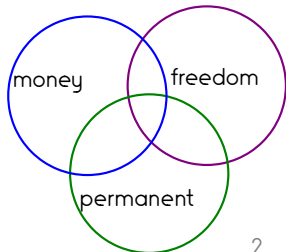


# A Hitchhiker's guide to Ontology

Fabian M. Suchanek  
Télécom ParisTech University  
Paris, France

# Fabian M. Suchanek

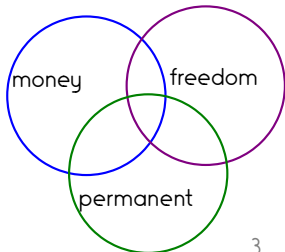


# Fabian M. Suchanek

2003: BSc in Cognitive Science  
Osnabrück University/DE

2005: MSc in Computer Science  
Saarland University/DE

2008: PhD in Computer Science  
Max Planck Institute/DE

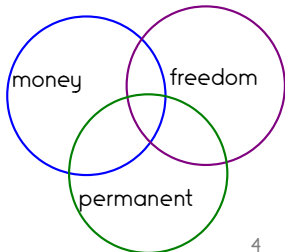


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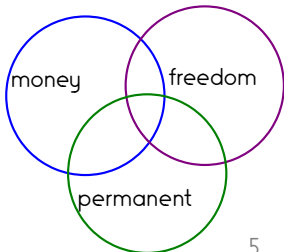
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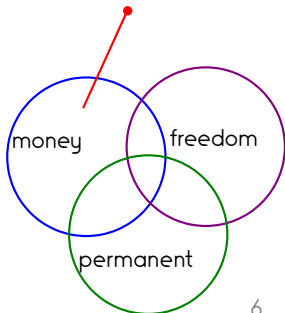
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2009: PostDoc at Microsoft Research  
Silicon Valley/US



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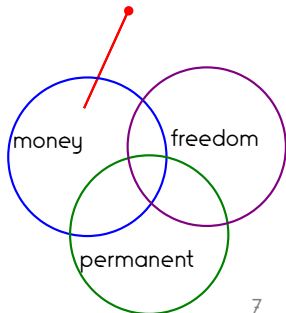
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2010: PostDoc

INRIA Saclay/FR



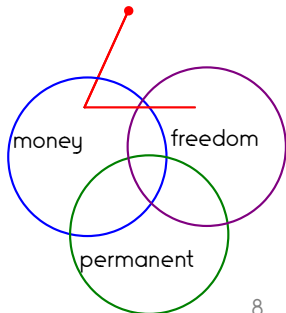
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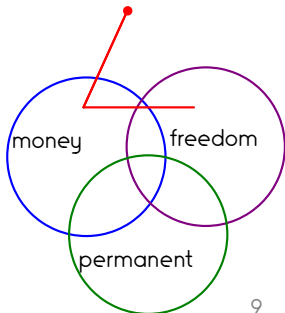


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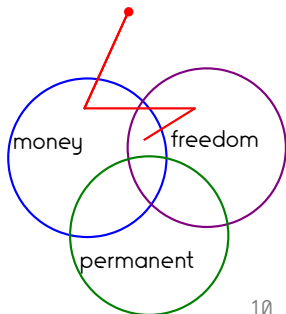


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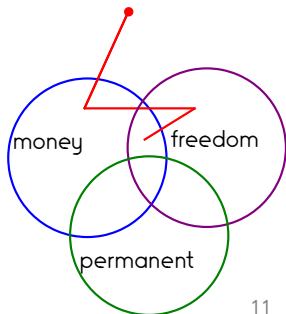
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Télécom ParisTech/FR



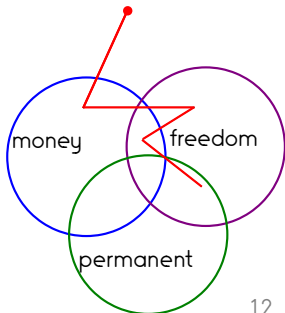
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# Fabian M. Suchanek

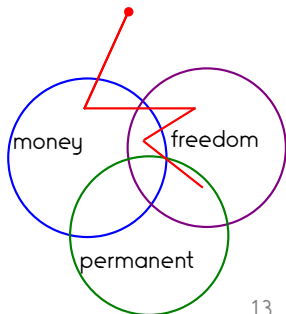
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Télécom ParisTech/FR

2016: Full Professor  
Télécom ParisTech/FR



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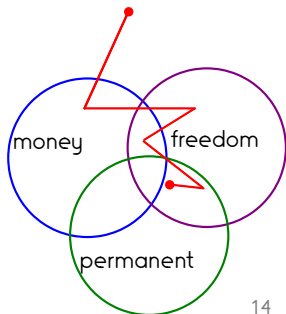
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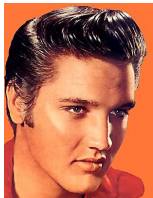
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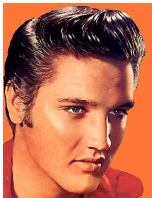
I am an Elvis Fan!



# Recent News Article: Elvis died (?)

Friday September 5th, 2018

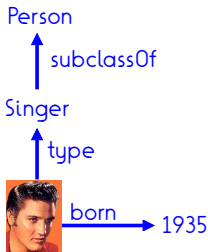
## Rock legend Elvis Presley (83) died



Pago Pago / American Samoa (dpo) - The King is dead. Already on Sunday, the former singer, musician and actor Elvis Presley (83) died peacefully in his adopted home Pago Pago on the Pacific island Tutuila in the circle of his family. Presley, who completed his active career in 1977, is considered the most successful solo artist in the world, with over one billion records sold.



# Knowledge Bases



For us, a knowledge base (KB) is a graph, where the nodes are entities and the edges are relations.

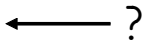
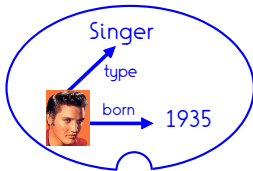
(We do not distinguish T-Box and R-Box.)

# Knowledge Base Life Cycle



Using  
knowledge bases->

Constructing  
knowledge bases->



Querying  
knowledge bases  
->

Mining  
incompleteness  
->

->end

# Extracting from Wikipedia

Elvis Presley



WIKIPEDIA  
The Free Encyclopedia

Elvis Presley was one of the best blah blah blub blah don't read this, listen to the speaker! blah blah blah blubl blah you are still reading this! blah blah blah blah blabbel blah



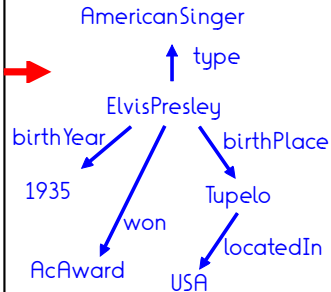
Born: 1935

In: Tupelo

...

Categories:

Rock&Roll, American Singers, Academy Award winners...



# Creating a large knowledge base

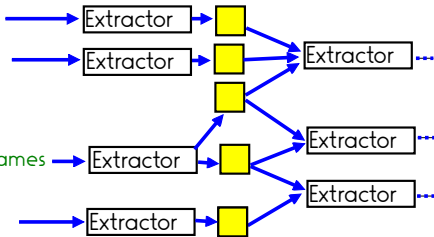


WIKIPEDIA  
The Free Encyclopedia



GeoNames

WordNet



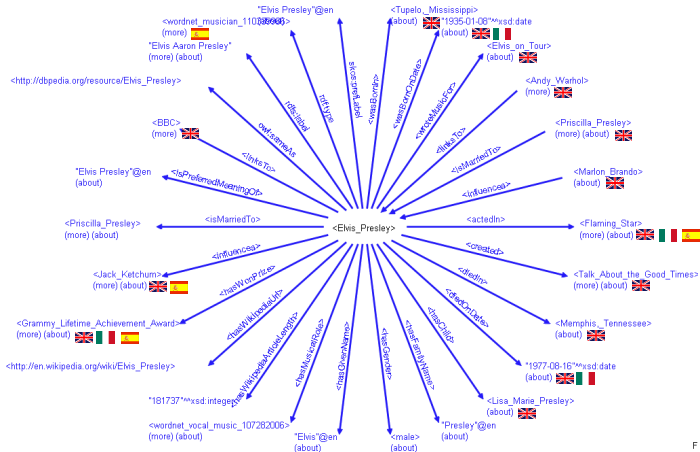
Intermediate extractors

- clean facts
- deduplicate facts and entities
- check consistency



ensuring high quality (95%)

# Example: YAGO about Elvis



# YAGO: a large knowledge base



<http://yago-knowledge.org>  
open code and open data

Wikipedia + WordNet  
time and space  
10 languages  
100 relations  
100m facts  
10m entities  
95% accuracy  
used by DBpedia  
and IBM Watson

Caveat:  
focus on  
precision!



[WWW'07, JWS'08, WWW'11 demo, AIJ'13, WWW'13 demo, CIDR'15, ISWC'16]



>regex

>regex&IBEX

22

# Repairing regular expressions

Regular expression: `([0-9]{3}/)+ [0-9][0-9][0-9]`

Missing word: `234 - 235 / 5 67`

# Repairing regular expressions

Regular expression: `(([0-9]{3}/)+[0-9][0-9][0-9]) | 234-235/567`

Missing word: `234 - 235 / 567`



# Repairing regular expressions

Regular expression:

$([0-9]\{3\}/)+ [0-9][0-9][0-9]$

Missing word:

234 - 235 / 5 67

1. Find the optimal partial matching

# Repairing regular expressions

Regular expression:

$([0-9]\{3\}/)+ [0-9][0-9][0-9]$

Missing word:

234 - 235 / 5 67

1. Find the optimal partial matching

# Repairing regular expressions

Regular expression:

`([0-9]{3} /? - ?)+ [0-9][0-9][0-9]`

Missing word:

234 - 235 / 5 67

1. Find the optimal partial matching
2. Find the optimal repair

# Repairing regular expressions

Regular expression:

$([0-9]\{3\}(/|-))+ [0-9][0-9][0-9]$

Missing word:

234 - 235 / 5 67

1. Find the optimal partial matching
2. Find the optimal repair

# Repairing regular expressions

Regular expression:

`([0-9]{3}[/-])+ [0-9]{3}`

Missing word:

234 - 235 / 567

1. Find the optimal partial matching
2. Find the optimal repair
3. Optimize and compress

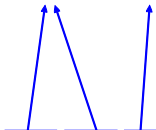
# Repairing regular expressions

Regular expression:

$(([0-9]{3})[/-])+ [0-9]{3}$

Missing word:

234 - 235 / 5 67



Caveat:

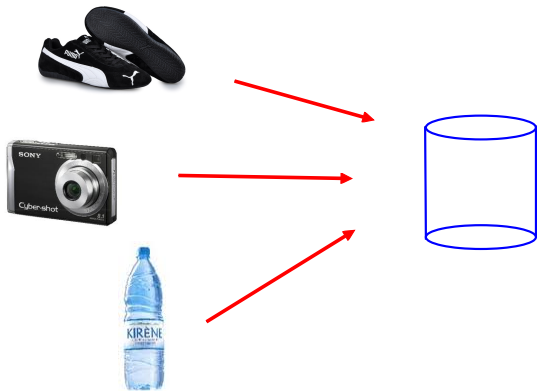
Repair  
defaults to  
disjunction

- better recall
- ca. 5 times shorter than a disjunction on 8 datasets



[ISWC 2017 demo,  
PAKDD 2018]

# Goal: Harvest entities from the Web



# IBEX: Collect unique ids

Puma PowerTech Blaze Running Shoe - Mens - Black/SilverSelect Width-M - UPC # 887128476661



© Whittleseacitylac

larger image

AUD99.02

Please Choose:

Size

- (EUR):40/(US):8.5/(UK):6
- (EUR):41/(US):9.5/(UK):7
- (EUR):42,(US):8.5,(UK):7.5
- (EUR):43,(US):9.5,(UK):8.5
- (EUR):44,(US):10,(UK):9
- (EUR):45,(US):11,(UK):10
- (EUR):46,(US):12,(UK):11

Add to Cart:



Item # 307110

UPC #887128476661

Go big or go home in the men's Puma PowerTech Blaze running shoe! This performance trainer has upgraded technical features with its OrthoLite® footbed, PowerTech™ cushioning and EverTrack™ abrasion-resistant outsole.

This men's running shoe is best for the **neutral** runner. What is pronation?

Breathable mesh upper with synthetic overlay for structured support  
Lace-up closure

887128476661

Unique identifiers can be found by a regular expression, and verified by a checksum.



# IBEX: Collect unique ids

Puma PowerTech Blaze Running Shoe - Mens - Black/SilverSelect Width-M - UPC # 887128476661



AUD99.02

Please Choose:

Size

- (EUR):40/(US)8.5/(UK):6
- (EUR):41/(US)9.5/(UK):7
- (EUR):42,(US):8.5,(UK):7.5
- (EUR):43,(US):9.5,(UK):8.5



Item # 307110

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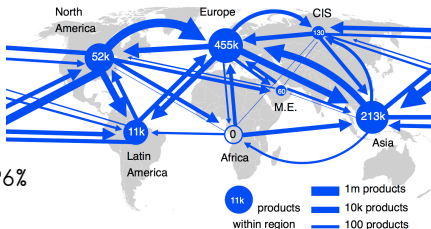
id	name	URL
1234	Puma PowerTech Blaze	u1
1234	Please choose	u1
1234	Puma PowerTech Blaze	u2
1234	Puma Shoe	u2
5678	Please choose	u3
5678	Sony Cybershot TS100	u3
...	...	...



# IBEX: analyses

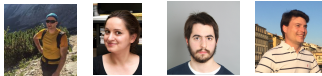
Found

- 13m email addresses with their name
- 235K chemical products
- 1.4m books
- 1.1m products
- ... with an accuracy of 73%-96%



Analyzed

- Global trade flow
- frequent email providers
- frequent people names and more



[WebDB 2015]

All data available online at

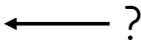
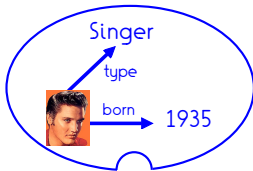
<http://resources.mpi-inf.mpg.de/d5/ibex/>

# Knowledge Base Life Cycle



Using  
knowledge bases->

Constructing ✓  
knowledge bases->

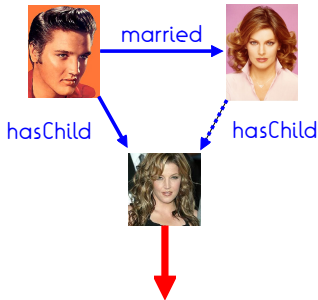


Querying  
knowledge bases  
->

Mining  
incompleteness  
->

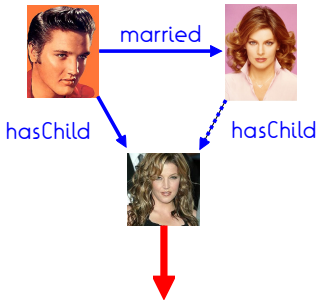
->end

# Incompleteness: Concrete facts



$$\text{married}(x,y) \wedge \text{hasChild}(x,z) \Rightarrow \text{hasChild}(y,z)$$

# Incompleteness: Concrete facts



$married(x,y) \wedge hasChild(x,z) \Rightarrow hasChild(y,z)$

But: Rule mining needs counter examples  
and RDF ontologies are positive only

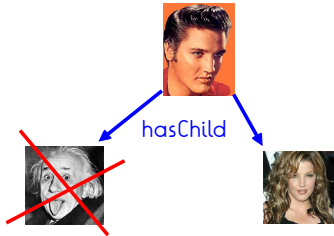
# Partial Completeness Assumption



Assumption:

If we know  $r(x, y_1), \dots, r(x, y_n)$ ,  
then all other  $r(x, z)$  are false.

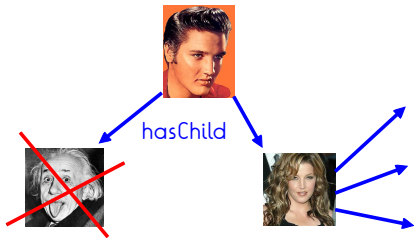
# Partial Completeness Assumption



Assumption:

If we know  $r(x, y_1), \dots, r(x, y_n)$ ,  
then all other  $r(x, z)$  are false.

# Partial Completeness Assumption



Assumption:

If we know  $r(x, y_1), \dots, r(x, y_n)$ ,  
then all other  $r(x, z)$  are false.



# AMIE finds rules in knowledge bases



AMIE

(5min)

$$r(x, y) \wedge r'(z, y) \Rightarrow r''(x, z)$$

AMIE is based on an efficient in-memory database implementation.

Caveat: rules cannot predict the unknown with high precision

# AMIE finds rules in knowledge bases



AMIE  
(5min)



$type(x, pope) \Rightarrow$   
 $diedIn(x, Rome)$



[WWW 2013, VLDB journal 2015]



>inc,rep,married

>inc

# Incompleteness: Existence of facts



marriedTo



the quality of YAGO w  
ls a precision of 95%, as  
tks to our brilliant algori

# Incompleteness: Existence of facts



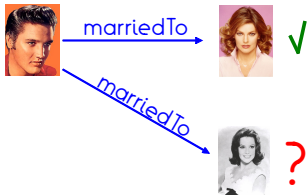
marriedTo



the quality of YAGO w  
is a precision of 95%, as  
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# Incompleteness: Existence of facts

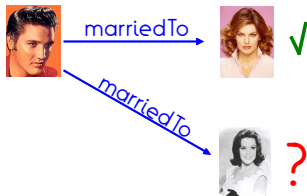


the quality of YAGO w  
ls a precision of 95%, as  
lks to our brilliant algori



Given a subject  $s$  and  
a relation  $r$ , do we know  
all  $o$  with  $r(s, o)$  ?

# Signals for Incompleteness



Closed World Assumption  
Partial Completeness Assumption  
Popularity oracle

No-change oracle  
Star-pattern oracle  
Class-oracle

AMIE oracle: Learn rules such as  
 $moreThan_1(x, hasParent) \Rightarrow complete(x, hasParent)$



# Signals for Incompleteness (F1)

Relation	CWA	PCA	card <sub>2</sub>	Popularity	No change	Star	Class	AMIE
diedIn	60%	22%	—	4%	15%	50%	<b>99%</b>	96%
directed	40%	96%	19%	7%	71%	0%	0%	<b>100%</b>
graduatedFrom	89%	4%	2%	2%	10%	89%	<b>92%</b>	87%
hasChild	71%	1%	1%	2%	13%	40%	<b>78%</b>	<b>78%</b>
hasGender	78%	<b>100%</b>	—	2%	—	86%	95%	<b>100%</b>
hasParent*	1%	54%	<b>100%</b>	—	—	0%	0%	<b>100%</b>
isCitizenOf*	4%	98%	11%	1%	4%	10%	5%	<b>100%</b>
isConnectedTo	87%	34%	19%	—	—	68%	88%	<b>89%</b>
isMarriedTo*	55%	7%	0%	3%	12%	37%	<b>57%</b>	46%
wasBornIn	28%	<b>100%</b>	—	5%	8%	0%	0%	<b>100%</b>



Relation	CWA	PCA	card <sub>2</sub>	Popularity	Star	Class	AMIE
alma_mater	<b>90%</b>	14%	5%	1%	87%	87%	87%
brother	93%	1%	—	1%	94%	<b>96%</b>	<b>96%</b>
child	70%	1%	—	1%	<b>79%</b>	72%	73%
country_of_citizenship*	42%	97%	10%	3%	0%	0%	<b>98%</b>
director	81%	<b>100%</b>	—	3%	94%	89%	<b>100%</b>
father*	5%	<b>100%</b>	6%	9%	89%	8%	<b>100%</b>
mother*	3%	<b>100%</b>	3%	10%	67%*	5%	<b>100%</b>
place_of_birth	53%	<b>100%</b>	7%	5%	55%	0%	<b>100%</b>
place_of_death	89%	35%	1%	2%	81%	81%	<b>96%</b>
sex_or_gender	81%	<b>100%</b>	6%	3%	92%	91%	<b>100%</b>
spouse*	<b>57%</b>	7%	—	1%	54%	54%	55%



\* = bi ased training sample

# Incompleteness: Existence of facts



marriedTo



marriedTo



AMIE can predict incompleteness

- bornIn: 100% F1-measure
- diedIn: 96%
- directed: 100%
- graduatedFrom: 87%
- hasChild: 78%
- isMarriedTo: 46%
- ... and more.



[WSDM 2017]

>rep&married

>married



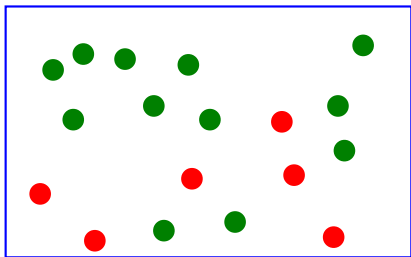
# Are all people married?



# Are all people married?



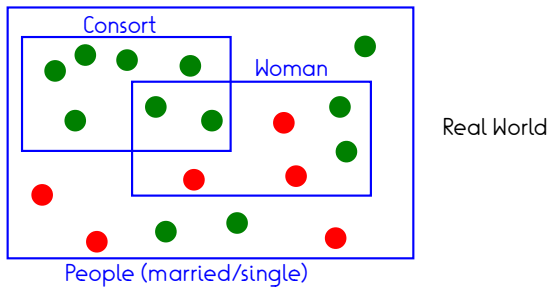
# Are all people married?



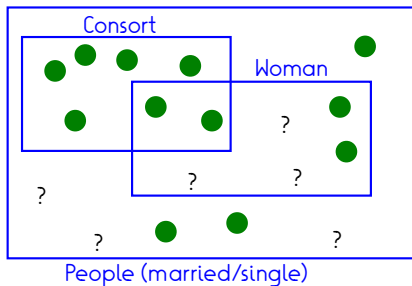
Real World

People (married/single)

# Are all people married?

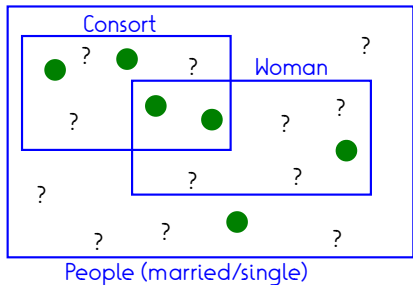


# Are all people married?



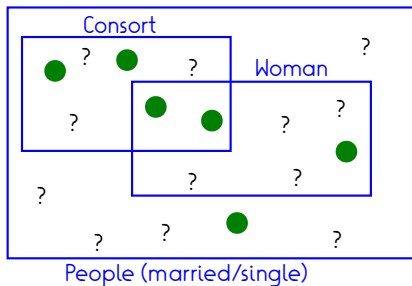
Knowledge base  
under the  
Open World Assumption

# Are all people married?



Knowledge base  
under the  
Open World Assumption  
and incompleteness

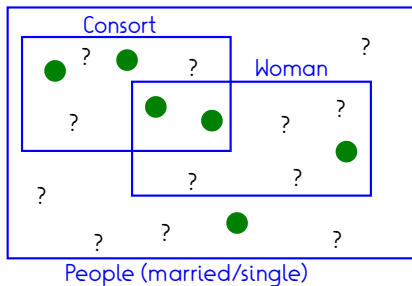
# Are all people married?



Knowledge base  
under the  
Open World Assumption  
and incompleteness

Baseline 1: Obligatory if all instances have it

# Are all people married?



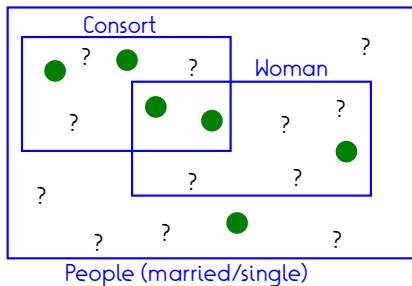
Knowledge base  
under the  
Open World Assumption  
and incompleteness

Baseline 1: Obligatory if all instances have it ✗

Baseline 2: Obligatory if at least n% of instances have it



# Are all people married?



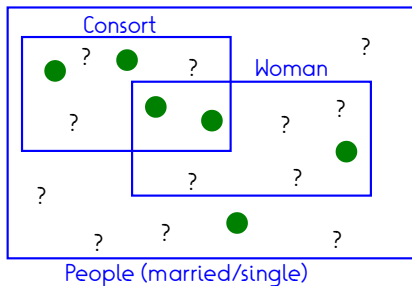
Knowledge base  
under the  
Open World Assumption  
and incompleteness

Baseline 1: Obligatory if all instances have it ✗

Baseline 2: Obligatory if at least n% of instances have it  $\rightarrow$  Woman ✗

Baseline 3: Obligatory if all instances that have it fall in the class

# Are all people married?



Knowledge base  
under the  
Open World Assumption  
and incompleteness

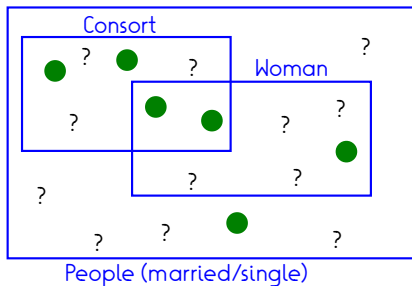
Baseline 1: Obligatory if all instances have it ✗

Baseline 2: Obligatory if at least n% of instances have it => Woman ✗

Baseline 3: Obligatory if all instances that have it fall in the class

=> Person ✗

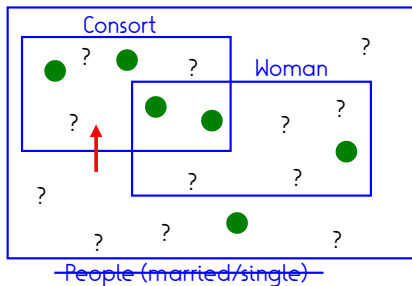
# Are all people married?



Knowledge base  
under the  
Open World Assumption  
and incompleteness

Theorem: If the KB is sampled randomly uniformly from the real world, and if the density of an attribute changes when we go into an intersecting class, then the attribute cannot be obligatory.

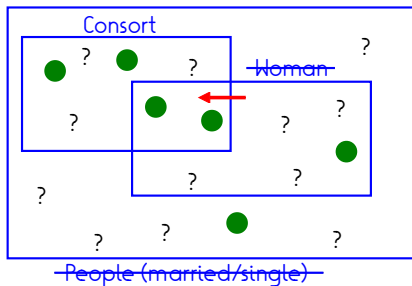
# Are all people married?



Knowledge base  
under the  
Open World Assumption  
and incompleteness

Theorem: If the KB is sampled randomly uniformly from the real world, and if the density of an attribute changes when we go into an intersecting class, then the attribute cannot be obligatory.

# Are all people married?

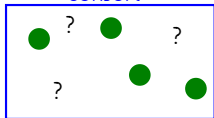


Knowledge base  
under the  
Open World Assumption  
and incompleteness

Theorem: If the KB is sampled randomly uniformly from the real world, and if the density of an attribute changes when we go into an intersecting class, then the attribute cannot be obligatory.

# Determining obligatory attributes

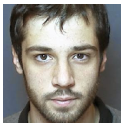
Consort



We can predict obligatory attributes of classes with up to 80% precision (at 40% recall).

Caveat:

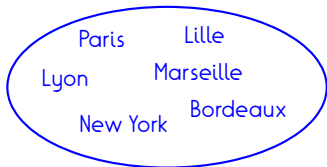
We do not actually predict, but exclude.



[WWW 2018]

# Incompleteness: Missing entities

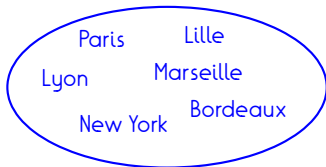
We have the following cities in our knowledge base:



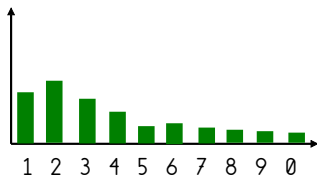
Are there any cities missing?

# Incompleteness: Missing entities

We have the following cities in our knowledge base:



Are there any cities missing?



- 1) Take the number of inhabitants of each city
- 2) Take the first digit
- 3) Plot the number of cities per first digit



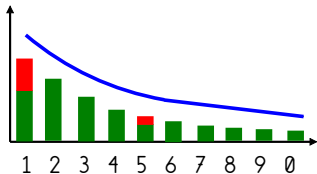
# Incompleteness: Missing entities

Benford's law says that the first digit  $d$  appears with probability

$$\log_{10}\left(1 + \frac{1}{d}\right)$$

=> We can give a minimum numbers of cities that are missing to make the distribution representative of the real world.

(For other classes, we can learn a parameter for a variant of the law.)



[ISWC 2018]

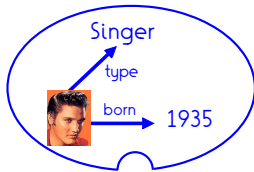


# Knowledge Base Life Cycle



Using  
knowledge bases->

Constructing ✓  
knowledge bases->



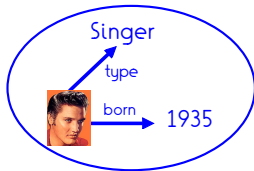
← ?  
Querying  
knowledge bases  
->

Mining ✓  
incompleteness  
->

->end

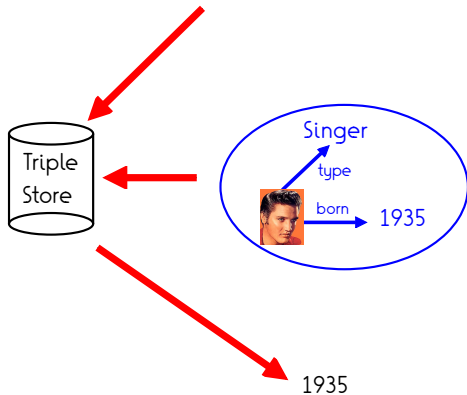
# Querying Knowledge Bases

When was Elvis born?



# Querying Knowledge Bases

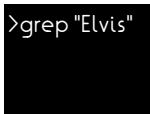
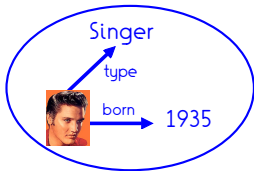
When was Elvis born?



# Querying Knowledge Bases

When was Elvis born?

If I have only  
a single query

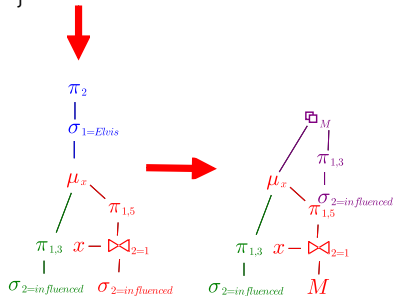


1935

# Querying Knowledge Bases

Who were the people that  
Elvis influenced (transitively)?

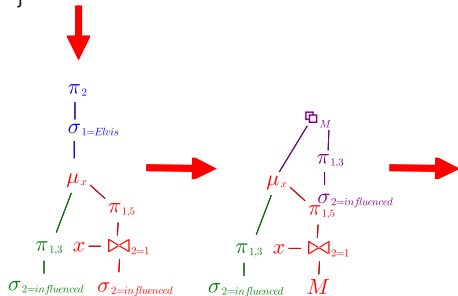
SELECT ?a {  
 <Elvis> <influenced>+ ?a  
}



# Querying Knowledge Bases

Who were the people that  
Elvis influenced (transitively)?

```
SELECT ?a {  
  <Elvis> <influenced>+ ?a  
}
```



```
while sort -t '$\t' -k 1 -k  
<(cat tmp/lock_mat1  
join -t '$\t' -1 2 -2 1 -o 1  
<(sort -t '$\t' -k 1 tmp/d  
l comm -23 - tmp/full2  
mv tmp/new2 tmp/del  
sort -u -merge -o tmp  
[ -s tmp/delta2 ];  
do continue; done
```

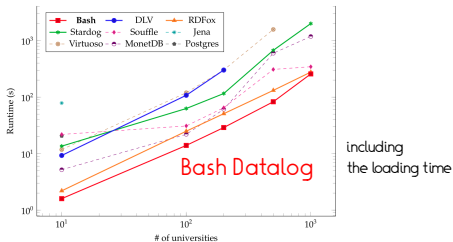
# Querying Knowledge Bases

VLDB reviewer: Unix Shell commands to run queries is not very innovative.  
The DB community exists to overcome the shortcomings of this approach



# Querying Knowledge Bases

VLDB reviewer: Unix Shell commands to run queries is not very innovative.  
The DB community exists to overcome the shortcomings of this approach



	Bash	RDFox	BigDatalog	Stardog
LiveJournal (69M edges)	2min	1min	9min	15min
Orkut (117M edges)	2.5min	2min	30min	18min
Friendster (2586M edges)	4:30h	OOM	OOS	>10h
WikiData (2100M edges)	1h	OOM		

# Convert SPARQL to Bash online

## Bash Datalog

Answering Datalog Queries with Unix Shell Commands

About

Datalog mode

SPARQL/OWL mode

API

## SPARQL query

```
BASE <http://yago-knowledge.org/resource/>
SELECT ?a WHERE {
  <Elvis_Presley> <influenced>+ ?a.
}
```

Convert to bash script

Download script

## Bash script

```
read_ntriples() { $awk -F" " '{ sub(" ", "\t"); sub(" ", "\t"); sub(/ \.\/, ""); print $0 }' "$@"; }
conv_ntriples() { $awk -F'\t' '{ print $1 " " $2 " " $3 " ." }'; }

touch tmp/mat0 tmp/mat1
$awk -v FS='\t' '($1 == "<http://yago-knowledge.org/resource/Elvis_Presley>" && $2 == "<http://yago-knowledge.org/resource/influenced>") { print $3 >> "tmp/mat0" }'
```

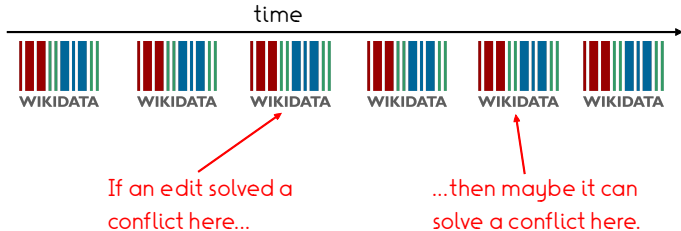


[ISWC 2018]

<https://thomasrebele.org/projects/bashlog/>

>wikihist

# Correcting Knowledge Bases



On January 8th, user Bob changed the gender from "m" to "man" for an entity that

- is a person
- is an American rock singer
- was born in 1935
- is a living being

can we do the same for all people?  
or just for American rock singers?  
or only for people born in 1935?  
or in general for all living beings?

# Correcting Knowledge Bases

time



WIKIDATA



WIKIDATA



WIKIDATA



WIKIDATA



WIKIDATA



WIKIDATA

We mine correction rules of the form

$$[I(\vec{x})]: E(\vec{x}, \vec{y}, \vec{z}) \rightarrow \langle M^-(\vec{x}, \vec{y}), M^+(\vec{x}, \vec{y}) \rangle$$



Remove "m"

Add "man"

If  $x$  is an instance of "person", and the gender is "m"

Constraint: The gender has to be "male", "female", "man", "woman", ...



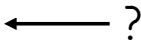
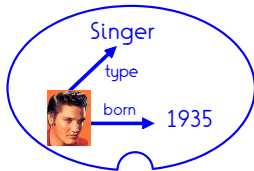
[WWW 2019]

# Knowledge Base Life Cycle



Using  
knowledge bases->

Constructing ✓  
knowledge bases->



Querying ✓  
knowledge bases  
->

Mining ✓  
incompleteness  
->



->end

# Combinatorial Creativity



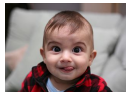
# Description Logics do not work

$Mop \equiv Tool \sqcap \exists has.Stick \sqcap \exists has.Strings$

$BabyMop \equiv$

$Romper \sqcap \exists has.(Mop \sqcap \neg \exists has.Stick) \sqcap \exists has.Baby$

$\equiv \dots \sqcap \exists has.\perp \sqcap \dots$



# Language for Combinatorial Creativity

$Mop \equiv Tool \sqcap \exists has.Stick \sqcap \exists has.Strings$

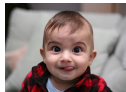
Subtraction:  $Mop - \exists has. \top \equiv Tool \sqcap \exists has.Strings$

Addition:  $Mop + \exists has. \top \equiv Mop$

Succession:  $Mop \rightarrow \exists u. \top \equiv Stick$

Selection\*:  $Mop \uparrow \exists has. \top \equiv \exists has.Stick$

$Romper + \exists has.(Mop - \exists has.Stick) + \exists has.Baby$   
 $\equiv BabyMop$





# Language for Combinatorial Creativity

$Mop \equiv Tool \sqcap \exists has.Stick \sqcap \exists has.Strings$

Subtraction:  $Mop - \exists has.T \equiv Tool \sqcap \exists Strings$

Addition:  $Mop + \exists has.T \equiv Mop$

Succession:  $Mop \rightarrow \exists r.T \equiv Stick$

Selection\*:  $Mop \uparrow \exists has.T \equiv \exists has.Stick$

## 1) Descriptive experiments

TECH

### The 25 Best Inventions

TIME Staff | Nov. 19, 2015



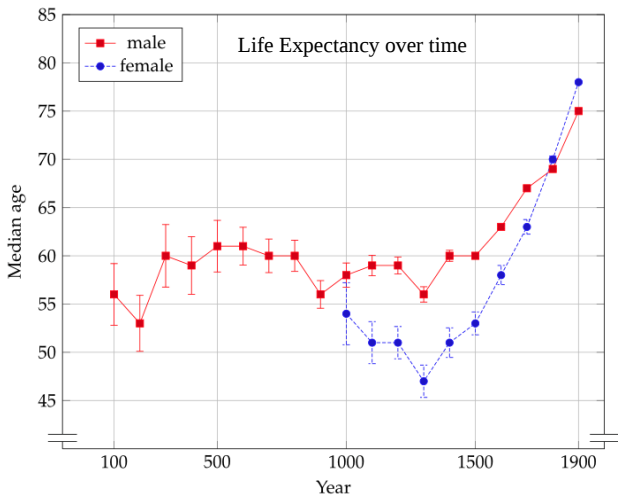
## 2) Generative experiments

1/3 nonsense, 1/3 exists,  
1/3 "imaginable"

[ISWC 2016  
paper & demo]

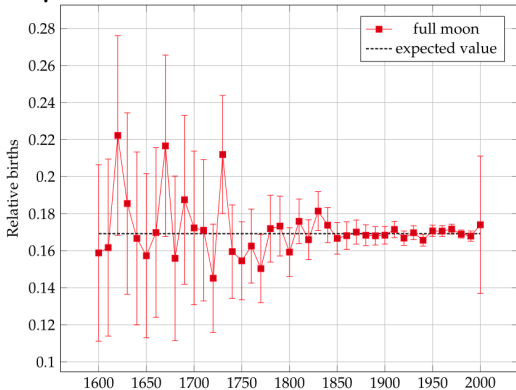
>DigitalHum

# YAGO for the Digital Humanities





# People born on a full moon day



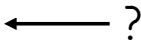
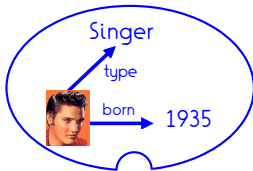
[AKBC 2013,  
VLDB 2014 vision,  
LDOW 2018]

# Knowledge Base Life Cycle



Using  
knowledge bases-> ✓

Constructing ✓  
knowledge bases->



Querying ✓  
knowledge bases  
->

Mining ✓  
incompleteness  
->



->end

# Is Elvis dead?

Friday September 5th, 2018

## Rock legend Elvis Presley (83) died



Pago Pago / American Samoa (dpo) - The King is dead. Already on Sunday, the former singer, musician and actor Elvis Presley (83) died peacefully in his adopted home Pago Pago on the Pacific island Tutuila in the circle of his family. Presley, who completed his active career in 1977, is considered the most successful solo artist in the world, with over one billion records sold.

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## Der Postillon

Ehrliche Nachrichten - unabhängig, schnell, seit 1845

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Magazine

↑ subclass

Satirical-Magazine

↑ type



**Der Postillon**

Ehrliche Nachrichten - unabhängig, schnell, seit 1845

# Fake news!!



# Knowledge Base Life Cycle

