Graph Machine Learning for Entity Linking

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Agenda

1. Graph Data Model
2. Entity Linking Problem
3. Graph Machine Learning
4. Entity Linking with GraphML
5. Other Applications of GraphML
6. Summary

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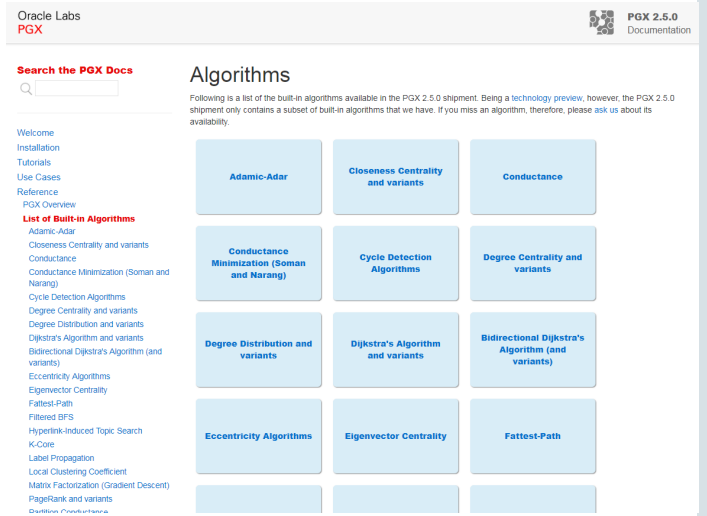
Benefits of Graph Models

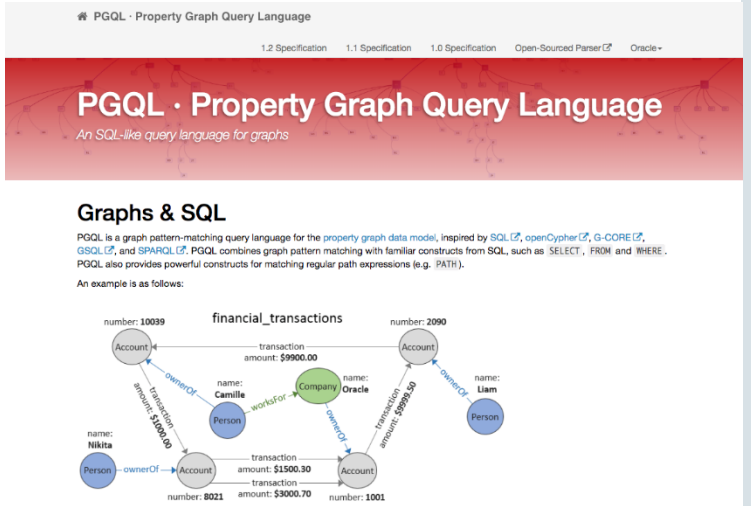
- Some of graph benefits
  - Intuitive data model
  - Aggregate information over heterogeneous data sources
  - Fast query over multi-hop relationships
  - Data visualization and interactive exploration

Parallel Graph AnalytiX (**PGX**)

- A fast, parallel graph analytics framework
  - Shared memory and distributed version
- Offers 40+ built-in, native graph analytics algorithms
  - PageRank, Centrality, WCC, SCC
- Offers Graph Machine Learning Algorithms
  - DeepWalk, PG2Vec
- Provides a graph-specific query language (**PGQL**)

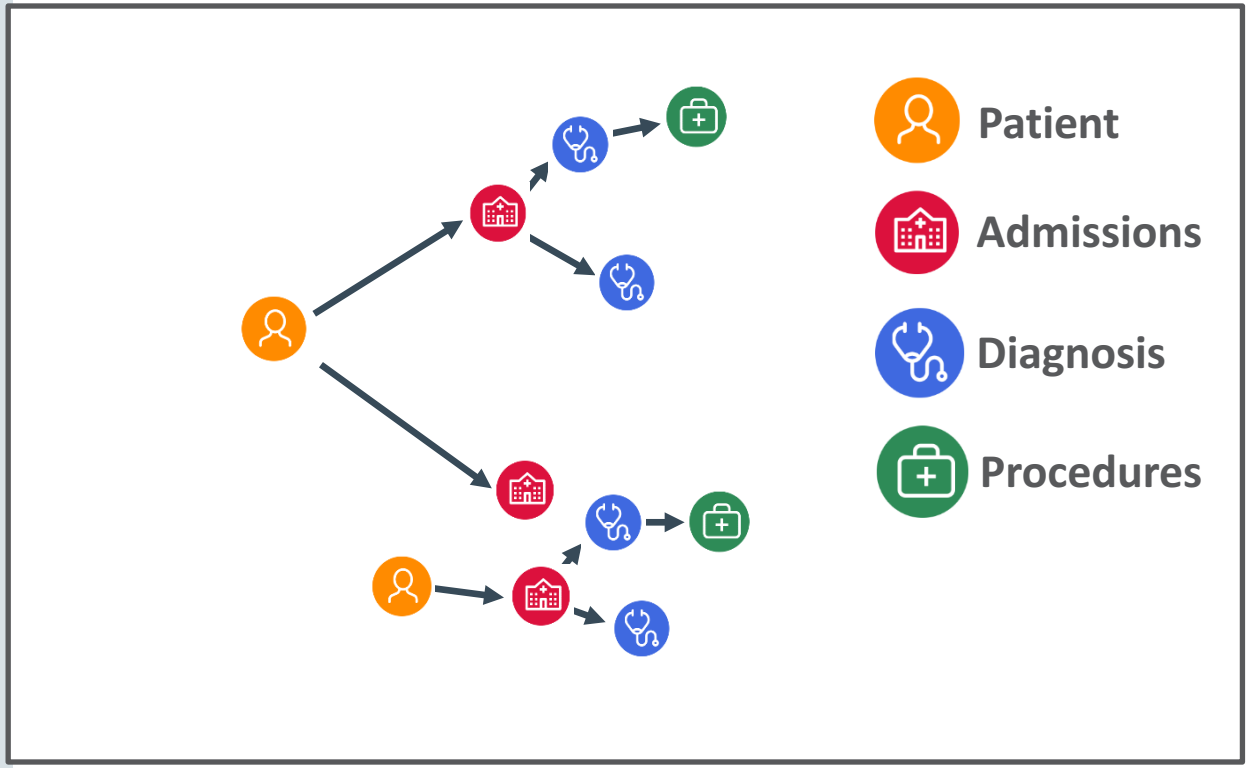
```
SELECT v, e, v2
FROM graph
MATCH (v)-[e]->(v2)
WHERE v.first_name ='Jerald'
AND v.last_name = 'Hilpert'
GROUP BY … ORDER BY … LIMIT …
```



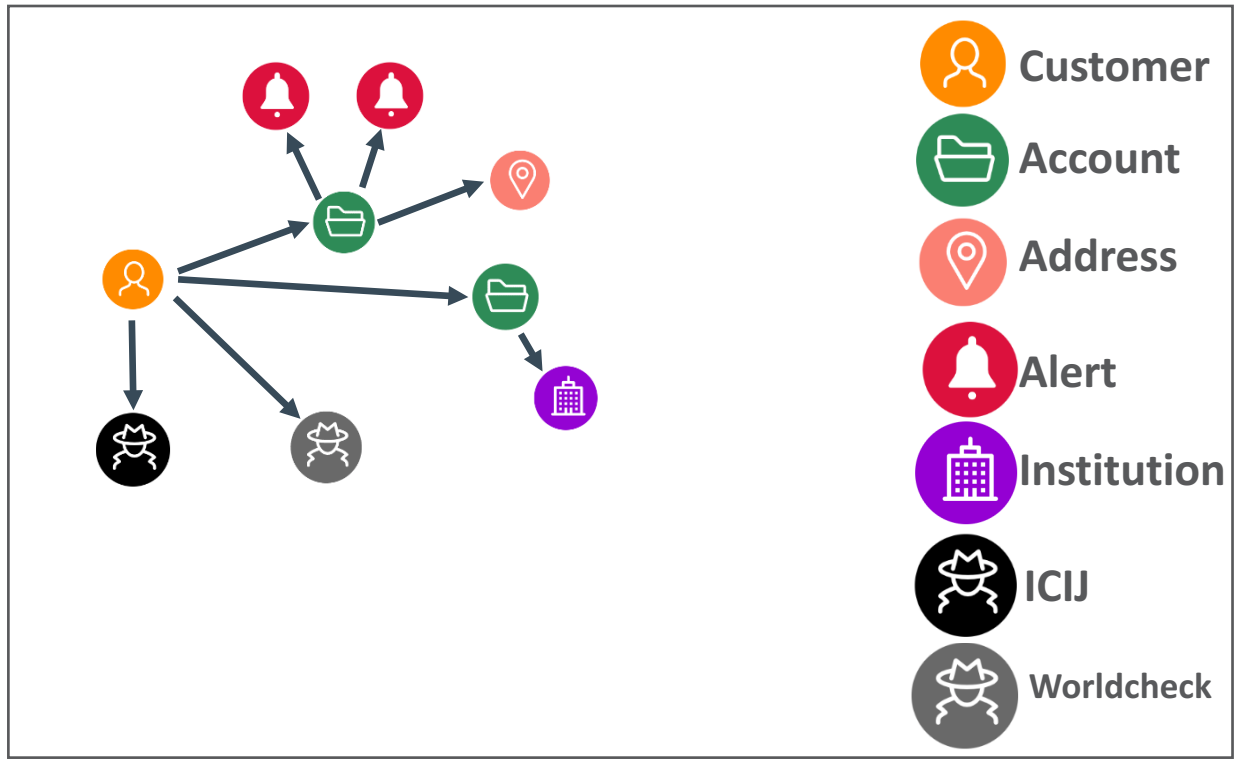


Graph in Various Domains

Health Science



Financial Services



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Entity Linking (EL)

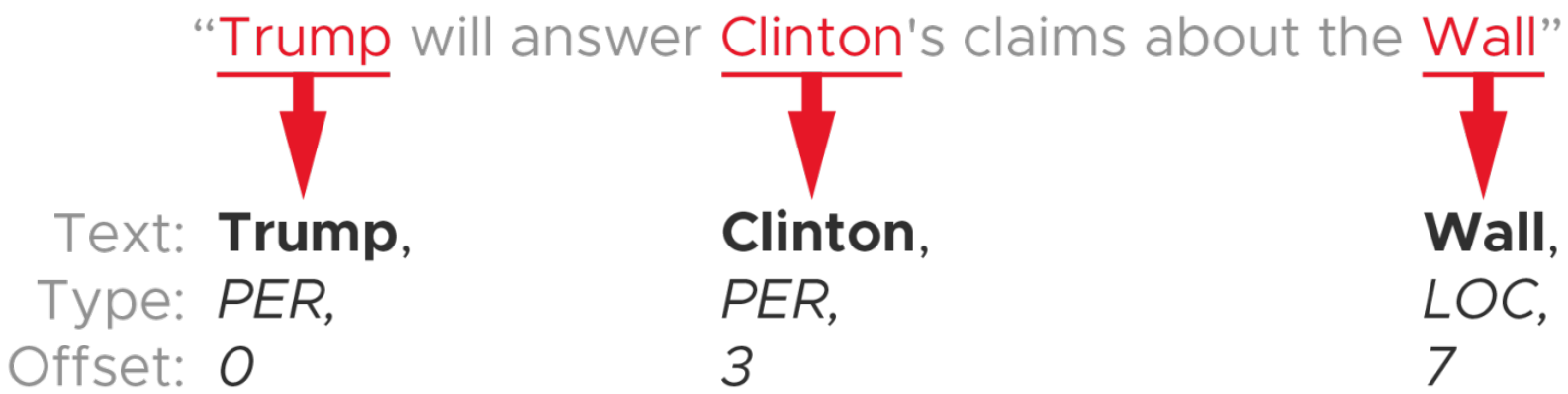
- Connecting words of interest to unique identities (e.g. Wikipedia Page)

- Use cases
  - Search Engines, for semantic search
  - Recommender Systems, to retrieve documents similar to each other
  - Chat bots, to understand intents and entities

Standard EL Pipeline

An EL system requires 2 steps:

1. Named Entity Recognition (NER): spot **mentions** (a.k.a. Named Entities)
   - ❖ High-accuracy in the state-of-the-art[1]

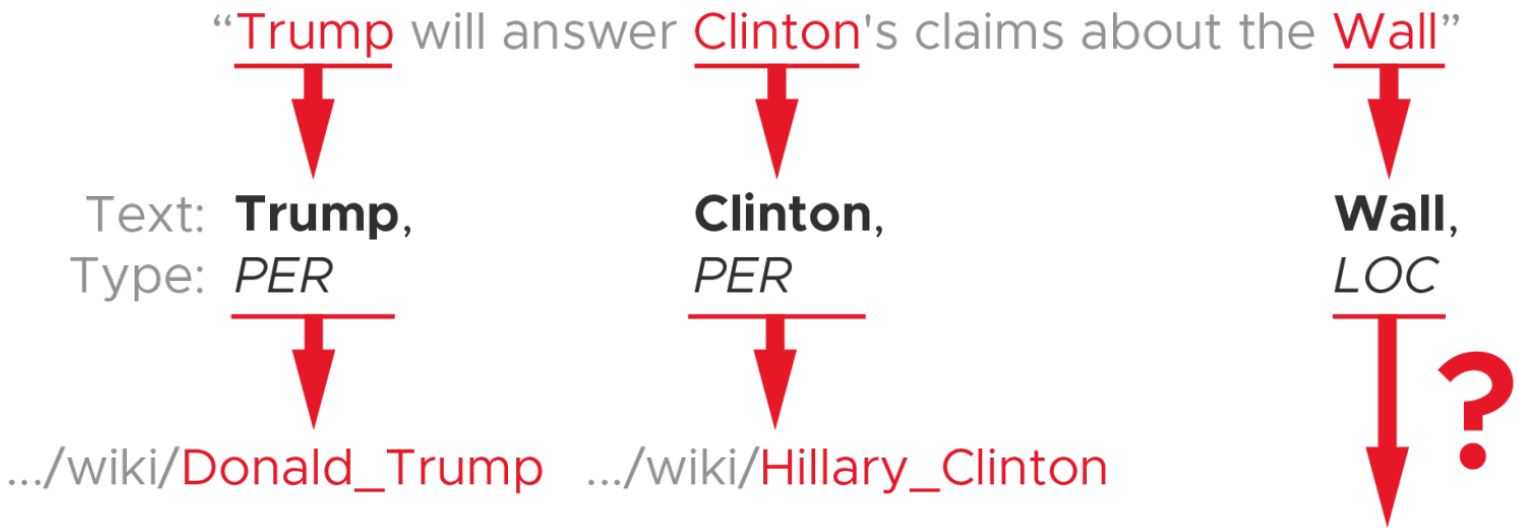


[1] Huang, Zhiheng, Wei Xu, and Kai Yu. "Bidirectional LSTM-CRF models for sequence tagging."

Standard EL Pipeline

An EL system requires 2 steps:

2. Entity Linking: connect mentions to entities



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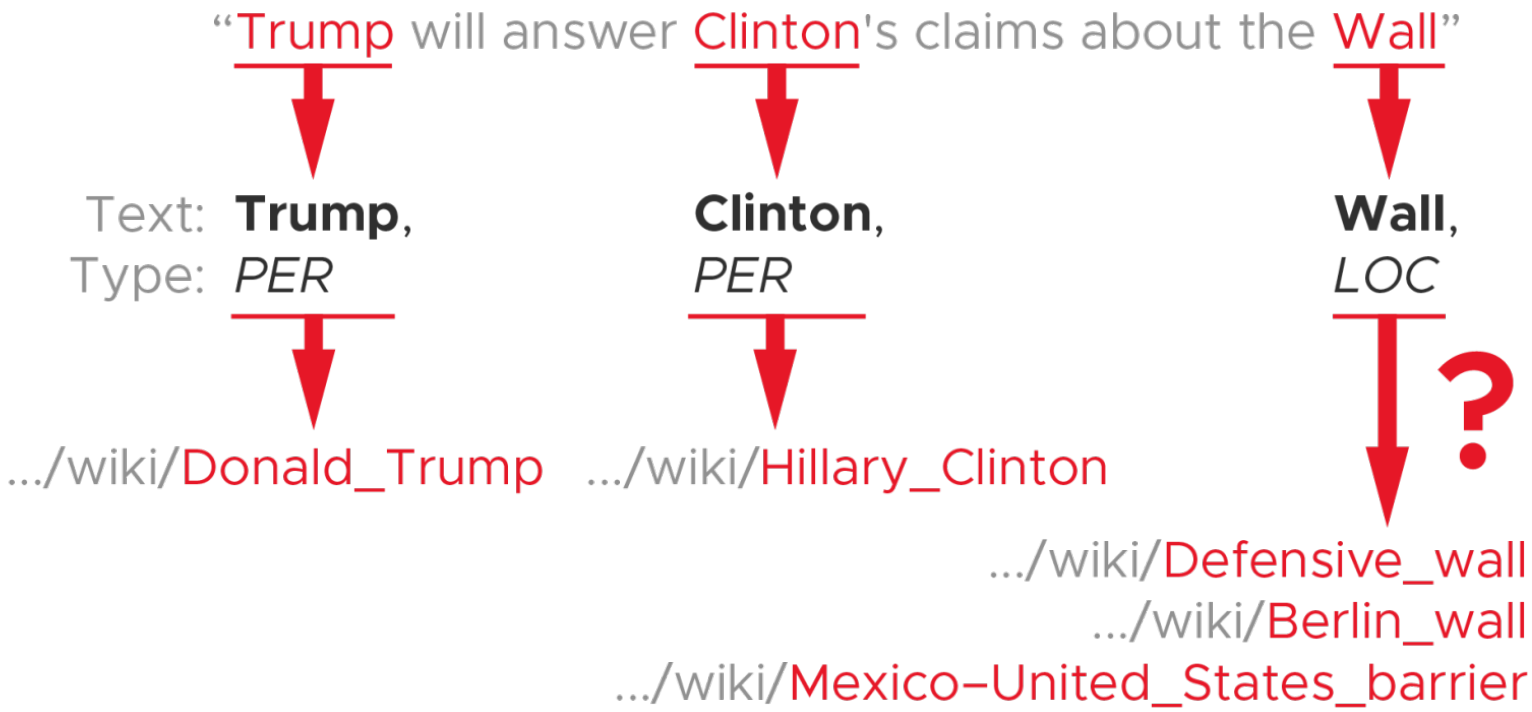

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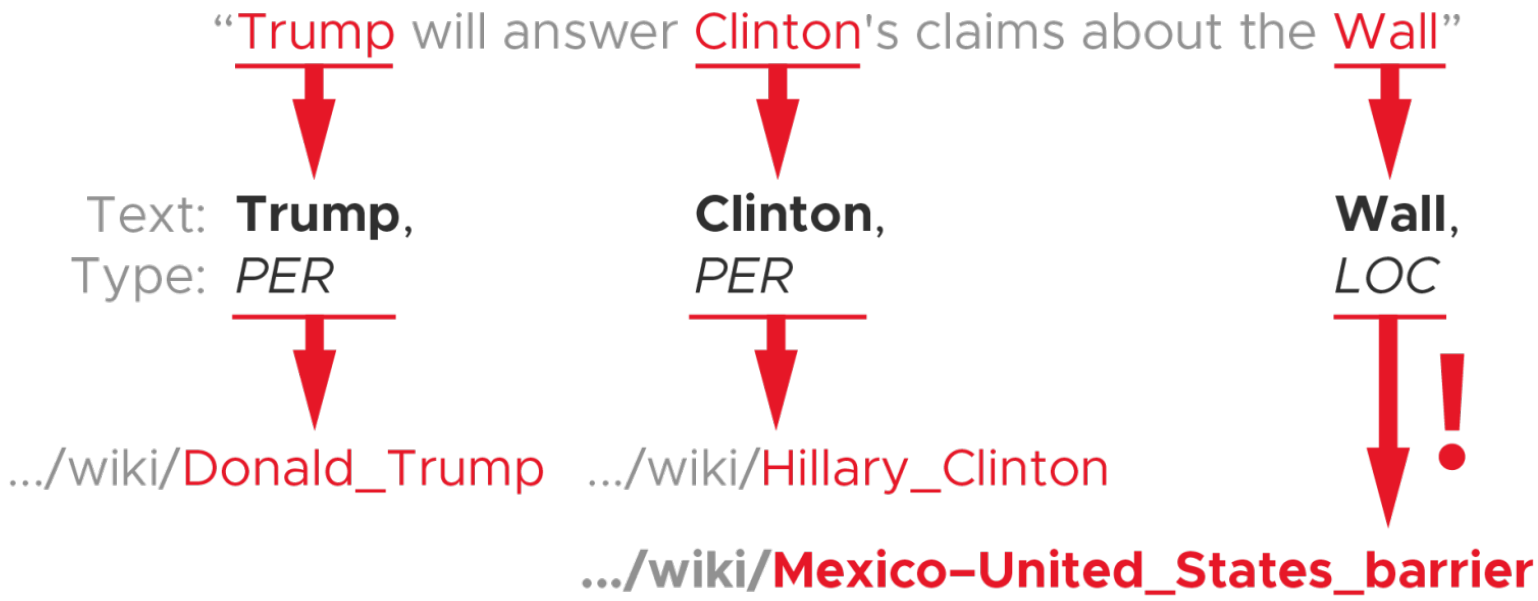
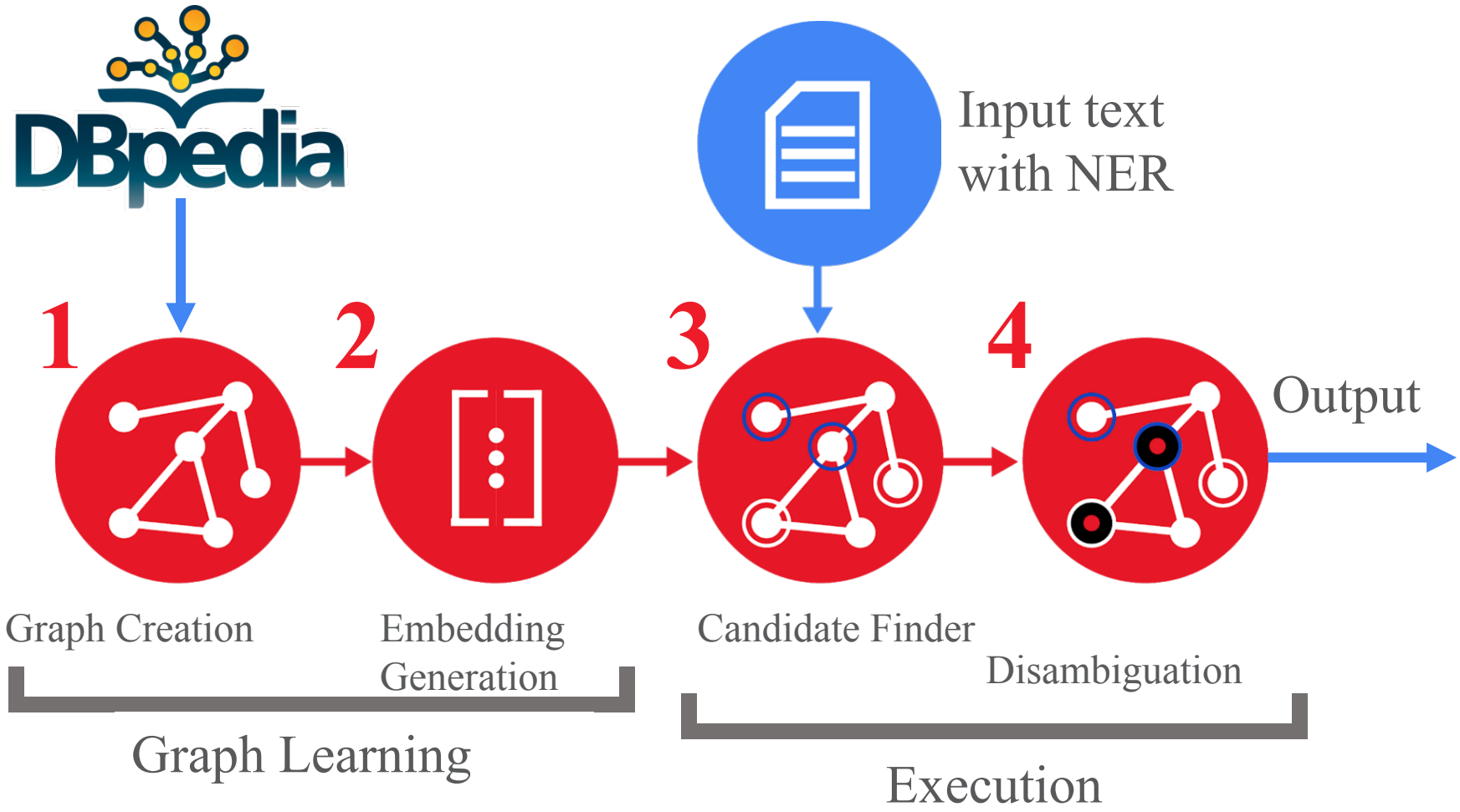


Our Graph-based EL Pipeline



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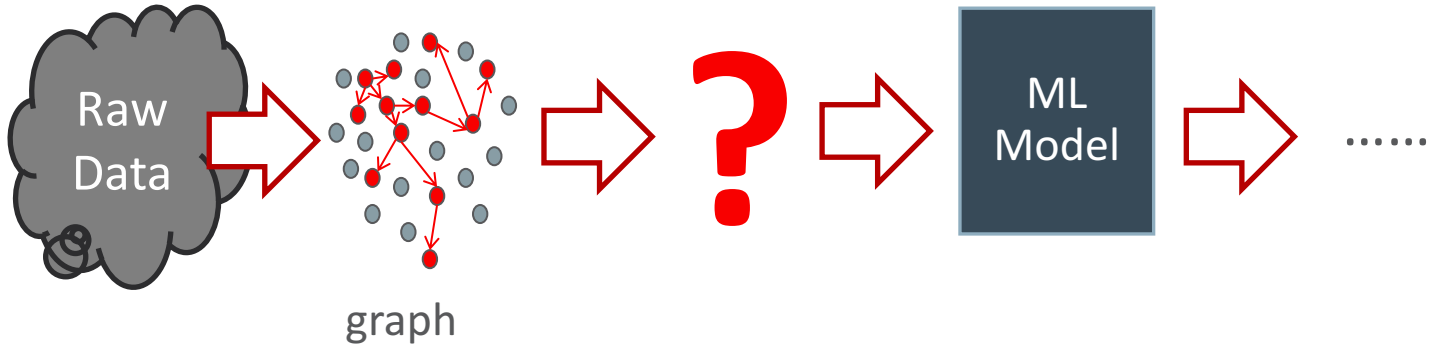
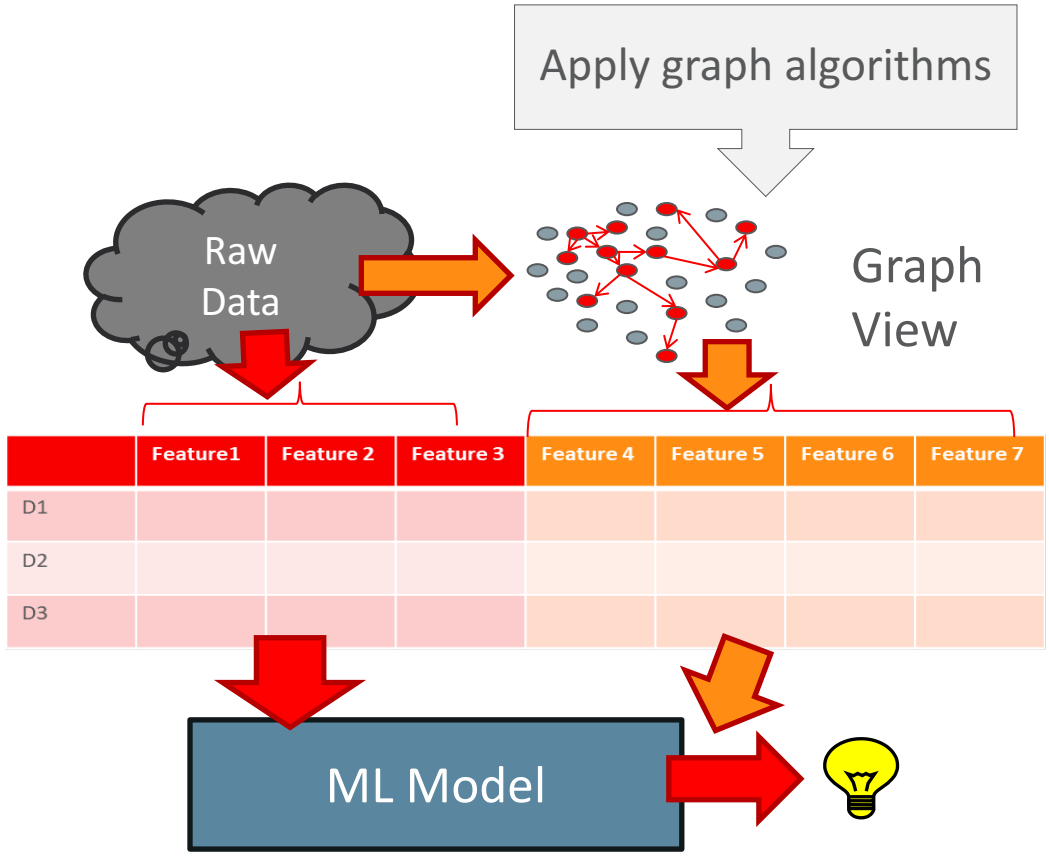
Feeding graph data into ML pipeline

- Goal: want to apply Machine Learning techniques using graph signals
  - Need some form that are suitable for feeding into conventional ML pipeline
  - but still carries the information in the graph
- … How can this be done?



Feature Generation via Graph Algorithm

- Approach
  - Compute (various) graph algorithms to generate some numeric values
    - In/out degree
    - Eigenvector centrality
    - Pagerank
    - Between-ness centrality
  - Feed the output of graph algorithms into ML model
- Rationale
  - Each graph algorithm result contains certain characteristics of the graph data
  - Combination of those result would keep information about the graph structure

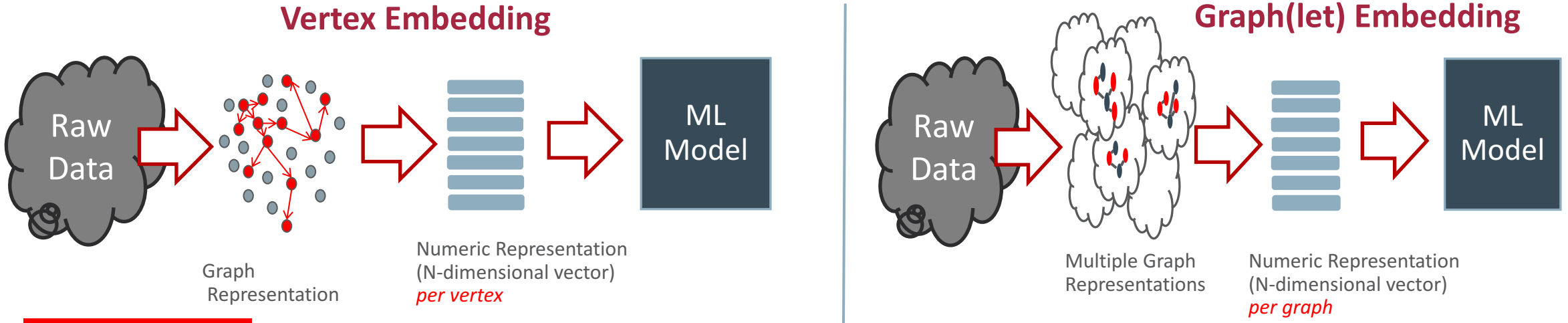


Machine Learning and Graphs

- Still there are issues
  - Applied seemingly arbitrary set of algorithms for extracting features
  - Would it work for other applications?

➢ Need a systematic methodology that turns graph information into n-dimensional numeric representation, i.e. embedding

➢ Embedding techniques: vertex embedding and graph embedding

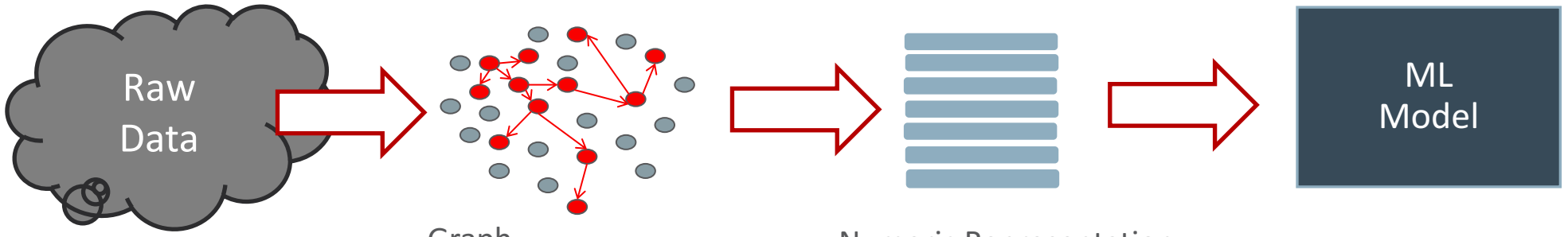


Vertex Embedding

- Goal: to turn graph into n-dimensional vector
- Want to keep graph (topology) information
  - i.e. Entity distance in distance

x, y: data entity (represented as vertex in graph)
v(x), *v(y)*: n- dimensional vector representation of x and y

x, y close in graph ←→ *v(x)* - *v(y)* close in vector space



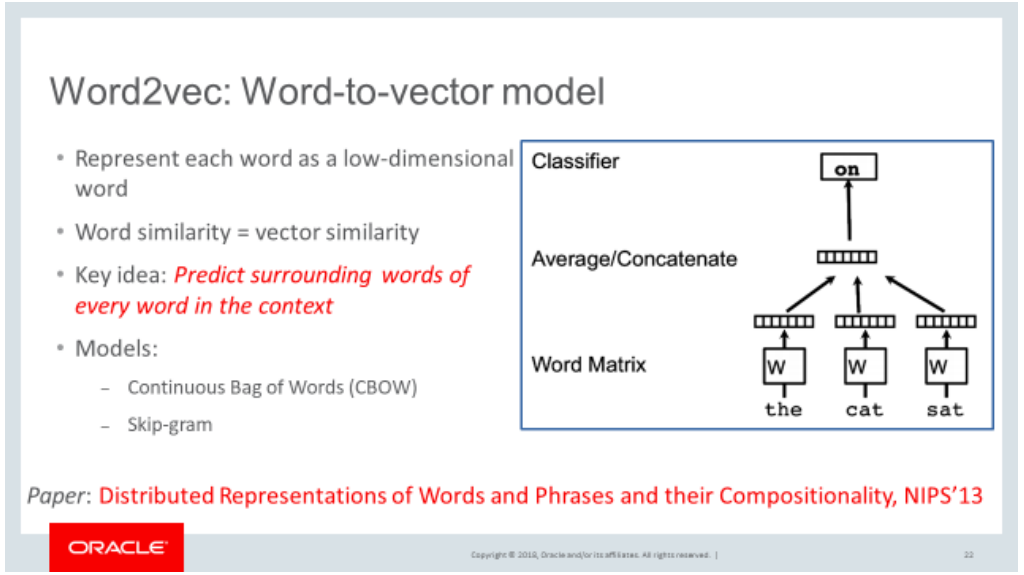
Graph
Representation

Numeric Representation
(N-dimensional vector)

How to achieve this?

- There are several approaches now
  - Academia and Industry
- DeepWalk
  - An early approach that exploits techniques from modern NLP
  - Word2Vec : a ML technique that learns closeness between words from large number of sentences
  - Perform many random walks on the graph and generate traces.
  - Apply W2V technique on them; treating vertices as words.

KDD'14



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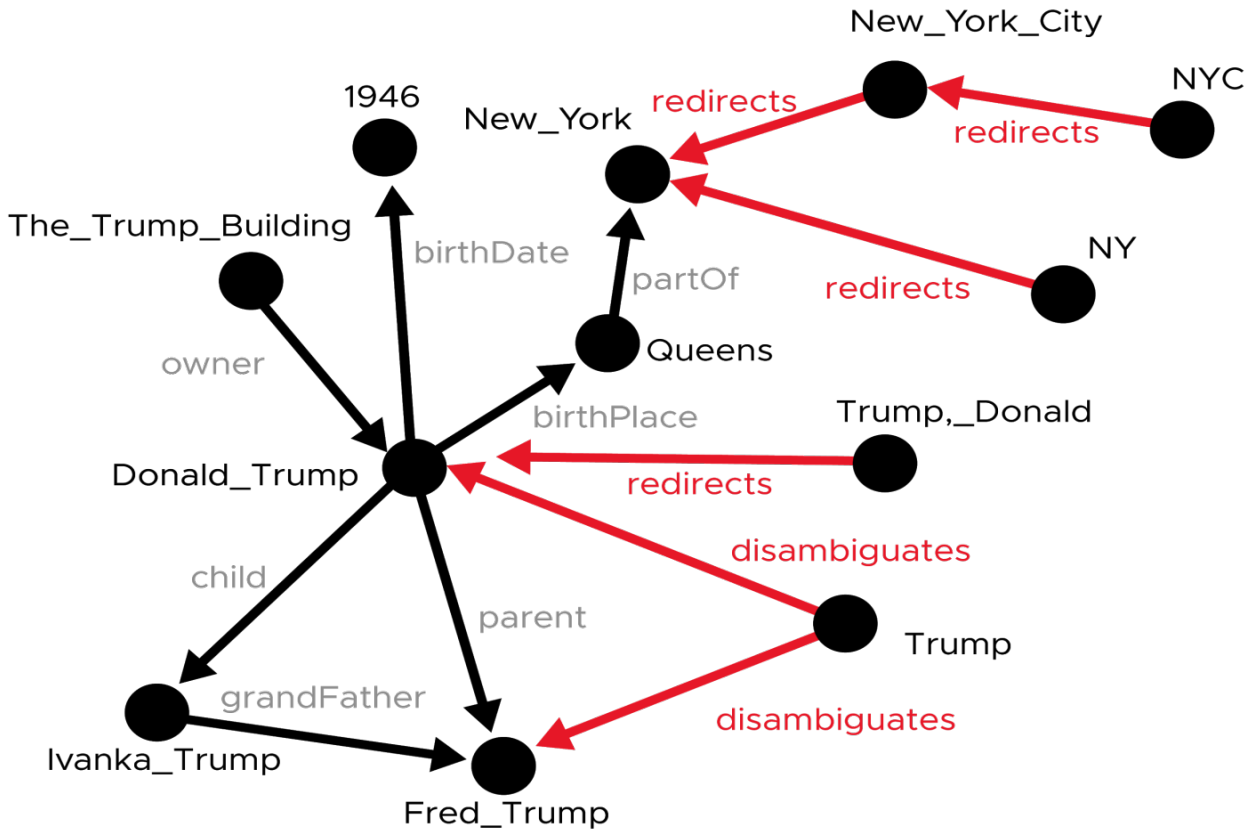
Graph Creation

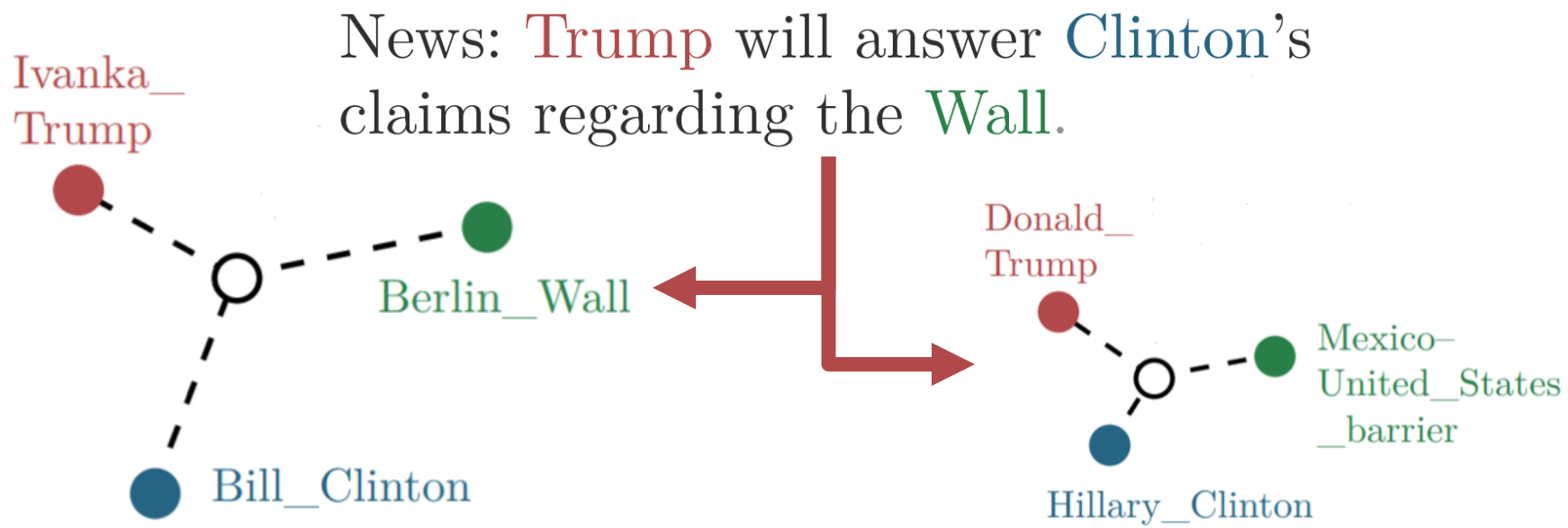
We obtain a large graph from DBPedia

- All the information of Wikipedia
- Stored as RDF triples
- 12M entities
- 170M links



Graph Embeddings

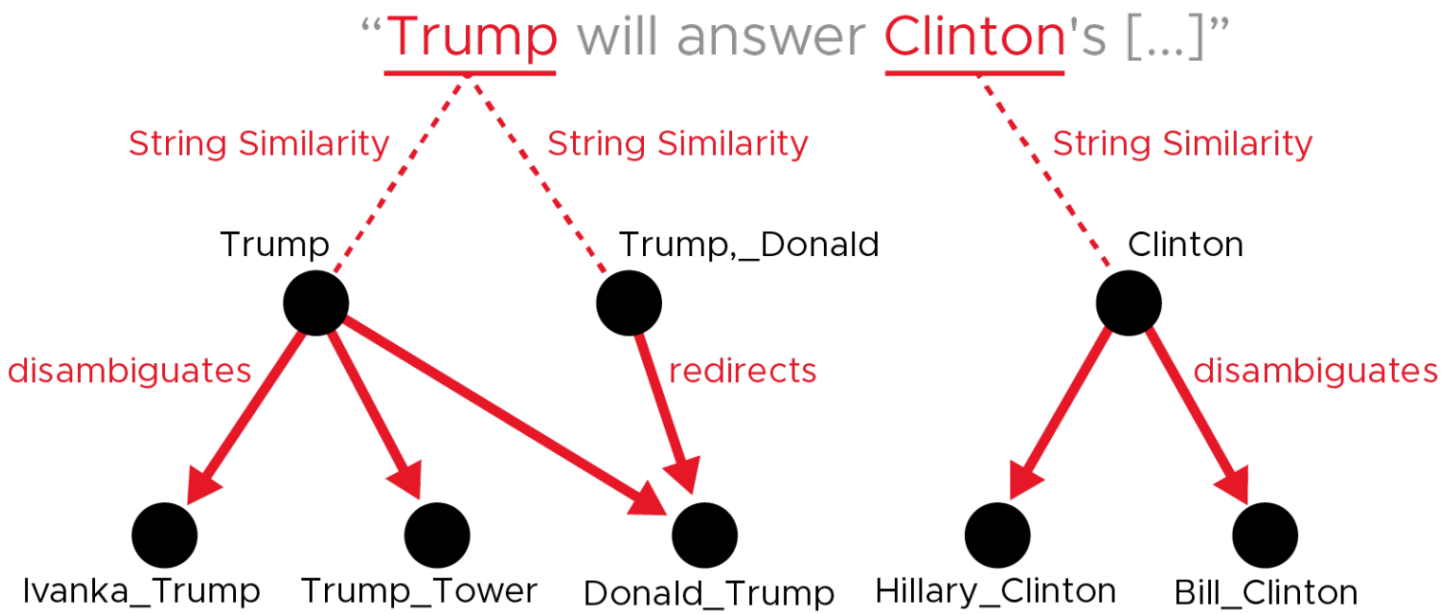
- Generate vertex embeddings using DeepWalk
- **Idea**: entities with the same context should have low embedding distance



Candidate Finder

Idea: for each mention, select a few candidate vertices with index-based **string similarity**

- Fuzzy matching with 2-grams and 3-grams



Empirical Evaluation

- We compared against 6 SoA EL algorithms, on 5 datasets
- Our Micro-averaged **F1** score is comparable with SoA supervised algorithms

Data Set	Ours	DoSeR	WK	AIDA	WAT	BB	SL
ACE2004	0.84	**0.90**	0.83	0.81	0.80	0.56	0.71
AQUAINT	**0.86**	0.84	**0.86**	0.53	0.77	0.65	0.71
MSNBC	**0.92**	0.91	0.85	0.78	0.78	0.60	0.51
N3-Reuters	0.82	**0.85**	0.70	0.60	0.64	0.53	0.58
N3-RSS-500	0.72	**0.75**	0.73	0.71	0.68	0.63	0.62

WK is Wikifier, **BB** is Babelfy, **SL** is Spotlight

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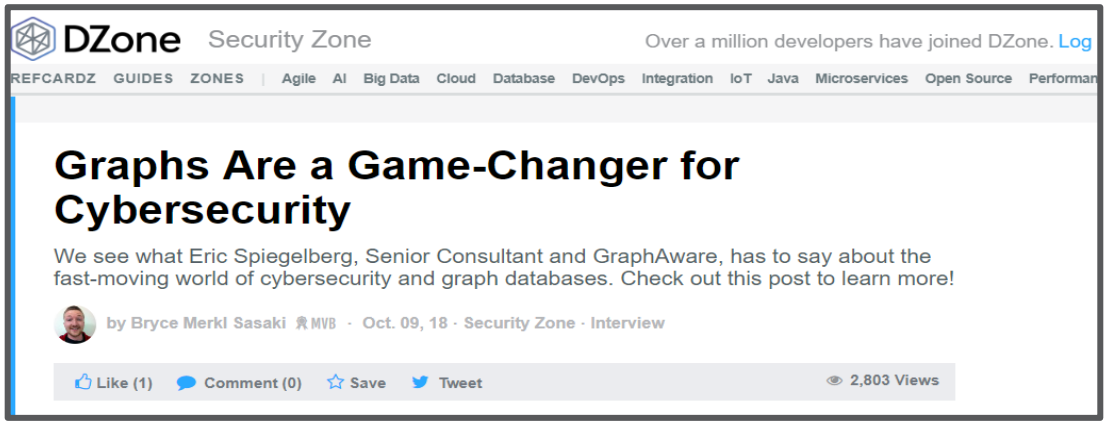
Cyber Security

- Cyber security is a very important topic in the battle for Cloud
  - Invalid traffic detection
  - Cyber threat hunting
  - Malware detection
  - …

- Solution
  - Use *graph* for enhancing cyber security



Cyber Security

- Use *graph* as a semi-structured *data model*
  - Combines heterogeneous data sources, i.e., security data comes from various logs, traces, events, etc.
  - Captures connections between them, e.g., same IP connects to multiple domains.

- Graph captures connections between data entities

➢ Exploit extra signals from graph for anomaly detection (e.g. via Graph ML techniques)

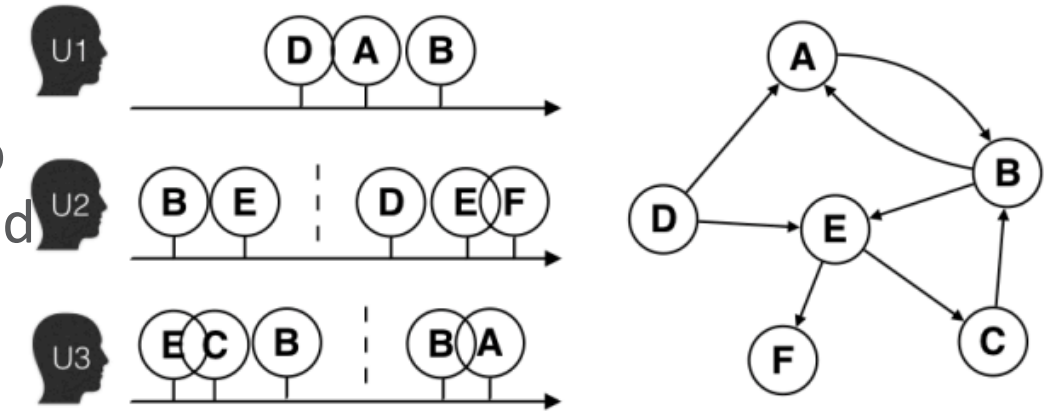
➢ Enhance cyber-threat detection

- Graph enables interactive, visual exploration of security data

➢ Environment for cyber-threat hunting

Retail/E-commerce

- Graph Machine Learning
  - Item-based Collaborative Filtering
  - Construct item-graph from user sessions
  - Compute item embeddings using DeepWalk to capture the sequence information (represented in the item-graph topology)
  - Employ the item embeddings to rank items



(a) Users' behavior sequences. (b) Item graph construction.

- Related literature
  - Taobao from Alibaba
    - *Billion-scale Commodity Embedding for E-commerce Recommendation in Alibaba* from KDD'18 -> link
  - PinSage from Pinterest
    - *Graph Convolutional Neural Networks for Web-Scale Recommender Systems* from KDD'18-> link

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Summary

- Novel EL algorithm that employs Graph Machine Learning
  - Paper on ACM: https://dl.acm.org/citation.cfm?id=3328499
- Applications of GraphML approaches to multiple other domains
  - Cyber-Security
  - Financial Crime Compliance
  - Health-Care
  - Retail/E-commerce
  - Program Analysis and others …
- PGX links:
  - Documentation: https://docs.oracle.com/cd/E56133_01/latest/index.html
  - Download: https://www.oracle.com/technologies/developer-tools/pgx-downloads.html
  - GitHub: https://github.com/oracle/pgx-samples

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