Numerical Relation Extraction with Minimal Supervision

MTP Presentation

Aman Madaan Ashish Mittal

Indian Institute of Technology Bombay, Mumbai

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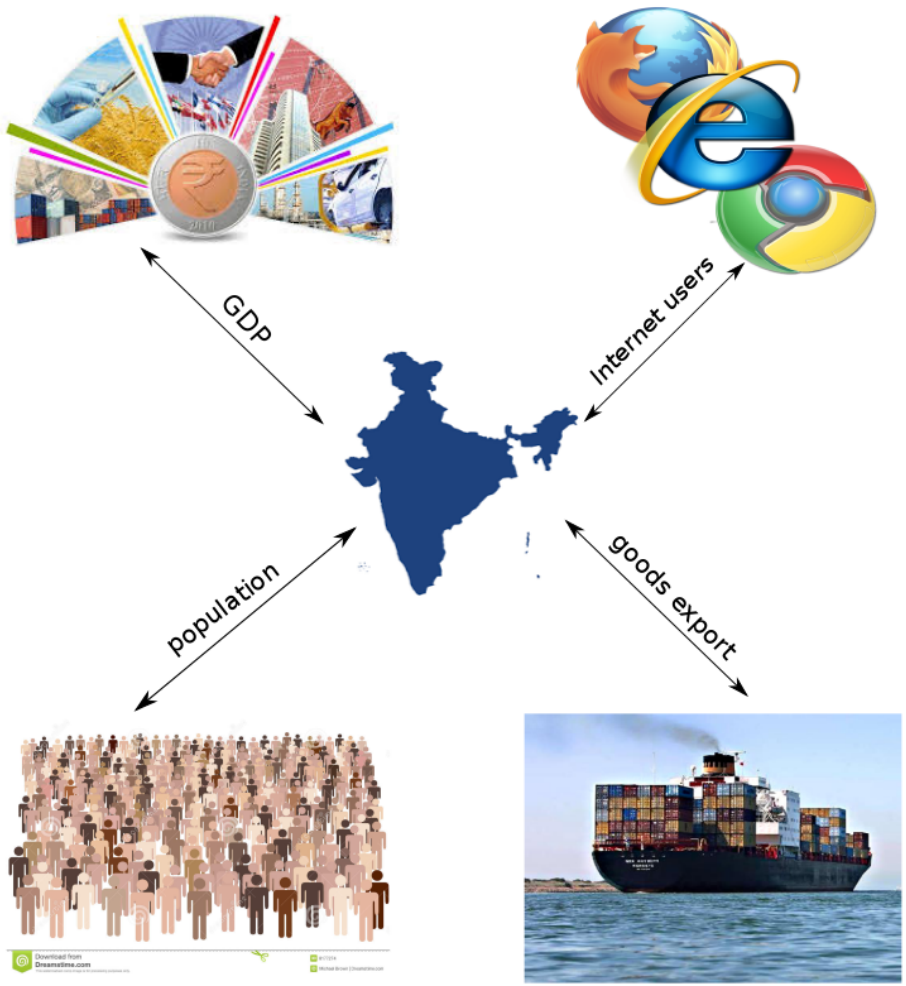
Outline

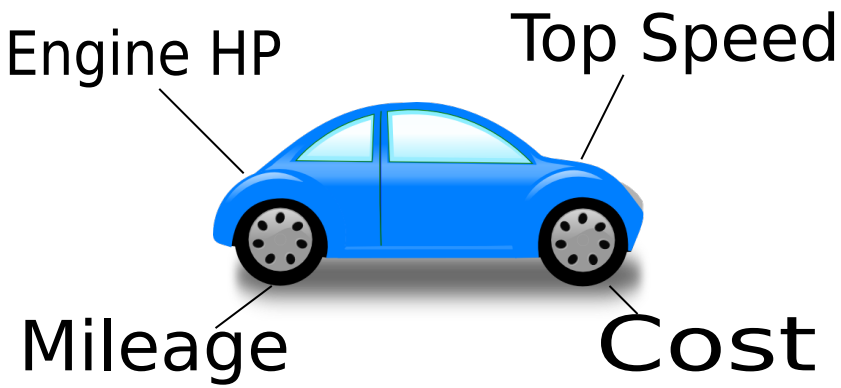
1. Introduction
2. Relation Extraction as a Machine Learning Problem
3. Peculiarities of Numerical Relation Extraction
4. NumberRule: Rule Based Relation Extraction
5. NumberTron: Probabilistic Relation Extraction

Introduction

Entities have Numerical Attributes



Entities have Numerical Attributes



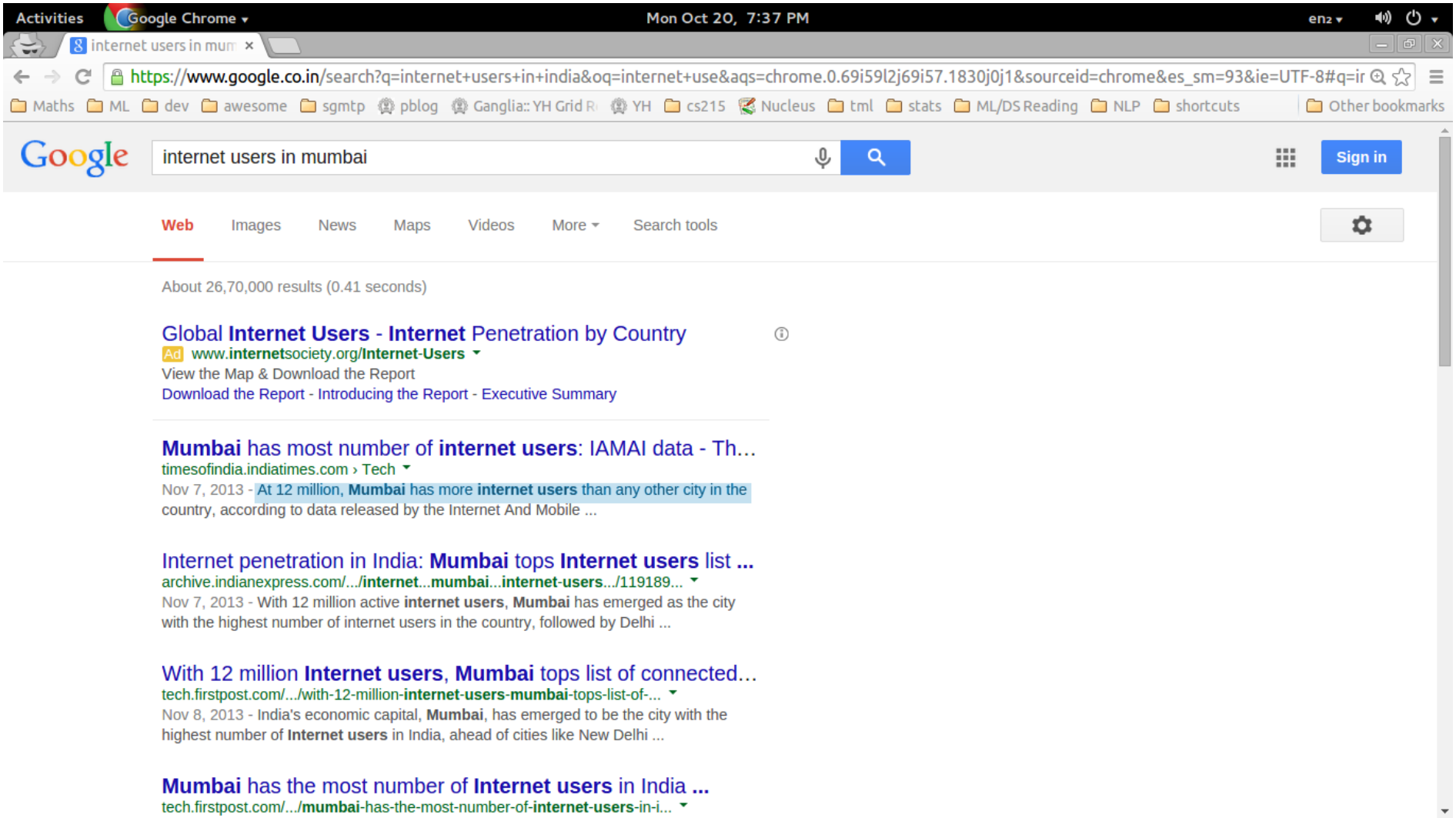
Entities and Numerical Attributes

- For popular entities, finding complete knowledge bases is possible.
- data.worldbank.org, Wikipedia infoboxes, freebase
- What about less popular entities?
  - What is the population of Arbit Apartments, Powai?
  - What is the GDP of Sugarcane Industry of India?
  - Percent of Internet users in Mumbai?

Motivation

Activities
Google Chrome
Mon Oct 20, 7:42 PM
internet users in india
https://www.google.co.in/search?q=internet+users+in+india&oq=internet+use&aqs=chrome.0.69i59l2j69i57.1830j0j1&sourceid=chrome&es_sm=93&ie=UTF-8#q=ir
Maths ML dev awesome sgmtp pblog Ganglia:: YH Grid YH cs215 Nucleus tml stats ML/DS Reading NLP shortcuts Other bookmarks
Google
internet users in india
Sign in
Web News Images Maps Videos More Search tools
About 2,49,00,000 results (0.23 seconds)
15.1% of the population (2013)
India, Internet users
15
10
5
0
1990
1995
2000
2005
2010
Explore more
Sources include: World Bank
Feedback
China
Afghanistan
Iran
Pakistan
India
Thailand
India
Country
India, officially the Republic of India, is a country in South Asia. It is the seventh-largest country by area, the second-most populous country with over 1.2 billion people, and the most populous democracy in the world.
Wikipedia
Related statistics
Population 1.252 billion (2013)
Life expectancy 66.21 years (2012)

Motivation


Activities
Google Chrome
Mon Oct 20, 7:37 PM
internet users in mum
https://www.google.co.in/search?q=internet+users+in+india&oq=internet+use&aqs=chrome.0.69i59l2j69i57.1830j0j1&sourceid=chrome&es_sm=93&ie=UTF-8#q=ir
Maths ML dev awesome sgmtp pblog Ganglia:: YH Grid R YH cs215 Nucleus tml stats ML/DS Reading NLP shortcuts Other bookmarks
Google
internet users in mumbai
Sign in
Web Images News Maps Videos More Search tools
About 26,70,000 results (0.41 seconds)
Global Internet Users - Internet Penetration by Country
Ad www.internetsociety.org/Internet-Users
View the Map & Download the Report
Download the Report - Introducing the Report - Executive Summary
Mumbai has most number of internet users: IAMAI data - Th...
timesofindia.indiatimes.com › Tech
Nov 7, 2013 - At 12 million, Mumbai has more internet users than any other city in the country, according to data released by the Internet And Mobile ...
Internet penetration in India: Mumbai tops Internet users list ...
archive.indianexpress.com/.../internet...mumbai...internet-users.../119189...
Nov 7, 2013 - With 12 million active internet users, Mumbai has emerged as the city with the highest number of internet users in the country, followed by Delhi ...
With 12 million Internet users, Mumbai tops list of connected...
tech.firstpost.com/.../with-12-million-internet-users-mumbai-tops-list-of-...
Nov 8, 2013 - India's economic capital, Mumbai, has emerged to be the city with the highest number of Internet users in India, ahead of cities like New Delhi ...
Mumbai has the most number of Internet users in India ...
tech.firstpost.com/.../mumbai-has-the-most-number-of-internet-users-in-i...

Motivation

- Web is huge.
- Probably, there is some page which contains the information we are looking for.
- The way in which you express a fact about an entity depends on the fact, and not the entity.
- We may expect **the sentence structure** [1] to be similar.

[1] More on this in the coming slides

Problem Statement

- Formally, train extractors that can harness the Web for numerical relations, where relations are 3-tuples linking an entity to a number
  - (India, **economy**, 1.842 trillion USD)
  - (China, **internet users**, 590.56 million)
  - (USA, **land area**, 2,959,054 square mile)

Relation Extraction as a Machine Learning Problem

Relation Extraction as a Machine Learning Problem

- **Structure** and **content** of sentences expressing the same relations can be *expected* to be similar.
    - The population of Australia is estimated to be 23,622,400 as of 7 October 2014.
    - According to an official estimate for 1 June 2014, the population of Russia is 143,800,000.

Relation Extraction as a Machine Learning Problem

- **Structure** and **content** of sentences expressing the same relations can be *expected* to be similar.
  - At 17,075,400 square kilometres, Russia is the largest country in the world.
  - With an area of 504,030 km^2, Spain is the second largest country in Western Europe.

Relation Extraction as a Machine Learning Problem

- Redundancy in grammatical features and dependencies of the sentences expressing same relation.

Relation Extraction as a Machine Learning Problem

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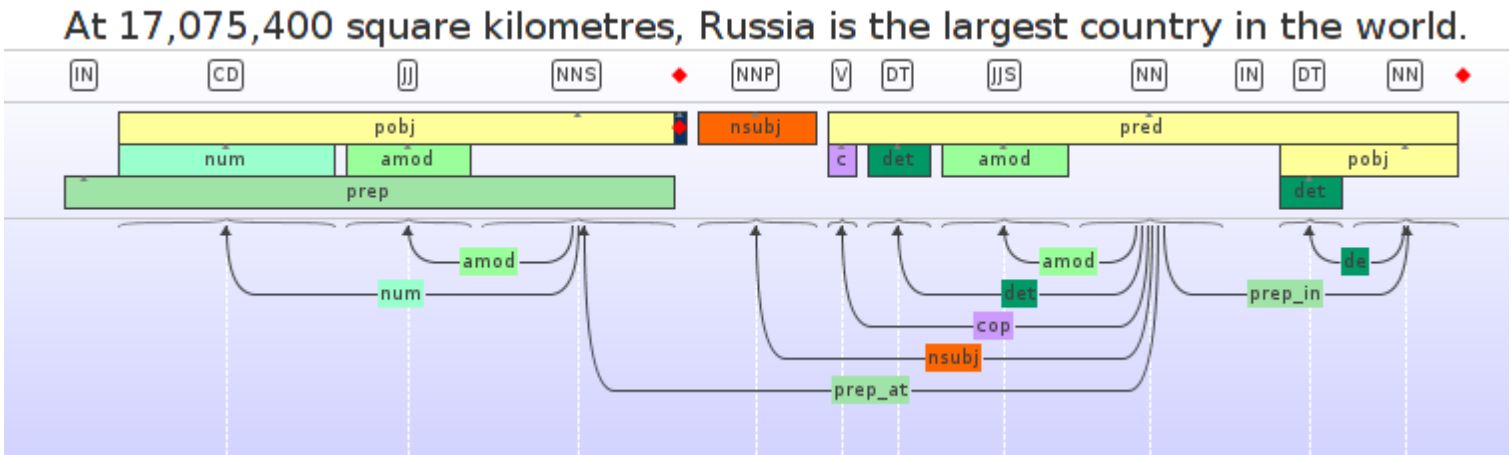
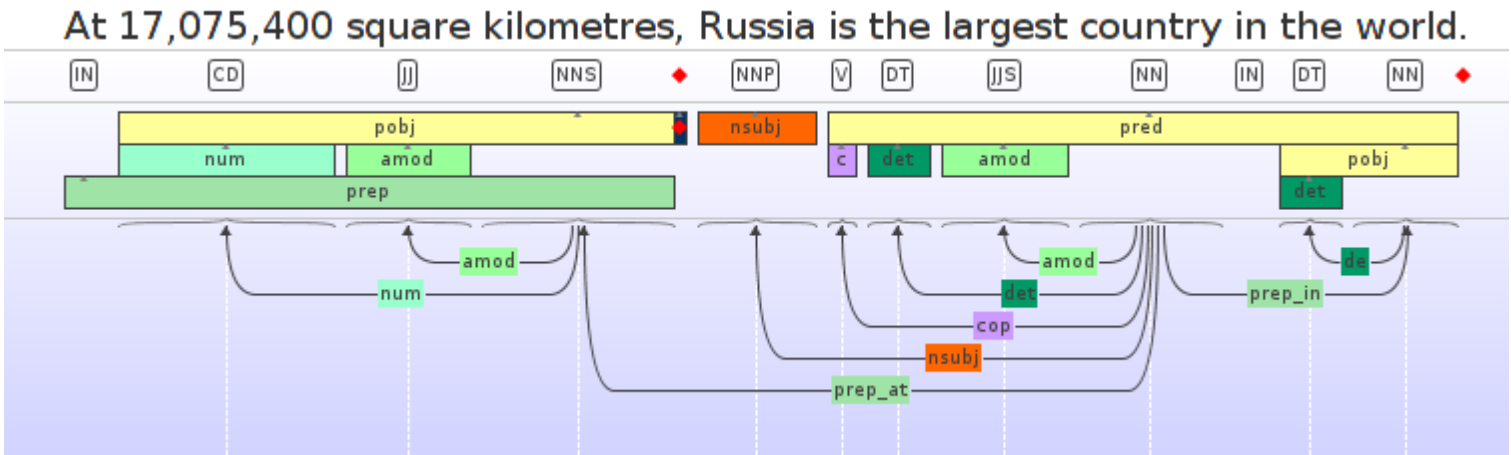
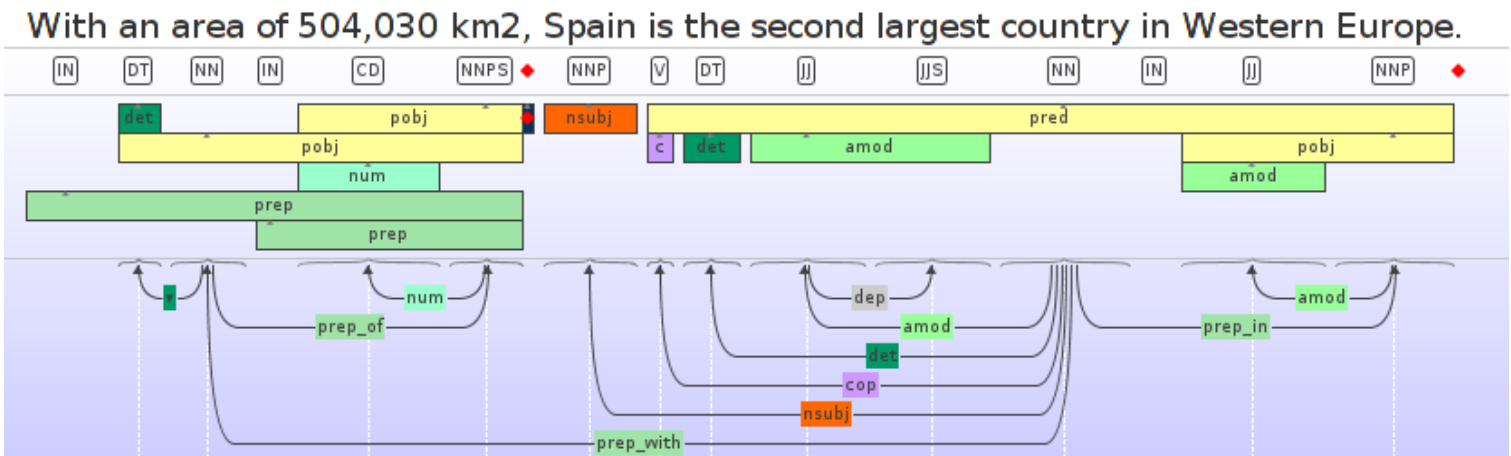


Relation Extraction as a Machine Learning Problem

- Redundancy in grammatical features and dependencies of the sentences expressing same relation.





Possible Workflow

Possible Workflow

1: **Collect enough examples** for each relation so that there are sufficient patterns and enough redundancy to exploit.

2: **Extract features** (important keywords, grammatical structure, parse trees, etc.) for these sentences.

3: **Train** a multi-class classifier on this training data.

4: **for** *sentence* $s \in$ *Corpus* **do**
5: **Extract** features for s.
6: **Predict** the relation using the model for these features.
7: **Store** the fact into a database.

Challenge

- Large Corpus ($\sim$16 million sentences), hand labeling is out of question

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- Need lots of training data to learn high quality extractors

Challenge

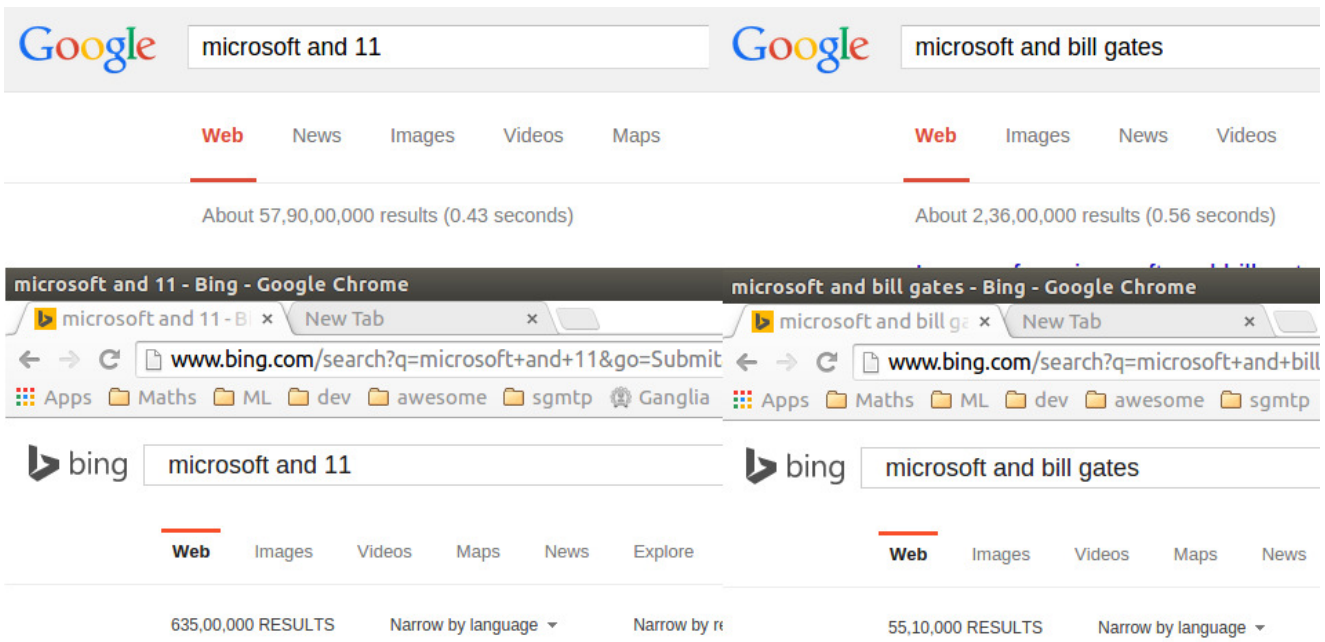
- Large Corpus ($\sim$16 million sentences), hand labeling is out of question
- Need lots of training data to learn high quality extractors
- What makes this problem interesting? Never Really Been Studied!

Peculiarities of Numerical Relation Extraction

Peculiarities of Numerical Relation Extraction

Numbers are weak entities

- Quantities can appear in far more contexts than typical entities. (”Bill Gates”, ”Microsoft”) vs. (”11”, ”Microsoft”)
- Regular IE have fewer cases of entity disambiguation as compared to numerical IE



Peculiarities of Numerical Relation Extraction

Numbers are weak entities

- Noise is more for the small whole numbers that are unitless or with popular units (e.g, percent)
- 1 or 5% vs. 11.42145 or 330 m/sec

Number	Frequency (Avg. 57.84)
3	85333
20	86359
2	91608
1	100014
10	100780

Peculiarities of Numerical Relation Extraction

Units

- Unit acts as types for numbers.
- Same quantity may be expressed with different unit
  - 20 kms or 12.4 miles
- Unit extractor needs to perform unit conversions for correct matching and extraction

Peculiarities of Numerical Relation Extraction

Delta Words

- Not uncommon to find sentences expressing change in the value of a relation (instead of, or in addition to, the actual value).
  - Amazon stock price *increased by* $35 to close at $510.
  - India's tiger population sees 30% *increase*.
  - Ford poised to raise dividend by 20% even as profit declines.

Peculiarities of Numerical Relation Extraction

Relation/Argument Scoping

- Additional modifiers to arguments or relation words may subtly change the meaning and confuse the extractor.
  - *rural* literacy rate of India
  - literacy rate of *rural* India
- The modifiers are usually adjectival modifiers

Peculiarities of Numerical Relation Extraction

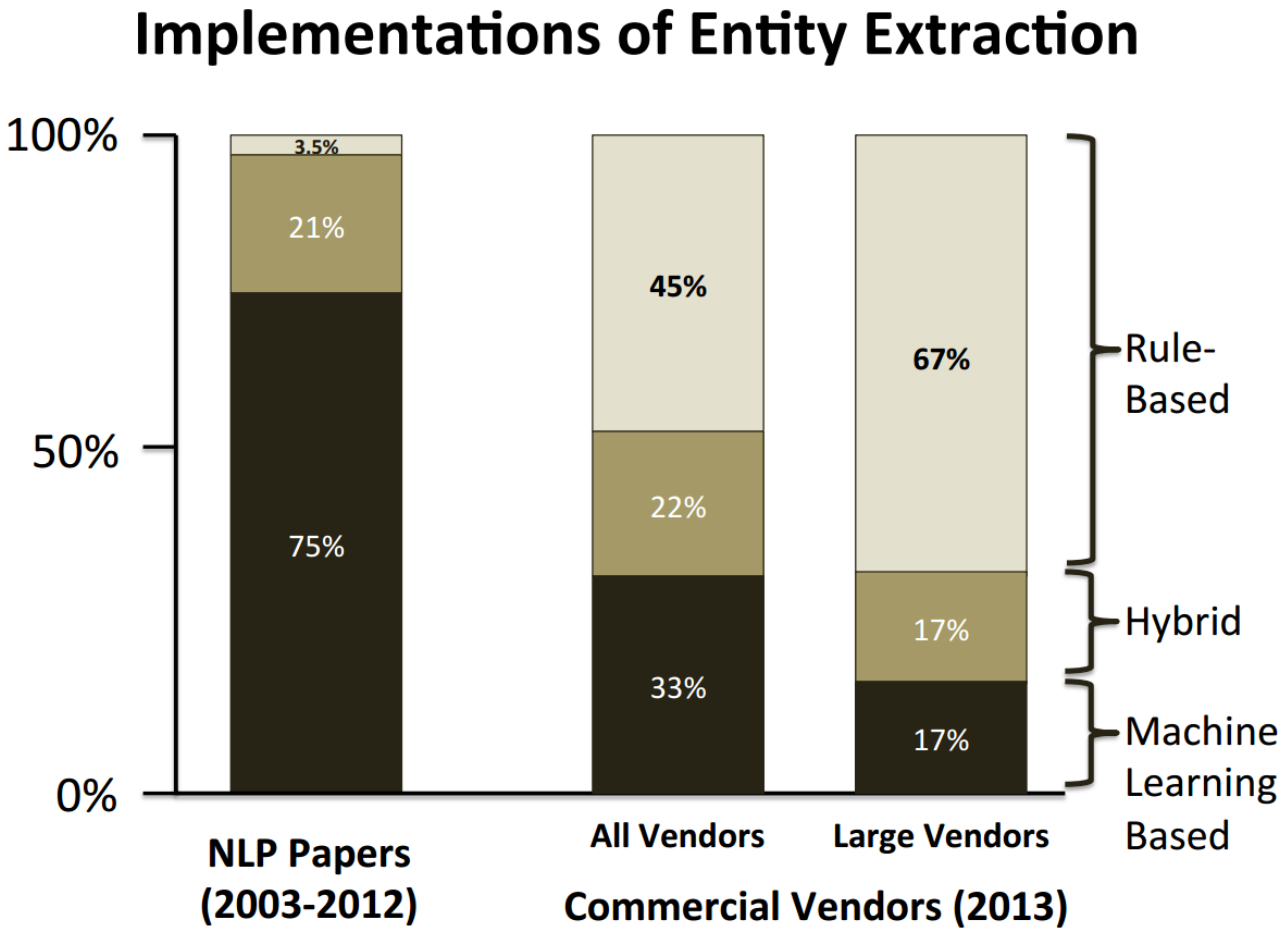
Keywords

- Sentences expressing many numerical relations usually include one or a handful of keywords.
- Sentences expressing the GDP of a country **without** mentioning the term *GDP*? Sentences expressing inflation without mentioning inflation?
- *Founder of* relation without the phrase *founder of*?
  - Bill Gates is the founder of Microsoft
  - Bill Gates founded Microsoft
  - Bill Gates is the father of Microsoft
  - Bill Gates laid the foundation stone of Microsoft
  - Bill Gates started Microsoft

NumberRule: Rule Based Relation Extraction

Rule Based IE

Academia vs. Industry



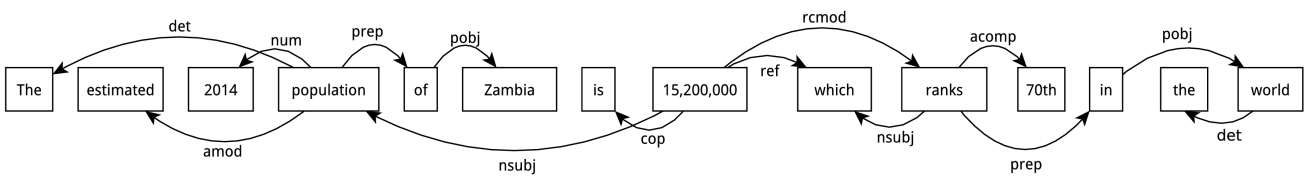
[2]

[2] from [CLR13]

- Dependencies are grammatical relation between two words, governor and dependent.
- The relation captures the way in which one of the words is affected by the other.
- For example, consider the sentence: *"The red ball was lost"*
  - **amod(ball,3,red,2)** "Red" is an adjective for "ball"
  - **det(ball,3,The,1)** "the" is a determiner of "ball"
  - **nsubjpass(lost,5,ball,3)** "ball is the subject of lost"
  - **auxpass(lost,5,was,4)** "was is an auxiliary of lost"

From [BM05]

If e_1 and e_2 are two entities mentioned in the same sentence such that they are observed to be in a relationship R, our hypothesis stipulates that the contribution of the sentence dependency graph to establishing the relationship $R(e_1, e_2)$ is almost exclusively concentrated in the shortest path between e_1 and e_2 in the undirected version of the dependency graph.



From [BM05]

If e_1 **and** e_2 are two entities mentioned in the same sentence such that they are observed to be in a **relationship R**, our hypothesis stipulates that the contribution of the sentence **dependency graph** to establishing the relationship $R(e_1, e_2)$ is almost **exclusively concentrated in the shortest path** between e_1 and e_2 in the undirected version of the dependency graph.

- When looking for clues for relation extraction, dependency path is a good place to start.
- In the case of Numerical Relations, we already know what to look for: *keywords*.
- Need to take care of modifications to the entities, delta words

NumberRule

Definitions

- **Keywords** Words that might help in identifying relations.(*GDP*, *internet*, *inflation*)
- **Delta words** Words that indicate that the mention expresses a change, and not the actual relation.
(*change*, *up*, *down*, *increased*, *changed*, *risen*)
- **Modifiers** A word *m* is said to be a modifier of the word *w* if there is a modifying dependency from *m* to *w*.
(*blue* modifies *whale* in **blue** *whale*, **urban** *population*).

NumberRule

Extraction Algorithm

1: **for** $(e, n) \in (E_S \times N_S)$ **do** //For all entity-number pairs
2: $P \leftarrow$ words in dependency path between e and n
3: **for** $r \in R$ **do**
4: **if** $P \cap K_r = \emptyset$ **then**
5: continue; //keyword is not present
6: **if** $P \cap \Delta \neq \emptyset$ **then**
7: continue; //delta words are present
8: **if** $Unit(n) \notin LegalUnits(r)$ **then**
9: continue; //incompatible units?
10: **if** $k_r \in P \cap K_r$ is modified/scoped **then**
11: continue; //keyword is modified/scoped
12: **if** e is modified/scoped **then**
13: continue; //entity is modified/scoped
14: Extract $r(e, r, n)$.

NumberRule

NumberRule: Extractions

- "The estimated population for 2014 of the Australian continent is about 36.25 million people"
- Australian $\xrightarrow{amod}$ continent $\xrightarrow{prep_of}$ 2014 $\xrightarrow{prep_for}$ **population** $\xrightarrow{nsubj}$ people $\xrightarrow{num}$ million $\xrightarrow{number}$ 36.25
- "The estimated population for 2014 of the Australian continent increased by about 3.25 million people"
- Australian $\xrightarrow{amod}$ continent $\xrightarrow{prep_of}$ 2014 $\xrightarrow{prep_for}$ **population** $\xrightarrow{nsubj}$ **increased** $\xrightarrow{prep_by}$ people $\xrightarrow{num}$ million $\xrightarrow{number}$ 36.25

Sentence	**Test**
The estimated population of Australia is about 36.25 million people.	-
The estimated population density of Australia is 36.25 million people **per sq km.**	Incompatible Units
The estimated population of Australia **increased** *by about 36.25 million people.*	Delta Word Present
The estimated population of **urban** *Australia is about 36.25 million people.*	Entity is Modified
The estimated **adolescent** *population of Australia is about 36.25 million.*	Keyword is Modified

Table : NumberRule outputs (Australia, Total Population, 36.25 million) only in the first sentence. The second column is test number that fails for other sentences. The input keyword is "population".

NumberTron: Probabilistic Relation Extraction

NumberTron

- An Unlabeled Corpus (Sentencified, pruned to retain sentences having a country and a number)
- A Database of numerical facts, derived from data.worldbank.org.
- A Database of keywords

Code	Num	Rel
/m/0hzlz	4.091616e+17	ELEC
/m/01nyl	9.27261850301	INF
/m/05qx1	2434964.0	POP
/m/03rt9	3538082.0	POP
/m/05v8c	22860078000.0	CO2
/m/07fsv	31824701.2783	GDP
/m/04w4s	32870000000.0	AGL
/m/035qy	15.5100261552	INF
/m/0d05q4	12.6628528269	INF
/m/088q4	1562886291.51	LIFE

Relation	Keywords
Internet User %	internet
Land Area	area, land
Population	population, people, inhabitants
GDP	gross, domestic, GDP
CO_2 emission	carbon, emission, CO2, kilotons
Inflation	inflation
FDI	foreign, direct, investment, FDI
Goods Export	goods, export
Life Expectancy	life, expectancy
Electricity Production	electricity

For an entity e (India)

- One Graph **per entity**
- Let S_e be the set of sentences that express the entity e.
- Let Q_e denote the distinct numbers with unit that appear in S_e [3]
- $\forall q \in Q_e$, let $S_{e,q} \subseteq S_e$ denote the sentences that mention e and q.

[3] We use the unit tagger by [SC14] to identity units of numbers in the text and to convert all unit variants like "mile", "km" to a canonical SI unit, "meter".

For $e =$ (China)

- $S_{china} = \{$*(i).. China says that annual inflation...to 4.3 percent, (ii)...China would initiate ... that its inflation rate ... 4.3 percent in October, (iii)...the number of chinese internet users has grown to 840 million...*$\}$
- $Q_{china} = \{$4.3 percent, 840000000$\}$
- $S_{china,4.3percent} = \{(i), (ii)\}$
- $S_{china,840000000} = \{(iii)\}$

For each entity e, for each number n_q

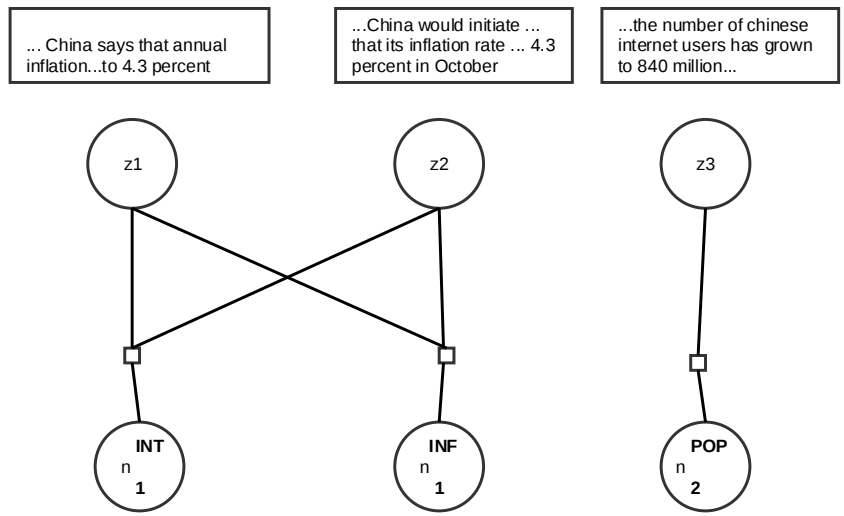
- n_r^q**, number nodes** Binary, 1 if the number q is related to e via relation r.

For each mention, $s \in S_{e,q}$

- z_s**, mention nodes** multi-ary, can take values $r \in \mathcal{R} = (R \cup \perp)$, set to $r \in R$ if the sentence expresses any of the R relations, else set to $z_s = \perp$.

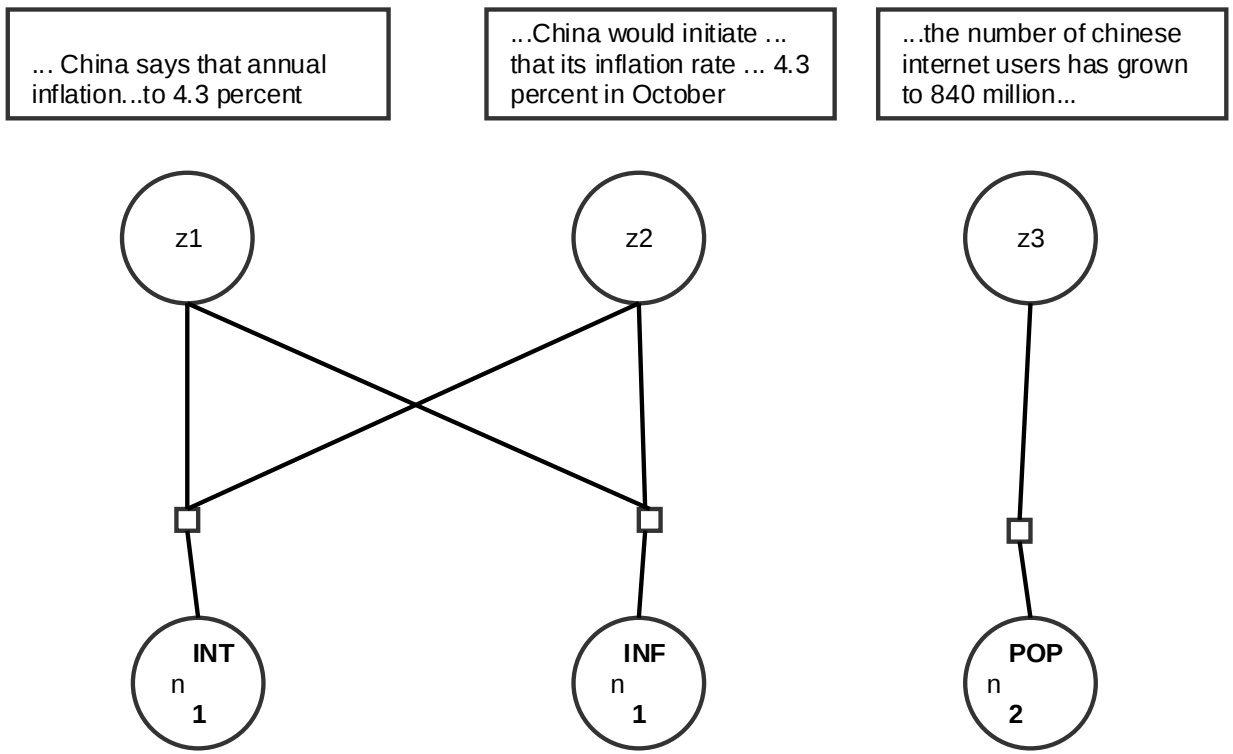
For $e = (\text{China})$

- $S_{china} = \{(i), (ii), (iii)\}$
- $Q_{china} = \{4.3\ \%, 840000000\}$
- $S_{china,4.3\%} = \{(i), (ii)\}$
- $S_{china,840000000} = \{(iii)\}$



NumberTron

Graphical Model



- **Mintz Features** Lexical and Synctactic features derived from POS tags and dependency path [MBSJ09]
- **Keyword Features** Derived from a pre-specified list of keywords per relation.
- **Number Features** Capture Information on the magnitude, type (whole, fraction) can also be useful for relation extraction.

Afghanistan , which is mostly rural , has one of the lowest life expectancy rate in the world at 44 year for both man and woman.

Feature type	Features
Fixed Keywords	key: life key: expect
Number Features	Num: Billion Num: Integer

Afghanistan , which is mostly rural , has one of the lowest life expectancy rate in the world at 44 year for both man and woman. *The time "44 year" is converted to the SI unit, which comes out to be around 1.3 billion and thus the feature Num: Billion is fired.*

NumberTron

Features

- *inverse_false*|*LOCATION*|**LONG**|*DURATION*, There is a long dependency path between the two entities, one of which is a location and other duration
- *inverse_false*|*B_-2 B_-1*|*LOCATION*|**LONG**|*DURATION*|*year for*, Same as above, but now with windows of text around entities of interest
- str:rural[rcmod]$-$ $>$ |LOCATION|[nsubj]$-$ $>$have[root]$<$ $-$at[prep]$<$ $-$year[pobj]$<$ $-$|DURATION , The typed dependency path
- dir:$-$ $>$ |LOCATION|$-$ $><$ $-$ $<$ $-$ $<$ $-$|DURATION , Direction of dependencies

Afghanistan , which is mostly rural , has one of the lowest life expectancy rate in the world at 44 year for both man and woman.

- The classical perceptron forms the core of our training procedure.

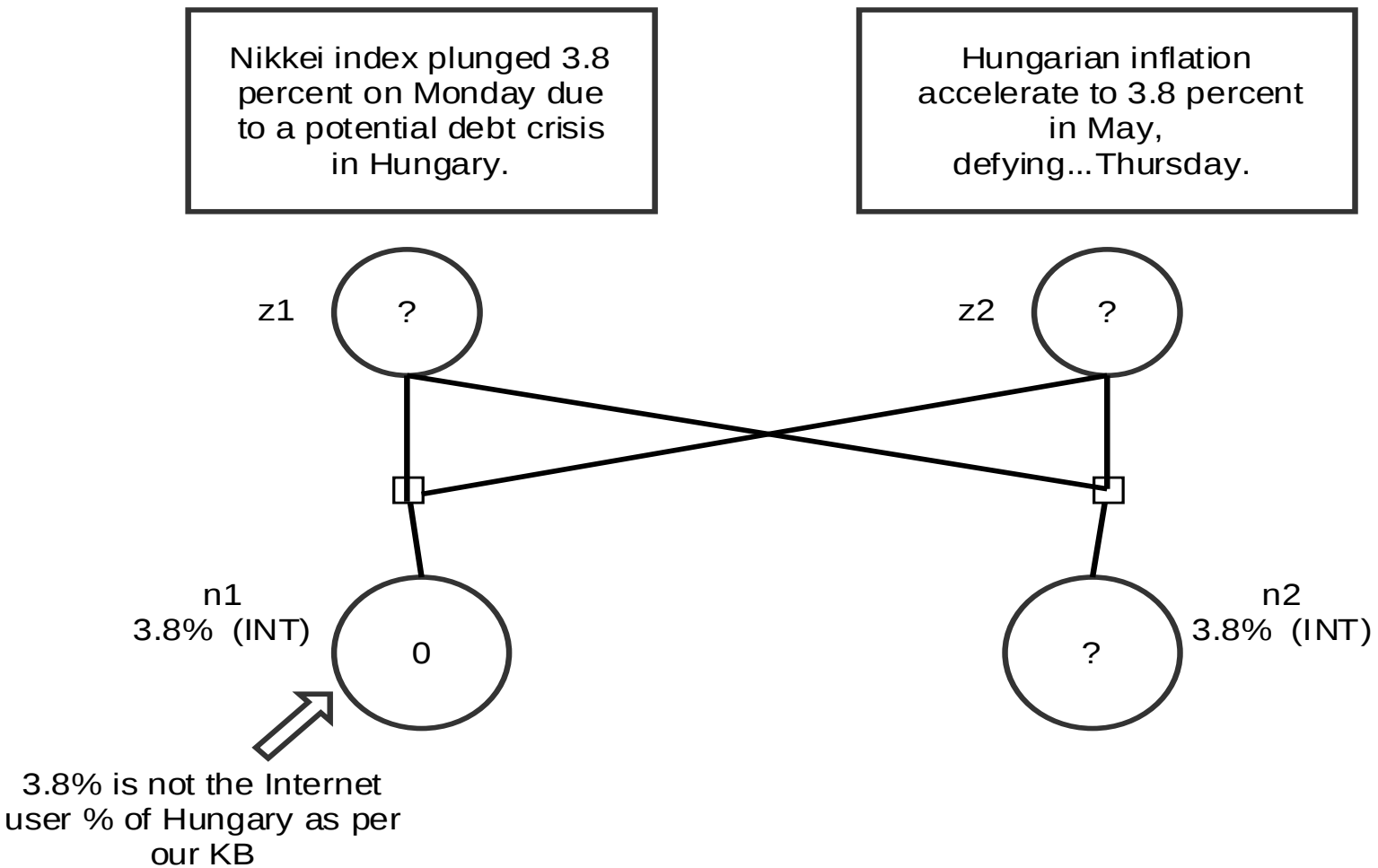
$$\theta \leftarrow \theta + \eta * (t_i - o_i) * x_i \tag{1}$$

$$\boxed{\theta} \leftarrow \boxed{\theta} + \eta * (\boxed{t_i} - \boxed{o_i}) * \boxed{x_i} \tag{2}$$

- Weights
- True Label
- Observed Label
- Feature (Binary)

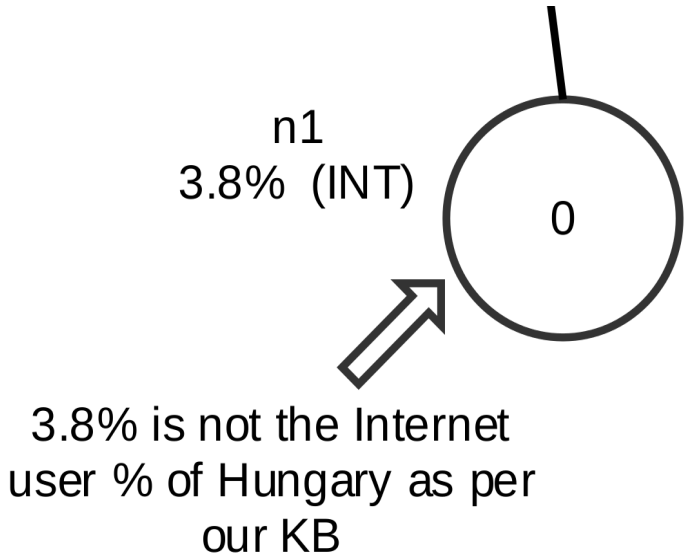
NumberTron Training

True Labels: Distant Supervision



NumberTron Training

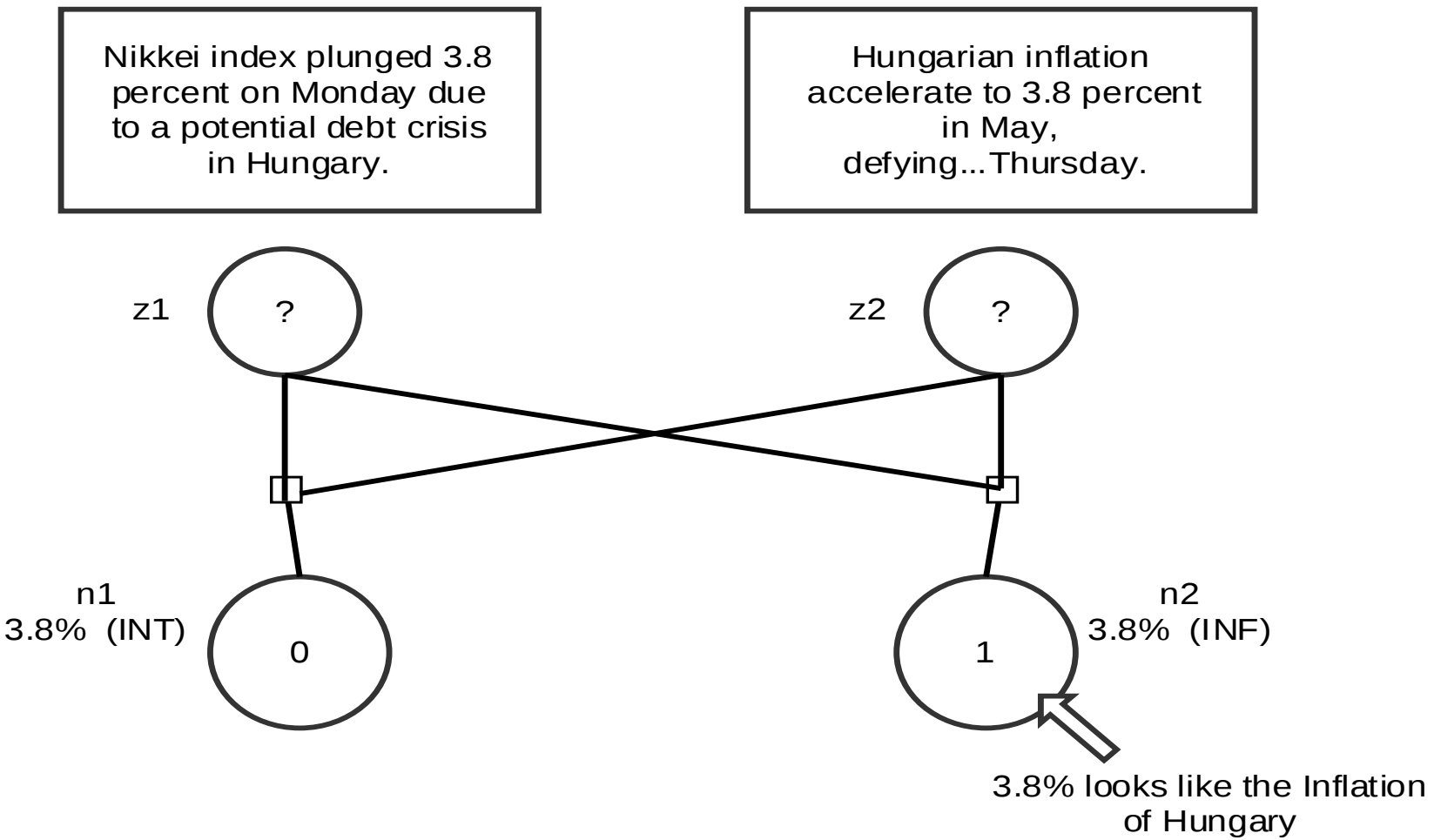
True Labels: Distant Supervision



- Is 3.8% within δ% of the values in the knowledge base for Internet User Percent of Hungary?
- $\delta = 20$

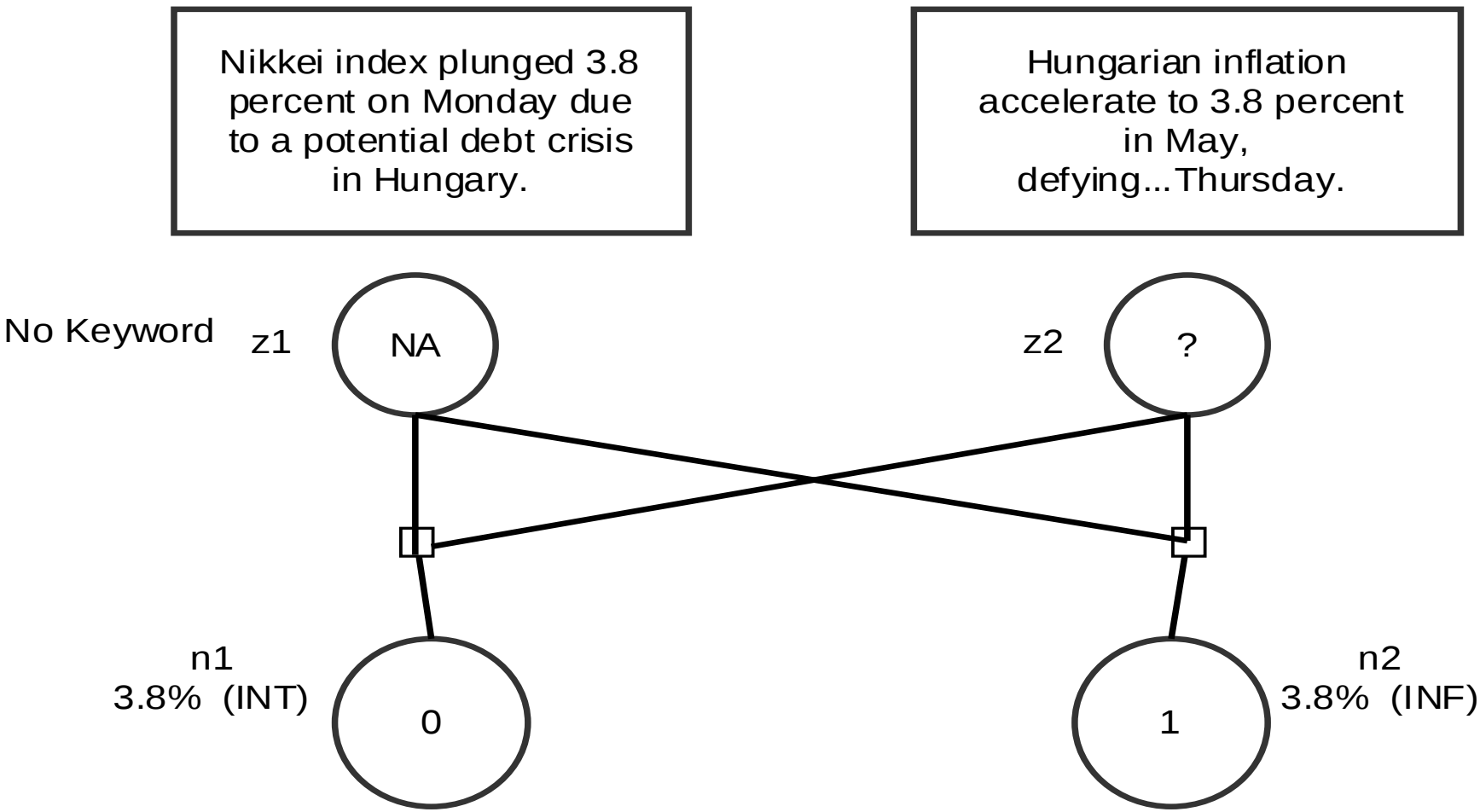
NumberTron Training

True Labels: Distant Supervision



NumberTron Training

True Labels: Distant Supervision



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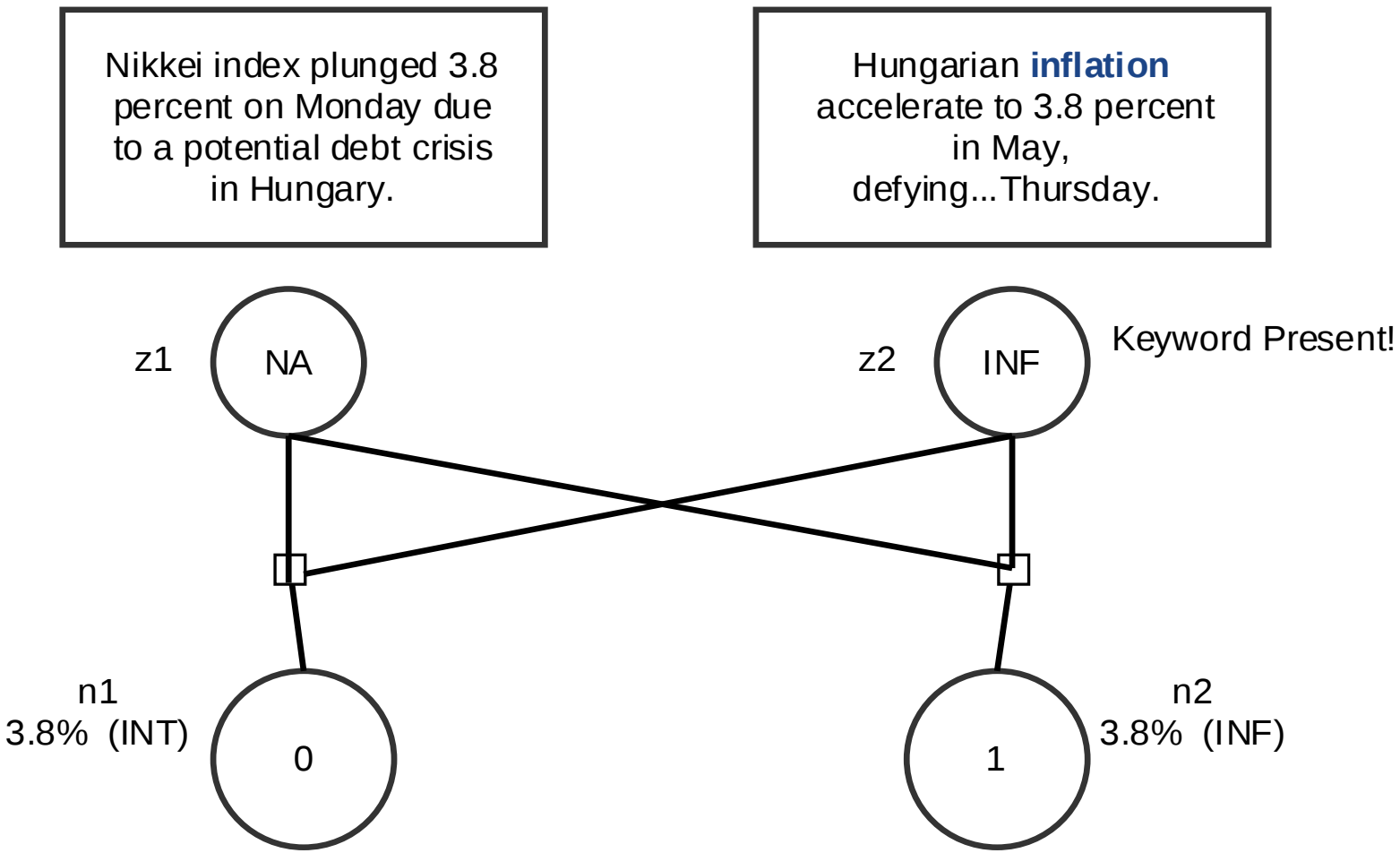
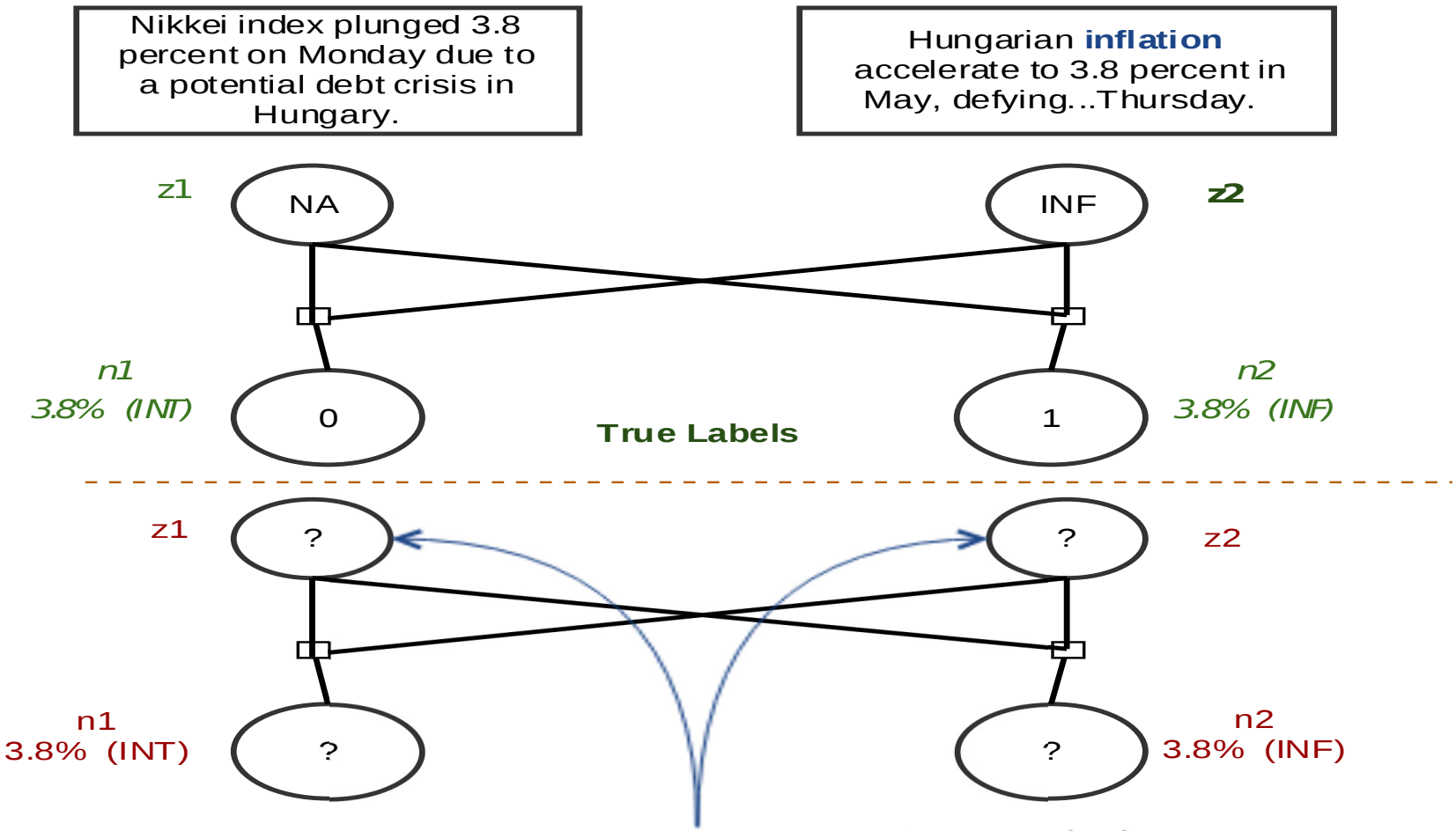


NumberTron Training

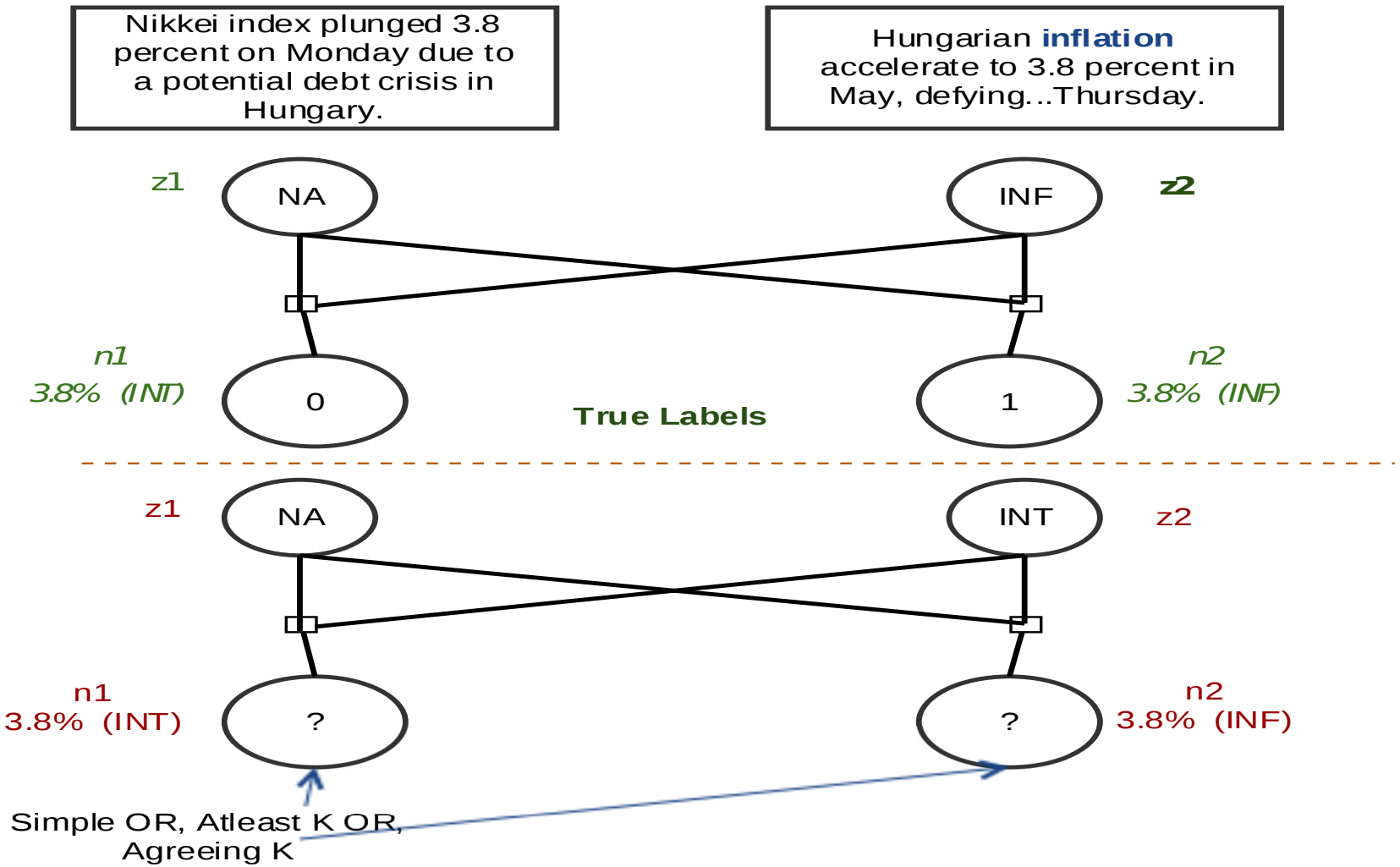
Observed Labels: Full Inference



Labels Inferred From Current Weights

NumberTron Training

Observed Labels: Full Inference



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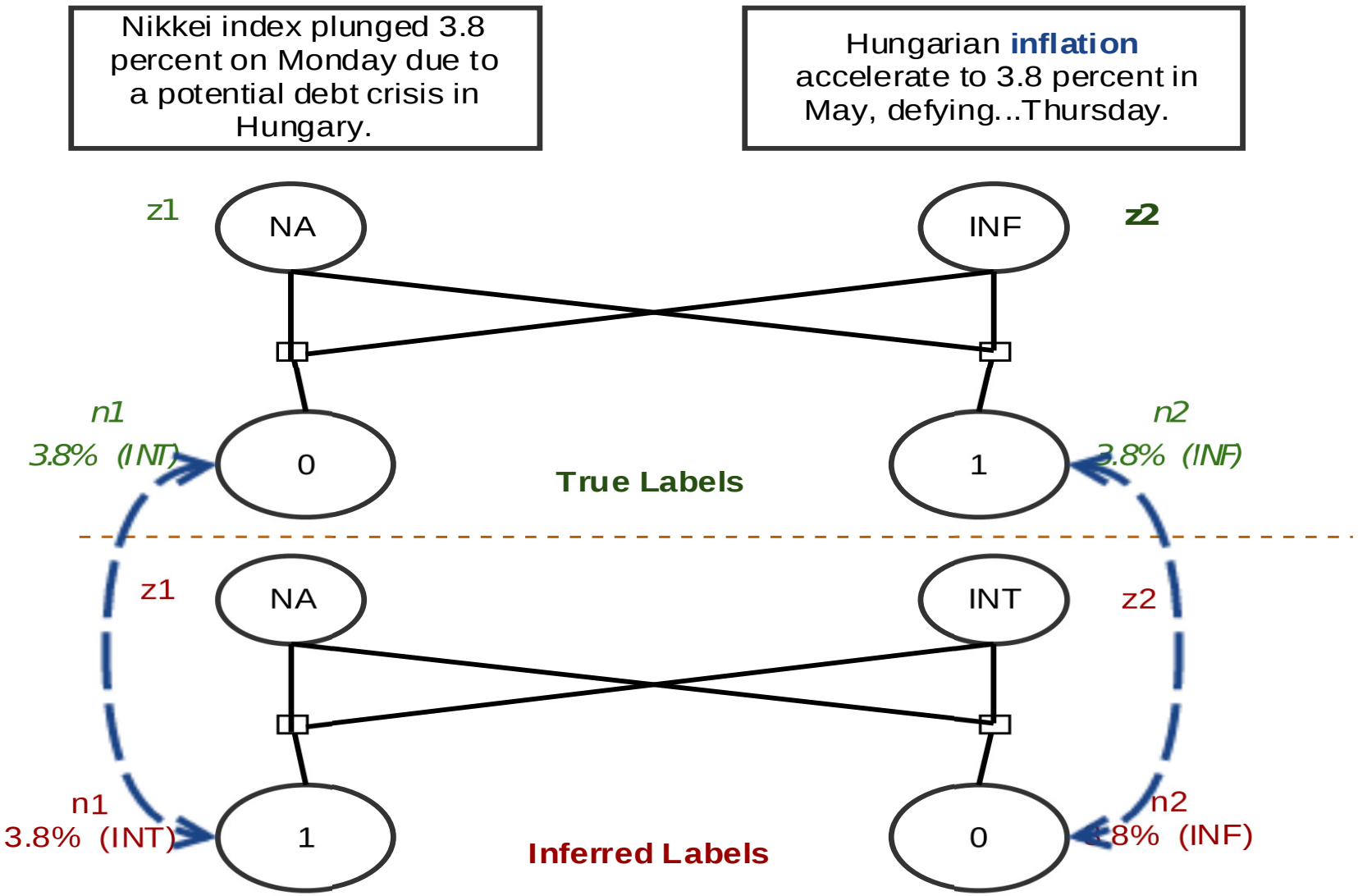
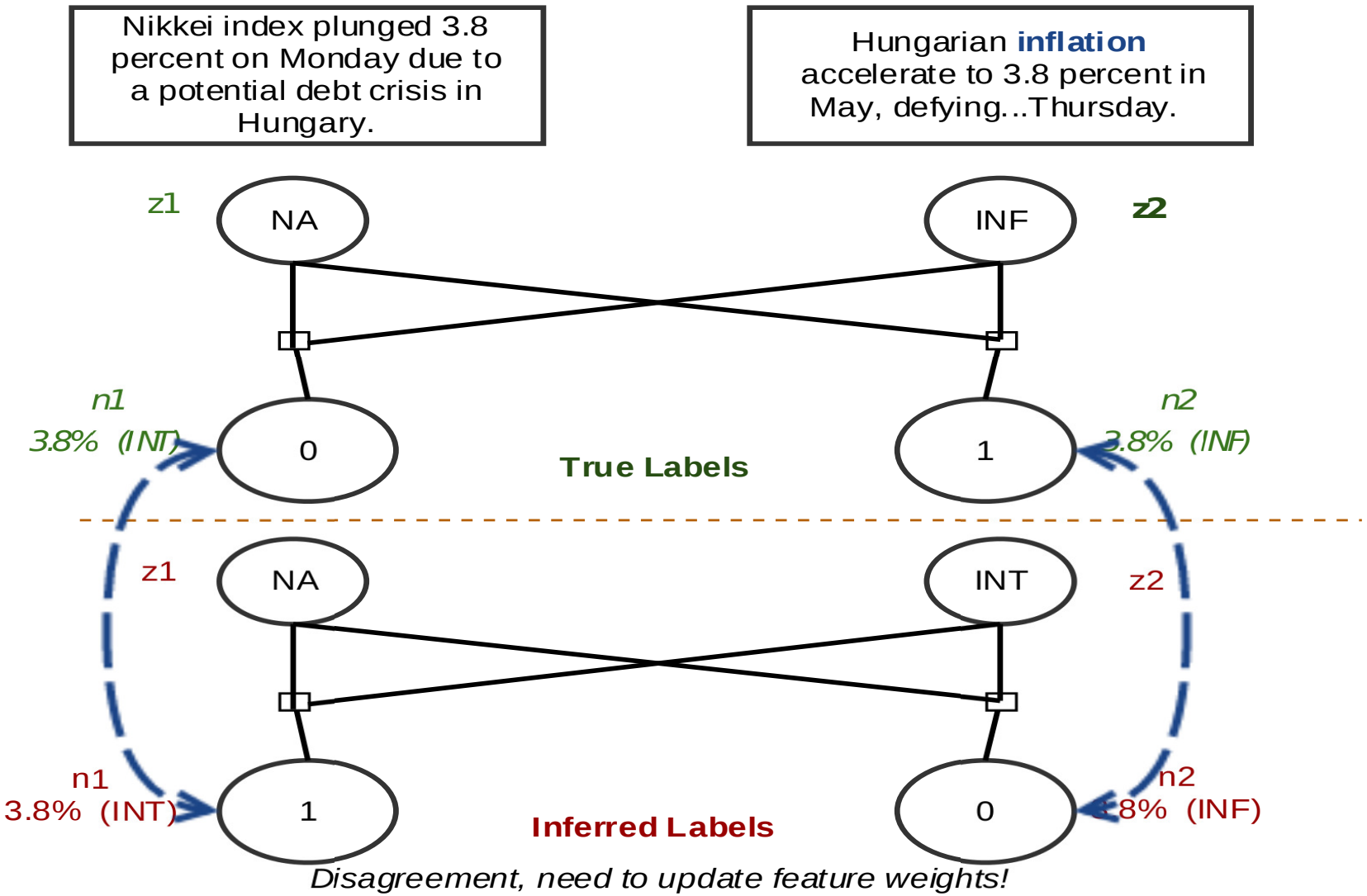
Observed Labels: Full Inference



NumberTron Training

Observed Labels: Full Inference



NumberTron Training

Updating Feature Weights

- Let $f_1, f_2, ..., f_k$ be the features fired for *Hungarian inflation accelerate to 3.8 percent in May, defying...Thursday.*
- Examples: **key: inflation**, **Num: Units** and so on.
- $\theta_{f_i}^{INT} \leftarrow \theta_{f_i}^{INT} - 1$
- $\theta_{f_i}^{INF} \leftarrow \theta_{f_i}^{INF} + 1$
- These features actually indicate inflation relation, and not the internet relation!

- **Sentence Level Extractions**
- Given a sentence S, let E be the set of entities and Q be the set of numbers that are present in the sentence.
- We then calculate a score(r, e, q) for a $e \in E$ and $q \in Q$ for being tagged r as $\theta_q^r \phi_q(n_q = 1) + \theta_s \phi_s(r)$ where ϕ_s captures the features in sentence S tied to entity e and number q.
- For each (e, q) we assign a label r if the min-max normalized score is greater than some threshold α.
- We use a cross validation set to obtain the $\alpha = 0.90$.

Results

Experiments

Training Corpus

- Tac KBP 2014 corpus comprising roughly 3 million documents from NewsWire, discussion forums, and the Web.
- Knowledge base is compiled from data.worldbank.org
  - Dataset contains 1,281 numeric indicators for 249 countries, with over 4 million base facts.
  - Dataset is normalized by converting all the values to their SI base unit value.

Experiments

Test Set

- Mix of 430 sentences from TAC corpus and sentences from Web search on relation name.

Relation	Units	Positive	Negative
Land Area	Sq. Km	57	17
Population	-	51	300
Inflation	percent	51	84
Internet Users	percent	15	
FDI	$ (USD)	10	35
GDP	$ (USD)	8	
Goods Export	$ (USD)	11	
Life Expectancy	year	15	34
Electricity Production	kWh	13	6
CO_2 Emissions	kiloton	8	16

Table : Test corpus statistics: The third column is the number of instances per relation and the fourth column is the number of "none-on-the-above" ($\perp$) grouped by relation of the same unit.

Baseline Algorithms

- **Recall –Prior Baseline:** For each unit, predict the relation with the highest *test* prior ignoring the "none-of-the-above" class.

Inflation	percent	51	84
Internet Users	percent	15	

  - All the numbers with the unit "percent" will be labeled 'Inflation' since it is most frequent class ignoring the "none-of-the-above" class.

Baseline Algorithms

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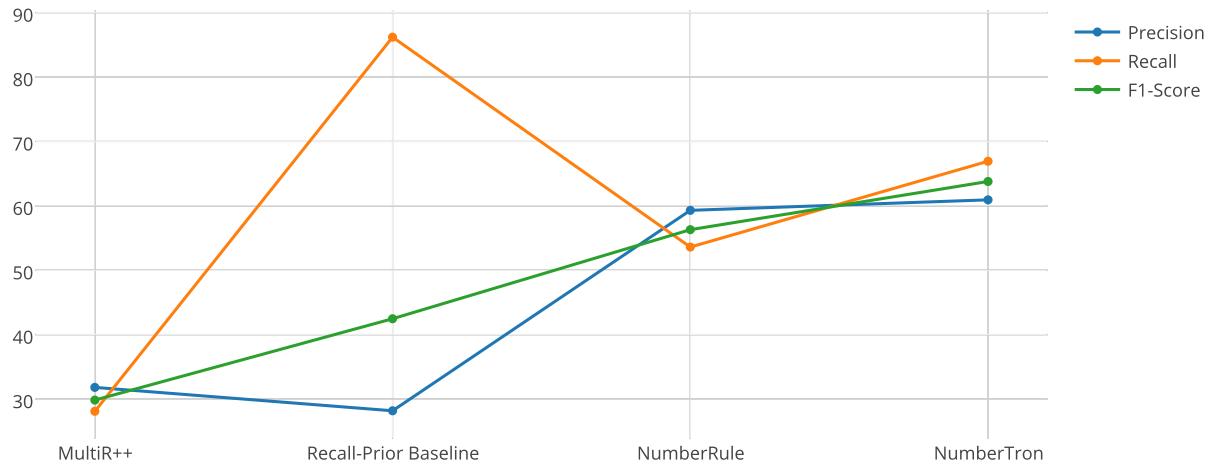
- **MultiR ++ : Adapting MultiR for Numerical Relations**
  - Added unit tagger as in our algorithms for identifying and normalizing numbers and units.
  - Added our partial matching (using $\pm\delta_r\%$) technique in distant supervision.

Results

Numbertron vs NumberRule vs Baselines



- Statistical method like NumberTron outperforms NumberRule on increased recall, which jumps from 53.6% to 67%
- MultiR++ performs poorly because it does not model peculiarities of numerical relations.

Analysis

NumberTron vs NumberRule

- NumberRule's missed recall is primarily because of not having a keyword on the dependency path.
  - "*Turkey's central bank said Wednesday it expects the annual inflation rate to reach 6.09 percent at the end of 2009 , lower than the official target of 7.5 percent.*"
  - Turkey $\xrightarrow{poss}$ bank $\xrightarrow{nsubj}$ said $\xrightarrow{ccomp}$ expects $\xrightarrow{xcomp}$ reach $\xrightarrow{dobj}$ percent $\xrightarrow{num}$ 6.09
  - Since keyword 'inflation' is not on the shortest dependency path between Turkey and 6.09, NumberRule does not extract.
  - Since NumberTron combines evidences from multiple features such as number's range, presence of 'inflation' in context and dependency path features.

Ablation tests

of various configurations of NumberTron

Distant Supervision	**Simple OR**			**Atleast-K**			**Agreeing-K**		
	P	R	F1	P	R	F1	P	R	F1
KB	43.24	50.93	46.54	40.05	53.93	45.97	35.20	44.52	39.35
Keywords	43.35	73.22	54.46	43.69	73.62	54.83	45.97	70.80	55.74
KB + Keywords	61.56	64.96	63.21	60.93	66.92	63.78	63.46	60.21	61.79

Table : Comparison of various configurations for NumberTron

- Keywords are crucial and KB in conjunction with keyword-based labeling adds significant value.

Ablation tests

of feature templates for NumberTron

Features	Precision	Recall	F1-score
Mintz features only	22.85	36.86	28.21
Keyword features only	51.24	52.55	51.89
Mintz + Keyword	47.10	39.04	42.71
Mintz + Number	17.80	35.03	23.67
Keyword + Number	45.15	69.70	54.80
Mintz + Keyword + Number	*60.93*	*66.92*	*63.78*

Table : Ablation tests of feature templates for NumberTron

- Large set of Mintz features confuses the classifier; Keyword features are much effective in learning.

Results

NumberTron vs NumberRule

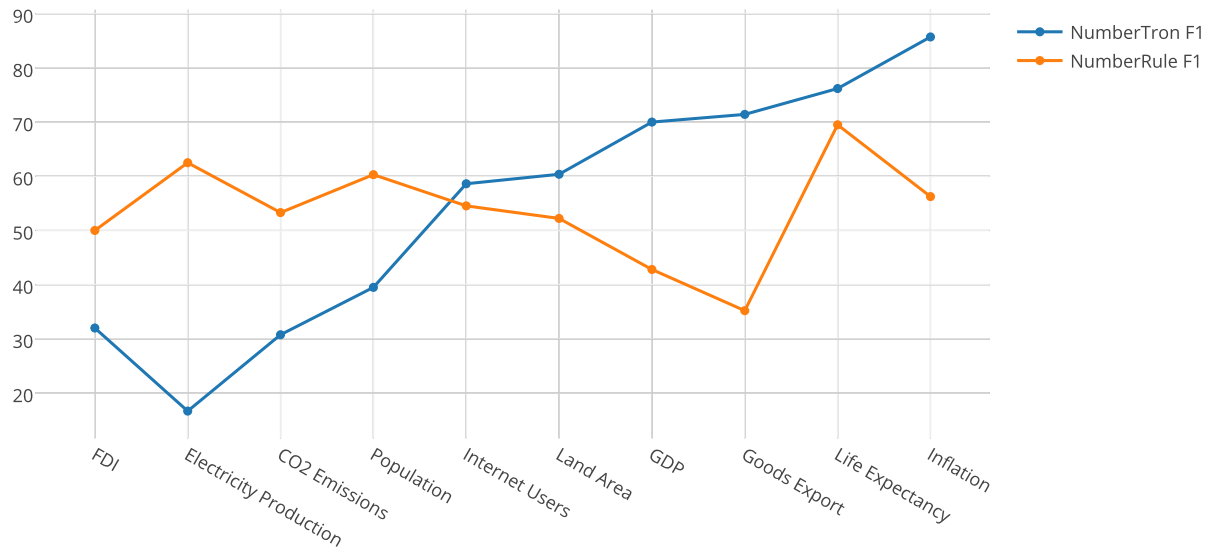


Figure : Per relation F1 scores for NumberRule and best configuration of NumberTron

Summary and Future Work

Future Work

- **Temporal Modeling** Many of the relations that we target are time dependent.
- **Soft constraints in NumberTron** Instead of hardcoding true assignments to the random variables, we can think of an alternative scheme in which the keyword nodes are added to the graphical model along with edge potentials that capture the similarity between potential relation and the keywords.
- **Extracting with Delta Words** NumberTron and NumberRule ignore mentions that express a change rather than the absolute fact.

Summary

- Numerical relation extraction has several peculiarities, more challenging than standard IE.
- **NumberRule**, a rule based system that can extract any numerical relation given input keywords for that relation.
- **NumberTron**, a probabilistic graphical model, that employs novel task-specific features and can be trained via distant supervision or other heuristic labelings.
- NumberTron aggregates evidence from multiple features and produces higher recall at a precision comparable to NumberRule.
- Both systems vastly outperform baselines and non-numeric IE systems, with NumberTron yielding over 33 point F-score improvement.

Thanks!

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Summary

NumberTron vs NumberRule

	NumberRule	**NumberTron**
Idea	Use dep path between the number and the entity in the mention	A Graphical Model with Perceptron like training algorithm
Supervision	Relation specific keywords.	Relation specific keywords + Numerical knowledge base.
Handling False +ves	Look for relation specific keywords in the dep path.	Keyword features.
Handling Mentions Expressing Change	No extraction if a delta word exists on the dep path.	Remove sentences having delta words on the dep path

NumberTron vs NumberRule

Use of Unit Tagger	Used to test compatibility of a relation and the number.	Used for training data creation and flattening to SI units.
Common Number Pruning	N/A	Features included to capture type (whole, fraction), magnitude and frequency.
Modified Relations	Handled by attaching words related via modifying dependencies, *urban* population.	Not handled in the model, can be handled at the time of extraction using a similar scheme.
Results	P = 59.30, R = 53.60, F-Score = 56.30	P = 60.93, R = 66.92, F-Score = 63.78