. The first aim of this thesis describes the methods and theory required to accurately extract geographic knowledge from existing sources of informal natural language text. The second and third aim then build on this chapter and consider the ability to generate place-based geographic insights from extracted place names.

Aim 1: *Improve the results of existing geoparsing systems for place name recognition, and outline the potential for unstructured text to provide informal geographic knowledge.*

Chapter 3 addresses this aim by constructing a transformer-based NER model, trained using text with place names manually annotated. This chapter demonstrates that existing models for place names identification do not necessarily perform as well as advertised, primarily due to the lack of task-specific corpora used for training. The methodology presented in this chapter provides the basis for Chapter 4 and Chapter 5, by demonstrating that more accurate geoparsing results may be achieved through training a task and data specific NER model. Chapter 3 also demonstrates that existing sources of online text may be harvested for place names, which augments them with a geographic component that has not been considered in detail in past research. Notably, these place names are often associated with vernacular geography, meaning many are colloquial, or informal, and do not exist within formal gazetteers.

The content of this chapter can be found in the following published journal article:

Berragan, C., Singleton, A., Calafiore, A. & Morley, J. (2023) ‘Transformer based named entity recognition for place name extraction from unstructured text’, *International Journal of Geographical Information Science*, 37(4), pp.747-766. doi:10.1080/13658816.2022.2133125

Aim 2: *Generate insights into place-based cognitive associations between locations, through the analysis of locations geoparsed from informal social media text.*

Chapter 4 utilises the methodology outlined in Chapter 3 to extract place names from a large corpus of social media text from the popular website Reddit, and develops a methodology to associate place names with coordinate information. This chapter then considers the ability to generate place-based cognitive associations between these geoparsed locations, captured through the mental maps of individuals that contributed to the corpus. Associations are built through co-occurring locational mentions, which used to generate a quantifiable measure of association strength. This strength is then assessed with respect to distance decay, to identify whether these associations capture cohesive geographic properties. This chapter demonstrates that social media text does capture a geographic component that appears to strongly correlate with place-based knowledge, but with interesting deviations.

The content of this chapter is *under review* for publication in *Transactions of the Institute of British Geographers*.

Aim 3: *Examine the geographic variation in the semantic properties of text associated with place names extracted from social media.*

Chapter 5 builds on the previous chapter and considers the ability to specifically compare the vernacular geographies emerging from text data in a social media corpus, by analysing and comparing the semantic properties of text relating to locations. This chapter uses a transformer neural network language model to build contextual semantic embeddings for each comment that contains a place name, these were then used to generate an aggregate measure of local authorities across the UK, which we name semantic footprints. This measure demonstrated that the ‘semantic footprint’ of locations across the UK incorporates geographic properties, and can be used to highlight areas that are semantically isolated from the rest of the country.

The content of this chapter is currently *under review* for publication in *Computers, Environment and Urban Systems*.

Chapter 2

Literature Review

The following chapter outlines literature relating to the geographic concept of ‘place’ and its connection with natural language. A renewed interest in the quantitative analysis of place-based concepts has been driven by the large volume of data produced through social media platforms, which is hypothesised to more closely align with place-based geographies compared with traditional data sources. However, few works have considered the textual component of social media platforms, and its ability to generate informal vernacular geographic knowledge. Geographic analysis of social media networks typically focusses on explicit geographic markers which exist as geotags, and consider the associated text to be a by-product of communication between users, with little geographic value. Instead, this chapter outlines that natural language text from these social media instead presents the opportunity to capture a much greater volume of place-based geographic knowledge, which has not been previously considered in detail.

2.1 Introduction

Unlike structured knowledge regarding space, which is dictated by formal administrative definitions, with strict coordinate systems and boundaries, natural language instead contributes knowledge regarding place. Informal communication on social media platforms contributes naive vernacular geographic knowledge, embedded within rich semantic detail, far beyond the level captured by point coordinate geotags. Understanding how we can capture this knowledge and use it to generate insights into the geographic concept of place, opens up a substantial volume of data to be considered for research, which is directly embedded with rich place-based geographic knowledge.

New developments in natural language processing (NLP) have generated what are known as large language models (LLMs), which have enabled much deeper semantic representations of text to be generated. Such models produce what are known as embeddings, which act as detailed numerical representations of text, capturing contextual semantic information, beyond the capabilities of former semantic models like Word2Vec (Mikolov *et al.*, 2013). This thesis extensively utilises LLMs to produce analysis of social media text that incorporates as much semantic information as is currently possible, improving both the accuracy of the

identification of place names from text, to generate processed text data used throughout this thesis, and to capture deeper semantic associations between locational mentions in Chapter 5.

Geographic information in text primarily exists as place names, and all real-world place names are theoretically attributable to a location in space, which may be formally or informally defined. For example, in an informal written conversation, someone suggesting they live in ‘near Liverpool’ has a specific view of where ‘near’ refers to (Stock and Hall, 2018). Additional geographic information in text also appears through prepositions, where places may be geographically associated; for example, ‘Liverpool is near Manchester’ (Montello, 2003). Informal written language contributes the subconscious information that individuals use to form their perception of geography, unrestricted by any formal geographic model of space. Geographic information may then be derived from this text which reflects a view of geography that is more strongly associated with the everyday experience of individuals, and captures a sense of place.

The prevalence of social media data for use in geographic research has generated a renewed interest in the concept of place (Westerholt, Mocnik and Zipf, 2018; Purves, Winter and Kuhn, 2019; Wagner, Zipf and Westerholt, 2020), as contributions to social media are theorised to capture informal knowledge that represents a place-based understanding of geography (Goodchild and Li, 2011; Sui and Goodchild, 2011). In the context of language, this place-based knowledge is generated through ‘vernacular geography’, which describes the natural language used when informally describing geographic locations (Waters and Evans, 2003; Hollenstein, 2008; Goodchild and Li, 2011; Gao, Janowicz, *et al.*, 2017). This informal knowledge incorporates biases regarding locations, better representing human perceptions of geography, compared with formal administrative definitions. While many works have considered the formalisation of place through geotagged social media posts, few have considered how associated text may directly generate insights into the vernacular geography of individuals.

In contrast to geotagged locations on social media, place names mentioned directly in social media text arguably more appropriately capture the informal nature of place. Embedded within a broad semantic context, and forming informal associations built directly through vernacular geography, these place names contribute a wealth of detailed and informal geographic information, that isn’t available through geotags alone. The volume of associated data is also much greater when text can be considered, as many Tweets do not contain geotags (~99% of Tweets) (Leetaru *et al.*, 2013), and alternative social media websites do not always have geographic metadata.

2.1.1 Thesis Scope

The overarching goal of this thesis is to expand research relating to the extraction of place-based knowledge from informal natural language text. To achieve this, embedded places

names are extracted from a large corpus of comments from the social media website Reddit¹, using a task and data specific geoparsing methodology. Chapter 3 first outlines limitations of existing geoparsing systems with respect to this goal, and demonstrates the ability to build task specific Named Entity Recognition (NER) models for place name identification, greatly improving geoparsing performance. In Chapter 4 and Chapter 5 this methodology is then implemented, to extract geographic locations from these informal comments, methods are outlined for harvesting the place-based knowledge that accompanies these locational mentions.

Section 2.2 first outlines the geographic concept of place, how natural language is inherently connected with this concept, and highlights existing formalisations of place. Section 2.3 then outlines how geotagged social media data have been used to quantify place, before demonstrating that non-geotagged social media may provide an even richer depth of place-based geographic knowledge through associated natural language text. Section 2.4 then details methodologies that enable geographic information to be extracted from text, and how these methods may be improved for the goals of this thesis. Section 2.5 then concludes this chapter.

2.2 Natural Language and Place Theory

The majority of geographical research considers analysis from the perspective of space, where locational boundaries are represented by administrative definitions and strict coordinate systems. While clearly defined geographical units allow for easily quantifiable geographical analysis, it rarely conforms with how people informally understand their own geography. Instead, the geographic concept ‘place’ considers how people perceive and interact with their geographic environment, encompassing personal experiences of the physical characteristics of locations, as well as the social and personal connections formed with them (Canter, 1977; Cresswell, 2014). To build an understanding of a place, people generate cognitive representations of their known geographic environment, capturing vague but useful spatial information (Lukermann, 1961; Smirnov, 2016), which is shared through informal communication with others (Hollenstein, 2008).

2.2.1 Formalisations of Place

Many works conceptualise this informal understanding of geography through ‘mental maps’. These typically refer to the cognitive visualisation of a geographic environment, representing collective and experiential geographic knowledge, relating to both places, and the relationships between them (Gould and White, 1968; Kaplan, 1976; Pocock, 1976). Mental maps exhibit a variety of biases, for example, they are more detailed with respect to locations that we are familiar with, while others may be less detailed or even absent entirely (Gould and White, 1986). The scale and distance between features in mental maps are warped (Peake and Moore, 2004); prominent roads may appear larger than in reality,

¹www.reddit.com

skyline features in a city may be perceived as less prominent due to their irrelevance to an individual at street level (Lynch, 1964; Gould and White, 1986), and good transport connections narrow the time it takes to reach connected locations, which in turn reduces the perceived distance between them (Massey, 2008). Intermediate features along common routes also have varying levels of importance to individuals; unimportant features may appear less prominent than in reality or absent altogether (Carr and Schissler, 1969; Kaplan, 1976).

The characterisation of mental maps has been well studied from a qualitative perspective, often featuring individual participation for the physical construction of hand-drawn sketches (Lynch, 1964; Lee, 1973; Goodey, 1974; Pocock, 1976; Canter, 1977; Haney and Knowles, 1978; Murray and Spencer, 1979; Gould and White, 1986; Montello *et al.*, 2003). Such approaches typically consider more localised areas that are familiar to selected participants (Pocock, 1976; Canter, 1977; Haney and Knowles, 1978), for example, mapping landmarks and regions within cities. Others have considered the broad characterisation of larger regions like entire countries (Gould and White, 1968; Goodey, 1974), where mental maps are less detailed, instead contributing generalised information regarding areas that are deemed important to the participant. Inherently, these techniques capture subjective information from individuals, which may not necessarily conform with a general collective knowledge of these geographic locations.

Informal communication contributes the information used to build these mental maps through ‘vernacular geography’ (Egenhofer and Mark, 1995), where places are described using imprecise referents, non-administrative names, and an understanding of footprints that do not conform with the formal administrative boundaries given to them (Goodchild and Li, 2011; Gao, Janowicz, *et al.*, 2017). There is therefore a clear link between informal written communication relating to geographic locations and the knowledge used to form the mental maps that encapsulate place-based geographic knowledge.

2.3 Quantifying Place

In attempts to quantify place, many works consider the ability to capture the informal footprints of landmarks that appear on mental maps, which are often named ‘cognitive regions’ (Montello, Friedman and Phillips, 2014). Like all components of mental maps, these cognitive regions form through experience and interaction with geographic environments (Montello, Friedman and Phillips, 2014). These vague regions vary between populations and individuals, generating perceptions of regions that do not agree with formal administrative definitions, or even intrinsic spatial concepts. For example, San Diego is perceived to be less part of Southern California than Los Angeles, despite being much further south, (Montello, Friedman and Phillips, 2014; Gao, Janowicz, *et al.*, 2017).

Early attempts to quantify these vague cognitive regions utilised participatory mapping exercises. For example, members of the public have been asked to delineate the area of a city they consider to be ‘downtown’ (Montello *et al.*, 2003). Other works have considered the

ability to use place names themselves to use topographic features to delineate place boundaries (Fisher, Wood and Cheng, 2004), or use web harvesting queries (Pasley, Clough and Sanderson, 2007). For example, the search engine query ‘Midwest cities such as’ returns a list of cities perceived to be within the vague Midwest region of the United States (Aramatzis *et al.*, 2006). In an early approach using unstructured text, the ‘Southwest’ in America was delineated using descriptions in publications, which were manually interpreted to identify locations internal or external to this vague region (Byrkit, 1992).

While early approaches considered individual participation through mapping exercises to generate cognitive regions and mental maps, alternative forms of data have generated a renewed interest in the study of place. Large volumes of *easily accessible*² social media data are now available that have strong associations with informal knowledge that reflects a place-based understanding of geography (Goodchild and Li, 2011). In a systematic literature review of place-based GIScience research, Wagner, Zipf and Westerholt (2020) note that place-based research is indeed increasing in popularity, which conforms with observations in other works (Westerholt, Mocnik and Zipf, 2018; Purves, Winter and Kuhn, 2019). Results show that the majority of studies use online geotagged social media data, and unlike in early research, qualitative mapping exercises are less common.

2.3.1 Capturing Place-based Knowledge through Alternative Forms of Data

With user generated, geographically referenced content through social media, mapping platforms and Wikipedia there is now a wealth of information that Goodchild (2007) terms ‘Volunteered Geographic Information’ (VGI). These data sources present a large collection of continually updated, informal references to places, providing insight into the vernacular geography and mental maps that derive from the sense of place. Unlike past work that considered active survey and participatory mapping exercises with limited participants, this data enables mental maps and vernacular geography to be studied in a much larger and comprehensive volume.

These data sources come in broadly two forms:

1. Spatially-explicit; GeoNames, and collaborative mapping platforms OpenStreetMap (OSM) and Wikimapia which embed the locational information as an attribute alongside other information.
2. Spatially-implicit; geotagged Tweets posted on Twitter, or photographs from Flickr, where the locational information is secondary to the communication between users (Antoniou, Morley and Haklay, 2010)

²During the write-up of this thesis, the Twitter API was restructured to remove all free academic access. This change prompted a similar decision to substantially restrict the free Reddit API. As a result, it is now debatable how easily accessible these data are. Despite this, this thesis is written with this footnote as a caveat, and future mentions will treat these data as open.

Collaborative mapping platforms like OSM and Wikimapia allow users to directly input geographic coordinates and place names onto a base map. In these cases, volunteers contribute geographic features, which may include vernacular geography as colloquial names through polygon boundaries and point locations (Leidner and Lieberman, 2011; Sui and Goodchild, 2011; Gao, Li, *et al.*, 2017). OSM for example contains neighbourhood names in London contributed by users, many of which are not formal administrative names (Clasper, 2018). OSM however, is curated in a way that closely follows a spatial view of mapping, focussing on vector information and single points for named places. Wikimapia differs from this, in that the place information is derived mainly from user contributed bounding boxes, includes descriptive information, images, and notably encourages a more place-based view of mapping. For this reason Ballatore and Jokar Arsanjani (2019) suggest that Wikimapia appears more suitable for information retrieval and search tasks where natural language is used, despite its decline in popularity and limited mention in research. However, unlike OSM, Wikimapia data is only accessible through a limited API. In a sense, these mapping platforms act as informal gazetteers, providing user contributed geographic information that isn't collated from administrative datasets.

Alternatively, spatially-implicit data sources can be seen to contribute place-based locations rather than space-based, as results derived from them represent the cognitive perceptions of place which do not necessarily correlate with any formal definitions (Sui, 2009; Hollenstein and Purves, 2010; Sui and Goodchild, 2011; Goodchild, 2011; Purves, Edwardes and Wood, 2011; Cresswell, 2014; Quesnot and Roche, 2015; Wolter and Yousaf, 2018)³. While traditional formalisations of space can be considered 'top-down', as boundaries and names generated primarily by government organisations (Agnew, 2005), formalising place is more appropriate through a 'bottom-up' approach, built from the collective knowledge that individuals contribute on these social media whose geographic knowledge is developed through experience (Sui and Goodchild, 2011).

A multitude of works have built on this ability to conceptualise place using implicit VGI (Wagner, Zipf and Westerholt, 2020), augmenting traditional gazetteers with place-based information (Goodchild and Li, 2011; Gao *et al.*, 2013; Quesnot and Roche, 2015; Gao, Janowicz and Couclelis, 2017), generating vague place-based footprints relating to landmarks and locations (McKenzie and Adams, 2017; Gao, Janowicz, *et al.*, 2017; Westerholt *et al.*, 2018; Jang and Kim, 2019; Twaroch *et al.*, 2019), or examining informal perspectives regarding locations (Solymosi *et al.*, 2021). Notably, the results derived from the generation of vague footprints appeared to largely agree with mapping exercises and questionnaires (Gao, Janowicz, *et al.*, 2017; Twaroch *et al.*, 2019).

³It is worth noting that the concept of VGI may not directly align with spatially-implicit sources, given they are not 'volunteered' (Purves, Edwardes and Wood, 2011). In this thesis however, I do consider spatially-implicit sources of user-generated content as a form of VGI, given this is a common observation in literature, and allows for a distinction between normal user-generated content, and those that contain a geographic element. Arguably, the content itself is volunteered, and geographic elements like geotags are often opt-in features of these social media.

The geographic component in these works almost always comes from ‘geotags’, where geographic metadata as a single coordinate pair is associated with a single social media post. This reliance on geotags limits the data available, on Twitter for example, they are only present in around 1-2% of Tweets (Leetaru *et al.*, 2013). Additionally, while specific coordinate information may be obtained from geotags with an apparent degree of accuracy, coordinates often do not truly reflect the vague nature of the content they are associated with. A person may perceive themselves as being at a particular location that they have cognitively defined, but when geotagging their location, the tag resolves to the formal administrative location (Quesnot and Roche, 2015). A similar issue was observed by Kropczynski *et al.* (2018) who note that Tweets that describe an incident in emergency situations frequently have a geotag that does not reflect the location being described. This reflects a broader problem with geotags; the content of Tweets does not necessarily relate to the geotagged location.

There are also a multitude of demographic biases to consider with social media platforms and user-generated content. Contributions to Wikipedia and Tweeting frequency are both influenced by demographic factors (Hecht and Stephens, 2014; Ballatore and De Sabbata, 2018, 2020), population density (Mullen *et al.*, 2015; Graham, Straumann and Hogan, 2015; Ballatore and De Sabbata, 2020), and urban areas have better coverage than rural ones (Hecht and Stephens, 2014; Ballatore and De Sabbata, 2020). Similar biases also appear in OSM and the GeoNames gazetteer (Jackson *et al.*, 2013; Graham, Straumann and Hogan, 2015). At a national level, these issues are likely attributable to the ad-hoc nature of VGI; volunteers contribute what they want, favouring well known and high population areas, without consideration of scientific sampling methods (Zhang and Zhu, 2018). Collaborative mapping platforms also suffer from few users contributing the majority of additions (Ballatore and Jokar Arsanjani, 2019), meaning that any research derived from them does not necessarily capture the perspective of a population. Text and image based (spatially-implicit) VGI like Twitter and Flickr do however suffer higher quality concerns in comparison with collaborative mapping platforms, in terms of the reliability of the data (Senaratne *et al.*, 2017), but with an overall much larger volume of contributions.

2.3.2 Text-based Volunteered Geographic Information

While much of this current place-based research focusses on select geotagged social media, and examines place through the generation of vague boundaries relating to vernacular place names, place may be conceptualised in many ways. This thesis instead considers how language itself can be examined to distil and quantify place-based knowledge, voluntarily expressed through informal text as direct communication between social media users. Potential formalisations of place generated from text move beyond just the generation of feature footprints within mental maps, opening up the opportunity to conceptualise and quantify alternative perceptions of geography, built directly from vernacular knowledge derived from these informal textual communications.

Past work that has considered the geographic properties of text is limited, however an early example delineated the American ‘Southwest’, a vague vernacular place name, by

identifying mentions in natural language text descriptions of associated locations (Byrkit, 1992). Place names have been automatically extracted from housing advertisements, identifying unknown informal place names, with vague boundaries delineated using co-occurring names (Hu, Mao and McKenzie, 2019). Hiking descriptions also provide frequently occurring place names that are fine-grained and often absent from existing gazetteers (Moncla *et al.*, 2014; Palacio, Derungs and Purves, 2015), while text posts on Twitter and FourSquare contribute fine-grained place names (Li and Sun, 2014; Han *et al.*, 2018), which are useful during emergency events (Grace, 2020). Automatically extracting place names from text-based VGI removes the requirement of empirical data collection regarding fine-grained or informal place names, which is both time-consuming and difficult to scale (Vasardani, Winter and Richter, 2013). Additionally, while geotags do provide quantifiable geographic information that may be used to derive vague cognitive footprints, they are limited compared to the depth of information theoretically contributed through unstructured semantic knowledge in text.

Twitter is by far the most popular social media website used in research, due to the accessible API, large data volume, and geotagged posts. The use of geotagged Tweets for text-focussed place-based research however presents several issues:

1. **Broad Topics;** even when Tweets are geotagged, their content is may be unrelated to the location geotagged.
2. **Limited context;** Tweets are very restrictive in character count, meaning their context is limited.
3. **Informal language;** While all language on social media is more informal compared with alternative text sources like news articles, the language on Twitter more frequently contains abbreviations and misspellings, particularly due to the limited number of characters.

Given the content of Tweets is often unrelated to the geotagged location, any semantic information extracted from Tweets cannot be directly associated with geography. As a result of this, many works that have considered geographic variations within the textual content of Tweets to be attributable to dialects (Russ, 2012; Han, Cook and Baldwin, 2012; Doyle, 2014; Gonçalves and Sánchez, 2014; Eisenstein *et al.*, 2014; Huang *et al.*, 2016; Zheng, Han and Sun, 2018; Arthur and Williams, 2019). This works under the assumption that Tweet authors are residents at the geotagged location.

With the ability to accurately geoparse locations from text, locations can be extracted that are embedded directly within a related semantic context. Instead of just dialects, this context presents a broad range of topics relating to locations, built from the mental associations of contributing authors, incorporating cultural information, and capturing cognitive biases. Importantly, this also means that any form of text may contain a geographic component, shifting the reliance away from solely using geotagged social media data.

Unlike the microblogging website Twitter, Reddit is a forum-based social media platform, encouraging open discussion regarding a range of topics in dedicated sub-forums called

subreddits. Subreddits are created and moderated by volunteers, meaning they cover a multitude and range of subjects. The use of Reddit comments for text-focussed place-based research comes with several benefits over alternative social media:

1. **Subreddits;** Reddit is split into individual ‘subreddits’ each with a specific topic of discussion, with many relating to locations across the UK. This limits the volume of noise in comments, as relevant subreddits can be targeted.
2. **Context;** Unlike Twitter, Reddit comments are much less restricted in character length, meaning they contain a greater semantic context, and are less likely to be filled with abbreviations.
3. **API;** There was a brief period following the Twitter API changes that Reddit still gave unrestricted access to data archives. This has since changed, but Reddit still provides a more open API with respect to the current Twitter policy.

The use of subreddits is a key driver in the ability to exclude noise from Reddit, that isn’t possible through alternative social media like Twitter. For example, the United Kingdom subreddit includes a list of smaller local British subreddits, ranging in scale from country level ([/r/England](#)), regional ([/r/thenorth](#), [/r/Teeside](#)), to cities ([/r/Manchester](#)) and small towns ([/r/Alnwick](#)). In total there are 213 subreddits that relate to ‘places’ within the United Kingdom⁴. By selecting these subreddits, all comments extracted relate to topics of discussion surrounding a range of locations across the UK, rather than general topics of discussion. A full archive of all comments from each subreddit is kept by the Pushshift Reddit archive (Baumgartner *et al.*, 2020)⁵.

Reddit however is underused in previous geographic research, primarily due to the complete lack of any accessible geographic component like geotags. This limitation was overcome in this thesis, by identifying place names and attributing coordinate information through a task-specific geoparsing methodology. The following section outlines geoparsing, and notes on the ability to build a model that targets the task of geoparsing for place-based research in social media.

2.4 Extracting Geographic Information from Text

The primary source of extractable geographic information in text exists as place names embedded within their surrounding semantic context. The primary method for associating geographic information with place names in unstructured text is known as ‘geoparsing’. In geoparsing systems, place names are first automatically identified in text, in a process called *toponym detection*, or *place name identification* (Stokes *et al.*, 2008; Leidner and Lieberman, 2011), then associated with geographic coordinates, in a stage generally known either as *geocoding*, *toponym disambiguation*, or *toponym resolution* (Leidner, 2008; Buscaldi and Paolo Rosso, 2008; Buscaldi and Paulo Rosso, 2008; Buscaldi, 2011; Gritta, 2019). In a typical geoparsing system, a Named Entity Recognition (NER) model first identifies any place

⁴https://www.reddit.com/r/unitedkingdom/wiki/british_subreddits

⁵Due to the Reddit API changes, this archive is now only available to Reddit moderators.

names in text, which are then resolved to their most likely coordinate using the document context, and a gazetteer (Purves *et al.*, 2018). Figure 2.1 gives an overview of this process.

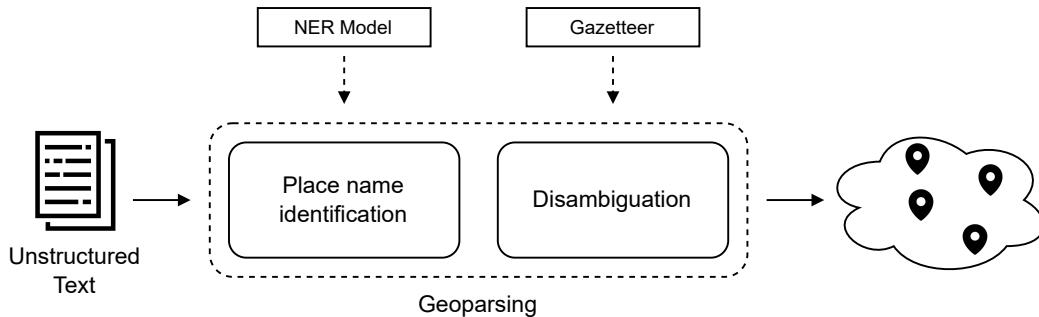


FIGURE 2.1: Overview of an example geoparsing methodology.

The terminology with respect to geoparsing systems often differs between different disciplines, for example geocoding in Geographic Information Retrieval (GIR) research is confusingly known as ‘geoparsing’ (Moncla *et al.*, 2014; Purves *et al.*, 2018). In this chapter I have therefore made the decision to avoid specialised terminology and instead use the following definitions. Geoparsing systems are split into two stages;

1. **Place name identification;** A technique is used to identify unique spans of text that contain a place name.
2. **Geocoding;** Place names are associated with coordinate information.

Once associated with coordinates, these are no longer solely place names, but ‘locations’ with an associated place name. I therefore avoid the usage of ‘toponyms’, which is a synonym of ‘place names’.

While geoparsing is widely used, especially in the context of querying and GIR research, there are key limitations of these systems when considering a focus on place-based knowledge extraction for this thesis. These issues may be broadly categorised into improvements to the two stages of geoparsing systems;

1. *Improvements to place name identification*
 - **Task specific;** Models should be trained using an annotation scheme that properly considers place names.
 - **Data specific;** Model should be trained on data relating to the specific task.
 - **Recognise non-locations in context;** Metonyms for example are common in social media text, e.g. Sporting teams named after cities, and may be identified by more complex models.
2. *Improvements to geocoding*
 - **Fine-grained locations;** Gazetteers exclude many fine-grained locations, and geoparsing systems usually only consider place names down to city level.
 - **Data representations;** Gazetteers only represent locations as single coordinate pairs, regardless of scale.

- **Relationships;** Locations are not considered in relation to each other, only as individual entities. Incorporating relationships between locations would assist in geocoding vague locations.

The following section first outlines how these two key stages are currently handled in existing geoparsing systems. The issues relating to these existing solutions are then outlined with respect to the goals of this thesis; extracting geographic place-based knowledge from unstructured social media text. recent developments in natural language processing are then highlighted, enabling both more accurate place name identification systems, and deeper semantic information to be extracted from text.

2.4.1 Place Name Identification

Place name identification techniques in geoparsers may be broadly allocated into two categories, gazetteer-based, and machine learning based, often utilising NER (Purves *et al.*, 2018). A simple system for the identification of place names using a gazetteer will simply look up each word within a document, and see if it matches an entry within a gazetteer. This method has low recall and accuracy, but is relatively fast, and recent implementations usually focus on live-streamed Twitter data to quickly identify locations being tweeted about in ongoing emergency situations (Middleton, Middleton and Modaffer, 2014; Itoh, Yoshinaga and Toyoda, 2016). Importantly, these locations have a limited spatial extent, so the number of queried locations can be limited, reducing the number of false-positives. Other systems may even forgo the use of a gazetteer and simply rely on the identification of *noun phrases*, assuming that any location would be expressed through nouns (Malmasi and Dras, 2016).

While gazetteer and rule-based approaches provide a simple method for the identification of place names, they suffer from two key issues. First, gazetteers may not be complete for all regions; even the widely used *GeoNames* gazetteer has incomplete information for the United Kingdom (Stock *et al.*, 2013). Second, words identified as a location in text may not be necessarily a referent to a location (For example ‘Reading’ or ‘Bath’ in the UK; See Figure 2.2), broadly defined as *place name ambiguity* (Wacholder, Ravin and Choi, 1997; Brunner and Purves, 2008; Gritta, 2019).

Wacholder, Ravin and Choi (1997) identify two types of place name ambiguity; *structural ambiguity*, in which the structure of the words constituting a place name are ambiguous (e.g. ‘North Yorkshire’; is ‘North’ part of the name?), solved in part with noun phrase extraction (Lieberman and Samet, 2011; Malmasi and Dras, 2016). The second being *semantic ambiguity* in which the type of entity being referred to is ambiguous (‘Paris’ the city, or ‘Paris Hilton’). For this reason, most modern geoparsing systems make use of NER for place name identification, which are typically able to infer from context whether phrases in text refer to place names.

A further consideration when dealing specifically with place name ambiguity is *metonymy*; defined as a figure of speech in which the speaker uses ‘*one entity to refer to another that is related to it*’ (Lakoff and Johnson, 1980). In terms of geoparsing, a location based metonym

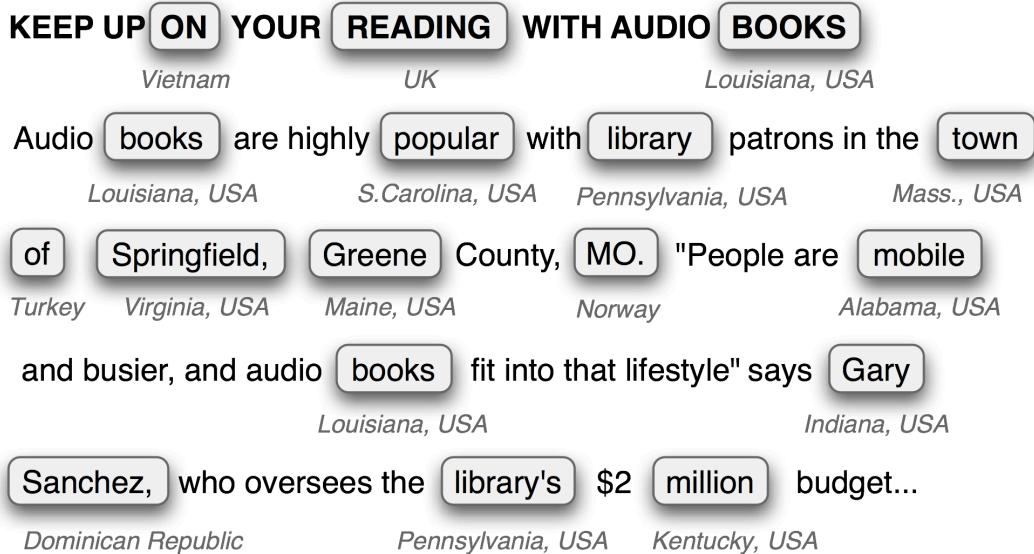


FIGURE 2.2: Place name identification by simple lookup (Bird, Klein and Loper, 2009)

does not refer to a location, but to a different but related entity (Leveling and Hartrumpf, 2008). Common geographic metonyms appear with language use in relation to political events, for example in the sentence '**London** voted against Brexit', the place name London refers to the people of London. Gritta *et al.* (2017a) note on the pitfall of misclassifying the sentence '**Moscow** talks to **Beijing**' as such a sentence does not inform the reader *where* talks are occurring. Use may also include elliptical constructions, '**Prescot** and **Liverpool road**' as both are street names, Liverpool road, and Prescot road (Leveling and Hartrumpf, 2008).

The reported performance of recent NER models is high, with current state-of-the-art models achieving an F_1 scores above 0.93 on the 'CoNLL 2003 NER Task' dataset (Tjong Kim Sang and De Meulder, 2003; Baevski *et al.*, 2019)⁶, approaching human levels of accuracy. As such, the place name identification stage of many geoparsing systems generally focus on using NER models (See Table 2.1), despite these models being built around the general identification of entities, rather than solely place names. Gritta (2019) suggest that this leads to most geoparsing systems ignoring issues like metonymy altogether, as it is not considered when annotating the corpora used to train these models.

Despite the primary focus of geoparsing systems being the single goal of identifying and geographically grounding place names, they are crucially only able to consider *entities* in the sense of the labelled corpora their NER models were trained on. Common NER training corpora typically focus on either the CoNLL 2003, or OntoNotes specifications. Such schemes do not specifically annotate place names, but consider a variety of related and unrelated entities.

⁶See <https://nlpprogress.com>

For example, models trained using the OntoNotes 5 corpus support the following entities that relate to place names:

- **FAC**: Buildings, airports, highways, bridges, etc.
- **ORG**: Companies, agencies, institutions, etc.
- **GPE**: Countries, cities, states.
- **LOC**: Non-GPE locations, mountain ranges, bodies of water.

Additionally, they support the following expressions that relate to geographic information:

- **QUANTITY**: Measurements, as weight or distance.
- **ORDINAL**: ‘first’, ‘second’, etc.
- **CARDINAL**: Numerals that do not fall under another type.

While models trained on the CoNLL 2003 corpus support the following entities that relate to place names:

- **LOC**: Name of politically or geographically defined location (cities, provinces, countries, international regions, bodies of water, mountains).
- **ORG**: Named corporate, governmental, or other organizational entity.

Note that **ORG** in both cases only refers to a geographic entity when it is associated with a building or site of a named organisation, for example schools or chain supermarkets. This tag would apply to both bold entities in the following sentences, despite only the second referring to a specific geographic location:

- a. ‘The new {**Apple**}_{ORG} iPhone.’
- b. ‘The {**Tesco**}_{ORG} is at the end of the road.’

It also makes little sense from a geographic point of view to split certain entities into separate categories. **FAC**, or **ORG** will often both refer to buildings, while **GPE** and **LOC** are both named locations, and collectively they should all be considered place names which are resolvable using a gazetteer.

2.4.2 Geocoding

While locational entities in text were among the first to be identified (Piskorski and Yanagarber, 2013), the need to resolve them was not considered until much later (Leidner, 2008). In general, geocoding approaches consider a place name t with n possible referents, within a document d , and using context place names c_0, \dots, c_k within the document d , t may be resolved to a single referent (Buscaldi, 2011). In this case, geocoding may be considered a specific implementation of the general task of ‘Word Sense Disambiguation’ (Buscaldi and Paolo Rosso, 2008). The referent place names are scored based on their likelihood to be correct, and the highest score selected. Methods for correctly geocoding an ambiguous place name may be split broadly into either rule-based or machine-learning based (Buscaldi and Paolo Rosso, 2008; Gritta, Pilehvar and Collier, 2018).

TABLE 2.1: Comparison between open source geoparsers

Geoparser	Detection	Resolution	Gazetteer
Edinburgh Geoparser	Rule-based	Rule-based	GeoCrossWalk/GeoNames
GeoTxt	NER	Rule-based	GeoNames
geotext	Rule-based	None	GeoNames
geography	NER	Rule-based	pycountry/GeoLite2
Mordecai	NER	ML	GeoNames
CLIFF-CALVIN	NER	Rule-based	Reuters
geography3	NER	Rule-based	Wikidata

Of rule-based methods, the most simplistic are those which consider the coordinate position of all place names (identified and ambiguous) on a map. For example Smith and Crane (2001) represent all possible locations for all identified place names within a document on a map, weighted by the number of times they appeared, removing those that appeared significantly outside the centroid of the map. Alternatively, if the source of a certain document is known, it is likely that place names identified as being significantly outside the source location may be incorrect (Buscaldi and Magnini, 2010). Meta information may also be used to remove less likely place names, such as those with a low population (Gelernter and Balaji, 2013). Some methods use contextual words in a document, for example *demonyms* (referring to residents of a place, e.g. Londoners) (Lieberman and Samet, 2011; Zhang and Gelernter, 2014). Other work has considered *location indicative words*, where unique words were automatically extracted from tweets with known locations, and used to geolocate text without requiring specific mentions of the location (Han, Cook and Baldwin, 2012, 2014; Chi *et al.*, 2016). Chi *et al.* (2016) for example are able to associate the tweet ‘*I plan to take a tram to the federation square this arvo to watch the cricket...*’ with the Australian city Melbourne due to the location indicative words ‘tram’, ‘federation square’, and ‘arvo’.

Some modern solutions rely on machine learning techniques to resolve place names to their most likely coordinates. The geoparser *Mordecai* for example uses Keras implemented neural networks trained on annotated data to identify correct gazetteer entries for place names (Haltermann, 2017). However, as outlined on Table 2.1, this is the only geocoding system that uses a machine learning methodology, while heuristic rules are typically implemented.

2.4.3 Geoparsing for Place-based Research

The concept of a place name as an entity defined by annotated NER corpora hinders the approach that geoparsing work takes, considering only (and any) defined place name as a geographic location within text (Gritta *et al.*, 2017a). The popular Python geoparser Mordecai, for example, uses an NER tagger provided through the SpaCy Python library (Honnibal and Montani, 2017), considering **GPE** (Geopolitical entities), **LOC** (Locations), and **FAC** (Facilities), which do not necessarily relate to geographic locations in certain contexts. Due to the reliance on large labelled corpora for NER training, and limited source of geography specific data (Stock *et al.*, 2013; Karimzadeh *et al.*, 2019; Gritta, 2019), little work has considered building NER models from the group up to specifically focus on the task of place name identification.

Existing annotated NER corpora are also typically built using American news articles (Tjong Kim Sang and De Meulder, 2003), meaning their performance on other text is limited. Social media text in particular is unique in comparison with more formally written and structured text, given documents themselves (e.g. Tweets) are typically short, context is limited, and abbreviations and vernacular language is common (Gelernter and Balaji, 2013). Additionally, capitalisation of proper nouns is not always used, which can make it difficult for existing models accurately parse place names.

Data annotation itself is not a simple task, requiring domain knowledge to ensure high accuracy (Petrillo and Baycroft, 2010), and being time-consuming to produce (Gey *et al.*, 2006; Middleton and Krivcovs, 2016; Wallgrün *et al.*, 2018). The lack of large, high quality, labelled geographic natural language data is well noted by many authors in this subject area (Tobin *et al.*, 2010; Speriosu and Baldridge, 2013; Weissenbacher *et al.*, 2015, 2019; Gritta, Pilehvar and Collier, 2018; Karimzadeh *et al.*, 2019), which likely contributes to the lack of task-specific models in geoparsing systems. Given context is limited and capitalisation is often missed in social media text, annotation can be difficult. For example, '*I love reading.*' is impossible to correctly annotate without considering broader context or associated metadata. If this comment was taken from an online forum dedicated to the discussion of Reading in southern England, then an annotator may make an educated decision to annotation this as a place name. However, if the forum is instead primarily associated with the discussion of Edinburgh in Scotland, it is far more likely to be a noun, not requiring annotation. These problems are more prevalent on Twitter, but are solved in part when using Reddit comments, given the language is typically more structured, context length is far greater, and comments are organised into sub-forums.

While existing NER annotation schemes are not optimised for place name identification, some work has considered the need to identify *geographic* or *spatial* entities. The ‘SemEval-2019 Task 12: Toponym Resolution in Scientific Papers’ considered an annotation scheme for building NER models that only focussed on place name identification (Weissenbacher *et al.*, 2019). Alternatively, SpatialML is a natural language annotation scheme that presents the **PLACE** tag for any mention of a location, also including and labelling nominal (non-specific) mentions of places (Mani *et al.*, 2010). Tasks identified by the Semantic Evaluation Workshop expanded this annotation scheme to include other entities that relate to spatial language (SemEval-2015 Task 8: SpaceEval, Pustejovsky *et al.*, 2015). The annotation scheme for this task is described by the ISO-Space specification (Pustejovsky, 2017):

- **PLACE:** Geographic entities including lakes and mountains, administrative entities like towns or counties, and general locations like buildings.
- **PATH:** Locations with the potential for traversal or boundaries, like roads, rivers, or coastlines.
- **SPATIAL_ENTITY:** Spatially relevant objects that do not fit into the above tags. In the context of this thesis this primarily relates to the person describing their location:
 - ‘{I}_{SE} am next to a building’

These entities also contain some metadata, particularly the `form` tag distinguishes whether the tagged text relates to a nominal form, or a proper name:

- a. ‘I camped next to the municipal {**building**}_{PL(form=NOM)}’
- b. ‘I travelled north to northern {**Italy**}_{PL(form=NAM)}’

In addition to these geographic entities, the **MEASURE** tag provides modifying information that relates to geographic entities.

- a. ‘I am {**300 meters**}_{MEASURE} south of a church.’
- b. ‘I am {**10 minutes**}_{MEASURE} from the coast.’

Similar works have considered the requirement for geography-specific corpora for training geoparsers, aiming to include a high proportion of geographic expressions and place names (Stock *et al.*, 2013; Wallgrün, Klippel and Baldwin, 2014; Wallgrün *et al.*, 2018). One corpus annotates place names identified in a collection of Tweets (Wallgrün *et al.*, 2018), intended for the training and evaluation of a short-context social media geoparsing system. Another presents a training dataset that considers metonyms in NER (Gritta *et al.*, 2017a), demonstrating that a deep learning model is capable to handling metonyms with improved accuracy compared with traditional heuristic approaches (Leveling and Hartrumpf, 2008; Lieberman and Samet, 2011)

Finally, geoparsers are typically intended as a general system for attributing locational information from documents. Due to this, the scope of geocoding is usually global, which causes many ambiguous place names to appear (e.g. *Cambridge, UK* vs *Cambridge, US*). The text being considered in these systems often contains a significant context that is not geographically focused, and as such does not provide any context to assist with geocoding. In this case, ambiguous entities appear in cases where the NER classifier incorrectly classifies other entities as geographic, such as people.

In this thesis, I instead consider that a geoparsing system may be built to specifically target locations within the United Kingdom, reducing the number of ambiguous place names that may occur, and allowing for fine-grained locations to be geoparsed. By specifically targeting subreddits that focus on local place discussions, the Reddit comments geoparsed in Chapter 4 and Chapter 5 incorporate larger proportion of place names and relevant context, compared with general text.

2.4.4 Developments in Natural Language Processing

The exponential increase in computational power has brought with it the ability to process large quantities of unlabelled text. This development has recently led to the creation of general purpose ‘large language models’ (LLMs) that implement the ‘transformer’ architecture, and use semi-supervised learning to train using very large corpora (Vaswani *et al.*, 2017). For example, Google’s pioneering BERT model was trained using the entirety of Wikipedia, and over 11,000 books (Devlin *et al.*, 2019).

The architecture specific to these models has enabled ‘transfer’ learning, by which a pre-trained model like BERT is used as a base, and fine-tuned to be task specific. Fine-tuning these pre-trained models in NLP has overtaken the popularity of manually trained word embeddings (Word2Vec; Mikolov *et al.* (2013)), which are limited by the volume of data provided to them, alternative pre-trained embeddings like ELMo (Peters *et al.*, 2018), as the transformer architecture provides improvements over the traditionally used Long Short-Term Memory (LSTM) Recurrent Neural Networks (RNN). Unlike previous models, transformers are more easily fine-tuned on new data, requiring only a single additional output layer to achieve task specific results.

Much recent attention has been given to language models, primarily through the development of ChatGPT⁷, which utilises a much larger language model compared with BERT, known as a generative pre-trained transformer (GPT), which focuses on text generation, rather than traditional NLP tasks like token classification for NER.

2.5 Conclusion

The primary goal of this thesis is to expand the knowledge relating to place in geography. This chapter has outlined limitations in past work that considered the use of alternative forms of data through social media for this task, where the reliance on explicit geographic markers on these data has limited the depth of knowledge accessible. This reliance on geo-tagged social media has resulted in a primary focus on the generation of cognitive regions, which only presents one potential aspect of the place-based knowledge available. Instead, I consider that additional informal geographic knowledge is embedded within informal communications between social media users, accessible directly through associated social media text. Unlike geotags however, geographic information in text is not directly quantifiable, relying on a method of extraction.

The extraction of geographic information from text primarily focusses around the task of geoparsing, where place names in text are attributed to geographic coordinate information. Existing work in this area has established that the best place name identification performance typically results from the use of pre-trained NER models, which are able to consider semantic context to accurately identify place names. These models however do not solely target place names in their annotation schemes, and are not usually trained on social media data. Attempts to generate geography specific annotated corpora for such models are limited, and not specific to the corpus primarily used in this thesis. Additionally, when geocoding identified place names, existing geoparsing models typically consider a global geographic scope, meaning specific countries like the United Kingdom are unable to be targeted. This therefore results in a large volume of unrelated place names within associated gazetteers, increasing the potential for noise in any outputs. Global gazetteers like GeoNames are also more limited when considering fine-grained locations like street names, which are an important component in place-based geographic knowledge.

⁷<https://openai.com/blog/chatgpt>

In this thesis I therefore construct a task and data specific geoparsing methodology, building an NER model for place name identification, trained specifically to identify place names from UK specific Reddit comments. The geocoding stage of this system similarly only considers a UK specific corpus, using the OS Open Names gazetteer, which includes fine-grained locations, but excludes locations external to the UK. With this methodology established, I accurately extract all UK specific geographic locations embedded within these Reddit comments, resulting in a large volume of informal geographic references to locations associated with coordinate information, allowing for place-based geographic analysis.

Instead of focussing on the generation of cognitive regions, this thesis instead demonstrates how text itself may be utilised to quantify alternative aspects of place-based knowledge. In Chapter 4 I first consider that while the strength of connection between geographic locations may be established through physical geographic movements and migration of populations, there exists an implicit knowledge of subconscious associations between locations, built on informal geographic knowledge. Associated text is used directly to establish these associations, taking inspiration from research that has established that co-occurring nouns typically share an implicit semantic association. In Chapter 5 I consider directly how embedded semantic information relating to locations varies geographically, generating semantic footprints through the use of a large language model, which embeds with geographic knowledge of the Reddit users in this corpus.

Chapter 3

Transformer based Named Entity Recognition for Place Name Extraction from Unstructured Text

The content of this chapter is *published as a research paper in The International Journal of Geographic Information Science:*

Berragan, C., Singleton, A., Calafiore, A. and Morley, J. (2023) ‘Transformer based named entity recognition for place name extraction from unstructured text’, *International Journal of Geographical Information Science*, 37(4), pp.747-766.

DOI: 10.1080/13658816.2022.2133125.

Chapter Overview

This chapter presents the first of three empirical chapters, achieving the first aim of this thesis, improving the results of current place name identification systems. This chapter demonstrates that both a task and data specific model is able to outperform pre-built NER models (e.g. SpaCy: Qi *et al.* (2018), or Stanza: Honnibal and Montani (2017)), that are widely used in existing geoparsing systems. Outputs from this model are used to demonstrate that online volunteered text presents a significant geographic component, expanding existing sources of Volunteered Geographic Information (VGI). The methodology outlined in this paper is then implemented to build a model used in both Chapter 4 and Chapter 5, enabling higher quality outputs that would not be possible by using existing systems.

Abstract

Place names embedded in online natural language text present a useful source of geographic information. Despite this, many methods for the extraction of place names from text use pre-trained models that were not explicitly designed for this task. Our paper builds five custom-built Named Entity Recognition (NER) models and evaluates them against three popular pre-built models for place name extraction. The models are evaluated using a set

of manually annotated Wikipedia articles with reference to the F1 score metric. Our best performing model achieves an F1 score of 0.939 compared with 0.730 for the best performing pre-built model. Our model is then used to extract all place names from Wikipedia articles in Great Britain, demonstrating the ability to more accurately capture unknown place names from volunteered sources of online geographic information.

3.1 Introduction

Place names are frequently encountered in natural language and provide an additional geographic dimension to much of the textual information present online, when associated with spatial coordinates and geographic locations. Despite this, research in place name extraction primarily concentrates on entities as described by annotation schemes that do not explicitly consider geographic place names (Haltermann, 2017; Karimzadeh *et al.*, 2019; Hu, Mao and McKenzie, 2019). Pre-built named entity recognition (NER) models based on these schemes are also not task specific; trained on data unrelated to the task they are used for, despite language involving place names varying significantly depending on the context (Purves *et al.*, 2018). When identifying place names in text, research typically only considers known administrative names and their associated strict boundaries, despite natural language often containing place names that either do not exist formally, are hyper-localised e.g. street names, or are alternative names that may be absent from administrative databases, which often only consider a single formal name.

The training corpora used by pre-built NER models typically identifies a number of entities that have no relevance to geographic place names, e.g. persons, and those that have some relevance in specific contexts; locations, geopolitical entities or facilities (Tjong Kim Sang and De Meulder, 2003; Weischedel *et al.*, 2013). Notably, they do not specifically target a ‘place name’ entity, meaning, while often these three related entity types may often refer to a place name, this is not always the case. Additionally, these corpora consist of text that often differs in structure, compared with the text being processed by models trained using them; for example, social media text is typically more informal compared with the news articles used to build the popular dataset, CoNLL03 (Tjong Kim Sang and De Meulder, 2003).

New forms of geographic information online present an opportunity to train and evaluate models on texts that contain a large volume of place names (Goodchild and Li, 2011), building models from the ground up, and using annotation schemes that are explicitly designed for the extraction of place names from text. Results from these models are expected to outperform existing pre-built models which use unrelated training data, and do not include a ‘place name’ entity type.

Our paper presents five NER models, trained on manually labelled Wikipedia data and used to identify and extract any span of text considered to be a place name, from articles relating to geographic locations in the United Kingdom. Our model is evaluated against pre-built solutions that are commonly used for this task, demonstrating the importance of model training with task specific data, and the consideration that named entity recognition as a task is not appropriate for place name extraction, due to the exclusion of a ‘place name’ entity type, and the inclusion of a number of unrelated entities. New developments in natural language processing (NLP) are utilised, outlining the benefit of selecting modern architectures that are not yet implemented by off the shelf models. Our paper considers the ability to extract place names from Wikipedia articles for the United Kingdom that do not

appear in the GeoNames Gazetteer, with the goal of identifying the additional geographic information that may be effectively extracted from unstructured sources of online text.

Section 3.2 outlines the research and concepts associated with geography in NLP, considering its relation to the new forms of geographic data present online, the techniques in natural language processing that explicitly deal with geography, and the developments in NLP that have enabled higher accuracy with limited labelled data. Section 3.3 presents the workflow undertaken for the models constructed in this paper, as well as the data collection and analysis of the entities extracted. The performance of each NER model is then presented in Section 3.4 and evaluated against pre-built solutions using a corpus of labelled test data. Place names are extracted using the model for the entire Wikipedia corpus, and compared against GeoNames, identifying names that are not present, discussing the reasons they may be found within Wikipedia articles, but not in an explicitly geographic gazetteer.

3.2 Literature review

Natural language often describes places using imprecise referents, non-administrative names, and an understanding of place footprints that does not conform with the formal administrative boundaries given to them (Goodchild and Li, 2011; Gao, Janowicz and Couclelis, 2017). Despite this, regions and place names in computational geography are usually formally defined by administrative datasets, meaning any informal place names are unable to be identified, or associated with a position in space. This distinction has given rise to a focus on *place* based GIS, rather than *space* based, which considers the ability to capture place references that may not appear in administrative datasets (Gao *et al.*, 2013).

Since the advent of Web 2.0, increased access to mobile devices which include passive GPS and open-access mapping information, several scientific disciplines have developed to take advantage of the data being produced, including crowdsourcing, and user-generated content (See *et al.*, 2016). With geographically referenced content through social media, mapping platforms and Wikipedia there is now a wealth of information that Goodchild (2007) terms ‘Volunteered Geographic Information’ (VGI). These data sources present a large collection of continually updated references to places, often providing informal and unstructured geographic information.

Much of the past work using VGI has concentrated either on explicitly geographic crowd-sourced mapping platforms like Open Street Map (Antoniou, Morley and Haklay, 2010), or ‘geotagged’ content which enables, often passively contributed, user-generated data through sites like Twitter or Flickr, used to extract geographic information. Gao, Janowicz and Couclelis (2017) for example present an approach for the construction of cognitive regions from various VGI sources, querying place names found in tags with associated geo-tags to create vague boundaries. A similar approach is taken by Hollenstein and Purves

(2010) who identified tags containing vague spatial concepts like ‘downtown’ and ‘citycentre’, deriving regions from geotags. These methods demonstrate the ability to derive informal geographic information from VGI, while giving similar results to that of manually collected questionnaire data (Gao, Janowicz and Couclelis, 2017; Twaroch *et al.*, 2019).

While this work concentrates solely on the use of geotags and short single phrase tags associated with social media documents to analyse ‘place’ focussed geographies, another source of online information that is less frequently considered to have geographic properties is unstructured text, which has the potential to provide an even larger source of geographically focussed information. Good results have been reported using basic semantic rules to identify places names found in unstructured text (Moncla *et al.*, 2014), however, these methods have relied on this text almost solely containing place names as entities. Alternatively to rule-based approaches, Hu, Mao and McKenzie (2019) demonstrate the use of four pre-trained NER models to extract local, informal place names from housing advertisements descriptions with associated coordinates, to enrich existing gazetteers with place names not normally present, alongside derived boundaries. The results of this paper show the promising ability for NER models to extract informal place names directly from text, also demonstrating a bottom-up approach to gazetteer construction, enabling informal place definitions to be captured from VGI, that may be absent from administrative datasets. Model evaluation however showed low precision and recall when evaluating against a labelled dataset, reflecting issues with the use of pre-built NER models for this task. Similar evaluation results are observed by Karimzadeh *et al.* (2019) when considering various pre-built NER models for use in the GeoTxt geoparsing system, which uses either SpaCy or Stanza pre-built models (Honnibal and Montani, 2017; Qi *et al.*, 2018). While the precision of these pre-built NER models can be relatively high for more sophisticated models, they all suffer from low recall. Karimzadeh *et al.* (2019) note particularly that while improved results would be expected by training a model from the ground up, the amount of labelled training data required to create a suitable model would be very large. To improve the accuracy of systems that rely on place name extraction, NER models should be constructed with more suitable training data, and with annotations tailored for this specific task.

While large, open-access, text-based sources of semantic geographic information are scarce, Wikipedia provides a large collection of articles about almost any subject, many of which relate to geographic locations. This presents an alternative data source for use in geographically focussed NLP applications, with place names, their semantic context, and article geotags providing geographic information. Various studies have used Wikipedia as a data source for the extraction of place names, DeLozier, Baldridge and London (2015) for example, identify place names in Wikipedia articles and use a clustering technique using document contexts to disambiguate their geographic locations. Speriosu and Baldridge (2013) use geotagged Wikipedia articles to provide contextual information regarding a range of place names for disambiguation. Both these works first use a pre-built Named Entity Recognition (NER) model to identify place names found in text, before further analysis. Improvements made to these NER models for place name extraction present a stronger foundation, leading

to both better recall, and precision of place names being identified, before they are resolved to coordinates (Leidner, 2008; Purves *et al.*, 2018). Our paper selects Wikipedia articles to demonstrate the geographic information that may be extracted from unstructured text, presenting a first-stage baseline approach for tasks that rely on accurate place name extraction.

3.2.1 Named entity recognition in the geographic domain

Natural language processing techniques involving geography typically focus around geoparsing; the automated extraction of place names from text, followed by the resolution of the identified place names to geographic coordinates (Leidner, 2008; Buscaldi, 2011; Gritta, Pilehvar and Collier, 2020). Modern place name extraction techniques primarily rely on named entity recognition (NER) to identify place names as entities within text (Purves *et al.*, 2018; Kumar and Singh, 2019). While most pre-built NER systems are able to identify ‘geopolitical entities’ and ‘locations’ as defined by popular annotation schemes¹, these only act as a proxy for place names in text. The majority of entities recognised by these systems are unrelated to place names, and as such simply contribute to lower overall recall when other entities are preferred by models over geographic place names. For example, a model may consider a named organisational headquarters as an ‘organisation’ entity, rather than a ‘location’, even when used as a locational reference.

The concept of a place name as an entity defined by the labelled corpora NER models were trained on hinders place name extraction, identifying only (and any) administrative place names in text (Gritta *et al.*, 2017b). The geoparser *Mordecai*² for example, uses an NER tagger provided through the *SpaCy* Python library, which provides a variety of entities including those unrelated to place names (e.g. **PER**: persons), and three entities that may be considered related, **GPE** (Geopolitical Entity), **LOC** (Location), and **FAC** (Facility). While these categories often do relate to place names, they do not consider whether the entity could be contextually considered a place name that could be geo-located. For example, geopolitical entities are often used in a metonymic sense; a figure of speech where a concept is substituted by a related concept. In the phrase ‘Madrid plays Kiev today’ for example, sports teams are replaced by their associated place name (Gritta, Pilehvar and Collier, 2020). As place name based metonyms do not explicitly relate to geographic locations, and instead a related entity, we are uninterested in their extraction. Due to the reliance on large labelled corpora for NER training, and limited source of geography specific data (Karimzadeh *et al.*, 2019), little work has considered explicitly targeting place names through new data, as it is often time-consuming to produce.

While at present pre-built NER models identify entities as defined by widely used annotated corpora, some work has considered the need to identify *spatial* entities. SpatialML is a natural language annotation scheme that presents the **PLACE** tag for any mention of a location (Mani *et al.*, 2010). Tasks identified by the Semantic Evaluation Workshop built on

¹CoNLL03: <https://www.clips.uantwerpen.be/conll2003/ner/>, OntoNotes 5: <https://catalog.ldc.upenn.edu/LDC2013T19>

²<https://github.com/openeventdata/mordecai>

this annotation scheme and defined several entities relating to spatial language (SemEval-2015 Task 8: SpaceEval, Pustejovsky *et al.*, 2015), described by the ISO-Space annotation specification (Pustejovsky, 2017). In order to more appropriately consider geography when parsing unstructured text for place related entities, models should be built from the ground up, taking into account an alternative annotation scheme that identifies place names, excluding unrelated entities.

Recent progress in NLP and the use of GPU accelerated training has brought with it the ability to process large quantities of unlabelled text. This development has recently led to the creation of general purpose ‘language models’ that implement the ‘transformer’ architecture, using semi-supervised learning to train using very large corpora (Vaswani *et al.*, 2017). For example, Google’s pioneering BERT model was trained using the entirety of English Wikipedia, and over 11,000 books (Devlin *et al.*, 2019). This development has led to models which perform well for many given tasks, even with relatively limited additional labelled training data.

Our paper proposes fine-tuning transformer-based language models for place name extraction using named entity recognition, to extract all place names from UK ‘place’ classed articles on Wikipedia. 200 of these articles are annotated, labelling place names to train and evaluate model performance. We train and compare the performance of three popular transformer-based NER models; BERT - a large, popular transformer model, RoBERTa - similar to BERT, using a different pre-training procedure, which has had better results on some tasks, and DistilBERT - a much smaller and less complex transformer model based on RoBERTa. In addition to these transformer models, two simpler Bidirectional LSTM (BiLSTM) models are compared, one using pre-trained GloVe embeddings, representing an equivalent complexity model used by Stanza or SpaCy pre-built NER solutions, and another showing a baseline model without any pre-trained word embeddings. These models are then evaluated against three pre-built NER systems that are popular for place name extraction, and used in existing geoparsing systems including GeoTxt and Mordecai.

3.3 Methodology

Figure 3.1 gives an overview of the model and data processing pipeline used in our paper. This section first outlines the computational infrastructure used. The data collection and data processing is then described, obtaining a corpus of Wikipedia articles for locations in Great Britain with place names labelled.

This dataset was then used to train custom NER models of various architectures, which were evaluated using separate test data against each other and popular pre-built NER models. We then selected our DistilBERT transformer model to extract all place names from the full corpus of Wikipedia articles, as this model performed well as indicated by its test F_1 score, despite its smaller size.

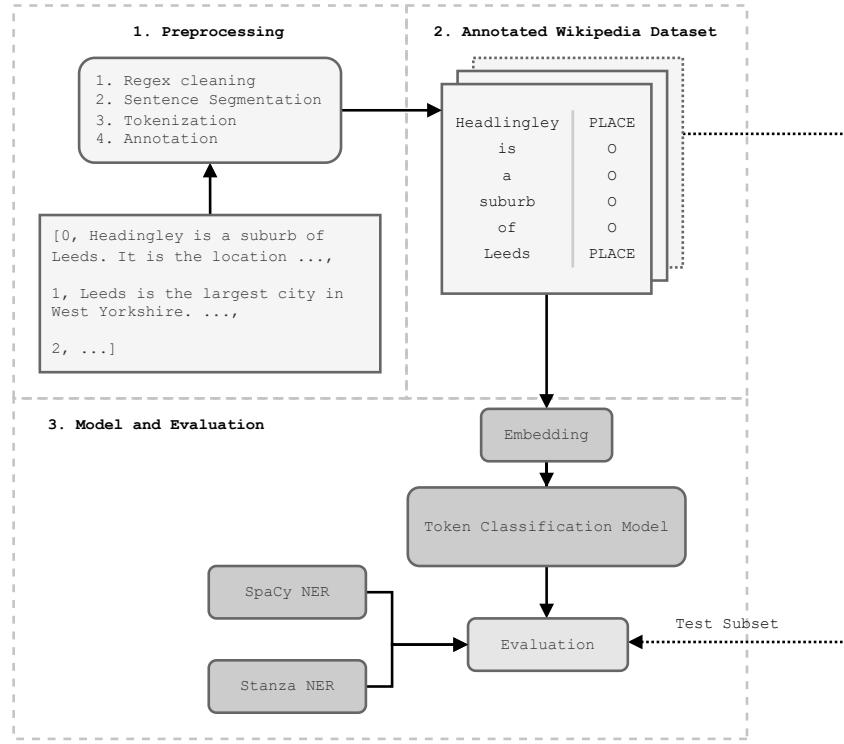


FIGURE 3.1: Overview of the model processing pipeline

3.3.1 Software & hardware infrastructure

Models used in our paper were written in Python using the AllenNLP library for deep learning in natural language processing (Gardner *et al.*, 2018). AllenNLP is built on top of PyTorch (Paszke *et al.*, 2019), providing abstractions to commonly used operations for working with state-of-the-art deep neural networks in natural language processing.

Model training was GPU accelerated using a single NVIDIA GeForce RTX 2070 SUPER with 8192MB memory paired with a Ryzen 3700x CPU with 8 physical and 16 logical cores. Python version 3.8.5 was used with AllenNLP version 1.5.0.

3.3.2 Annotation & data collection

3.3.2.1 Wikipedia data collection

Wikipedia presents a large collection of well-formatted text contributed by a variety of users, with frequent instances of place names, a consistent written style and without misspellings. Existing NER models are trained on either CoNLL-03 or OntoNotes 5, both of which are well-formatted text datasets, consisting primarily of news articles. As such, it was considered appropriate to select Wikipedia for a comparison between these models and ours, compared with other sources of VGI that are of lower overall quality.

The Wikipedia text data used in our paper was accessed through DBpedia (Auer *et al.*, 2007), a community gathered database of information from Wikipedia, presented as an open knowledge graph, with ontologies that link and define information in articles. A query was

built to obtain English Wikipedia abstracts for each DBpedia article with the `Place` class in Great Britain, using the DBpedia SPARQL endpoint. Querying just for `Place` articles within Great Britain ensured that articles extracted contained a large number of place names and language indicative of place names, without additional, unnecessary information.

These abstracts are the text provided at the top of each article, before any headings, sometimes called the summary. As an example, the Wikipedia abstract for Rowlatts Hill, a suburb of Leicester, UK is as follows, with hyperlinks indicated in bold:

Rowlatts Hill (also known as Rowlatts Hill Estate, or R.H.E.) is an eastern, residential suburb of the **English city of Leicester**. It contains mostly **council-owned housing**.

The suburb is roughly bordered by Spencefield Lane to the east and Whitehall Road to the south, which separates it from neighbouring **Evington**. A second boundary within the estate consists of Coleman Road to Ambassador Road through to Green Lane Road; Rowlatts Hill borders **Crown Hills** to the west. To the north, at the bottom of Rowlatts Hill is Humberstone Park which is located within Green Lane Road, Ambassador Road and also leads on to Uppingham Road (the **A47**), which is also Rowlatts Hill.

Using DBpedia enabled a fast executing query which, when combined with the `Place` class from the DBpedia ontology, returned a complete dataset of Wikipedia pages for many geographic locations in Great Britain. A total 42,222 article abstracts were extracted.

3.3.2.2 Input format

For use in the models, a random subset of 200 articles were annotated using the CoNLL-03 NER format, which uses line delimitation to separate tokens, with entities associated with each token sharing the same line, separated by a space. Articles were first cleaned using regular expressions to remove quotation marks, text inside parentheses, and non-ascii characters. The SpaCy large web-based pre-trained model pipeline (`en_core_web_lg`) was used for further processing, using a non-monotonic arc-eager transition-system for sentence segmentation (Honnibal and Johnson, 2015), and tokenisation using a rule-based algorithm. Each sentence-length sequence of tokens was treated as a separate instance to be fed as batches into models for training. Each token in every sequence was annotated as being a place name or not, assisted through the open source annotation tool Doccano (Nakayama *et al.*, 2018).

For place names that span multiple tokens, the *BIOUL* tagging scheme was used, which stands for the ‘*Beginning*, *Inside* and *Last* tokens of multi-token chunks’; for place names that span more than one token (e.g. *B-Place*: New, *L-Place*: York). ‘*Unit-length* chunks and *Outside*’, place names of only a single token, and outside for any token that isn’t a place name. This scheme was used over the simpler BIO scheme which is more difficult for models to learn (Ratinov and Roth, 2009). During annotation it became clear that the length of

certain multi-token place names could be considered ambiguous. For example, it may not be clear when a cardinal direction is part of a place name, ‘northern Ireland’ may refer to a northern region in Ireland, while ‘Northern Ireland’ refers to the constituent country in the United Kingdom. To unify labelling decisions we chose to consider capitalisation as an indication of multi-token noun phrases that constituted a single place name. The following sentence shows a sequence of tokens with their corresponding tags, demonstrating the annotation scheme with *BIOUL* information prepending each tag:

<i>Kingston</i>	<i>upon</i>	<i>Hull</i>	is usually abbreviated to <i>Hull</i>				
B-PLACE	I-PLACE	L-PLACE	O	O	O	O	U-PLACE

From these 200 labelled Wikipedia abstracts, 10% were kept for both validation and testing, leading to a training set of 21,080 labelled tokens, a validation dataset of 2,907 labelled tokens, and a testing dataset of 3,347 labelled tokens.

3.3.3 Building the entity recognition models

Named entity recognition is a subset of token classification where a sequence of tokens $\mathbf{x} = \{x_0, x_1 \dots x_n\}$ are taken as input, and the most likely sequence tags $\mathbf{y} = \{y_0, y_1, \dots y_n\}$ are predicted. The models constructed in our paper may be divided into three main components, outlined on Figure 3.1:

- **Embedding Layer:** Each token in a sequence represented as high dimension numerical space, they may be either:
 - Randomly initialised
 - Pre-trained: GloVe, transformer
- **Intermediate Layers:** A deep neural network that input embeddings propagate through, either:
 - Bidirectional LSTM
 - Transformer
- **Classification layer:** The final layer of the model that takes a high dimensional output from the previous layers, and projects them to the classification dimension. The argmax from this layer corresponds to the label selected for each token. Each model uses a Conditional Random Field (CRF) to classify tokens which are popular in NER tasks, as they consider tagging decisions between all input tokens (Lample *et al.*, 2016). This is necessary given the inside tag for a place (I-PLACE), cannot directly follow a unit tag (U-PLACE) for example.

Table 3.1 gives an overview of the model architectures built through our paper. First a simplistic model was constructed as a baseline, using untrained randomly initialised 50 dimension token embeddings, fed into a two-layer Bidirectional LSTM (BiLSTM) with 200 hidden dimensions. The output from the BiLSTM was input into a conditional random field classifier. A second BiLSTM model was also created based on the architecture described in Peters *et al.* (2018), adding pre-trained GloVe token embeddings (Pennington, Socher

TABLE 3.1: Overview of the models trained through our paper, detailing the architecture used. Integers in brackets indicate the vector dimensions

Name	Embeddings	Intermediate	Output	Optimiser
BiLSTM-CRF (Basic)	Token {50}	2-layer BiLSTM {200}	CRF	Adam
BiLSTM-CRF	GloVe Token {50} Character {16}	2-layer BiLSTM {200}	CRF	Adam
BERT	BERT {768}	12-layer Transformer {768}	CRF	AdamW
RoBERTa	RoBERTa {768}	12-layer Transformer {768}	CRF	AdamW
DistilBERT	DistilBERT {768}	6-layer Transformer {768}	CRF	AdamW

and Manning, 2014) with 50 dimensions and 16 dimension character embeddings. Both models used the Adam optimiser which makes use of stochastic gradient descent for weight optimisation (Kingma and Ba, 2017).

Three BERT-based transformer models were also created, using BERT (Devlin *et al.*, 2019), RoBERTa which attempts to optimise the training process of BERT (Liu *et al.*, 2019), and DistilBERT, which distils the data used in pre-training to create a smaller, faster model (Sanh *et al.*, 2020). The primary architecture of transformers is ‘attention’ which enables them to consider and weight each word in a sequence against each other word simultaneously. This allows them to be highly parallel, providing significant improvements to computational speed with GPUs which can handle highly parallel tasks, and benefits over traditional architectures like Long Short-Term Memory (LSTM) which are only able to consider sequences sequentially (Vaswani *et al.*, 2017). These models were pre-trained on very large general text corpora, enabling ‘transfer learning’, where a pre-trained model like BERT is used as a base and fine-tuned to be task specific. Conceptually, these pre-trained models learn deep embedded weights for words based on comprehensive contextual information extracted from the large general text corpora, these then only require smaller adjustments in fine-tuning to achieve good task-specific results. Fine-tuning these pre-trained models in NLP has produced results that often outperform models using traditional architectures that include manually trained word embeddings (Word2Vec, Mikolov *et al.*, 2013), which are limited by the volume of data provided to them and pre-trained embeddings like GloVe (Pennington, Socher and Manning, 2014).

Pre-trained transformer models replace both the BiLSTM layers of the previous models and token embeddings, taking encoded sequences, associating each token with a 768 dimension vector representation from a vocabulary, feeding them into sequential transformer layers and outputting into a CRF classifier. Each model was initialised with pre-trained weights provided by the `transformers` Python library (Wolf *et al.*, 2020), these weights are initialised in both the embedding layers and intermediate layers. For weight optimisation, these models used the weight decay Adam algorithm (AdamW, Loshchilov and Hutter, 2019). Every layer of the transformer models was updated during training, which enabled the pre-trained weights to adjust and learn for the specific task. Hyper-parameters selected for each model were largely based on the values as suggested for token classification by their respective implementation papers.

For every model, weights were adjusted each epoch to minimise the training loss. Following the final intermediate layer of a model, a token representation $C \in \mathbb{R}^H$ feeds into the classification layer weights $W \in \mathbb{R}^{K \times H}$, where K is the number of unique labels. Classification loss is then calculated using $\log(\text{softmax}(CW^T))$.

Early stopping was used in each model, stopping training early if no improvement was made to the validation F_1 score in eight subsequent epochs. Automatic Mixed Precision (AMP) was used throughout training to use half-precision (16 bit) floating point numbers in some operations which reduced the memory overhead and increased computation speed. For transformers, the learning rate was optimised towards the end of training, using a `reduce on plateau` learning rate scheduler, reducing the learning rate by 1/10th once the overall F_1 validation metric had stopped improving after two epochs, this only increased training time on the BiLSTM models with no improvement, so was excluded. Following training, the weights from the best performing epoch were automatically chosen for the final model.

3.3.4 Evaluation against pre-built models

Following the training of each model, their accuracy, precision, recall and F_1 score was evaluated using a corpus of test data, against three popular modern pre-built NER models provided through the `SpaCy` and `Stanza` Python packages. A `SpaCy` model is used in the *Mordecai* geoparser and optionally in the *GeoTxt* geoparser, while the `Stanza` model is a more recent implementation of the Stanford NLP model used by the *GeoTxt* geoparser.

As these pre-built models were not trained to recognise ‘place names’, their tags were adjusted so that anything labelled as ‘GPE’ (Geopolitical Entity), ‘LOC’ (Location), or ‘FAC’ (facility) was considered to be a ‘place name’, mirroring the process used to discard unrelated entities by geoparsing systems that use these models. The default `Stanza` NER model, and two `SpaCy` models (`en_core_web_sm`, `en_core_web_lg`) were evaluated on the labelled test data. Table 3.2 gives an overview of these pre-built models.

Each model was evaluated on 3 separate subsets of the annotated test dataset, giving a range of scores for each model. Significance testing was then performed using paired t-tests to test the null hypothesis:

H_0 : There will be no statistically significant difference between the mean F_1 score of each custom built model against the best performing pre-built model (`Stanza`).

Significant results that reject this null hypothesis were indicated by $p < 0.05$ and are shown on Table 3.3.

The best performing model trained on the annotated Wikipedia data was also evaluated using paired t-tests against each other model trained on the same data, to test the null hypothesis:

TABLE 3.2: Pre-built NER models

Name	Training Data	Architecture	Reported NER F_1
SpaCy (small)	OntoNotes 5	CNN	0.84 ^a
SpaCy (large)	OntoNotes 5	CNN	0.85 ^a
Stanza	OntoNotes 5	BiLSTM CRF	0.89 ^b

a <https://spacy.io/models/en>

b <https://stanfordnlp.github.io/stanza/performance.html>

H₀: There will be no statistically significant difference between the mean F_1 score of the best performing custom built model trained on annotated Wikipedia data and each other model trained on this data.

Significant results that reject this null hypothesis were also indicated by $p < 0.05$.

It should be noted that significance testing is not common in deep learning research (Dror and Reichart, 2018), but papers that do report the significance of mean scores between models tend to use paired t-tests, despite potentially violating the parametric assumptions made. Dror and Reichart (2018) suggest that while normality may be assumed due to the Central Limit Theorem, it is likely that future progress in this field will present more appropriate statistical significance testing.

3.3.5 Output processing

A predictor was created from the DistilBERT model to run inference over the total corpus of Wikipedia articles. Place names extracted from the Wikipedia articles by this model were saved to a CSV file with the context sentence, the associated article, and coordinate information for the article that contained the place.

Place names were compared against a full corpus of British place names from the GeoNames gazetteer, to examine which names are excluded from the gazetteer, but identified within Wikipedia articles.

3.4 Results & discussion

This section first evaluates the results of the models presented against each other, and in relation to existing pre-built NER solutions. The place names extracted by our best performing model are compared with pre-built models, showing how our method improves on those used in existing place name extraction methods. Following this, examples from the corpus of place names extracted from Wikipedia articles are noted, demonstrating use-cases for the method presented that wouldn't be possible or as effective, through pre-built NER solutions.

TABLE 3.3: Geographic entity recognition mean (\pm SD) performance metrics over 3 runs of annotated Wikipedia test data subsets. Pre-built NER models are shown in italics. Bold values indicate statistically significant F1 scores of fine-tuned models in relation to ‘*Stanza*’ (Paired t-tests $p < 0.05$).

	Accuracy	Precision	Recall	F1
BERT	0.985 ± 0.0050	0.947 ± 0.0241	0.932 ± 0.038	0.939 ± 0.0256
DistilBERT	0.980 ± 0.0015	0.930 ± 0.0065	0.918 ± 0.015	0.924 ± 0.0065
RoBERTa	0.982 ± 0.0055	0.916 ± 0.0069	0.931 ± 0.015	0.923 ± 0.0086
CRF biLSTM	0.967 ± 0.0068	0.909 ± 0.0104	0.813 ± 0.017	0.859 ± 0.0124
CRF biLSTM (basic)	0.947 ± 0.0040	0.836 ± 0.0546	0.698 ± 0.023	0.760 ± 0.0135
<i>Stanza</i>	0.941 ± 0.0259	0.757 ± 0.0542	0.705 ± 0.068	0.730 ± 0.0586
<i>SpaCy (Large)</i>	0.910 ± 0.0191	0.724 ± 0.0422	0.451 ± 0.050	0.554 ± 0.0382
<i>SpaCy (small)</i>	0.900 ± 0.0225	0.720 ± 0.0594	0.345 ± 0.082	0.464 ± 0.0835

3.4.1 Model performance

Table 3.3 shows three popular pre-built NER models, evaluated on the labelled Wikipedia test data, compared with the models produced through our paper. The BiLSTM-CRF (basic) model gives a baseline reference for a typical NER model with a simple architecture. Out of the pre-built models, *Stanza* performs the best, achieving precision and accuracy just below the trained baseline model, with an F_1 score which isn’t significantly worse (paired t-test $p > 0.05$), both *SpaCy* models however show notably worse results compared with *Stanza*. The primary issue with the pre-built models is recall, which is far below any of the custom-built models, reflecting a high number of false negatives.

It is worth noting that due to class imbalances, i.e. many more ‘other’ (0) entities relative to the small number of PLACE entities, accuracy should be considered a poor metric, and is only included for completeness. This class imbalance means that as only approximately 15% of tokens are labelled as entities, it is possible to achieve 85% accuracy and high precision by labelling all tokens as not entities. F_1 score is often used to compensate for these issues in multiple classification tasks, but it should be known that it is not itself a perfect metric. With respect to the best performing pre-built model *Stanza*, all transformer models fine-tuned on the Wikipedia annotated data, have significantly higher F_1 scores (paired t-test $p < 0.05$).

The DistilBERT transformer model is less complex than both the BERT and RoBERTa model, with a total of 260 MB in model weights, compared with 433 MB and 498 MB respectively. Despite this, the DistilBERT model achieves similar results to RoBERTa on test data (Table 3.3). While all transformer models perform significantly better than the best performing pre-built model, *Stanza*, both CRF models do not give significantly better F_1 scores (paired t-test $p > 0.05$). BERT performs best overall, with an F_1 score of 0.939 on the test data, a result that is only significantly better than the two CRF models (paired t-test $p < 0.05$).

Figure 3.2 shows the output of the chosen fine-tuned NER model DistilBERT alongside *SpaCy (large)* and *Stanza*, applied to a simple Wikipedia article summary. Figure 3.2 (A)

gives promising results for DistilBERT, with the summary for the Wikipedia page ‘Rowlatts Hill’, correctly identifying all place names.

While evaluation metrics indicate that Stanza performs reasonably well, it primarily suffers from the annotation scheme used, some place names are misidentified as ‘Person’, or ‘Organisation’, meaning a standard geoparsing system would miss several place names here, given they are not otherwise identifiable (Figure 3.2).

(A) DistilBERT

The suburb is roughly bordered by Spencefield Lane PLACE to the east and Whitehall Road PLACE to the south, which separates it from neighbouring Evington PLACE. A second boundary within the estate consists of Coleman Road PLACE to Ambassador Road PLACE through to Green Lane Road PLACE; Rowlatts Hill PLACE borders Crown Hills PLACE to the west. To the north, at the bottom of Rowlatts Hill PLACE is Humberstone Park PLACE which is located within Green Lane Road PLACE, Ambassador Road PLACE and also leads on to Uppingham Road PLACE (the A47 PLACE), which is also Rowlatts Hill PLACE.

(B) SpaCy (large)

The suburb is roughly bordered by Spencefield Lane FAC to the east and Whitehall Road FAC to the south, which separates it from neighbouring Evington GPE. A second ORDINAL boundary within the estate consists of Coleman Road FAC to Ambassador Road FAC through to Green Lane Road FAC; Rowlatts Hill FAC borders Crown Hills GPE to the west. To the north, at the bottom of Rowlatts Hill FAC is Humberstone Park FAC which is located within Green Lane Road FAC, Ambassador Road FAC and also leads on to Uppingham Road FAC (the A47 FAC), which is also Rowlatts Hill FAC.

(C) Stanza

The suburb is roughly bordered by Spencefield Lane PERSON to the east and Whitehall Road FAC to the south, which separates it from neighbouring Evington GPE. A second ORDINAL boundary within the estate consists of Coleman Road FAC to Ambassador Road through to Green Lane Road FAC; Rowlatts Hill PERSON borders Crown Hills GPE to the west. To the north, at the bottom of Rowlatts Hill GPE is Humberstone Park GPE which is located within Green Lane Road FAC, Ambassador Road PERSON and also leads on to Uppingham Road (the A47 ORG), which is also Rowlatts Hill PERSON.

FIGURE 3.2: Comparison of outputs between the best performing fine-tuned transformer model and the two best performing pre-built NER models.

Figure 3.3 demonstrates the ability for our DistilBERT transformer model to accurately ignore entities that do not relate to place names. This example paragraph only refers to a single geographic location in text, the location of the 1952 Summer Games, in Helsinki, Finland. While Stanza identifies a large number of GPE tags, they either relate to China used in a metonymic sense, meaning the Chinese Olympic team ('China competed'), or as a related geopolitical noun ('delegation of ROC'), which is not considered to be a place name referring to a geographic location in this context. Our model correctly infers the single mention of a geographic place name based on the contextual information, meaning a large amount of unrelated information is excluded. Particularly, recognising and ignoring these nouns related to place names is something that is noted as an issue in current geoparsing systems

(A) DistilBERT

Originally having participated in Olympics as the delegation of the Republic of China (ROC) from 1924 (Summer Olympics) to 1976 (Winter Olympics), China competed at the Olympic Games under the name of the People's Republic of China (PRC) for the first time in 1952, at the Summer Games in Helsinki PLACE, Finland PLACE.

(B) BiLSTM CRF

Originally having participated in Olympics PLACE as the delegation of the Republic of China PLACE (ROC PLACE) from 1924 (Summer Olympics PLACE) to 1976 (Winter Olympics), China competed PLACE at the Olympic Games PLACE under the name of the People's Republic of China (PRC PLACE) for the first time in 1952, at the Summer Games PLACE in Helsinki PLACE, Finland PLACE.

(C) Stanza

Originally having participated in Olympics EVENT as the delegation of the Republic of China GPE (ROC GPE) from 1924 DATE (Summer Olympics) EVENT to 1976 DATE (Winter Olympics) EVENT , China GPE competed at the Olympic Games EVENT under the name of the People's Republic of China ORG (PRC GPE) for the first ORDINAL time in 1952 DATE , at the Summer Games EVENT in Helsinki GPE , Finland GPE .

FIGURE 3.3: Ability for trained model to distinguish between metonymic usage of place names.

(Gritta, Pilehvar and Collier, 2020). This figure also demonstrates the importance of using a pre-trained model base for this task, as the BiLSTM CRF performs poorly. It is likely that this issue stems from the limited training data used, as the model is unable to learn more complex cases where place names are less obvious (Figure 3.3 (B)). Using a pre-trained transformer enables the model to correctly identify instances where proper nouns do not relate to place names, taking information learned through its pre-training procedure.

3.4.2 Identified place names from Wikipedia

Table 3.4 gives an overview of the most common place names identified by the DistilBERT model and the SpaCy model. Notably, the SpaCy model appears to struggle with correctly aligning entities, including ‘the’ with ‘United Kingdom’, and partially missing place names containing ‘Tyne’ (e.g. ‘Tyne and Wear’ or ‘River Tyne’). The DistilBERT model also extracts around 6 times the number of place names compared with SpaCy, reflected by the low recall noted above. One example where the DistilBERT model appears confused is by giving the place name ‘Church of England’, this problem relates to the language used in Wikipedia articles, when churches are described as a ‘Church of England church’, a nominal mention of a place rather than specific.

The total number of place names extracted from the Wikipedia summaries by the DistilBERT model was 614,672, with 99,697 unique place names. In total 62,178 unique place names were extracted that are not found within the GeoNames gazetteer. These entities primarily exist as granular names mentioned in single instances (e.g. road names:

TABLE 3.4: Top and bottom named places by frequency, excluding any present in the GeoNames gazetteer or mentioned less than 100 times.

IDX	Place (DistilBERT)	Count	IDX	Place (SpaCy)	Count
70	Great Western Railway	236	3	the United Kingdom	458
77	Ceredigion	220	4	Tyne	353
78	West Riding of Yorkshire	217	5	Ceredigion	282
79	East Lindsey	217	6	the City of London	211
83	Midland Railway	212	7	Methodist	205
87	London Underground	195	8	the Metropolitan Borough of	200
...
176	M4	108	14	France	129
180	North Norfolk	106	15	Baptist	127
181	M1	106	16	Sutherland	119
182	Church of England	106	17	the City of	116
191	Hull	104	18	Richmondshire	109
199	Great Northern Railway	101	19	Thameslink	102

Shady Lane, Chapeltown Road), organisational names used in a place related context (e.g. describing locations along the Great Western Railway route), and alternative names that are not captured by GeoNames. For example, ‘M1’ appears in GeoNames as ‘M1 Motorway’³. While the ‘M1 motorway’ is used in Wikipedia articles, it is often also referred to as just the ‘M1’.

3.5 Conclusion

Our paper demonstrates a new approach towards the extraction of place names from text by building an NER model using data annotated with geographic place names. This work aims to direct geographic NLP research towards the use of models which move away from the generalisable annotation schemes of pre-built NER solutions, to include task-specific, relevant training data. Notably this differs from the perceived generalisability of pre-built models used for general geoparsing. We believe this is an important approach for geographic place name extraction given geographic language differs greatly based on context (Purves *et al.*, 2018), with contexts varying greatly based on the corpora used for inference. This is demonstrated by the poor results observed in previous work when applying pre-built NER solutions, which use training data unrelated to the task-specific data they are being applied to (Hu, Mao and McKenzie, 2019; Karimzadeh *et al.*, 2019). Wallgrün *et al.* (2018) recognise this problem, developing GeoCorpora, a task-specific training dataset for micro-blog geoparsing, notably describing increased issues with annotation ambiguity compared with more traditional text-sources. Additionally, recent work with transformer models, typically only built to be generalisable, have considered moving from fully generalised self-supervised training towards more dataset-specific models (e.g. TweetEval; Barbieri *et al.* (2020)), with results that outperform generalisable transformer models (Nguyen, Vu and Nguyen, 2020).

Ultimately, the decision to produce a model explicitly designed to be non-generalisable to

³<https://www.geonames.org/8714914/m1-motorway.html>

other corpora may be considered a limitation of the scope of this paper. We have demonstrated a best-case scenario where time-frames allow for manual annotation of task-specific data. Future research may consider the construction of a more generalisable place name extraction model, which takes inspiration from the alternative annotation scheme employed by our paper, allowing for use in general purpose geoparsers.

Additionally, while our paper selects Wikipedia for place name extraction, due to its large volume, ease of validation and data retrieval, future work may consider the ability to apply our methodology to other text sources. With suitable models constructed, using annotated training data that is relevant to the corpus being considered, we expect future work applied to other data sources may present the opportunity to further contribute to place names that are absent from gazetteers, as vernacular place names. We believe that given a suitable combination of data sources, our methodology is the first step towards the construction gazetteers from the bottom-up, directly taking place names from passive contributions, without relying on pre-built datasets.

The recent development of pre-trained language models and their suitability for fine-tuning in many tasks, including NER, presents a method for the construction of accurate models that are task specific, using relatively small labelled corpora⁴ that defines entities more suited to the task of place name extraction. The architecture in our paper is more simplistic to implement than other attempts at similar tasks (e.g. Weissenbacher *et al.*, 2019), with most of the complexity hidden within the transformer layers. This, combined with libraries that abstract and implement state of the art models, provides a more accessible approach for research in place name extraction, without requiring a deep understanding of semantic rules, or the construction of deep multi-layered models from the ground up.

Evaluation against pre-built NER models on Table 3.3 shows that performance for place name extraction is greatly improved, particularly with respect to recall, a notable issue with past studies (Hu, Mao and McKenzie, 2019; Karimzadeh *et al.*, 2019). The construction of an NER model for the task specific extraction of place names moves towards systems that appropriately consider the geographic elements present in natural language. The large number of place names that are absent from the GeoNames gazetteer suggests that geoparsing and related work likely misses a substantial amount of geographic information present in text. The dataset produced through this work aims to assist with filling these gaps, while the methodology described enables an approach that may be mirrored and applied to further work on other data sources.

Finally, both ‘place’ focussed annotation schemes describe the use of ‘nominal’ place related entities (Mani *et al.*, 2010; Pustejovsky, 2017). While out of the scope of our work, we would like to encourage the focus on extracting this additional geographic information from text. Often in language the use of these non-specific terms are used, for example ‘I visited the shops’, ‘York is a city’, provide geographically specific information. ‘The shops’ with enough

⁴Compared with the Reuters corpus used for CoNLL03 for example

context may provide a specific geographic location, and similarly the link between ‘York’ -> ‘city’ could be explored (Coulcelis, 2010).

Data and codes availability statement

The data and codes that support the findings of this study are available at the public FigShare link (<https://doi.org/10.6084/m9.figshare.13415255.v1>). Instructions for using the data and code are provided as a README within the FigShare repository.

Disclosure statement

No potential competing interest was reported by the authors.

Chapter 4

Mapping Cognitive Place Associations within the United Kingdom through Online Discussion on Reddit

The content of this chapter is *under review* for publication in *Transactions of the Institute of British Geographers*.

Chapter Overview

To achieve the second aim of this thesis, this chapter considers the ability to extract place-based geographic knowledge from comments on the social media website Reddit. By implementing the geoparsing methodology outlined in Chapter 3, a large volume of place names are identified in these comments, and associated with coordinate information, using the OS Open Names gazetteer. ‘Cognitive place associations’ are generated from these locational mentions, presenting a formalisation of subconscious links between locations that form through the mental maps of individuals in this corpus. To explore the geographic properties of these associations, this chapter generates a measure of distance decay using a gravity model.

Abstract

This paper explores cognitive place associations; conceptualised as a place-based mental model that derives subconscious links between geographic locations. Utilising a large corpus of online discussion data from the social media website Reddit, we experiment on the extraction of such geographic knowledge from unstructured text. First we construct a system to identify place names found in Reddit comments, disambiguating each to a set of coordinates where possible. Following this, we build a collective picture of cognitive place associations in the United Kingdom, linking locations that co-occur in user comments and evaluating the effect of distance on the strength of these associations. Exploring these geographies nationally, associations were shown to be typically weaker over greater distances.

This distance decay is also highly regional, rural areas typically have greater levels of distance decay, particularly in Wales and Scotland. When comparing major cities across the UK, we observe distinct distance decay patterns, influenced primarily by proximity to other cities.

4.1 Introduction

The importance of relational thinking to understand geographical phenomena has been widely acknowledged in human and computational geography (Lukermann, 1961; Bergmann and O’Sullivan, 2018; Glückler and Panitz, 2021). Spatial networks have been explored from a variety of perspectives, to uncover the dynamics underpinning the spatial behaviours of individuals (González, Hidalgo and Barabási, 2008; Noulas *et al.*, 2011), or to challenge conceptualisations of regions as bounded by administrative definitions (Alessandretti, Aslak and Lehmann, 2020; Calafiore *et al.*, 2021).

Within computational geography, most research has explored direct connections between places by investigating physical movements of individuals, using population movement data from both traditional data sources such as Census or surveys (Rae, 2009; Titheridge *et al.*, 2009), or through alternative forms of data like transport records (Farber and Li, 2013; Allard and Moura, 2016; Yang, Li and Li, 2019; Gong *et al.*, 2021), mobile phone data (Lin, Wu and Li, 2019; SafeGraph, 2022; Rowe *et al.*, 2022), and geotagged social media (Steiger *et al.*, 2015; Ostermann *et al.*, 2015; Arthur and Williams, 2019; Li *et al.*, 2021). However, focussing only on connections built through population movement conceals associations that persist through individuals or community subconscious, regardless of any physical movement.

Literature discussing the role of human cognition in constructing mental images of cities (Lynch, 1964), and how they can be represented through mental maps (Gould and White, 1986), reveals that the way humans conceive spatial structures and associations between places are substantially entrenched in individuals’ experiences and geographic knowledge, which only partially derive from movements. Places represent a complex network of socio-spatial relationships that emerge from linked individual experiences (Pierce, Martin and Murphy, 2011), enabling the definition of collectively recognised place associations. While movements in geographic space are limited by time and distance (Patterson and Farber, 2015; Miller, 2018), representational spaces expressed through mental maps are not necessarily bounded by spatio-temporal constraints (Merrifield, 1993). Modern developments in transport and communication access warp the perceptions of distance between places (Massey, 2008), and in turn their perceived level of connectivity (Fabrikant *et al.*, 2002).

Alternatively, online sources of data offer novel opportunities to explore place associations, built directly from the passive contributions of individual users. Recent work has demonstrated how digital social friendships (Bailey *et al.*, 2018), or embedded links in Wikipedia articles (Salvini and Fabrikant, 2016), may be used to provide insight into social place connections. Other works have instead considered that text itself can be used to quantify relationships between geographic terms, described as ‘geo-semantic relatedness’ (Ballatore,

Bertolotto and Wilson, 2014). Work building on this concept has applied it to city and region names identified in news articles, social media, and general web pages (Liu *et al.*, 2014; Hu, Ye and Shaw, 2017; Meijers and Peris, 2019; Ye, Gong and Li, 2021).

Distance is a key influence on observed levels of connectivity in spatial interaction literature (Haynes and Fotheringham, 1985), and Tobler's first law of geography, where locations that are further apart are typically less well-connected (Tobler, 1970), has generated the term 'distance decay' (Taylor, 1983), which has various forms of mathematical representation. Given a legacy of empirical evidence, distance decay in its various forms can be sensibly assumed in place connections when both temporal and spatial constraints are considered in our physical environment. However, when considering the links between locations from the perspective of cognitive associations built through mental maps, such constraints are no longer as restrictive (Fabrikant *et al.*, 2002). Quantifying the effect of distance on cognitive place associations may therefore result in unexpected patterns in the effect of distance on associations, that reveal the cognitive biases used to construct mental maps.

The objective of this paper is to quantify cognitive place associations across the UK¹ to build mental maps, while evaluating the effect of distance on the strength of these associations, measuring the level of distance decay through a gravity model. To generate association measures from a cognitive rather than geographic perspective, we infer associations through co-occurring locations extracted from a large corpus of informal, unstructured and discursive text from the social media website Reddit. Locations when mentioned in informal comments are drawn from a cognitive process associated with mental maps of these locations, subconsciously illustrating associations between places from memory and based on experience.

Section 4.2 outlines existing literature relating to cognitive place associations, detailing methods that can be used for the automated extraction and grounding of place names² from a large corpus of unstructured text. Section 4.3 provides details on our data sources, our methodology for geoparsing place names, and the computation of a gravity model to examine the effects of distance decay on the strength of associations. In Section 4.4 we present the results of our gravity model and demonstrate variations in distance decay with respect to six locations. In Section 4.5 we conclude our findings and outline the scope for future work.

4.2 Cognitive Place Associations

The term 'mental map' typically refers to the cognitive visualisation of a geographic environment. They represent collective, experiential geographic knowledge, relating to both places, and the relationships between them (Kaplan, 1976). Mental maps exhibit a variety

¹Ordnance Survey UK does not include data for Northern Ireland.

²In our work we consider 'place names' to be ambiguous noun phrases found in text, without associated coordinates, while 'locations' are place names that have attributed coordinates. We use 'place associations' to capture the vagueness involved in cognitive associations.

of biases, for example, they are often more detailed with respect to locations that we are familiar with, while others may be less detailed or even absent entirely (Gould and White, 1986). The scale and distance between features in mental maps can be warped (Peake and Moore, 2004; Marston, Jones III and Woodward, 2005); prominent roads may appear larger than in reality, skyline features in a city may be perceived as less prominent due to their irrelevance to an individual at street level (Lynch, 1964; Gould and White, 1986), and good transport connections narrow the time it takes to reach connected locations, which in turn reduces the perceived distance between them (Merrifield, 1993; Massey, 2008). Intermediate features along common routes also have varying levels of importance to individuals; unimportant features may appear less prominent than in reality or absent altogether (Carr and Schissler, 1969; Kaplan, 1976).

The characterisation of mental maps has been well studied from a qualitative perspective, often featuring individual participation for the physical construction of hand-drawn sketches (Lynch, 1964; Lee, 1973; Goodey, 1974; Pocock, 1976; Canter, 1977; Haney and Knowles, 1978; Murray and Spencer, 1979; Gould and White, 1986; Montello *et al.*, 2003). Such approaches typically consider more localised areas that are familiar to selected participants (Pocock, 1976; Canter, 1977; Haney and Knowles, 1978), focussing on mapping landmarks and regions within cities. Others have considered the broad characterisation of larger regions like entire countries (Gould and White, 1968; Goodey, 1974), where mental maps are less detailed, instead contributing generalised information regarding areas that are deemed important to the participant. Inherently, these techniques capture subjective information from individuals, which may not necessarily conform with a generalised collective knowledge of these geographic locations.

4.2.1 Quantifying associations

Within mobility research, connections between locations are broadly quantified through mapping the flow of populations, goods, services or other entities between origin and destination locations (Shaw and Hesse, 2010). This relates to the concept of *Spatial Interaction*, which describes a mathematical or statistical representation of physical movements over space, typically observed in the context of commuting, migration or information and commodity flows (Haynes and Fotheringham, 1985; Shaw and Hesse, 2010; Singleton, Wilson and O'Brien, 2012; Dennett and Wilson, 2013; Rowe, Lovelace and Dennett, 2022; Rowe *et al.*, 2022). In spatial interaction literature, the strength of connectivity between locations is generally quantified through gravity models, which incorporate the effect of relative distance on the strength of interaction between origin and destination locations (Erlander, 1980; Haynes and Fotheringham, 1985). Typically, an increase in distance leads to a decrease in spatial interaction, known as 'distance decay' (Taylor and Openshaw, 1975). While conceptualising geographic connections in this manner builds a picture that is constrained by spatio-temporal movement, this is not necessarily a requirement for a more generalised understanding of associations as a geographic concept (Merriman, 2012).

Unlike physical connections, which are described by movements across Euclidean space, cognitive associations are decoupled from the restriction of physical movements; both the distance between locations, and the time taken to travel between them, do not directly influence the strength of cognitive associations. Instead, they capture the persistent perceived associations that reflect the experiential geographic knowledge used by individuals to generate ‘mental maps’ (Gould and White, 1986). Such associations capture non-specific subconscious links between locations, influenced by personal experiences, incorporating cultural similarities (Greenberg Raanan and Shoval, 2014), distortion through commuting methods and navigation technologies (Peake and Moore, 2004), online communication (Zook, 2006), and other influences on cognitive bias. For example, transport access and telecommunication warp a general sense of perceived geographic distance between certain locations (Massey, 2008), and the cognitive understanding of ‘nearness’ does not necessarily correlate with Euclidean distance (Montello, 1993; Worboys, 2001; Fabrikant *et al.*, 2002). These implicit associations between places are generated through a complex network of socio-spatial relationships, built through linked individual experiences, and allow for shared experiences of places to be captured (Pierce, Martin and Murphy, 2011).

Traditional approaches to the exploration of differences between cognitive and real-world associations would have relied on the use of large-scale studies and active individual participation to derive these associations, for example through volunteered geographic information (VGI) (Goodchild, 2007), or participatory mapping (Chambers, 2006; Pánek, 2016). Additionally, while mental maps may be generated through hand-drawn sketches, such methods do not scale well to derive a population level understanding.

By contrast, alternative forms of data online present an opportunity to infer associations between places, by capturing persistent links that are not temporally or spatially bounded. Facebook for example has been used to generate social connections between locations, geographically grounded based on the home location of two friends (Bailey *et al.*, 2018). Geographic networks may also be generated from crowdsourced databases like Wikipedia (Salvini and Fabrikant, 2016), which demonstrate connections between cities based on hyperlinks embedded in articles that contain general knowledge. Unlike these structured data sources, unstructured online text also provides embedded geographic information as place names, which may be extracted through computational techniques, such as natural language processing (Purves *et al.*, 2018; Berragan *et al.*, 2023b).

Relationships between locational mentions in text are typically examined through co-occurrences, where locations that are frequently mentioned in a shared context are assumed to have a real-world relationship (Liu *et al.*, 2014; Ballatore, Bertolotto and Wilson, 2014; Hu, Ye and Shaw, 2017; Meijers and Peris, 2019; Ye, Gong and Li, 2021). Current research has however concentrated primarily on examining the relationships between city names on news articles (Hu, Ye and Shaw, 2017), or general web pages (Liu *et al.*, 2014), where locational mentions do not necessarily capture a collective and generalised view generated from the mental perceptions of geography that exist within populations.

Alternative sources include online social media, which contribute a large volume of natural language text submitted by many unique users, discussing a range of informal topics, typically with shared user interactions. Place names discussed on social media more frequently include fine-grained locations (Li and Sun, 2014; Han *et al.*, 2018), and given interactions are often more informal, the information captured likely exhibit user cognitive biases related to their own mental maps (Jang and Kim, 2019). While past work has built co-occurring place names from single news articles or documents, they may instead be built from a user facing perspective, building co-occurrences from comments associated with each user in a large corpus of social media data. We argue that this approach more appropriately captures the cognitive information each user uses to associate two locations, which can then be generalised by combining associations across each user in the corpus.

There are however concerns with the use of passively contributed, user-generated data for place-focussed geographic research; primarily with the representativeness of populations, and the bias in contributions (Graham, Straumann and Hogan, 2015; Gardner *et al.*, 2020). For example, despite having over 300 million users, Twitter users typically post from high-density urban areas, rather than where they live (Ballatore and De Sabbata, 2020), demographic groups have variable propensity to contribute (Hecht and Stephens, 2014; Ballatore and De Sabbata, 2018; Gardner *et al.*, 2020), and contributions to gazetteers or digital maps are increased in more densely populated, urban locations (Graham, Straumann and Hogan, 2015; Laurier, Brown and McGregor, 2016; Smith *et al.*, 2020). Another concern with user-generated data comes from the tendency for few users to contribute the greatest proportion of activity (Haklay, 2016), meaning that despite a large volume of unique users, there may be bias towards the contributions of certain individuals. In other research methods like participatory mapping, biases often reflect the social and cultural background of the communities contributing their understanding of geographies (Corbett and Rambaldi, 2009; Pánek, 2016), which in our work equates to the experiential knowledge used to construct those mental maps that inform our cognitive place associations.

4.2.2 Extracting Locations from Text

Past works that considered links between locational mentions in text have identified locations either by querying articles for city names (Hu, Ye and Shaw, 2017), or simply using a word list of city names to parse articles for their occurrences (Meijers and Peris, 2019). Such approaches suffer with performance, Meijers and Peris (2019) for example identified that 2.8% of their target place names could refer to multiple locations, while 1% of names were words that appeared in the English vocabulary. In total, they identify that around 15% of their place names displayed some level of ambiguity, and quantitative assessment of the effect of this demonstrated that it negatively impacted the quality of the associations identified. To avoid such issues, instead of a simple rule-based approach for the extraction of place names from our text, we construct a structured process using machine learning. This implements geoparsing, which is the process of extracting place names from unstructured text and matching them to the correct associated geographic coordinates (Purves *et al.*,

2018). This task can be divided into two stages; identifying place names in text, followed by the association of these place names with a unique identifier in a knowledge base (typically a gazetteer) in a process called geocoding or toponym disambiguation.

Modern geoparsing processes use Named Entity Recognition (NER) to identify place names from natural language text (Haltermann, 2017; Purves *et al.*, 2018; Karimzadeh *et al.*, 2019). Unlike simpler methods which use knowledge or rule-based methods (Leidner and Lieberman, 2011), NER uses more complex supervised machine learning to identify place names. The use of machine learning allows for the identification of place names that do not already appear within formal gazetteers, which is particularly useful in research considering colloquial names (Hollenstein, 2008). Word context may also be used to improve accuracy, as words may appear in a gazetteer but not be used in a geographic context (Reading could be considered a place in the UK or a noun) (Purves *et al.*, 2018). This is particularly important when considering informal text, where capitalisation may not always indicate the use of proper nouns, misspellings may be frequent, and names that do not often appear in gazetteers are common.

Recent work however has noted that current geoparsing systems using existing NER models do not necessarily perform well for the task of place name extraction (Berragan *et al.*, 2023b). Such pre-built models do not always consider geographically specific issues like the use of metonyms (Gritta, Pilehvar and Collier, 2020), and are typically trained on news articles, which limits their performance on other forms of text, like social media (Won, Murrieta-Flores and Martins, 2018; Berragan *et al.*, 2022). For toponym disambiguation, the global GeoNames³ database is typically used as a gazetteer in these geoparsing systems, which has limited data for fine-grained locations in the United Kingdom (Stock *et al.*, 2013; Moncla *et al.*, 2014), while increasing potential noise with the inclusion of place names outside the UK. As such, existing geoparsers were considered unsuitable for our task; geoparsing UK place names within Reddit comments, with the inclusion of fine-grained locations.

4.3 Methodology

We first developed a task-specific geoparsing process to identify all place names contained within the Reddit comment corpus, resolving them to geographic coordinates within the United Kingdom. Cognitive associations were then generated between each identified location using co-occurrence: when identified locations are mentioned by the same author, they create an association between places. These associations are therefore built from the mental maps of individual Reddit users, unbounded from the typical space-time constraints of traditional spatial relationships derived from movements. We then investigate the strength of these associations by deriving aggregate geographic representations derived from each user, and determine the role of distance in shaping the strength of these associations through a gravity model. Finally, we select four urban and four rural regions to map the strength of associations geographically, demonstrating variations in distance decay patterns.

³<https://www.geonames.org>

4.3.1 Geoparsing Reddit Comments

Reddit⁴ is a public discussion, news aggregation social network, and among the top 20 most visited websites in the United Kingdom. As of 2020, Reddit had around 430 million active monthly users, comparable to the number of Twitter users (Murphy, 2019; Statista, 2022). Reddit is divided into separate independent *subreddits* each covering specific topics of discussion, where *users* may submit *posts* that have dedicated nested conversational threads enabling users to add and respond to *comments*. Subreddits cover a wide range of topics, and in the interest of geography, they also act as forums for the discussion of local places. The United Kingdom subreddit⁵ acts as a general hub for related topics, notably including a list of smaller and more geographically specific related subreddits. This list provides a ‘Places’ section, a collection of local British subreddits, ranging in scale from country level (/r/England), regional (/r/thenorth, /r/Teeside), to cities (/r/Manchester) and small towns (/r/Alnwick). In total there are 213 subreddits that relate to ‘places’ within the United Kingdom⁶. For each subreddit, every single historic comment was retrieved using the Pushshift⁷ Reddit archive (Baumgartner *et al.*, 2020). In total 8,070,827 comments were extracted, submitted by 490,534 unique users, between 2011-01-01 and 2022-04-17, this represents a very large corpus of text comprising 262 million words.

We then implemented our own geoparsing methodology to extract and geolocate any place name mention within each comment text. We first identified all place name mentions using a custom-built NER model⁸. This model was built using a large language model called BERT (Devlin *et al.*, 2019), which is pre-trained on a large corpus of general human text, meaning for tasks like NER it performs better compared with simpler models. Our NER model was then trained to identify all place names within this corpus. Coordinate information was attributed with all identified place names, using OS Open Names⁹, and ‘natural’ locations from the Gazetteer of British Place Names¹⁰. Given place names typically appear multiple times in gazetteers, a disambiguation method was required. We therefore disambiguated place names by finding their minimum distance to a collection of contextual locations. Contextual locations in this case referred to all gazetteer entries matching place names that appear in sentences with this target place name, within the same subreddit. This worked under the assumption that each unique place name in a single subreddit is likely to refer to the same location, and that locations mentioned in surrounding text are likely geographically close together (Kamaloo and Rafiei, 2018). When associating locations with coordinate information, we excluded any location that was larger than a city, for example countries or regions.

Our final dataset therefore consisted of a collection of place names with their geographic

⁴<https://reddit.com>

⁵<https://reddit.com/r/unitedkingdom>

⁶https://www.reddit.com/r/unitedkingdom/wiki/british_subreddits

⁷<https://pushshift.io/>

⁸URL provided following submission

⁹<https://www.ordnancesurvey.co.uk/business-government/products/open-map-names>

¹⁰<https://gazetteer.org.uk>

coordinates, corpus location, and an anonymised user ID for the user of the comment the place name was taken from. In total, 213,764 unique users mentioned at least one place name in our corpus, 39,050 mentioned more than 10 place names, and 3,158 over 100. 1% of these contributed 32% of all place names, representing the top 2,137 users. As is common in user-generated content, our data are skewed in that proportionally few users mention a large proportion of our total place names. The large volume of unique users that contribute low volumes of comments do however mean that we likely still achieve a broad representation, particularly compared with past work that generated mental maps for a limited number of individuals (Goodchild and Li, 2012). As our comments spanned a period of over 10 years, we also examined the temporality of contributions made by users. The mean time between a user's first and final comment is 318.1 days, with a maximum of 4112 days. As such, the contributor distribution is highly skewed, as the majority of users (55%) only have commented a maximum of 1 day apart.

4.3.2 Place associations through Co-occurrence

'Cognitive association strength' is defined in our paper as the normalised proportion of co-occurrences between two locations in our corpus, where co-occurrences represent the total collection of locations mentioned by a single user. The following section first outlines the construction of distance decay measures using a gravity model that incorporates cognitive association strength alongside distance, then details how we generate a scaled measure of this cognitive association strength. The first measure enables us to quantify how distance impacts our association strength, determining whether there is an observable distance decay effect when considering locational co-occurrences in user comments. The second enables the direct strength of association between locations to be examined, without the incorporation of distance in the calculation.

To measure the effect of distance decay we employ the same gravity model used by both Liu *et al.* (2014) and Hu, Ye and Shaw (2017), shown on Equation 4.1:

$$\mathbf{S}_{ij} \propto \frac{\mathbf{S}_i \mathbf{S}_j}{d_{ij}^\beta}, \quad (4.1)$$

where \mathbf{S}_{ij} is the total number of users that mention both places i and j , and $\mathbf{S}_i \mathbf{S}_j$ is the total number of users that mention place i , multiplied by the total number of users that mention place j . d_{ij} is the distance between the two locations i and j , and β is the friction factor. Larger values for β indicate a stronger distance decay effect. Estimating the value of β generates a quantifiable measure of the distance decay effect (Hu, Ye and Shaw, 2017).

We can decompose Equation 4.1 into the following multiple linear regression model (Taaffe, 1996):

$$\log(\mathbf{S}_{ij}) = b_0 + b_1 \log(\mathbf{S}_i \mathbf{S}_j) + b_2 \log(d_{ij}), \quad (4.2)$$

where $b_2 = -(\beta * b_1)$, meaning we can calculate our β coefficient using $\beta = -(b_2/b_1)$ (Li and Sun, 2014; Hu, Ye and Shaw, 2017).¹¹

While this approach enables the calculation of a global β to measure distance decay, a spatial regression model would enable us to calculate local values of β , quantifying the distance decay effect on individual locations (Rey, Arribas-Bel and Wolf, 2023). We therefore additionally implement a spatial regression model which incorporates a fixed spatial effect for the H3 polygon name, allowing for β coefficients to be calculated for each location in our study, to explore spatial heterogeneity.

Finally, we generate a normalised cognitive association measure to assess the strength between two locations. Unlike the previous gravity models, co-occurrences are not incorporated alongside distance. This mirrors similar work that considered the strength of social connections between Facebook (Bailey *et al.*, 2018), and Twitter users (Li *et al.*, 2021), enabling the direct strength of associations to be generated:

$$\frac{\mathbf{S}_{ij}}{\sqrt{\mathbf{S}_i \mathbf{S}_j}} \quad (4.3)$$

In this equation, dividing by $\sqrt{\mathbf{S}_i \mathbf{S}_j}$ normalises our values, given locations with higher populations are expected to be mentioned by a larger number of users. Values therefore range from 0 indicating no association, to 1, showing a complete overlap in user mentions.

To present the results of our analysis we aggregate our user location mentions into H3 hexagons¹², a hierarchical spatial indexing system which partitions all locations across earth into a uniform hexagonal grid, available for different levels of aggregation. We select an H3 resolution of 5 which equates to an average hexagon area of 252 km² and an edge length of 9.8 km. All associations between each location contained within a shared H3 hexagon are then combined, forming association measures between hexagons, rather than unique point locations. To name hexagons we select the most frequently occurring location.

The use of fixed unit size hexagons for aggregating data in our analysis is beneficial for several reasons. Firstly, hexagons are geometries that enable us to obtain results that are statistically more robust especially when analysing distance decay between locations, because of the constant number of neighbours, with an equal distance separating them (Birch, Oom and Beecham, 2007). Secondly, hexagon grids help to minimise misrepresentation in spatial visualisation (Langton and Solymosi, 2021), and allow us to capture inter-region heterogeneity. Finally, aggregation is essential given the data representations of locations within gazetteers; despite many locations having large footprints, they are all represented as a single coordinate pair (Goodchild and Hill, 2008). This problem means that despite users mentioning locations like parks within cities, without aggregation they are treated as two distinct points, with a geographic distance separating them. Alternatively OpenStreetMap

¹¹For a more detailed mathematical explanation see Hu, Ye and Shaw (2017)

¹²<https://www.uber.com/en-GB/blog/h3/>

can be used to provide more accurate place footprints, but at the cost of a very large data volume when considering the entirety of the UK (Haklay and Weber, 2008).

Additionally, we classify our H3 hexagons into both rural and urban using the England and Wales Rural Urban Classification¹³ and Scotland Rural Urban Classification¹⁴. For Scotland classes 1 and 2 were considered Urban.

4.4 Results

In the following section, we first examine the performance of our geoparsing methodology, identifying any potential noise and how this was mitigated. We then examine our cognitive place associations, exploring how distance impacts the strength of association by generating gravity models to calculate β coefficients both globally and locally. Finally, we examine the patterns in association strength across a selection of targeted geographic locations.

4.4.1 Extracting Names and Locations: Assessing Geoparsing performance

In total, 26.8% of all comments within the Reddit corpus contained at least one place name: 5,001,261 place names were identified, with 2,848,310 (57.0%) being attributable to a set of coordinates¹⁵. From these locations, 42,333 were found to be unique, of which 21,014 were only mentioned a single time, while London was the most frequently encountered location, at 283,521 mentions. The most ambiguous place name was found to be ‘High Street’, with 47 total unique coordinate locations. As expected, many of the most ambiguous place names were street names, including ‘Church Street’ (36 locations), ‘Bridge Street’ (34 locations), and ‘London Road’ (34 locations).

In Figure 4.1 we consider three examples where place names may have been incorrectly geoparsed. Figure 4.1 (a) shows the geographic distribution of all 47 ‘High Street’ locations. The percentage values indicate the proportion of ‘High Street’ mentions within a particular H3 polygon, compared to all other locations in this polygon. Aggregation here appears to mitigate the risk of noise in most cases, given most ‘High Street’ locations contribute lower than 1% towards polygon associations. A similar case is shown in Figure 4.1 (b), where ‘City Centre’ mentions only account for 3.2% of the Manchester hexagon. Figure 4.1 (c) instead demonstrates a location that is impossible to correctly geoparse in our model, and despite there being 13 unique locations in the UK called ‘California’, this issue only appears prominent in one hexagon. This hexagon named ‘California’ does potentially generate noise in our analysis, given the high contribution of 85.1%. However, as users that mention ‘California’ are spread across the country, it is less likely to largely impact our associations.

Notably, despite both ‘High Street’ and ‘City Centre’ being shared with non-specific geographic concepts, the model is still able to distinguish between them depending on context.

¹³<https://www.gov.uk/government/collections/rural-urban-classification>

¹⁴<https://www.gov.scot/publications/scottish-government-urban-rural-classification-2020>

¹⁵Note that many names absent from our gazetteer include locations outside the UK



FIGURE 4.1: Locations of three place names that appear in the UK gazetteer that are difficult to correctly disambiguate. Size of the green points indicate frequency in mentions, black points are user locations determined through mean locational mentions. Values indicate the proportional contributions of each disambiguated location to their respective polygon (Top four percentages shown).

For example, ‘city centre’ appears 23,961 times in our corpus, but is only tagged by our NER model 3,008 times. While ‘high street’ appears 7,773 times and is only tagged 768 times. These results suggest that the model is often able to correctly understand that identical phrases may or may not refer to place names, depending on their semantic context.

4.4.2 Measuring Distance Decay of Cognitive Association Strength

In the following section we present the levels of distance decay observed when evaluating place association strength through the gravity model specified in Equation 4.1, quantifying the level of distance decay using a β coefficient. As calculated, higher β coefficient values indicate a stronger distance decay effect, meaning that co-occurrences between locations that are geographically more distant tend to be less frequent. A β value of zero would indicate that distance has no effect on the frequency of co-occurrences between locations.

Our gravity model gives a β coefficient of 1.00 (Pearson’s R^2 : 0.772), reflecting a distance decay from co-occurrences in Reddit comments that is stronger than decay observed in other studies that explored news articles (0.23) (Hu, Ye and Shaw, 2017), or general web queries (0.2) (Liu *et al.*, 2014). Confirming the existence of a general distance decay effect for Reddit derived places demonstrates that distance typically contributes to lower co-occurrences in locations that are further apart, a similarity that is shared with past work that examines decay from the perspective of true population movements (Yang, Li and Li, 2019; Gong *et al.*, 2021), and the social relationships of regions examined through social media (Bailey *et al.*, 2018; Li *et al.*, 2021). Our place associations generated from users on Reddit therefore appear to more appropriately incorporate a geographic component, compared with city mentions in news articles or general web pages. However, while this gravity model gives us an indication of the global level of distance decay in our corpus, it is likely that the level of distance decay varies by location. In the following analysis we therefore consider locations where the gravity model does not achieve a good approximation.

Figure 4.2 (a) and (b) plots the top (most positive) and bottom (most negative) 20 residuals from our gravity model, demonstrating associations that are stronger or weaker than expected, when accounting for the distance between two regions. Many of the top residuals concern associations shared with London and other major cities in the UK, with some associations between urban areas in Scotland. The most positive residual is the association between London and Edinburgh (3.89), Glasgow and London in second (3.84), and Glasgow and Edinburgh in third (3.81). As expected, these residuals reflect a strong association between regions over larger distances (mean 293 km), highlighting associations where distance decay is less effective. Notably, there is an incorrect association here between a natural feature named ‘London Bridge’ and London, which has appeared due to the lack of urban landmarks in our gazetteer. The bottom residuals are more sporadic, typically showing associations over shorter distances (mean 156 km), between lesser known locations that are unusually weak. For example, highlighted on this figure is the association between Swansea Bay and Southampton (-2.55). Figure 4.2 (c) plots the model residuals against cognitive association strength, showing that for locations with a greater proportion of co-occurrences,

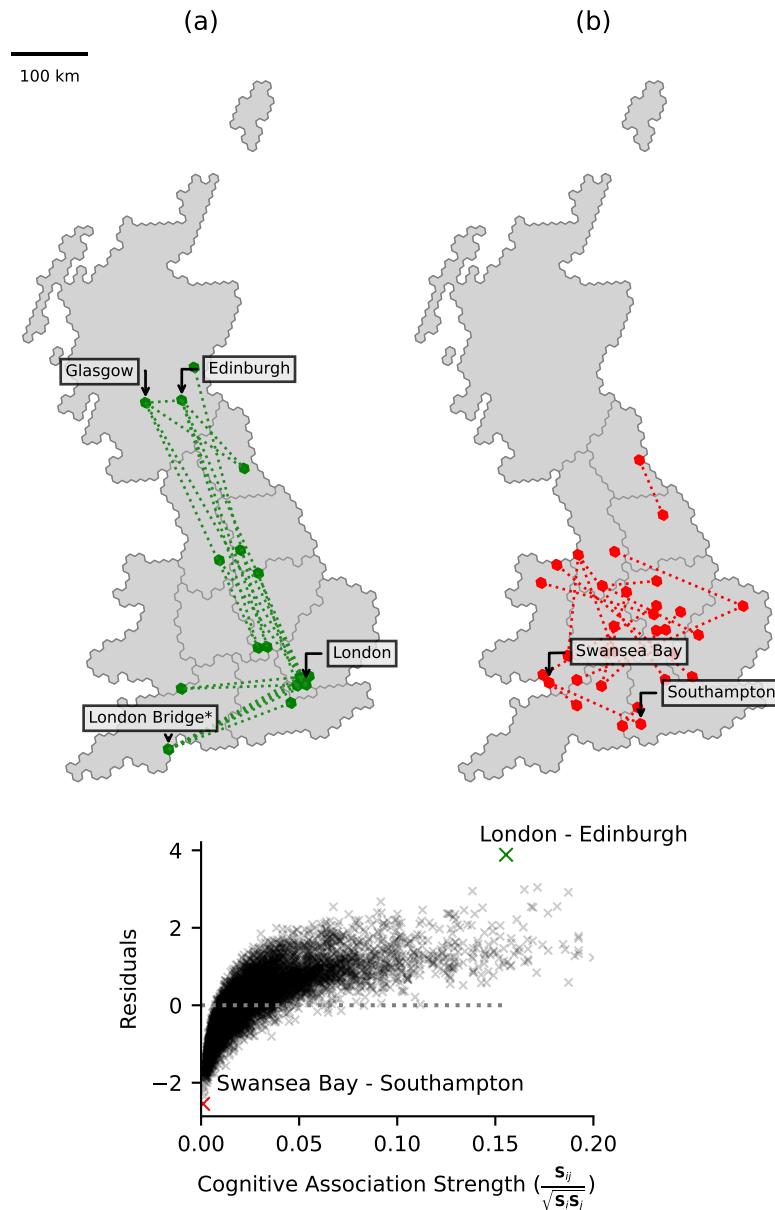


FIGURE 4.2: H3 polygons showing (a) Top 20 associations by residual values in green (>0), and (b) bottom 20 associations by residual values (<0) in red. (c) Residuals taken from Equation 4.2 against co-occurrence strength (10,000 samples). (*) Indicates a location that is incorrectly geoparsed.

the model is likely to be under-estimating in prediction, leading to an over-prediction in distance decay, with the inverse true for locations with a lower proportion of co-occurrences.

4.4.3 Regional Difference in Distance Decay

Figure 4.2 demonstrates that there are clear regional variations in the observed level of distance decay, which do not conform with the general decay effect calculated through our proposed gravity model approximation. To examine regional effects on distance decay, we implement a spatial regression model (a mixed linear model with spatial fixed effects), allowing β values to change depending on the location of each polygon.

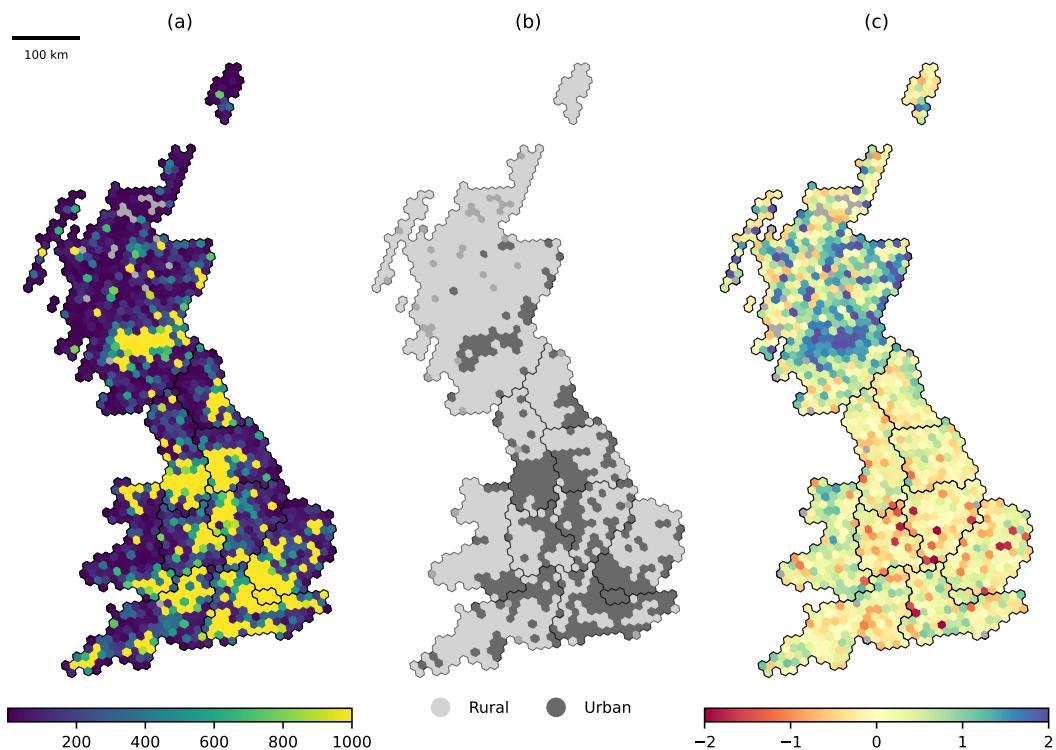


FIGURE 4.3: H3 polygons showing (a) Distribution of geoparsed locations. (b) Urban rural classification index for England, Wales, and Scotland, re-classified into binary ‘Urban’ or ‘Rural’. (c) Calculated β coefficients for the spatial regression model; higher β values indicate a greater distance decay strength.

Incorporating this spatial information gives a more effective approximation of our gravity model, and achieves an improved Pearson’s R^2 of 0.946, suggesting that distance decay is not uniform across all regions in our study. Figure 4.3 (a) shows the distribution of locations mentioned in our study, which broadly conform with the binary urban rural classification shown on Figure 4.3 (b). Figure 4.3 (c) maps the spatial β coefficients obtained through our spatial regression model, with high distance decay present across Scotland, Wales, and areas in the South West and North East of England. Users that mention locations in these regions typically do not mention other locations that are geographically distant, highlighting areas that are either more isolated from the rest of the UK, or have stronger associations with nearby locations.

In the North East, this perceived isolation from the rest of the UK mirrors lexical research, where Tweets in the North East have been shown to be unlike other regions (Arthur and Williams, 2019). This region in particular has been known to suffer economically following the historic decline of local industries (Middleton and Freestone, 2008), where lack of job opportunities has resulted in poor inward migration, with among the lowest population growth in the country (Office for National Statistics, 2022). Alternatively, this observation may be also attributable to a general sense of identity that is associated with these regions. Both the South West and North East of England are known to exhibit a strong sense of localised identity (Deacon, 2007; Middleton and Freestone, 2008), which is similarly translatable to the national identity that generates strong associations within Scotland and Wales, that are not shared with England (Haesly, 2005).

To explicitly quantify the difference in distance decay between urban and rural areas we calculate separate β coefficient values based on the binary split of areas into urban or rural. Urban areas have a β coefficient of 0.68, while rural areas had a β coefficient of 1.14, indicating that urban areas do appear to have a lower overall level of distance decay compared with rural regions. This correlates with the results of traditional mobility studies where more populated areas tend to exhibit a lower distance decay (Thomas, 1981), largely dictated by the improved accessibility to external locations through public transport, the road network or job opportunities (Findlay, Short and Stockdale, 2000; Moseley, 2023), and the general cultural significance that is more frequently associated with urban locations (Lynch, 1964; Borer, 2006).

We have demonstrated that not only does distance decay vary between rural and urban locations, but within these classes there is also apparent heterogeneity. In the following section, we therefore consider the ability to directly map the strength of cognitive associations with respect to a selection of both rural and urban regions in our study, to understand the variation in distance decay patterns.

4.4.4 Mapping Cognitive Place Associations

In Figure 4.4 we map the cognitive association strength of each H3 polygon in our study, with respect to four major cities, and four rural locations in the UK, also indicating the associated β coefficients. Mapped cognitive association values are given by Equation 4.3, and indicate the proportion of users that have comments that mention locations both within the target polygon (e.g. London), and locations in other polygons. Distance decay curves for each polygon are shown below these maps, indicating patterns in decay associated with each location. London has the lowest β coefficient of all cities, indicating that locations at increasing distance from London decay in their association at a slower rate compared with other cities. This is reflected by the shallow overall decay curve for London, increasing at points associated with main urban conurbations in England and Scotland, observable on the map for Figure 4.4 (a). Such trends are perhaps unsurprising given London's prominence as the capital city. Manchester on Figure 4.4 (b) reveals a different decay pattern, showing a sharp drop in associations initially, that reduces and reverses when cities like London or

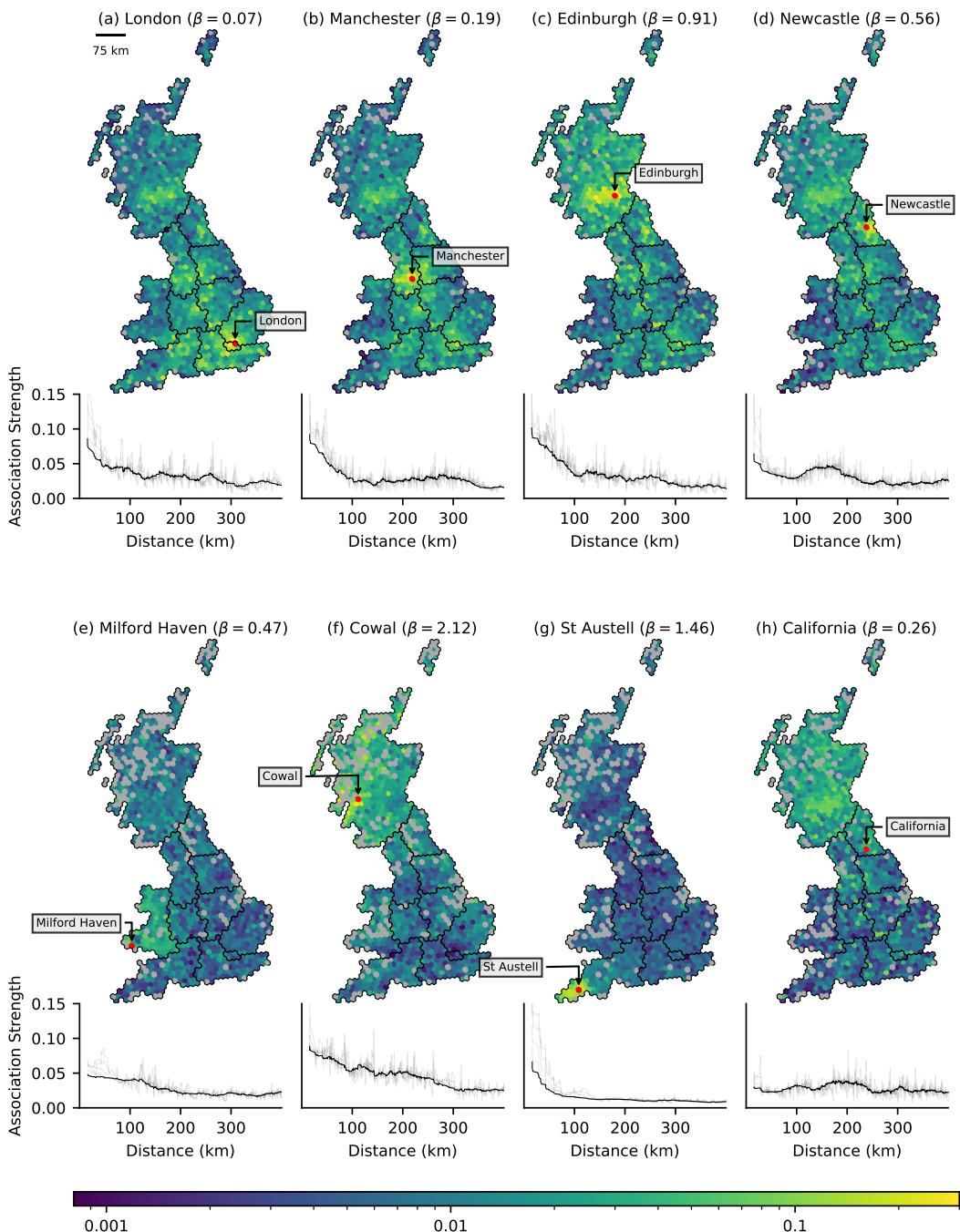


FIGURE 4.4: Data subsets with respect to eight selected locations showing cognitive association strength associated with each H3 polygon containing each named location (highlighted in green), β values generated from data subsets. Distance decay plots below maps show association strength against distance for each selected location. Lines show rolling mean for 250 samples in black and lower samples in grey.

Edinburgh are included in the distribution. Unlike Manchester, Newcastle (d) has an overall greater β coefficient, where association strength drops more quickly and is less persistent across England, only increasing with urban locations in Scotland, and slightly with London. While both are major cities in England, Manchester is both physically more well connected to the rest of the country through existing rail routes (Miyoshi and Givoni, 2013), and is a greater economic centre compared with Newcastle. These factors likely contribute to the perceived strength of associations with these cities, which is captured in our analysis.

Edinburgh (c) is distinct compared with other cities, with a steeper initial decay curve compared with London, largely dictated by stronger initial associations with Scottish locations. Again, as is common for many cities in the UK, this city also shares a strong association with London, regardless of the distance. This increased strength of association with locations within Scotland gives Edinburgh the highest β coefficient, an effect that captures the strong sense of identity between areas in Scotland (Haesly, 2005).

Figure 4.4 (e-g) give examples of variable distance decay curves for rural locations across the UK. Both '(e) Milford Haven' in Wales, and '(f) Cowel' in Scotland share general associations across each respective country, which appears to drop past the border into England. This similarly captures the sense of national identity associated with both Wales and Scotland, and conforms with results from the analysis of both physical and networks, where strong 'boundary effects' often see intra-connectivity within regions, that becomes weaker when moving across borders (Yin *et al.*, 2017; Bailey *et al.*, 2018; Arthur and Williams, 2019; Li *et al.*, 2021). Given a national identity is less prominent in England, the town '(g) St Austell' gives a steep distance decay curve, with low association strength between any location more than 50 km away, a noticeably different curve compared with the rural locations analysed in Scotland and Wales.

We also examine the incorrectly disambiguated '(h) California' polygon, and confirm that the distance decay curve does not appear to show a geographically cohesive pattern, with no noticeable gradient. The positive β coefficient appears to relate with an unexplained increase in association with Scotland, however values remain low.

4.5 Conclusions, Implications and Future Work

In our work we present an alternative method for determining subconscious associations between locations, generating quantifiable measures of association strength solely using user-generated social media text. Unlike physical or online social interactions, our cognitive associations are intended as persistent measure of strength between locations across the UK, built from the naive, place-based geographic knowledge of individuals. Our geoparsing process means that no explicitly geographic information like geotags are required in our data source, allowing for the inclusion of fine-grained and informally defined locations, and associations may be examined between any two locations identified in our corpus.

By utilising a distance-based gravity model, we demonstrate that our associations do broadly conform with established real-world geographic restrictions, through an observed distance-decay effect, but with notable deviations. Unlike past work that only considered co-occurring city names, we expand our analysis to incorporate place name mentions of any scale, which enables the exploration of both rural and suburban decay. We are therefore able to demonstrate that distance decay is greater in rural areas compared with urban areas, and that cities across the UK have varying patterns in distance decay. Associations between major cities like Manchester and London are demonstrably stronger than less prominent intermediate locations, an effect that challenges the notion of Euclidean distance in a mental understanding of geography (Carr and Schissler, 1969; Kaplan, 1976), and conforms with the suggestion that ‘nearness’ is not a uniform concept (Montello, 1993; Worboys, 2001; Fabrikant *et al.*, 2002; Massey, 2008). Alternative patterns are also demonstrated, particularly for locations in Scotland, where distance appears to have little impact on association strength, until locations across the border into England are reached. This observation appears to correlate with the concept of a ‘boundary effect’, that has been captured in both physical and online networks (Yin *et al.*, 2017; Bailey *et al.*, 2018; Arthur and Williams, 2019; Li *et al.*, 2021). This example is particularly interesting, replicating past research that generated mental maps from individuals through participatory mapping, which captured strong desirability towards areas within Scotland from residents, that did not persist across the border into England (Gould and White, 1968)

The distinct patterns in distance decay that we observe demonstrate differences in associations between cities that capture real-world perceptions of these locations. For example, regions of low association across the UK may reflect the lack of desire to connect more broadly with the rest of the country (Roos Breines, Raghuram and Gunter, 2019). This is particularly noticeable in Scotland, Wales, and the North East of England, regions where populations often exhibit a strong sense of independence from the UK, driven by a sense of regional or national pride (Haesly, 2005; Middleton and Freestone, 2008; Nayak, 2016). Strong associations with London and Manchester are also indicative of their importance nationally, while cities like Newcastle are perceived as less important, resulting in lower associations. Imbalance in rural locations may also be driven by an increasing dependence on digital maps (Farman, 2020); rural landmarks are far less common compared with cities with named streets and buildings (Laurier, Brown and McGregor, 2016), limiting our ability to conceptualise rural environments (Smith *et al.*, 2020).

Finally, Reddit is unique compared with alternative social media sources; general activity is centred around discussing specific topics or themes within communities, relative to more general social networks such as Twitter or Facebook (Medvedev, Lambiotte and Delvenne, 2019; Sylla *et al.*, 2022). Communities on Reddit therefore present the opportunity to generate collective, but geographically disaggregated representations of spatial knowledge. Locations identified from within these communities likely represent urban areas of interest

which may be derived based on their frequency of mentions (Chen, 2019), or semantic regions that reflect mental perceptions of places (Gao, Janowicz, *et al.*, 2017). These unstructured comments also provide contextual lexicons relating to places names, meaning there is also the opportunity to explore associations between these communities through their associated typology (Gao, Janowicz, *et al.*, 2017; Arthur and Williams, 2019). While count-based lexical approaches have been traditionally used to explore geographic variation in text, large language models are now able to capture deep contextual semantic information (Devlin *et al.*, 2019), allowing for a deeper connection between language and geography to be explored.

Chapter 5

Mapping Great Britain's Semantic Footprints through a Large Language Model Analysis of Reddit Comments

The content of this chapter is *under review* for publication in *Computers, Environment and Urban Systems*.

Chapter Overview

Utilising the corpus of locational mentions developed in Chapter 4, this chapter explores how the semantic properties of text associated with locational mentions vary across geographic space, achieving the third aim of this thesis. While Chapter 4 explores the subconscious associations between locations that exist within mental maps, this chapter instead considers more broadly how the vernacular geography of users may exhibit geographic heterogeneity. To capture the semantic properties of text this chapter generates ‘semantic footprints’, which are numerical representations of the vernacular geography relating to locations, generated through a large language model. The findings of this chapter consider more broadly how place-based knowledge may be represented, abstracting from specific concepts, like the way people conceptualise associations within mental maps. Instead, this chapter explores how general vernacular geographic knowledge can be represented through semantic footprints, and analysed geographically.

Abstract

Observed regional variation in geotagged social media text is often attributed to dialects, where features in language are assumed to exhibit region-specific properties. While dialects are seen as a key component in defining the identity of regions, there are a multitude of other geographic properties that may be captured within natural language text. In our

work, we consider locational mentions that are directly embedded within comments on the social media website Reddit, providing a range of associated semantic information, and enabling deeper representations between locations to be captured. Using a large corpus of geoparsed Reddit comments from UK related local discussion subreddits, we first extract embedded semantic information using a large language model, aggregated into local authority districts, representing the semantic footprint of these regions. These footprints broadly exhibit spatial autocorrelation, with clusters that conform with the national borders of Wales and Scotland. London, Wales, and Scotland also demonstrate notably different semantic footprints compared with the rest of Great Britain.

5.1 Introduction

The prevalence of social media data for use in geographic research has generated a renewed interest in the concept of ‘place’ (Westerholt, Mocnik and Zipf, 2018; Purves, Winter and Kuhn, 2019; Wagner, Zipf and Westerholt, 2020), as contributions to social media are theorised to capture informal knowledge that represents a place-based understanding of geography (Goodchild and Li, 2011; Sui and Goodchild, 2011). In the context of language, this place-based knowledge is generated through ‘vernacular geography’, which describes the natural language used when informally describing geographic locations (Waters and Evans, 2003; Hollenstein, 2008; Goodchild and Li, 2011; Gao, Janowicz, *et al.*, 2017). This informal knowledge incorporates biases regarding locations, better representing human perceptions of geography, compared with formal administrative definitions. In this sense, associations of geography drawn from social media capture place through a ‘bottom-up’ approach, building knowledge through experience rather than administrative formalisations (Agnew, 2005; Sui and Goodchild, 2011). While many works have considered the formalisation of place through geotagged social media data, few have considered how the semantic properties of text may reveal geographic heterogeneity between regions, generated directly through vernacular geography. The components of vernacular geography are closely coupled with the identity of regions, where culture, topics, and general perceptions are captured through the language associated with locational mentions in text (Paasi, 2003; Buttmer, 2015).

Many works have considered the geographic variation in geotagged social media text (Russ, 2012; Doyle, 2014; Gonçalves and Sánchez, 2014; Eisenstein *et al.*, 2014; Huang *et al.*, 2016; Pérez *et al.*, 2019; Arthur and Williams, 2019), focussing primarily on how dialect changes may be observed through differences in the vocabulary (lexicons) of contributors over geographic space. For example; Tweet lexicons originating in the North East of England are noticeably different compared with the South (Arthur and Williams, 2019). While dialects do demonstrate geographic heterogeneity, they only present one component of language that may exhibit geographic variation, and do not directly contribute properties associated with vernacular geography. This limitation stems primarily from the reliance of these works on geotagged social media, where the textual content rarely relates to the geotagged location (Kropczynski *et al.*, 2018), meaning dialects are the only explainable trait that results in geographic heterogeneity.

In our work we instead consider the ability to compare the geographic variation in semantic information relating to locational mentions embedded directly within social media text. This approach means that instead of solely focussing on dialects, our semantic differences capture a broad range of associations between locations, contributed by the vernacular geography of users. While a lexical approach explores the vocabulary of a language, we instead generate sentence embeddings using new developments in natural language processing, which enable nuanced semantic information to be numerically represented (Devlin *et al.*, 2019), allowing for deeper associations with locations to be captured (Hu *et al.*, 2020). We name these representations the ‘semantic footprints’ of locations. We then analyse these

semantic footprints, to determine whether they exhibit spatial autocorrelation or geographically cohesive clustering. Additionally, to generate an explainable characteristic of these footprints, we explore whether generated national identities of location associated text correlates with regions where footprints appear more semantically isolated. To achieve this, we utilise the emergent properties of large language models (LLMs), where a task known as zero-shot classification enables models to assign labels to text, without any annotated training data. We therefore query an LLM to attribute a specific sub-nationality within the United Kingdom to each of our comments, and explore whether the varying strength of these nationalities correlate with differences in our semantic footprints.

Section 5.2 first gives an overview of work exploring semantic variation in social media text, regional identities, and how our approach differs to related work. Section 5.3 describes our data, then outlines the processing used to generate semantic footprints and describes our geographic analysis of these footprints. Section 5.4 presents our results and Section 5.5 concludes with suggestions for future work.

5.2 Geographic Variation in Social Media Text

While formal geographic regions within Great Britain are typically designed for administrative and political purposes, they are non-restrictive in how populations can move between them. The level of geographic cohesion between regions across Great Britain is often studied from the context of mobility, where data sources like Census or transport records describe the physical movement of populations and individuals across geographic space (Rae, 2009; Titheridge *et al.*, 2009), or through non-physical networks using phone records (Lambiotte *et al.*, 2008; Reades, Calabrese and Ratti, 2009; Sobolevsky *et al.*, 2013; Zheng, 2015), and social media (Sui and Goodchild, 2011; Lengyel *et al.*, 2015; Arthur and Williams, 2019). When these networks are examined, cohesive clusters develop, which broadly appear to correlate with administrative boundaries (Ratti *et al.*, 2010; Arthur and Williams, 2019).

Alternatively, many works have taken advantage of the abundance of geotagged social media text, to examine regional differences in dialects (Russ, 2012; Han, Cook and Baldwin, 2012; Eisenstein *et al.*, 2014; Gonçalves and Sánchez, 2014; Doyle, 2014; Huang *et al.*, 2016; Zheng, Han and Sun, 2018; Arthur and Williams, 2019). Many of these works have noted that, like online or physical networks, geographically cohesive properties emerge, which appear to correlate with administrative boundaries (Eisenstein *et al.*, 2014; Gonçalves and Sánchez, 2014; Huang *et al.*, 2016; Arthur and Williams, 2019). These results conform with the idea that dialects are an important component in the identity of regions (Haesly, 2005; Llamas, 2009; Llamas and Watt, 2014). Despite this, dialects only present a single component of language that contributes to a sense of geographic identity between regions (Haesly, 2005; Middleton and Freestone, 2008), ignoring the wealth of vernacular geography that may also be captured in text (Evans and Waters, 2007; Sui and Goodchild, 2011; Berragan *et al.*, 2023b).

Studies that consider dialect variation in social media text only consider geotags to be a geographically relatable feature of this data source. Given social media communication comprises a broad range of topics that do not necessarily relate to locational discussion, these geotags and associated text are unlikely to be directly related. Any observed regional variation is therefore only attributable to the dialect of the contributing author, with the assumption that the author is a resident in the geotagged location. In contrast to this approach, locational mentions embedded directly within text present an alternative method to explore how the language regarding locations varies geographically. Place names embedded within text directly can also be related with the surrounding context of their use, capturing the vernacular geography of contributing users (Evans and Waters, 2007; Sui and Goodchild, 2011). Lexicons associated with locations identified in this manner therefore incorporate a broad range of topics, associations, and cultural information, rather than solely dialects, more broadly capturing the components of language that contribute to the identity of locations (Haesly, 2005). In our work, we therefore extract place names from a collection of UK specific comments taken from the social media website Reddit, attributing coordinate information through a process called geoparsing (Purves, Winter and Kuhn, 2019), allowing for us to explore the geographic heterogeneity of text associated with identified locations.

While past works have primarily considered the statistical comparison between location-based lexicons, where word counts are associated with aggregate regions generated through geotagged Tweets, this approach is limited when considering the more nuanced semantic variations in vernacular geography. Recent progress in natural language processing have led to the development of large language models (LLMs) which are able to capture deep contextual semantic information from text, through sentence and word embeddings (Devlin *et al.*, 2019). Unlike a lexical approach, where word order and semantic information is not captured, these embeddings act as numerical representations of text which incorporate contextual semantic information in depth. Embeddings that are more semantically similar are closer together in their embedding space, meaning, like lexicons, these embeddings may be statistically compared. We therefore generate sentence embeddings for each comment in our corpus that contains a place name, which are then aggregated by location, forming what we call a semantic footprint. These footprints represent the collective geographic knowledge of each individual user in our corpus, built through their vernacular geography, capturing informal, place-based information through their perception of geoparsed locations (Sui and Goodchild, 2011; Goodchild and Li, 2011).

In this work we generate a new comparative measure between regions in the UK through an examination of text associated with locations, extracted from comments on the social media website Reddit. While past work has examined variation between regions from the perspective of social media networks, or by examining lexicons associated with geotagged social media messages, we examine regional variations derived from geoparsed embeddings generated from a large language model. Unlike using geotags, which ascribe linguistic features such as dialect to specific locations, our method instead captures any comment that mentions a location alongside its semantic context. Quantified information therefore does

not reflect dialects associated with locations, but common semantic associations, embedding cultural information, or location specific topics and opinions. Given users mentioning locations are not necessarily residents, these semantic associations represent a collective informal geographic knowledge generated through the vernacular geography of people across the UK, embedding their general semantic footprint.

5.3 Methodology

The following section first introduces our main data source; the social media website Reddit, from which we access a collection of user submitted comments. Following this, we detail our methodology for generating semantic footprints from each of these comments, and how we analyse the geographic properties of these footprints.

5.3.1 Data

Reddit is a public discussion, news aggregation social network, and among the top 20 most visited websites in the United Kingdom. In 2020, Reddit had around 430 million active monthly users, comparable to the number of Twitter users (Murphy, 2019; Statista, 2022). Reddit is divided into separate independent *subreddits* each with specific topics of discussion, where *users* may submit *posts* which each have dedicated nested conversation threads that users can add *comments* to. Subreddits cover a wide range of topics, and in the interest of geography, they also act as forums for the discussion of local places. The United Kingdom subreddit acts as a general hub for related topics, notably including a list of smaller and more specific related subreddits. This list provides a ‘Places’ section, a collection of local British subreddits, ranging in scale from country (*/r/England*), region (*/r/thenorth*, */r/Teeside*), to cities (*/r/Manchester*) and small towns (*/r/Alnwick*). In total there are 213 subreddits that relate to ‘places’ within the United Kingdom¹. We use the corpus generated by Berragan *et al.* (2023a), which consists of a collection of all Reddit comments taken from each UK related subreddit (Baumgartner *et al.*, 2020), with place names identified by a custom transformer-based named entity recognition model². In total 8,282,331 comments were extracted, submitted by 490,535 unique users, between 2011-01-01 and 2022-04-17. Table 5.1 gives an example entry from this geoparsed Reddit corpus.

There are a total of 40,429 unique locations in this corpus, with a highly skewed distribution in mentions. Many locations were only mentioned a single time (37%), while ‘London’ was mentioned in 283,521 comments. To reduce this skew, we sampled any location mentioned more than 5,000 times, retaining only up to 5,000 randomly sampled comments per location. The goal with this processing was to ensure that our generated embeddings did not simply become biased towards the word embedding for a single location, and instead capture a broader sense of an aggregate region. In our data subset, we find that 1% of users (1,734) mention 29% of our place names. This subset leaves a total of 852,461 comments containing

¹https://www.reddit.com/r/unitedkingdom/wiki/british_subreddits

²https://huggingface.co/cjber/reddit-ner-place_names

TABLE 5.1: Example entry from the geoparsed Reddit corpus.

Variable	Value	Description
text	A Mexicana meal with extra wings from Tex in Leytonstone.	Comment
word	leytonstone	Identified Place Name
easting	539,268	Place Name Easting
northing	187,540	Place Name Northing
region	London	Administrative Region
lad	Waltham Forest	Local Authority District
author	t2_eklyq	Anonymised Unique Author ID
word_count	855	Total location mentions
author_count	431	Unique authors mentioning this location

TABLE 5.2: Summary of comments relating to each region in our study.

RGN22NM	Total Comments	Unique Words	Word Count	Total Places
London	222,745	454,971	26,144,378	6,338
Scotland	180,275	434,552	22,868,507	7,796
South East	146,887	384,919	16,565,810	7,935
North West	122,010	346,764	14,591,529	7,279
South West	100,291	304,622	11,209,793	6,117
Yorkshire and The Humber	92,690	286,316	10,801,344	6,304
East Midlands	90,785	280,912	10,179,007	6,557
East of England	79,511	260,249	8,495,673	4,936
West Midlands	61,346	233,914	7,285,005	4,846
North East	37,100	163,772	4,345,753	2,446
Wales	30,436	130,288	3,833,168	2,276
None	14,366	104,003	1,425,291	1,075
Total	852,461	1,265,587	137,745,258	40,428

place names. Comments range from 1 to 3,555 words in length, with a mean length of 79. Table 5.2 gives an overview of the number of comments, word count and number of places that were identified within each administrative region of the UK.

5.3.2 Generating and Analysing Geographic Footprints

Statistical comparisons between two or more distinct texts first relies on an appropriate method for processing the text into a numerical format. Typically, a TF-IDF approach is used to generate document embeddings (Daniel and James H, 2007), which assigns word importance based on the frequency of mentions within a corpus. TF-IDF however does not have the capability to capture broader semantic information, given that there is no knowledge of the meaning behind words. Large Language Models (LLMs) instead are pre-trained on a very large corpus of natural language text, which, alongside their architecture, enables them to more appropriately consider semantic information (Devlin *et al.*, 2019). As with TF-IDF, text is input into these models and output as a numerical representation, which embeds words as high dimensional vectors, capturing contextual semantic information.

This approach differs from past work that only considered a lexical analysis, where semantic information and context is not preserved, instead building vectors that act as semantic representations of locations identified in our corpus, which we name ‘semantic footprints’. Given semantic information is preserved, locational embeddings are able to reflect the deeper associations between geographic locations, built from a multitude of contexts and perspectives, forming an aggregate representation. Any geographically cohesive relationships between footprints therefore demonstrate a direct association between geography and language, which hasn’t been captured previously.

Once we generate these footprints we first explore how they produce emerging spatial structures from the bottom-up, generating clusters of small-scale geographic units to capture larger scale aggregations based on semantic information. In this analysis we find that our generated spatial structures broadly conform with larger scale administrative aggregations. We therefore then consider a top-down approach, using these larger administrative regions to generate a comparative analysis of aggregate footprints. To derive explainable characteristics of observed differences between these regions, we observe how national identities can be captured through text, and how these identities vary geographically.

5.3.3 Creating Embeddings

We first create semantic embeddings for each comment in which a location was mentioned, using the `sentence-transformers` Python library (Reimers and Gurevych, 2019), with the `all-mpnet-base-v2` model³. With our selected embedding model, we then performed the following steps to generate embeddings for each Local Authority District (LAD) in Great Britain.

1. Masked any place name with a generic token: ‘PLACE’.
2. Generate sentence embeddings for each comment.
3. Group embeddings by LAD using identified locations, taking the mean embedding.

To visualise the outputs from this processing we consider an example comment $s_1 = \text{"I live in London."}$, shown on Equation 5.1.

$$\begin{aligned}
 s_i &= \text{'I live in London'} \\
 1. \downarrow & \\
 s_i &= \text{'I live in PLACE'}, \\
 2. s_i \rightarrow & \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}, & 3. LAD_j = & \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,t} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,t} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n,1} & x_{n,2} & \cdots & x_{n,t} \end{bmatrix} \rightarrow & \begin{bmatrix} \bar{x}_1 \\ \bar{x}_2 \\ \vdots \\ \bar{x}_n \end{bmatrix} & (5.1)
 \end{aligned}$$

In Equation 5.1, n is the `sentence-transformers` embedding dimension (768), and t is the total number of unique comments that relate to a single LAD region (LAD_j). Values (x_i) in step 2. are model weights that represent the embedding for the comment s_i , capturing semantic information. All comment embeddings associated with LAD_j are then processed into one dimension by taking the mean (step 3.), producing the semantic footprint. Given

³<https://huggingface.co/sentence-transformers/all-mpnet-base-v2>

sentence embeddings are the mean average of word embeddings, and are used in many tasks like topic identification or sentence similarity with good results (Reimers and Gurevych, 2019), taking the mean of our embeddings to form lower dimensional semantic footprints is expected to perform well.

By masking place names we ensure that no comment embeddings accidentally incorporate geographically grounded information. For example, comments in South Eastern local authorities are likely to frequently mention London, given they are geographically proximal. Embeddings for these locations would therefore capture an association through the mention of London, rather than general semantic information. For our work, we want to exclude any geographic information, ensuring that embeddings solely capture semantic associations.

Given that transformers are a relatively new architecture in natural language processing, and the creation of these models require significant computational resources and training time, their use to date has been limited in related research. Our choice to use the transformer architecture stems from the emphasis we place on the extraction of nuanced and contextual semantic information, which is lost with lexical count-based methods like TF-IDF. It should be noted however that while TF-IDF methods are less complex, they are typically more interpretable; for instance, words that contribute importance to an embedding may be extracted from a TF-IDF model. The numerical representations of any text generated by transformers are not directly interpretable in this manner. The following section therefore analyses our semantic footprints with respect to their numerical representations, rather than through their lexicons.

5.3.4 Spatial Clustering and Autocorrelation

It is reasonable to assume that there are LADs within our corpora that generate embeddings that capture similar semantic properties. A typical method to group unlabelled multivariate data based on shared properties uses unsupervised clustering (Likas, Vlassis and J. Verbeek, 2003; Sinaga and Yang, 2020). Therefore, to explore whether geographically cohesive clusters appear within our semantic embeddings, we generate hierarchical clusters, which are non-geographically bounded, using agglomerative clustering. We used a dendrogram to determine the suitable number of clusters to be 3, balancing interpretability with in-cluster homogeneity. These clusters were visualised geographically, to examine whether geographically cohesive groupings occurred. The proportion of clusters present within each administrative region (RGN)⁴ in Great Britain was also plotted to determine whether clusters appeared to correlate with administrative boundaries.

We also considered whether embeddings demonstrated spatial autocorrelation through the Moran's I metric, and identify geographic clusters of shared semantic attributes, using a Local Indicators of Spatial Autocorrelation (LISA) analysis (Anselin, 1995; Rey, Arribas-Bel and Wolf, 2023). As spatial autocorrelation analysis is only univariate, we reduce embeddings into 2 dimensions using a UMAP decomposition for this analysis, rather than the original

⁴The highest tier of sub-national division in England. For Scotland and Wales we use the full national extents.

768 dimensional embeddings, producing two distinct LISA figures. It is important to note that the magnitude of these embeddings does not convey any definable information, values therefore only highlight differences in semantic information between regions, rather than importance. For example, an embedding value of 0 is not less important than a value of 1 or -1.

5.3.5 Semantic Similarity

In our analysis of LAD semantic footprints, we found that clusters broadly conformed with larger scale administrative regions. We therefore explore our semantic footprints from a top-down perspective, aggregating LADs into established large-scale RGNs across Great Britain, taking the mean of the collective semantic footprints. Each RGN is therefore represented by a single 768 dimension semantic footprint embedding. We then calculate the cosine similarity between each RGN embedding, demonstrating the level of inter-region semantic cohesion across Great Britain.

Cosine similarity is a common metric for comparing embeddings, as it is invariant to the magnitude of the vectors, and only considers the direction. This is important as the magnitude of embeddings is not meaningful, and only the direction of the vector conveys information. For example, the embedding for the ‘South East’ cannot be twice as important as the embedding for the ‘North West’.

5.3.6 Capturing National Identities through Text

To generate explainable characteristics of any geographically distinct semantic footprints generated in our analysis, we consider how a language model associates national identities with the semantic properties of text. In our approach we mirror qualitative data collection methodologies in political science research, where individuals are typically queried as to their chosen national identity (Haesly, 2005; Griffiths, 2022), instead generating the categorisations of comments by querying a large language model (LLM).

LLMs are pre-trained on a large corpus of natural language text, building representations of this text that emulate a human understanding of language. The underlying theory is that these representations capture the collective knowledge of humans that contributed the natural language text used to build them. Therefore, in addition to factual information, when posed with non-deterministic questioning, these models are able to contribute the biased information that is incorporated into their model weights.

Recent research has noted on the ability to perform zero-shot classification using LLMs, where class predictions may be made without the model ever having previously seen the labels (Wei, Bosma, *et al.*, 2022; Wei, Tay, *et al.*, 2022). While research has considered the use of questionnaires to query the strength of national identities within the UK (Haesly, 2005; Griffiths, 2022), an LLM may instead be used. For example, an LLM may be questioned whether it personally feels a sequence of text appears to be ‘British’, ‘English’, ‘Scottish’, or ‘Welsh’. Through this zero-shot classification, we are able to determine the strength of

national identity associated with each region in our work, to examine whether this appears to correlate with any cohesion between the semantic footprints that we generate. Importantly, we are also able to generate confidence values from the chosen LLM, allowing for the strength of these national identities to be captured.

Semantic information within our comments is expected to capture both explicit information contributed by users; for example stating ‘London is a British city’, in addition to implicit semantic information that exists within language. For example the phrase ‘bonnie Scotland’ may suggest a strong identity due to the inclusion of Scottish slang⁵. Unlike our semantic footprints, we do not mask place name mentions in these embeddings, enabling the model to make its own decisions regarding place name mentions.

To identify regional identities through semantic information, we build on the emergent properties of large language models, which enable a task known as ‘Zero-Shot Classification’. This allows models to predict a class that was not seen during training, by generating a prompt that contains the labels required. For this task we select the typeform/distilbert-base-uncased-mnli model⁶, which is tailored towards zero-shot classification, therefore generating slightly different embeddings compared with those used for our semantic footprints. For our task the following gives an example prompt with a portion of a comment taken from our corpus:

```
Classify the following input text into one of the following four categories:  
[British, English, Scottish, Welsh]
```

Input Text: My favourite was in Livingston: 'Rab, I'm gonnae find you.'

The output would then be given as a sequence of confidence values for each label:

```
'labels': ['Scottish', 'British', 'Welsh', 'English']  
'scores': [0.761, 0.144, 0.052, 0.043]
```

5.4 Results

Figure 5.1 (a) shows clusters of LAD transformer embeddings UMAP decomposed into two dimensions, indicating embeddings that share similar semantic properties. These clusters appear to broadly correlate with three distinct regions within Great Britain, where cluster 0 most closely identifies with England, 1 with London and surrounding areas, and 2 with Scotland and Wales (Figure 5.1 (b-c)). The few areas that appear as cluster 0 in Wales and Scotland are major urban centres like Cardiff, Glasgow, and Edinburgh. Overall these clusters appear to be geographically restricted, and even broadly conform with administrative regions like the Welsh and Scottish borders.

⁵See ‘Scottish English’ or ‘Scots’; (Stuart-Smith, 2008)

⁶<https://huggingface.co/typeform/distilbert-base-uncased-mnli>

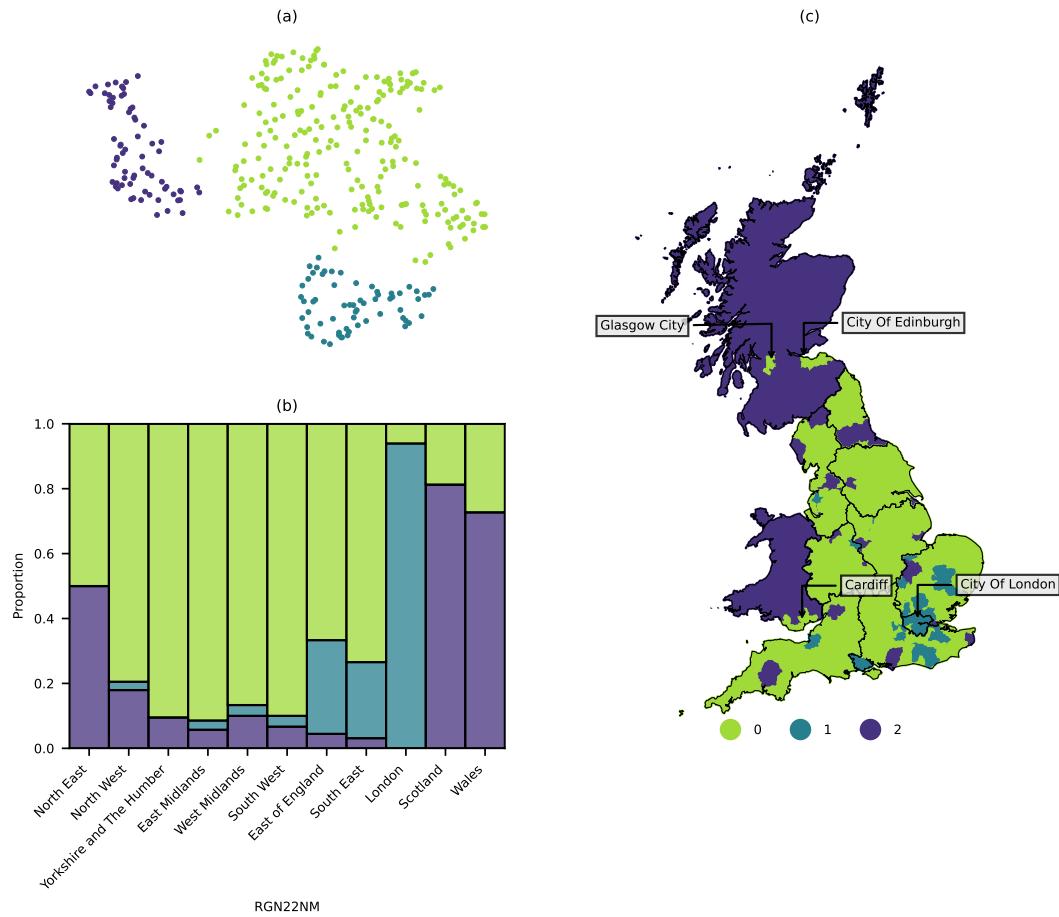


FIGURE 5.1: Semantic footprints associated with each LAD corpus coloured by hierarchical agglomerative clusters where $K = 3$. (a) Footprints UMAP decomposed into two dimensions. (b) Proportion of clusters by RGN. (c) Geographic location of clusters.

These findings appear to share similarities with past work that has observed strong ‘boundary effects’, where lexical similarity between geotagged Tweets often correlates with administrative boundaries (Yin *et al.*, 2017; Bailey *et al.*, 2018; Arthur and Williams, 2019; Li *et al.*, 2021). Our embeddings also exhibit the general geographically coherent patterns that have been observed in geographical lexical variations in social media (Russ, 2012; Doyle, 2014; Gonçalves and Sánchez, 2014; Eisenstein *et al.*, 2014; Huang *et al.*, 2016; Pérez *et al.*, 2019; Arthur and Williams, 2019). Notably, unlike dialects, where a geographic component is expected, the geographic association of our general semantic embeddings has not been demonstrated in past work. Results therefore demonstrate that despite no pre-existing geographic information like geotags or place names, general text associated with locations appears to embed a geographic component. The geographic coherence in our results is particularly strong at the borders of Scotland and Wales, which conforms with our hypothesis that the vernacular geography that exists within social media text embeds components that contribute to the strength of national identities (Haesly, 2005).

Interestingly, Glasgow, Edinburgh and Cardiff share a cluster with English LADs rather than their respective country, suggesting that these locations are more semantically connected with the rest of Great Britain. This observation mirrors the results of work that considered co-occurring locational mentions between cities, where shared city mentions in text often appear irrespective of distance, and across administrative borders (Berragan *et al.*, 2023a).

Cluster 1 presents in areas surrounding London and suggests distinctiveness of this region relative to the rest of Great Britain. This is interesting given London’s extensive connectivity relative to the rest of the country, and the general sense of strong association with other cities, given it is the capital city (Berragan *et al.*, 2023a). Our results therefore suggest that despite London’s importance nationally, semantic information is able to capture a deeper context that dissociates it from other regions. This effect may be due to factors unique to London, for example its prominence globally, influencing both tourism and business external to the United Kingdom, which alter the cultural landscape of the city. The isolated characteristics of London are particularly observable through its economic differences, where high costs of living have generated the need for a ‘London weighting’⁷ of salaries (Hirsch, 2016).

The following section formalises the level of geographic coherence that the embeddings exhibit, and highlights the key locations that drive the relationship between text and geography.

5.4.1 Moran’s I Analysis

To quantify whether our embeddings demonstrate spatial autocorrelation, we consider the Moran’s I metric, which identifies the spatial relationship between each observation and its geographic neighbours (Anselin, 1995). Given that this analysis requires univariate data, we explore global spatial autocorrelation of our UMAP decomposed embeddings by plotting

⁷https://en.wikipedia.org/wiki/London_weighting

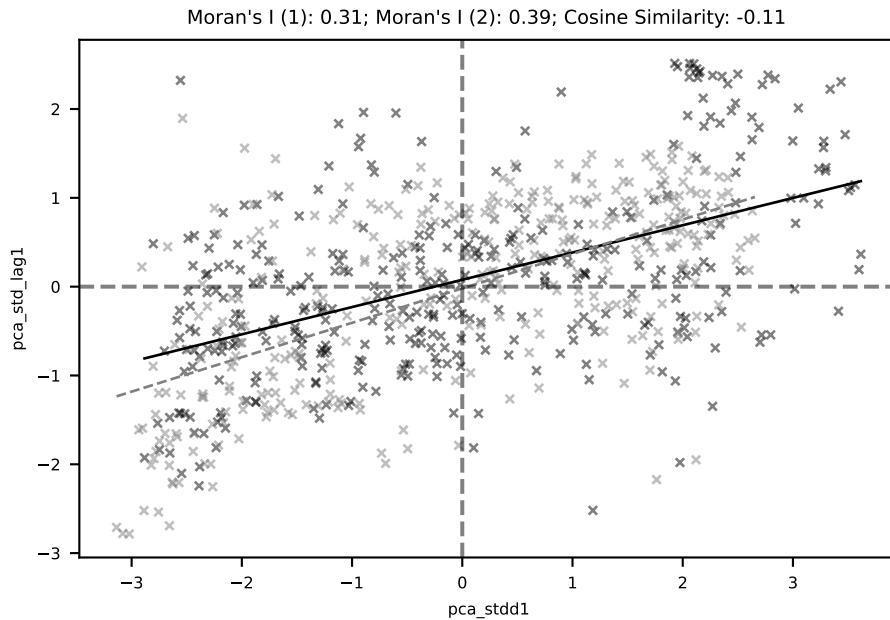


FIGURE 5.2: Moran's I plot: LAD embeddings decomposed into 2 dimensions and standardised, plotted against spatial lag of standardised embeddings.

both dimensions against their spatial lag on Figure 5.2. The Moran's I values of 0.31 and 0.39 indicate a reasonably strong spatial autocorrelation with both embedding dimensions, confirming that semantic footprints are typically more similar between nearby locations. While the Moran's I values for both dimensions are similar, their cosine similarity is negative (-0.11), meaning it is likely that these two decomposed dimensions capture distinctly different semantic traits.

While spatially coherent results have been demonstrated from the perspective of dialects on social media (Russ, 2012; Doyle, 2014; Gonçalves and Sánchez, 2014; Eisenstein *et al.*, 2014; Huang *et al.*, 2016; Pérez *et al.*, 2019; Arthur and Williams, 2019), we have demonstrated that this phenomenon can also be captured from general semantic information. Notably, while dialects have always been considered to have strong geographical grounding (Trudgill, 2004), it is more surprising that general semantic information regarding locations similarly exhibits this relationship.

To explore local indicators of spatial autocorrelation (LISA) we plot each decomposed embedding on Figure 5.3 (a/d), each local Moran's I value on (b/e) and all significant ($p < 0.05$) HH and LL LISA quadrants on (c/f). Note that only selecting significant p values on Figure 5.3 (c/f) ensures that no regions are included that have values that could demonstrate autocorrelation even if randomly distributed geographically. From Figure 5.3 (c/f), we can see that notable large areas with significant levels of spatial correlation include;

- Scotland
- Wales
- London and surrounding LADs

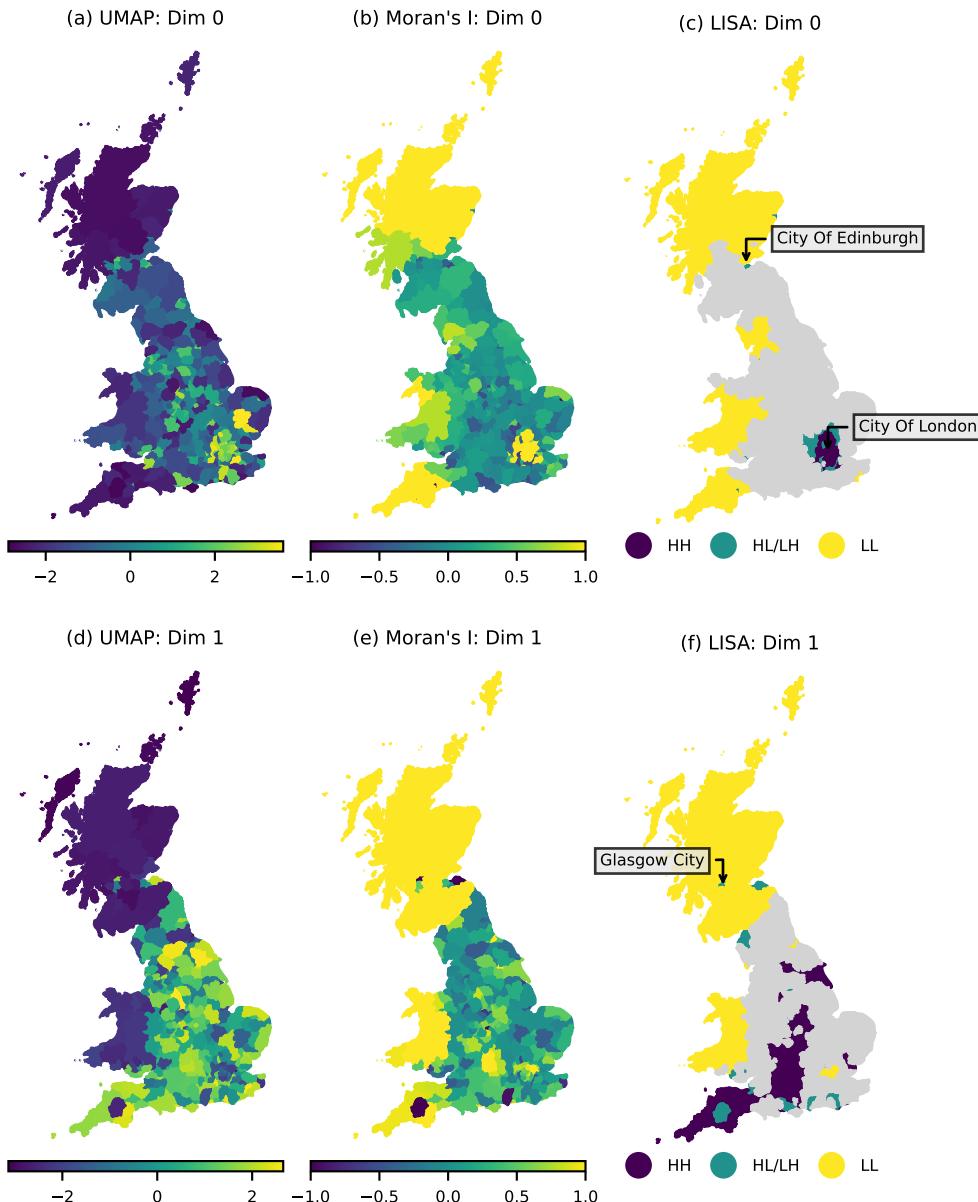


FIGURE 5.3: Local Indicators of Spatial Auto-correlation (LISA). (a/d) 1 dimensional embedding values. (b/e) Local Moran's I values (I_s). (c/f) LISA HH and LL significant values ($p < 0.05$), both are included as the value of embeddings do not convey information.

- the South West; towards Cornwall

As demonstrated by the low cosine similarity between our UMAP embeddings, they appear to capture distinctly different semantic information. London for example only appears in dimension 0, while dimension 1 captures broader spatial autocorrelation across Scotland and Wales. In Scotland we can see that from both LISAs, Glasgow and Edinburgh represent areas of HL/LH, where semantic information in these cities is not the same as surrounding LADs, an effect that is also captured in some LADs surrounding London. England overall appears to be a less semantically cohesive country based on this analysis, where most LADs do not contribute significant levels of spatial autocorrelation.

These results again demonstrate geographic cohesion between semantic footprints, which notably appear to correspond with the national boundaries of Wales and Scotland. This mirrors the observations of past work where dialect differences appeared to correlate with administrative boundaries (Yin *et al.*, 2017; Bailey *et al.*, 2018; Arthur and Williams, 2019; Li *et al.*, 2021). In addition to Wales and Scotland, we have also identified a notable grouping in the South West, which potentially reflects the Cornish identity (Deacon, 2007), as well as a grouping associated with London.

5.4.2 Semantic Similarity and Identity

Given the regions highlighted as having strong spatial autocorrelation in their semantic footprints appear to broadly conform with the administrative regions of Wales, Scotland, and London, we examine these footprints from a top-down analysis using pre-defined larger scale aggregations.

Figure 5.4 compares the cosine similarity between each RGN embedding, allowing for inter-regional cohesion to be explored. The North West has the overall highest level of cosine similarity, displaying comparatively high similarity with most regions across England, excluding London. London has the lowest overall similarity, only sharing positive cosine similarity values with the South and South East of England. As expected, Scotland and Wales have low overall cosine similarity values, with Wales sharing even lower similarity with respect to London and the South East compared with Scotland. Mean values show clearly that the least cohesive regions appear to be London, Wales, and Scotland, three regions that are also those with the strongest levels of spatial autocorrelation.

Excluding London, the North East is the region in England with the lowest overall cosine similarity with the rest of Great Britain. This is perhaps reflective of distinct differences with this region, for example the distinctly lower gross value added (GVA) compared with other regions (Fenton, 2018), or the general sense of strong identity that is often noted by residents (Middleton and Freestone, 2008). Alternatively, the North West is home to large urban conurbations especially between Manchester and Liverpool (Oguz and Walton, 2022), likely generating the highest overall semantic similarity of this region compared with the rest of the UK. These cities do however have rich and culturally unique identities (Knowles, 1973; Cruttenden, 2000), meaning the derived semantic footprint is still distinct compared

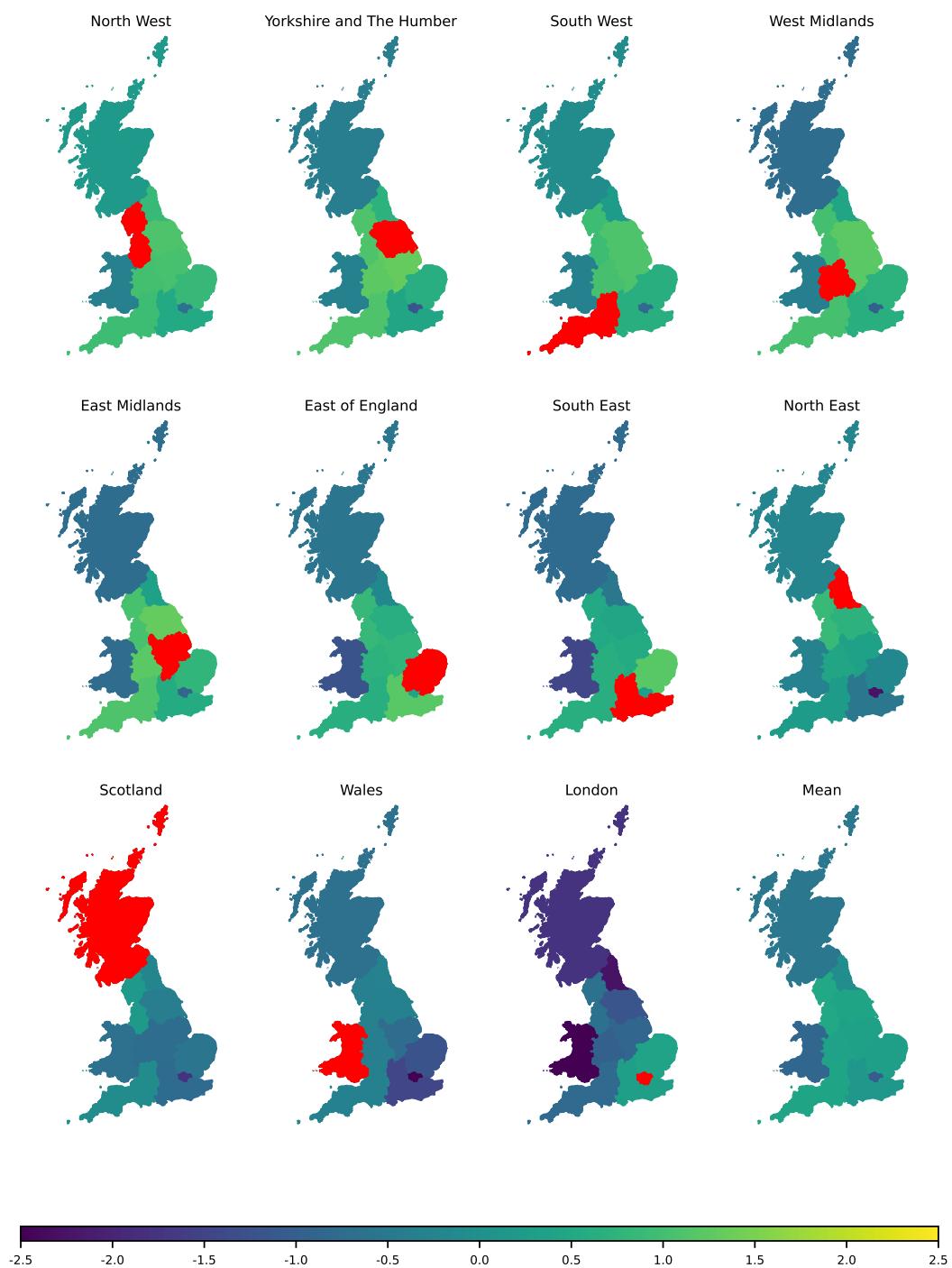


FIGURE 5.4: Scaled cosine similarity of embeddings for administrative regions across the UK. Higher values indicate greater cosine similarity. Regions shown in descending order by mean cosine similarity value.

with other regions. Comparatively, the East of England, South East and London are neighbouring regions that share high similarities with each other, but exhibit low similarity with the rest of Great Britain, suggesting there are semantic components that distinguish this region of the country from the rest. The slightly higher mean similarity with Scotland compared with Wales appears due to slightly higher similarity with some regions in England, like the North West and South East. Major urban centres in Scotland are relatively well connected to Great Britain through rail routes, and Edinburgh and Glasgow are historically important UK cities, captured by their distinct difference in embedding values during the spatial autocorrelation analysis. This factor likely increases the cosine similarity of Scotland with regions in England, while Wales in this sense is less directly associated with the rest of the UK.

To determine whether regional identities generated by a large language model aligns with these semantically isolated regions in our analysis, we plot the distribution of regional identities identified through our zero-shot classification on Figure 5.5.

Across each region, the ‘English’ identity is always lower than ‘British’, suggesting that regions within England are typically more strongly associated with the United Kingdom⁸ than solely England. Unlike English regions however, comments relating to both Scottish and Welsh locations are more strongly associated with their respective nationalities. However, comments relating to Welsh locations appear on average to have stronger confidence values with respect to the British classification, compared with Scottish locations. Similar observations have been captured from qualitative interviewing, where Welsh residents similarly appear to more strongly associate themselves with the British identity, compared with Scottish residents (Haesly, 2005; Llamas, 2009; Carman, Johns and Mitchell, 2014; Llamas and Watt, 2014). Of the English regions, London has a distinctly higher average confidence value of both British and English identities compared with all other regions. Notably, Scotland, Wales, and London also have the lowest overall cosine similarity values indicated on Figure 5.4 (Mean), suggesting that these differences in generated identity compared with other regions are a likely component in their semantic differences.

5.5 Conclusion

Our paper demonstrates a new method to compare aggregate semantic information for local authorities and regions within the UK, from Reddit comments that mention geoparsed locations, which we name semantic footprints. When examining the semantic footprints of each LAD in the UK, we find that geographically cohesive clusters appear, with significant levels of spatial autocorrelation. Clusters broadly conform with the national borders of Scotland and Wales, while London also appears to be semantically distinct from the rest of the England. Through an examination of generated national identities associated with

⁸Note that despite etymologically relating to ‘Great Britain’, the term ‘British’ refers to ‘belonging to or relating to the United Kingdom of Great Britain and Northern Ireland’

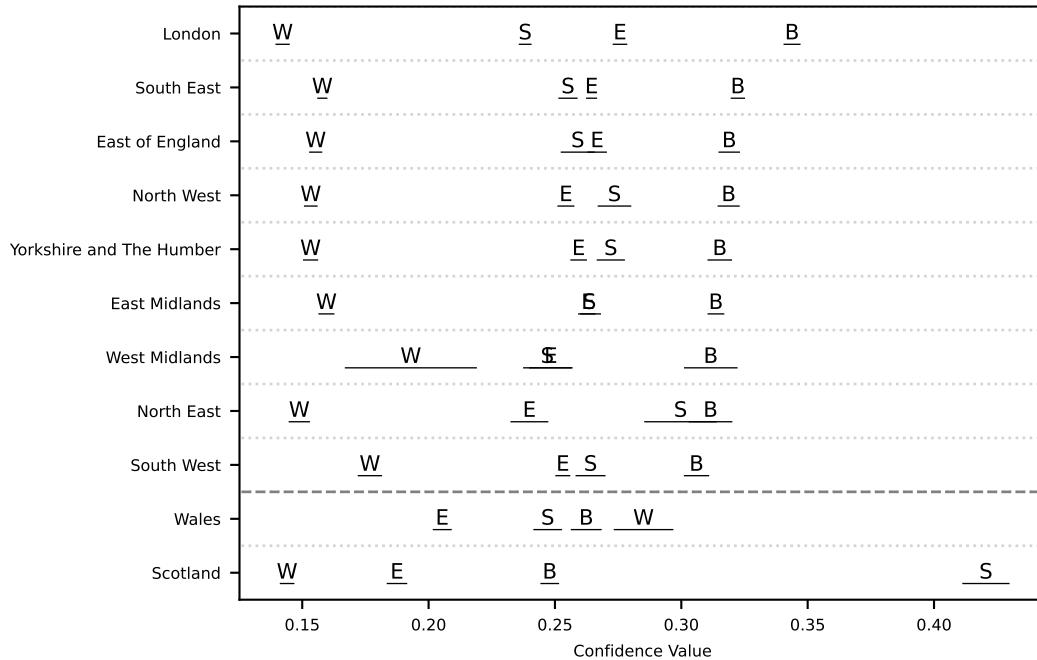


FIGURE 5.5: Zero Shot classification of each corpus into regional identities; [B]ritish, [E]nglish, [S]cottish, [W]elsh. Values show mean confidence value across each comment, lines indicate standard error. Descending order by [B]ritish confidence.

each region, we find that these distinct geographic groupings are a likely result of associated identities, which are generated through general associations captured through the vernacular geography of all users in our social media corpus.

As demonstrated in past work that has examined both physical and non-physical networks, our observed semantic information similarly appears to correlate with pre-defined administrative boundaries, particularly the national boundaries of Scotland and Wales (Yin *et al.*, 2017; Bailey *et al.*, 2018; Arthur and Williams, 2019; Li *et al.*, 2021). The distinct difference in footprints between each constituent country in the UK conforms with the idea that vernacular geography captures a sense of identity, given our zero-shot classification demonstrates distinct nationalities between Scotland and Wales, unlike English regions where the generated national identity is typically considered British rather than English. Notably however, the slightly stronger British identity within Wales has been observed previously through qualitative interviewing (Haesly, 2005; Carman, Johns and Mitchell, 2014), suggesting that even the nuanced properties of text appear to correlate with the true perceptions of individuals. It is also worth noting that, given the exclusion of place names in our embeddings, these distinct differences are not simply the result of differences in place names (e.g. place names in Wales are distinct from England), which may have influenced the results of past lexical work.

Despite most locations across Scotland and Wales appearing disconnected with the rest of the UK, major cities like Glasgow and Edinburgh are more semantically similar, a distinction

that was also observed when the distance decay of locational co-occurrences in text was examined (Berragan *et al.*, 2023a). This suggests that these cities do appear to be typically more semantically connected with the UK, regardless of geographic distance and borders, while other locations typically share semantic properties within the same nation, captured through stronger spatial autocorrelation.

When considering the cosine similarity between RGN embeddings, we see evidence of an alternative North-South divide that is often considered in England, which from a semantic context appears to be more related to proximity to London. Unlike typical representations of this divide therefore, the South West of England appears to be distinct from the South East, with a stronger association with the North. South Eastern regions however do share lower similarity to the Midlands and North of England, which conforms with a typical view of the English North-South divide (Jewell, 1994).

Geoparsing methods enable a geographic dimension to be added to non-geotagged social media data, allowing for a much larger repository of informal natural language geographic text to be used for research. Future work may consider the use of Reddit comment data to derive notable urban areas of interest (Chen, 2019). This area of research in particular would benefit from methodologies focussing on the extraction of fine-grained locations from text, which at present is a challenging task (Han *et al.*, 2018).

Chapter 6

Conclusion

This final chapter first summarises the key findings of this thesis in Section 6.1, then outlines the contributions in Section 6.2. Limitations of the thesis are then considered in Section 6.3, before suggesting areas for future related research in Section 6.4.

6.1 Summary of Research Findings

This thesis addressed the three key aims introduced in Chapter 1; the following section restates these aims and summarises how each empirical chapter achieved them.

Aim 1: *Improve the results of existing geoparsing systems for place name recognition, and outline the potential for unstructured text to provide geographic knowledge.*

Chapter 3 fulfilled this aim by building a custom NER model for place name extraction and evaluating the performance of this model against existing geoparsing systems. Given NER models have been traditionally more difficult to implement, as good results were usually only achieved through complex neural network models, which require large volumes of training data, many geoparsing systems use pre-built models. These pre-built models are intended for general entity recognition, meaning place names are not specifically targeted by them, resulting in lower-quality outputs. However, recent developments in deep learning have enabled simpler implementations of these complex models, where good results on NER tasks may be achieved without the iterative construction of deep neural networks from the ground up. The introduction of pre-trained transformer models, commonly known as Large Language Models (LLMs), has shifted model construction for NLP tasks in this direction. Fine-tuning transformer models for specific tasks only requires the addition of a head layer to the model architecture, and given they are pre-trained, fine-tuning often achieves good results with comparably small training data.

To demonstrate the ability to build a task-specific NER model from the ground up for place name identification in this chapter, a corpus of 200 Wikipedia article abstracts relating to ‘place’ articles in the United Kingdom were annotated with place names. This corpus represented a collection of text that is both data-specific; targeting only place names in the United

Kingdom, and task-specific; place names were annotated, rather than general entities like persons or geopolitical entities. This corpus was then used to train a collection of three of the most common pre-trained transformer models (BERT, DistilBERT, RoBERTa), and evaluated against pre-built NER models that are used in existing geoparsing systems (SpaCy, Stanza). The best performing fine-tuned transformer model was BERT, which achieved an F_1 score of 0.939 compared with 0.730 from the Stanza pre-built NER model. This result demonstrated the performance gap that can be expected between a pre-built model like Stanza, and the task and data-specific model built in the paper.

Finally, this chapter notes that with accurate geoparsing systems, existing sources of online text present the opportunity to harvest large volumes of geographic data, that have been previously underutilised. To demonstrate this, the fine-turned BERT model was used to extract place names from all UK Wikipedia article abstracts. In total 62,178 unique place names were identified on Wikipedia that did not already exist within the GeoNames gazetteer. Notable instances occurred with colloquial differences in place names, for example when articles referred to the ‘M1 motorway’ as simply the ‘M1’, or fine-grained locations like street names.

Aim 2: *Generate insights into the place-based cognitive associations between locations, through the analysis of locations geoparsed extracted from informal social media text.*

This aim was achieved in Chapter 4, using a large corpus of informal comments taken from the social media website Reddit. Following on from the observations made in Chapter 3, Chapter 4 demonstrates that, by building a task and data specific NER model and broader geoparsing system, a large volume of informal geographic knowledge may be extracted directly from these comments. Reddit is a notably underused source of social media data, particularly in geographic research, given the lack of geography-specific metadata like geotags. This chapter demonstrates that despite having no geographic metadata, the unstructured text through communication between users Reddit may be geoparsed directly to generate geographic information in the form of place names with associated coordinate information.

The primary focus of this chapter is the generation of the perceived strength of associations between geographic regions in Great Britain from Reddit comments. While physical geographic networks have been examined in detail, few works have considered how the persistent perceived associations between locations may be measured. Foundational geographic research noted on the role of human cognition in the generation of mental images of geographic environments (Lynch, 1964), where perceived spatial structures and associations are influenced by individuals’ experience and geographic knowledge. Chapter 4 suggests that informal text from social media captures this informal geographic knowledge, enabling mental maps to be quantified and aggregated from the perspective of a large volume of individuals. These mental maps contribute the perceived associations between places, where association strength is numerically represented through the proportion of co-occurring locational mentions in geoparsed text.

To explore the geographic properties of these associations, this chapter demonstrates the impact of distance on the strength of these associations, using a gravity model to measure the level of distance decay. While a distance decay effect is a noted and well established concept in physical interactions, due to the spatial and temporal constraints of physical movements, the perceived associations between locations are not bounded by these constraints. This chapter therefore hypothesises that unexpected patterns may be derived when considering association strength and distance decay, that may not correspond with physical interactions.

Chapter 4 found that a distance decay effect was present from the perspective of perceived associations between places, suggesting that geographic properties are embedded within this informal text. However, these associations generated divergent patterns, particularly in major cities like London, where perceived associations were strong regardless of distance, and locations in Scotland, where associations with England were weaker.

Aim 3: *Examine the geographic variation in the semantic properties of text associated with place names extracted from social media.*

Chapter 5 achieves this aim by extracting semantic embeddings relating to geoparsed locations from the Reddit corpus. These aggregate semantic representations of locations and regions generated were named ‘semantic footprints’, representing the collective informal geographic knowledge of each user in this corpus, built through their vernacular geography.

While other works have considered the ability to quantify geographic heterogeneity in social media text, they have relied on geotags, which rarely relate directly with semantic information that exists within any associated text. These works therefore typically examine the lexicons associated with geotagged posts and attribute the geographic heterogeneity of these lexicons to the dialects of users. Instead, this chapter suggests that given the identity of geographic locations is built from a multitude of informal geographic knowledge, deeper semantic representations instead capture the vernacular geography embedded within social media text that contributes to these identities.

To achieve this goal, two key changes were made to past work that examined geographic heterogeneity between geotagged social media text. First, place names directly embedded within text present the opportunity to directly capture vernacular geography contributing informal geographic knowledge relating to embedded locations, rather than geotags. Secondly, deep semantic representations of associated text were generated using a large language model (LLM). Unlike lexicons, where word order is not preserved, and no semantic information is captured, these embeddings act as high dimensional numerical semantic representations of comments associated with locations, allowing for a direct comparison between semantic footprints.

In Chapter 5, like dialects and physical networks, semantic footprints also exhibit geographically cohesive properties, where there is a global positive level of spatial autocorrelation. The shared similarity of embeddings are typically clustered in select areas across Great

Britain, like Wales, Scotland, and London. This also conforms with past work that found these spatially cohesive properties of text and networks often conform with administrative boundaries. When examining the differences between larger scale administrative aggregations, these three regions are the most semantically distinct from the rest of the country. When generating identities associated with these regional corpora using an LLM, identity is likely captured through the vernacular geography embedded within these footprints, given Welsh and Scottish locations are typically more strongly associated with their respective national identities.

6.2 Contributions

The contributions of this thesis are broadly categorised into the physical data and code produced as part of each empirical chapter, and the theoretical contributions that have been developed. The theoretical contributions particularly relate to the expansion of place-based geographic research, presenting new methodologies that enable alternative forms of embedded geographic knowledge to be extracted from informal natural language text. Data and code contributions are intended to assist with future research for place-based knowledge extraction from social media text, giving researchers access to all data used, and the code that enables results to be replicated, or reproduced with alternative data.

6.2.1 Data and Code Contributions

This thesis contributes the Reddit comment data, consisting of a collection of over 8 million comments relating to locations across the UK, with embedded locations geoparsed, allowing future research to utilise this new source of geographic information. This data source represents a collection of 4,616,290 locational mentions, with 305,104 unique locations, and 54,285 unique geocoded locations. Additionally, the processed Reddit comments data highlighting cognitive associations from Chapter 4, and the semantic footprints from Chapter 5 are made available for future research. All code associated with the empirical chapters of this thesis are hosted and version controlled across individual GitHub repositories. The annotated corpus of Wikipedia and Reddit comments used to train NER models in Chapter 3 and Chapter 4 are also made available, allowing future research to consider the ability to directly extract place names, without relying on unrelated existing NER corpora. The trained NER model for place name extraction from Reddit is also made available, and hosted on the Hugging Face Model Hub.

The following outlines all data and code contributions for each empirical chapter:

Chapter 3:

- GitHub Repository
- Wikipedia abstracts with place names annotated for NER training

Chapter 4:

- GitHub Repository
- DagsHub Repository
- Reddit NER Model for place name extraction
- Reddit Comments with place names manually annotated for NER training
- UK Reddit comments with identified place names
- UK Reddit comments with identified place names (excluding non geocoded locations)
- Place associations aggregated to H3
- Place associations aggregated to UK LAD
- Place associations with no aggregation

Chapter 5:

- GitHub Repository
- DagsHub Repository
- Semantic footprints aggregated to UK LAD
- Semantic footprints aggregated to H3
- Semantic footprints aggregated to RGN
- Zero Shot Classifications

6.2.2 Theoretical Contributions

In addressing the aims outlined in the introduction, this thesis has broadened the scope of place-based geographic research, allowing for an additional geographic dimension from unstructured text to be captured. While text was previously considered a by-product of communications between users on social media, and without much geographic value, the geoparsing methodology presented in Chapter 3 allows for geographic information to be directly quantified. While explicit geographic information through geotags is often available on social media platforms, the depth and scale of geographic knowledge that exists within text is much greater. By geoparsing locational mentions from a large corpus of informal geographic discussions from Reddit, Chapter 4 and Chapter 5 both demonstrate that alternative place-based representations may be generated, deriving insights from the semantic properties of text that capture vernacular geography.

Particular contributions to place-based literature are presented through the methodologies developed in Chapter 4 and Chapter 5. While most place-based geographic research has predominantly relied on geotags to harvest informal geographic knowledge from social media to generate informal cognitive footprints, embedded geographic information within text allows for alternative place-based representations to be captured.

Chapter 4 first notes that when locations are mentioned in a shared context within text, they form an implicit subconscious association. This theory then allows for association strengths to be generated between each geoparsed location, analogous to the strength of interaction between locations that are captured through the physical movements of populations. This

chapter theorises that while physical movements may be used to generate interaction measures, they may not necessarily be representative of the informal and subconscious associations between locations that individuals hold. By harvesting informal associations through co-occurring locational mentions on social media however, this knowledge is more accurately captured, directly relating with the informal nature of place.

In Chapter 5, vernacular knowledge regarding locations is embedded within the comments of Reddit users when locations are mentioned. This chapter explores whether this vernacular geography exhibits cohesive geographic properties, and whether certain regions within Great Britain are more semantically isolated. ‘Semantic footprints’ of geoparsed locations are first generated; embedded representations of the text associated with locational mentions, created using a large language model. These semantic footprints capture contextual semantic information regarding each location identified in our corpus, representing the informal geographic knowledge contributed by each user. Given these are numerical representations, they may be directly compared using cosine similarity and tested for geographic cohesion through a spatial autocorrelation analysis.

While the primary focus of existing quantitative place-based research tends to concentrate on generating cognitive footprints through geotagged social media, this thesis instead demonstrates that social media text may also be harvested for this place-based information. In particular the methods developed through these chapters capture a new dimension to the study of place, that has not been achieved in past work, enabled through the consideration of the vernacular geography that is present within informal social communications.

6.2.3 Substantive Contributions

The first substantive contributions highlight problems with existing NER systems used in geoparsing, and how they are addressed. Chapter 3 demonstrates that pre-built NER models that are commonly used in geoparsing systems do not appear to perform as well as advertised, achieving F1 scores for place name extraction that fall below the advertised scores for these models. Few works consider building custom NER models due to the requirement of annotated data and complex model building, however, using simpler, pre-trained language models, the volume of annotated data required to achieve good results is lower than expected. Finally, this chapter finds that when place names are extracted from a large volume of natural language text on Wikipedia, many are absent from the GeoNames gazetteer. These names come from fine-grained locations like street names, or alternative colloquial names like the ‘M1’ rather than the ‘M1 motorway’.

Other substantive contributions come through the methodologies used to analyse locational references geoparsed from Reddit comments. By examining the strength of associations between locations, Chapter 4 finds that while a distance decay effect is observable, it is variable across geographic space. As expected, associations do not necessarily respect distance, particularly between major cities like London and Manchester, where there is a stronger association, despite being geographically distant. Other association patterns are observed in

Scotland, where larger distances have an overall lower effect on the reduction in association strength compared to locations in England.

In Chapter 5, the semantic footprints generated are broadly geographically cohesive, correlating with distinct national boundaries of Great Britain. While semantic information regarding locations is similar across Scotland, Wales and London, it appears less cohesive in England, where spatial autocorrelation is lower. The results of the analysis in this chapter suggest that the strength of locational identities across Scotland, Wales, and London are stronger compared with most of England, where identities are likely more localised, rather than permeating across broader regions.

The contributions of these two chapters highlight the perception of locations that are captured through language and generated subconsciously by the collective users in the corpus of Reddit comments. These results therefore present an aggregate perception with respect to UK locations, capturing a bias that is more representative of the broader population of the UK, compared with the perception of individuals.

6.3 Limitations

6.3.1 Representativeness of contributions

Contributions to social media platforms are voluntary, meaning they are not representative of the population, compared with large scale surveys with known research designs. Many users contribute a significantly larger volume of comments compared with the average, and Reddit itself consists of a non-representative demographic. Despite this, the number of users that contribute to Reddit is very large and doesn't rely on active participation through contributions to traditional VGI. In total almost 500,000 unique users contribute over 8 million comments that form this corpus, representing a collection of volunteered geographic knowledge that would be unfeasible to capture through alternative data sources.

While the demographic information regarding contributing users is not accessible, Chapter 4 explores the imbalance in contributions made by each author. While 213,764 users mentioned at least one place name, 1% accounted for 32% of all place name mentions, representing 2,137 users. While this does suggest that a proportionally low volume of users are capable of shaping the outputs of our analysis, there are still a large volume of users contributing place names.

6.3.2 Accuracy of Geoparsing

While the methods developed in this thesis improve on existing geoparsing methodologies for the task undertaken, there are still issues to consider. The NER model trained in Chapter 4 to identify place names in Reddit comments achieves an F_1 score of 0.752, which suggests that there are instances where the model does not accurately identify place names. This may have led to bias; for example the model may struggle to identify Welsh place names compared with English place names, particularly when users use the Welsh language,

which is unable to be parsed by the model. This is however difficult to accurately assess, given the volume of place names that would need to be considered. The geocoding stage is also imperfect, particularly given the inclusion of all fine-grained place names within the UK. For example, many place names that are mentioned in comments relate to locations external to the UK, but exist as lesser known locations in the UK (e.g. Dublin, Suffolk¹). This problem primarily stems from the use of the Ordnance Survey Open Names (OSON) dataset as a knowledge base for the geocoding of identified locations. OSON is not primarily intended as a gazetteer and is only used over GeoNames as OSON has far better coverage of fine-grained locations in the United Kingdom. These fine-grained locations however are typically much more difficult to accurately geoparse, and OSON does not include metadata that would assist with some ambiguous place names, like population sizes. The geocoding stage of the geoparsing system in this thesis therefore balances this potential noise with the ability to capture more fine-grained locations compared with existing systems.

6.3.3 Geographic Representations of Place

The final limitation of the methodology implemented in this thesis relates to the strictly defined models of space, that are implemented by the majority of gazetteers and other geographic datasets (Goodchild and Li, 2011; Westerholt, 2021). In object based spatial models, points, lines, or polygons are used to represent spatial objects at varying generalisations; for example, depending on scale, a building may be considered a point or a polygon (Purves *et al.*, 2018). While representing building footprints as a polygon is sensible, given they generally have definite boundaries, for other spatial objects this isn't the case. Many named places have vague spatial extents, particularly with non-administrative or vernacular names; for example, the extent of 'the North' in England is often debated (Jewell, 1994).

As with many formal geographic data sources, gazetteers typically represent place footprints using the typical object based model of space, where location is represented using 2D coordinate information (Goodchild and Hill, 2008; Goodchild and Li, 2011; Purves *et al.*, 2018). Despite the variety of geospatial representations possible (See Table 6.1; Hill (2000)), places are also typically represented as a single 2D point at the estimated centre location, with the view that each place should have a single officially defined name, which isn't always the case (Goodchild and Hill, 2008). For example, the 'M1 Motorway' as listed in GeoNames may be colloquially referred to as just 'the M1' both in informal and official contexts (highlighted in Chapter 3). Gazetteers are additionally generally limited in resolution, excluding a large volume of intra-urban detail that is found in natural language, like street names, neighbourhoods, or landmarks (Machado *et al.*, 2010).

Traditional gazetteers therefore do not permit an interface between the vagueness of place and the formality of their data representations (Fisher and Unwin, 2005; Goodchild and Li, 2011; Cresswell, 2014), excluding the vague boundaries and names associated with vernacular geography (Ke, 2009; Bär, 2016). Alternative ontologies for the 'platial' representation of space have been described in depth (Jones, Alani and Tudhope, 2001; Machado *et al.*, 2010;

¹<https://gridreferencefinder.com?gr=TM1638869500|dublin|1&t=dublin&v=r>

TABLE 6.1: Types of geographic representation

Type of Representation	Description
Point	Single pair of latitude & longitude coordinates
Bounding Box	Double pair of coordinates representing the maximum and minimum longitude extent
Line	Set of points that do not enclose a space
Polygon	Set of points that do enclose a space
Grid Representation	Grid references to a location according to an identified grid referencing scheme

Gantner, 2011; Laurini, 2015; Westerholt, Mocnik and Comber, 2020; Westerholt, 2021), with some models that consider the ability to capture imprecise but stronger semantic associations such as the ‘south of France’, or ‘up-state New York’ (Jones *et al.*, 2008), which are commonly encountered in natural language. Given vagueness is a prominent concept in place-based research, better representations particularly rely on moving away from single coordinate pairs to represent locations (Purves *et al.*, 2018). Progress has however been limited, given the complexity of computing with such representations, where established geographic methodologies typically focus solely on Euclidean space.

The spatial representations used by the gazetteer in this thesis have limited the geocoding accuracy of place names identified in Reddit comments; alternative place names are unable to be captured, and footprints are all represented as a single point. For example, London as geoparsed has the same spatial extent as a small town or even a named road. To combat this limitation, we aggregate locations identified in our Reddit comments in Chapter 4 and Chapter 5. Aggregation enables these nearby locations to be combined, where they are likely to share a spatial footprint, which provides a more accurate representation (e.g. parks within a city).

6.4 Future Research

The research presented by this thesis has generated ideas and evidence for several innovative extensions and future work. Firstly, While the primary geographic component in natural language text exists as place names, they are not the only geographic information that may be harvested. Geoparsing systems and studies focus purely on the identification and resolution of place names that are contained within gazetteers, which ignores a significant proportion of the geographic natural language that is present within most of the text being processed. As an example, Zhang and Gelernter (2014) present ‘*Van ploughs into Salvation Army Store in Sydney*’ to highlight issues associated with ambiguous place names (the tweet refers to a city in Canada). However, any practical use case for the geographic information extracted from such a Tweet relies on a finer geographic resolution. In this example, conceptually, the named location ‘*Salvation Army Store*’ is resolvable, and the tweet contains additional geographic expressions which relate the identifiable geographic objects in the sentence, here in bold; ‘*Van ploughs into Salvation Army Store in Sydney*’.

The ability to extract this geographic information has been considered for some time, for example Jones *et al.* (2008) outline key research areas and challenges in Geographic Information Retrieval:

- Detecting geographic references in the form of place names and associated spatial natural language qualifiers within text documents.
- Geometric interpretation of the meaning of vague place names, such as the ‘Midlands’ and of vague spatial language such as ‘near’.

To better understand the geographic components in natural language, two improvements to geoparsing may be drawn;

1. All geographic elements in text should be considered and classified, without focussing purely on place names.
2. Gazetteers should consider the representation of place, rather than a single resolved point.

There are therefore two key geographic components in text that are largely ignored by existing research; *non-specific locations*, and *spatial relations*. The following two sections outline in more detail the existing work that considers this information and what could be done to improve this research.

6.4.1 Non-Specific Locations

Existing research primarily focusses on the extraction of coordinate information of points of interest (POI) from social media. Li and Sun (2014) for example identify named point of interest POI mentions within tweets using a POI inventory built from *Foursquare*² user-generated data, and extend their processing methods to determine whether the user is currently at the POI mentioned. Gao, Janowicz and Couclelis (2017) demonstrate a more heuristic method by considering only the general terms for a POI such as park or restaurant to construct a POI gazetteer by identifying instances of these words in geotagged text. Middleton, Middleton and Modafferi (2014) note that from their analysis of tweets relating to a flooding event, the locational information often includes references to specific buildings, road and other geographic features like local parks, rivers, and beaches. Members of the public may also use more vague information relating to their location, the expression ‘rural area’, or ‘industrial area’ require a qualitative interpretation, requiring an understanding of the demographic, sociological or economic characteristics areas (Bilhaut *et al.*, 2003).

Alternatively Al-Olimat *et al.* (2019) explore *geocoding spatial expressions*, in which they note that the expression ‘beaches near Dayton’ requires an understanding of the term ‘beaches’, and the spatial extent of the toponym ‘Dayton’. The ability to quantify these spatial expressions is therefore essential for future work to consider the ability to geoparse fine-grained, non-specific locations from text.

²<https://foursquare.com>

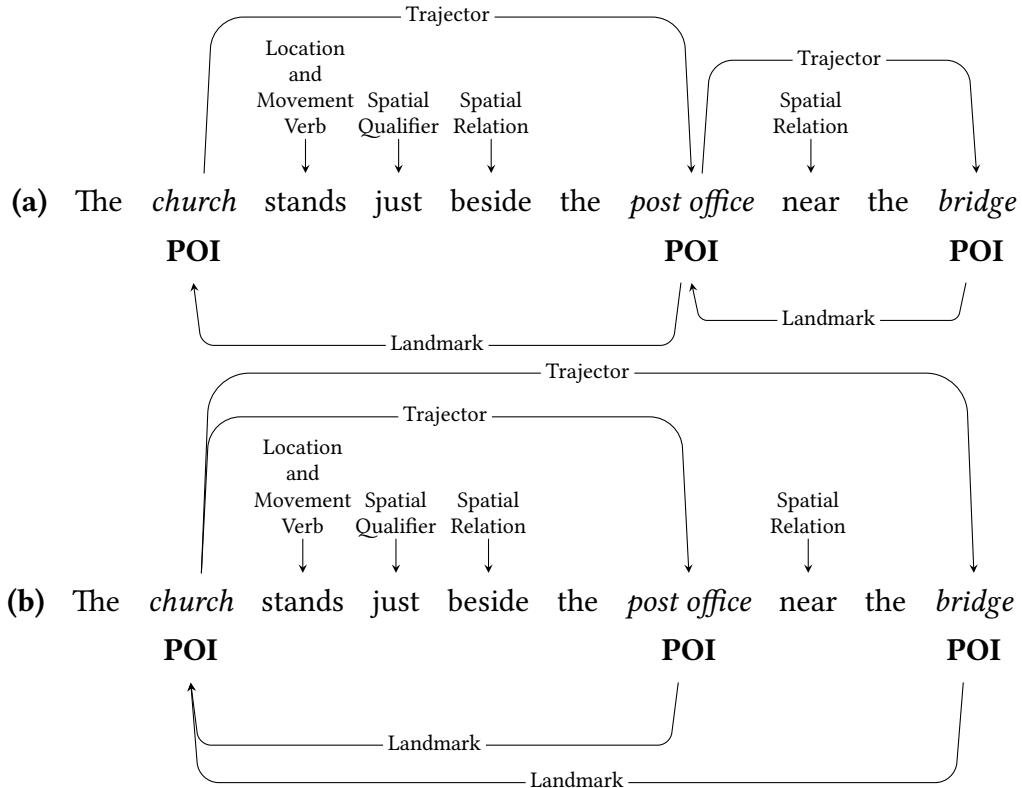


FIGURE 6.1: Geographic spatial relationship diagram demonstrating the ability for an entity to be both a landmark and trajector (post office) in (a), and the ambiguity of some language; church may be the trajector for just the post office (a), or for both the post office and bridge (b). Entities are italicised with entity type displayed in bold underneath.

6.4.2 Spatial Role Labelling

Kordjamshidi, Otterlo and Moens (2010) present Spatial Role Labelling (SpRL) as the task of identification and labelling of *spatial expressions* in natural language, capturing individual spatial entities, and the spatial relationships between them. The *spatial relationships* (SR) between these entities are formed of three components. The *trajector* objects (TR); spatial entities where a spatial reference is being described, *landmark* objects (LM); spatial entities used as a reference point in a spatial relationship, and *spatial indicators* (SI); the connecting phrase, usually a preposition, which links the spatial components in a particular relation. Figure 6.1 gives an example sentence where these three components are highlighted with semantic links (Aflaki and Russell, 2018).

Additionally, region connection calculus could potentially be used to classify specific geographic relationships, shown on Figure 6.2 (Randell, Cui and Cohn, 1992; Cohn *et al.*, 1997).

Using this theory, we can then consider an implementation of SpRL using the following extract from a Wikipedia abstract:

Headingley is a suburb of Leeds, West Yorkshire, England, approximately two miles out of the city centre, to the north west along the A660 road.

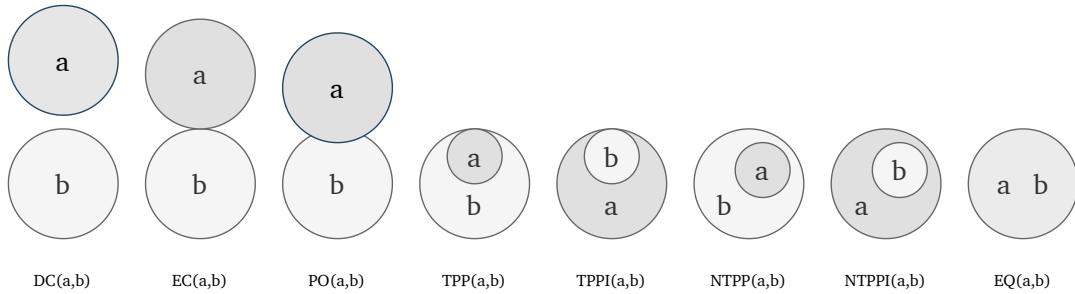


FIGURE 6.2: Visual correspondence of RCC8 relations.

This may be split into the following geographic relationships:

Relationship: Headingley_{e1} is a suburb in Leeds_{e2}...

Label: NTPP(e1, e2)

Relationship: Headingley_{e1} is a suburb_{e2} in Leeds...

Label: EQ(e1, e2)

Relationship: Headingley_{e1} ... two miles out of the city centre_{e2}...

Label: DC(e1, e2) (mod: two miles)

Relationship: Headingley_{e1} ... along the A660_{e2} road.

Label: EC(e1, e2)

Note that eq() relationships can only exist between a named entity and a nominal. All other relationships must exist between two named entities.

6.4.3 Alternative Non-text Based Place Representations

Moving away from text, alternative approaches have also been demonstrated that enable the capture of place-based information from traditional sources of VGI. For example, network analysis has been used to replicate foundational work on the image of cities (Lynch, 1964), demonstrating that geographical representations of nodes and edges contribute importance to individuals, where results share similarities with qualitative mapping participation (Filomena, Verstegen and Manley, 2019).

6.5 Concluding Remarks

This thesis has demonstrated the ability to extract place-based geographic knowledge from the perspective of numerous individuals contributing to informal discussions on social media platforms. While traditional explorations of place have utilised explicit geographic markers like geotags, the abundant volume of informal natural language text, produced through informal communication between users, instead presents the opportunity to harvest alternative geographic knowledge. The contextual semantic information that directly relates to embedded place names in this text has enabled the development of alternative methodologies to generate place-based geographic analysis in this thesis.

The improvements to geoparsing methods in Chapter 3 first enable this knowledge to be associated with existing formalisations of geography, by identifying place names in text, which are then associated with coordinate information. The following chapters then consider how this new form of geographic knowledge may be used to generate alternative formalisations of place. Chapter 4 explores how cognitive representations of geography incorporate subconscious associations between locations, that do not necessarily reflect formal geographic concepts like the Euclidean distance between them. While Chapter 5 notes that semantic footprints of locations tend to exhibit geographically cohesive variation, with clusters appearing in regions like Wales, Scotland, or London.

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Appendix A

Chapter 3 Appendix

A.1 Additional Model Metrics

?@tbl-model-metrics shows additional information regarding the models trained in Chapter 3. This table highlights the trade-offs in model size and training time, particularly between CRF biLSTM and transformer models.

TABLE A.1: Model test performance for each model trained on annotated Wikipedia data. Best F₁ score in bold. Italics indicate a significant difference in F₁ score with respect to 'DistilBERT'.

Model	Size (MB)	Time (S)	F1 Overall
DistilBERT	260.8	100	0.933
RoBERTa	498.7	168	0.931
BERT	433.4	184	0.928
<i>CRF</i>	<i>7.4</i>	<i>159</i>	<i>0.908</i>
<i>CRF (basic)</i>	<i>6.3</i>	<i>110</i>	<i>0.695</i>

Appendix B

Chapter 4 Appendix

B.1 Additional Figures

Figure B.1 gives a more detailed overview of the data processing of Reddit comments.

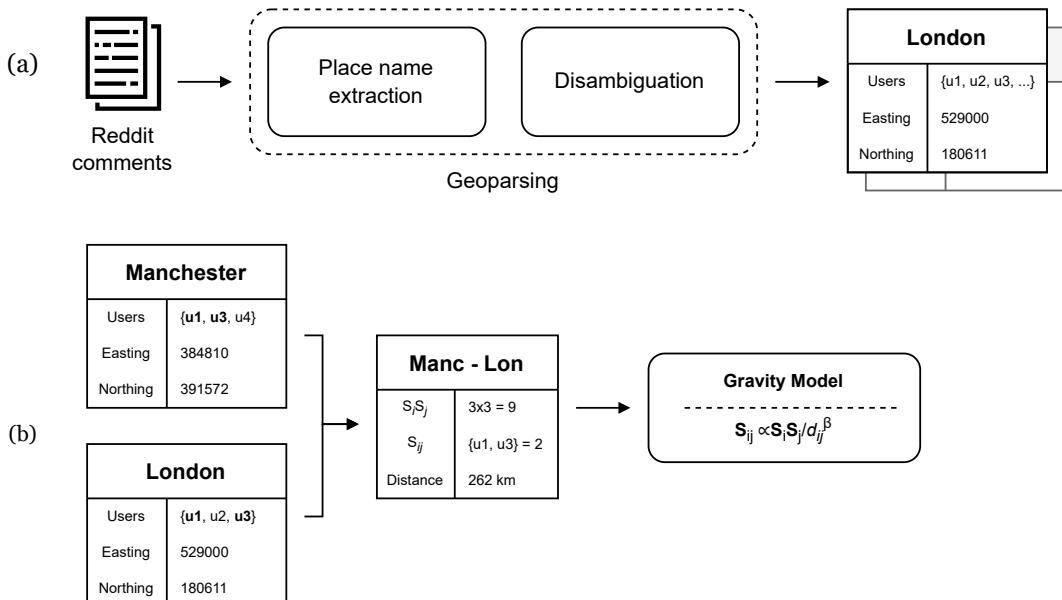


FIGURE B.1: Overview of the (a) Pre-processing pipeline, showing the generation of locations with their associated users, where users are associated if they mention the target location at least once in a comment. (b) Co-occurrence pipeline, demonstrating generation of S_iS_j and S_{ij} for a connection between $i = \text{Manchester}$ and $j = \text{London}$.

B.2 Detailed Model Training

An annotated corpus created at the Workshop on Noisy User-generated Text (WNUT) 2017 used to train the NER model built in this study¹. This workshop defined the shared task on ‘Novel and Emerging Entity Recognition’ with the goal of creating an annotated corpus of informal text from various online sources, with entities that are not frequently encountered. In total this corpus covers 5,690 individual documents from Reddit, Twitter, YouTube, and

¹https://huggingface.co/datasets/wnut_17

StackExchange (Derczynski *et al.*, 2017). In addition, 1,001 individual comments from the Reddit corpus were annotated to first evaluate the performance of our model, before re-training our model used for inference, with this data included.

To prepare the WNUT-17 data for model training, all unrelated entities were removed, keeping only those with the ‘location’ tag, considering any other token to be ‘other’. This ensured that the model did not attempt to learn any irrelevant information regarding other tags found within WNUT (e.g. persons). The model was built using the BERT-base pre-trained transformer language model as a base (Devlin *et al.*, 2019), fine-tuned on the WNUT data using the Hugging Face NER model architecture, which adds a linear head to the BERT transformer. PyTorch lightning was used to handle the training loop, including optimisation and performance evaluation, using 10% of the data as a validation subset taken from the WNUT corpus, to perform early stopping. Once trained, the model weights that performed the best with respect to their F_1 score on this validation subset were evaluated by finding the F_1 score using a random selection of 1001 manually labelled Reddit comments. After obtaining this F_1 score, we then re-trained the model using this manually annotated data, to ensure as much data as possible was used for training. This model was then used to obtain mentions of place names in all Reddit comments and is available on the HuggingFace Model Hub, with instructions for implementing the model in Python.

Table B.1 compares the place name extraction performance of NER models trained on a selection of the most popular NER corpora, evaluated on a collection of 1,001 Reddit comments. First the WNUT 17 corpus is considered, which is relatively small, and less popular than alternatives, but considers social media text specifically. Second is the CoNLL 2003 corpus which is by far the most popular NER corpus used to train models, and is trained on a collection of Reuters news articles. We also consider CoNLLpp, which fixes around 5% annotation mistakes in the original CoNLL 2003 corpus. All of these corpora use the CoNLL03 annotation style, meaning to identify place names only the ‘LOC’ entity is used. Finally, the ‘OntoNotes 5’ corpus is considered, which contains a larger number of examples compared with CoNLL 2003, and uses a different annotation style, again this corpus is trained primarily on news articles. In terms of locational entities OntoNotes 5 considers ‘GPE’ (geopolitical entities), ‘LOC’ (locations), and ‘FAC’ (facilities), all of which are designated as locations in this comparison².

Interestingly, each of these corpora achieve similar F_1 scores, with CoNLLpp slightly ahead. Differences appear in the test loss where WNUT 17 is notably lower, which appears to correlate with a notably higher recall. WNUT 17 precision is however lower overall compared with the other corpora. This result is interesting and reflects the distinction in corpora given WNUT 17 is trained on social media text, while others are trained primarily on news articles.

In the work presented in Chapter 4, given place names are geocoded to known geographic locations, recall was considered to be the most important metric, and WNUT 17 was chosen

²Entities chosen by the Mordecai geoparser.

TABLE B.1: Performance of NER models trained on a selection of the most popular NER corpora, evaluated on a collection of 1,001 Reddit comments.

Model	Corpus Size	Time Taken (m)	Test Loss	Test Recall	Test Precision	Test F1
WNUT 17	5,690	7.26	0.0338	0.850	0.708	0.752
CoNLL 2003	20,744	34.32	0.0543	0.726	0.830	0.750
CoNLLpp	20,744	43.9	0.545	0.728	0.834	0.753
OntoNotes5	76,714	109.00	0.487	0.731	0.813	0.749

as the baseline model, which was then augmented with the 1,001 Reddit comments in the model used for inference.

B.3 Detailed Geocoding

Many identified place names identified in Reddit comments appear multiple times within the Ordnance Survey Open Names gazetteer, but with different coordinates. For example in England there are two cities named ‘Newcastle’, and over 60 streets named ‘High Street’. To identify the most appropriate associated coordinate information, a disambiguation technique was used that relies on other contextual place names. The following gives an overview of this processing for a single target place name.

1. For a target place name, find all other place names mentioned within the same sentence, within the same subreddit. These are contextual place names.
2. Match each contextual place name and the target place name to every entry within the gazetteer. This gives a large collection of place names each with multiple possible coordinates.
3. Find the mean distance between all contextual coordinates and every target coordinate.
4. Select the target place name with the smallest mean distance to the contextual place names.

Appendix C

Chapter 5 Appendix

C.1 Additional Figures

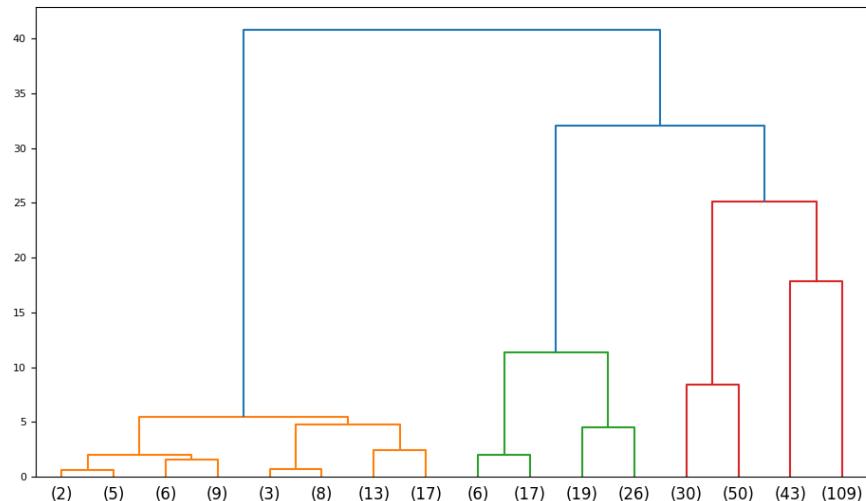


FIGURE C.1: Dendrogram showing distribution of cluster members.

Figure C.1 shows a dendrogram highlighting the hierarchical clusters of LAD embeddings. This figure suggests that there are three main clusters in these semantic embeddings.

Appendix D

A Note on API Restrictions

Alterations made to social media API (particularly Reddit and Twitter), have significantly impeded further research, limiting ease of access by introducing prohibitive costs. Arguably these changes directly conflict with the open standards of the web as originally outlined by Tim Berners-Lee (Berners-Lee, 2010; CERN, 2023), preventing free and open access to a repository of knowledge that is contributed voluntarily by unpaid users. As a result, despite API restrictions, it is possible to access this data indirectly through automated web-scraping, which is itself a grey area.

The most prominent use of scraped web data comes from the training of Large Languages Models (LLMs) using the Common Crawl, and despite using data from both Twitter and Reddit, these LLMs are typically not considered to be infringing on API terms¹. While the removal of open access to the Reddit archive Pushshift does imply that the use of scraped data dumps are unlawful, the legality of web scraping is in fact debatable. For non-commercial use in particular, I personally do not have any ethical concerns in the use of open web data, and present an alternative Reddit data dump through The Eye.

¹Elon Musk has however suggested that Microsoft illegally trained models using Twitter data.