

Geographic Knowledge Graph

GEOG 176C

Gengchen Mai

STKO Lab, Dept. of Geography, UC Santa Barbara, CA, USA

May 21st, 2018



Knowledge



- Facts, information, and skills acquired through experience or education; the theoretical or practical understanding of a subject. (*Oxford Dictionary*)

Graph



simple graph



multigraph



pseudograph



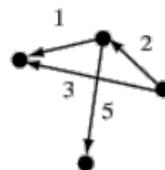
undirected graph



oriented graph



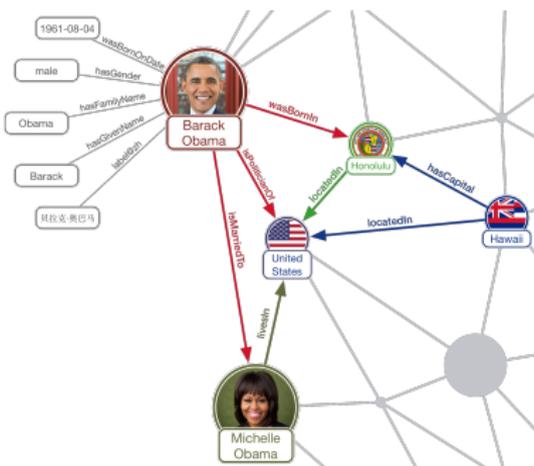
directed graph



network

- A graph is an ordered pair $G = (V, E)$; where V is a set of vertices (nodes) and E is a set of edges (arcs) which are 2-element subsets of V (every edge is connected to two vertices)

Knowledge Graph

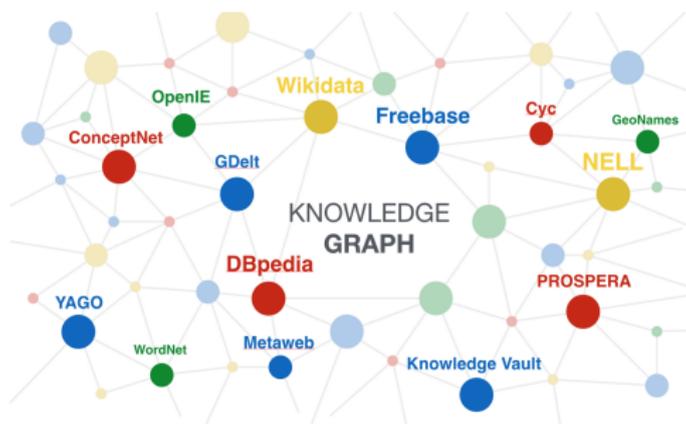


- A KG is typically organized in the form of a graph, e.g., a directed multi-relational graph, such that the nodes represent (real-world) entities and edges represent their relations.
- A knowledge graph (KG) is a data repository that describes entities and their relationships across domains according to some schema, e.g., an ontology

Knowledge Graph

- A collection of triples/statement in the form of (*subject - predicate - object*)
 - (dbr:Santa_Barbara,_California , dbo:isPartOf , dbr:California)
- Example: Google Knowledge Graph, Microsoft's Satori, and Freebase to KGs based on W3C technologies such as DBpedia, YAGO, and Wikidata.

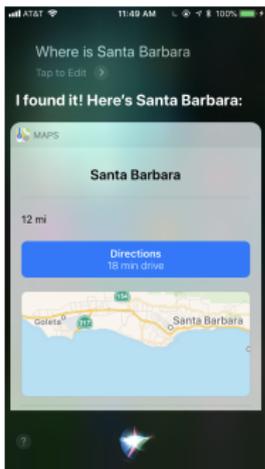
Knowledge Graph



- These data repository can be linked with each other based on ontology alignment (`owl:equivalentClass`) and instance level alignment (`owl:sameAs`)
 - (`dbr:Place`, `owl:equivalentClass`, `schema-org:Place`)
 - (`dbr:Santa_Barbara,_California`, `owl:sameAs`, `freebase:Santa_Barbara,_California`)

Applications of Knowledge Graph

- Questions and Answering, e.g. Apple Siri, Google Duplex



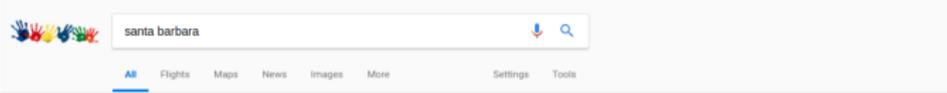
Apple Siri



Google Duplex

Applications of Knowledge Graph

- Information Retrieval, e.g. Google Knowledge Graph



About 1,250,000 results (0.60 seconds)

Santa Barbara, CA | Hotels, Restaurants, Events & Activities
<https://santabarbarca.com/>
 Welcome to Santa Barbara—The American Riviera®. Plan your trip, find restaurants, things to do, wine tasting, shopping, outdoor activities and more.
 Santa Barbara Beauty in the ... · Santa Barbara Bowl · Santa Barbara County ...

Visit Santa Barbara (@SantaBarbara) · Twitter
<https://twitter.com/SantaBarbara>

<p>Delicious food, great cocktails and stunning views of the Stearns Wharf. What more could you ask for at Blue Water Grill?</p> <p>#AmericanRiviera 🍷 @SogdanRestly pic.twitter.com/MQPMrLk...</p> <p>2 days ago · Twitter</p>	<p>Modern chic meets Spanish romance. Introducing the new @HiltonGBResort. #AmericanRiviera bit.ly/2K4axWlx pic.twitter.com/9x0Z2KH...</p> <p>2 days ago · Twitter</p>	<p>Winery-hopping around the Santa Barbara area just got a little easier with UberWINE. 🍷 tandl.me/2zqohml via @TravelLeisure</p> <p>2 days ago · Twitter</p>
---	--	---

Santa Barbara, California - Wikipedia
https://en.wikipedia.org/wiki/Santa_Barbara_California
 Santa Barbara (Spanish for "Saint Barbara") is the county seat of Santa Barbara County in the U.S. state of California. Situated on a south-facing section of ...
 History of Santa Barbara · Santa Barbara County, California

Things to do in Santa Barbara

 <p>Mission Santa Barbara 18th-century mission & Catholic church</p>	 <p>Santa Barbara Zoo Compact zoo with hundreds of animals</p>	 <p>Santa Barbara Presidio Green space featuring a 1782 fortress</p>	 <p>Santa Barbara County Courthouse Spanish Colonial Revival courthouse</p>
--	--	--	---

[Santa Barbara travel guide](#)



Santa Barbara
City in California

Santa Barbara is a city on the central California coast, with the Santa Ynez Mountains as dramatic backdrop. Downtown, Mediterranean-style white stucco buildings with red tile roofs reflect the city's Spanish colonial heritage. Upscale boutiques and restaurants offering local wines and seasonal fare line State Street. On a nearby hill, Mission Santa Barbara, founded in 1786, houses Franciscan friars and a museum.

Weather: 62°F (17°C), Wind S at 6 mph (10 km/h), 67% Humidity
Population: 91,530 (2016)

Plan a trip

- [Santa Barbara travel guide](#)
- 3-star hotel averaging \$230, 5-star averaging \$492
- Upcoming Events

Colleges and Universities: University of California, Santa Barbara, MORE

People also search for View 10+ more

 California	 United States of America	 Los Angeles	 San Diego	 San Francisco
---	---	---	--	--

[More about Santa Barbara](#)

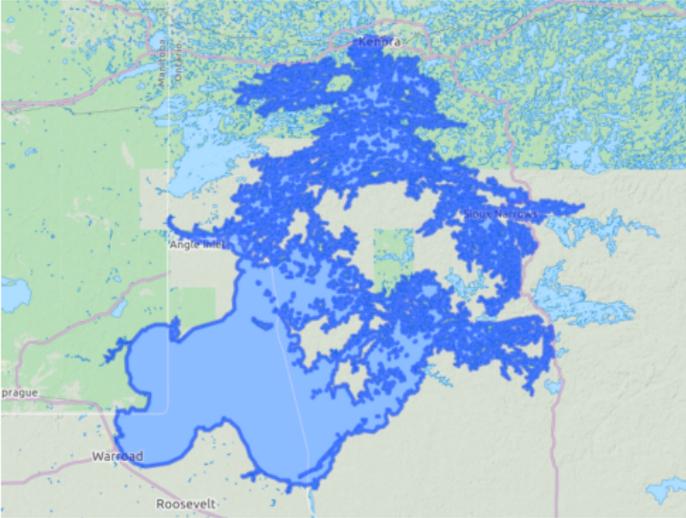
Geographic Knowledge Graph

- Specific problems for geographic knowledge graphs ¹:
 - **How to meaningfully encode geographic information (complex geometries) in a KG? [7]**
 - **How to meaningfully visualize geographic knowledge graphs? [6]**
 - **How to enable GIS computations on geographic knowledge graphs on the fly?**

¹Some works are done by other STKO members

Representations of Complex Geometries in Geographic KG

- How to serialize complex geometries in geographic knowledge graphs?



- GeoSPARQL
- Awesemantic-Geo [7]

Multipart polygon representing the Lake of the Woods [7]

GeoSPARQL

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .

@prefix geo: <http://www.opengis.net/ont/geosparql#> .

@prefix ex: <http://www.example.org/POI#> .

@prefix sf: <http://www.opengis.net/ont/sf#> .

ex:NationalMall a ex:Park;

    rdfs:label "National_Mall";

    geo:hasGeometry ex:NMPoly .

ex:NMPoly a sf:Polygon;

    geo:asWKT "POLYGON((-77.050125_38.892086,_-77.039482_38.892036,_-77.039482_
    ↪ 38.895393,_-77.033669_38.895508,_-77.033585_38.892052,_-77.031906_
    ↪ 38.892086,_-77.031883_38.887474,_-77.050232_38.887142,_-77.050125_
    ↪ 38.892086))"^^geo:wktLiteral.
```

- Store the entire geometry and the coordinate system in a single RDF literal, thus eliminating any issues brought on by embedding complex structures as RDF

GeoSPARQL

- pros:
 - storing serialized geometry data within RDF triples;
 - supporting coordinate reference systems;
 - maintaining the distinction between entities and their geometric representation;
 - enabling geospatial queries on linked geographic data;
- cons:
 - Challenges associated with the storage and transmission of large WKT strings;
 - Timely execution of SPARQL queries that make use of geospatial functions.

Awesemantic-Geo

base uri geometry ID
http://ex.co/geometry/polygon/12345#113.05281,-38.11945/153.30671,-11.15957
 geometry type WGS84 bounding box coordinates

Encoding scheme used to mint URIs representing a geometry [7]

- Using dereferencable Uniform Resource Identifiers (URIs) to represent the geometry as a resource;
- Including important information (geometry type; bounding box) in the URIs;
- Can not get raw geometries information using SPARQL.

Visualize Geographic KG in Multiple Ways

- Graph View

The screenshot displays the 'GeoLink: Cruises' interface. The main area shows a network graph on a parchment-like background. Nodes are represented by colored boxes: red for 'Cruises' (e.g., 51491, 517869, 51482, 51748, 51749, 51750, 51737, 51758, 51708, 51738) and blue for 'Researchers' (e.g., 51749, 51750, 51737, 51708, 51738). A 'More Path...' button is visible in the center of the graph. On the right, a 'Relationship Finder' sidebar allows for node selection and query configuration. The sidebar includes fields for 'First Node' (Type: Cruises) and 'Second Node' (Type: Researchers, Select: http://data.geolink.org/id/pers). The 'Relationship Query Setting' section includes 'Path Max Distance' (3), 'Max Num. of Paths' (10), and a checked 'Show TBBox Relationship' option. A 'Relationship Query' button is at the bottom of the sidebar. The top of the interface features the EarthCube logo and a 'Switch to a different view' dropdown menu. The bottom left shows various data source logos (BCO-DMO, DataONE, etc.), and the bottom right credits 'Design & developed by STKO Lab'.

Visualize Geographic KG in Multiple Ways

● Map View

The screenshot displays the EarthCube GeoLink: Cruises interface. At the top, the header includes the EarthCube logo, the title "GeoLink: Cruises", and a search bar with the text "Type your search keyword here..." and a "Search" button. Below the header, there is a "Layer Legend" section on the left with a checked box for "Cruises". The main area is a satellite map of the North Atlantic, showing the eastern coast of North America and the western coast of Europe. A small yellow-green area is highlighted on the map. On the right side, there is a "Result Count: 1" section with a list containing the entry "AE0904". Below the list is a "Map Result" button. At the bottom of the interface, there are logos for various data providers and a footer that reads "Designed & developed by STKO Lab".

Visualize Geographic KG in Multiple Ways

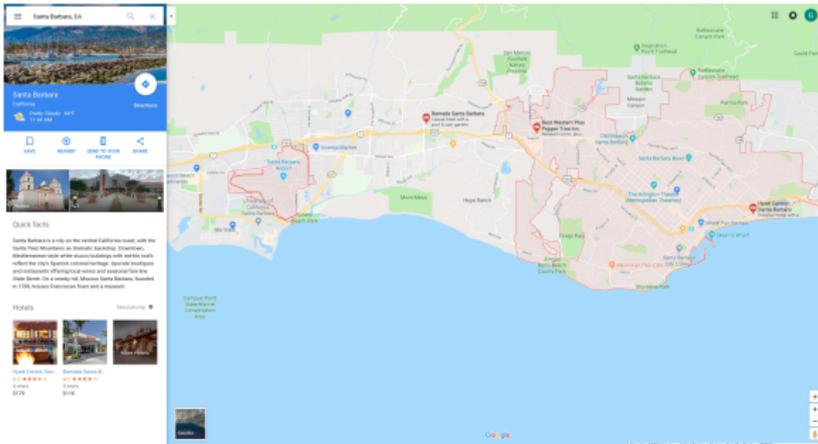
- Table View

The screenshot shows the GeoLink: Cruises interface. At the top, there are logos for EARTH CUBE and GeoLink: Cruises. A search bar is present with the text "Type your search keyword here..." and a "Search" button. Below the search bar, the "Item Count" is displayed as 1000. The main content area shows a table view for the item AE0904. The table has two columns: "Property" and "Value". The table contains the following rows:

Property	Value
is gl:hasCruise of	:455653
is gl:hasCruise of	:455906
is gl:hasCruise of	:543850
is gl:hasCruise of	:3818
is gl:hasCruise of	:3906
is gl:hasCruise of	:543808
is owl:sameAs of	:58917
is	:50759
gl:isChiefScientistOf	of
is gl:hasCruise of	nodeID://b6136900
is gl:hasCruise of	nodeID://b6137074
is gl:hasCruise of	nodeID://b6152477
is gl:hasCruise of	nodeID://b6152963
:hasAward	NSF 06-48016
:hasAward	NSF 07-52366
:hasChiefScientist	Johnson, Rodney
:hasCruiseType	http://voc.rvdata.us/cruise/op_science
:hasEndPortCall	Atlantic Explorer : 2009-03-20 : arrivePort

A Semantically Enriched Visualization

- **Maps:** extensively used to visualize GI and spatial relationships.



- Difficult to directly express non-spatial relationships (semantic similarity) using such maps.

A Semantically Enriched Visualization

A Semantically Enriched Visualization: An **analogy** of thematic maps to visualize the distribution of geographic features in a semantic space.

- Points: Geographic Coordinates → Locations in the Semantic Space
- Polygons: Administration Regions/Continents → Semantic Continents

A Semantically Enriched Visualization

A Semantically Enriched Visualization:

- Semantically similar entities are clusters within the same region;
- The distance between geographic features represents how similar they are.

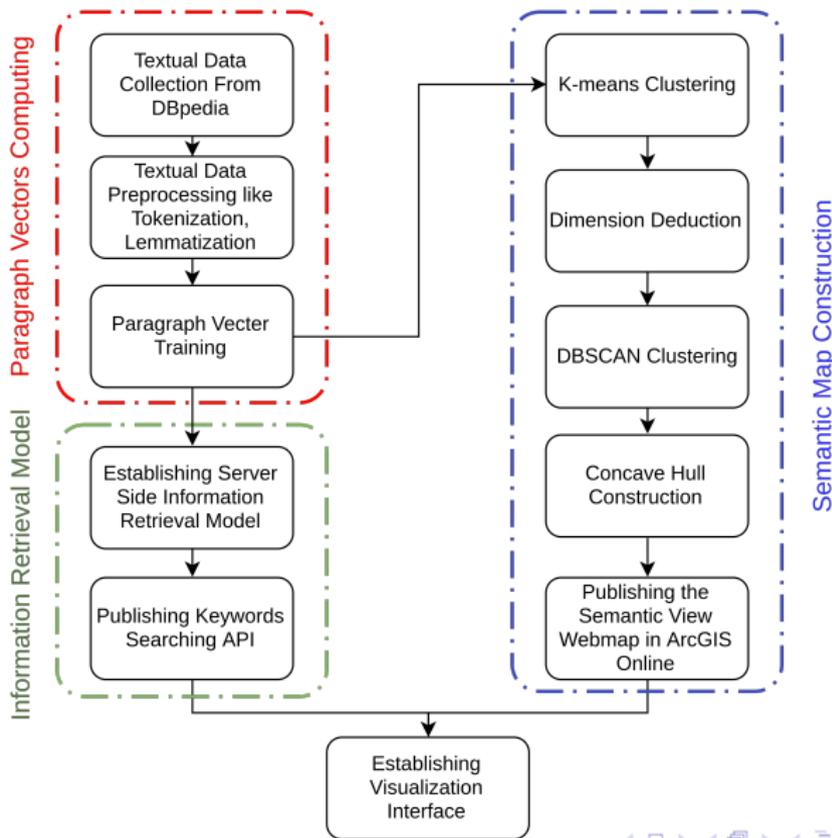
A Semantically Enriched Visualization

- In this work, a **semantically enriched** geospatial data **visualization** and **searching** framework are presented.
- We evaluate it using a subset of places from DBpedia.



- Multiple techniques:
 - Paragraph Vector
 - Spatial Clustering
 - Concave Hull Construction
 - Information Retrieval (IR) Model

The Workflow



Paragraph Vectors Computing

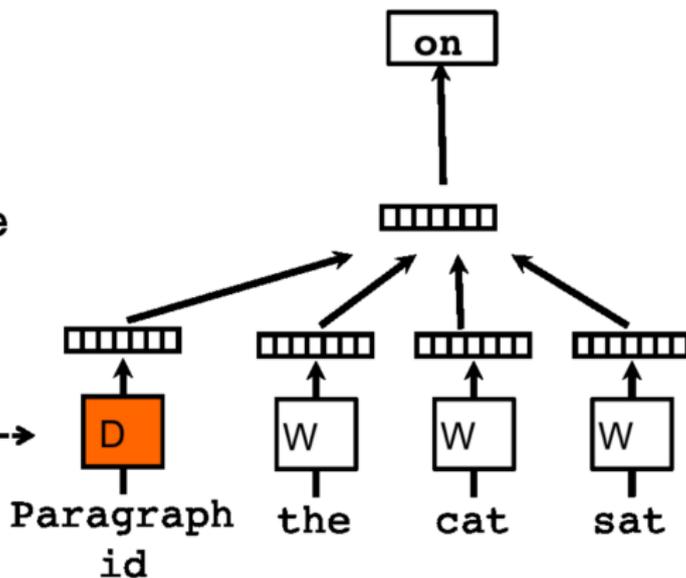
- **Paragraph Vector** (or called **Doc2Vec**) is a representation learning method proposed by Natural Language Processing community.
- **Idea**: Give a collection of documents, Doc2Vec learns a high-dimensional continuous vector (embedding) for each document.
- The **cosine similarity** between the learned document vectors represents the **semantic similarity** between their corresponding documents.

Paragraph Vectors Computing

Classifier

Average/Concatenate

Paragraph Matrix



The two-layer neural network architectural of Doc2Vec

Paragraph Vectors Computing

Outputs of Doc2Vec:

- Embeddings of documents;
- Embeddings of word tokens in the document corpus.

Paragraph Vectors Computing

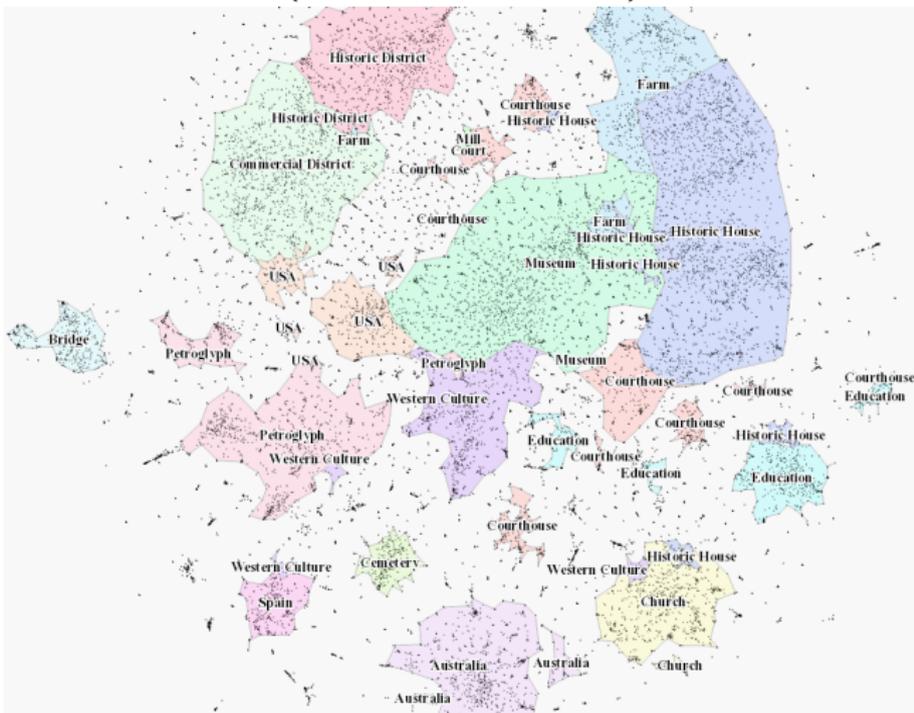
- **Data Source:** All entities typed dbo:HistoricalPlace in DBpedia (21010 places)
 - Each historic place has an abstract, comments, images, and geographic coordinates.
- **Method:** Doc2Vec Model (PVDM [5])
 - **Textual data collection:** Treat each place as a document whose content is its abstract and comments
 - **Textual data preprocessing:** tokenization and lemmalization
 - **Paragraph vector training:** embedding dimension $K = 300$; window size $N = 10$; learning rate $\alpha = 0.025$

Information Retrieval Model

- **Place Embeddings:** the learned embedding of each historic place from Doc2Vec.
- **Query Embeddings:**
 - Utilize the `Doc2Vec.infer_vector()` function from gensim's Doc2Vec package
 - The TF-IDF score weighted embedding based on word embeddings of query word tokens
 - **The simple average of the query tokens' embeddings after stop words removal**
- **Semantic Similarity Score Function:** the cosine similarity between the query embedding and place embeddings
- An API ² is provided for the semantic searching functionality among *DBpedia* historic places.

Semantic Similarity Map Construction

Spatialization: how to construct an overview of the semantic distribution of geographic entities such that it follows a cartographic tradition (*semantic continent*).



Semantic Similarity Map Construction

K-means clustering: group these place embeddings into different clusters;

- Try $\#(\text{clusters})$ from 2 to 30 and compute silhouette coefficient [8] of the clustering results;
- $\#(\text{clusters}) = 16$ gives the highest silhouette coefficient;
- The descriptions of places in each cluster are combined as one document;
- Word clouds are produced from 10 word with highest TF-IDF score;
- Each cluster is named according to the its top 10 words.

Elementary
Frame Maine
Library
Shaker
Schoolhouse
Oneroom

The word cloud for *Education* cluster

Semantic Similarity Map Construction

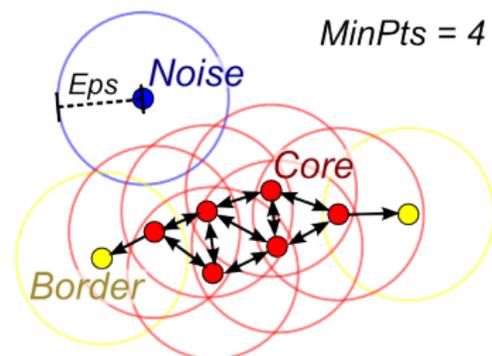
Dimension reduction: to visualize the semantic distribution of geographic entities in a 2-dimensional space

- Different dimension deduction methods including PCA and t-SNE are experimented;
- t-SNE performs best and the clusters derived from k-means are still well separated.

Semantic Similarity Map Construction

DBSCAN:

- Although t-SNE produces a good dimension reduction result, some points are far away from their cluster centroids and scattered in the 2D space.
- We apply DBSCAN [3] to each projected k-means cluster to extract the “core” parts of them.
- Visual interpretation are used to select the parameter combination for DBSCAN. ($Eps = 1.1$ and $MinPts = 6$)



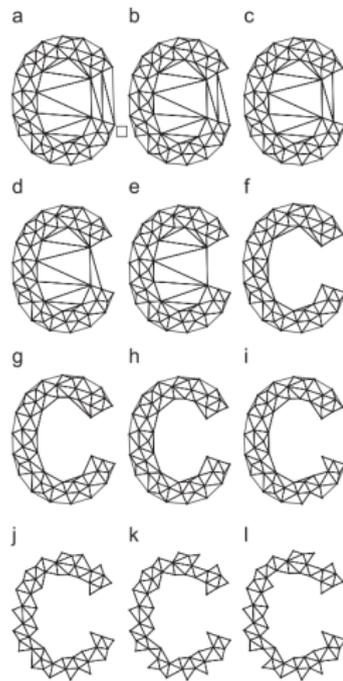
Semantic Similarity Map Construction

Concave Hull Construction: *Chi-shape* algorithm [2]

- It first constructs a Delaunay triangulation;
- It erodes the boundary by deleting boundary's edges until the longest edge less than a threshold.
- A normalized length parameter $\lambda_p \in [1, 100]$ controls this threshold;
- To get optimal λ_p , a fitness score function [1] is used to balance the *complexity* and *emptiness* of the resulting concave hull.

$$\phi(P, D) = \text{Emptiness}(P, D) + C * \text{Complexity}(P) \quad (1)$$

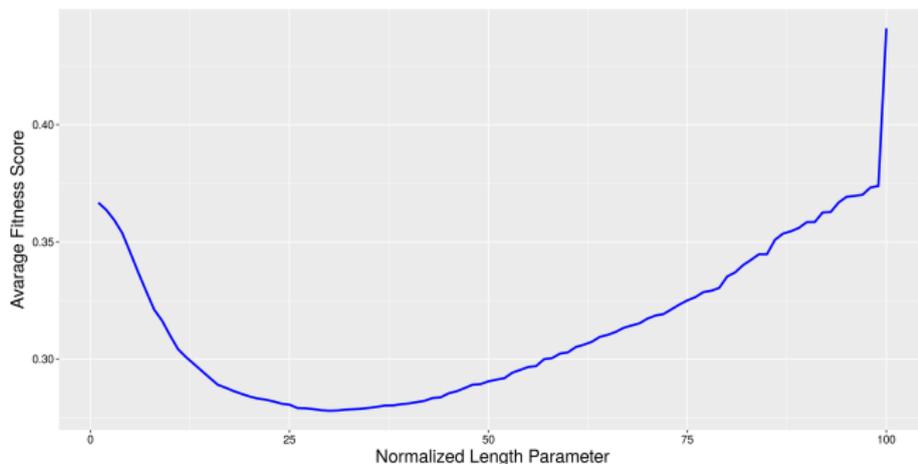
P : the derived simple polygon; D : the Delaunay triangulation of the corresponding point cluster.



Semantic Similarity Map Construction

Concave Hull Construction:

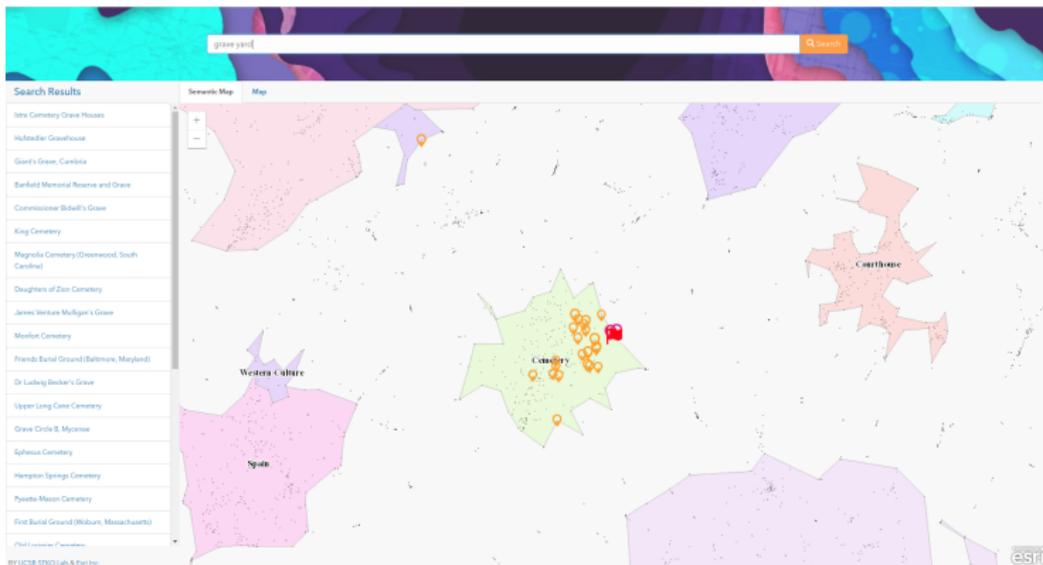
- We iterate λ_p from 1 to 100 and compute the average fitness score of all point clusters produced by DBSCAN;
- The optimal λ_p with the lowest average fitness score is 30.



The average fitness score for different λ_p among all DBSCAN clusters.

Result

We have deployed a web-based user interface⁴ to showcase the functionality using the historical places dataset.



the search result of “grave yard” in the semantic space

Result

Search Results

Istre Cemetery Grave Houses

Mulhuller OneHouse

Coast's Grove, Canby

Barfield Memorial Reserve and Grave

Commissaire DeWitt's Drive

King Cemetery

Magnolia Cemetery (Greenwood, South Carolina)

Daughters of Zion Cemetery

James Warkie Mulligan's Grave

Mulhull Cemetery

Friends Burial Ground (Baltimore, Maryland)

Dr Ludwig Beckler's Grave

Hopewell Long Cave Cemetery

Grave Christ B. Myron

Sophron Cemetery

Hampton Springs Cemetery

Pequot Mason Cemetery

First Burial Ground (Watson, Massachusetts)

gravel yard

Istre Cemetery Grave Houses
(Lat: 30.1156 Long: -92.5647) [Similarity Score: 0.7]

The Istre Cemetery Grave Houses are three historic grave houses located in Istre Cemetery in Monroeville, Louisiana. The houses are the only three known surviving examples of traditional Acadiana grave houses. The structures were built in 1825, 1925, and circa 1900; they each resemble a small gable-roofed house. It is important to distinguish between grave shelters and grave houses. Shelters, common in Protestant southern cemeteries, are primarily built with a roof, four corner posts and a base plate...

View on OpenStax View on Wikidata

Western Sprat
Plot Grave
Burial Graf
Rondo
Lorraine
Ancestors

Capitane

Cemetery

Western Culture

Sprat

esri

The pop-up window shows some basic information for

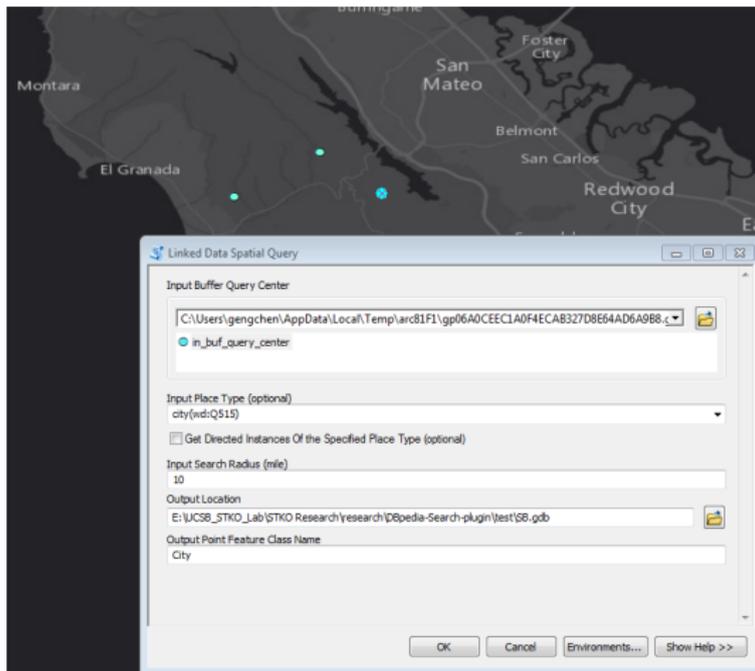
dbo: Istre_Cemetery_Grave_Houses .

A Deep Integration of Geographic Linked Data with GIS

- From a GIS perspective, Linked Data seems almost like a one-way street.
- Considerations when integrate Linked Data with GIS:
 - How GIS and its users should interact with Linked Data?
 - How these key benefits of Linked Data can be maintained during conversion into GIS data formats and analysis without having to flatten the data back to a tabular format?
 - How to utilize the ontologies used to semantically lift Linked Data instead of merely relying on strings?

ESRI Linked Data Connector

- Buffer Search on Geographic KG:
 - Find cities around the search center



ESRI Linked Data Connector

- Property Enrichment for Geographic Entities (Utilize Semantic Web reasoning and ontologies to extract additional properties by using subsumption reasoning and (inverse) partonomical relations as examples):
 - People that died in San Francisco / Bay Area?

Table

SanMateoCounty_wikiURL_subDivisionRL_DBpediaRL_is_deathPlace_Of

OBJECTID	DBpediaIRI *	is_deathPlace_Of
1	http://dbpedia.org/resource/Santa_Mateo_California	http://dbpedia.org/resource/Lyette_Thomas
2	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Robert_Cottle
3	http://dbpedia.org/resource/Pacifica_California	http://dbpedia.org/resource/Christian_Theodore_Pedersen
4	http://dbpedia.org/resource/Menlo_Park_California	http://dbpedia.org/resource/Charles_N_Feton
5	http://dbpedia.org/resource/Milbrae_California	http://dbpedia.org/resource/Albert_Johnson_(jockey)
6	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Greta_Johansson
7	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Walle_Herzer
8	http://dbpedia.org/resource/South_San_Francisco_California	http://dbpedia.org/resource/John_L_Wasserman
9	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Nan_Wood_Graham
10	http://dbpedia.org/resource/La_Honda_California	http://dbpedia.org/resource/Ben_Keath
11	http://dbpedia.org/resource/Burlingame_California	http://dbpedia.org/resource/Michael_T_Gottlieb
12	http://dbpedia.org/resource/Burlingame_California	http://dbpedia.org/resource/Lurline_Matson_Roth
13	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Bill_Werle
14	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Con_Dempsey
15	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Morris_Kirkeby
16	http://dbpedia.org/resource/Burlingame_California	http://dbpedia.org/resource/Dick_Jones_(baseball)
17	http://dbpedia.org/resource/Daly_City_California	http://dbpedia.org/resource/Babe_Pfeiff
18	http://dbpedia.org/resource/Pacifica_California	http://dbpedia.org/resource/Calley_Stewart
19	http://dbpedia.org/resource/Menlo_Park_California	http://dbpedia.org/resource/Cucio_Cristensen
20	http://dbpedia.org/resource/Daly_City_California	http://dbpedia.org/resource/Henry_Liu
21	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Wagner_Jorgensen
22	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Ray_Apolakis
23	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Bob_Garber
24	http://dbpedia.org/resource/Atherton_California	http://dbpedia.org/resource/John_R_Beckett
25	http://dbpedia.org/resource/Hiloborough_California	http://dbpedia.org/resource/Eugenia_Lopez_Jr
26	http://dbpedia.org/resource/San_Carlos_California	http://dbpedia.org/resource/Oran_Ahmed_gholican
27	http://dbpedia.org/resource/Milbrae_California	http://dbpedia.org/resource/Ronnie_Montrose
28	http://dbpedia.org/resource/Menlo_Park_California	http://dbpedia.org/resource/Thomas_A_Bakey
29	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Robert_R_Barry
30	http://dbpedia.org/resource/Atherton_California	http://dbpedia.org/resource/Rajeev_Motwani
31	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Alan_Nevins
32	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Jim_Davenport
33	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Marjorie_Desaine
34	http://dbpedia.org/resource/Portola_Valley_California	http://dbpedia.org/resource/Bert_Cole
35	http://dbpedia.org/resource/Menlo_Park_California	http://dbpedia.org/resource/Albert_H_Bowker
36	http://dbpedia.org/resource/Menlo_Park_California	http://dbpedia.org/resource/Abraham_Maslow
37	http://dbpedia.org/resource/Pacifica_California	http://dbpedia.org/resource/Ragnar_Hasselgren
38	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Wally_Jay
39	http://dbpedia.org/resource/San_Bruno_California	http://dbpedia.org/resource/Mosheim_Feaster
40	http://dbpedia.org/resource/San_Carlos_California	http://dbpedia.org/resource/Tom_Tennant
41	http://dbpedia.org/resource/Atherton_California	http://dbpedia.org/resource/Samuel_M_Shortridge
42	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Harry_Desaine
43	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Harry_Chaik
44	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Ray_Maderias
45	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Bob_Hoskins_(American_football)
46	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Jennison_Heaton
47	http://dbpedia.org/resource/Redwood_City_California	http://dbpedia.org/resource/Helen_Levitov_Sobell
48	http://dbpedia.org/resource/San_Mateo_California	http://dbpedia.org/resource/Chang-Lin_Tien
49	http://dbpedia.org/resource/Daly_City_California	http://dbpedia.org/resource/Dave_Breeden
50	http://dbpedia.org/resource/Portola_Valley_California	http://dbpedia.org/resource/Janine_Hatford
51	http://dbpedia.org/resource/Belmont_California	http://dbpedia.org/resource/Ernie_Despres
52	http://dbpedia.org/resource/Belmont_California	http://dbpedia.org/resource/Julio_Bonetti
53	http://dbpedia.org/resource/Millwood_California	http://dbpedia.org/resource/Chauk_Tamala

1 (out of 174 Selected)

SanMateoCounty_wikiURL_subDivisionRL_DBpediaRL_is_deathPlace_Of

References I

- [1] Akdag, Fatih, Eick, Christoph F, & Chen, Guoning. 2014. Creating polygon models for spatial clusters. *Pages 493–499 of: International Symposium on Methodologies for Intelligent Systems*. Springer.
- [2] Duckham, Matt, Kulik, Lars, Worboys, Mike, & Galton, Antony. 2008. Efficient generation of simple polygons for characterizing the shape of a set of points in the plane. *Pattern Recognition*, **41**(10), 3224–3236.
- [3] Ester, Martin, Kriegel, Hans-Peter, Sander, Jörg, Xu, Xiaowei, *et al.* . 1996. A density-based algorithm for discovering clusters in large spatial databases with noise. *Pages 226–231 of: Kdd*, vol. 96.

References II

- [4] Janowicz, Krzysztof, Hu, Yingjie, McKenzie, Grant, Gao, Song, Regalia, Blake, Mai, Gengchen, Zhu, Rui, Adams, Benjamin, & Taylor, Kerry. 2016. Moon landing or safari? A study of systematic errors and their causes in geographic linked data. *Pages 275–290 of: International Conference on Geographic Information Science*. Springer.
- [5] Le, Quoc, & Mikolov, Tomas. 2014. Distributed representations of sentences and documents. *Pages 1188–1196 of: International Conference on Machine Learning*.
- [6] Mai, Gengchen, Janowicz, Krzysztof, Prasad, Sathya, & Yan, Bo. 2018. Visualizing The Semantic Similarity of Geographic Features.
- [7] Regalia, Blake, Janowicz, Krzysztof, & McKenzie, Grant. 2017. Revisiting the Representation of and Need for Raw Geometries on the Linked Data Web. *In: LDOW@ WWW*.

References III

- [8] Rousseeuw, Peter J. 1987. Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. *Journal of computational and applied mathematics*, **20**, 53–65.