Enriching Knowledge Bases with Counting Quantifiers

Paramita Mirza ● Simon Razniewski ● Fariz Darari ● Gerhard Weikum
Counting Quantifiers (CQs)

• Fully qualified facts: <S, P, O>
  <California, hasCounty, Monterey>  <Donald Trump, hasSpouse, Melania Knauss>

• Counting information: <S, P, ∃O>
  <California, hasCounty, ∃58>  <Donald Trump, hasSpouse, ∃3>

  “There exists a specific number of O for a given SP pair”

• OWL description logics
  ClassAssertion(ObjectExactCardinality(58 :hasCounty) :California)
Why CQs?
Question Answering: “How many...”

5-10% “How many” questions in TREC 2003, 2004 and 2007 QA datasets

how many spouses has Donald Trump been with?

3
Donald Trump / Spouse / Count

how many spouses had Isaac Newton been with?

Take a look at these results. The first is from Quora

Why didn't Isaac Newton get married? - Quora
https://www.quora.com › Why-didnt-Isa...
Why CQs?
KB Quality Estimation: “How complete…”

Who are the children of George HW Bush?

- George W. Bush
- Jeb Bush
- Neil Bush
- Marvin P. Bush
- Dorothy Bush Koch

Marriage and college years

How to get CQs?

- CQs not part of mainstream KBs
- Counting objects not always reliable
- Texts contain counting information

→ CQ Extraction from texts
Problem: CQ Extraction

Given: \( S \)

\( P \) hasChild

Determine: \( \exists 6 \)
Why is CQ Extraction difficult?

1. **Systematic errors in automated training data due to incomplete KBs**
   - \(<\text{Jolie}, \text{hasChild}, \exists 4\) instead of \(<\text{Jolie}, \text{hasChild}, \exists 6\)\
   - Promote spurious patterns\
     - “won **four** Oscar”\
   - at the cost of correct patterns\
     - “has **six** children”

2. **Sparse and skewed observations**
   - Non-existence of children rarely mentioned\
   - The **first** Oscar mentioned more often
Why is CQ Extraction difficult? (2)

3. **Linguistic diversity**

   - Various expressions
     1. Explicit numerals (cardinal numbers)  “has five children”
     2. Lower bounds (ordinal numbers)  “his third wife”
     3. Number-related noun phrases  ‘twins’ or ‘quartet’
     4. Existence-proving articles  “has a brother”
     5. Non-existence adverbs  ‘never’ or ‘without’

   - Compositionality
     - In 2016, Jolie brought her twins, one daughter and three adopted children to the gala.
Overview

1. Counting Quantifiers (CQs)
   - Fully qualified facts: <S, P, O>
     - California, hasCounty, Monterey
     - Donald Trump, hasSpouse, Melania Knauss
   - Counting information: <S, P, 3O>
     - California, hasCounty, 3SB
     - Donald Trump, hasSpouse, 33
   - There exists a specific number of O for a given SP pair
   - OWL description logics

   ClassAssertion ObjectExactCardinality(S :hasCounty :California)

2. CINEX: Counting Information Extraction
   Stage 1: CQ Recognition
   Stage 2: CQ Consolidation

3. Evaluation: Stage 2 CQ Consolidation

<table>
<thead>
<tr>
<th>Relation</th>
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</tr>
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<tbody>
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</tr>
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</tr>
<tr>
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<td>53.8</td>
</tr>
<tr>
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<td>37.0</td>
</tr>
<tr>
<td>hasSpouse</td>
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</tr>
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<td>50.0</td>
<td></td>
</tr>
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<td>58.1</td>
<td></td>
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4. KB Enrichment Potential
   - Enrich KB with facts knowledge that facts exist
   - Apply CINEX on all Wikidata relations:
     - Filter out functional properties
     - Relations paired with 10 most frequent subject classes
     - Per relation: Evaluate CINEX on 10% (up to 200) most popular subjects as test set
     - CINEX yields >50% precision + 110 relations + having good extracted CQs
     - Apply 110 CINEX models on all subject entities of corresponding classes
     - CINEX enrich KB (for 110 relations) with existence of 28.3% more facts

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CINEX: Counting INformation EXtraction

Stage 1: CQ Recognition
- CRF
- LSTM

Stage 2: CQ Consolidation
- Composition
- Preferences
- Thresholding

Seeds → Input Text → CQ Candidates → CQs
1. She has a grand total of six children together: three biological and three adopted.

2. Angelina Jolie and four of her kids soaked up the last few days of summer over Labor Day.

3. She has received an Academy Award, two Screen Actors Guild Awards, and three Golden Globe Awards, and has been cited as Hollywood’s highest-paid actress.

4. Divorced from actors Jonny Lee Miller and Billy Bob Thornton, she separated from her third husband, actor Brad Pitt, in September 2016.

5. The arrival of the first biological child Jolie and Pitt caused an excited flurry with fans.


7. In 2016, Jolie brought her twins, one daughter and three adopted children to the gala.
In 2016, Jolie brought her **twins**, **one** daughter and **three** adopted children to the gala.

**Sequence labelling task**

- One model learned per **predicate**
- Feature-based model (CRF) vs **Neural model** (bi-LSTM-CRF)
Stage 1: CQ Recognition

- In 2016, Jolie brought her **twins**, **one** daughter and **three** adopted children to the gala.

Incompleteness-aware **distant supervision**

- COUNT DISTINCT <Angelina Jolie, hasChild, *> as **seed counts**
- **Label** the tokens with COUNT (and COMP) when
  - the token itself, OR
  - the sum of several tokens **match the seed count**
- Filtering training data based on subject popularity
Stage 2: CQ Consolidation

She has a grand total of six children together: three biological [and] three adopted. → 6, 6

Angelina Jolie and four of her kids soaked up the last few days of summer over Labor Day. → 4

The arrival of the first biological child Jolie and Pitt caused an excited flurry with fans. → 1

On July 12, 2008, she gave birth to twins: a son, Knox Leon, [and] a daughter, Vivienne Marcheline. → 2, 2

1. cardinals 6
2. numterms 2
3. ordinals 1
4. articles 2 threshold = 0.5
Overview

1

Counting Quantifiers (CQs)

- Fully qualified facts: ⟨S, P, O⟩
  - ⟨California, hasCounty, Monterey⟩
  - ⟨Donald Trump, hasSpouse, Melania Knauss⟩
- Counting information: ⟨S, P, 3O⟩
  - ⟨California, hasCounty, 35B⟩
  - ⟨Donald Trump, hasSpouse, 33⟩

“There exists a specific number of O for a given SP pair”

- OWL description logics

```
ClassAssertion ObjectExactCardinality50 :hasCounty :California
```

2

CINEX: Counting Information Extraction

- Stage 1: CQ Recognition
  - CRF
  - LSTM
- Stage 2: CQ Consolidation
  - Composition
  - Preferences
  - Thresholding

3

Evaluation: Stage 2 CQ Consolidation

<table>
<thead>
<tr>
<th>Method</th>
<th>containsWork</th>
<th>hasMember</th>
<th>containsAdmin</th>
<th>hasChild</th>
<th>hasSpouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milne et al., 2017</td>
<td>43.0</td>
<td>11.8</td>
<td>51.8</td>
<td>37.0</td>
<td>26.8</td>
</tr>
<tr>
<td>CINEX-CRF</td>
<td>49.2</td>
<td>64.3</td>
<td>78.6</td>
<td>50.0</td>
<td>58.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cardinality</th>
<th>Precision</th>
<th>Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>CINEX-CRF</td>
<td>85.7</td>
<td>87.4</td>
</tr>
<tr>
<td>NUMERICAL</td>
<td>62.5 (80.7)</td>
<td>76.0</td>
</tr>
<tr>
<td>ORDINAL</td>
<td>20.0 (23.6)</td>
<td>14.3 (21.0)</td>
</tr>
<tr>
<td>ORDINAL (lower bound)</td>
<td>86.7</td>
<td>89.5</td>
</tr>
</tbody>
</table>

4

KB Enrichment Potential

- Enrich KB with facts knowledge that facts exist

- Apply CINEX on all Wikidata relations:
  - Filter out functional properties
  - Relations paired with 10 most frequent subject classes
  - Per relation, Evaluate CINEX on 1% (up to 200) most popular subjects as test set
  - CINEX yields 50% precision + 110 relations + having good extracted CQs
  - Apply 110 CINEX models on all subject entities of corresponding classes
  - CINEX enrich KB (for 110 relations) with existence of 28.3% more facts

```
Property  Class  KB Facts  CQ Facts
has part  rock band  1,147  1,616 (+32.2%)
```
Experimental Setup

- **Wikidata** as source KB, **Wikipedia** pages of subject $S$ as input texts
  - Version: March 20, 2017

- **5 relation/predicate $P$**

<table>
<thead>
<tr>
<th>Wikidata Subject Class</th>
<th>Wikidata Property</th>
<th>Relation</th>
<th>#Subjects</th>
<th>#Sentences</th>
</tr>
</thead>
<tbody>
<tr>
<td>series of creative works</td>
<td>has part</td>
<td>containsWork</td>
<td>642</td>
<td>7,984</td>
</tr>
<tr>
<td>musical ensemble</td>
<td>has part</td>
<td>hasMember</td>
<td>8,901</td>
<td>96,056</td>
</tr>
<tr>
<td>admin. territorial entity</td>
<td>contains admin...</td>
<td>containsAdmin</td>
<td>6,266</td>
<td>13,199</td>
</tr>
<tr>
<td>human</td>
<td>child</td>
<td>hasChild</td>
<td>40,145</td>
<td>319,807</td>
</tr>
<tr>
<td>human</td>
<td>spouse</td>
<td>hasSpouse</td>
<td>45,261</td>
<td>408,974</td>
</tr>
</tbody>
</table>

- **Training set**: Wikidata object counts as seed counts
- **Test set**: manually annotated CQs

At least one object
Evaluation: Stage 1 CQ Recognition

- CRF models **more robust** than bi-LSTMs (57% vs 40% avg F1-score)
  - Neural models much more prone to overfitting to noisy training data

- CRF and neural models **outperform the state-of-the-art:**
  - Mirza et al., Cardinal Virtues: Extracting Relation Cardinalities from Text, ACL 2017
  - extract only cardinal numbers

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<tr>
<td>Mirza et al., 2017</td>
<td>23.1</td>
<td>2.2</td>
<td>57.0</td>
<td>11.4</td>
<td>3.3</td>
</tr>
<tr>
<td>CINEX-CRF</td>
<td>39.8</td>
<td>56.1</td>
<td>77.3</td>
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**Evaluation: Stage 2 CQ Consolidation**

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<table>
<thead>
<tr>
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<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>containsWork</td>
</tr>
<tr>
<td>CARDINAL</td>
<td>55.0 (33.9)</td>
</tr>
<tr>
<td>NUMT.+ART.</td>
<td>62.5 (40.7)</td>
</tr>
<tr>
<td>ORDINAL</td>
<td>20.0 (25.4)</td>
</tr>
<tr>
<td>ORDINAL (as lower bound)</td>
<td>86.7</td>
</tr>
</tbody>
</table>
Evaluation: Error Analysis

• Confusion of relations having similar CQs
  • <Ladysmith Black Mambazo, hasMember, 36>
    • “…Mazibuko (the eldest of the six brothers) joined Mambazo…”
    • Confused with hasSibling
  • <Ruth W. Khama, hasSpouse, 32>
    • “…and twins Anthony and Tshekedi were born in…”
    • Confused with hasChild

• Confusion of entity type granularity
  • <Scandal (TV series), containsWork, 310>
    • “…the first season consisting of ten episodes.”
    • TV series contains seasons
    • seasons contains episodes
Overview

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- Fully qualified facts: <S, P, O>
  
  - California, hasCounty, Monterey
  - Donald Trump, hasSpouse, Melania Knauss

- Counting information: <S, P, O>
  
  - California, hasCounty, 358
  - Donald Trump, hasSpouse, 333

  “There exists a specific number of O for a given SP pair”

- OWL description logics

  - ClassAssertion(ObjectExactCardinality(58, hasCounty), :California)

Evaluation: Stage 2 CQ Consolidation

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Precision (% of CQs)

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<td>55.9 (42.1)</td>
<td>62.6 (42.1)</td>
<td>85.7 (42.1)</td>
<td>67.3 (42.1)</td>
<td>75.0 (42.1)</td>
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<td>NUM, ART</td>
<td>42.5 (42.1)</td>
<td>65.0 (42.1)</td>
<td>33.3 (42.1)</td>
<td>43.8 (42.1)</td>
<td></td>
</tr>
<tr>
<td>ORDINAL</td>
<td>55.0 (42.1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>43.8 (42.1)</td>
<td></td>
</tr>
</tbody>
</table>

(less lower bound)

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<th></th>
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<th>hasChild</th>
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<tr>
<td>ORDINAL</td>
<td>88.7</td>
<td>0</td>
<td>0</td>
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KB Enrichment Potential

- Enrich KB with facts knowledge that facts exist

- Apply CINEX on all Wikidata relations:
  - Filter out functional properties
  - Relations → properties paired with 10 most frequent subject classes
  - Per relation → Evaluate CINEX on 10% (up to 200) most popular subjects as test set
  - CINEX yields +50% precision + 110 relations + having good extracted CQs
  - Apply 110 CINEX models on all subject entities of corresponding classes
  - CINEX enrich KB (for 110 relations) with existence of 28.3% more facts

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Conclusions

1. **Counting quantifiers (CQs)** important for KBs, yet **under-researched**

2. **CQ extraction is challenging** → principled differences with classical fact extraction

3. End-to-end system for CQ extraction, **CINEX**:
   - 49.2% to 78.6% precision on 5 Wikidata relations
   - enrich 110 Wikidata relations with existence of 28.3% more facts

4. CINEX on **GitHub** (github.com/paramitamirza/CINEX)

5. Extracted CQs on a **linked data endpoint** (cinex.cs.ui.ac.id)
(How many) Questions?

https://cinex.cs.ui.ac.id/
CINEX – Count Zero

<table>
<thead>
<tr>
<th>label</th>
<th>countingQuantifier</th>
<th>evidence</th>
<th>evidenceSource</th>
</tr>
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<tbody>
<tr>
<td>Isaac Newton</td>
<td>&quot;0&quot;xsd:int</td>
<td>Although it was claimed that he was 1 time engaged, Newton married [[0]] time.</td>
<td><a href="https://en.wikipedia.org/wiki?curid=14627">https://en.wikipedia.org/wiki?curid=14627</a></td>
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</table>

Text preprocessing of sentences containing **not-any, never and without**

- They didn’t have any children → They had no children
- He has never been married → He has been married 0 time
- The marriage was without children → The marriage was with no children

- no is treated as CARDINAL and interpreted as 0

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<tr>
<td>hasZeroChild</td>
<td>92.3</td>
</tr>
<tr>
<td>hasZeroSpouse</td>
<td>71.9</td>
</tr>
</tbody>
</table>

CINEX-CRF
“How many spouses had Isaac Newton been with?”

https://cinex.cs.ui.ac.id/

```sql
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX wd: <http://www.wikidata.org/entity/>
PREFIX wdt: <http://www.wikidata.org/prop/direct/>
PREFIX cn: <https://cinex.cs.ui.ac.id/ns#>
PREFIX cne: <https://cinex.cs.ui.ac.id/entity/>

WHERE {
  SERVICE <https://cinex.cs.ui.ac.id/countsparsql> {
    FILTER (?subject=wd:Q9385) . # Isaac Newton
    FILTER (?prop=wdt:P26) . # spouse property
    ?cinexEntity a cn:cardinal ;
    cn:subject ?subject ;
    cn:property ?prop ;
    cn:predictedCount ?countingQuantifier ;
    cn:evidence ?evidence ;
  }
}
```

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</tr>
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</table>
“How many children does George HW Bush have?”

https://cinex.cs.ui.ac.id/

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX wd: <http://www.wikidata.org/entity/>
PREFIX wdt: <http://www.wikidata.org/prop/direct/>
PREFIX cn: <https://cinex.cs.ui.ac.id/ns#>
PREFIX cne: <https://cinex.cs.ui.ac.id/entity/>

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX wd: <http://www.wikidata.org/entity/>
PREFIX wdt: <http://www.wikidata.org/prop/direct/>
PREFIX cn: <https://cinex.cs.ui.ac.id/ns#>
PREFIX cne: <https://cinex.cs.ui.ac.id/entity/>

WHERE {
  # count children facts in Wikidata
  SELECT (COUNT(?o)) AS ?wikidataCount
  WHERE {
    SERVICE <https://query.wikidata.org/bigdata/namespace/wdq/sparql> {
    }
  }
  SERVICE <https://query.wikidata.org/bigdata/namespace/wdq/sparql> {
    FILTER (?childProp = wd:Q23585). # child property of George HW Bush
  }
  SERVICE <https://query.wikidata.org/bigdata/namespace/wdq/sparql> {
    FILTER (?prop = wdt:P40) . # child property
  }
  SERVICE <https://query.wikidata.org/bigdata/namespace/wdq/sparql> {
    cn:predictedCount ?countingQuantifier .
    cn:subject ?subject .
  }
  SERVICE <https://query.wikidata.org/bigdata/namespace/wdq/sparql> {
    cn:cardinal ?countingQuantifier .
    FILTER (?cinexEntity = cn:countingQuantifier).
  }
  SERVICE <https://query.wikidata.org/bigdata/namespace/wdq/sparql> {
  }
  FILTER (?countingQuantifier = "5"^^xsd:int) .
  FILTER (?countingQuantifier = "6"^^xsd:int)
}

# retrieve counting quantifiers from CINEX
SERVICE <https://cinex.cs.ui.ac.id/counts/sparql> {
  FILTER (?prop = wdt:P40) .
  SERVICE <https://query.wikidata.org/bigdata/namespace/wdq/sparql> {
  }
}
```

<table>
<thead>
<tr>
<th>label</th>
<th>wikidataCount</th>
<th>countingQuantifier</th>
<th>evidence</th>
<th>evidenceSource</th>
</tr>
</thead>
</table>
Stage 1: CQ Recognition

- In 2016, Jolie brought her **twins**, **one** daughter and **three** adopted children to the gala.

<table>
<thead>
<tr>
<th>...her</th>
<th>twins</th>
<th>,</th>
<th>one</th>
<th>daughter</th>
<th>and</th>
<th>three</th>
<th>adopted</th>
<th>children</th>
<th>to...</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>COUNT</td>
<td>COMP</td>
<td>COUNT</td>
<td>O</td>
<td>COMP</td>
<td>COUNT</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

**P hasChild**

- Incompleteness-aware **distant supervision**
  - COUNT DISTINCT <Angelina Jolie, hasChild, *> as **seed counts**
  - Filtering **training data** based on subject popularity
  - Ignoring higher **counts**, unless > upper bound (count at 99th percentile)
    - e.g., 2016 cannot be number of children
  - Ignoring counts with low entropy
    - Count ‘1’ appears abundantly in the text
Experiment Results: CQ Recognition

- CRF models **more robust** than bi-LSTMs (avg precision)
  - Neural models much more prone to overfitting to noisy training data
- CRF and neural models **outperform the state-of-the-art** (Mirza et al., ACL 2017)
  - Mirza et al., 2017: extract only cardinal numbers

<table>
<thead>
<tr>
<th></th>
<th>containsWork</th>
<th>hasMember</th>
<th>containsAdmin</th>
<th>hasChild</th>
<th>hasSpouse</th>
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</thead>
<tbody>
<tr>
<td>Mirza et al., 2017</td>
<td>23.1</td>
<td>2.2</td>
<td>57.0</td>
<td>11.4</td>
<td>3.3</td>
</tr>
<tr>
<td>CINEX-CRF</td>
<td>39.8</td>
<td>56.1</td>
<td>77.3</td>
<td>49.0</td>
<td>62.4</td>
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<tr>
<td>CARDINAL</td>
<td>28.1</td>
<td>40.0</td>
<td>83.5</td>
<td>64.9</td>
<td>83.3</td>
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<tr>
<td>NUMT.+ART.</td>
<td>68.9</td>
<td>59.6</td>
<td>0</td>
<td>39.1</td>
<td>0</td>
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<tr>
<td>ORDINAL</td>
<td>31.7</td>
<td>40.0</td>
<td>0</td>
<td>3.5</td>
<td>72.5</td>
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F1-scores