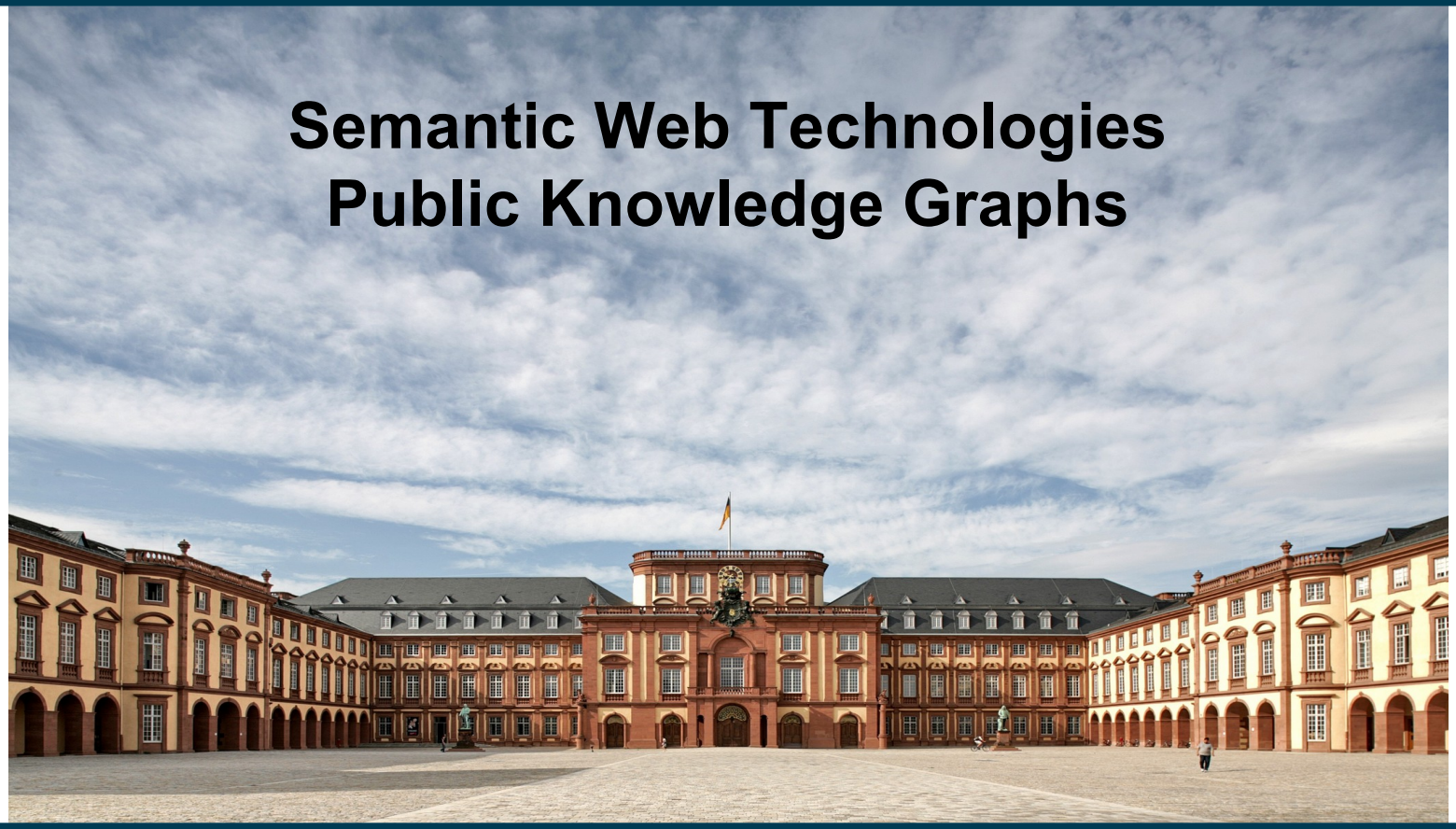
UNIVERSITÄT MANNHEIM

Semantic Web Technologies
Public Knowledge Graphs



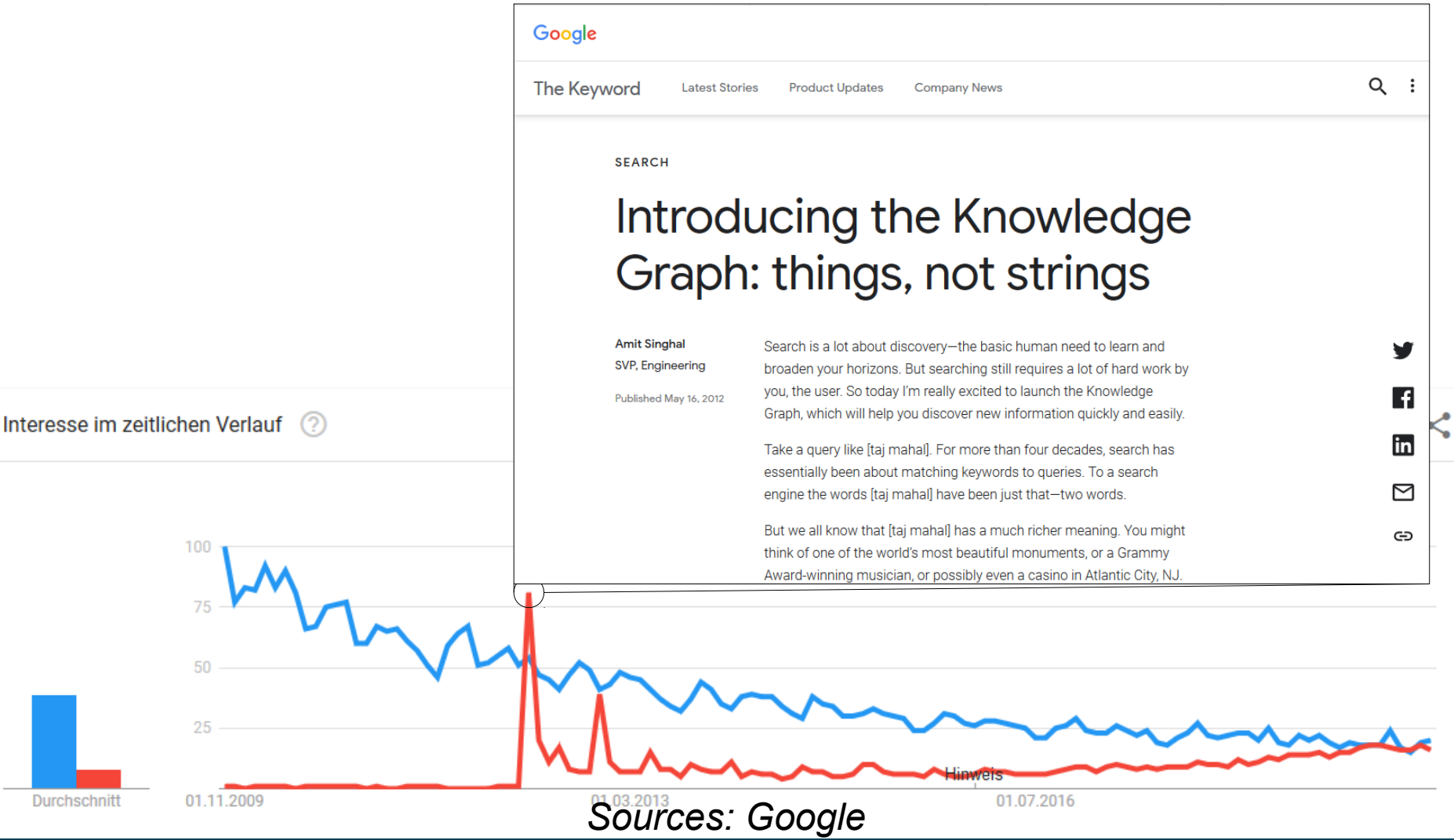
Heiko Paulheim

Previously on “Semantic Web Technologies”

- Linked Open Data
  - We know the principles
  - We have seen examples for some datasets

- Today
  - A closer look on actual examples
  - Some useful, large-scale resources

Growing Interest in Knowledge Graphs



Sources: Google

Introduction

- Knowledge Graphs on the Web
- Everybody talks about them, but what *is* a Knowledge Graph?
  - I don't have a definition either...

Journal Paper Review, (Natasha Noy, Google, June 2015):
"Please define what a knowledge graph is – and what it is not."

Definitions

- *Knowledge graphs could be envisaged as a network of all kind things which are relevant to a specific domain or to an organization. They are not limited to abstract concepts and relations but can also contain instances of things like documents and datasets.*
  (Blumauer, 2014)
- *We define a Knowledge Graph as an RDF graph.*
  (Färber and Rettinger, 2015)
- *Knowledge graphs are large networks of entities, their semantic types, properties, and relationships between entities.*
  (Kroetsch and Weikum, 2016)
- *[...] systems exist, [...], which use a variety of techniques to extract new knowledge, in the form of facts, from the web. These facts are interrelated, and hence, recently this extracted knowledge has been referred to as a knowledge graph.*
  (Pujara et al., 2013)

Ehrlinger and Wöß: Towards a Definition of Knowledge Graphs. 2016

Definitions

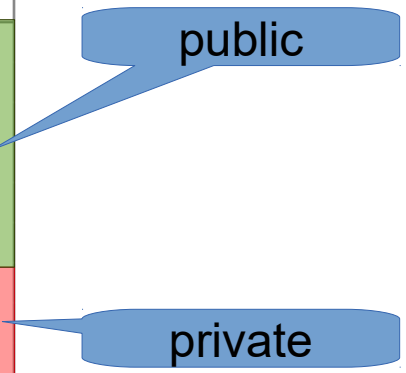
- My working definition: a Knowledge Graph
  - *mainly* describes instances and their relations in a graph
    - Unlike an ontology
    - Unlike, e.g., WordNet
  - Defines possible classes and relations in a *schema* or *ontology*
    - Unlike schema-free output of some IE tools
  - Allows for interlinking *arbitrary* entities with each other
    - Unlike a relational database
  - Covers *various* domains
    - Unlike, e.g., Geonames

Paulheim: Knowledge graph refinement:
A survey of approaches and evaluation methods, 2017.

Introduction

- Knowledge Graphs out there (not guaranteed to be complete)

Name	Instances	Facts	Types	Relations
DBpedia (English)	4,806,150	176,043,129	735	2,813
YAGO	4,595,906	25,946,870	488,469	77
Freebase	49,947,845	3,041,722,635	26,507	37,781
Wikidata	15,602,060	65,993,797	23,157	1,673
NELL	2,006,896	432,845	285	425
OpenCyc	118,499	2,413,894	45,153	18,526
Google's Knowledge Graph	570,000,000	18,000,000,000	1,500	35,000
Google's Knowledge Vault	45,000,000	271,000,000	1,100	4,469
Yahoo! Knowledge Graph	3,443,743	1,391,054,990	250	800

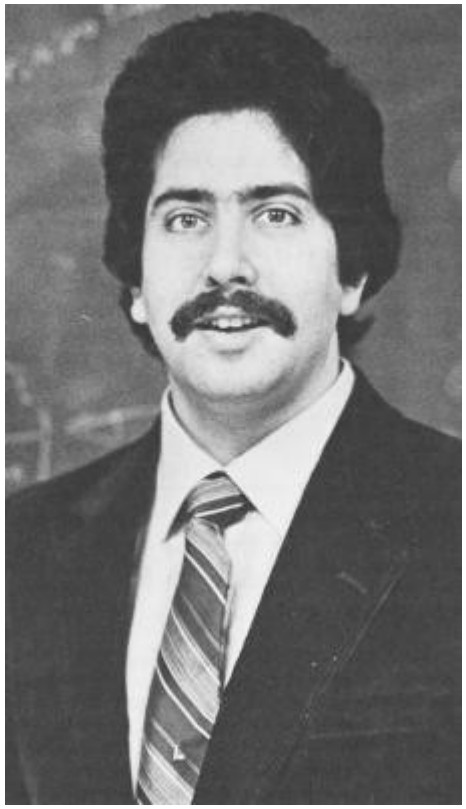


Paulheim: *Knowledge graph refinement: A survey of approaches and evaluation methods.* Semantic Web 8:3 (2017), pp. 489-508

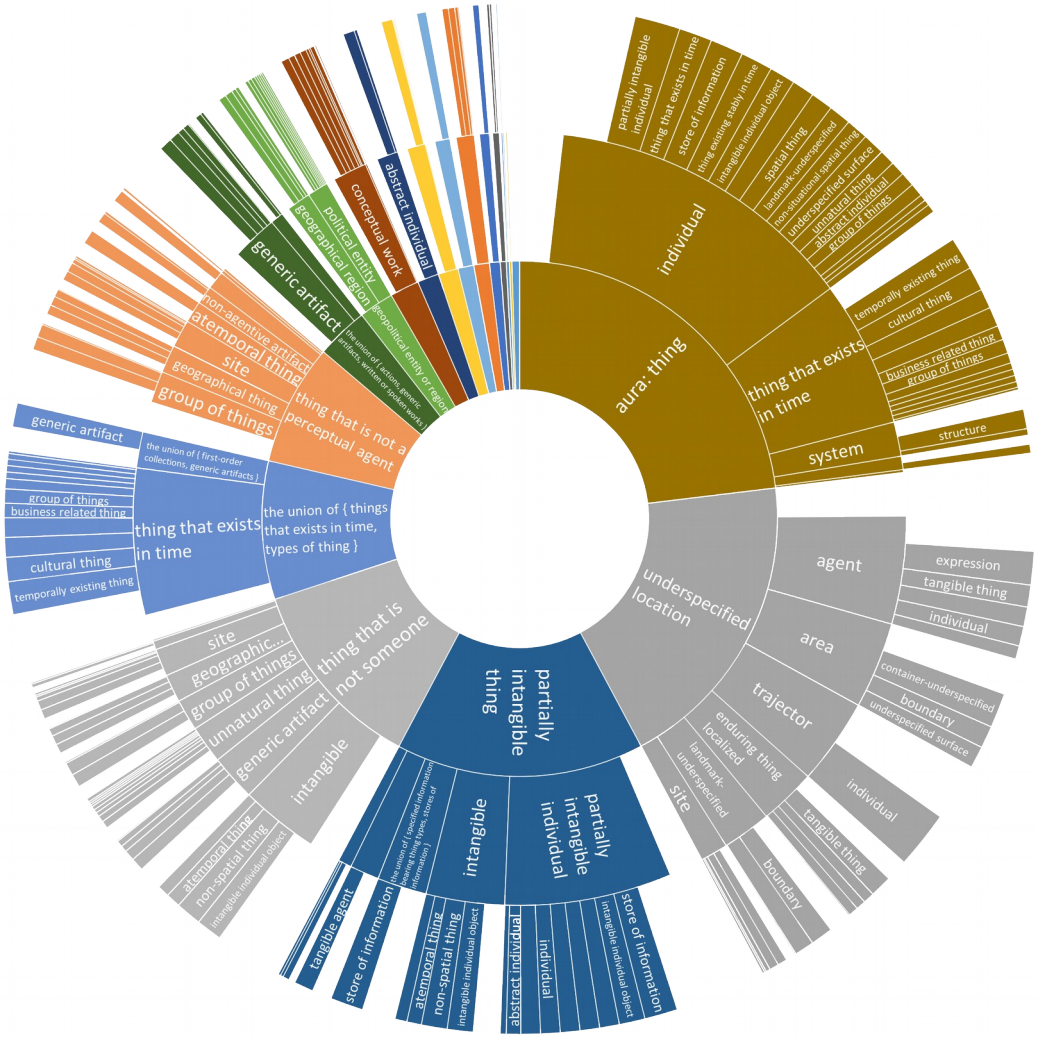
Knowledge Graph Creation: CyC

- The beginning
  - Encyclopedic collection of knowledge
  - Started by Douglas Lenat in 1984
  - Estimation: 350 person years and 250,000 rules should do the job of collecting the essence of the world's knowledge

- The present (as of June 2017)
  - ~1,000 person years, $120M total development cost
  - 21M axioms and rules
  - Used to exist until 2017

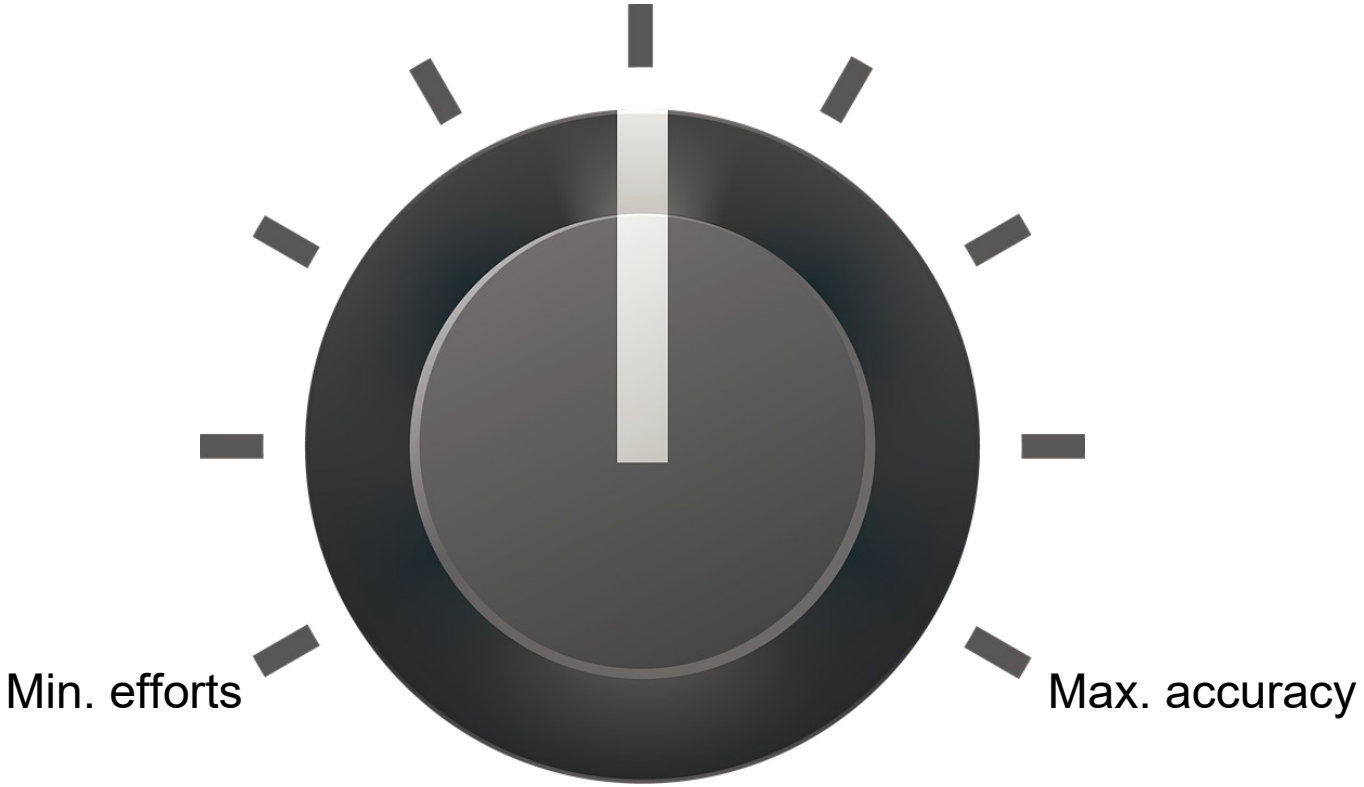


Knowledge Graph Creation: CyC



Knowledge Graph Creation

- Lesson learned no. 1:
  - Trading efforts against accuracy



Knowledge Graph Creation: Freebase

- The 2000s
  - Freebase: collaborative editing
  - Schema not fixed

- Present
  - Acquired by Google in 2010
  - Powered first version of Google's Knowledge Graph
  - Shut down in 2016
  - Partly lives on in Wikidata (see in a minute)

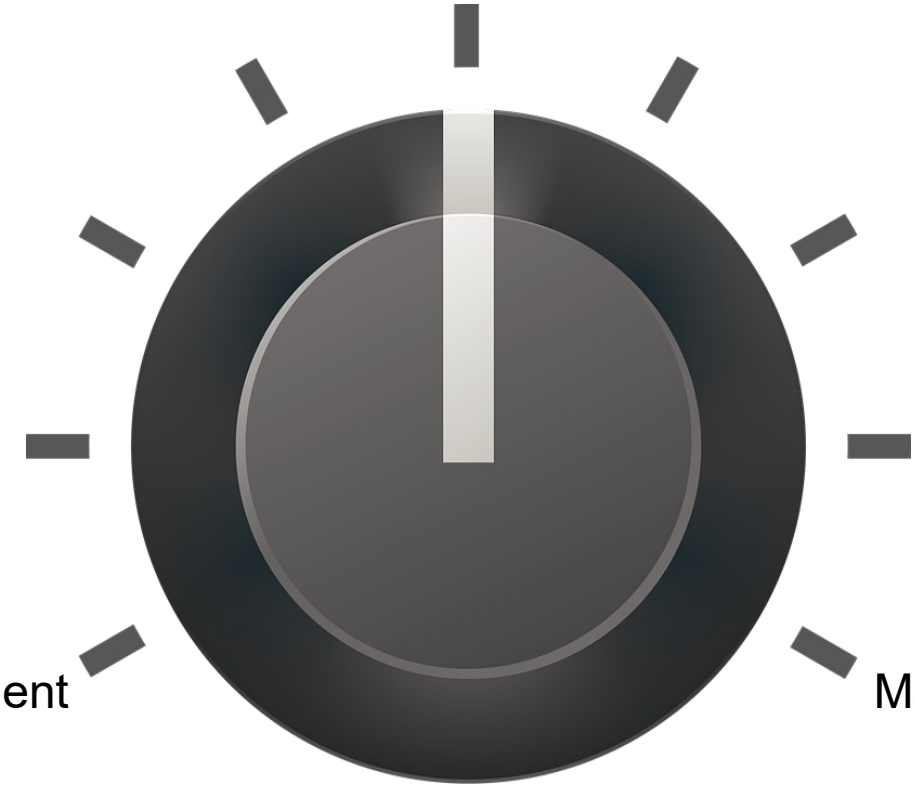
coming up soon:
was it a good deal or not?

Knowledge Graph Creation: Freebase

- Community based
- Like Wikipedia, but more structured

Knowledge Graph Creation

- Lesson learned no. 2:
  - Trading formality against number of users



Max. user involvement

Max. degree of formality

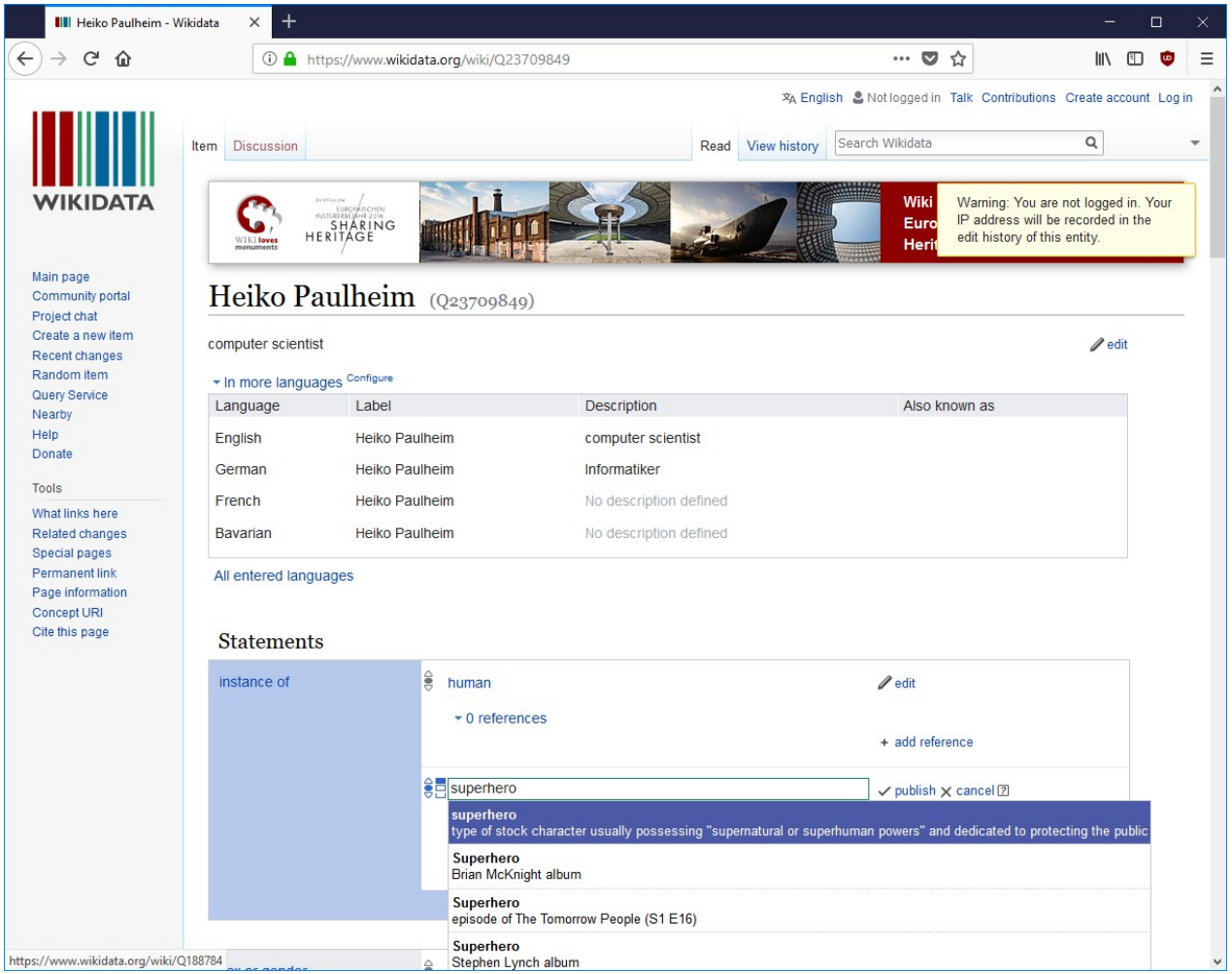
Knowledge Graph Creation: Wikidata

- The 2010s
  - Wikidata: launched 2012
  - Goal: centralize data from Wikipedia languages
  - Collaborative
  - Imports other datasets

- Present
  - One of the largest public knowledge graphs (see later)
  - Includes rich provenance

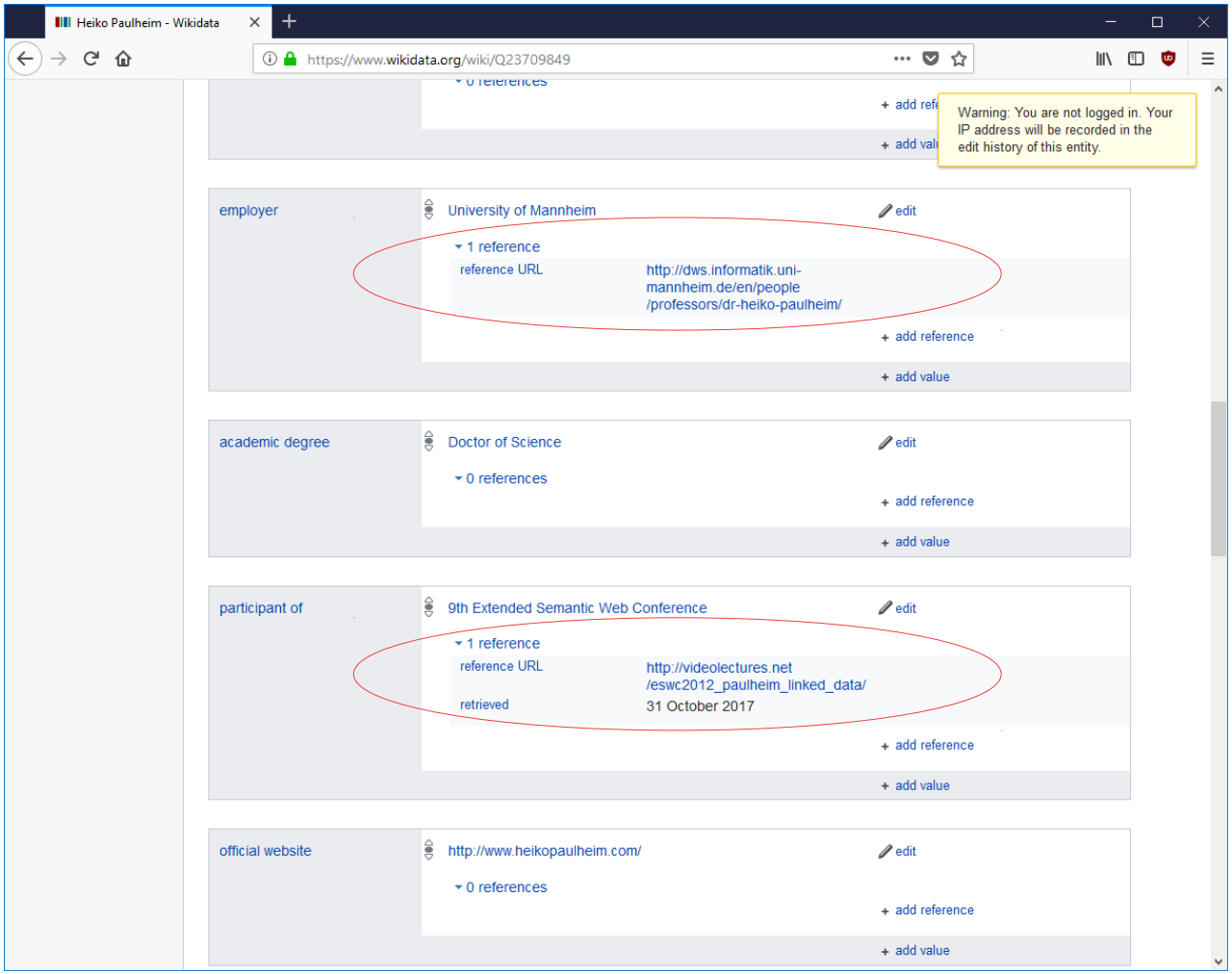
Knowledge Graph Creation: Wikidata

- Collaborative editing

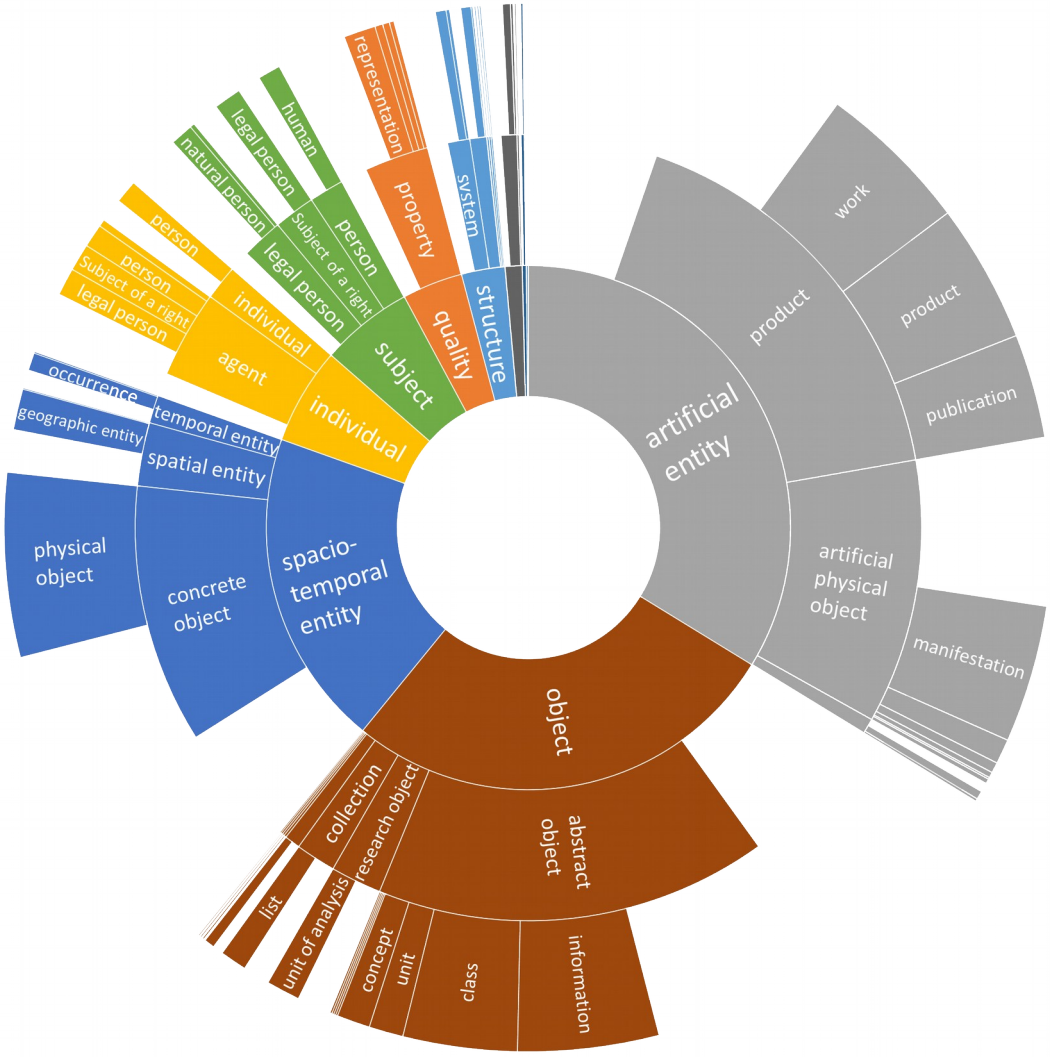


Knowledge Graph Creation: Wikidata

- Provenance

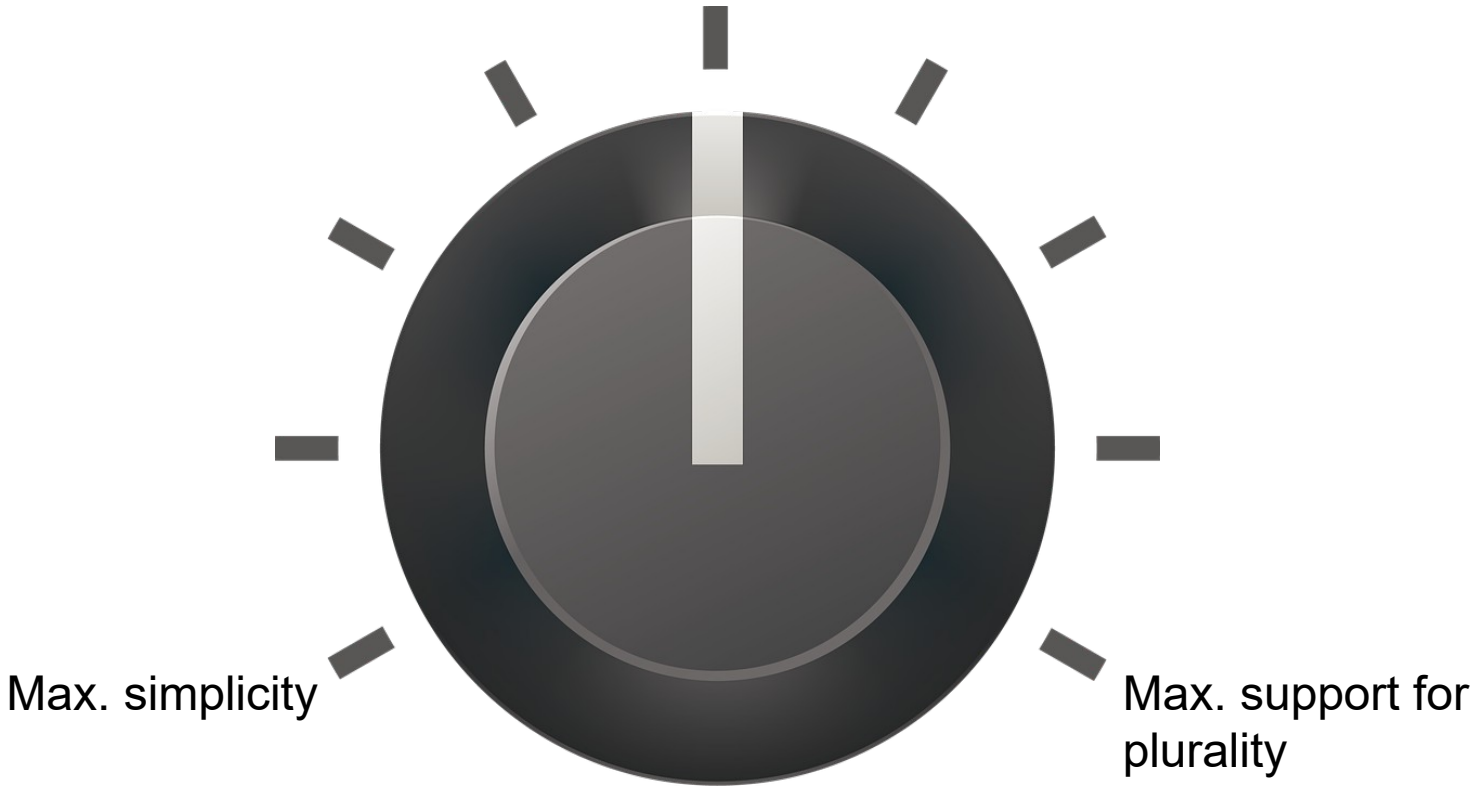


Wikidata


artificial entity
product
work
product
publication
artificial physical object
manifestation
object
abstract object
collection
research object
list
unit of analysis
concept
unit
class
information
spacio-temporal entity
physical object
concrete object
spatial entity
occurrence
geographic entity
temporal entity
agent
individual
person
person
Subject of a right
legal person
individual
subject
person
Subject of a right
legal person
natural person
legal person
human
quality
property
representation
structure
system

Knowledge Graph Creation

- Lesson learned no. 3:
  - There is not one truth (but allowing for plurality adds complexity)

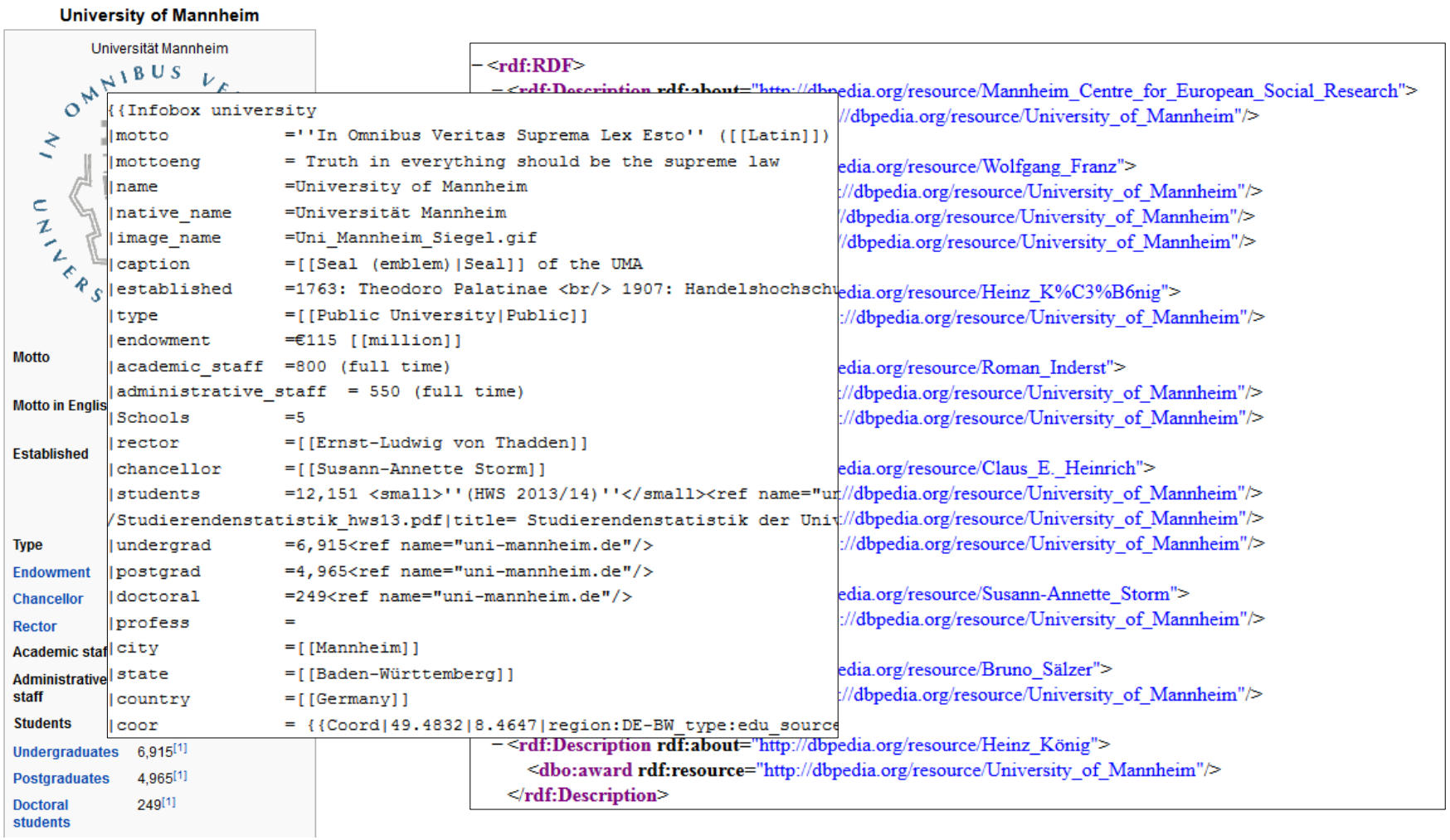


Knowledge Graph Creation: DBpedia & YAGO

- The 2010s
  - DBpedia: launched 2007
  - YAGO: launched 2008
  - Extraction from Wikipedia using mappings & heuristics

- Present
  - Two of the most used knowledge graphs
  - ...with Wikidata catching up

DBpedia


University of Mannheim
Universität Mannheim
IN OMNIBUS VE
UNIVERS
Motto
Motto in Englis
Established
Type
Endowment
Chancellor
Rector
Academic staf
Administrative staff
Students
Undergraduates 6,915[1]
Postgraduates 4,965[1]
Doctoral students 249[1]
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 1907: Handelshochschu
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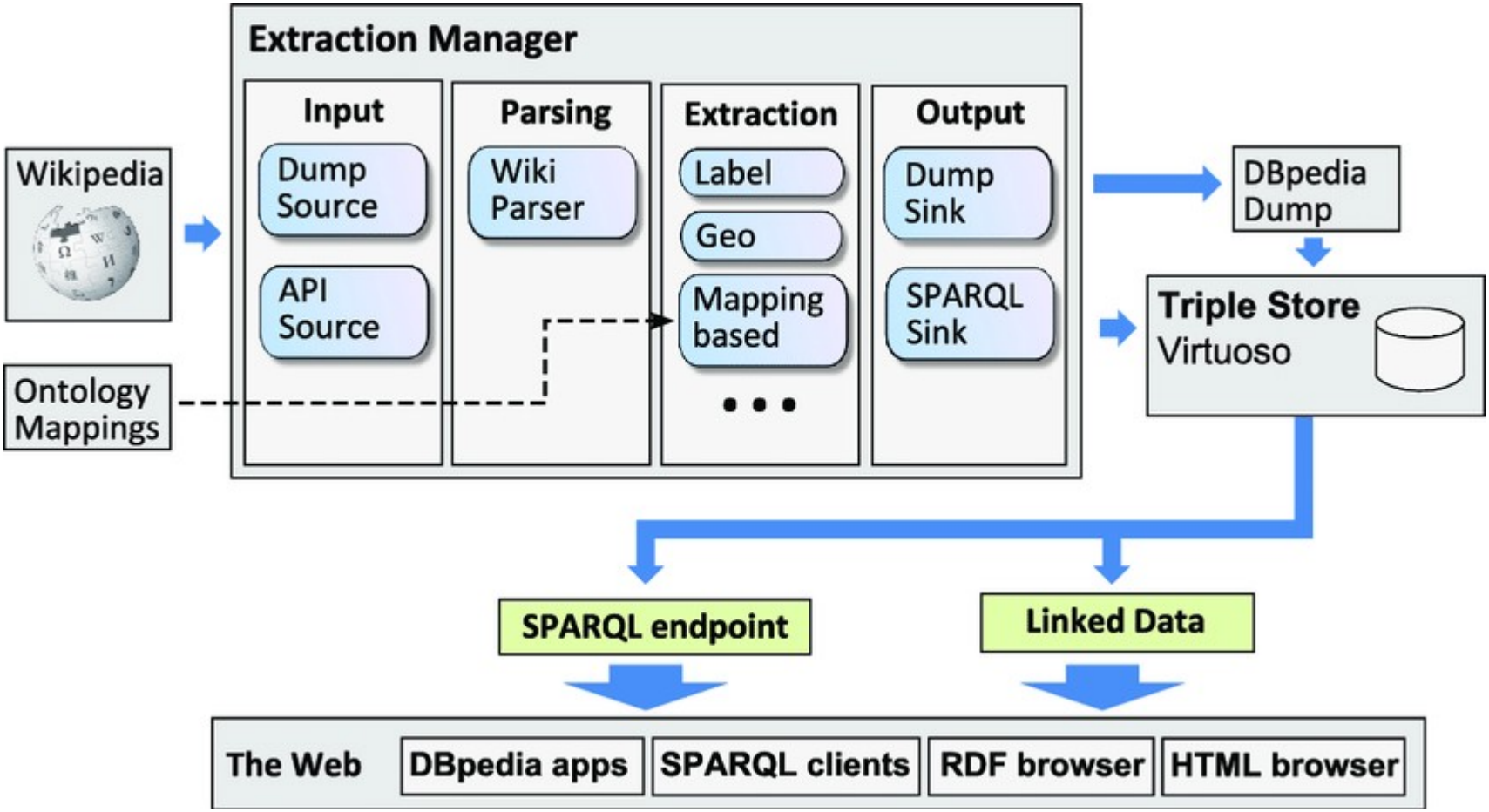
DBpedia



Lehmann et al.: *DBpedia – A Large-scale, Multilingual Knowledge Base Extracted from Wikipedia.* 2014

DBpedia

Mapping en:Infobox film

This is the mapping for the Wikipedia template Infobox film. Find usages of this Wikipedia template here.

Test this mapping (or in namespace File or Creator) with some example Wikipedia pages. Check which prop

Read more about mapping Wikipedia templates.

Template Mapping (help)	
map to class	Film

Mappings

Property Mapping (help)	
template property	director
ontology property	director

Property Mapping (help)	
template property	producer
ontology property	producer

OntologyClass:Film

This is the definition of an ontology class.

Show all properties available for this class.

Show class in class hierarchy.

Read more about editing the ontology schema.

You can see the result of your edit on DBpedia Live (this is

Ontology class (help)	
rdfs:label (en)	film
rdfs:label (en)	movie
rdfs:label (nl)	film
rdfs:label (da)	film
rdfs:label (de)	Film
rdfs:label (el)	ταινία
rdfs:label (fr)	film
rdfs:label (ko)	영화
rdfs:label (ja)	映画
rdfs:label (ar)	فيلم
rdfs:label (pl)	film
rdfs:label (ga)	scannán
rdfs:label (es)	película
rdfs:subClassOf	Work
owl:equivalentClass	schema:Movie, wikidata:Q11424
owl:disjointWith	

OntologyProperty:director

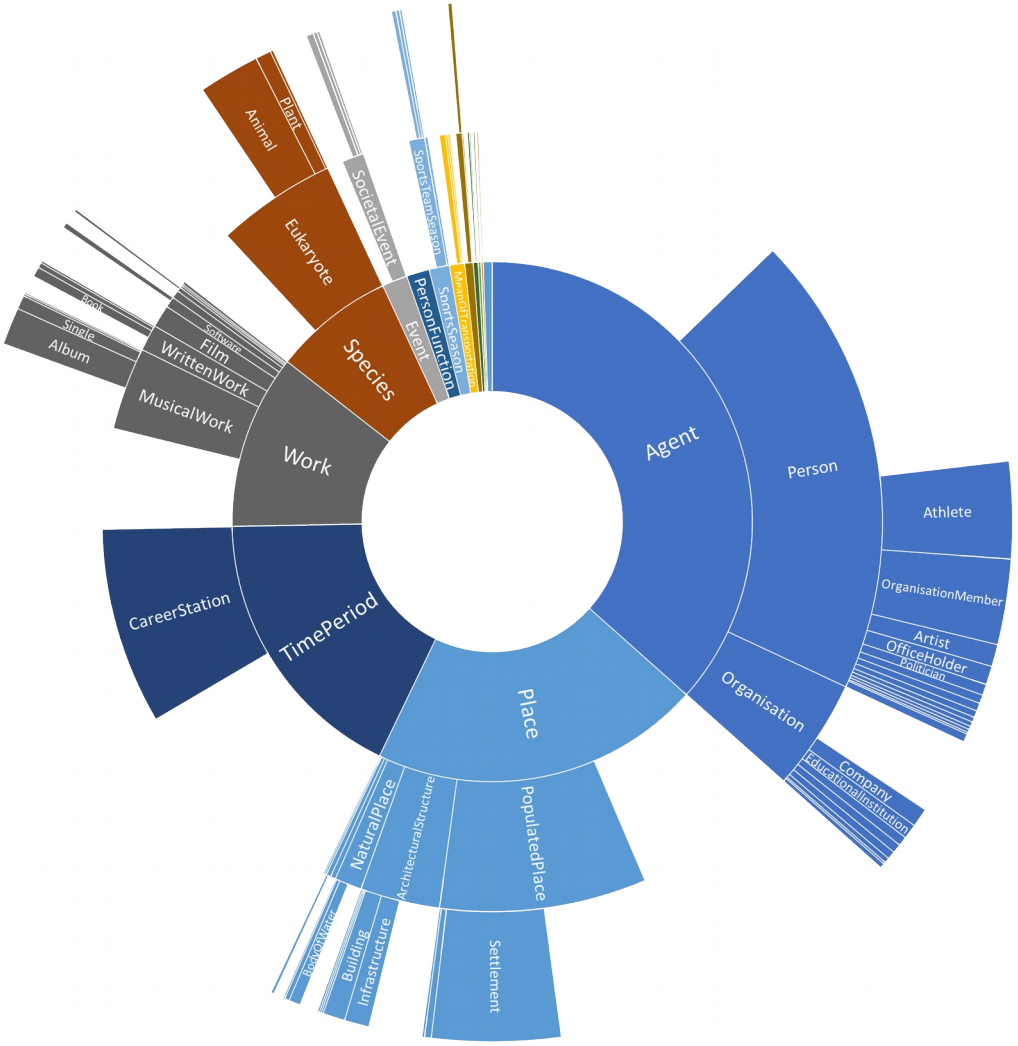
This is the definition of an ontology property.

Read more about editing the ontology schema.

You can see the result of your edit on DBpedia Live (this is BETA!).

Ontology object property (help)	
rdfs:label (en)	director
rdfs:label (en)	film director
rdfs:label (nl)	regisseur
rdfs:label (da)	instruktør
rdfs:label (de)	regisseur
rdfs:label (ru)	директор
rdfs:label (el)	σκηνοθέτης
rdfs:label (es)	director de cine
rdfs:label (fr)	réalisateur
rdfs:comment (en)	A film director is a person who directs the making of a film.[1]
rdfs:comment (fr)	Un réalisateur (au féminin, réalisatrice) est une personne qui dirige la fabrication d'une œuvre audi cinéma ou la télévision.[2]
rdfs:domain	Film
rdfs:range	Person
rdf:type	
rdfs:subPropertyOf	dul:coparticipatesWith
owl:equivalentProperty	schema:director, wikidata:P57
owl:propertyDisjointWith	

DBpedia


Agent
Person
Athlete
OrganisationMember
Artist
OfficeHolder
Politician
Organisation
Company
EducationalInstitution
Place
PopulatedPlace
Settlement
NaturalPlace
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BodyOfWater
BuildingInfrastructure
TimePeriod
CareerStation
Work
MusicalWork
Album
Single
Book
WrittenWork
Film
Software
Species
Eukaryote
Animal
Plant
Event
SocietalEvent
PersonFunction
SportsSeason
MeanOfTransportation
SportsTeamSeason

YAGO

- Wikipedia categories for types
  - Plus WordNet as upper structure
- Manual mappings for properties

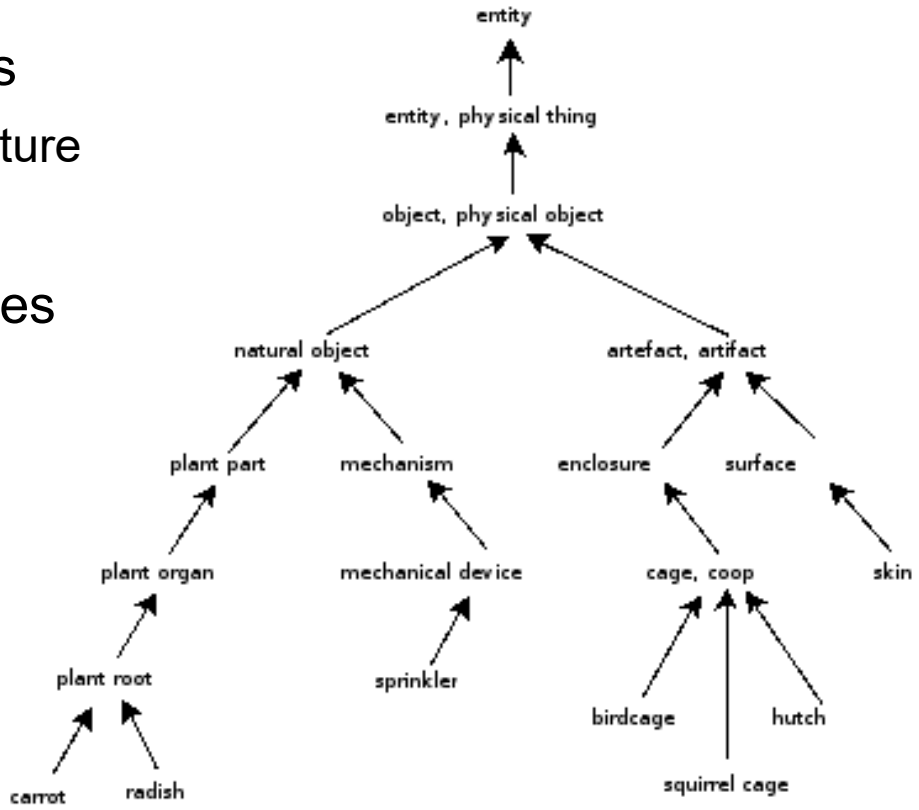
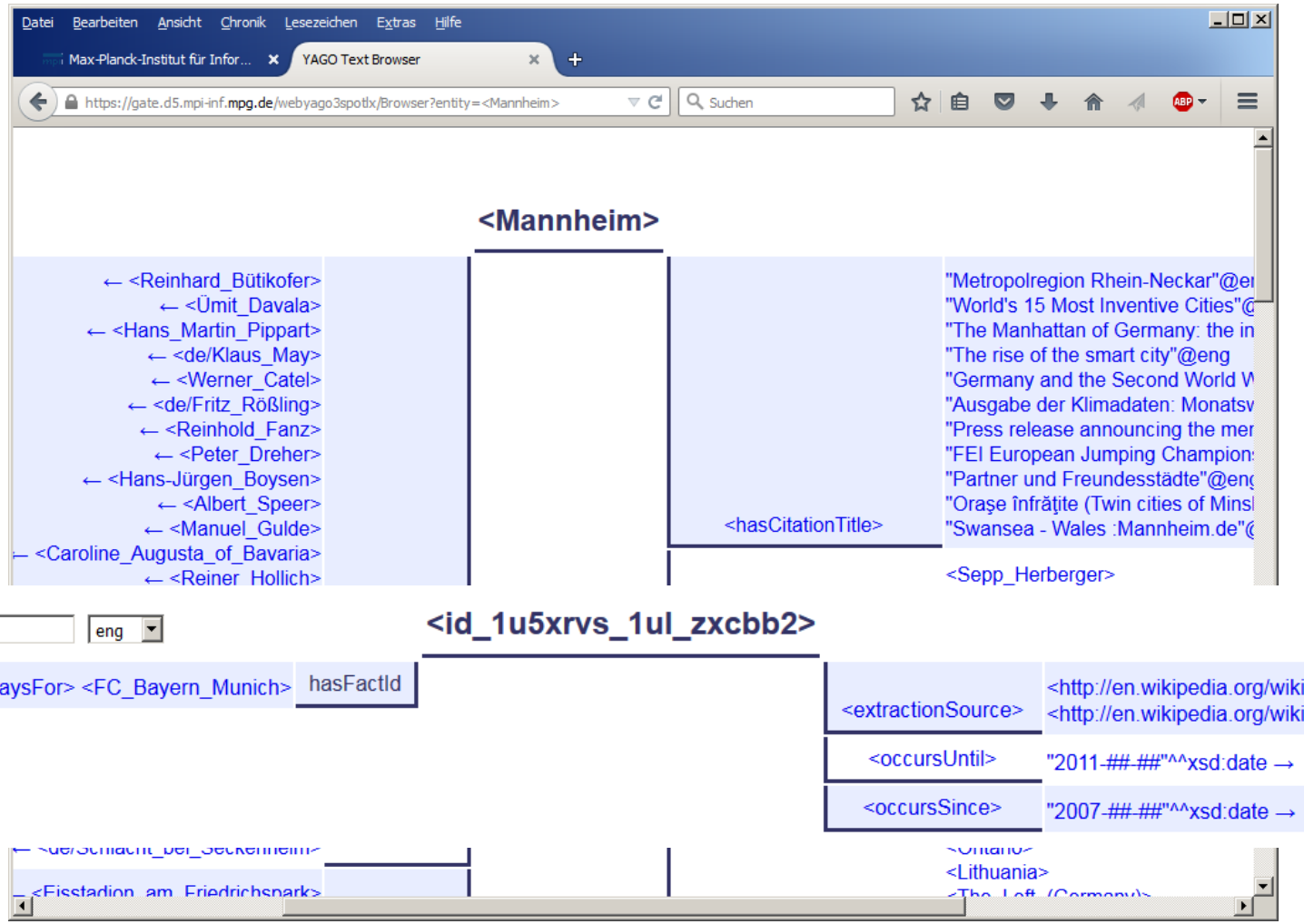


Figure 1. "is a" relation example

https://www.cs.princeton.edu/courses/archive/spring07/cos226/assignments/wordnet.html

YAGO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Max-Planck-Institut für Infor...
YAGO Text Browser
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Suchen
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← <Reinhard_Bütikofer>
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← <de/Fritz_Rößling>
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"The rise of the smart city"@eng
"Germany and the Second World W
"Ausgabe der Klimadaten: Monatsv
"Press release announcing the mer
"FEI European Jumping Champion
"Partner und Freundesstädte"@eng
"Oraşe înfrăţite (Twin cities of Minsk
"Swansea - Wales :Mannheim.de"@
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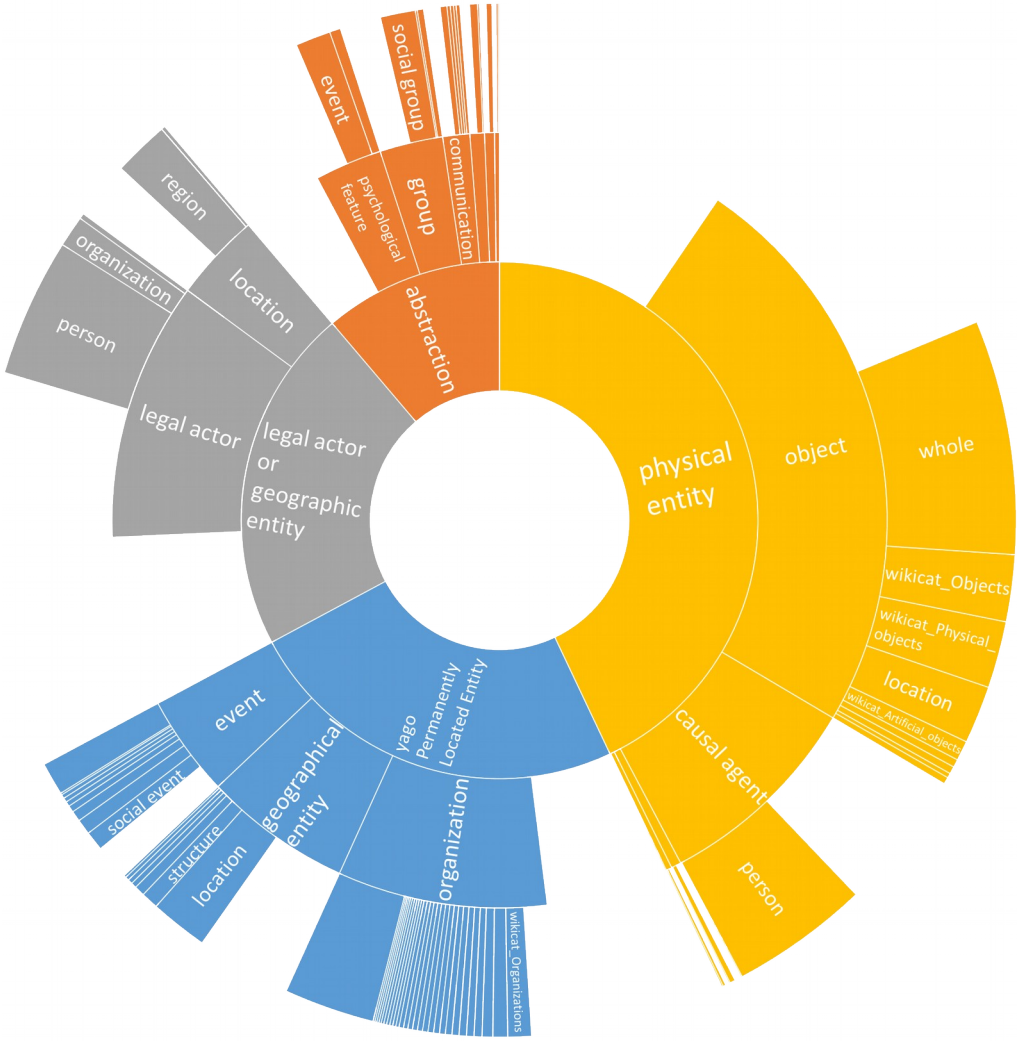
YAGO


event
social group
communication
psychological feature
group
abstraction
region
organization
person
location
legal actor
legal actor or geographic entity
physical entity
object
whole
wikicat_Objects
wikicat_Physical_objects
location
wikicat_Artificial_objects
causal agent
person
yago Permanently Located Entity
event
social event
geographical entity
structure
location
organization
wikicat_Organizations

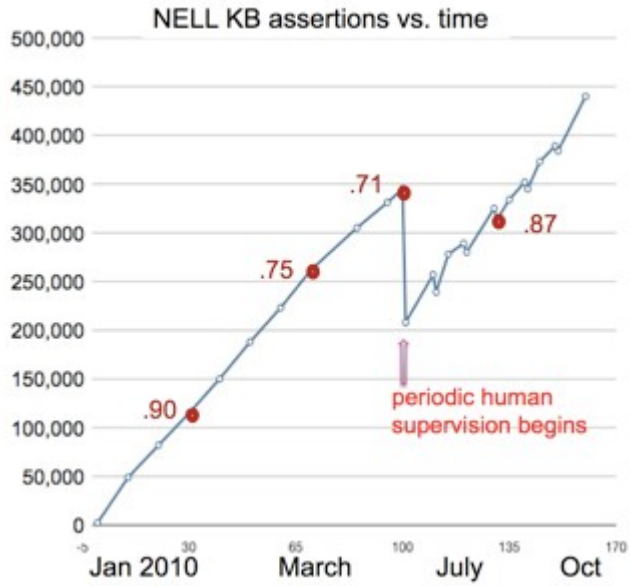
Knowledge Graph Creation

- Lesson learned no. 4:
  - Heuristics help increasing coverage (at the cost of accuracy)

Knowledge Graph Creation: NELL

- The 2010s
  - NELL: Never ending language learner
  - Input: ontology, seed examples, text corpus
  - Output: facts, text patterns
  - Large degree of automation, occasional human feedback

- Until 2018
  - Continuously ran for ~8 years
  - New release every few days



http://rtw.ml.cmu.edu/rtw/overview

Knowledge Graph Creation: NELL

- Extraction of a Knowledge Graph from a Text Corpus

Nine Inch Nails singer Trent Reznor, bor 19

...as stated by Filter singer Richard Pa

...says Slipknot singer Corey Taylo 44, in the interview.

patterns

"X singer Y" → band_member(X,Y)

facts

band_member(Nine_Inch_Nails, Trent_Reznor)
d_member(Filter,Richard_Patrick)
band_member(Slipknot,Corey_Taylor)

Recently-Learned Facts twitter Refresh

instance	iteration	date learned	confidence
conversion_table is an item found on the floor	1111	06-jul-2018	99.8
arlene_martel is a commedian	1111	06-jul-2018	94.0
cigar_rights is a socio-political term	1111	06-jul-2018	95.7
linton_zoological_gardens is an aquarium	1111	06-jul-2018	100.0
robb_miller coaches a sports team	1111	06-jul-2018	91.4
eric_e__schmidt is a person who was written about in new_york_times	1111	06-jul-2018	100.0
rodin is a visual artist in the field of sculpture	1115	03-sep-2018	99.6
the_today_show is a company in the economic sector of news	1114	25-aug-2018	93.0
china is a country located in the geopolitical location other_countries	1111	06-jul-2018	100.0
jerusalem is a city located in the geopolitical location israel	1114	25-aug-2018	99.8

Knowledge Graph Creation: NELL

Knowledge Graph Creation

- Lesson learned no. 5:
  - Quality cannot be maximized without human intervention

Min. human intervention

Max. accuracy

Summary of Trade Offs

- (Manual) effort vs. accuracy and completeness
- User involvement (or usability) vs. degree of formality
- Simplicity vs. support for plurality and provenance

→ all those decisions influence the shape of a knowledge graph!

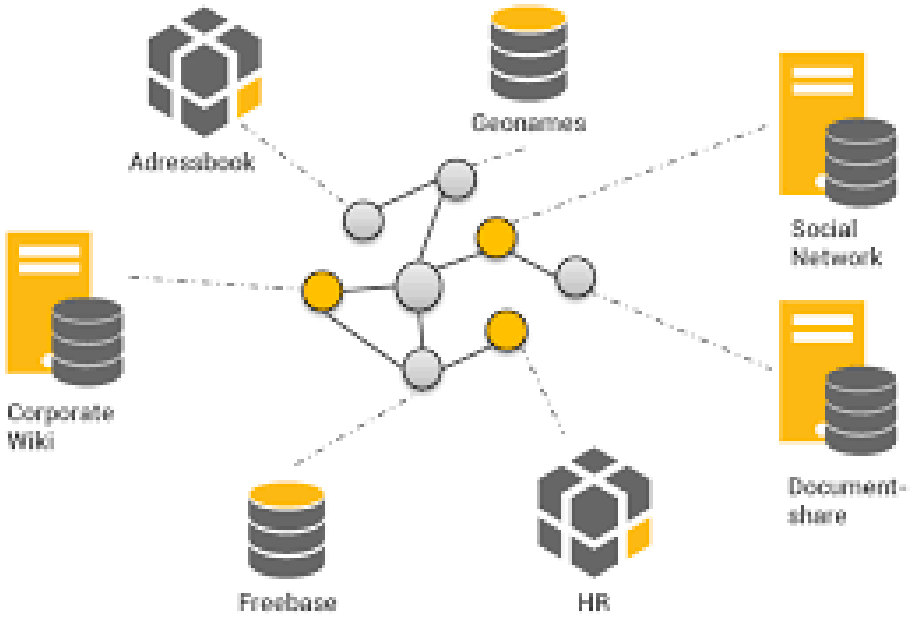
Non-Public Knowledge Graphs

- Many companies have their own private knowledge graphs
  - Google: Knowledge Graph, Knowledge Vault
  - Yahoo!: Knowledge Graph
  - Microsoft: Satori
  - Facebook: Entities Graph
  - Thomson Reuters: permid.org (partly public)

- However, we usually know only little about them

Non-Public Knowledge Graphs

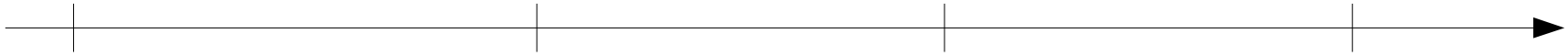
- Knowledge Graphs are used…
- …in companies and organizations
  - collect, organize, and integrate knowledge
  - link isolated information sources
  - make information searchable and findable



Masuch, 2014

Comparison of Knowledge Graphs

- Release cycles



Instant updates: DBpedia live, Freebase, Wikidata

Days: NELL

Caution!

Months: DBpedia

Years: YAGO, Cyc

- Size and density

Table 1: Global Properties of the Knowledge Graphs compared in this paper

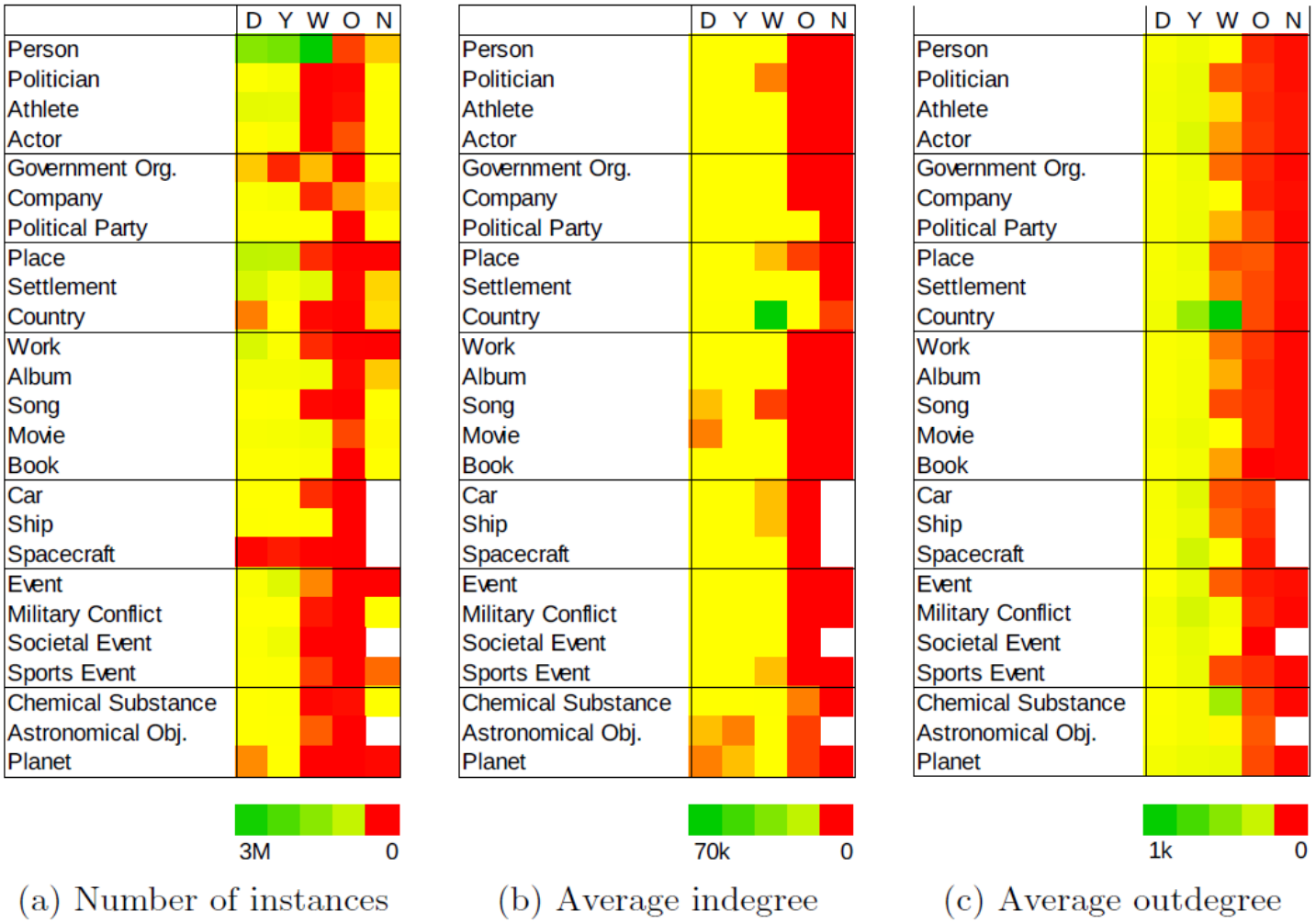
	DBpedia	YAGO	Wikidata	OpenCyc	NELL
Version	2016-04	YAGO3	2016-08-01	2016-09-05	08m.995
# instances	5,109,890	5,130,031	17,581,152	118,125	1,974,297
# axioms	397,831,457	1,435,808,056	1,633,309,138	2,413,894	3,402,971
avg. indegree	13.52	17.44	9.83	10.03	5.33
avg. outdegree	47.55	101.86	41.25	9.23	1.25
# classes	754	576,331	30,765	116,822	290
# relations	3,555	93,659	11,053	165	1,334

Ringler & Paulheim: *One Knowledge Graph to Rule them All?* KI 2017

Comparison of Knowledge Graphs

- What do they actually contain?
- Experiment: pick 25 classes of interest
  - And find them in respective ontologies
- Count instances (coverage)
- Determine in and out degree (level of detail)

Comparison of Knowledge Graphs



(a) Number of instances (b) Average indegree (c) Average outdegree

Ringler & Paulheim: *One Knowledge Graph to Rule them All?* KI 2017

Comparison of Knowledge Graphs

- Summary findings:
  - Persons: more in Wikidata
    (twice as many persons as DBpedia and YAGO)
  - Countries: more details in Wikidata
  - Places: most in DBpedia
  - Organizations: most in YAGO
  - Events: most in YAGO
  - Artistic works:
    - Wikidata contains more movies and albums
    - YAGO contains more songs

Ringler & Paulheim: *One Knowledge Graph to Rule them All?* KI 2017

Caveats

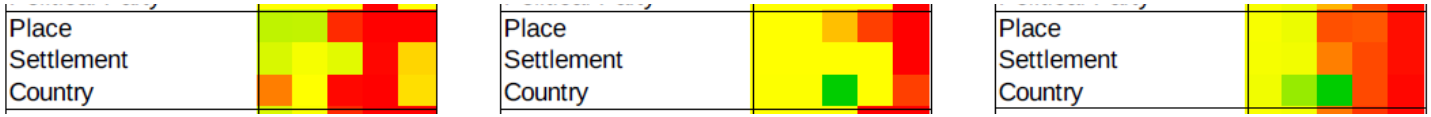
- Reading the diagrams right…

- So, Wikidata contains more persons
  - but less instances of all the interesting subclasses?

- There are classes like *Actor* in Wikidata
  - but they are hardly used
  - rather: modeled using *profession* relation

Caveats

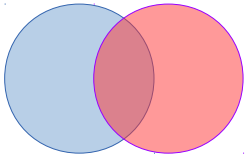
- Reading the diagrams right… (ctd.)

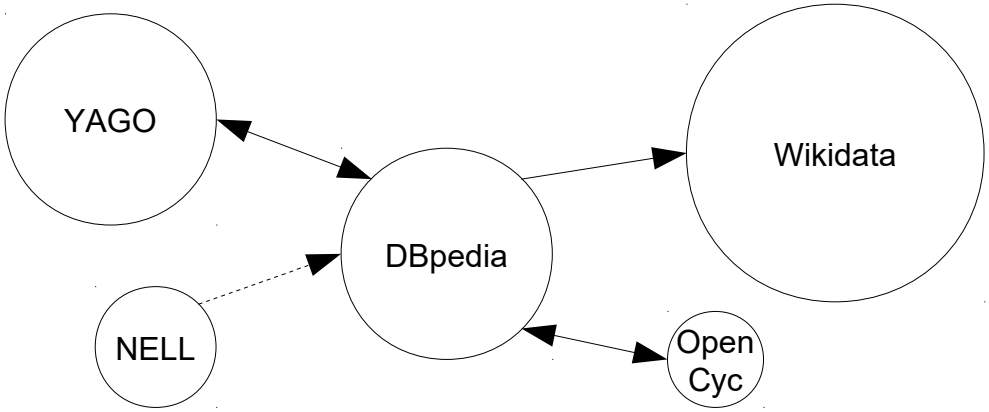


- So, Wikidata contains more data on countries, but less countries?
- First: Wikidata only counts current, actual countries
  - DBpedia and YAGO also count historical countries
- “KG1 contains less of X than KG2” can mean
  - it actually contains less instances of X
  - it contains equally many or more instances, but they are not typed with X (see later)
- Second: we count single facts about countries
  - Wikidata records some time indexed information, e.g., population
  - Each point in time contributes a fact

Overlap of Knowledge Graphs

- How largely do knowledge graphs overlap?
- They are interlinked, so we can simply count links
  - For NELL, we use links to Wikipedia as a proxy





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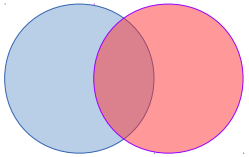
Overlap of Knowledge Graphs



- How largely do knowledge graphs overlap?
- They are interlinked, so we can simply count links
  - For NELL, we use links to Wikipedia as a proxy

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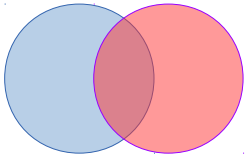
Overlap of Knowledge Graphs

- Links between Knowledge Graphs are incomplete
  - The Open World Assumption also holds for interlinks



- But we can estimate their number
- Approach:
  - find link set automatically with different heuristics
  - determine precision and recall on existing interlinks
  - estimate actual number of links

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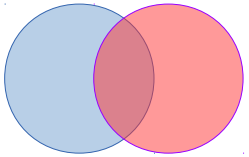
Overlap of Knowledge Graphs



- Idea:
  - Given that the link set F is found
  - And the (unknown) actual link set would be C

- Precision P: Fraction of F which is actually correct
  - i.e., measures how much |F| is *over*-estimating |C|
- Recall R: Fraction of C which is contained in F
  - i.e., measures how much |F| is *under*-estimating |C|

- From that, we estimate $|C| = |F| \cdot P \cdot \frac{1}{R}$

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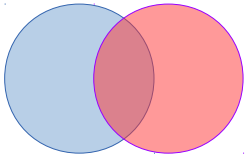
Overlap of Knowledge Graphs

- Mathematical derivation:
  - Definition of recall: $R = \frac{|F_{correct}|}{|C|}$
  - Definition of precision: $P = \frac{|F_{correct}|}{|F|}$

unknown



- Resolve both to $|F_{correct}|$, substitute, and resolve to $|C|$

$$|C| = |F| \cdot P \cdot \frac{1}{R}$$

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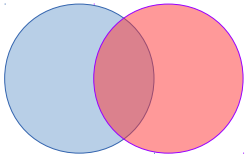
Overlap of Knowledge Graphs

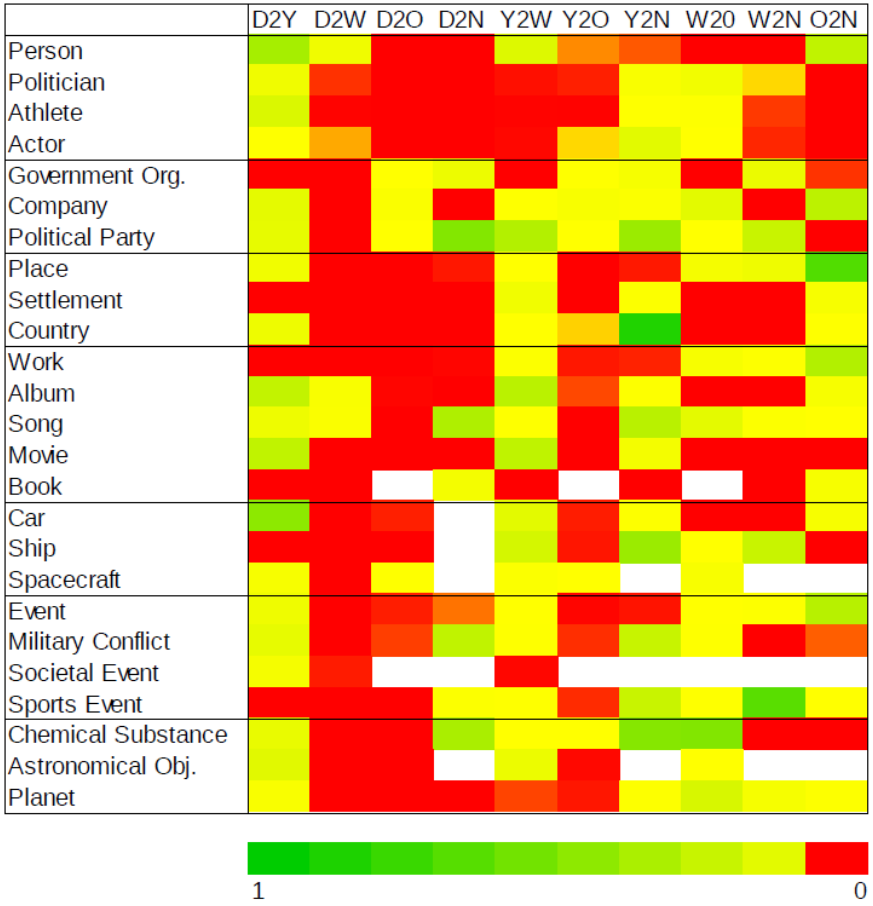


- Experiment:
  - We use the same 25 classes as before
  - Measure 1: overlap relative to smaller KG (i.e., potential gain)
  - Measure 2: overlap relative to explicit links (i.e., importance of improving links)

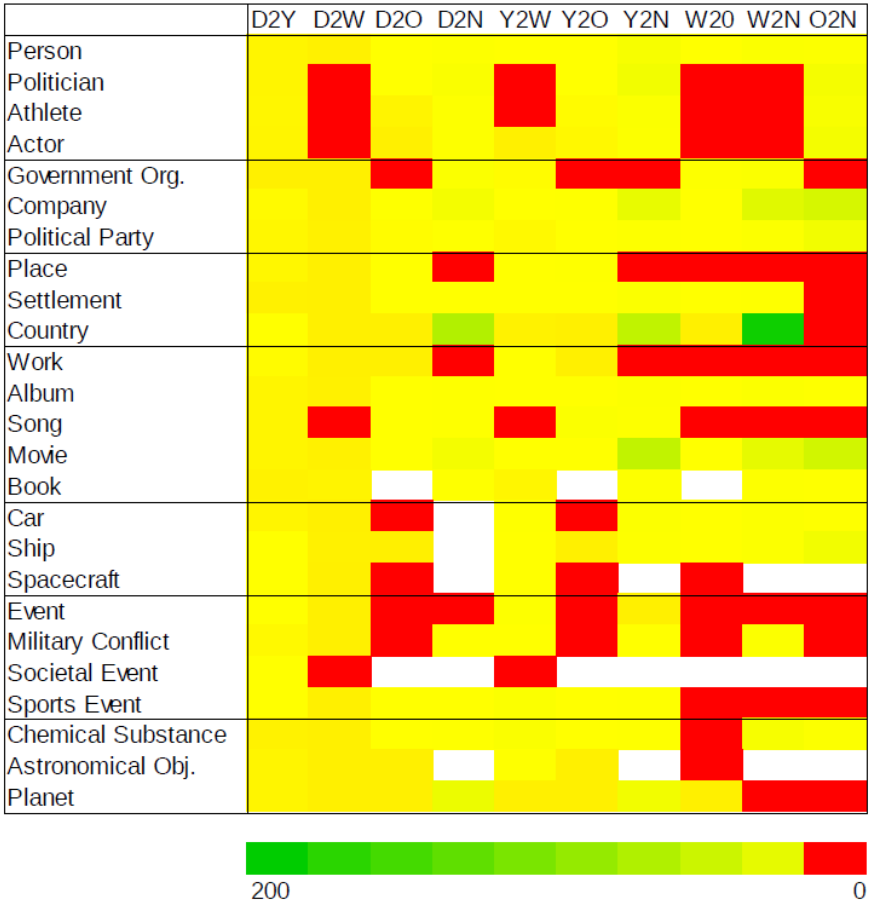
- Link generation with 16 different metrics and thresholds
  - Intra-class correlation coefficient for |C|: 0.969
  - Intra-class correlation coefficient for |F|: 0.646
- Bottom line:
  - Despite variety in link sets generated, the overlap is estimated reliably
  - The link generation mechanisms do not need to be overly accurate

Ringler & Paulheim: *One Knowledge Graph to Rule them All?* KI 2017

Overlap of Knowledge Graphs



(a) Overlap as potential gain



(b) Overlap relative to existing links

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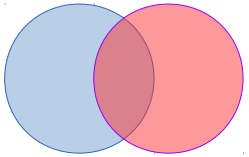
Overlap of Knowledge Graphs

- Summary findings:
  - DBpedia and YAGO cover roughly the same instances (not much surprising)
  - NELL is the most complementary to the others
  - Existing interlinks are insufficient for out-of-the-box parallel usage



Ringler & Paulheim: *One Knowledge Graph to Rule them All?* KI 2017

Intermezzo: Knowledge Graph Creation Cost

- There are quite a few metrics for evaluating KGs
  - size, degree, interlinking, quality, licensing, ...

Table 2

Data quality metrics related to accessibility dimensions (type QN refers to a quantitative metric, QL to a qualitative one).

Dimension	Abr	Metric	Description	Type
Availability	A1	accessibility of the SPARQL endpoint and the server	checking whether the server responds to a SPARQL query [18]	QN
	A2	accessibility of the RDF dumps	checking whether an RDF dump is provided and can be downloaded [18]	QN
	A3	dereferenceability of the URI	checking (i) for dead or broken links i.e. when an HTTP-GET request is sent, the status code `404 Not Found` is not be returned (ii) that useful data (particularly RDF) is returned upon lookup of a URI, (iii) for changes in the URI i.e the compliance with the recommended way of implementing redirections using the status code `303 See Other` [18,30]	QN
	A4	no misreported content types	detect whether the HTTP response contains the header field stating the appropriate content type of the returned file e.g. `application/rdf+xml` [30]	QN
	A5	dereferenced forward-links	dereferenceability of all forward links: all available triples where the local URI is mentioned in the subject (i.e. the description of the resource) [31]	QN
Licensing	L1	machine-readable indication of a license	detection of the indication of a license in the VoID description or in the dataset itself [18,31]	QN
	L2	human-readable indication of a license	detection of a license in the documentation of the dataset [18, 31]	QN
	L3	specifying the correct license	detection of whether the dataset is attributed under the same license as the original [18]	QN
Interlinking	I1	detection of good quality interlinks	(i) detection of (a) interlinking degree, (b) clustering coefficient, (c) centrality, (d) open sameAs chains and (e) description richness through sameAs by using network measures [25], (ii) via crowdsourcing [1,65]	QN
	I2	existence of links to external data providers	detection of the existence and usage of external URIs (e.g. using `owl:sameAs` links) [31]	QN
	I3	dereferenced back-links	detection of all local in-links or back-links: all triples from a dataset that have the resource's URI as the object [31]	QN
Security	S1	usage of digital signatures	by signing a document containing an RDF serialization, a SPARQL result set or signing an RDF graph [13,18]	QN
	S2	authenticity of the dataset	verifying authenticity of the dataset based on a provenance vocabulary such as author and his contributors, the publisher of the data and its sources (if present in the dataset) [18]	QL
Performance	P1	usage of slash-URIs	checking for usage of slash-URIs where large amounts of data is provided [18]	QN
	P2	low latency	(minimum) delay between submission of a request by the user and reception of the response from the system [18]	QN
	P3	high throughput	(maximum) no. of answered HTTP-requests per second [18]	QN
	P4	scalability of a data source	detection of whether the time to answer an amount of ten requests divided by ten is not longer than the time it takes to answer one request [18]	QN

Zaveri et al.: *Quality Assessment for Linked Open Data: A Survey.* SWJ 7(1), 2016

Table 14

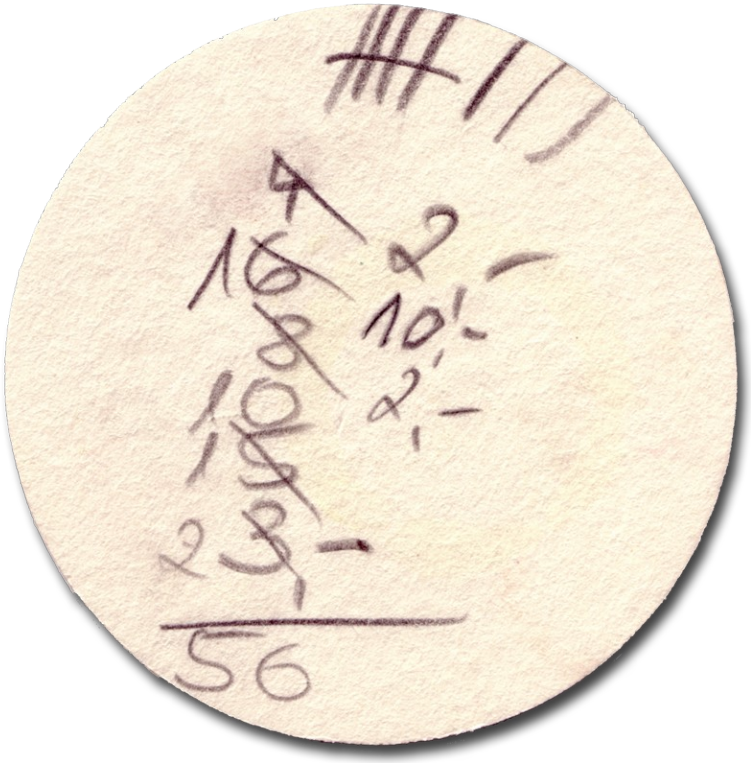
Framework with an example weighting which would be reasonable for a user setting as given in [30].

Dimension	Metric	DBpedia	Freebase	OpenCyc	Wikidata	YAGO	Example of User Weighting w_i
Accuracy	m_{synRDF}	1	1	1	1	1	1
	m_{synLit}	0.994	1	1	1	0.624	1
	$m_{semTriple}$	1	1	1	1	1	1
Trustworthiness	m_{graph}	0.5	0.5	1	0.75	0.25	1
	m_{fact}	0.5	1	0	1	1	2
	m_{NoVal}	0	1	0	1	0	1
Consistency	$m_{checkRestr}$	0	1	0	1	0	1
	$m_{conClass}$	0.875	1	0.999	1	0.333	1
	$m_{conRelat}$	0.991	0.45	1	0	0.992	1
Relevancy	$m_{Ranking}$	0	0	0	1	0	1
Completeness	$m_{cSchema}$	0.905	0.762	0.921	1	0.952	1
	m_{cCol}	0.402	0.425	0	0.285	0.332	1
	m_{cPop}	0.93	0.94	0.48	0.99	0.89	3
Timeliness	m_{Freq}	0.5	0	0.25	1	0.25	3
	$m_{Validity}$	0	1	0	1	1	1
	m_{Change}	0	1	0	0	0	1
Ease of understanding	m_{Descr}	0.704	0.972	1	0.9999	1	3
	m_{Lang}	1	1	0	1	1	2
	m_{uSer}	1	1	0	1	1	1
	m_{uURI}	1	0.5	1	0	1	2
Interoperability	m_{Reif}	1	0.5	0.5	0	0.5	1
	$m_{iSerial}$	1	0	0.5	1	1	2
	m_{extVoc}	0.61	0.108	0.415	0.682	0.134	2
	$m_{propVoc}$	0.15	0	0.513	0.001	0	1
Accessibility	m_{Deref}	1	0.437	1	0.414	1	2
	m_{Avai}	0.9961	0.9998	1	0.9999	0.7306	2
	m_{SPARQL}	1	0	0	1	1	1
	m_{Export}	1	1	1	1	1	0
	m_{Negot}	0.5	0	0	1	1	1
	m_{HTML_RDF}	1	1	0	1	1	0
	m_{Meta}	1	0	1	0	0	1
Licensing	$m_{machLicense}$	1	0	0	1	0	1
Interlinking	m_{Inst}	0.592	0.018	0.443	0	0.305	2
	m_{URIs}	0.929	0.954	0.894	0.957	0.956	1
Unweighted Average		0.708	0.605	0.498	0.738	0.625	
Weighted Average		0.718	0.575	0.516	0.742	0.646	

Färber et al.: *Linked data quality of DBpedia, Freebase, OpenCyc, Wikidata, and YAGO* SWJ 9(1), 2018

Intermezzo: Knowledge Graph Creation Cost

- ...but what is the cost of a single statement?



Some back of the envelope calculations...

Paulheim: How much is a triple?
Estimating the Cost of Knowledge Graph Creation, 2018

Intermezzo: Knowledge Graph Creation Cost

- Case 1: manual curation
  - Cyc: created by experts
    Total development cost: $120M
    Total #statements: 21M

    → **$5.71 per statement**
  - Freebase: created by laymen
    Assumption: adding a statement to Freebase
    equals adding a sentence to Wikipedia
    - English Wikipedia up to April 2011: 41M working hours (Geiger and Halfaker, 2013),

      size in April 2011: 3.6M pages, avg. 36.4 sentences each
    - Using US minimum wage: $2.25 per sentence

    → **$2.25 per statement**

    (Footnote: total cost of creating Freebase would be $6.75B)

acquisition by Google estimated as $60-300M

Intermezzo: Knowledge Graph Creation Cost

- Case 2: automatic/heuristic creation
  - DBpedia: 4.9M LOC, 2.2M LOC for mappings

    software project development: ~37 LOC per hour (Devanbu et al., 1996)

    we use German PhD salaries as a cost estimate

    → **1.85c per statement**
  - YAGO: made from 1.6M LOC

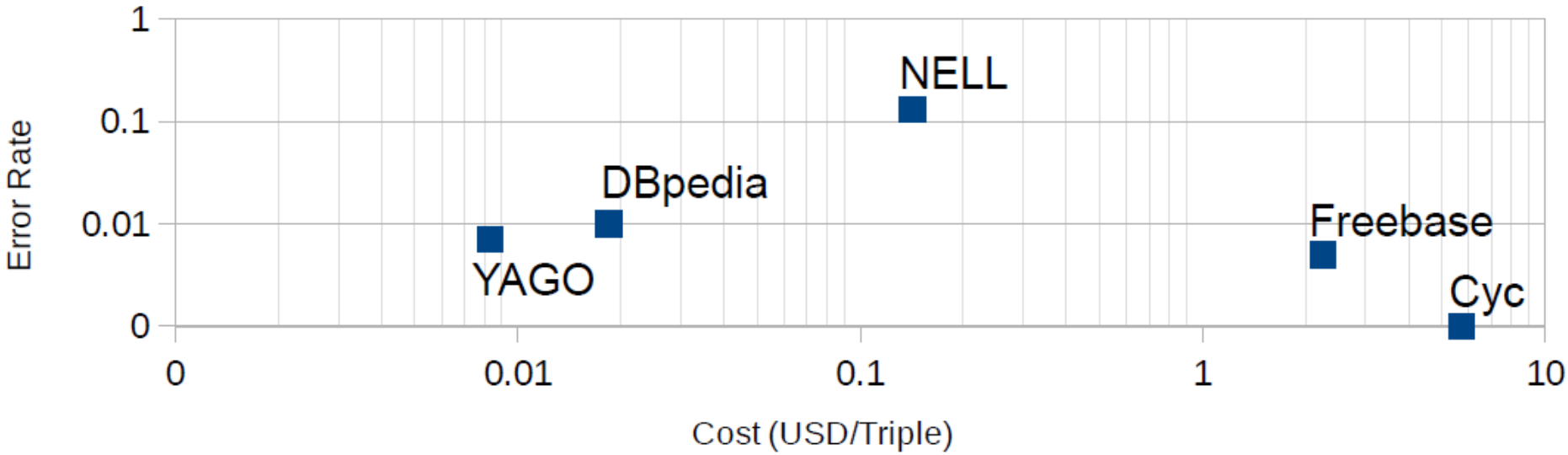
    uses WordNet: 117k synsets, we treat each synset like a Wiki page

    → **0.83c per statement**
  - NELL: 103k LOC

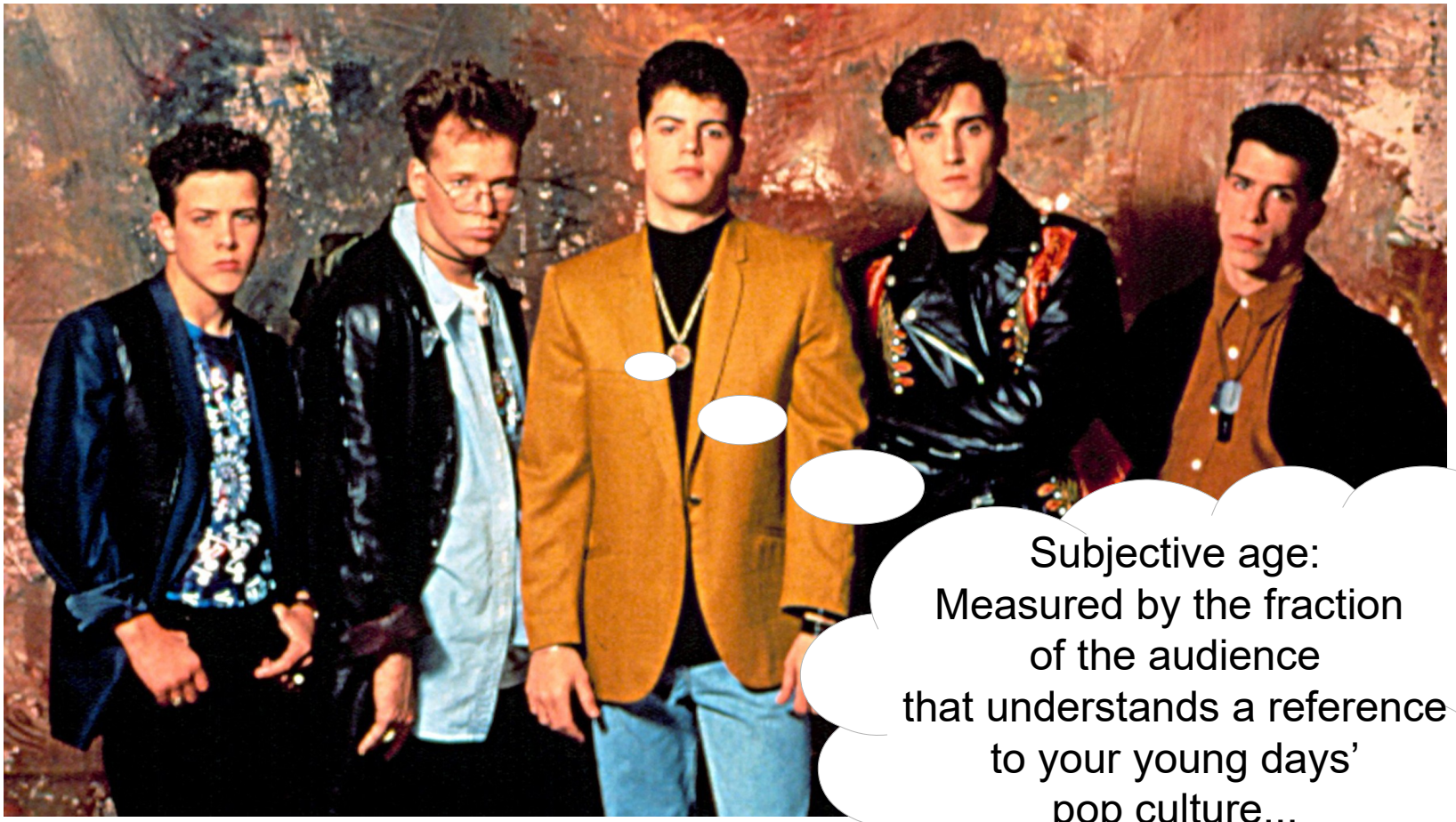
    → **14.25c per statement**
- Compared to manual curation: saving factor 16-250

Intermezzo: Knowledge Graph Creation Cost

- Graph error rate against cost
  - we can pay for accuracy
  - NELL is a bit of an outlier

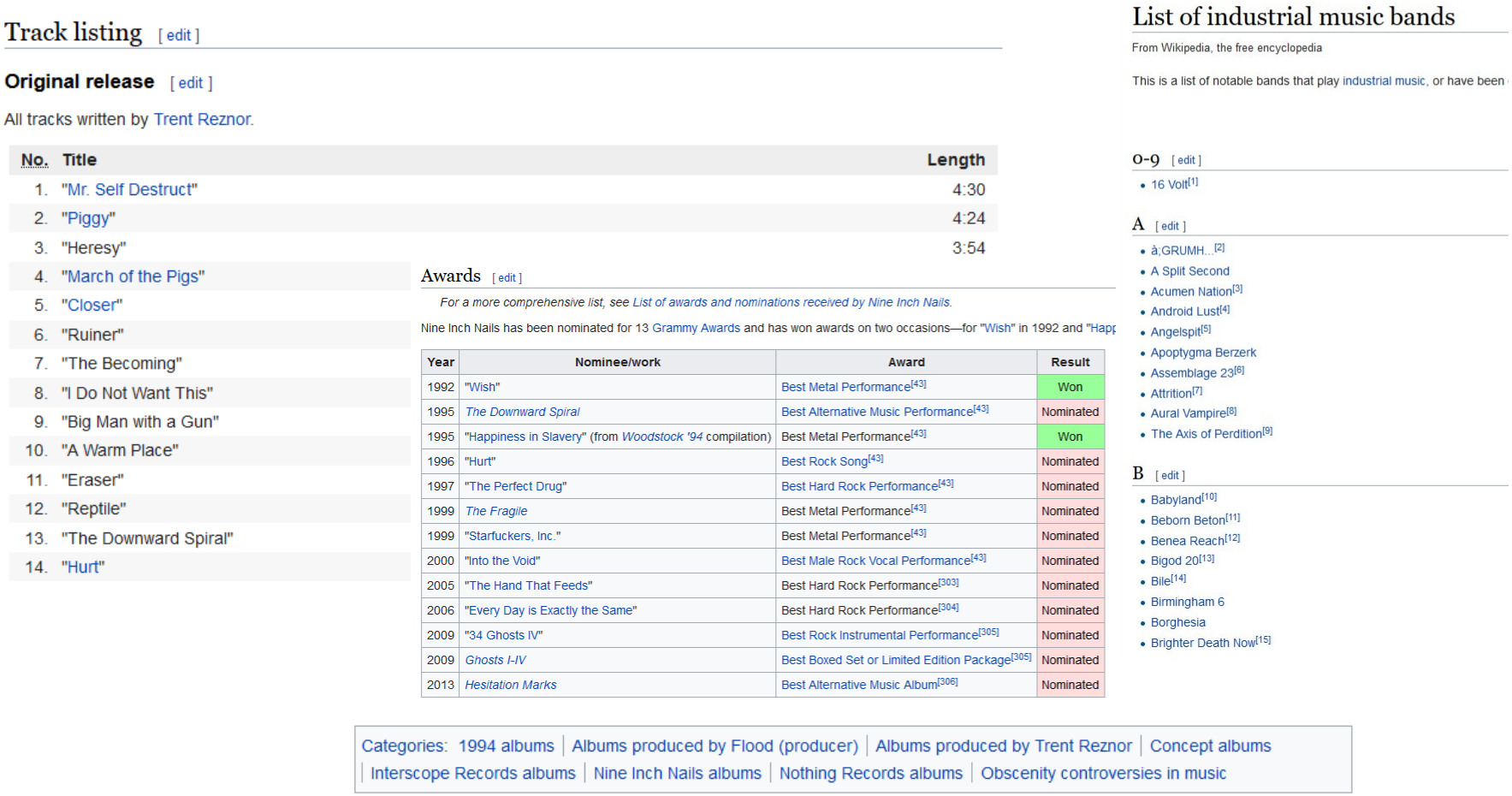


New Kids on the Block



Further Sources of Knowledge in Wikipedia

- show: list pages, categories, tables, ...



Track listing [edit]

Original release [edit]

All tracks written by Trent Reznor.

No.	Title	Length
1.	"Mr. Self Destruct"	4:30
2.	"Piggy"	4:24
3.	"Heresy"	3:54
4.	"March of the Pigs"	
5.	"Closer"	
6.	"Ruiner"	
7.	"The Becoming"	
8.	"I Do Not Want This"	
9.	"Big Man with a Gun"	
10.	"A Warm Place"	
11.	"Eraser"	
12.	"Reptile"	
13.	"The Downward Spiral"	
14.	"Hurt"	

Awards [edit]

For a more comprehensive list, see List of awards and nominations received by Nine Inch Nails.

Nine Inch Nails has been nominated for 13 Grammy Awards and has won awards on two occasions—for "Wish" in 1992 and "Happ

Year	Nominee/work	Award	Result
1992	"Wish"	Best Metal Performance[43]	Won
1995	*The Downward Spiral*	Best Alternative Music Performance[43]	Nominated
1995	"Happiness in Slavery" (from *Woodstock '94* compilation)	Best Metal Performance[43]	Won
1996	"Hurt"	Best Rock Song[43]	Nominated
1997	"The Perfect Drug"	Best Hard Rock Performance[43]	Nominated
1999	*The Fragile*	Best Metal Performance[43]	Nominated
1999	"Starfuckers, Inc."	Best Metal Performance[43]	Nominated
2000	"Into the Void"	Best Male Rock Vocal Performance[43]	Nominated
2005	"The Hand That Feeds"	Best Hard Rock Performance[303]	Nominated
2006	"Every Day is Exactly the Same"	Best Hard Rock Performance[304]	Nominated
2009	"34 Ghosts IV"	Best Rock Instrumental Performance[305]	Nominated
2009	*Ghosts I-IV*	Best Boxed Set or Limited Edition Package[305]	Nominated
2013	*Hesitation Marks*	Best Alternative Music Album[306]	Nominated

List of industrial music bands

From Wikipedia, the free encyclopedia

This is a list of notable bands that play industrial music, or have been

0-9 [edit]

- 16 Volt[1]

A [edit]

- à;GRUMH...[2]
- A Split Second
- Acumen Nation[3]
- Android Lust[4]
- Angelspit[5]
- Apoptygma Berzerk
- Assemblage 23[6]
- Attrition[7]
- Aural Vampire[8]
- The Axis of Perdition[9]

B [edit]

- Babyland[10]
- Beborn Beton[11]
- Benea Reach[12]
- Bigod 20[13]
- Bile[14]
- Birmingham 6
- Borghesia
- Brighter Death Now[15]

Categories: 1994 albums | Albums produced by Flood (producer) | Albums produced by Trent Reznor | Concept albums | Interscope Records albums | Nine Inch Nails albums | Nothing Records albums | Obscenity controversies in music

CaLiGraph Idea

- Entities co-occur in surface patterns
  - e.g., enumerations, table columns, …
- Co-occurring entities share semantic patterns
  - e.g., types, relations, attribute values
- Existing entities co-occur with new entities

Track listing [edit]

Original release [edit]

All tracks written by Trent Reznor.

No.	Title
1.	"Mr. Self Destruct"
2.	"Piggy"
3.	"Heresy"
4.	"March of the Pigs"
5.	"Closer"
6.	"Ruiner"
7.	"The Becoming"
8.	"I Do Not Want This"
9.	"Big Man with a Gun"
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14.	"Hurt"

Categories: 1994 albums | Albums produced by Flood (producer) | Albums produced by Trent Reznor | Concept albums | Interscope Records albums | Nine Inch Nails albums | Nothing Records albums | Obscenity controversies in music

CaLiGraph Idea

- Surface patterns and semantic patterns also exist outside of Wikipedia

TABLE 3
Results of the CCR-DEA (DEA_{CRS}), BCC-DEA (DEA_{VRS}) and NIR-DEA (DEA_{NIR}) for urban WSAs, indicating scale efficiency (Sc. Eff) and returns to scale (RTS) for municipal year 2009/2010

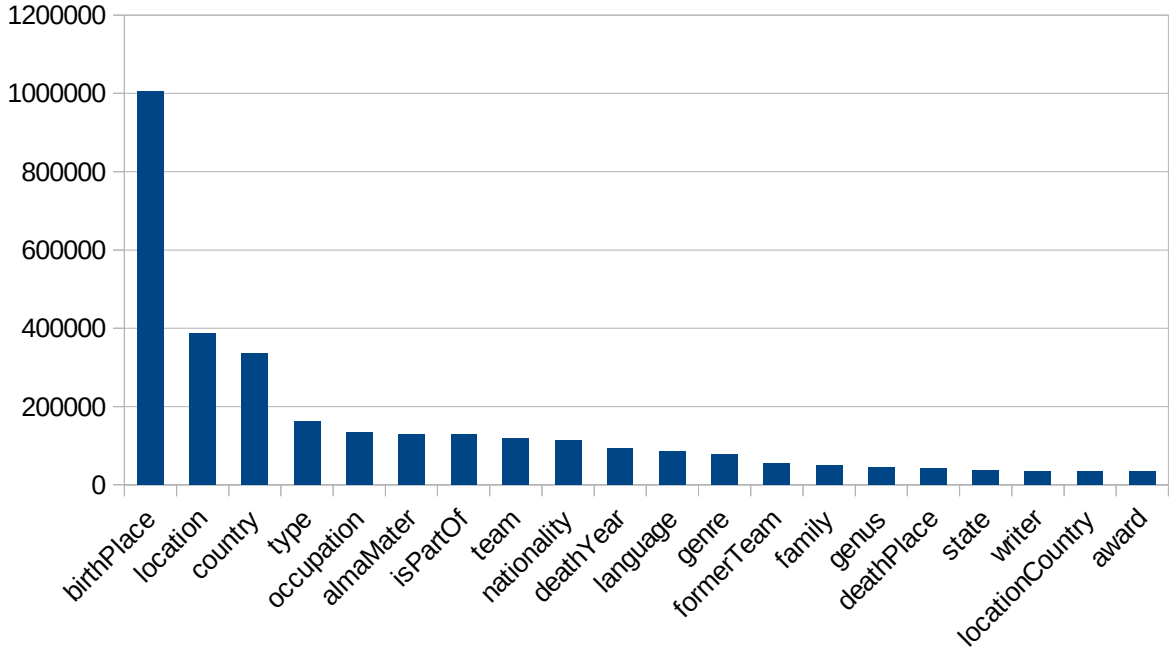
Rank	Municipality	Pr	Cat	DEA_{VRS}	DEA_{CRS}	DEA_{NIR}	Sc. Eff	RTS
1	Dihlabeng	FS	B2	1	1	1	1	Con
1	Kungwini	GT	B2	1	1	1	1	Con
1	Bela Bela	LIM	B2	1	1	1	1	Con
1	Emakhazeni	MP	B2	1	1	1	1	Con
1	Matlosana	NW	B1	1	0.901	1	0.901	Dec
1	Mangaung	FS	A	1	0.499	1	0.499	Dec
1	City of Tshwane	GT	A	1	0.392	1	0.392	Dec
1	Ekurhuleni	GT	A	1	0.343	1	0.343	Dec
1	City of Cape Town	WC	A	1	0.301	1	0.301	Dec
1	City of Johannesburg	GT	A	1	0.292	1	0.292	Dec
11	Mbombela	MP	B1	0.902	0.489	0.902	0.543	Dec
12	Mogalakwena	LIM	B2	0.88	0.688	0.88	0.782	Dec
13	Polokwane	LIM	B1	0.854	0.512	0.854	0.6	Dec
14	Nelson Mandela Bay	EC	A	0.8	0.32	0.8	0.399	Dec
15	Moqhaka	FS	B2	0.788	0.694	0.788	0.88	Dec
16	Sol Plaatjie	NC	B1	0.766	0.539	0.766	0.704	Dec
17	Newcastle	KZN	B1	0.712	0.51	0.712	0.717	Dec
18	Ethekwini	KZN	A	0.707	0.231	0.707	0.326	Dec
19	Emfuleni	GT	B1	0.706	0.287	0.706	0.407	Dec
20	Khara Hais	NC	B2	0.687	0.663	0.663	0.965	Inc
21	Buffalo City	EC	A	0.637	0.298	0.637	0.467	Dec
22	Matjhabeng	FS	B1	0.612	0.372	0.612	0.608	Dec
23	Msukaligwa	MP	B2	0.564	0.519	0.564	0.92	Dec
24	Tlokwe	NW	B1	0.555	0.554	0.554	0.998	Inc
24	Saldanha Bay	WC	B2	0.555	0.54	0.54	0.972	Inc
26	Rustenburg	NW	B1	0.541	0.295	0.541	0.546	Dec
27	Mogale City	GT	B1	0.528	0.368	0.528	0.698	Dec
28	Drakenstein	WC	B1	0.518	0.456	0.518	0.881	Dec
29	Makana	EC	B2	0.504	0.48	0.504	0.953	Dec
30	Breede Valley	WC	B2	0.487	0.471	0.487	0.967	Dec
31	Steve Tshwete	MP	B1	0.474	0.436	0.474	0.921	Dec
32	Umhlathuze	KZN	B1	0.463	0.247	0.463	0.534	Dec
33	Randfontein	GT	B2	0.42	0.357	0.42	0.851	Dec
34	Govan Mbeki	MP	B1	0.385	0.354	0.385	0.92	Dec
35	Merafong City	GT	B2	0.372	0.282	0.372	0.757	Dec
36	Nokeng Tsa Taemane	GT	B2	0.365	0.359	0.365	0.986	Dec
37	Mossel Bay	WC	B2	0.352	0.334	0.352	0.95	Dec
38	Westonaria	GT	B2	0.319	0.269	0.319	0.843	Dec
39	Midvaal	GT	B2	0.314	0.307	0.307	0.978	Inc
40	Metsimaholo	FS	B2	0.295	0.283	0.295	0.959	Dec
41	Knysna	WC	B2	0.266	0.253	0.266	0.951	Dec
42	George	WC	B1	0.239	0.218	0.239	0.911	Dec
43	Msunduzi	KZN	B1	0.237	0.19	0.237	0.803	Dec
44	Overstrand	WC	B2	0.183	0.18	0.18	0.983	Inc

People

- Intro
- Professors
- Administration
- Researchers
  - Dr. Sanja Stajner
  - Dr. Ioana Hulpus
  - Dr. Melisachew Wudage Chekol
  - Dr. Christian Meilicke
  - Dr. Federico Nanni
  - Dr. Dmitry Ustalov
  - Taha Alhersh
  - Alexander Diete
  - Manuel Fink
  - Nicolas Heist
  - Sven Hertling
  - Jakob Huber
  - Amirhossein Kardoost
  - Elena Kuss
  - Anne Lauscher
  - Oliver Lehmberg
  - Robert Litschko
  - Andre Melo
  - Yaser Oulabi
  - Daniel Ruffinelli
  - Christoph Kilian Theil
  - Timo Sztyler
  - Kiril Gashteovski
  - Samuel Broscheit
  - Anna Primpeli
  - Benedikt Kleppmann
  - Yanjie Wang
  - Jonathan Kobbe
- Affiliated PhD students
- Visiting researchers
- Alumni

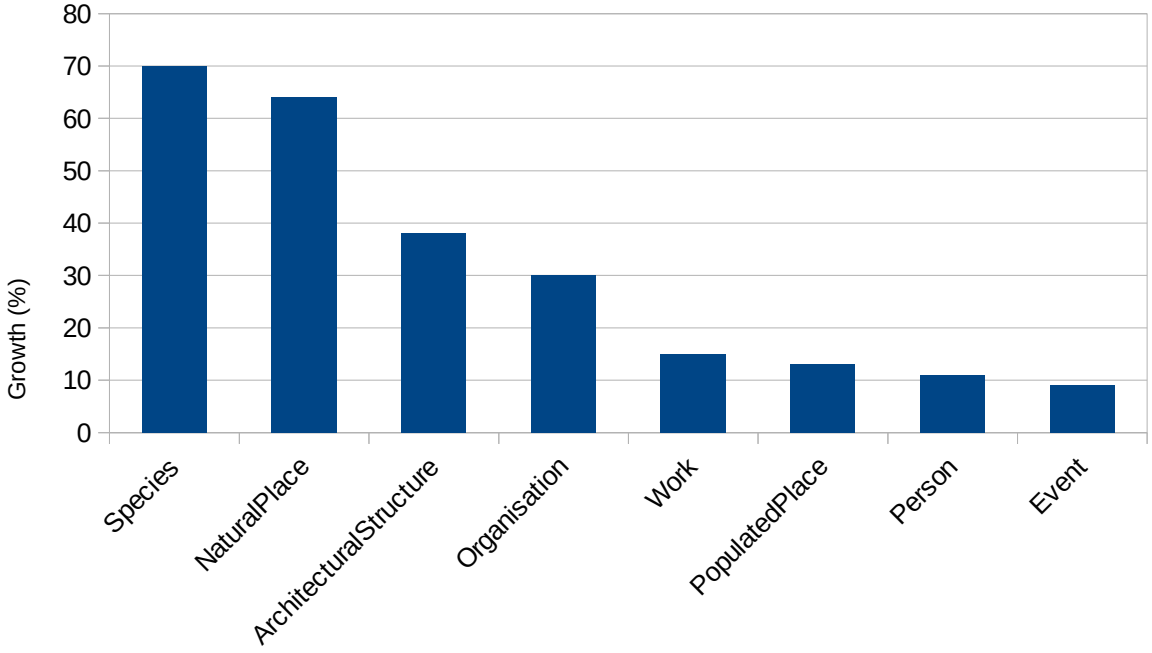
CaLiGraph – Current State

- Significant coverage enhancements of DBpedia Properties



CaLiGraph – Current State

- Significant instance set enhancements by list extraction



From DBpedia to DBkWik

- Wikipedia-based Knowledge Graphs will remain an essential building block of Semantic Web applications
- But they suffer from...
  - ...a coverage bias
  - ...limitations of the creating heuristics

From DBpedia to DBkWik

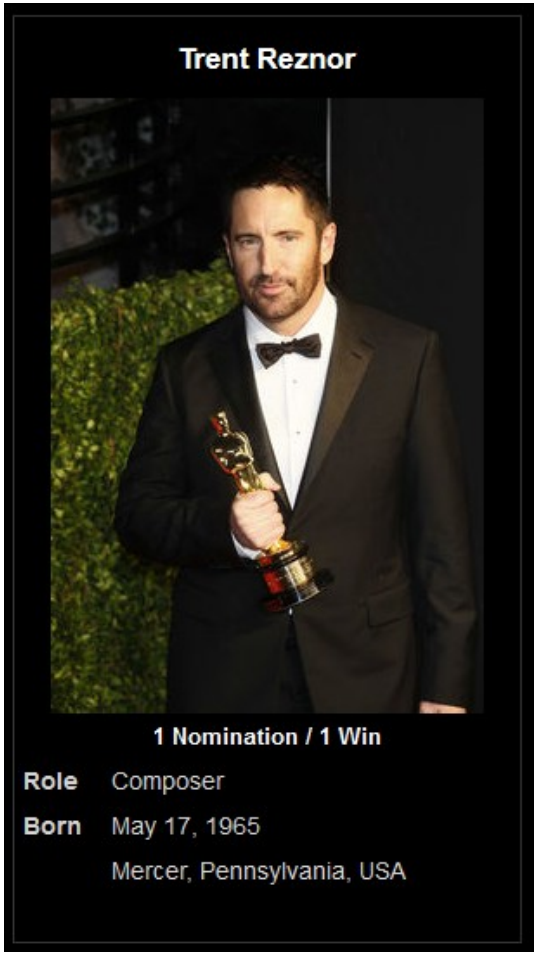
- One (but not the only!) possible source of coverage bias
  - Articles about long-tail entities become deleted

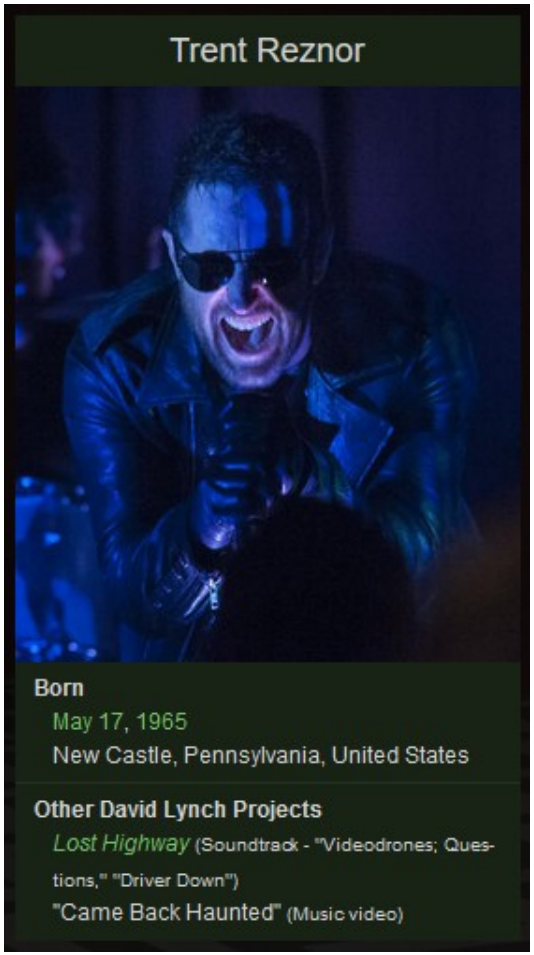
From DBpedia to DBkWik

- Why stop at Wikipedia?
- Wikipedia is based on the MediaWiki software
  - ...and so are thousands of Wikis
  - Fandom by Wikia: >385,000 Wikis on special topics
  - WikiApiary: reports >20,000 installations of MediaWiki on the Web

From DBpedia to DBkWik

- Collecting Data from a Multitude of Wikis



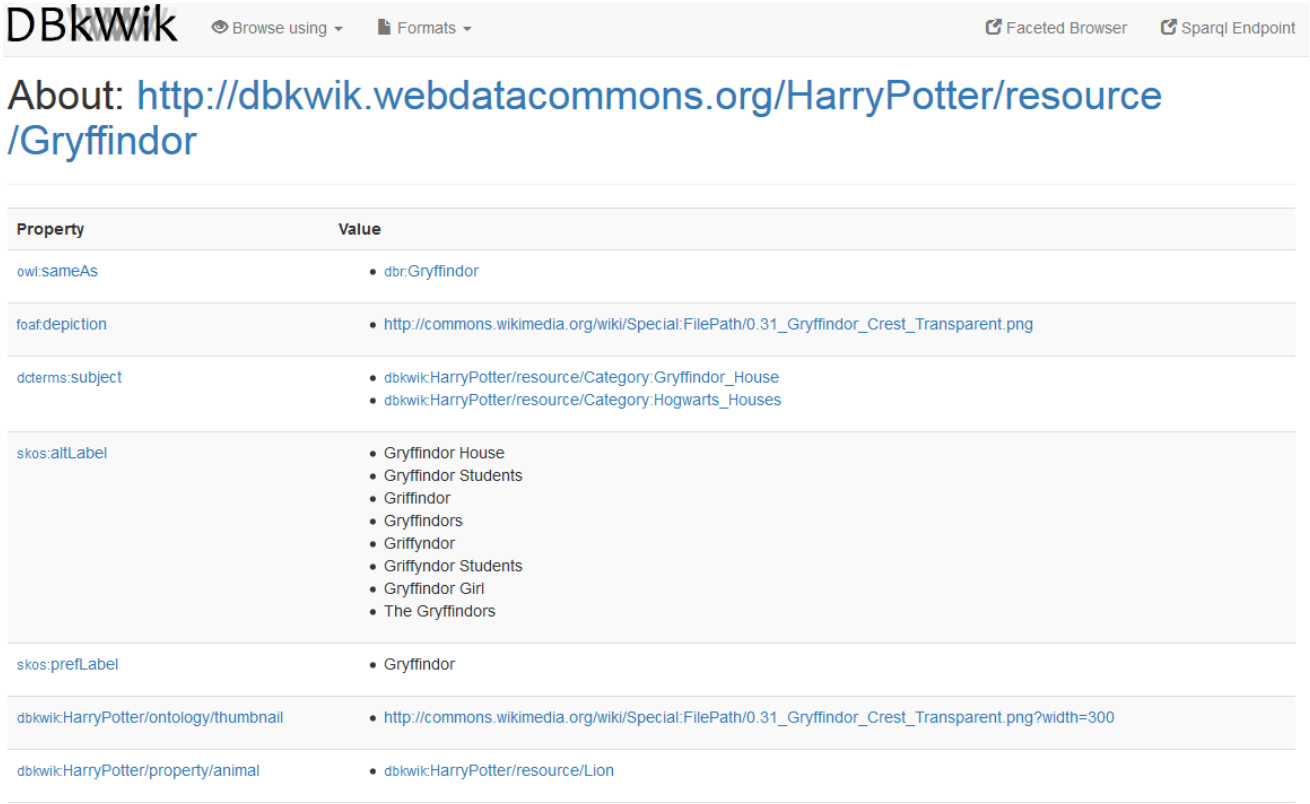


From DBpedia to DBkWik

- The DBpedia Extraction Framework consumes MediaWiki dumps
- Experiment
  - Can we process dumps from arbitrary Wikis with it?
  - Are the results somewhat meaningful?

From DBpedia to DBkWik

- Example from Harry Potter Wiki



http://dbkwik.org/

From DBpedia to DBkWik

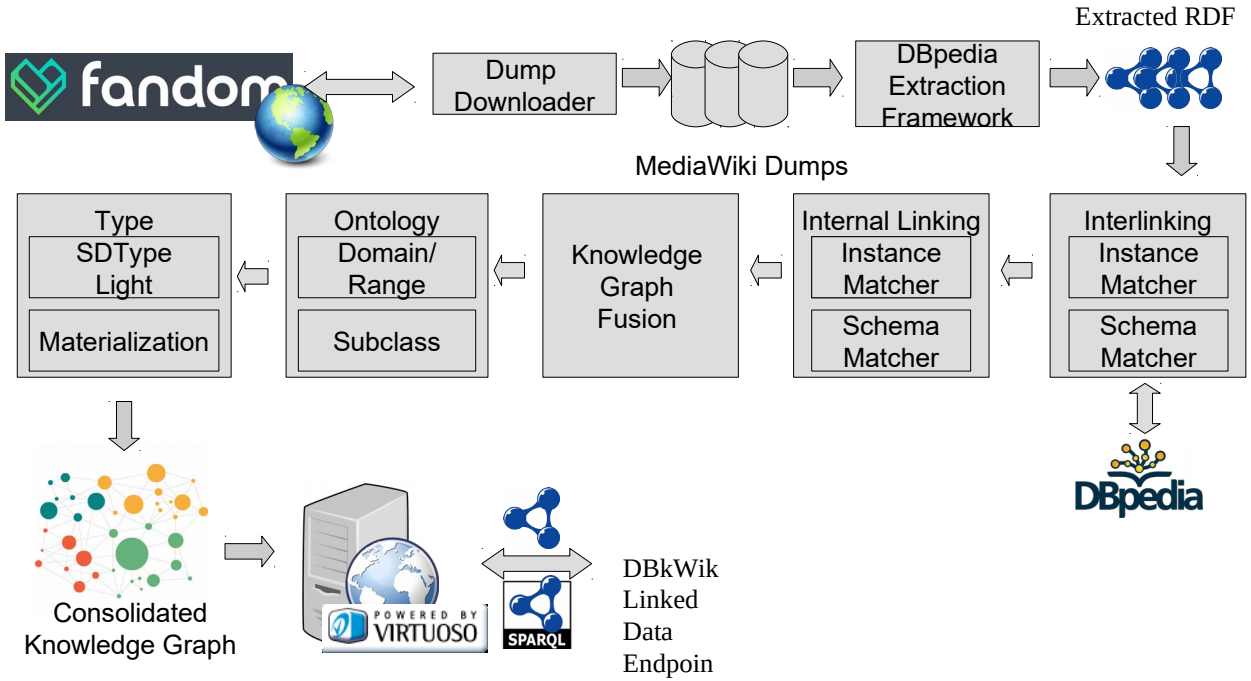
- Differences to DBpedia
  - DBpedia has manually created mappings to an ontology
  - Wikipedia has one page per subject
  - Wikipedia has global infobox conventions (more or less)

- Challenges
  - On-the-fly ontology creation
  - Instance matching
  - Schema matching

Hertling & Paulheim: *DBkWik: A Consolidated Knowledge Graph from Thousands of Wikis.* ICBK 2018

From DBpedia to DBkWik

- Heuristics
  - Ontology induction
  - Instance/Schema Matching



Hertling & Paulheim: *DBkWik: A Consolidated Knowledge Graph from Thousands of Wikis.* ICBK 2018

From DBpedia to DBkWik

- Downloaded ~15k Wiki dumps from Fandom
  - 52.4GB of data, roughly the size of the English Wikipedia
- Prototype: extracted data for ~250 Wikis
  - 4.3M instances, ~750k linked to DBpedia
  - 7k classes, ~1k linked to DBpedia
  - 43k properties, ~20k linked to DBpedia
  - ...including duplicates!
- Link quality
  - Good for classes, OK for properties (F1 of .957 and .852)
  - Needs improvement for instances (F1 of .641)

Solving the Integration Problems in DBkWik

- A new task at OAEI since 2018
  - Benchmark for schema/instance matching tools
  - Turned out to be non-trivial

			class				property				instance				overall			
System	Time	#testcases	Size	Prec.	F-m.	Rec.	Size	Prec.	F-m.	Rec.	Size	Prec.	F-m.	Rec.	Size	Prec.	F-m.	Rec.
AGM	10:47:38	5	14.6	0.23 (0.23)	0.09 (0.09)	0.06 (0.06)	49.4	0.66 (0.66)	0.32 (0.32)	0.21 (0.21)	5169.0	0.48 (0.48)	0.25 (0.25)	0.17 (0.17)	5233.2	0.48 (0.48)	0.25 (0.25)	0.17 (0.17)
AML	0:45:46	4	27.5	0.78 (0.98)	0.69 (0.86)	0.61 (0.77)	58.2	0.72 (0.91)	0.59 (0.73)	0.49 (0.62)	7529.8	0.72 (0.90)	0.71 (0.88)	0.69 (0.86)	7615.5	0.72 (0.90)	0.70 (0.88)	0.69 (0.86)
baselineAltLabel	0:11:48	5	16.4	1.00 (1.00)	0.74 (0.74)	0.59 (0.59)	47.8	0.99 (0.99)	0.79 (0.79)	0.66 (0.66)	4674.2	0.89 (0.89)	0.84 (0.84)	0.80 (0.80)	4739.0	0.89 (0.89)	0.84 (0.84)	0.80 (0.80)
baselineLabel	0:12:30	5	16.4	1.00 (1.00)	0.74 (0.74)	0.59 (0.59)	47.8	0.99 (0.99)	0.79 (0.79)	0.66 (0.66)	3641.2	0.95 (0.95)	0.81 (0.81)	0.71 (0.71)	3706.0	0.95 (0.95)	0.81 (0.81)	0.71 (0.71)
DOME	1:05:26	4	22.5	0.74 (0.92)	0.62 (0.77)	0.53 (0.66)	75.5	0.79 (0.99)	0.77 (0.96)	0.75 (0.93)	4895.2	0.74 (0.92)	0.70 (0.88)	0.67 (0.84)	4994.8	0.74 (0.92)	0.70 (0.88)	0.67 (0.84)
FCAMap-KG	1:14:49	5	18.6	1.00 (1.00)	0.82 (0.82)	0.70 (0.70)	69.0	1.00 (1.00)	0.98 (0.98)	0.96 (0.96)	4530.6	0.90 (0.90)	0.84 (0.84)	0.79 (0.79)	4792.6	0.91 (0.91)	0.85 (0.85)	0.79 (0.79)
LogMap	0:15:43	5	26.0	0.95 (0.95)	0.84 (0.84)	0.76 (0.76)	0.0	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.0	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	26.0	0.95 (0.95)	0.01 (0.01)	0.00 (0.00)
LogMapBio	2:31:01	5	26.0	0.95 (0.95)	0.84 (0.84)	0.76 (0.76)	0.0	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.0	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	26.0	0.95 (0.95)	0.01 (0.01)	0.00 (0.00)
LogMapKG	2:26:14	5	26.0	0.95 (0.95)	0.84 (0.84)	0.76 (0.76)	0.0	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	29190.4	0.40 (0.40)	0.54 (0.54)	0.86 (0.86)	29216.4	0.40 (0.40)	0.54 (0.54)	0.84 (0.84)
LogMapLt	0:07:28	4	23.0	0.80 (1.00)	0.56 (0.70)	0.43 (0.54)	0.0	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	6653.8	0.73 (0.91)	0.67 (0.84)	0.62 (0.78)	6676.8	0.73 (0.91)	0.66 (0.83)	0.61 (0.76)
POMAP++	0:14:39	5	2.0	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.0	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.0	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	19.4	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Wiktionary	0:20:14	5	21.4	1.00 (1.00)	0.80 (0.80)	0.67 (0.67)	75.8	0.97 (0.97)	0.98 (0.98)	0.98 (0.98)	3483.6	0.91 (0.91)	0.79 (0.79)	0.70 (0.70)	3581.8	0.91 (0.91)	0.80 (0.80)	0.71 (0.71)

WebIsALOD

- Background: Web table interpretation
- Most approaches need typing information
  - DBpedia etc. have too little coverage on the long tail
  - Wanted: extensive type database

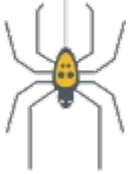
Rank	Country/Territory	Capital	Population	Year	Percent of Population
1	China	Beijing	20,693,000[1]	2012	1.52%
2	India	New Delhi	16,787,949[2]	2014	0.90%
3	Japan	Tokyo	13,189,000[3]	2011	10.32%
4	Philippines	Manila	12,877,253[4]	2015	12.44%
5	Russia	Moscow	11,541,000[5]	2011	8.07%
6	Egypt	Cairo	10,230,350	2012	11.10%
7	Indonesia	Jakarta	10,187,595[6]	2011	4.18%
8	Democratic Republic of the Congo	Kinshasa	10,125,000[7]	2012	12.30%
9	South Korea	Seoul	9,989,795[8]	2015	20.47%
10	Bangladesh	Dhaka	8,906,000 [9]	2011	5.56%
11	Mexico	Mexico City	8,851,080[10]	2010	7.51%
12	Iran	Tehran	8,846,782	2014	9.91%
13	United Kingdom	London	8,630,100[11]	2015	13.25%
14	Peru	Lima	8,481,415[12]	2012	28.29%
15	Thailand	Bangkok	8,249,117[13]	2010	12.42%
16	Colombia	Bogotá	7,613,303[14]	2011	16.17%
17	Vietnam	Hanoi	7,587,800[15]	2014	8.22%
18	*Hong Kong (China)*	Hong Kong	7,298,600[16]	2015	100%
19	Iraq	Baghdad	7,216,040[17]		21.59%
20	Singapore	Singapore	5,535,000[18]	2015	100%
21	Turkey	Ankara	5,150,072	2014	6.72%
22	Chile	Santiago	5,084,038[19]	2012	29.12%
23	Saudi Arabia	Riyadh	4,878,723[20]	2009	18.20%
24	Germany	Berlin	3,520,000[21]	2012	4.38%
25	Syria	Damascus	3,500,000		15.32%
26	Algeria	Algiers	3,415,811		8.45%
27	Spain	Madrid	3,233,527[22]	2012	6.84%
28	North Korea	Pyongyang	3,144,005		12.63%
29	Afghanistan	Kabul	3,140,853		10.28%
30	Kenya	Nairobi	3,138,369	2010	7.67%

Hertling & Paulheim: *WebIsALOD: Providing Hypernymy Relations extracted from the Web as Linked Open Data.* ISWC 2017

WebIsALOD

- Extraction of type information using Hearst-like patterns, e.g.,
  - T, such as X
  - X, Y, and other T
- Text corpus: common crawl
  - ~2 TB crawled web pages
  - Fast implementation: regex over text
  - “Expensive” operations only applied once regex has fired
- Resulting database
  - 400M hypernymy relations

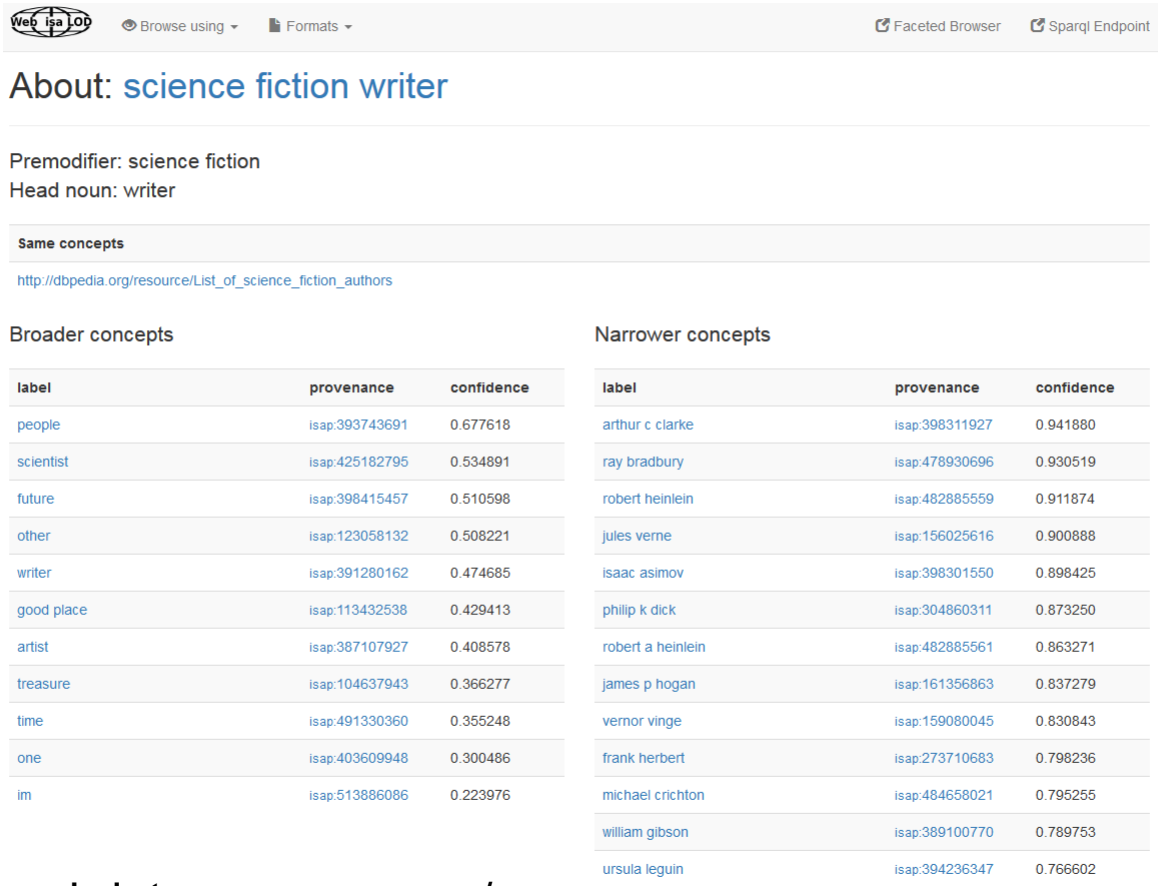
Common Crawl



Seitner et al.: *A large DataBase of hypernymy relations extracted from the Web.* LREC 2016

WebIsALOD

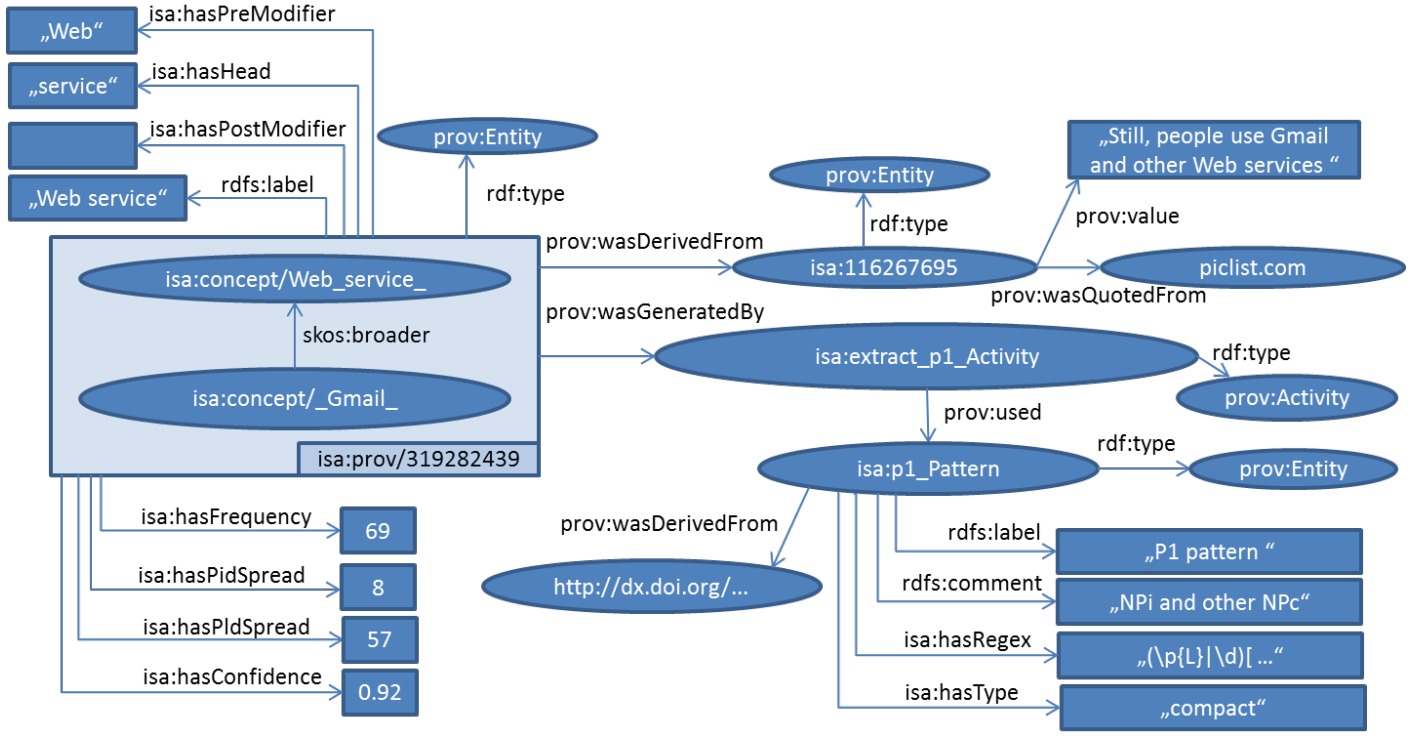
- Example:



http://webisa.webdatacommons.org/

WebIsALOD

- Initial effort: transformation to a LOD dataset
  - including rich provenance information



Hertling & Paulheim: *WebIsALOD: Providing Hypernymy Relations extracted from the Web as Linked Open Data.* ISWC 2017

WebIsALOD

- Estimated contents breakdown

Hertling & Paulheim: *WebIsALOD: Providing Hypernymy Relations extracted from the Web as Linked Open Data.* ISWC 2017

WebIsALOD

- Main challenge
  - Original dataset is quite noisy (<10% correct statements)
  - Recap: coverage vs. accuracy
  - Simple thresholding removes too much knowledge
- Approach
  - Train RandomForest model for predicting correct vs. wrong statements
  - Using all the provenance information we have
  - Use model to compute confidence scores

Hertling & Paulheim: *WebIsALOD: Providing Hypernymy Relations extracted from the Web as Linked Open Data.* ISWC 2017

WebIsALOD

- Current challenges and works in progress
  - Distinguishing instances and classes
    - i.e.: subclass vs. instance of relations
  - Splitting instances
    - *Bauhaus is a goth band*
    - *Bauhaus is a German school*
  - Knowledge extraction from pre and post modifiers
    - *Bauhaus is a goth band* → genre(Bauhaus, Goth)
    - *Bauhaus is a German school* → location(Bauhaus, Germany)

Hertling & Paulheim: *WebIsALOD: Providing Hypernymy Relations extracted from the Web as Linked Open Data.* ISWC 2017

Summary

- We have seen a couple of Knowledge Graphs
  - How they are built
  - What they contain
- For your project
  - Have a look at the fit for your domain
  - Try different options
- For a master's thesis later
  - Work on recent developments in our group

Questions?