Graph-Based Entity-Oriented Search

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Thesis submitted to Faculty of Engineering of the University of Porto for the Doctor Degree in Computer Science within the Joint Doctoral Program in Computer Science of the Universities of Minho, Aveiro and Porto.

Porto, Portugal – January 26, 2021

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Blade Runner

1984

Akira

E.T. the Extra-Terrestrial

Back to the Future

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List of science fiction films of the 1980s - Wikipedia

A list of **science fiction** films released in the **1980s**. These **films** include core elements of **science fiction**, but can cross into other genres. They have been ...

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Documents

Google

sci-fi movies from the 80s

All | Images | Shopping | Videos | News | More | Settings | Tools

Services

Type | Attributes

Movies | Sci-fi | 1980s | Adventure | Horror | Comedy | YouTube | Drama | Google Play | Superhero | Love | Thriller | Disney

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List o[Attribute]ction film[Attribute]80s -[Type]ia

A list of **science fiction** films released in the **1980s**. These **films** include core elements of **science fiction**, but can cross into other genres. They have been ...

Documents

Entity-oriented search is the search paradigm of organizing and accessing information centered around entities, and their attributes and relationships.

– Krisztian Balog, 2018

- Entities and their relations
- Documents mentioning entities

- Knowledge bases
- Corpora

- Triplestores
- Inverted indexes

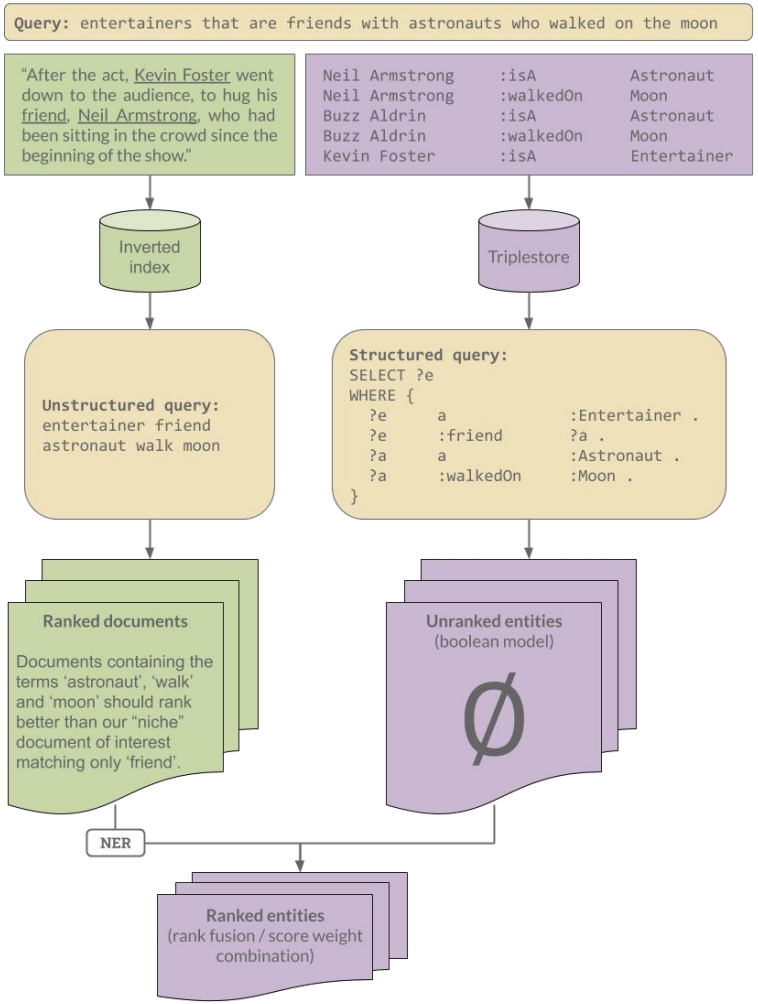
- Triplestores

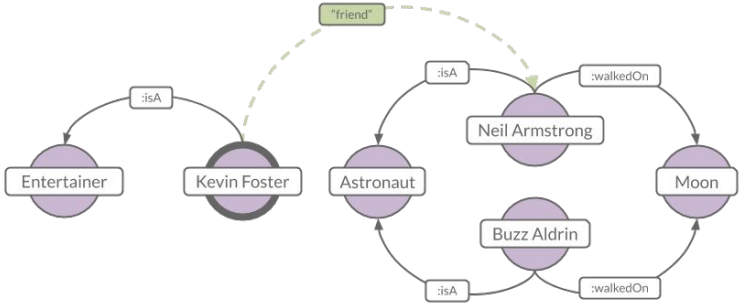
Opportunity for a unified framework

- Inverted indexes

- Structured data and queries

- Unstructured data and queries





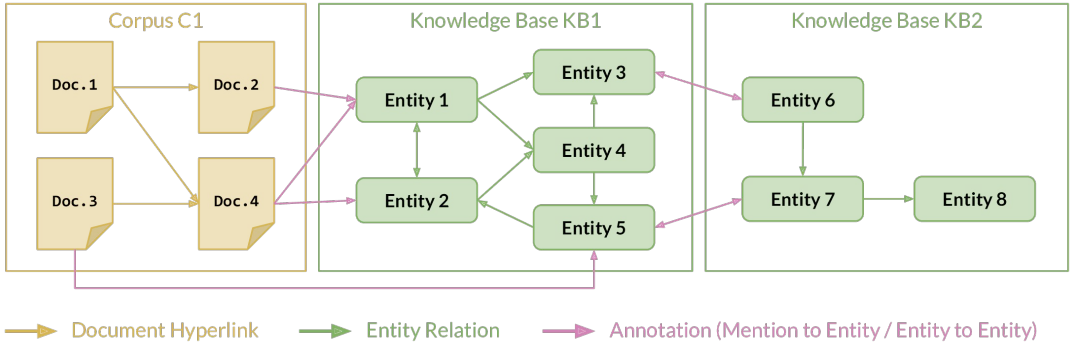
Motivation

- Separate representation models requires integration
- Opportunity for a joint model
  - Reach a wider range of answers
  - Generalize retrieval tasks

A unified model for entity-oriented search

Combined data

- Text
- Entities
- Relations



A unified model for entity-oriented search

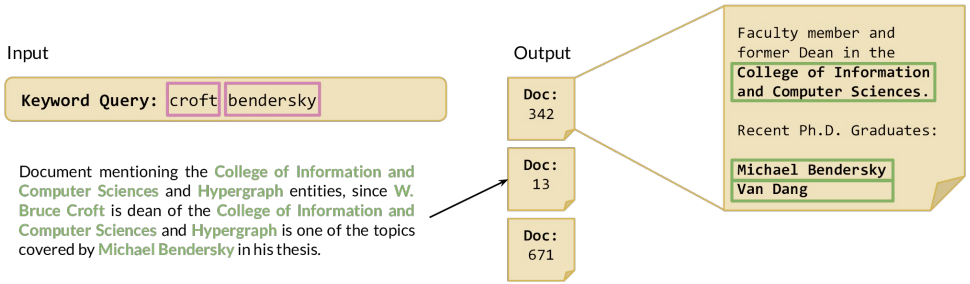
Retrieval tasks

- Ad hoc document retrieval
- Ad hoc entity retrieval
- Related entity finding
- Entity list completion

A unified model for entity-oriented search

Retrieval tasks

- Ad hoc document retrieval
- Ad hoc entity retrieval
- Related entity finding
- Entity list completion



A unified model for entity-oriented search

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- Ad hoc entity retrieval
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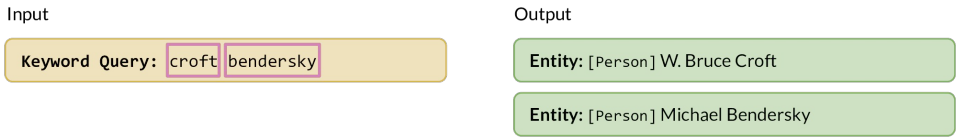

A unified model for entity-oriented search

Retrieval tasks

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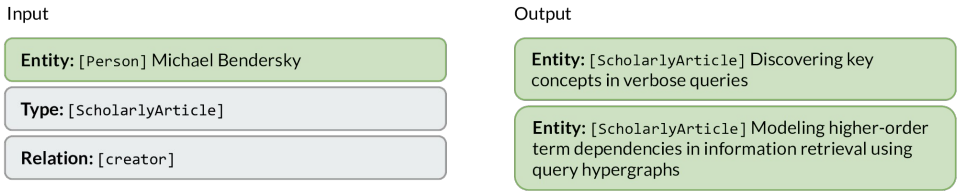
- Entity list completion



A unified model for entity-oriented search

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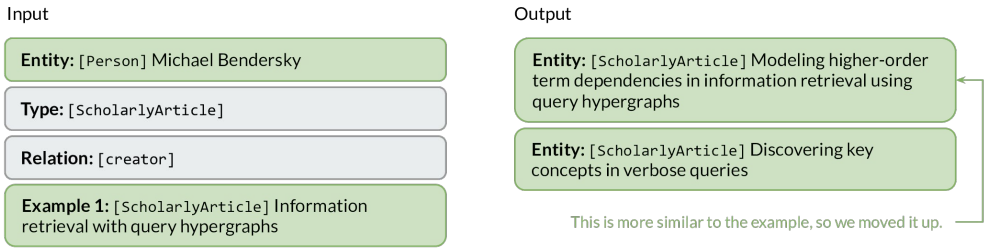


THESIS STATEMENT

Graphs can be used to jointly index corpora and knowledge bases, supporting retrieval for multiple entity-oriented search tasks.

Main objectives

- Joint representation of terms, entities, and their relations
- Universal ranking function for multiple entity-oriented search tasks
- Improved retrieval effectiveness through the unification of information sources

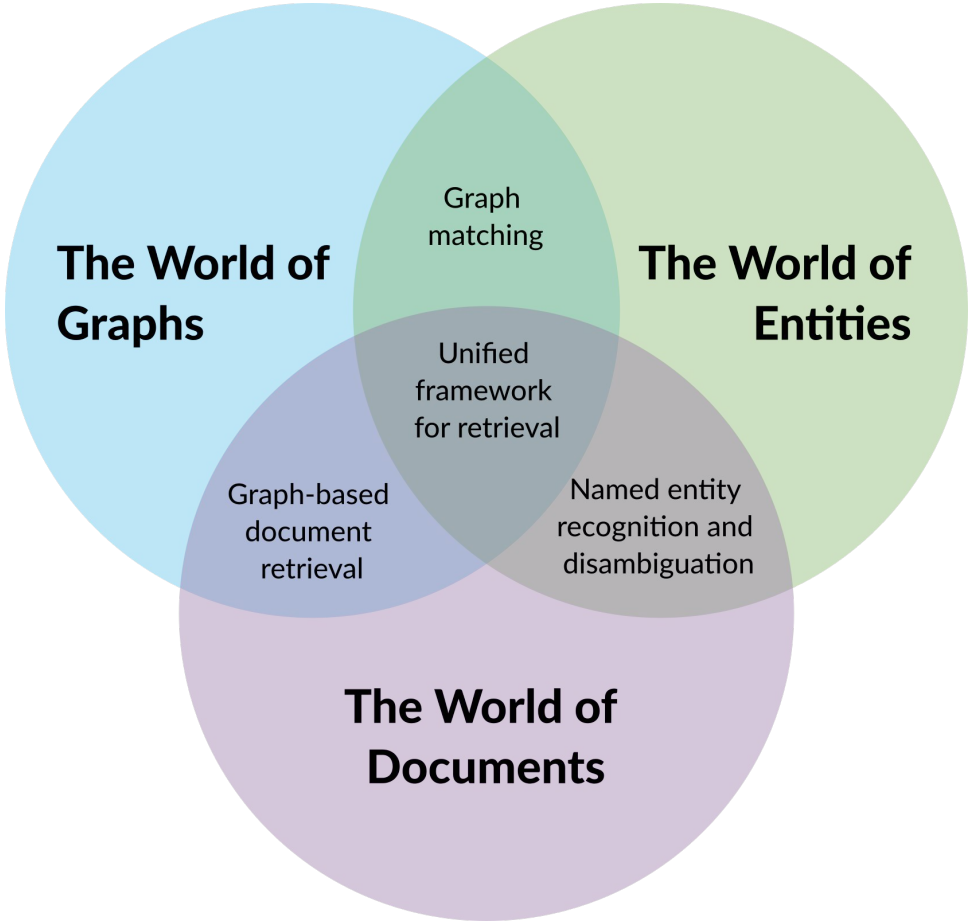
State of the art

A breadth-first search for intersecting concepts in the worlds of documents, entities, and graphs.

Three axes covered

Research around a “common denominator”:

- Documents as graphs of words
- Entity relations as knowledge graphs
- Generic graph-based models and applications



Key references

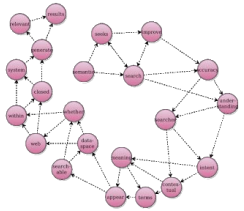
2007

"73-87% of all queries contain entities"

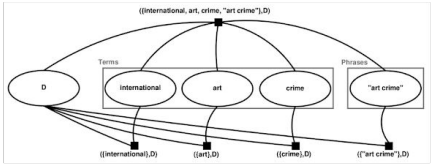
Concordance-Based Entity-Oriented Search
Bautin, M. and Skiena, S.

2010

Ad-hoc object retrieval in the web of data
Pound, J., Mika, P. and Zaragoza, H.

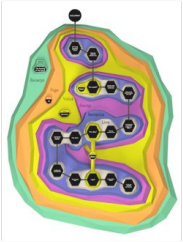


2012



Modeling Higher-order Term Dependencies in Information Retrieval Using Query Hypergraphs
Bendersky, M. and Croft, W. B.

2013



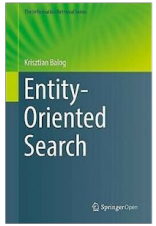
It's more than just overlap: Text As Graph
Dekker, R. H. and Birnbaum, D.

Index for Efficient Semantic Full-text Search
Bast, H. and Buchhold, B.

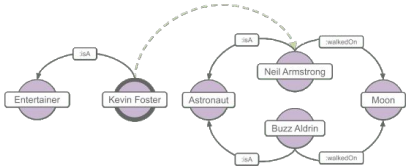
Graph-of-word and TW-IDF: new approach to ad hoc IR
Rousseau, F. and Vazirgiannis, M.

2017

2018



Entity-Oriented Search
Balog, K.



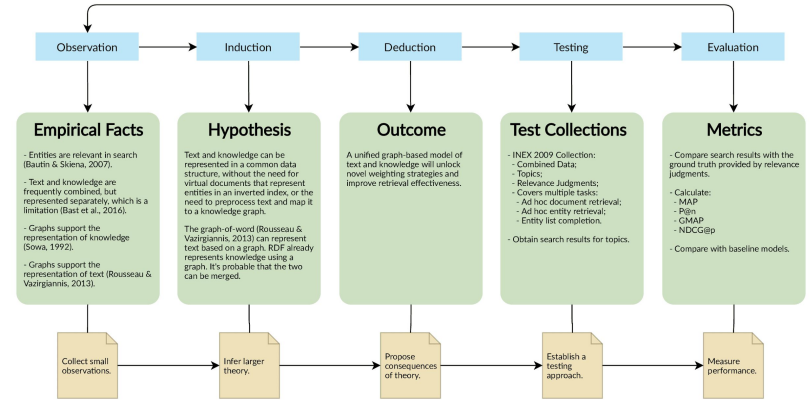
II

Materials and methods

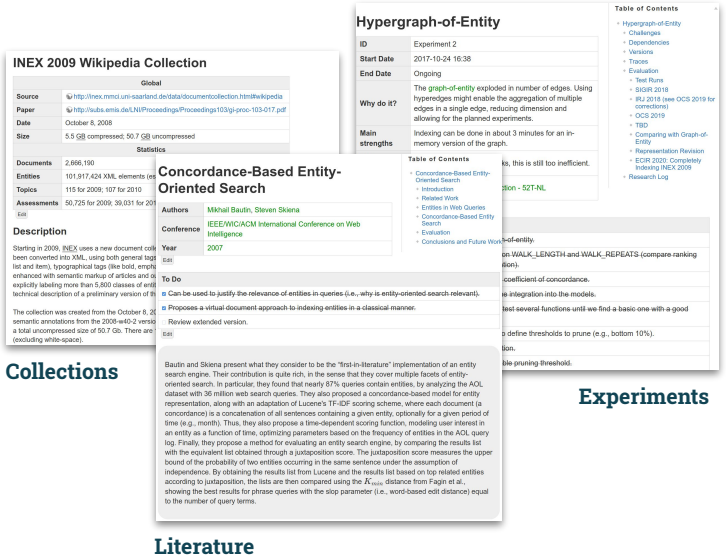
Empirical research supported on test collections and software

Research methodology

Empirical research



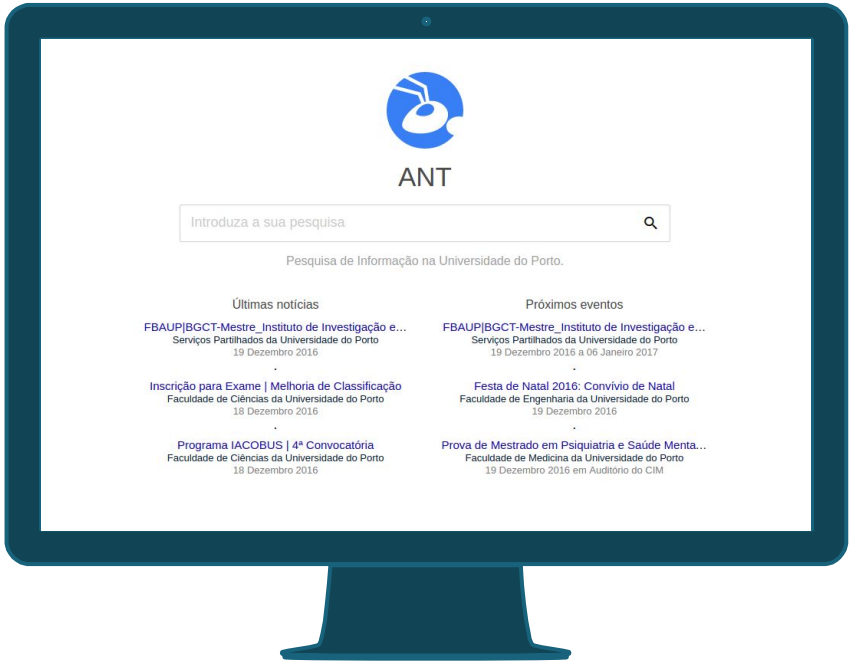
Systematic documentation



Test collections

	Num. Docs.	Year(s)	Evaluation	Document ranking	Entity ranking	List completion
INEX 2009 Wikipedia Collection	2.6M XML	2009–2010	Offline	✓	✓	✓
TREC Washington Post Corpus	595K JSON	2018	Offline	✓	✗	✗
Social Science Open Access Repository	32K JSON	2017	Online	✓	✗	✗

Software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Inscrição para Exame | Melhoria de Classificação
Faculdade de Ciências da Universidade do Porto
18 Dezembro 2016
Programa IACOBUS | 4ª Convocatória
Faculdade de Ciências da Universidade do Porto
18 Dezembro 2016
Próximos eventos
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Serviços Partilhados da Universidade do Porto
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Festa de Natal 2016: Convívio de Natal
Faculdade de Engenharia da Universidade do Porto
19 Dezembro 2016
Prova de Mestrado em Psiquiatria e Saúde Menta...
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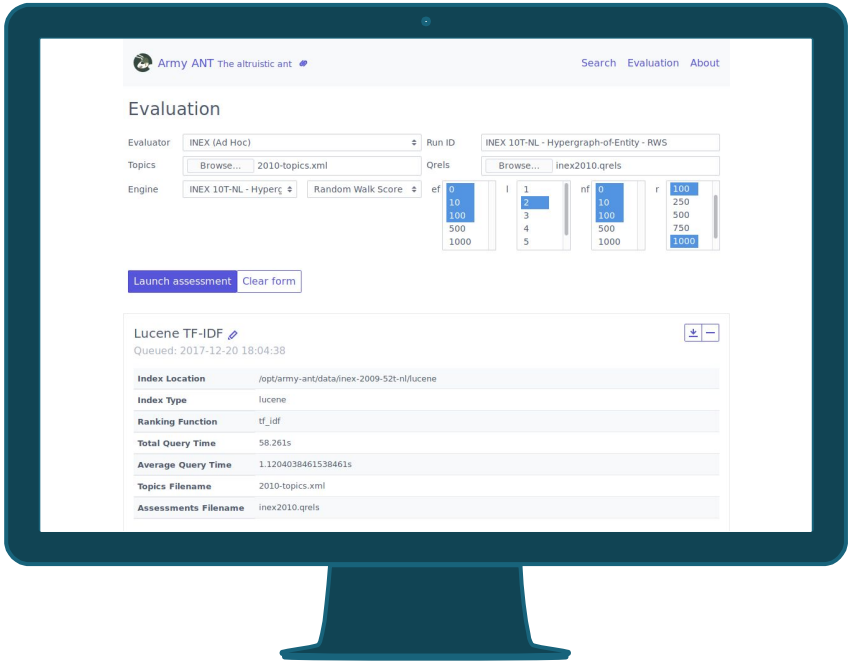
19 Dezembro 2016 em Auditório do CIM


Army ANT The altruistic ant
Search
Evaluation
About
Evaluation
Evaluator
INEX (Ad Hoc)
Run ID
INEX 10T-NL - Hypergraph-of-Entity - RWS
Topics
Browse...
2010-topics.xml
Qrels
Browse...
inex2010.qrels
Engine
INEX 10T-NL - Hyperç
Random Walk Score
ef
0
10
100
500
1000
l
1
2
3
4
5
nf
0
10
100
500
1000
r
100
250
500
750
1000
Launch assessment
Clear form
Lucene TF-IDF
Queued: 2017-12-20 18:04:38
Index Location
/opt/army-ant/data/inex-2009-52t-nl/lucene
Index Type
lucene
Ranking Function
tf_idf
Total Query Time
58.261s
Average Query Time
1.1204038461538461s
Topics Filename
2010-topics.xml
Assessments Filename
inex2010.qrels

III

Contributions

- Graph-of-entity
- Hypergraph-of-entity

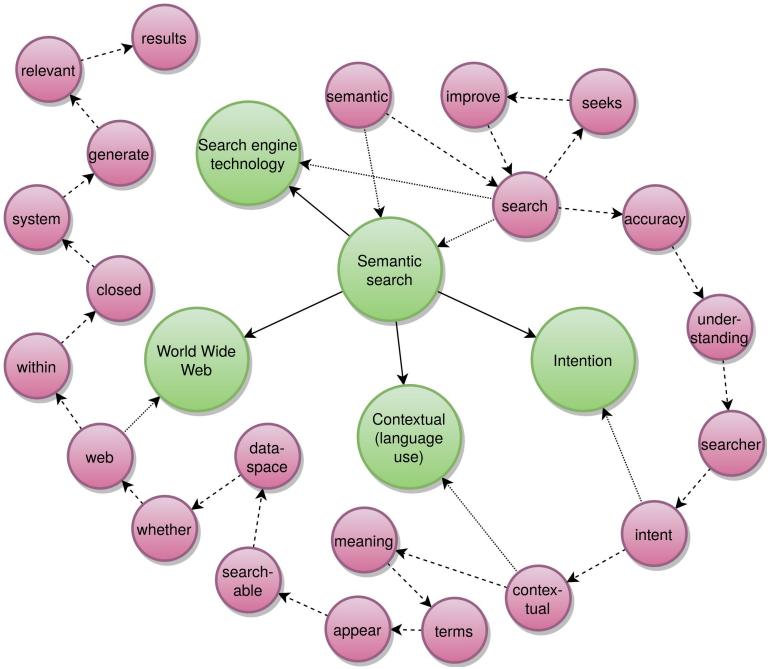
Example document

Semantic search seeks to improve search [Search Engine Technology] accuracy by understanding the searcher's intent [Intention] and the contextual [Contextual (language use)] meaning of terms as they appear in the searchable dataspace, whether on the Web [World Wide Web] or within a closed system, to generate more relevant results.

– 'Semantic search', Wikipedia, 9:10am, January 7, 2016

Graph-of-entity: representation

- Nodes
  - ‘term’
  - ‘entity’
- Edges (directed and unweighted)
  - ‘before’
  - ‘related_to’
  - ‘contained_in’



Note: The direction for ‘related_to’ edges has been corrected.

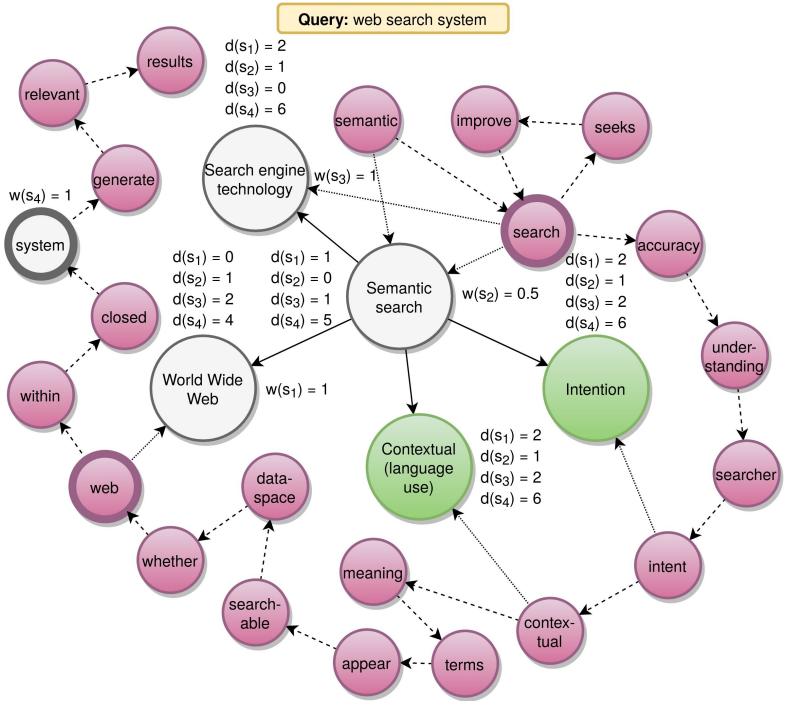
Seed nodes

- Map the query to the graph
- Can be expanded to adjacent entities
- Weighted according to their representability of the query

Graph-of-entity: retrieval

Three components:

- Coverage
- Confidence weight
- Entity weight



Note: The direction for 'related_to' edges has been corrected.

Scaling issues

INEX 2009 Wikipedia subset

- 7,484 documents
- Graph-of-entity
  - 981,647 nodes
  - 9,942,647 edges

Scaling issues

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2 orders of magnitude

Scaling issues

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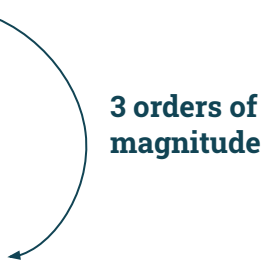

Scaling issues

INEX 2009 Wikipedia subset

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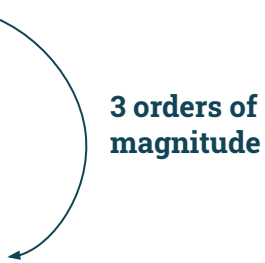
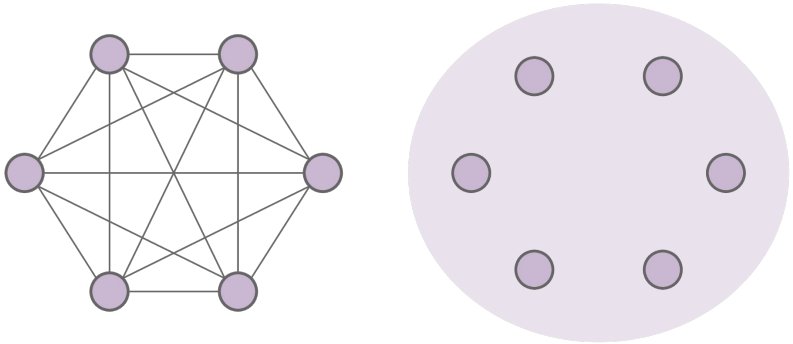
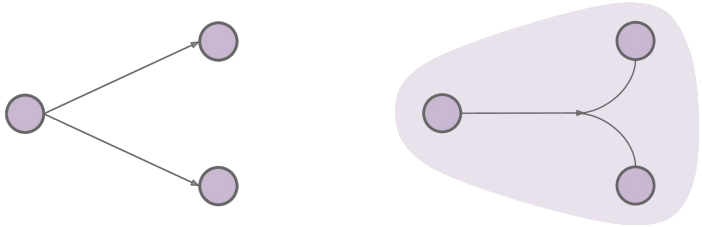


How could I reduce the number of edges per node?

From graphs to hypergraphs



Representing full connectivity
(e.g., synonyms)

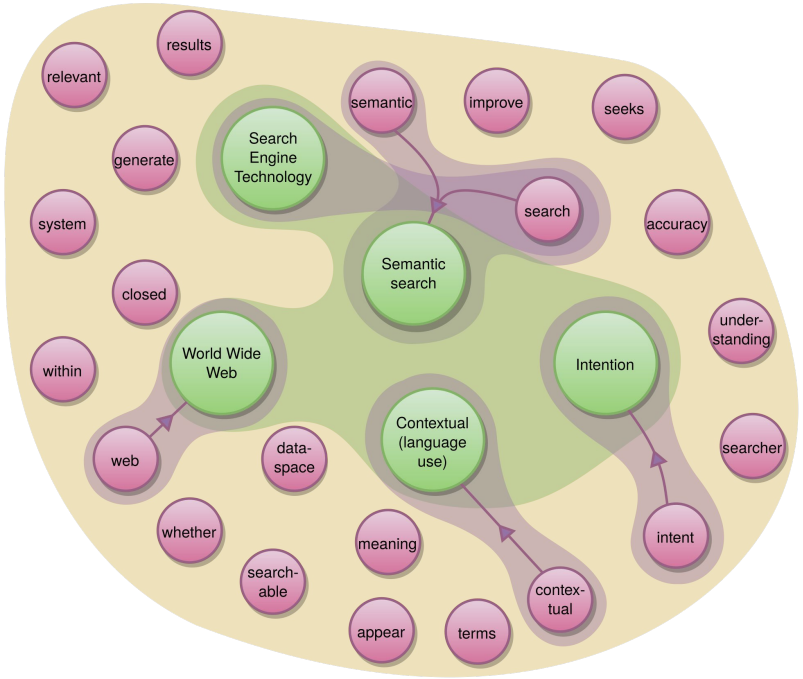


Representing directed n-ary connectivity
(e.g., e-mail message)

Hypergraph-of-entity: joint representation model

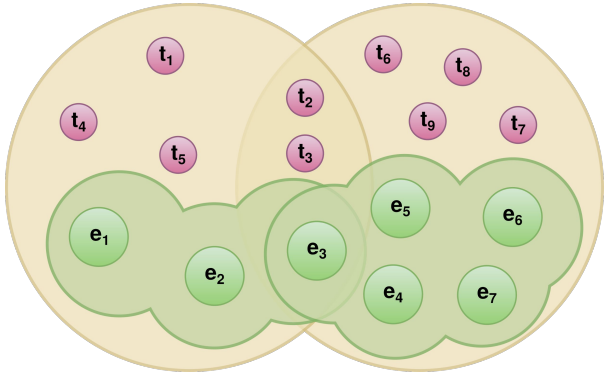
Base model

- Nodes
  - ‘term’
  - ‘entity’
- Hyperedges
  - ‘document’
  - ‘related_to’
  - ‘contained_in’

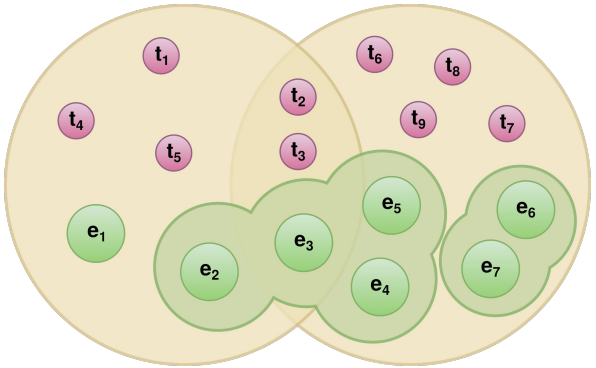


Hypergraph-of-entity: joint representation model

‘related_to’ hyperedges



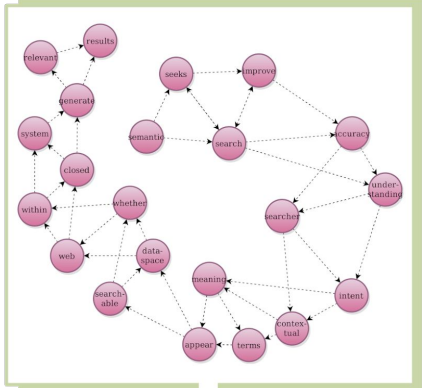
Grouped by co-occurrence



Grouped by subject

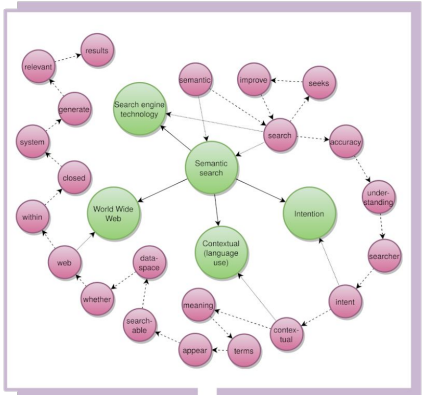
Scaling issues: mitigated

Graph-of-word



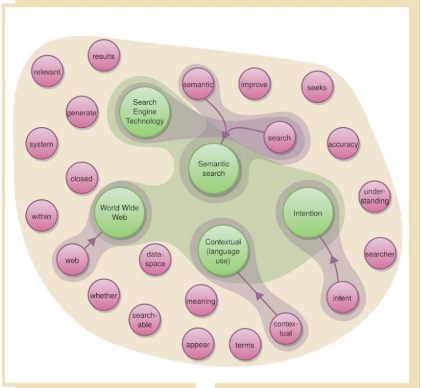
- 7,487 documents
- 492,185 vertices
- 22,906,803 edges
- |E| = 46.5 x |V|

Graph-of-entity



- 7,487 documents
- 981,647 vertices
- 9,942,647 edges
- |E| = 10.1 x |V|

Hypergraph-of-entity



- 7,487 documents
- 607,213 vertices
- 253,154 hyperedges
- |E| = 0.4 x |V|

Hypergraph-of-entity: joint representation model

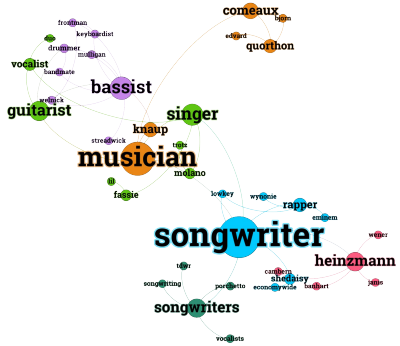
Extensions

Synonyms

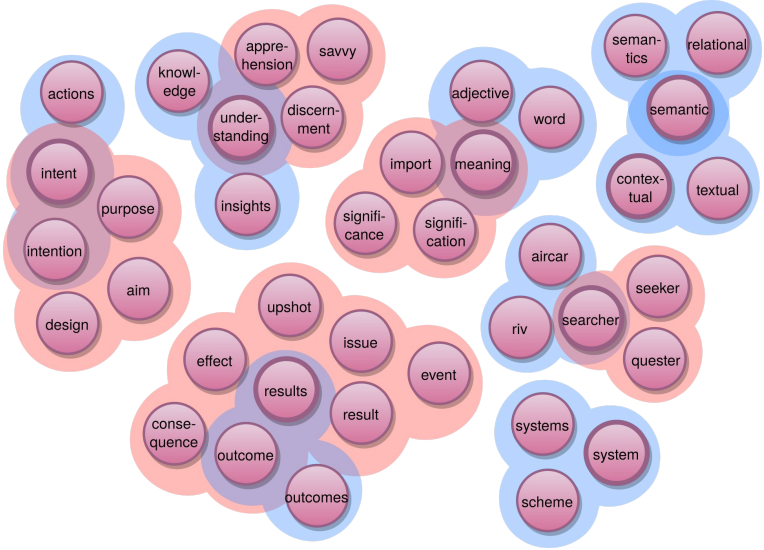
- WordNet 3.0 Nouns

Context

- Word2vec SimNet
  - size=100, window=5
  - 2-NN, cosine similarity > 0.5
  - Hyperedge per term neighborhood



Word2vec SimNet:
Ego Network for
'musician', with depth 3



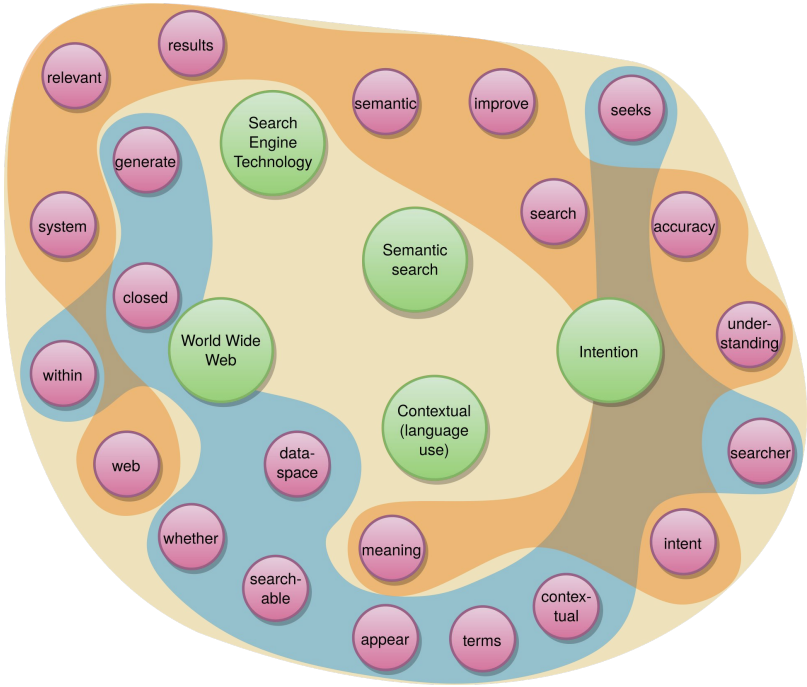
Synonyms + Context

Hypergraph-of-entity: joint representation model

Extensions

TF-bins (low TF / high TF)

- Discretization of term frequency
- Optionally weighted by percentile order, e.g.:
  - For P_2 = {50, 100}
  - w_{50}=½, w_{100}=1



TF-bins:
bin width = 2

Hypergraph-of-entity: joint representation model

Extensions

Weights

- To further constraint or guide the ranking function
- Add a bias that can affect both node and hyperedge sampling

Hypergraph-of-entity: universal ranking function

Random walk score

- Random walks on a hypergraph
- Launched from each seed node
- Final score computed as:
  - ∑ weighted sum
    - Confidence weight
    - × visitation probability
  - × coverage

Hypergraph-of-entity: universal ranking function

Table 7.4: Mapping entity-oriented search tasks to the hypergraph-of-entity.

	Query	Input	Results	Output
Ad hoc document retrieval	Keyword	Term nodes	Documents	Hyperedge ranking
Ad hoc entity retrieval	Keyword	Term nodes	Entities	Node ranking
Related entity finding	Entity	One entity node	Entities	Node ranking
Entity list completion	Entity	Multiple entity nodes	Entities	Node ranking

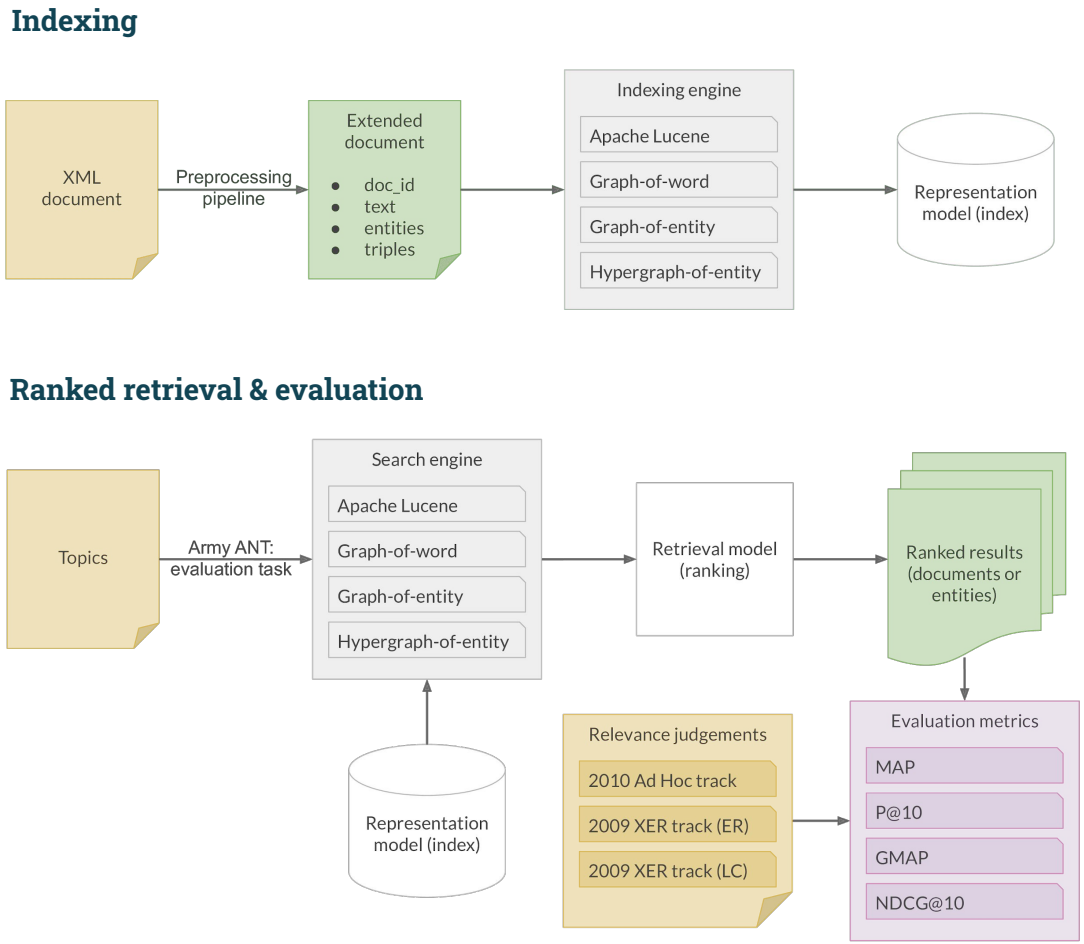
Hypergraph-of-entity: universal ranking function

Table 7.5: Random walk score parameters and chosen configuration.

Parameter	Description	Configuration
ℓ	Length of the random walk.	2
r	Number of repeated random walks per seed node.	10,000
Δ_{nf}	Number of cycles of node fatigue (see Section B.2).	0
Δ_{ef}	Number of cycles of (hyper)edge fatigue (see Section B.2).	0
expansion	Whether to expand query to neighboring entities.	*false*
directed	Whether to consider or ignore direction.	*true*
weighted	Whether to consider node and hyperedge weights.	*false*

Evaluation: workflow

Indexing, retrieval and ranking, and evaluation



Evaluation: main experiments

Retrieval performance over different representations:

- Text-only
- Base model
- Synonyms
- Context
- Syns+Cont.
- Cont.+Syns
- Syns+Cont.+Weights

Over different ranking function parameter configurations:

- Best results for:
  - Low ℓ
  - High r
  - No fatigue
- Variable results for:
  - Expansion
  - Weights

And for multiple tasks over the same index.

Evaluation: INEX 2009 10T-NL Wikipedia subset

Task

- Ad hoc document retrieval
  2010 Ad Hoc track qrels

Goal

- Compare graph-of-entity and hypergraph-of-entity

Evaluation: INEX 2009 10T-NL Wikipedia subset

Ad hoc document retrieval

Graph-of-entity vs hypergraph-of-entity

Table 9.5: Graph-of-entity (GoE) vs hypergraph-of-entity (HGoE) with $\ell = 2$.

(a) Effectiveness (highest values for Lucene and graph-based models in bold).

Index	Ranking	GMAP	MAP	Precision	Recall	NDCG@10	P@10
Lucene	TF-IDF	0.1540	0.1710	0.1389	0.8007	0.2671	0.2800
	BM25	**0.2802**	**0.2963**	**0.1396**	**0.8241**	**0.5549**	**0.5000**
GoE	EW	0.0003	0.0399	**0.1771**	0.2233	0.1480	0.1500
HGoE	RWS($r = 10^1$)	0.0000	0.0485	0.0734	0.3085	0.1229	0.1200
	RWS($r = 10^2$)	0.0546	0.1118	0.0342	0.7554	0.1474	0.1500
	RWS($r = 10^3$)	0.1017	0.1492	0.0199	0.9122	**0.2074**	**0.2200**
	RWS($r = 10^4$)	**0.1224**	**0.1689**	0.0167	**0.9922**	0.1699	0.1700

(b) Efficiency (lowest times for Lucene and graph-based models in bold).

Index	Ranking	Indexing Time (Total)	Search Time (Avg./Query)	Nodes	Edges
Lucene	TF-IDF	**27s 769ms**	**209ms**	N/A	N/A
	BM25		316ms		
GoE	EW	1h 38m	21s 557ms	981,647	9,942,647
HGoE	RWS($r = 10^1$)	**53s 922ms**	**943ms**	607,213	253,154
	RWS($r = 10^2$)		11s 134ms		
	RWS($r = 10^3$)		1m 17s 540ms		
	RWS($r = 10^4$)		13m 04s 057ms		

Evaluation: INEX 2009 10T-NL Wikipedia subset

Ad hoc document retrieval

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Evaluation: INEX 2009 10T-NL Wikipedia subset

Ad hoc document retrieval

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Evaluation: INEX 2009 10T-NL Wikipedia subset

Ad hoc document retrieval

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	RWS($r = 10^2$)		11s 134ms		
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	RWS($r = 10^4$)		13m 04s 057ms		

Evaluation: INEX 2009 52T-NL Wikipedia subset

Task

- Ad hoc document retrieval
  2010 Ad Hoc track qrels

Goal

- Compare representation models based on the hypergraph-of-entity

Evaluation: INEX 2009 52T-NL Wikipedia subset

Ad hoc document retrieval

Comparing representation models

Table 9.4: Best overall parameter configuration according to the mean average precision.

(a) Effectiveness (highest values for Lucene and hypergraph-of-entity in bold; differences in MAP are not statistically significant, except between the Lucene baselines and the hypergraph-of-entity indexes).

Index	Ranking	GMAP	MAP	Precision	Recall	NDCG@10	P@10
Lucene	TF-IDF	0.1345	0.1689	**0.0650**	0.8476	0.2291	0.2346
	BM25	**0.2740**	**0.3269**	0.0647	**0.8598**	**0.5607**	**0.5250**
Hypergraph-of-Entity: Random Walk Score ($\ell = 2$, $r = 10^3$)							
Base Model	RWS	0.0285	0.0864	0.0219	0.8003	**0.1413**	**0.1269**
Syns	RWS	0.0281	0.0840	0.0225	0.8099	0.1301	0.1231
Context	RWS	0.0134	0.0811	0.0220	0.8027	0.1218	0.1192
Syns+Context	RWS	0.0299	0.0837	0.0236	0.8069	0.1310	0.1231
Context+Syns	RWS	0.0296	0.0814	0.0242	**0.8148**	0.1256	0.1250
Syns+Cont.+Weights	RWS	**0.0313**	**0.0884**	**0.0274**	0.8059	0.1256	0.1154

(b) Efficiency (lowest times for Lucene and hypergraph-of-entity in bold).

Index	Ranking	Indexing Time		Search Time	
		Avg./Doc	Total	Avg./Query	Total
Lucene	TF-IDF	2.16ms	1m 21s 382ms	**1s 148ms**	**59s 698ms**
	BM25			1s 220ms	1m 03s 461ms
Hypergraph-of-Entity: Random Walk Score ($\ell = 2$, $r = 10^3$)					
Base Model	RWS	6.52ms	4m 05s 612ms	**3m 22s 826ms**	**2h 55m 47s**
Syns	RWS	**6.22ms**	**3m 54s 587ms**	3m 31s 038ms	3h 02m 54s
Context	RWS	6.35ms	3m 59s 446ms	3m 35s 623ms	3h 06m 52s
Syns+Context	RWS	6.29ms	3m 57s 264ms	3m 33s 000ms	3h 04m 36s
Context+Syns	RWS	6.33ms	3m 58s 659ms	3m 36s 487ms	3h 07m 37s
Syns+Cont.+Weights	RWS	6.52ms	4m 05s 984ms	10m 55s 590ms	9h 28m 11s

Evaluation: INEX 2009 52T-NL Wikipedia subset

Ad hoc document retrieval

Comparing representation models

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Context+Syns	RWS	6.33ms	3m 58s 659ms	3m 36s 487ms	3h 07m 37s
Syns+Cont.+Weights	RWS	6.52ms	4m 05s 984ms	10m 55s 590ms	9h 28m 11s

Evaluation: INEX 2009 52T-NL Wikipedia subset

Ad hoc document retrieval

Comparing representation models

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Syns+Cont.+Weights	RWS	6.52ms	4m 05s 984ms	10m 55s 590ms	9h 28m 11s

Evaluation: INEX 2009 52T-NL Wikipedia subset

Ad hoc document retrieval

Comparing representation models

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Evaluation: INEX 2009 Wikipedia full collection

Tasks

- Ad hoc document retrieval
  2010 Ad Hoc track qrels
- Ad hoc entity retrieval
  2009 XER track entity ranking qrels
- Entity list completion
  2009 XER track list completion qrels

Goal

- Assess the viability of a general retrieval model

Reduced representation

- Keyword-based document profiles

Evaluation: INEX 2009 Wikipedia full collection

Multiple tasks

Keyword-based document profiles

Note: The entity index was created from sentence-based entity profiles

Table 10.6: Overall comparison of retrieval performance, for multiple entity-oriented search tasks, based on the complete INEX 2009 Wikipedia collection.

Index	Ranking	MAP	P@10	Index Time	Avg./Query	Nodes	Edges
AD HOC DOCUMENT RETRIEVAL							
Lucene	TF-IDF	0.0228	0.0692	15h 06m	460ms	–	–
	BM25	0.0324	0.1173		370ms	–	–
Fixed parameters over HGoE variations: $RWS(\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F)$							
Base Model	RWS	0.0863	0.2462	33h 53m	23s 405ms	3,506,823	7,721,743
Syns	RWS	0.0937	0.2615	33h 05m	55s 555ms	3,510,462	7,734,931
Cont.	RWS	0.0869	0.2654	34h 37m	24s 348ms	3,604,185	7,929,841
TF-Bins$_2$	RWS	0.0172	0.0500	35h 26m	2m 58s	3,506,823	10,338,867
Syns+Cont.	RWS	0.0882	0.2692	37h 16m	23s 265ms	3,606,693	7,945,083
AD HOC ENTITY RETRIEVAL							
Lucene	TF-IDF	0.0373	0.0636	59h 17m	1s 370ms	–	–
	BM25	0.0668	0.1182		798ms	–	–
Fixed parameters over HGoE variations: $RWS(\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F)$							
Base Model	RWS	0.1390	0.2455	33h 53m	26s 330ms	3,506,823	7,721,743
Syns	RWS	0.1337	0.2473	33h 05m	30s 232ms	3,510,462	7,734,931
Cont.	RWS	0.1304	0.2364	34h 37m	27s 620ms	3,604,185	7,929,841
TF-Bins$_2$	RWS	0.0300	0.1145	35h 26m	4m 41s	3,506,823	10,338,867
Syns+Cont.	RWS	0.1313	0.2509	37h 16m	26s 877ms	3,606,693	7,945,083
ENTITY LIST COMPLETION							
Lucene	TF-IDF	0.0558	0.1000	59h 17m	1s 230ms	–	–
	BM25	0.0666	0.1250		1s 221ms	–	–
Fixed parameters over HGoE variations: $RWS(\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F)$							
Base Model	RWS	0.0879	0.0769	33h 53m	19s 162ms	3,506,823	7,721,743
Syns	RWS	0.0857	0.0635	33h 05m	19s 875ms	3,510,462	7,734,931
Cont.	RWS	0.0875	0.0692	34h 37m	19s 422ms	3,604,185	7,929,841
TF-Bins$_2$	RWS	0.0006	0.0058	35h 26m	1m 08s	3,506,823	10,338,867
Syns+Cont.	RWS	0.0884	0.0788	37h 16m	19s 824ms	3,606,693	7,945,083

Evaluation: INEX 2009 Wikipedia full collection

Multiple tasks

Keyword-based document profiles

Note: The entity index was created from sentence-based entity profiles

Table 10.6: Overall comparison of retrieval performance, for multiple entity-oriented search tasks, based on the complete INEX 2009 Wikipedia collection.

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	BM25	0.0324	0.1173		370ms	–	–
Fixed parameters over HGoE variations: RWS($\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F$)							
Base Model	RWS	0.0863	0.2462	33h 53m	23s 405ms	3,506,823	7,721,743
Syns	RWS	0.0937	0.2615	33h 05m	55s 555ms	3,510,462	7,734,931
Cont.	RWS	0.0869	0.2654	34h 37m	24s 348ms	3,604,185	7,929,841
TF-Bins$_2$	RWS	0.0172	0.0500	35h 26m	2m 58s	3,506,823	10,338,867
Syns+Cont.	RWS	0.0882	0.2692	37h 16m	23s 265ms	3,606,693	7,945,083
Ad hoc entity retrieval							
Lucene	TF-IDF	0.0373	0.0636	59h 17m	1s 370ms	–	–
	BM25	0.0668	0.1182		798ms	–	–
Fixed parameters over HGoE variations: RWS($\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F$)							
Base Model	RWS	0.1390	0.2455	33h 53m	26s 330ms	3,506,823	7,721,743
Syns	RWS	0.1337	0.2473	33h 05m	30s 232ms	3,510,462	7,734,931
Cont.	RWS	0.1304	0.2364	34h 37m	27s 620ms	3,604,185	7,929,841
TF-Bins$_2$	RWS	0.0300	0.1145	35h 26m	4m 41s	3,506,823	10,338,867
Syns+Cont.	RWS	0.1313	0.2509	37h 16m	26s 877ms	3,606,693	7,945,083
Entity list completion							
Lucene	TF-IDF	0.0558	0.1000	59h 17m	1s 230ms	–	–
	BM25	0.0666	0.1250		1s 221ms	–	–
Fixed parameters over HGoE variations: RWS($\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F$)							
Base Model	RWS	0.0879	0.0769	33h 53m	19s 162ms	3,506,823	7,721,743
Syns	RWS	0.0857	0.0635	33h 05m	19s 875ms	3,510,462	7,734,931
Cont.	RWS	0.0875	0.0692	34h 37m	19s 422ms	3,604,185	7,929,841
TF-Bins$_2$	RWS	0.0006	0.0058	35h 26m	1m 08s	3,506,823	10,338,867
Syns+Cont.	RWS	0.0884	0.0788	37h 16m	19s 824ms	3,606,693	7,945,083

Evaluation: INEX 2009 Wikipedia full collection

Multiple tasks

Keyword-based document profiles

Note: The entity index was created from sentence-based entity profiles

Table 10.6: Overall comparison of retrieval performance, for multiple entity-oriented search tasks, based on the complete INEX 2009 Wikipedia collection.

Index	Ranking	MAP	P@10	Index Time	Avg./Query	Nodes	Edges
Ad hoc document retrieval							
Lucene	TF-IDF	0.0228	0.0692	15h 06m	460ms	–	–
	BM25	0.0324	0.1173		370ms	–	–
Fixed parameters over HGoE variations: RWS($\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F$)							
Base Model	RWS	0.0863	0.2462	33h 53m	23s 405ms	3,506,823	7,721,743
Syns	RWS	0.0937	0.2615	33h 05m	55s 555ms	3,510,462	7,734,931
Cont.	RWS	0.0869	0.2654	34h 37m	24s 348ms	3,604,185	7,929,841
TF-Bins$_2$	RWS	0.0172	0.0500	35h 26m	2m 58s	3,506,823	10,338,867
Syns+Cont.	RWS	0.0882	0.2692	37h 16m	23s 265ms	3,606,693	7,945,083
Ad hoc entity retrieval							
Lucene	TF-IDF	0.0373	0.0636	59h 17m	1s 370ms	–	–
	BM25	0.0668	0.1182		798ms	–	–
Fixed parameters over HGoE variations: RWS($\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F$)							
Base Model	RWS	0.1390	0.2455	33h 53m	26s 330ms	3,506,823	7,721,743
Syns	RWS	0.1337	0.2473	33h 05m	30s 232ms	3,510,462	7,734,931
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Entity list completion							
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Evaluation: INEX 2009 Wikipedia full collection

Multiple tasks

Keyword-based document profiles

Note: The entity index was created from sentence-based entity profiles

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AD HOC DOCUMENT RETRIEVAL							
Lucene	TF-IDF	0.0228	0.0692	15h 06m	460ms	–	–
	BM25	0.0324	0.1173		370ms	–	–
Fixed parameters over HGoE variations: RWS($\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F$)							
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AD HOC ENTITY RETRIEVAL							
Lucene	TF-IDF	0.0373	0.0636	59h 17m	1s 370ms	–	–
	BM25	0.0668	0.1182		798ms	–	–
Fixed parameters over HGoE variations: RWS($\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F$)							
Base Model	RWS	0.1390	0.2455	33h 53m	26s 330ms	3,506,823	7,721,743
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Syns+Cont.	RWS	0.1313	0.2509	37h 16m	26s 877ms	3,606,693	7,945,083
ENTITY LIST COMPLETION							
Lucene	TF-IDF	0.0558	0.1000	59h 17m	1s 230ms	–	–
	BM25	0.0666	0.1250		1s 221ms	–	–
Fixed parameters over HGoE variations: RWS($\ell = 2, r = 10^4, \Delta_{nf} = 0, \Delta_{ef} = 0, exp = F, wei = F$)							
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				Entity list completion			
Lucene	TF-IDF	0.0558	0.1000	59h 17m	1s 230ms	–	–
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Syns+Cont.	RWS	0.0884	0.0788	37h 16m	19s 824ms	3,606,693	7,945,083

IV

Conclusions

Discussion, final remarks and future work

Discussion

- Efficiency / effectiveness trade-off:
  - Lower r is more efficient
  - Higher r is more effective
- Current implementation is:
  - Less efficient overall when compared to Lucene
  - More effective in the experiments using keyword-based document profiles

Discussion

- The hypergraph-of-entity is a novel indexing model for EOS
- The random walk score is the first attempt at a universal ranking function
  - Able to approximate or even beat TF-IDF and BM25
- Performance was better for:
  - Small datasets
  - Reduced document representations

Final remarks

- I have proven that a graph-based model is viable in EOS...
- ...as a joint representation of corpora and knowledge bases...
- ...using a universal ranking function to solve multiple EOS tasks.

- I improved retrieval effectiveness in some particular cases...
- ...motivating the continued research of hypergraph-based models...
- ...and unified frameworks in information retrieval.

Future work

- Optimize overall performance:
  - Prune nodes and hyperedges
  - Test different weighting functions
- Explore algebraic approaches:
  - Tensor-based representation
  - Personalized multilinear PageRank
- Expand supported tasks, e.g.:
  - Personalized search (‘user’ hyperedges)

THANK YOU!

https://ant.fe.up.pt/
https://github.com/feup-infolab/army-ant/

J J. Devezas and S. Nunes. "Characterizing the hypergraph-of-entity and the structural impact of its extensions". In: Applied Network Science - Special Issue of the 8th International Conference on Complex Networks and Their Applications 5.1 (2020), p. 79. issn: 2364-8228. doi: 10.1007/s41109-020-00320-z

C J. Devezas. "Graph-Based Entity-Oriented Search: A Unified Framework in Information Retrieval". In: Advances in Information Retrieval - 42nd European Conference on IR Research, ECIR 2020, Lisbon, Portugal, April 14-17, 2020, Proceedings, Part II. ed. by J. M. Jose, E. Yilmaz, J. Magalhães, P. Castells, N. Ferro, M. J. Silva, and F. Martins. Vol. 12036. Lecture Notes in Computer Science. Springer, 2020, pp. 602-607. doi: 10.1007/978-3-030-45442-5_78

C J. L. Devezas and S. Nunes. "Army ANT: A Workbench for Innovation in Entity-Oriented Search". In: Advances in Information Retrieval - 42nd European Conference on IR Research, ECIR 2020, Lisbon, Portugal, April 14-17, 2020, Proceedings, Part II. ed. by J. M. Jose, E. Yilmaz, J. Magalhães, P. Castells, N. Ferro, M. J. Silva, and F. Martins. Vol. 12036. Lecture Notes in Computer Science. Springer, 2020, pp. 449-453. doi: 10.1007/978-3-030-45442-5_56

J J. Devezas and S. Nunes. "Hypergraph-of-entity: A unified representation model for the retrieval of text and knowledge". In: Open Computer Science 9.1 (June 2019), pp. 103-127. doi: 10.1515/comp-2019-0006

C J. Devezas and S. Nunes. "Characterizing the Hypergraph-of-Entity Representation Model". In: Complex Networks and Their Applications VIII - Volume 2 Proceedings of the Eighth International Conference on Complex Networks and Their Applications COMPLEX NETWORKS 2019, Lisbon, Portugal, December 10-12, 2019. 2019, pp. 3-14. doi: 10.1007/978-3-030-36683-4_1

C J. Devezas and S. Nunes. "Graph-of-Entity: A Model for Combined Data Representation and Retrieval". In: Proceedings of the 8th Symposium on Languages, Applications and Technologies (SLATE 2019). Vila do Conde, Portugal, 2019. doi: 10.4230/OASIcs.SLATE.2019.1

D J. Devezas and S. Nunes. Simple English Wikipedia Link Graph with Clickstream Transitions 2018-12 [dataset]. INESC TEC research data repository. Mar. 2019. doi: 10.25747/83vk-zt74

C J. L. Devezas, S. Nunes, A. Guillén, Y. Gutiérrez, and R. Muñoz. "FEUP at TREC 2018 Common Core Track - Reranking for Diversity using Hypergraph-of-Entity and Document Profiling". In: Proceedings of the Twenty-Seventh Text REtrieval Conference, TREC 2018, Gaithersburg, Maryland, USA, November 14-16, 2018. Ed. by E. M. Voorhees and A. Ellis. Vol. 500-331. NIST Special Publication. National Institute of Standards and Technology (NIST), 2018. url: https://trec.nist.gov/pubs/trec27/papers/FEUP-CC.pdf

C J. Devezas and S. Nunes. "Social Media and Information Consumption Diversity". In: Proceedings of the Second International Workshop on Recent Trends in News Information Retrieval co-located with 40th European Conference on Information Retrieval (ECIR 2018), Grenoble, France, March 26, 2018. 2018, pp. 18-23. url: http://ceur-ws.org/Vol-2079/paper5.pdf

C J. L. Devezas, C. T. Lopes, and S. Nunes. "FEUP at TREC 2017 OpenSearch Track Graph-Based Models for Entity-Oriented". In: Proceedings of The Twenty-Sixth Text REtrieval Conference, TREC 2017, Gaithersburg, Maryland, USA, November 15-17, 2017. Ed. by E. M. Voorhees and A. Ellis. Vol. 500-324. NIST Special Publication. National Institute of Standards and Technology (NIST), 2017. url: https://trec.nist.gov/pubs/trec26/papers/FEUP-O.pdf

R J. Devezas. Army ANT: A Workbench for Innovation in Entity-Oriented Search - External Option: Scientific Activities - TREC Open Search. Research rep. Faculty of Engineering, University of Porto, June 2017. url: https://hdl.handle.net/10216/110181

R J. Devezas. Auditing Open Access Repositories - Free Option: Supervised Study - Digital Archives and Libraries. Research rep. Faculty of Engineering, University of Porto, May 2017. url: https://hdl.handle.net/10216/104152

C J. Devezas and S. Nunes. "Information Extraction for Event Ranking". In: 6th Symposium on Languages, Applications and Technologies (SLATE 2017). Ed. by R. Queirós, M. Pinto, A. Simões, J. P. Leal, and M. J. Varanda. Vol. 56. OpenAccess Series in Informatics (OASIcs). Dagstuhl, Germany: Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik, 2017, 18:1-18:14. isbn: 978-3-95977-056-9. doi: 10.4230/OASIcs.SLATE.2017.18

J J. Devezas and S. Nunes. "Graph-Based Entity-Oriented Search: Imitating the Human Process of Seeking and Cross Referencing Information". In: ERCIM News. Special Issue: Digital Humanities 111 (Oct. 2017), pp. 13-14. url: https://ercim-news.ercim.eu/en111/special/graph-based-entity-oriented-search-imitating-the-human-process-of-seeking-and-cross-referencing-information

C T. Devezas, J. Devezas, and S. Nunes. "Exploring a Large News Collection Using Visualization Tools". In: Proceedings of the First International Workshop on Recent Trends in News Information Retrieval colocated with 38th European Conference on Information Retrieval (ECIR 2016), Padua, Italy, March 20, 2016. 2016, pp. 48-53. url: http://ceur-ws.org/Vol-1568/paper9.pdf

C J. L. Devezas and S. Nunes. "Index-Based Semantic Tagging for Efficient Query Interpretation". In: Experimental IR Meets Multilinguality, Multimodality, and Interaction - 7th International Conference of the CLEF Association, CLEF 2016, Évora, Portugal, September 5-8, 2016, Proceedings. Ed. by N. Fuhr, P. Quaresma, T. Gonçalves, B. Larsen, K. Balog, C. Macdonald, L. Cappellato, and N. Ferro. Vol. 9822. Lecture Notes in Computer Science. Springer, 2016, pp. 208-213. doi: 10.1007/978-3-319-44564-9_17

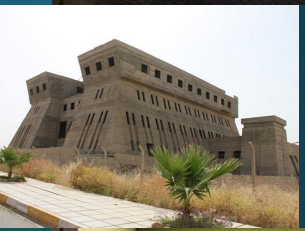
Appendix

Extra detail to aid discussion

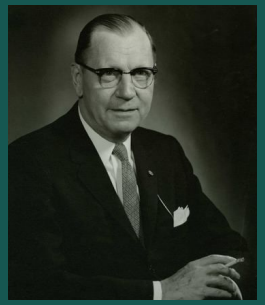
Historical perspective

For centuries, information has been organized, stored, and retrieved

- Clay tablets in Ashurbanipal
- Books in modern libraries
- Digitally encoded documents in computers
- Entities and their relations in knowledge bases



Library of Ashurbanipal (The British Museum)



Term Frequency

The weight of a term that occurs in a document is simply proportional to the term frequency.

– Hans Peter Luhn, 1957

Inverse Document Frequency

> The specificity of a term can be quantified as an inverse function of the number of documents in which it occurs.
>
> – Karen Spärck Jones, 1972

Inverted Files

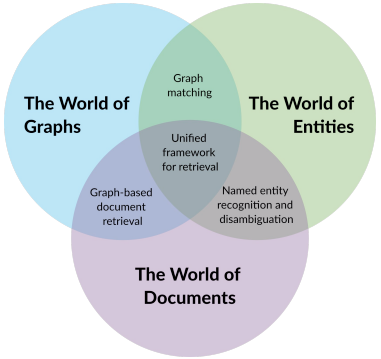
The first important class of techniques for secondary key retrieval is based on the idea of an inverted file. This does not mean that the file is turned upside down; it means that the roles of records and attributes are reversed. Instead of listing the attributes of a given record, we list the records having a given attribute.

– Donald Ervin Knuth, 1973

Consolidating models

- From physics to machine learning
  - Efforts to unify theories and models
- Towards general approaches to IR
  - Identifying commonalities along the pipeline and tasks
- Graphs as general representation models
  - Combining all available information sources
- Unified framework for IR
  - Solving the information need is the only task

Three axes covered



Classical models

- Virtual documents
- Triplestores
- Combined signals (single task or chained tasks)
- Joint indexing of text and triples (very few contributions)

Learning to rank

- Entity profiles represented as virtual documents
- Entity features
- Joint learning of word and entity representations

Graph-based models

- Link analysis
- Text as a graph
- Knowledge graphs
- Entity graph from text
- Entity graph as a tensor
- Graph matching
- Hypergraph-based
- Random walk based

Classical models

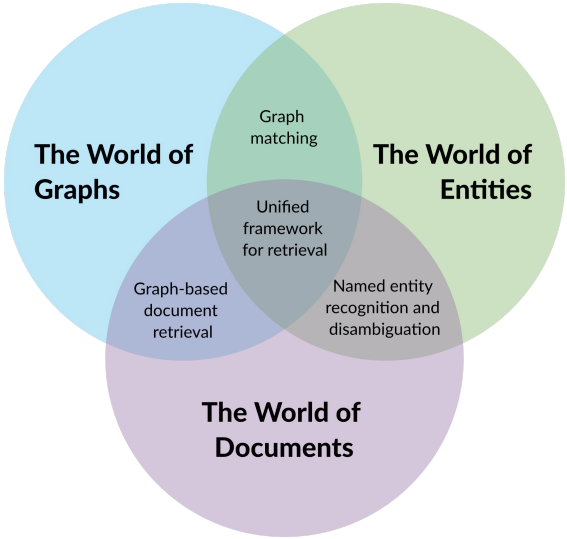
- Ranking
  - From TF-IDF
  - To Markov networks
- Representation
  - Virtual documents
  - Triplestores
- Hybrid approaches
  - Combined signals (single task or chained tasks)
  - Joint indexing of text and triples (very few contributions)

Learning-to-rank models

- Entity ranking based on:
  - Entity features
    - Text features from the Wikipedia article
    - Graph features from the knowledge graph
  - Entity profiles represented as virtual documents
    - “Flattened” data from RDF
    - Passages of text mentioning the entity
- Joint learning of representations for words and entities

Graph-based models

- Link analysis
- Text as a graph
- Knowledge graphs
- Entity graph from text
- Entity graph as a tensor
- Graph matching
- Hypergraph-based
- Random walk based



Anchor / core references

Title:
Entity-Oriented Search

Authors:
K. Balog

Year:
2018

DOI:
10.1007/978-3-319-93935-3

- First complete reference in the area
- Clear definitions of fundamental concepts
- Identification of tasks and applications
- Provides a compilation and a convergence of information

Anchor / core references

Title:
Concordance-Based Entity-Oriented Search

Authors:
M. Bautin and S. Skiena

Year:
2007

DOI:
10.1109/WI.2007.84

- Analyzes the presence of entities in queries (based on AOL query log):
  - 18-39% queries directly reference entities
  - 73-87% queries contain at least one entity
- "First-in-literature" implementation of an entity search engine
- Archetype for approaches based on virtual documents

Anchor / core references

Title:
Ad-hoc object retrieval in the web of data

Authors:
J. Pound, P. Mika, and H. Zaragoza

Year:
2010

DOI:
10.1145/1772690.1772769

Five query categories for ad hoc entity retrieval:

- Entity query
- Type query
- Attribute query
- Relation query
- Keyword query

Applied to the ANT search engine

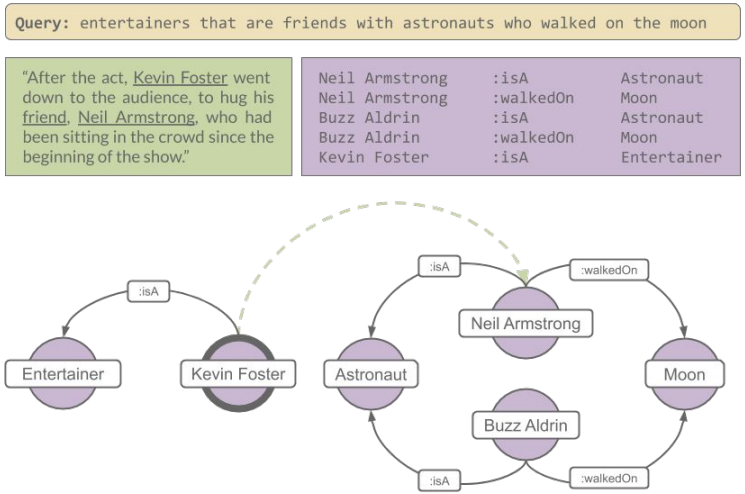
Anchor / core references

Title:
An Index for Efficient Semantic Full-text Search

Authors:
H. Bast and B. Buchhold

Year:
2013

DOI:
10.1145/2505515.2505689



Anchor / core references

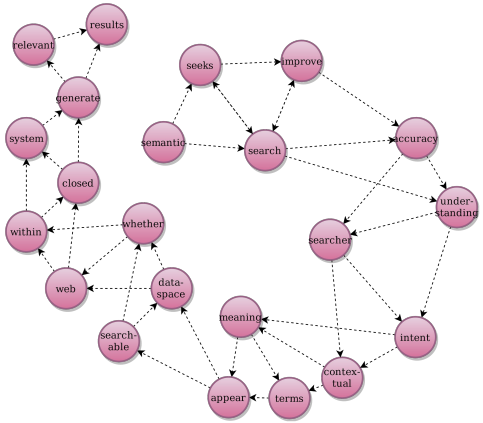
Title:
Graph-of-word and TW-IDF: new approach to ad hoc IR

Authors:
F. Rousseau and M. Vazirgiannis

Year:
2013

DOI:
10.1145/2505515.2505671

- Nodes represent terms
- Edges represent following terms within a window of size N
- TW is given by the indegree



Anchor / core references

Title:
Modeling Higher-order Term Dependencies in Information Retrieval Using Query Hypergraphs

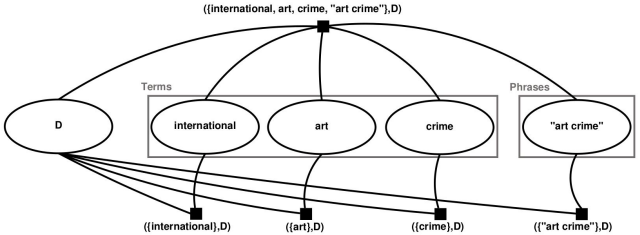
Authors:
M. Bendersky and W. B. Croft

Year:
2012

DOI:
10.1145/2348283.2348408

Query hypergraph model

- Log-linear retrieval model
- Solved through a factor graph
- Similar to Markov networks
- But captures higher-order relations (e.g., bigrams, named entities)



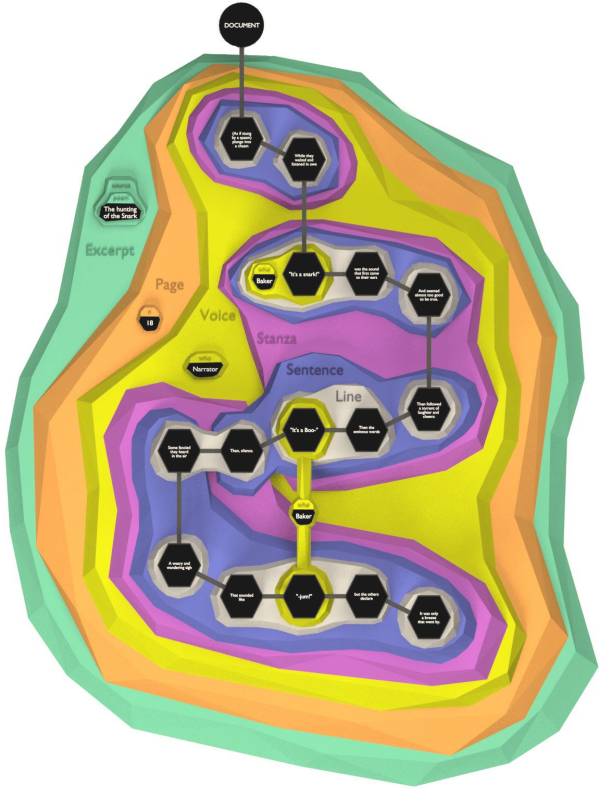
Anchor / core references

Title:
It's more than just overlap: Text As Graph

Authors:
R. Haentjens Dekker and D. J. Birnbaum

Year:
2017

DOI:
10.4242/BalisageVol19.Dekker01



COMBINED DATA

Combined data is a collection of corpora and knowledge bases, which includes not only the natural relations between documents (e.g., hyperlinks in the web), and entities (e.g., object properties in triplestores), but also cross-context relations, from mentions found in documents to entities in knowledge bases, and from entities found in knowledge bases to instances of the same entity in other knowledge bases.

THESIS STATEMENT

A graph-based joint representation of unstructured and structured data has the potential to unlock novel ranking strategies, that are, in turn, able to support the generalization of entity-oriented search tasks and to improve overall retrieval effectiveness by incorporating explicit and implicit information derived from the relations between text found in corpora and entities found in knowledge bases.

THESIS STATEMENT

A graph-based joint representation of unstructured and structured data has the potential to unlock novel ranking strategies, that are, in turn, able to support the generalization of entity-oriented search tasks and to improve overall retrieval effectiveness by incorporating explicit and implicit information derived from the relations between text found in corpora and entities found in knowledge bases.

Test collections

INEX 2009 Wikipedia collection

- 2.6M XML documents
- 2010 Ad Hoc track
  - Document ranking
- 2009 XER track
  - Entity ranking
  - List completion

TREC Washington Post Corpus

- 595K JSON documents
- 2018 Common Core track

Social Science Open Access Repository

- 32K JSON documents
- 2017 OpenSearch track
- Team-draft interleaving

Contributed datasets

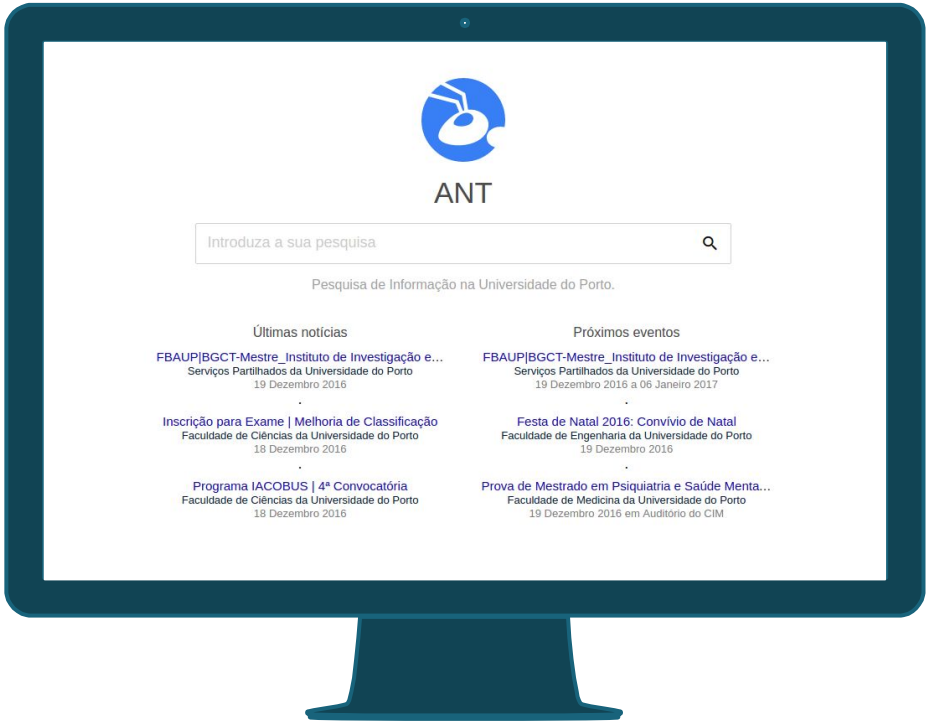
Simple English Wikipedia Link Graph with Clickstream Transitions 2018-12

DOI: 10.25747/83vk-zt74

ANT

Entity-oriented search engine for the University of Porto

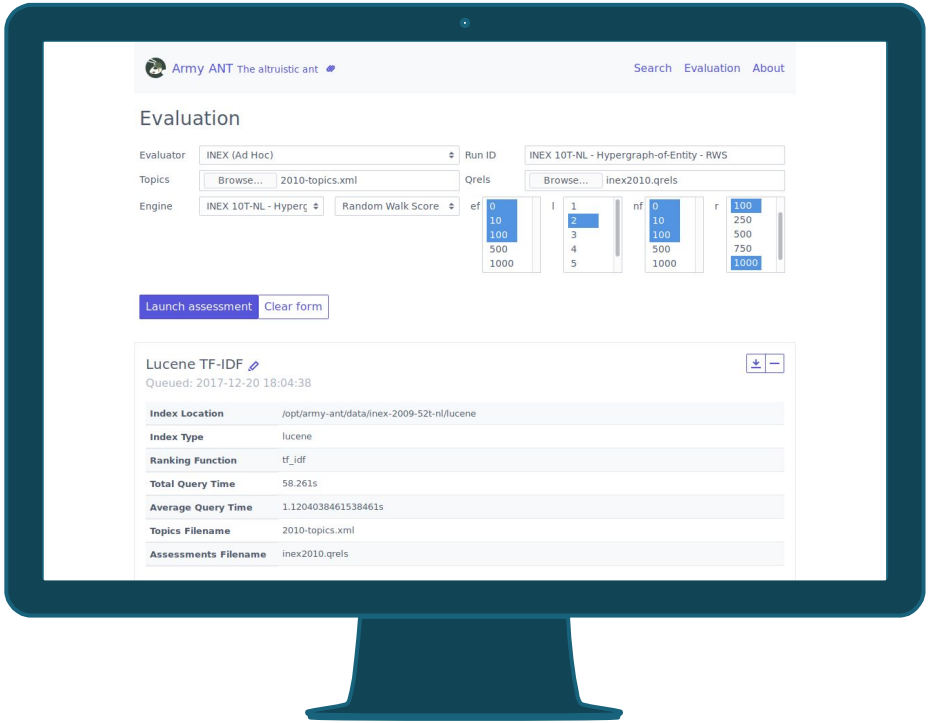
- Working prototype (https://ant.fe.up.pt)
- Exposure to ~1,000 weekly users
- Manifested interest by some of the faculty's content managers



Army ANT

Workbench for innovation in entity-oriented search

- Promotes freedom and exploration
- Supports IR research in a flexible way
- Available at GitHub
  (https://github.com/feup-infolab/army-ant)



Hypergraph-of-entity: characterization

Basic statistics over time (i.e., as the index grows):

- Number of nodes and hyperedges per type and direction
- Node-based and hyperedge-based degree distributions
- Hyperedge cardinality distribution
- Clustering coefficient
- Average path length & diameter
- Density

- Shortest distances computed based on random walks
- Two-node clustering coefficients
  - Based on a set of sampled nodes
  - And a large sample of their neighbors
- Density based on a corresponding bipartite graph
  - Hyperedge-cardinality notation recognized as useful by the community

$$D = \frac{2\sum_k k|E_U^k| + \sum_{k_1,k_2}(k_1+k_2)|E_D^{k_1,k_2}|}{2(n+m)(n+m-1)}$$

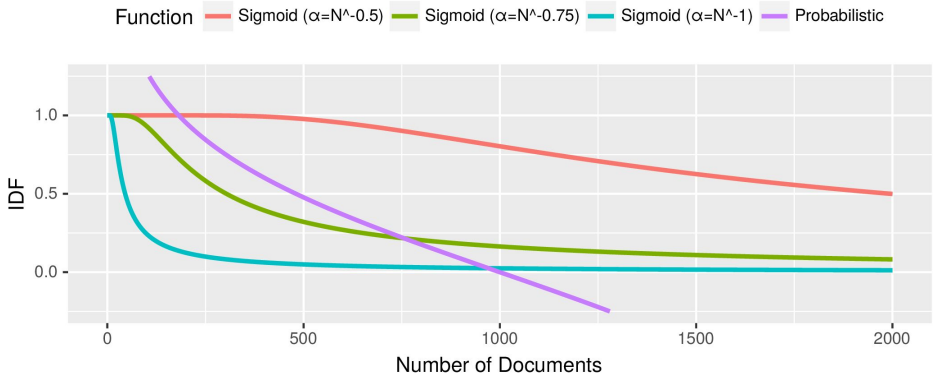
Hypergraph-of-entity: joint representation model

Extensions: weights

Table 7.2: Hypergraph-of-entity weighting functions.

(a) Nodes.

Node / Weight	Description
term $2S\left(\alpha\frac{N-n_t}{n_t}\right)-1$	We used a variation of the IDF, with a tunable $\alpha < 1$ parameter to control how fast the function decreases. - S is the sigmoid function - N is the number of documents in the collection - n_t is the number of documents where a given term t occurs. - We used $\alpha = N^{-0.75}$.
entity Same as *term*.	In the future, we will experiment with different values of α for terms and entities, in particular alternative exponents to -0.75.



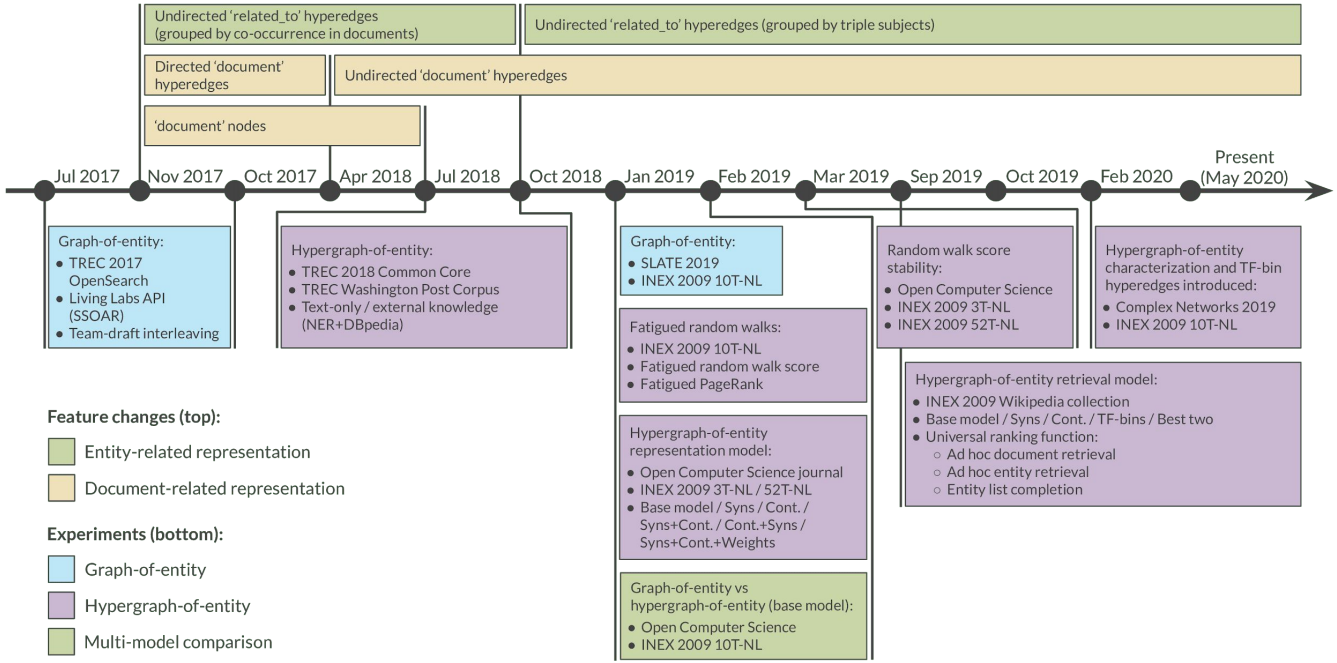
Hypergraph-of-entity: joint representation model

Extensions: weights

(b) Hyperedges.

Hyperedge / Weight	Description
document 0.5	Linking a term or entity simply through document co-occurrence is weak, so we use a constant weight lower than one.
related_to $\frac{1}{\lvert e_r \rvert} \sum_{v \in e_r} \frac{\lvert \{u \in e'_r : e'_r \in E_r \setminus \{e_r\} \wedge v \in e'_r\} \rvert}{\lvert e_r \rvert}$	For each entity within the hyperedge, we calculate the fraction of reachable other entities and average all results. - E_r is the set of all *related_to* hyperedges. - $e_r \in E_r$ is the specific *related_to* hyperedge, for which we are calculating the weight.
contained_in $\frac{1}{\lvert t \rvert}$	Links with fewer terms t, where t refers to the tail set in $(t, h) \in E_c \wedge t \subseteq V_t$, should be more frequently followed, since the certainty that the hyperedge leads to the entity is higher.
synonym $\frac{1}{\lvert e_s \rvert}$	The higher the number of possible synonyms $e_s \in E_s \wedge e_s \subseteq V_t$, the less certain we are about the hyperedge — we rely on the synonyms of the first (and most probable) sense according to WordNet.
context $\frac{1}{\lvert e_x \rvert} \sum_{t_i \in e_x \setminus \{t_k\}} \frac{\text{sim}(t_k, t_i) - \text{min}_{\text{sim}}}{1 - \text{min}_{\text{sim}}}$	A context $e_x \in E_x$ is only as good as the average of all similarities between the original term $t_k \in e_x$ and all other terms $t_i \in e_x \setminus \{t_k\}$. We normalize the weight taking into account the threshold used to create the word2vec SimNet.

Evaluation: experimentation timeline



Evaluation: main experiments (pt. 2)

Rank stability:

- Average Kendall's coefficient of concordance
  - Over 100 similar runs per configuration
  - For different values of ℓ and r
- For $\ell \in \{2, 3, 4\}$:
  - 84–90% stable for r=100
  - 94–97% stable for r=1,000
  - 99% stable for r=10,000

Evaluation: INEX 2009 Wikipedia collection

Three subsets:

- INEX 2009 3T-NL (2.2k docs)
- INEX 2009 10T-NL (7.5k docs)
- INEX 2009 52T-NL (37.8k docs)

Created through:

- Random sampling of n topics
- Retained relevance judgments for selected topics
- Retained only judged documents

However:

- Exclusively for assessing ad hoc document retrieval
- Based on the qrels for the 2010 Ad Hoc track
- Goal: eventually index the full collection
- Challenge: scalability

Discussion

Ad hoc document retrieval

- Best MAP: **0.1689** (vs 0.1710 TF-IDF)
  - Base model
  - INEX 2009 10T-NL
  - ℓ=2, r=10,000, exp.=true
- Best P@10: **0.2692** (vs 0.0692 TF-IDF)
  - Synonyms+Context model
  - INEX 2009 full collection
  - ℓ=2, r=10,000, exp.=false

Note: In bold the best scores for the hypergraph-of-entity; in parenthesis the baseline result of Lucene TF-IDF for the same experiment.

Discussion

Ad hoc entity retrieval

- Best MAP: **0.1390** (vs 0.0373 TF-IDF)
  - Base model
  - INEX 2009 full collection
  - ℓ=2, r=10,000, exp.=false
- Best P@10: **0.2509** (vs 0.0636 TF-IDF)
  - Synonyms+Context model
  - INEX 2009 full collection
  - ℓ=2, r=10,000, exp.=false

Entity list completion

- Best MAP: **0.0884** (vs 0.0558 TF-IDF)
  - Synonyms+Context model
  - INEX 2009 full collection
  - ℓ=2, r=10,000, exp.=false
- Best P@10: **0.0788** (vs 0.1000 TF-IDF)
  - Synonyms+Context model
  - INEX 2009 full collection
  - ℓ=2, r=10,000, exp.=false

Note: In bold the best scores for the hypergraph-of-entity; in parenthesis the baseline result of Lucene TF-IDF for the same experiment.