Data mining in unusual domains with information-rich knowledge graph construction, inference and search

Mayank Kejriwal, Pedro Szekely

Information Sciences Institute,

USC Viterbi School of Engineering





- Unusual domains
- Knowledge graphs
- KG construction
- **Case study**

Knowledge graph completion Entity resolution Probabilistic soft logic KGs in latent space Searching knowledge graphs

Unusual domains

Disaster Assistance In Regions Using Low Resource Languages

Data

Social media and news in low resource languages Akan, Amharic, Hausa, Tagalog, Uyghur, Wolof, Yoruba, ...

Example Questions

Identify areas where people are in greatest need Identify threats to relief personnel Characterize the evolution of the disaster

Technical Challenges

Very noisy translation Clustering documents according to need, location and entities Streaming data

Identify Illegal Firearm Sales

Data

Classified ads and forums Open and dark web

Example Questions

Identify buyers who purchase on behalf of others Identify people who buy and sell without proper licenses Identify vendors who illegally sell across state lines Identify stolen firearms for sale

Technical Challenges

Most firearm sales are legal Huge volume of pages and web sites Unusual language model

Identify Counterfeit Electronics Vendors

Data

Online catalogs and forums Internal sources containing suspicious vendors, shipping addresses

Example Questions

Identify clusters of companies under control of one organization Identify fraudulent ads across vendor sites

Technical Challenges

Many pages in Chinese Fake images on catalogs Frequent creation of new shell vendor companies

Identify Narcotics Vendors In The Dark Web

Data

Dark web marketplace and forum pages Open web social media sites

Example Questions

Identify dark web personas in the open web ???

Technical Challenges

Pages in multiple languages Unusual language model Deception, fake vendors, fake reviews Careful concealment of identifying information

Combat Fraud In The Penny Stock Market

Data

Web pages and social media about companies in the Over The Counter (OTC) market

Example Questions

Identify in-progress pump-and-dump scams Identify chain of shell companies and individuals involved Identify promoters, attorneys, etc. Identify evidence of unlawful behavior (e.g., false statements in promotional materials)

Technical Challenges

Pump-and-dump scams are carefully planned and controlled to look legal Wide variety of page genres: company profiles, press releases, promotions, financial data

Identify Human-Trafficking Victims & Prosecute Traffickers

Data

100,000,000 escort ads published on the web 50,000 images

Example Questions

Identify all ads for an escort given soft identifies Tag ads as high-risk for human trafficking Identify stables of escorts controlled by one trafficker Identify fake images Identify networks of phone numbers

Technical Challenges

Noise, obfuscation, deception and large size Unique language model Long-tailed set of sources Lack of identifiers and reference data Kejriwal, Szekely

Work on unusual domains has significant **Social impact**

Find Locations Where An Escort Was Advertised

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Number Of HT Investigations Increased



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SFGATE LOCAL NEWS SPORTS BUSINESS A&E FOOD LIVING TRAVEL REAL ESTATE C



Man sentenced to 97 years in human trafficking case

By Vivian Ho Updated 7:07 am, Friday, April 22, 2016



97-TO-LIFE

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- Las Vegas, Oakland. SF
- Diego, SF

forced

• Arr. 4/2016 for possession for sale Co-de said she was •

jail Present for victim 1

- "Z"
- 653.23 on Capp St.
- Friend of Geeter •
- Was assisting in • bringing in character witnesses (minors)

4 ACCOMPLICES

Victims



Candise Burns

- Mother of Geeter's first child
- Reached out post verdict to SFDA about victimization
- Sgt. Flores has been in contact



Yasmine Malone

- Missing 15 yo Victimized in 12/2014
- MH issues; assaulted SFSD officer
- Birden/Walls in contact posttrial and assisting in exploitation (2016)



Shakarri Miller

- Missing 15 yo Victimized
- Arrested in Broadmoor, CA with Geeter



Courtney Taylor

- Missing 17 yo Victimized
- Arrested in Garden Grove, CA with Geeter and Birden



Zurline Hurst



+20 additional, possible victims of ring

>25 VICTIMS

Case Study 4: Recovery of Missing Juvenile



Report a sighting

Problem: Missing juvenile via NCMEC who reached out to friends, saying she was being trafficked throughout CA

Outcome: A. Green was recovered in Atlanta, Georgia by the FBI after I provided NCMEC and local law enforcement with her most recent sex ad and location.



DON'T HESITATE!

ANYONE HAVING INFORMATION SHOULD CONTACT

CALL 911 or 1-800-843-5678 (1-800-THE-LOST®) Hanford Police Department (California) 1-559-585-2540

CALIFORNIA VICTIM

Usual	Unusual		
Good English	Jargon, ungrammatical		
Mostly correct information	Obfuscation & deception		
Large reference datasets	No reference datasets		
Small number of sources	Long tail		
Sources readily available	Ephemeral pages, dark web, anti-crawling measures		

Two guiding questions

How do we model, and represent knowledge in, unusual domains?

Are there general lessons to be learned across domains?

How do we do search and inference in unusual domains?

how to represent KGs?

KG Definition

a directed, labeled multi-relational graph representing facts/assertions as triples

(h, r, t) head entity, relation, tail entity(s, p, o) subject, predicate, object

Simplest Knowledge Graph Entities



Easiest to build

Simple, But Useful KG Entities + properties



Semantic Web KG (RDF/OWL)

Entities + properties + classes



Very hard to build

"Ideal" KG

Entities + properties + classes + qualifiers



How about Ontologies?



Domain ontologies don't exist for unusal domains

Build new one or extend existing one? Deep or shallow?



Goal is to help users solve problems

Let users tell you what entities matter to them

Build the shallowest, simplest ontology that captures the entities users care about



Domain ontologies don't exist for unusal domains

Build new one or extend existing one? Deep or shallow?

Where to Store KGs?

Serializing Knowledge Graphs

Resource Description Framework (RDF)

Database (triple store): AllegroGraph, Virtuoso, Query: SPARQL (SQL-like)

Key-Value, Document Stores

Data model: Node-centric Databases: Hbase, MongoDB, Elastic Search, ... Query: filters, keywords, aggregation (no joins)

Graph Databases

Data model: graph Databases: Neo4J, Cayley, MarkLogic, GraphDB, Titan, OrientDB, Oracle, ... Query: GraphQL, Gremlin, Cypher

Popularity Ranking Of Graph Databases

DB-Engines Ranking of Graph DBMS



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https://db-engines.com/en/ranking_trend/graph+dbms

ElasticSearch, MongoDB & Neo4J Have Wide Adoption



https://db-engines.com/en/ranking_trend/graph+dbms

KGs I can **Reuse**





RDF graph derived from Wikipedia http://wiki.dbpedia.org/

4.58 million things

4.22 million are classified in a consistent ontology

1,445,000 persons

735,000 places

478,000 populated places),

411,000 creative works

123,000 music albums, 87,000 films and 19,000 video games

241,000 organizations

58,000 companies and 49,000 educational institutions

251,000 species

Kejriwal, Szelen 000 diseases

YAGO Knowledge Base

http://www.mpi-inf.mpg.de/departments/databases-and-information-systems/research/yago-naga/yago/downloads

Derived from Wikipedia WordNet and GeoNames

10 million entities120 million assertionspersons, organizations, cities, etc.

350,000 dasses

many fine grained classes, inferred from the data
Wikidata

The "wikipedia" of data https://www.wikidata.org/wiki/Wikidata:Main_Page

Collaborative, multilingual

collecting structured data to provide support for Wikipedia

31,419,072 items

534,615,360 edits since the project launch

Google Knowledge Graph

https://developers.google.com/knowledge-graph/how-tos/search-widget-example

derived from many sources, including the CIA World Factbook, Wikidata, and Wikipedia

powers a "knowledge panel"

the Knowledge Graph now holds 70 billion facts

search: APPL



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Group

Feedback

Other Knowledge Graphs

Internet Movie Firearms Database

Firearms used or featured in movies, television shows, video games, and anime 22,159 articles, extensive coverage and ontology http://www.imfdb.org/wiki/Category:Gun

Microsoft Satori

Large knowledge graph similar to Google KG, e.g., 1.8 million bottles of wine Many streaming channels of real-time data, e.g., bitcoin, transportation, ... https://www.satori.com/

LinkedIn Knowledge Graph

450M members, 190M historical job listings, 9M companies, 28K schools, 1.5K fields of study, 600+ degrees, 24K titles and 35K skills in 19 languages https://engineering.linkedin.com/blog/2016/10/building-the-linkedin-knowledge-graph

Knowledge 'base' vs 'graph'

Terms often used interchangeably in the literature

Knowledge base is more of a catch-all e.g., Wikipedia vs. DBpedia

We use the term 'knowledge graph' where possible

Why Knowledge Graphs? Combine advantages of databases and unstructured text

Machine and human understandable

Useful in search and data mining

Many interesting extensions

Interest in multiple communities incl. NLP, data mining... Many more!

KGS in Unusual domains

Knowledge Graphs In Unusual Domains Many challenges (and frontier research questions)!

Data skew

Lack of training data

Importance of data exploration

Keeping domain experts in the loop Multi-faceted prediction and inference Scalability

 $\bullet \bullet \bullet$

KG For Unusual Domains

Entities + properties + provenance + confidence + qualifiers

Simple, shallow ontology

customized to domain, if not needed, leave it out

Rich provenance and confidences

essential for end-users, useful for knowledge graph improvement

Hybrid text/structured representation

keep the text, essential for machine learning and search



KG For Unusual Domains

Entities + properties + provenance + confidence + qualifiers



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Knowledge Graph Construction

How can I build a KG?

KG Construction Problem





Steps To Build a KG



Crawing the web





Crawling Research Challenges

Domain discovery

Identifying relevant sites, datasets and pages

Crawling

Building models of relevant content Identifying new content Downloading dynamic content Overcoming anti-crawling measures Exhibiting human-like behavior



Scrapy (targeted crawling)

Open source and collaborative framework for extracting data from websites https://scrapy.org/ACHE

Apache Nutch (massive crawling)

highly extensible, highly scalable Web crawler http://nutch.apache.org

Deep Deep (Adaptive crawler)

reinforcement learning to learn which links to follow https://github.com/TeamHG-Memex/deep-deep

ACHE (focused crawler)

https://github.com/ViDA-NYU/ache

ScrapingHub (service)

https://scrapinghub.com/data-on-demand

Unusual Domains Have Long Tails



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principles and challenges in Information Extraction

Information Extraction (IE)



IE On The Web Is Challenging

Less grammar, more formatting & linking

Newswire

Apple to Open Its First Retail Store in New York City

MACWORLD EXPO. NEW YORK--July 17, 2002--Apple's first retail store in New York City will open in Manhattan's SoHo district on Thursday, July 18 at 8:00 a.m. EDT. The SoHo store will be Apple's largest retail store to date and is a stunning example of Apple's commitment to offering customers the world's best computer shopping experience.

"Fourteen months after opening our first retail store, our 31 stores are attracting over 100,000 visitors each week," said Steve Jobs, Apple's CEO. "We hope our SoHo store will surprise and delight both Mac and PC users who want to see everything the Mac can do to enhance their digital lifestyles."

🐞 InvestorPlace DOW 22.049 T-0.17% NASDAQ 6.352 0.00% S&P 500 2.474 T OOXT - FIRST TRUST NASDAQ-100 EX-TECH SECTOR INDE LEGACY VENTURES INTL, Inc. (LGYV) @Financial 0 ow Symbols fro 8/9/2017 46.49 -0.43 -0.93% Portfolio Accou 6.01 0.00 (0.00%) 07/14/17 NAVELLIER RATINGS Watch List Latest Quotes 🛊 OOG MSFT LEGACY VENTURES NTL, Inc. Stock Multiple Charts... Analysis Fidelity o to Watch List LGVV Stock Chart Historical I GVV Pric dd QQXT to Watch Li Analysis Breakdow Select Watch List... 🛊 ELEGACY VENTURES INTL. Inc. (LGYV LGYV STOCK GRADE N/A (N/A cent Symbo Market Car 391.03H LGYV Earning -38648.00 Earnings Growt Earnings Moment Dav's Rang 6.01 - 6.01 1.05 - 15.00 1 CVO/ Einang Operating Margin Gro LGYV STOCK PREDICTIONS, ARTICLES, AND LEGACY VENTURES INTL Return on Equil 4_traders Corpora Sales per Replo Sign up now. Senior Managing Director & GM-Administrat 🖣 AFGVF 🏭 VectorVest Click Here

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profitsp



Dimensions of IE

Document features

Scope

Pattern complexity

Relevance

Document Features

Text paragraphs without formatting

Astro Teller is the CEO and co-founder of BodyMedia. Astro holds a Ph.D. in Artificial Intelligence from Carnegie Mellon University, where he was inducted as a national Hertz fellow. His M.S. in symbolic and heuristic computation and B.S. in computer science are from Stanford University. His work in science, literature and business has appeared in international media from the New York Times to CNN to NPR.

Grammatical sentences plus some formatting & links

Dr. Steven Minton - Founder/CTO Dr. Minton is a fellow of the American Association of Artificial Intelligence and was the founder of the Journal of Artificial Intelligence Research. Prior to founding Fetch, Minton was a faculty member at USC and a project leader at USC's Information Sciences Institute. A graduate of Yale University and Carnegie Mellon University, Minton has been a Principal Investigator at NASA Ames and taught at Stanford, UC Berkeley and USC. Press
 Contact
 General information

Directions
 maps

Frank Huybrechts - COO Mr. Huybrechts has over 20 years of

Non-grammatical snippets, rich formatting & links

Barto, Andrew G.	(413) 545-2109	barto@cs.umass.edu	CS276
Professor. Computational neuroscie motor control, artificial n control, motor developme	nce, reinforcement le eural networks, adag nt.	earning, adaptive tive and learning	a
Berger, Emery D.	(413) 577-4211	emery@cs.umass.edu	CS344
Assistant Professor.			a
Brock, Oliver	(413) 577-033	4 <u>oli@cs.umass.edu</u>	CS246
Assistant Professor.			i
Clarke, Lori A.	(413) 545-1328	clarke@cs.umass.edu	CS304
Professor. Software verification, tes and design.	ting, and analysis; so	ftware architecture	a
Cohen, Paul R.	(413) 545-3638	cohen@cs.umass.edu	CS278
Professor. Planning, simulation, nat intelligent data analysis, i	ural language, agent intelligent user interf	-based systems, faces.	a

Tables

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Corporate information	Chairman of the Board	Masahiro Toyoda	Chief Executive Officer
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 Organization Chart 	President	Yasuo Imai	Chief Operating Officer
Business Location			
Business Keyword Corporate History	Vice President	Kikuo Toyoda	Chief Representative for Tokyo Operations President, Medical Company
		Akira Fujita	Chief Representative for Hokkaido Operations
Stock Information		Yuu Karato	Finance & Administration Officer, Chemical Officer
President	Senior Managing	Yukio Matsubara	President, Industrial Company
2150	Director	Masato Machida	President, Agriculture & Food Company
Last Share Price & Chart		Kiyoshi Shirai	Corporate Planning Officer: General Manager, Corporate Planning
by Euroland.com		Hideo Tsutsumi	General Manager, Business Planning
		Minoru Negeta	General Manager, Kanto Branch President, Kanto Air Water Inc.

Charts



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Web site specific

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Pattern Complexity E.g., word patterns

<u>Closed set</u>

U.S. states

He was born in <u>Alabama</u>...

The big <u>Wyoming</u> sky...

<u>Regular set</u>

U.S. phone numbers

Phone: <u>(413) 545-1323</u>

The CALD main office can be reached at <u>412-268-1299</u>

Complex pattern

U.S. postal addresses

University of Arkansas <u>P.O. Box 140</u> <u>Hope, AR 71802</u>

Headquarters: <u>1128 Main Street, 4th Floor</u> <u>Cincinnati, Ohio 45210</u> <u>Ambiguous patterns,</u> <u>needing context and</u> <u>many sources of evidence</u>

Person names

...was among the six houses sold by <u>Hope Feldman</u> that year.

<u>Pawel Opalinski</u>, Software Engineer at WhizBang Labs. "YOU don't wanna miss out on ME :) Perfect lil booty Green eyes Long curly black hair Im a Irish, Armenian and Filipino mixed princess :) • Kim • 707~7tw07~7four77 • HH 80 roses • Hour 120 roses • 15 mins 60 roses"



IE In Unusal Domains

Full spectrum of in all dimensions

Document Features	Scope	Pattern Complexity	Relevance
 text paragraphs 	• website specific	 closed set 	• all relevant
• grammatical, some formatting	• genre-specific	 regular set 	• significant irrelevant content
 ungrammatical, rich formatting 	• wide	 complex pattern 	 active deception
 tables 		 ambiguous pattern 	 purposeful obfuscation
• charts		 unusual language model 	

How to adapt existing techniques without much supervision?

currently, only one universal extractor



Practical Considerations

How good (precision/recall) is necessary?

High precision when showing extractions to users High recall when used for ranking results

How long does it take to construct?

Minutes, hours, days, months

What expertise do I need?

None (domain expertise), patience (annotation), simple scripting, machine learning guru

What tools can I use?

Many ... Kejriwal, Szekely

Practical IE Technologies

	Glossary	Regex	NLP Rules	Semi- Structured	CRF	NER	Table
Effort	assemble glossary	hours	hours	minutes	O(1000) annotations	zero	O(10) annotations
Expertise	minimal	high, programmer	low	minimal	low-medium	zero	minimal
Precision	medium (ambiguity)	high	high	high	medium-high	medium-high	high
Recall	medium (formatting)	low f(# regex)	medium f(# rules)	high	medium	medium	high
Coverage	wide	wide	wide	single site	genre	news wire	narrow

Case Study Combating fraud in the penny stock market

Microcap Stock Fraud

Microcap stock fraud is a form of securities fraud involving stocks of "microcap" companies, generally defined in the United States as those with a market capitalization of under \$250 million. Its prevalence has been estimated to run into the billions of dollars a year.

Pump and dump schemes, involving use of false or misleading statements to hype stocks, which are "dumped" on the public at inflated prices. Such schemes involve telemarketing and Internet fraud

https://en.wikipedia.org/wiki/Microcap_stock_fraud 69

Most Relevant Websites

4-traders.com advfn.com analystratings.net barchart.com bitcointalk.org blogspot.com blogspot.in businessinsider.com businessprofiles.com dividend.com dynamoo.com etf.com facebook.com

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Microcap Fraud Ontology defined by two SEC users in 45 minutes

Property	Description
address	US postal service address
city	specific cities mentioned in a page
compensation_amount	amount a promoter was compensated
counsel	counsel
country	countries mentioned in a page
date_of_post	post date of the blog or article
disclaimer	disclaimer in promotion
email	email addresses mentioned in the page
industry	industry of organization
market	stock market of the issuer
message_board	name of message board
message_board_category	category of the message board
Keiriwa Szekely name	name of the organization

Property	Description
org_registration_date	date organization was created
org_registration_number	state registration number for the organization
organization_status	status of the organization's state registration
paying_party	entity that is paying for the promotion
phone	phone numbers mentioned in the page
posted_date	any date mentioned in a page
promoter_name	name of the promoter
state	specific states mentioned in a page
stock_ticker	stock tickers mentioned in the page
twitter_tag	tags in a tweet
user_registration_date	date the user registered for the site
username	user name in a website
website	website where page was published

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setting up a new domain (after crawling)

setting up a new domain (after crawling)

Specifying websites

Defining the domain ontology

Defining extractors

Building the knowledge graph

Customizing the search engine
Featured Extractors

	Glossary	Regex	NLP Rules	Semi- Structured	CRF	NER	Table
Effort	assemble glossary	hours	hours	minutes	O(1000) annotations	zero	O(10) annotations
Expertise	minimal	high, programmer	low	minimal	low-medium	zero	minimal
Precision	medium (ambiguity)	high	high	high	medium-high	medium-high	high
Recall	medium (formatting)	low f(# regex)	medium f(# rules)	high	medium	medium	high
Coverage	wide	wide	wide	single site	genre	news wire	narrow





Publish Project Files

Upload all the project files to the myDIG protected GitHub repository, backing up your files to allow going to previous versions or preserving files in case of disk failure.

GO

Run Extractions and Load Index For Sample Pages

Run all extractors currently defined and load the extracted data into a new ElasticSearch index. You need to perform the Update To New Index command to replace your current Kejriwal Szekely the new index.

Inferlink Extractor Automatic extraction from semi-structured pages https://github.com/inferlink

Inferlink Extractor



Inferlink Extraction Accuracy firearms domain, 10 websites, 5 pages each

	fields										
	Title	Desc	Seller	Date	Price	Loc	Cat	Member Since	Expires	Views	ID
Perfect	1.0	.76	.95	.83	.87	.51	.68	1.0	.52	.76	.97
	(50/50)	(37/49)	(40/42)	(40/48)	(39/45)	(23/45)	(34/50)	(35/35)	(15/29)	(19/25)	(35/36)
Pretty	1.0	.98	.95	.83	.98	.84	.88	1.0	.55	1.0	1.0
Good	(50/50)	(48/49)	(40/42)	(40/48)	(44/45)	(38/45)	(44/50)	(35/35)	(16/29)	(25/25)	(36/36)

Pretty Good: useful to user

- extra tokens present
- non-essential tokens missing

Glossary Extraction

Simple in principle

list of words or phrases to extract

Challenges

Ambiguity: Charlotte is a name of a person and a city Colloquial expressions: "Asia Broadband, Inc." vs "Asia Broadband"

Research

Improving precision of glossary extractions Extending glossaries automatically

Extraction Using Regular Expressions

Too difficult for non-programmers

regex for North American phone numbers:

Brittle and difficult to adapt to unusual domains

unusual nomenclature and short-hands obfuscation

NLP Rule-Based Extraction

Tokenization for unusual domains

tokenize on white-space, punctuation and emojis

Token properties

literal, part of speech tag, lemma, in/out of dictionary dependency parsing relationships (advanced) type (alphanumeric, alphabetic, numeric) shape (pattern of digits and characters), capitalization, prefix and suffix number of characters, range (numbers)

Pattern

Sequence of required/optional tokens positive and negative patterns

Named Entity Recognizers

Machine learning models (Conditional Random Field)

people, places, organizations and a few others

SpaCy

complete NLP toolkit, Python (Cython), MIT license code: https://github.com/explosion/spaCy demo: http://textanalysisonline.com/spacy-named-entity-recognition-ner

Stanford NER

part of Stanford's NLP software library, Java, GNU license code: https://nlp.stanford.edu/software/CRF-NER.shtml demo: http://nlp.stanford.edu:8080/ner/process

myDIG: A KG Construction Toolkit

Python, MIT license, https://github.com/usc-isi-i2

Enable end-users to construct domain-specific KGs

end users from 5 government orgs constructed KGs in less than one day

Suite of extraction techniques

semi-structured HTML pages, glossaries, NLP rules, NER, tables (coming soon)

KG includes provenance and confidences

enable research to improve extractions and KG quality

Scalable

runs on laptop (~100K docs), cluster (> 100M docs)

Robust

Deployed to many law enforcement agencies

Easy to install

Aug 31 2017: Docker deployment with single "docker componse up" installation Kejriwal, Szekely

Knowledge Graph Completion

Our thanks to Lise Getoor for some slides on Entity Resolution and PSL



Extractions are noisy

Noise is not random

Postal code got extracted as phone Email ID, social network ID got interchanged Entity Disambiguation: Charlotte, NC vs. Charlotte the person

Complete the knowledge graph by inferring wrong

links, new links

Some solutions we'll cover today

Entity Resolution (ER)

Probabilistic Soft Logic (PSL)

Knowledge Graphs in Latent Space aka knowledge graph embeddings

Entity Resolution (ER)

Entity Resolution (ER)

The problem of dustering mentions that refer to the same underlying entity



Example: Linking Dbpedia to Freebase



Knowledge graphs contain duplicate entities



Knowledge graph nodes are multitype



How to do ER?

Popular methods use some form of machine learning; see surveys by Kopcke and Rahm (2010), Elmagarmid et al. (2007), Christophides et al. (2015)

Probabilistic Matching Methods	Supervised, Semi- supervised	Active Learning	Rule Based	Distance Based	Unsupervised EM Winkler (1993)	
	Marlin (SVM based) Bilenko and Mooney (2003)				Hierarchical Graphical Models Ravikumar and Cohen (2004) SVM Christen (2008)	

Kejriwal, Szekely

With graph representation

Can propagate similarity decisions Melnik, Garcia-Molina and Rahm (2002)

More expensive but better performance

Can be generic or use domain knowledge e.g., citation/bibliography domain Bhattacharya and Getoor (2006,2007)

Example (co-authorship)









Bhattacharya and Getoor (2006,2007)

Feature functions - I

First line of attack is *string matching*



Available Packages: SecondString, FEBRL, Whirl...

Kejriwal, Szekely

Feature functions - II

Unusual domains have many non-text fields Feature functions may have to be hand-crafted or learned from data:

Tracking numbers for mail fraud/narcotics Review IDs for human trafficking Stock tickers for SEC

Learnable string similarity

Example: adaptive edit distance







Apply classifier i.e. similarity function to every pair of nodes? Quadratic complexity!





Like a configurable inverted index function



?

What is a good blocking key?

Achieves high recall

Achieves high reduction

Good survey on blocking: Christen (2012)

How do we learn a good blocking key?

Key idea in existing work is to learn a DNF rule with indexing functions as atoms

CharTriGrams(Last_Name) U (Numbers(Address) X Last4Chars(SSN))

Michelson and Knoblock (2006), Bilenko, Kamath and Mooney (2006), Kejriwal and Miranker (2013; 2015)...

Kejriwal, Szekely

Putting it together: two-step ER





Not many, still tend to be inefficient or for specific domain

FEBRL was designed for biomedical record linkage (Christen, 2008)

Dedupe crashes on graphs with fewer than a million nodes <u>https://github.com/dedupeio/dedupe</u>

LIMES, Silk mostly designed for RDF data, often require pre-specified similarity functions (Ngonga Ngomo and Auer, 2008; Isele et al. 2010)

Not all attributes are equal

Phones/emails important in human trafficking

(names are unreliable)

Names can be important in SEC

(nothing special about phones)

How do we use this knowledge?

Domain knowledge

Especially important for unusual domains but how do we express and use it?

Use rules? Too brittle, don't always work!

Use machine learning? Training data hard to come by, how to encode rulebased intuitions?

Probabilistic Soft Logic (PSL)

Practical methods to resolve logic/probability dilemma

Statistical Relational Learning (SRL)

Stochastic Logic Programs (SLPs) Muggleton (1996) Probabilistic Relational Models (PRMs) Koller (1999) Bayesian Logic Programs (BLPs) Kersting and De Raedt (2001) Markov Logic Networks (MLNs) Richardson and Domingos (2006) Probabilistic Soft Logic (PSL) Kimmig et al., (2012)

Intuitive example (PSL)





Continuous Random Variables

Mathematical Foundation

Logic Foundation

Inference & Learning

Sets and Aggregators

Extensible

High Performance
Probabilistic Soft Logic (PSL)

Good framework for expressing domain constraints

Code available, many tutorials and videos on how to get started

http://psl.linqs.org/index.html

Rules need to be pre-specified

But weights can be learned from training data

 $vote(A, P) \land friend(B, A) \rightarrow vote(B, P)$:?

 $vote(A, P) \land spouse(B, A) \rightarrow vote(B, P)$:?

Some recent work has also tried to learn rules (but may lose interpretability)

Case Study: Toponym Resolution

Toponym resolution: resolving extracted location mention to a canonical geolocation in a KB like GeoNames

Applied to human trafficking domain

... I'm from beautiful downtown London in Ontario, Canada...

Rules for toponym resolution

Can easily encode rules (in PSL) such as a city can only be in one state and one country, a city must actually exist in a state and country...

Use elements like population to assign weights

Knowledge Graphs in Latent Space

Low-dimensional vector spaces

Very popular for documents, graphs, words...



Knowledge graph embeddings

Many ways to model the problem: entities are usually vectors, relations could be vectors or matrices



Objective/loss/energy functions

What is an 'optimal' vector/matrix for an entity or relation?

Model	Score function $f_r(\mathbf{h}, \mathbf{t})$	# Parameters
TransE (Bordes et al. 2013b)	$\ \mathbf{h} + \mathbf{r} - \mathbf{t}\ _{\ell_{1/2}}, \mathbf{r} \in \mathbb{R}^k$	$O(n_e k + n_r k)$
Unstructured (Bordes et al. 2012)	$\ \mathbf{h} - \mathbf{t}\ _{2}^{2}$	$O(n_e k)$
Distant (Bordes et al. 2011)	$ W_{rh}\mathbf{h} - W_{rt}\mathbf{t} _1, W_{rh}, W_{rt} \in \mathbb{R}^{k \times k}$	$O(n_e k + 2n_r k^2)$
Bilinear (Jenatton et al. 2012)	$\mathbf{h}^{\top} W_r \mathbf{t}, W_r \in \mathbb{R}^{k \times k}$	$O(n_e k + n_r k^2)$
Single Layer	$\begin{vmatrix} \mathbf{u}_r^{T} f(W_{rh}\mathbf{h} + W_{rt}\mathbf{t} + \mathbf{b}_r) \\ \mathbf{u}_r, \mathbf{b}_r \in \mathbb{R}^s, W_{rh}, W_{rt} \in \mathbb{R}^{s \times k} \end{vmatrix}$	$O(n_ek + n_r(sk + s))$
NTN (Socher et al. 2013)	$\begin{vmatrix} \mathbf{u}_r^{T} f(\mathbf{h}^{T} \mathbf{W}_r \mathbf{t} + W_{rh} \mathbf{h} + W_{rt} \mathbf{t} + \mathbf{b}_r) \\ \mathbf{u}_r, \mathbf{b}_r \in \mathbb{R}^s, \mathbf{W}_r \in \mathbb{R}^{k \times k \times s}, W_{rh}, W_{rt} \in \mathbb{R}^{s \times k} \end{vmatrix}$	$O(n_ek + n_r(sk^2 + 2sk + 2s))$
TransH ($ \begin{aligned} \ (\mathbf{h} - \mathbf{w}_r^\top \mathbf{h} \mathbf{w}_r) + \mathbf{d}_r - (\mathbf{t} - \mathbf{w}_r^\top \mathbf{t} \mathbf{w}_r) \ _2^2 \\ \mathbf{w}_r, \mathbf{d}_r \in \mathbb{R}^k \end{aligned} $	$O(n_e k + 2n_r k)$



Typically evaluate on Freebase and WordNet

Data	WN18	FB15K	WN11	FB13
#Rel	18	1,345	11	13
#Ent	40,943	14,951	38,696	75,043
#Train	141,442	483,142	112,581	316,232
#Valid	5,000	50,000	2,609	5,908
#Test	5,000	59,071	10,544	23,733

Application 1: Triples completion

Dataset		WN	18			FB	15k	
Metric	ME Raw	AN Filt.	HITS Raw	S@10 Filt.	MEA Raw	AN Filt.	HITS Raw	6@10 Filt.
Unstructured (Bordes et al. 2012)	315	304	35.3	38.2	1,074	979	4.5	6.3
RESCAL (Nickel, Tresp, and Kriegel 2011)	1,180	1,163	37.2	52.8	828	683	28.4	44.1
SE (Bordes et al. 2011)	1,011	985	68.5	80.5	273	162	28.8	39.8
SME (Linear) (Bordes et al. 2012)	545	533	65.1	74.1	274	154	30.7	40.8
SME (Bilinear) (Bordes et al. 2012)	526	509	54.7	61.3	284	158	31.3	41.3
LFM (Jenatton et al. 2012)	469	456	71.4	81.6	283	164	26.0	33.1
TransE (Bordes et al. 2013b)	263	251	75.4	89.2	243	125	34.9	47.1
TransH (unif.) TransH (bern.)	318 400.8	303 388	75.4 73.0	86.7 82.3	211 212	84 87	42.5 45.7	58.5 64.4

Wang et al. (2008)

Application 2: Triples classification

Dataset	WN11	FB13	FB15k
Distant Model	53.0	75.2	-
Hadamard Model	70.0	63.7	-
Single Layer Model	69.9	85.3	-
Bilinear Model	73.8	84.3	-
NTN	70.4	87.1	66.5 ($\approx 40h$)
TransE (unif.)	75.85	70.9	79.7 ($\approx 5m$)
TransE (bern.)	75.87	81.5	87.3 (≈ 5m)
TransH (unif.)	77.68	76.5	80.2 (≈ 30 <i>m</i>)
TransH (bern.)	78.80	83.3	87.7 (≈ 30m)



Code availability

Code for replicating experiments can be found at https://github.com/glorotxa/SME ; implemented using both theano/tensorflow backend Unclear how to extend to new, sparse data, how to scale to much bigger KGs

Application 3: Featurizing nodes

E.g. Convering 'locations' into feature vectors

Relevant for toponym resolution, building rich

graphs...

Kejriwal, Mayank; Szekely, Pedro (2017): Neural Embeddings for Populated GeoNames Locations. figshare. <u>https://doi.org/10.6084/m9.figshare.5248120</u>

https://github.com/mayankkejriwal/Geonames-embeddings

Features encode spatial proximity

But could encode much else, lots of room for new

ITUIVEY)LD Carrington Hazen Beulah Valley City Jamestown 94 New Salem Steele Bismarck Cannon Ball

research!

In unusual domains...

Not clear to what extent these techniques work (which objective function is better?)

Several questions persist

How to acquire training data for triples classification? How to model the concept of an entity? How to regularize with sparse mentions?

Searching Knowledge Graphs

Motivation

Direct query execution does not succeed because of noise/incomplete data

What is the phone number provided in the ad that contains the email address brianna.elite@dummy-email.com, the price \$600/hour, and the location manhattan midtown east 33rd & 2nd ave?

Keyword vs. faceted search

Enter Ko brianr	eywords (Advanced Search On) na elite	q	×	\$	≡
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Faceted search form

Other kinds of search: many research opportunities

Clustering and network queries

Find all massage parlor ads linked either directly or indirectly to phone 12345678

Aggregate queries

Find the most common ethnicity in the massage parlor ads linked either directly or indirectly to phone 12345678

Key technique: Query reformulation

Traditional work tends to reformulate if original query

returns no results

Does not work well in presence of noise or in interactive session

Use weighted combination of reformulated queries instead, execute in NoSQL database

Semantic Query Reformulation



Other applicable techniques

Entity set learning and expansion

E.g., can expand red to red, auburn, fiery...

Use machine learning to learn weights of reformulated sub-queries

Relatively unexplored research area: similar to learning to rank in IR community, but weights strategies, not features

Wrap up and review



Unusual domains

Interesting, fun, high social impact

Knowledge graphs

Wide-spectrum of representations

Knowledge graph construction

Many tools to help, easy to create interesting graphs

Case study

Tools make it possible to build a KG in a day

Knowledge graph completion

Inferring wrong and missing links

Entity resolution

Clustering/linking mentions referring to the same underlying entity

Probabilistic soft logic

Correcting outputs of KG construction and entity resolution through logical probabilistic rules

KGs in latent space

Performing inference in low-dimensional vector spaces

Searching knowledge graphs

Using semantic query reformulation to answer complex queries over noisy knowledge graphs

Mona Lisa

Da Vinci

1

Date of birth: April 15, 1452 Date of death: May 2, 1519 (age 67 years)

Thank you!

Michelangelo

Italy