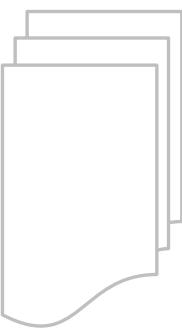


Conclusion

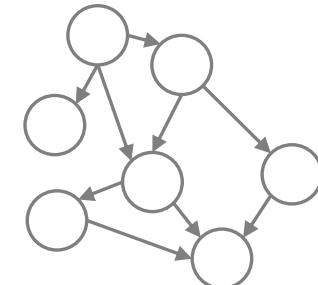
- CRITICAL SUMMARY
- SUCCESS STORIES
- DATASETS, SHARED TASKS, SOFTWARE
- FUTURE DIRECTIONS

Part 1: Knowledge Graphs



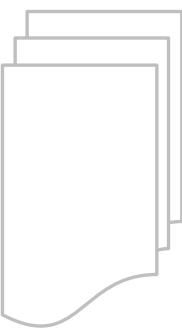
**Part 2:
Knowledge
Extraction**

**Part 3:
Graph
Construction**



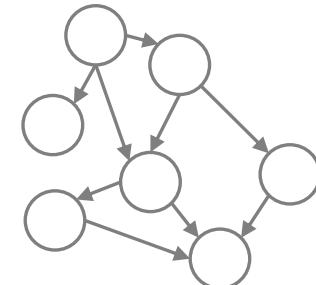
Part 4: Critical Analysis

Part 1: Knowledge Graphs



**Part 2:
Knowledge
Extraction**

**Part 3:
Graph
Construction**

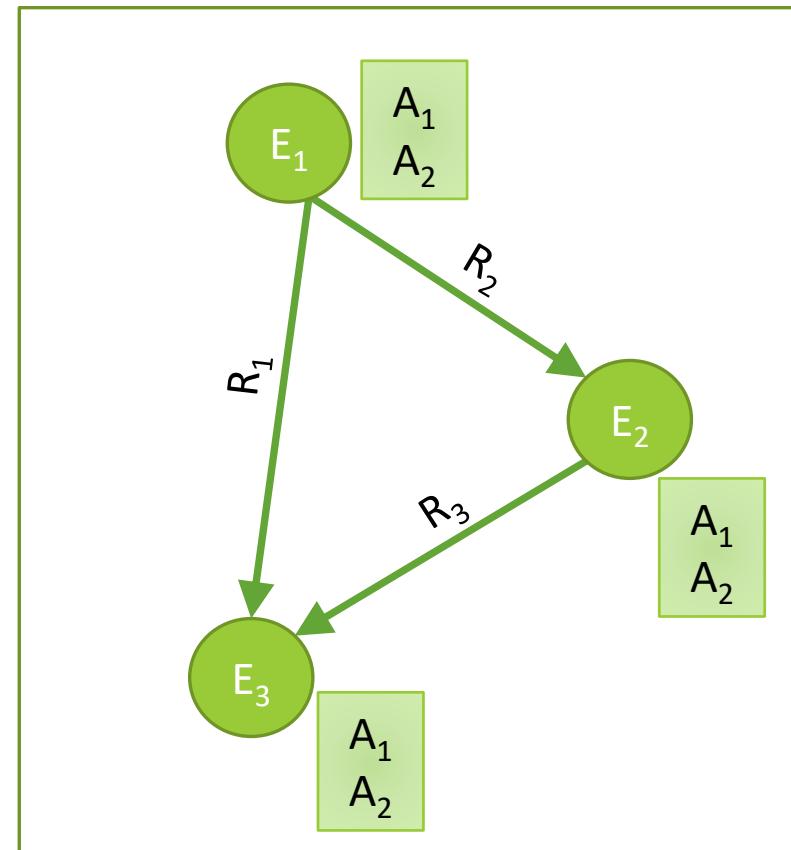


Part 4: Critical Analysis

Critical Summary

Basic problems

- **Who** are the entities (nodes) in the graph?
- **What** are their attributes and types (labels)?
- **How** are they related (edges)?



Two perspectives

Knowledge Extraction

- **Who** are the entities (nodes) in the graph?
 - Named Entity Recognition
 - Entity Coreference
- **What** are their attributes and types (labels)?
 - Named Entity Recognition
- **How** are they related (edges)?
 - Relation Extraction
 - Semantic Role Labeling

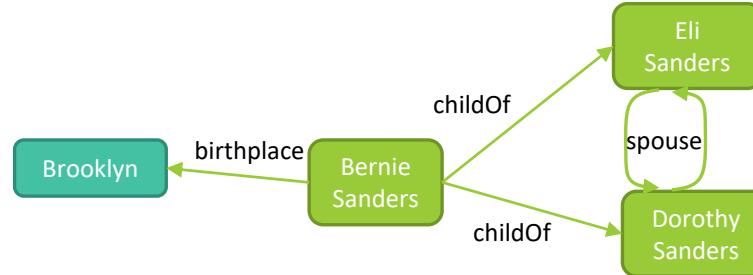
Graph Construction

- **Who** are the entities (nodes) in the graph?
 - Entity Linking
 - Entity Resolution
- **What** are their attributes and types (labels)?
 - Collective Classification
- **How** are they related (edges)?
 - Link Prediction

NLP

Corpus

Entity resolution,
Entity linking,
Relation extraction...



Document

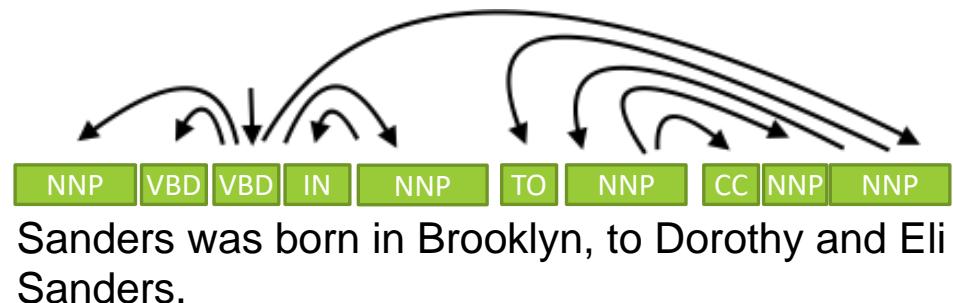
Within-doc Coreference...

Bernie..
Bernie Sanders...
the city
Mrs. Sanders..
.. his mother ..
his father
he Eli

Person Location Person Person
Sanders was born in Brooklyn, to Dorothy and Eli
Sanders.

Sentence

Dependency Parsing,
Part of speech tagging,
Named entity recognition...



Dependency Parsing



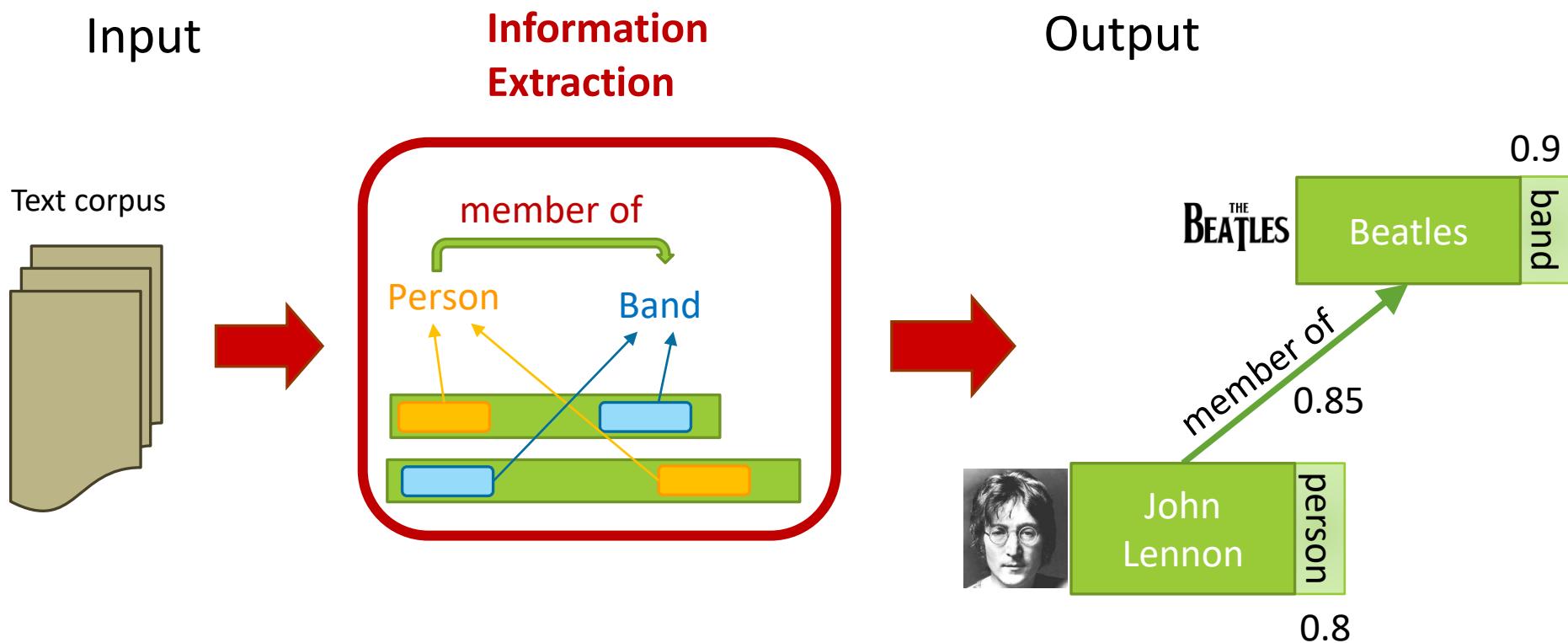
How it is done:

- Model: score trees using features
 - Lexical: words, POS, ...
 - Structure: distance, ...
- Prediction: Search over trees
 - greedy, spanning tree, belief propagation, dynamic prog, ...

Uses in KG Construction:

- Incredibly useful for relations!
 - What verb is attached?
 - Relation to which mention?
- Incredibly useful for attributes!
 - Appositives: "X, the CEO, ..."
- Paths are used as surface relations

Information Extraction



Information Extraction

Single extractor



Fusing multiple extractors

Graph Construction Issues

Extracted knowledge is:

- ambiguous



- incomplete



- inconsistent



Two classes of Probabilistic Models

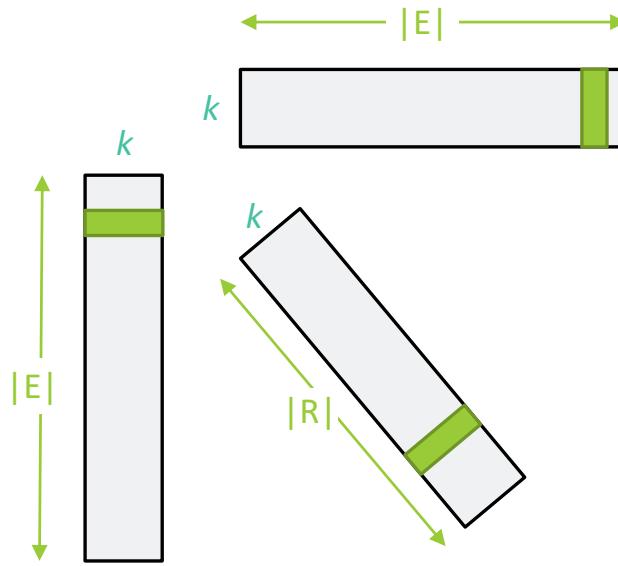
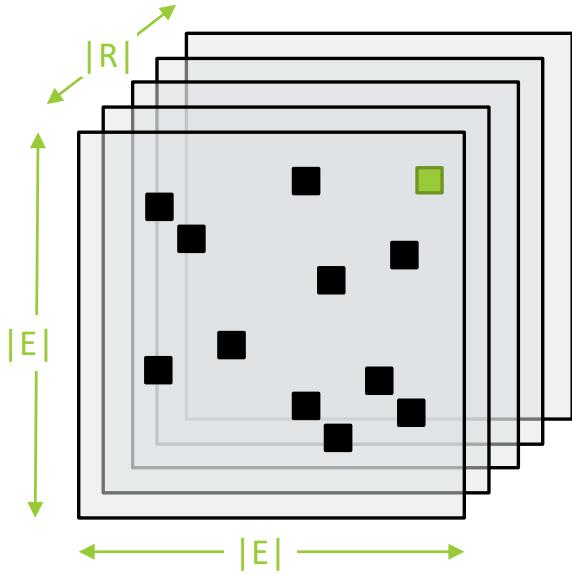
GRAPHICAL MODELS

- Possible facts in KG are variables
- Logical rules relate facts
- Probability \propto satisfied rules
- Universally-quantified

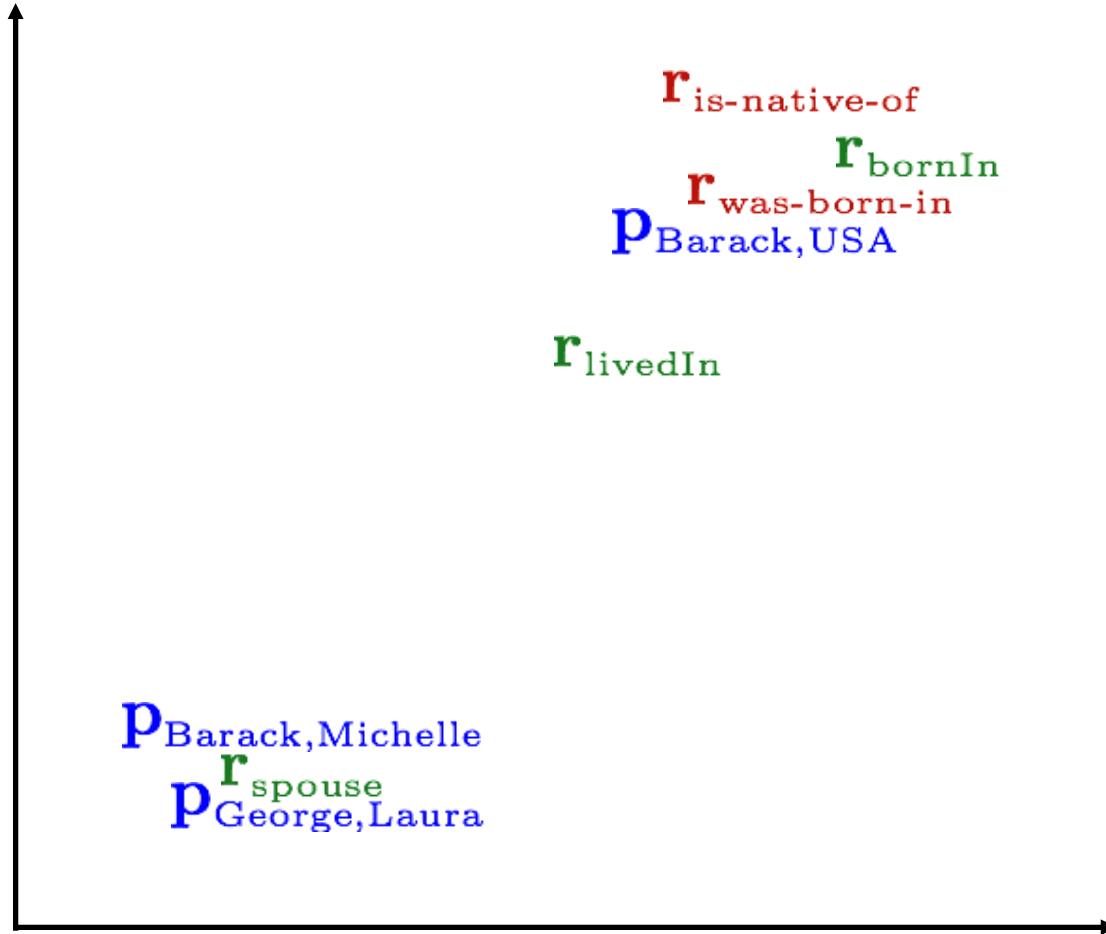
RANDOM WALK METHODS

- Possible facts posed as queries
- Random walks of the KG constitute “proofs”
- Probability \propto path lengths/transitions
- Locally grounded

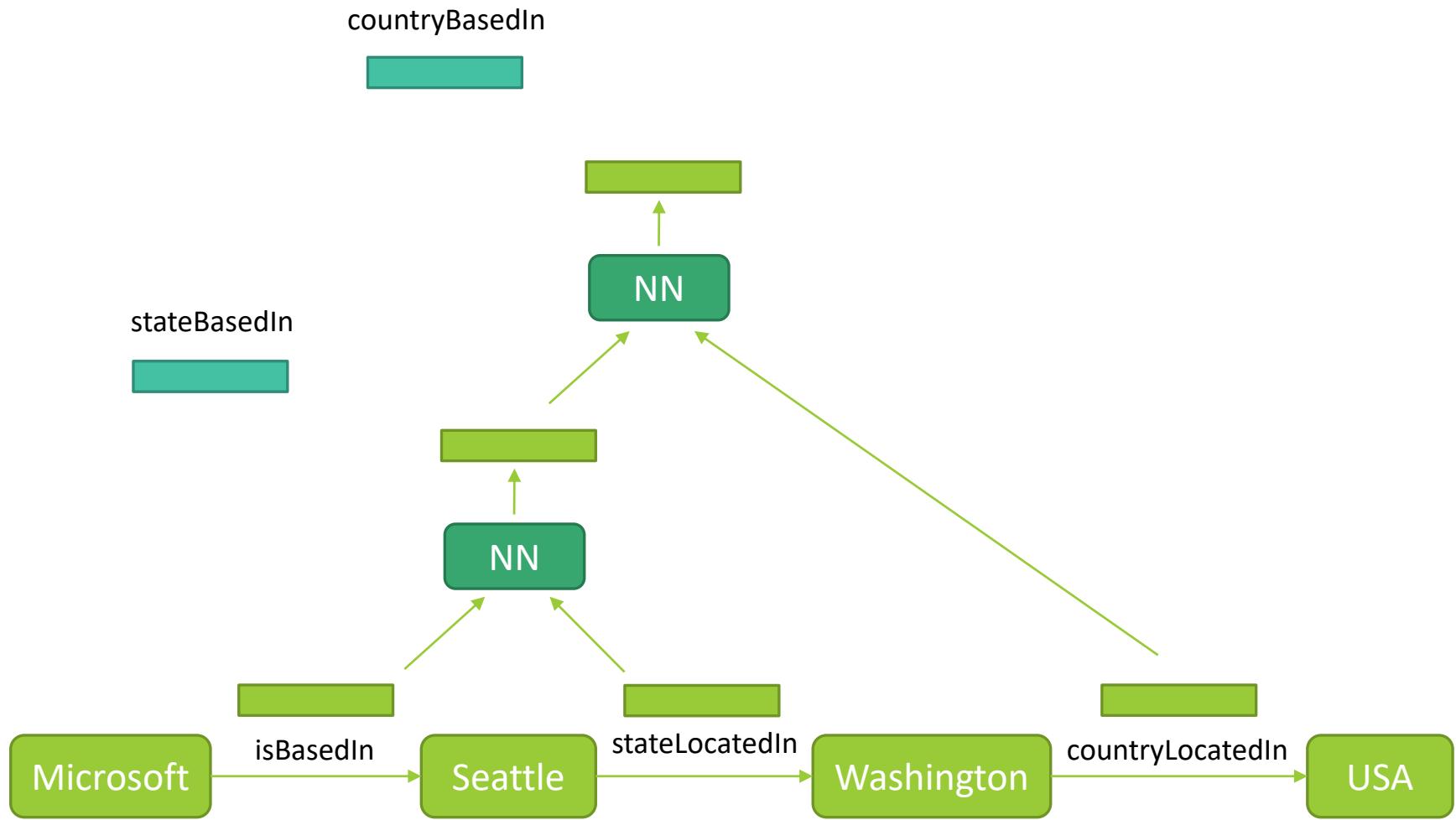
Factorize the KG Tensor



Relation Embeddings



Neural KG Completion



Success Stories

Success story: OpenIE

- **Key contributions:**
 - No need for human defined relation schemas
 - First ever successful open-source open domain IE
- ReVerb
 - Input = Clueweb09 corpus (1B web pages)
 - Output = 15M high-precision extractions

Success story: OpenIE (ReVerb)



Open Information Extraction

openie.allenai.org



Argument 1: entity:The Beatles

Relation:

Argument 2:

All Search

all

location (21)

film location (18)

statistical region (16)

name source (15)

travel destination (14)

misc.

[more types](#)

were bigger than **Jesus** (100)

came to America (95)

appeared on **The Ed Sullivan Show** (88)

broke up in 1970 (56)

Here Comes the Sun (46)

came to America (45)

is for the future (44)

are a great band (42)

perform on **The Ed Sullivan Show** (39)

were **Musical ensemble** (36)

are a great band

x

Extracted Synonyms:

were
is
was

Extracted from these sentences:

are **The Beatles** are the **best band** , hands down but Oasis did make a great cover . (via ClueWeb12)

The Beatles are a **great band** . (via ClueWeb12)

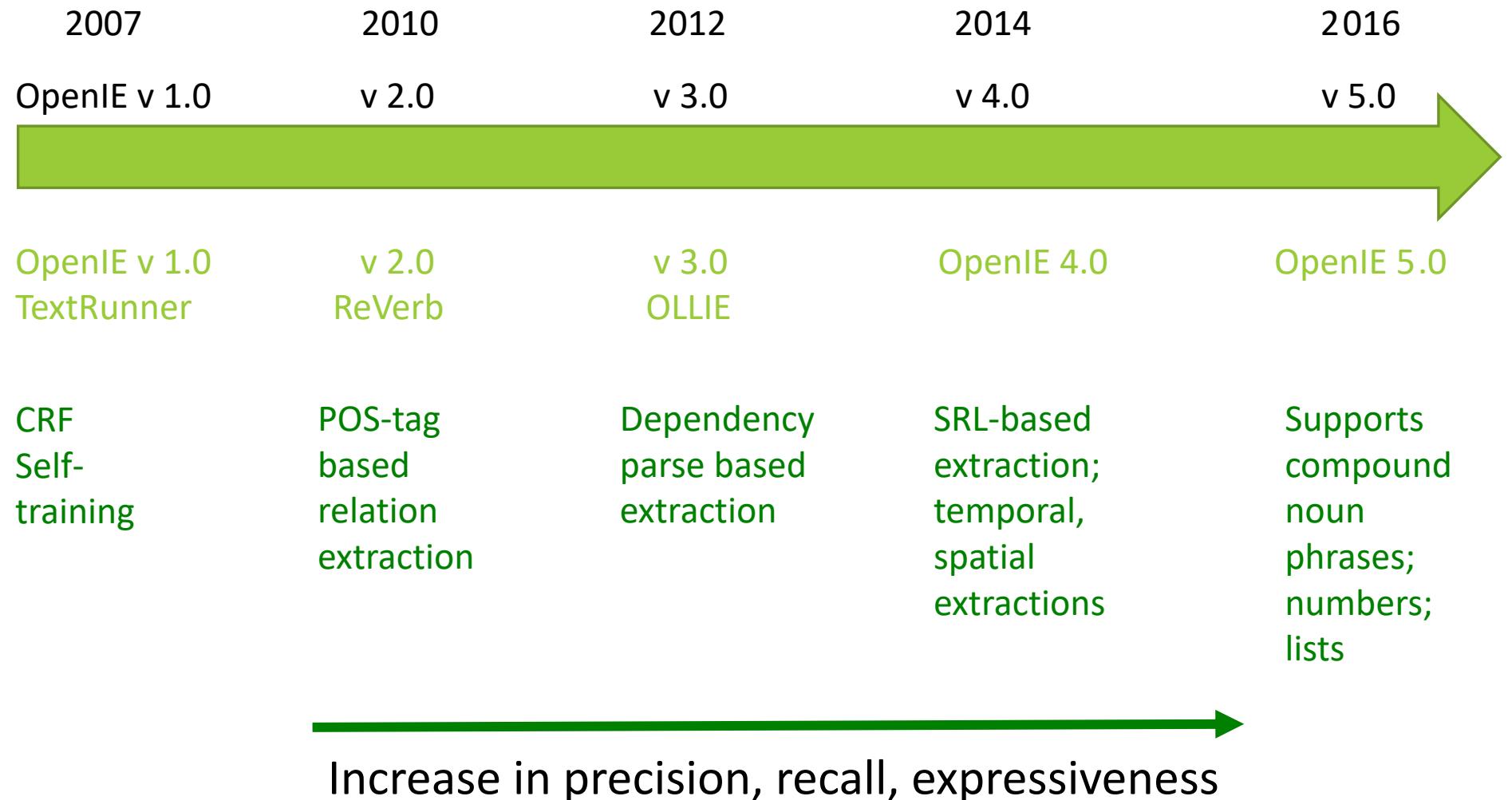
The Beatles are the **best band** . (via ClueWeb12)

The Beatles are the **greatest band** ... Started 1 month ago by georgedcc Yeah , Songs in the Key of Life is a bit much for 1 listen . (via ClueWeb12)

The Beatles , arguably , are the **greatest band** , and may or may not have the greatest name . (via ClueWeb12)

The point is , from my view , **The Beatles** are a **good band** , but way behind the greatest artists to ever grace rock . (via ClueWeb12)

Open IE Systems



Success story: NELL

NELL Knowledge Base Browser

CMU Read the Web Project

Search

log in | preferences | help/instructions | feedback

categories relations

everypromotedthing
abstractthing
event
convention
musicfestival
protestevent
meetingeventtitle
conference
mlconference
weatherphenomenon
sportsevent
sportsgame
race
olympics
grandprix
crimeorcharge
earthquakeevent
election
bombingevent
militaryeventtype
militaryconflict
productlaunchevent
filmfestival
roadaccidenteve
meetingeventtype
eventoutcome
mlalgorithm
physiologicalcondition
disease

beatles (musicartist)

literal strings: [BEATLES](#), [Beatles](#), [beatles](#)

Help NELL Learn!

NELL wants to know if these beliefs are correct.
If they are or ever were, click thumbs-up. Otherwise, click thumbs-down.

- [beatles](#) is a [musical artist](#)  
- [beatles](#) is a musician in the [genre classic_pop](#) (musicgenre)  
- [beatles](#) is a musician in the [genre pop](#) (musicgenre)  
- [beatles](#) is a musician in the [genre rock](#) (musicgenre)  
- [beatles](#) is a musician in the [genre classic_rock](#) (musicgenre)  

categories

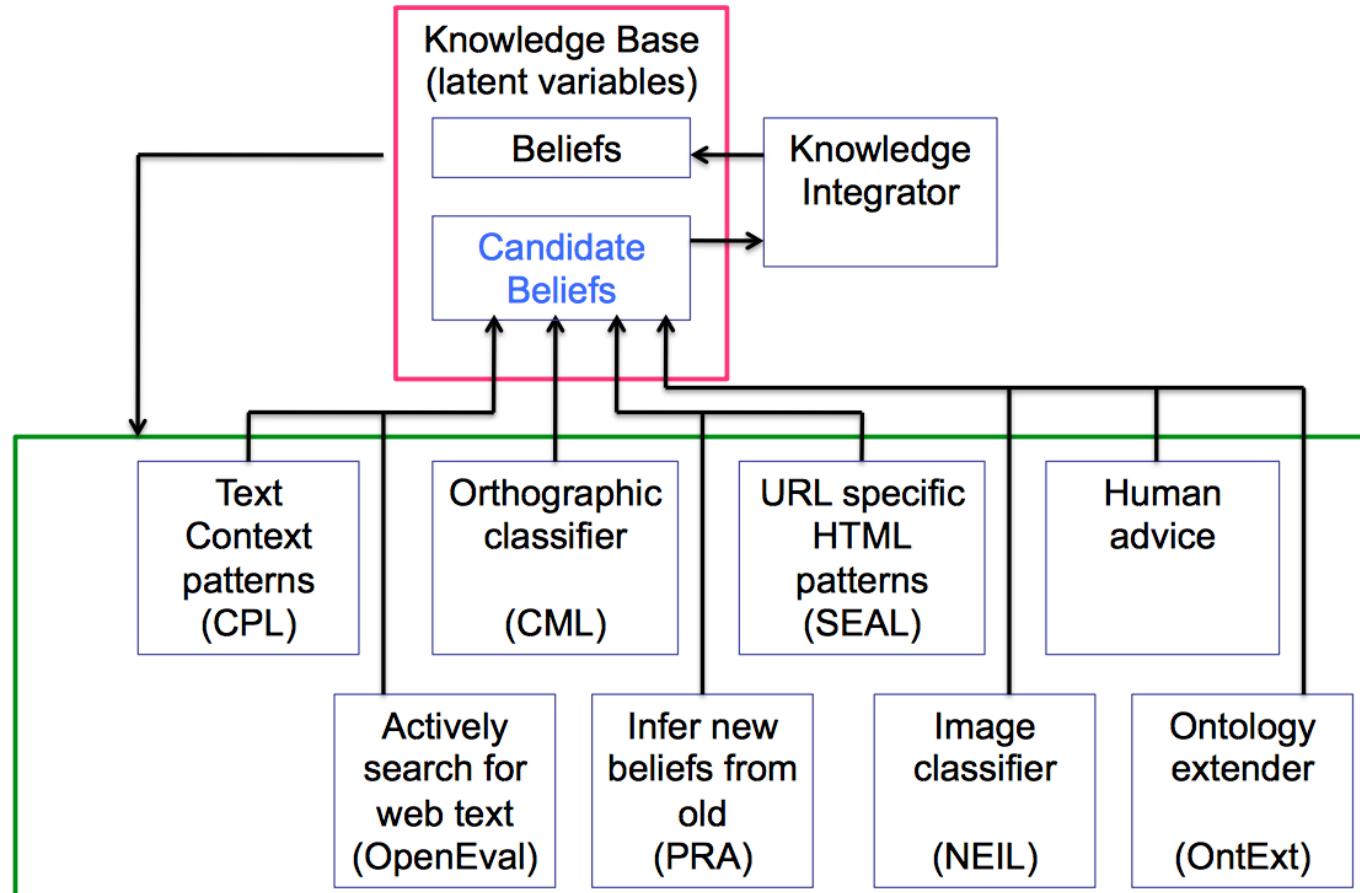
- [musicartist](#)(100.0%)
 - MBL @198 (100.0%) on 07-feb-2011 [Promotion of musicartist:beatles musicartistgenre musicgenre:classic_rock]
 - CPL @1021 (80.9%) on 14-oct-2016 ["numerous other artists including _ "traducidas de _ " incluidas en" _ had a guitar player" "early pioneers such as _ "controversial photo of _ "distressed image of _ "D-tracks of _ "Beatles Come Together" "ohne die _ "opening band for _ "American acts like _ "classic acts like _ "performance footage of _ " were the perfect band" _ "record label" "record album by _ "les paroles de _ " never recorded the song" "such renowned artists as _ " did a few songs" "Top artists include _ "crazy lives of _ "UK artists such as _ "Lennon started _ " "musical talent" " 'Birthplace" " 'harmonies" "Tour , starring _ " "last days" " 'fourth album" " _ sixth studio album" " _ original recordings" "They were also pushing _ "She Said by _ "Other artists featured include _ "Post general comments related to _ "track also shows _ "such major artists as _ "time favorite band is _ "past masters such as _ "pop hooks of _ "popular musicians like _ "pop icons such as _ "music artists like _ "music bands like _ "pop stars such as _ "pop influenced by _ "

Success story: NELL

- 2362 predicates
- 738K constraints between predicates
mutual exclusion, subset and generalization constraints
- 50 million candidate beliefs
3 million high-confidence beliefs
- **Key technical contributions:**
 - Never ending learning,
 - Coupled bootstrapping

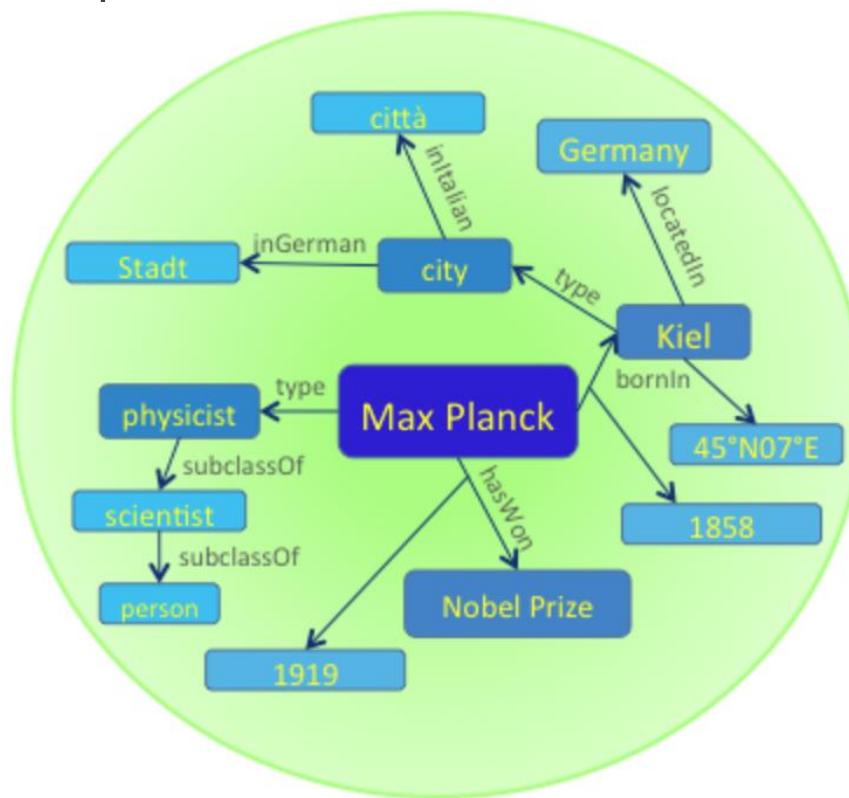
Success story: NELL

NELL Architecture



Success story: YAGO

- Derived from Wikipedia infoboxes, WordNet and GeoNames
- 350K entity types, 10M entities, 120M facts
- Temporal and spatial information



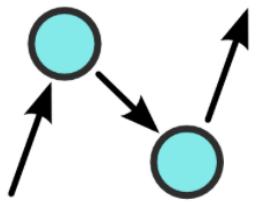
Success story: YAGO

- **Key contributions:**

- **Rich Ontology:** Linking Wikipedia categories to WordNet, providing a rich taxonomy
- **High Quality:** High precision extractions (accuracy ~95%)

Success story: ConceptNet

- Commonsense knowledge base
- ConceptNet4 was manually built using inputs from thousands of people
 - 28 million facts expressed in natural language
 - spanning 304 different languages
- **Key contributions:**
 - **Freely available resource:** covers wide range of common sense concepts and relations organized in a easy-to-use semantic network
 - **NLP toolkit based on this resource:** supports analogy, text summarization, context dependent inferences



ConceptNet

An open, multilingual knowledge graph



fur

An English term in ConceptNet 5.5

Sources: Open Mind Common Sense contributors, DBpedia 2015, JMDict 1.07, OpenCyc 2012, Verbosity players, German Wiktionary, English Wiktionary, French Wiktionary, and Open Multilingual WordNet

[View this term in the API](#)

Related terms

- en** cover →
- en** hair →
- en** wool →
- fr** fourrer →
- en** flea →
- en** attractive →
- en** clothing →
- en** mink →
- en** coat →
- en** sheep →
- en** coating →
- en** squirrel →
- en** debris →

Things with fur

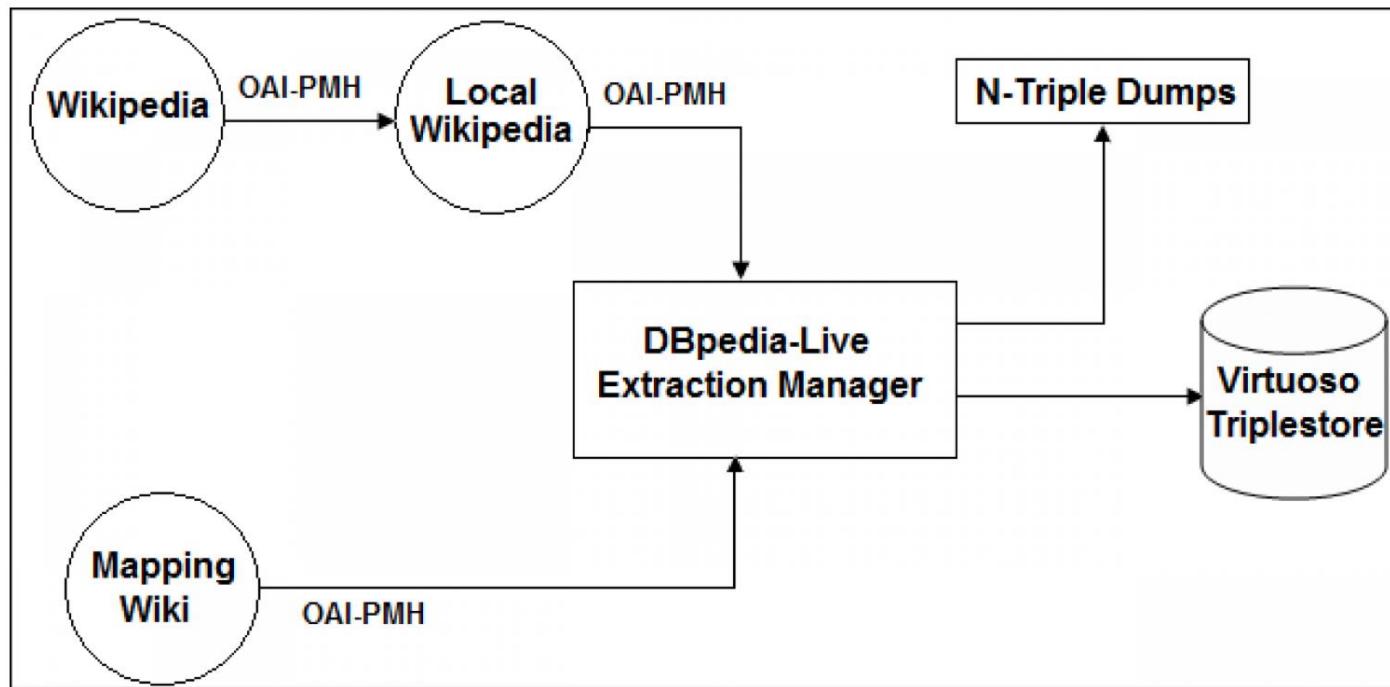
- en** cats →
- en** A dog →
- en** Mammals →
- en** animals →
- en** bears →
- en** Dogs →
- en** All mammals →
- en** Leopards →
- en** A cat →
- en** Horses →
- en** Horses are mammals, they →
- en** kittens →
- en** Lions →

Types of fur

- en** Hair →
- en** astrakhan (n) →
- en** bearskin (n) →
- en** beaver (n) →
- en** chinchilla (n) →
- en** ermine (n) →
- en** fox (n) →
- en** lambskin (n) →
- en** lapin (n) →
- en** leopard (n) →
- en** mink (n) →
- en** muskrat (n) →
- en** otter (n) →

Success story

- Wikipedia is manually built encyclopedia project
- DBpedia is automatically extracted structured data from Wikipedia
 - 17M canonical instances
 - 88M type statements
 - 72M infobox statements

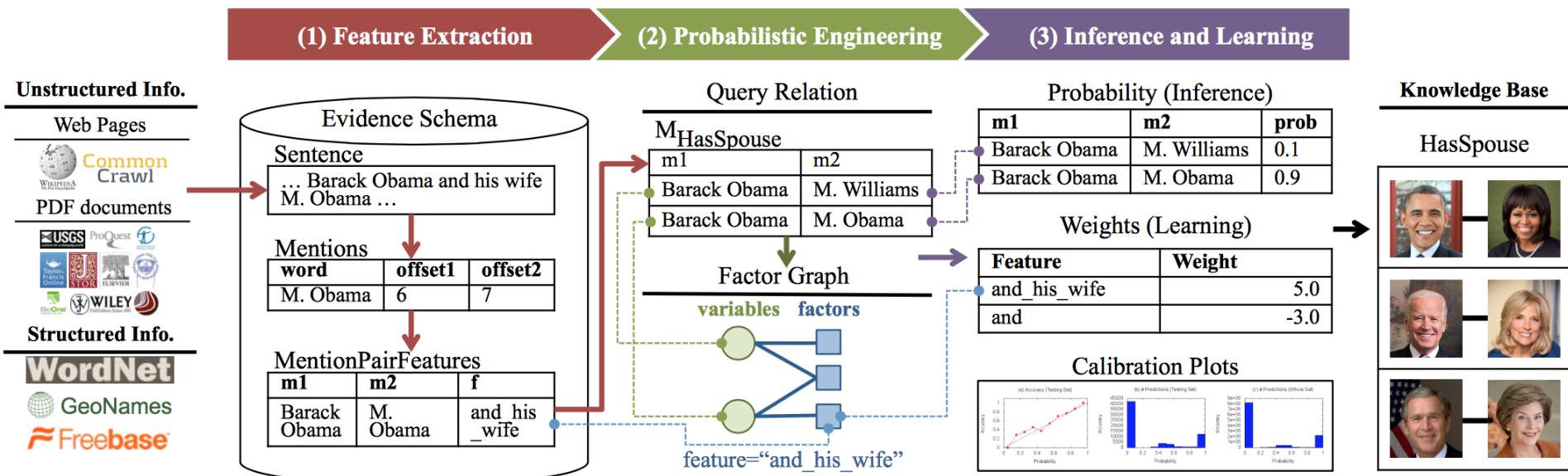


DeepDive



- Machine learning based extraction system
- Key contributions:
 - **scalable, high-performance inference and learning engine**
 - **Developers contribute features (rules) not algorithms**
 - **Combines data from variety of sources (webpages, pdf, figures, tables)**

DeepDive



- Best Precision/recall/F1 in KBP-slot filling task 2014 evaluations (31 teams participated)

Datasets, Tasks, Softwares

Datasets

- KG as datasets
 - [FB15K-237](#) Knowledge base completion dataset based on Freebase
 - [DBpedia](#) Structured data extracted from Wikipedia
 - [NELL](#) Read the web datasets
- Text datasets
 - [Clueweb09](#): 1 billion webpages (sample of Web)
 - [FACC1](#): Freebase Annotations of the Clueweb09 Corpora
 - [Gigaword](#): automatically-generated syntactic and discourse structure
 - [NYTimes](#): The New York Times Annotated Corpus
- Datasets related to Semi-supervised learning for information extraction
 - [Link](#): entity typing, concept discovery, aligning glosses to KB, multi-view learning

Shared tasks

- Text Analysis Conference on Knowledge Base Population (TAC KBP)
 - Cold Start KBP Track
 - Tri-Lingual Entity Discovery and Linking Track (EDL)
 - Event Track
 - Validation/Ensembling Track

Softwares: NLP

- Stanford CoreNLP: a suite of core NLP tools
[\[link\]](#) (Java code)

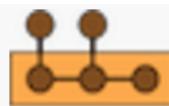


Stanford CoreNLP

- FIGER: fine-grained entity recognizer
assigns over 100 semantic types
[link](#) (Java code)

UNIVERSITY *of* WASHINGTON

- FACTORIE: out-of-the-box tools for NLP and information integration
[link](#) (Scala code)
- EasySRL: Semantic role labeling
[link](#) (Java code)



FACTORIE

UNIVERSITY *of* WASHINGTON

Softwares: Information Extraction

- Open IE

(University of Washington) Open IE 4.2 [link](#) (Scala code)



Stanford Open IE [link](#) (Java code)



- Interactive Knowledge Extraction (IKE)
(Allen Institute for Artificial Intelligence)
[link](#) (Scala code)



- Universal schema
[link](#) (Java + Scala code)



- Stanford Named Entity Recognizer (NER)
[link](#) (Java code)



Softwares: Knowledge Graphs

- **AMIE:** Association Rule Mining under Incomplete Evidence in Ontological Knowledge Bases

[link](#) (Java code)



- **PSL:** Probabilistic soft logic

[link](#) (Java code)



- **Junto:** graph based semi-supervised learning methods

[link](#) (Scala code)



Exciting Active Research

- INTERESTING APPLICATIONS OF IE
- AMBITIOUS PROJECTS
- MULTI-MODAL INFORMATION EXTRACTION

Exciting active research: Interesting application of Knowledge Graphs

- **The Literome Project [[link](#)]**

Search for directed genic interactions: [help](#)

Search for genotype-phenotype associations: [help](#)

- Automatic system for extracting genomic knowledge from PubMed articles
- Web-accessible knowledge base

Exciting active research: Interesting application of Knowledge Graphs

Microsoft
Research

PROJECT HANOVER

OVERVIEW

MACHINE READING

CANCER DECISION SUPPORT

CHRONIC DISEASE MANAGEMENT

ABOUT

AI FOR PRECISION MEDICINE

Exciting active research: Ambitious Projects

Aristo Science QA challenge



... ARISTO ...

Answering Science Questions using Machine Reading

What is Aristo?

Question: During which season of the year would a rabbit's fur be thickest?

Hide

Answer: (D) winter

Because: A bear's fur would be thickest during winter.

Confidence: 60.14%

Source: Barrons 4th Grade Study Guide

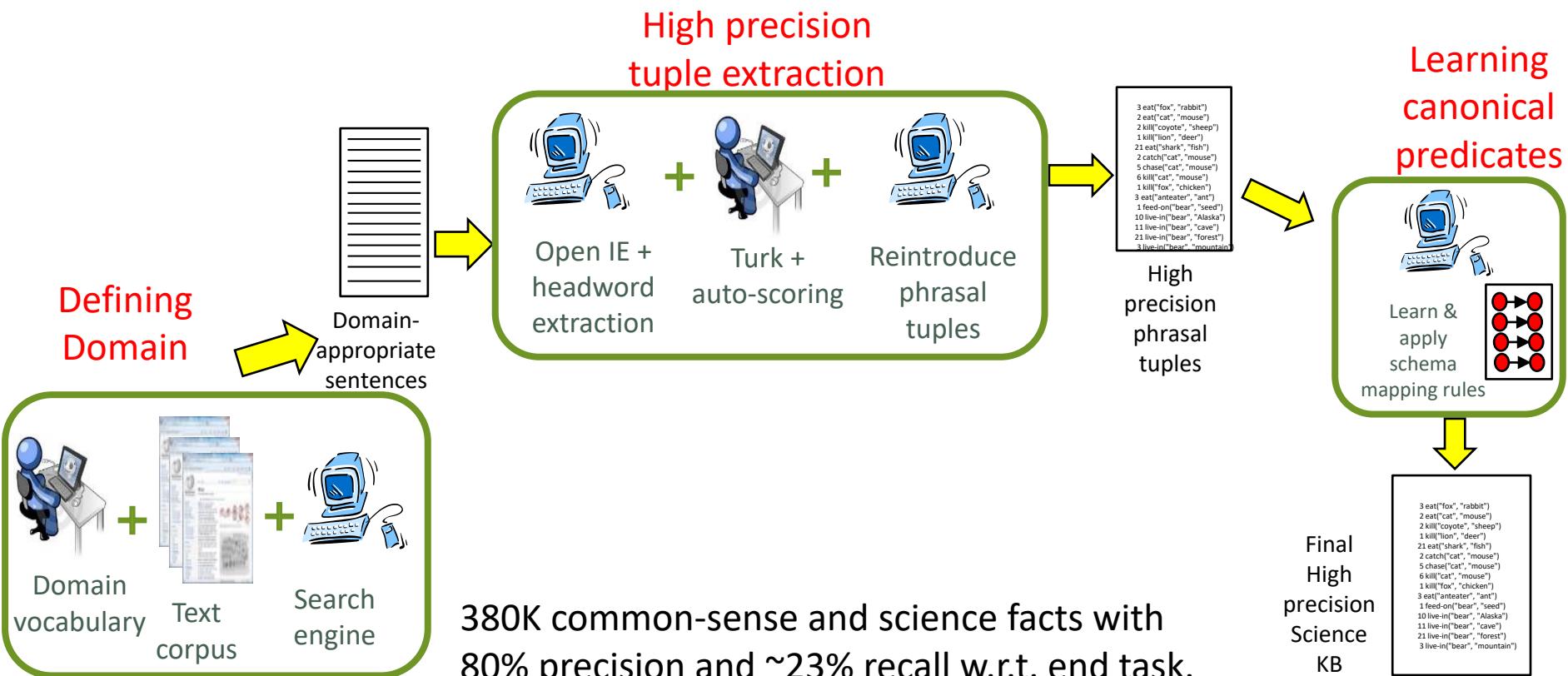
Aristo Science QA challenge

- Science questions dataset

~5K 4-way multiple choice questions

Frogs lay eggs that develop into tadpoles and then into adult frogs. This sequence of changes is an example of how living things

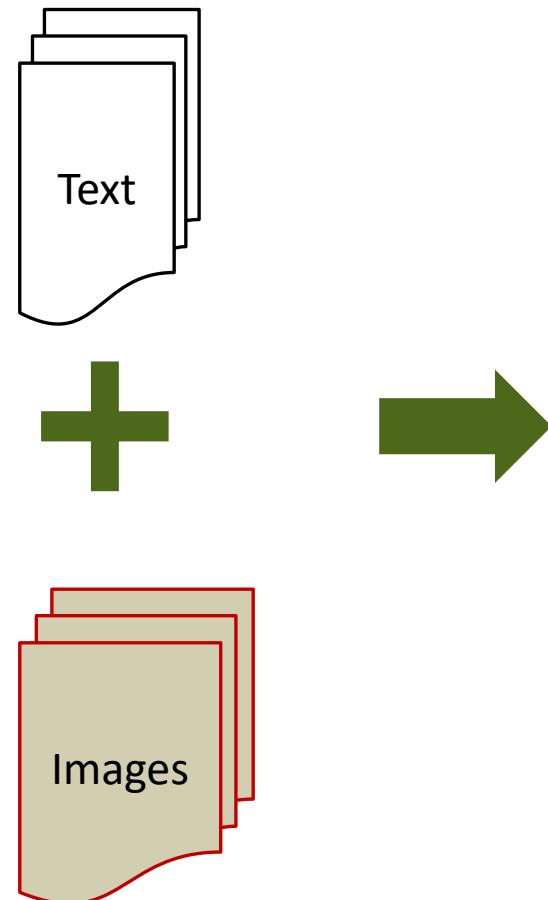
- (A) go through a life cycle
- (B) form a food web
- (C) act as a source of food
- (D) affect other parts of the ecosystem



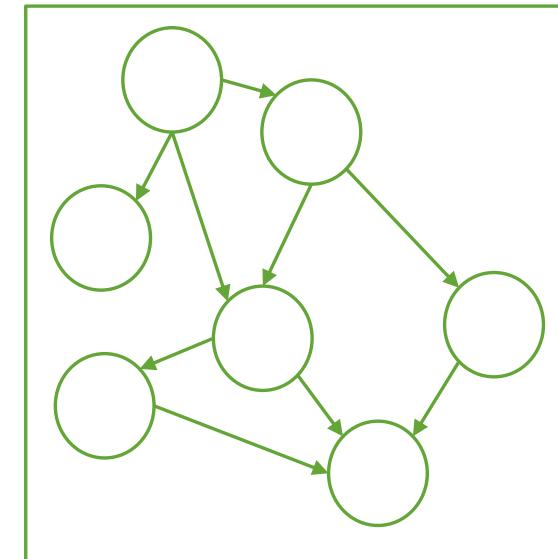
Aristo ScienceKB

- Open problems
 - KB construction for Science domain
 - Domain targeted KB completion
 - Measuring recall w.r.t. end task
- Upcoming datasets: stay tuned

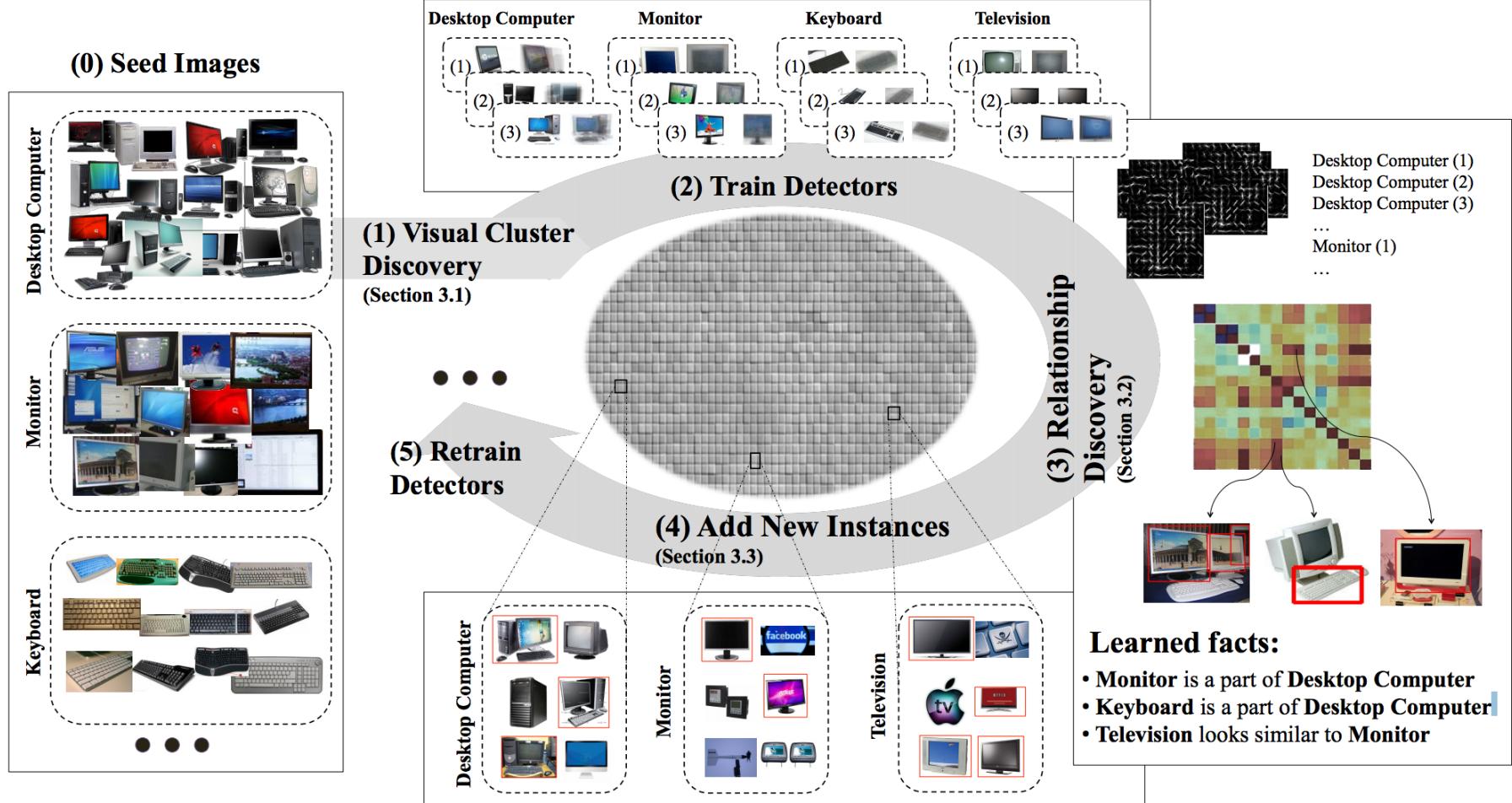
Exciting active research: Multi-modal information extraction



Multi-modal Knowledge Graph



NEIL: Extracting Visual Knowledge from Web Data



WebChild: Text + Images

WEBCHILD Commonsense Browser

e.g. car,bicycle OR car OR a:fix bicycle



Guess the concept

Domain ▲

Comparable ▲

Physical Part ▲

Activity ▲

Property ▲

Location ▲

Ask me!

mouse



a hand-operated electronic device that controls the coordinates of a cursor on your computer screen as you move it around on a pad; on the bottom of the device is a ball that rolls on the surface of the pad; 'a mouse takes much more room than a trackball'

keyboard



device consisting of a set of keys on a piano or organ or typewriter or typesetting machine or computer or the like

Future Research Directions

GOING BEYOND FACTS

CONTINUOUSLY LEARNING AND SELF-CORRECTING SYSTEMS

Future research directions:

Going beyond facts

- Representing and learning complex models
- Represent higher level structures like frames, activities, events, processes

Future research directions:

Going beyond facts

- **Fact:** Individual knowledge tuples
(plant, absorb, sunlight)

subject	plant
predicate	absorb
object	sunlight
time	daytime

- **Event frame:**
more context how, when, where?

- **Processes:**
representing larger structures,
sequence of events

Process	photosynthesis
agent	Plant, leaf
input	Sunlight, water, carbon dioxide
output	Oxygen, sugar
events	(Plant, absorb, sunlight) (leaf, produce, sugar) (leaf, produce, oxygen)

Future research directions: Online KG Construction

- One shot KG construction → Online KG construction
 - Consume online stream of data
 - Temporal scoping of facts
 - Discovering new concepts automatically
 - Self-correcting systems

Future research directions:

Online KG Construction

- **Continuously learning and self-correcting systems**
 - *[Selecting Actions for Resource-bounded Information Extraction using Reinforcement Learning, Kanani and McCallum, WSDM 2012]*
 - Presented a reinforcement learning framework for budget constrained information extraction
 - *[Never-Ending Learning, Mitchell et al. AAAI 2015]*
 - Tom Mitchell says “Self reflection and an explicit agenda of learning subgoals” is an important direction of future research for continuously learning systems.

Future.....



- Knowledge graphs construction systems

Can consume online stream of data at Web scale,

Represent context beyond facts,

Update existing KG with new evidence,

Support domains like medicine, science to help humanity

Can correct its own mistakes over time

Thank You

