

# Annotating and Spotting in Mathematical Corpora (concepts and tools)

Jan Frederik Schaefer

FAU Erlangen-Nürnberg

**Prospects of Formal Mathematics – Bridging between informal and formal**

Hausdorff Research Institute for Mathematics

Bonn

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# Natural Language Processing and Mathematical Language

- Natural language processing has benefitted from a long tradition of annotation tasks and benchmarks
- STEM documents pose problems: formulae, tables, ... *not really unicode strings*
- Why care?  
     $\rightsquigarrow$  Semantic services

## Motivation: semantic services

Q 1.5 eV

↗ with an energy of  $1.43 \pm 0.09 \text{ eV}$

↗ which gives  $E = 2.4 \cdot 10^{-19} \text{ J}$

Q  $\sum_{k=-\infty}^{\infty} \exp(-\pi k^2)$

↗  $\sum_{n=-\infty}^{\infty} e^{-\pi n^2} = \dots$

*Example from [Kri22]*

equivalent to Eq. 4 can be written as follows:

$$P_{extcorr} = e^{\alpha(X_{\odot} - 1)} \times P_{meas}, \quad (5)$$

where  $\alpha = 0.92103k_{\lambda}$ .

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*"the Sun's airmass"*

Amount of air in direction of sun

If relative: Divided by amount of air at zenit

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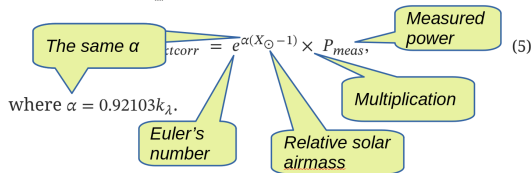
$\alpha$ :	<input type="text" value="0.11"/>
$X_{\odot}$ (air mass coefficient):	<input type="text" value="1.3"/>
$P_{meas}$ (measured power):	<input type="text" value="1 kW"/>
<input type="button" value="Compute"/>	<input type="button" value="Plot"/>

## Motivation: semantic services

For all those services  
**we need semantic annotations!**

*(full formalization not necessary)*

equivalent to Eq. 4 can be written as follows:



The diagram shows the equation 
$$P_{atcorr} = e^{\alpha(X_{\odot}-1)} \times P_{meas}, \quad (5)$$
 with several semantic annotations in yellow callout boxes: "The same  $\alpha$ " points to the  $\alpha$  in the exponent; "Euler's number" points to the  $e$  base; "Relative solar airmass" points to the  $X_{\odot}$  term; "Measured power" points to the  $P_{meas}$  term; and "Multiplication" points to the  $\times$  operator. Below the equation, the text "where  $\alpha = 0.92103k_{\lambda}$ ." is present.

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The diagram shows Equation (5) with several semantic annotations in yellow callout boxes. The equation is 
$$P_{corr} = e^{\alpha(X_{\odot}-1)} \times P_{meas}, \quad (5)$$
 where  $\alpha = 0.92103k_{\lambda}$ . Annotations include: 'The same  $\alpha$ ' pointing to  $\alpha$ ; 'Euler's number' pointing to  $e$ ; 'Relative solar airmass' pointing to  $X_{\odot}$ ; 'Measured power' pointing to  $P_{meas}$ ; and 'Multiplication' pointing to the  $\times$  operator.

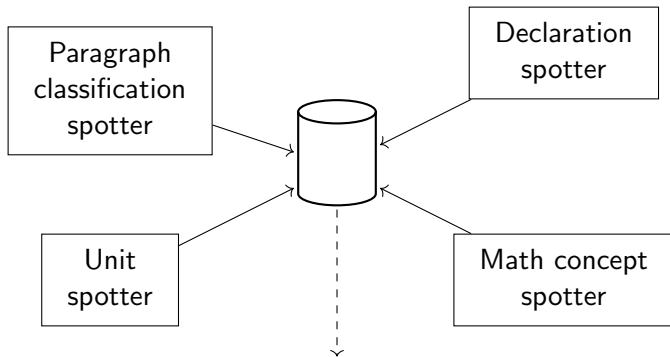
where  $\alpha = 0.92103k_{\lambda}$ .

Authors don't provide them  $\rightsquigarrow$  We have to infer them



# Accumulating semantic annotations with spotters

**Spotter:** specialized tool for finding a particular type of annotation



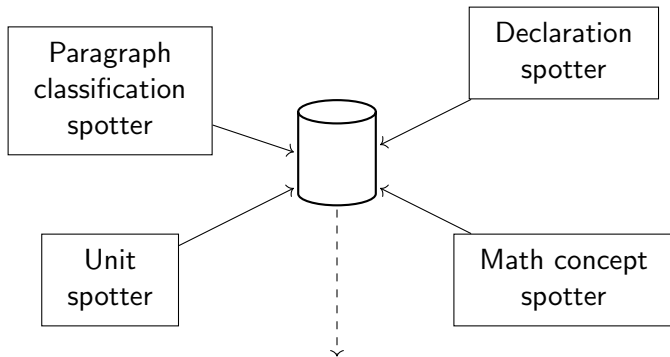
**Theorem 1.** *Let  $F$  be a graph with  $m$  edges and no isolated vertices. Then, for  $k \geq 3$  it holds*

$$r_k(F) \leq k^{3 \cdot 2^{-1/3}} k m^{2/3} + k(2m)^{1/3} 8m.$$

*Example from [JP13]*

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# What is the problem?

## ① Getting a corpus:

- arXMLiv/ar5iv dataset [Gin20]
- SIGMathLing [SML]

*Working with PDF is difficult*

*convert .tex to .html*

*NDA-cooperative to work around licensing issues*

## ② Re-inventing the wheel:

- Need to obtain plaintext representation
- Need to store annotations
- Need to create manual annotations

*for training/evaluation*

## ③ Cannot re-use existing annotations/combine results:

- No agreed-upon annotation format
- Original documents modified

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**Utterly incompatible!**



## A new annotation standard

- Supports development of re-usable tools, datasets and benchmarks
- Uses RDF (Resource Description Framework)
  - ∃ *databases, query language (SPARQL), serialization formats*
- Based on W3C Web Annotation Recommendations

# A new annotation standard

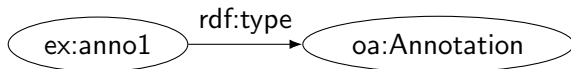
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  - Uses RDF (Resource Description Framework)
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## RDF Primer

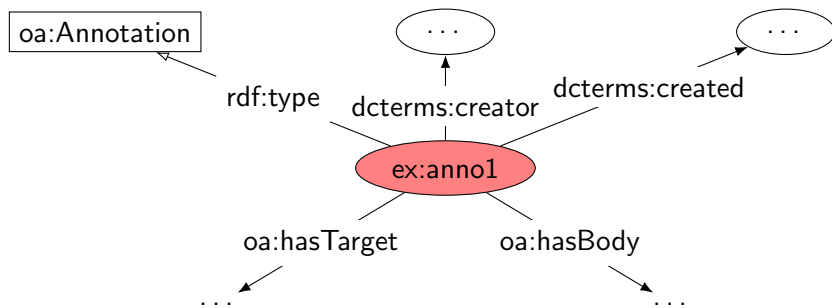
subject-predicate-object triple

ex:anno1 rdf:type oa:Annotation

directed graph



# Annotation structure (following W3C Web Annotation Recommendation)

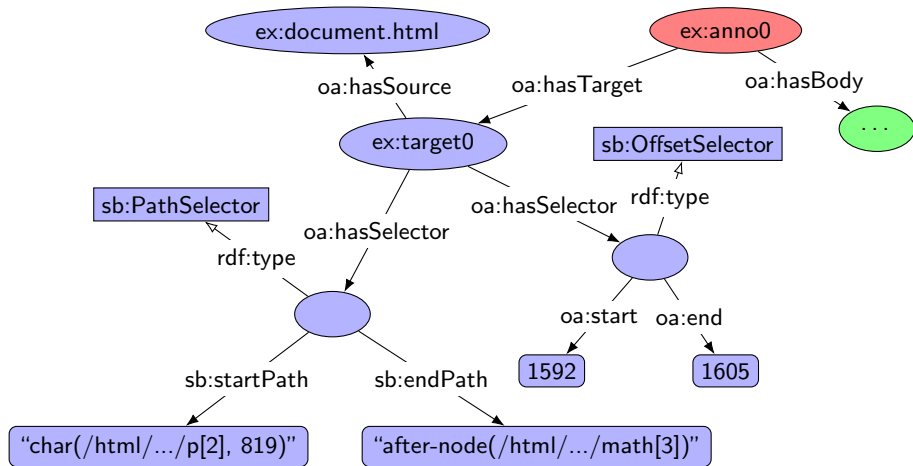


**Theorem 2.** Let  $F$  be a **bipartite graph** with  $m$  edges and isolated vertices. Then for  $k > 2$  it holds

*Example from [JP13]*

`wd:Q174733`  
(WikiData: bipartite graph)

# Annotation Targets



# Prototype datasets and imported datasets

- Imported datasets:
  - Quantity expressions dataset [Rab17]
  - Formula grounding dataset [AMA22]
  - Paragraph classification dataset [GM20]
- Generated datasets (prototype spotters)
  - Part-of-speech tags
  - References to math concepts
  - Variable declarations
- Stats from running last two spotters:
  - 100 000 documents
  - 50 million annotations
  - 800 million triples
  - loading into triple store: several hours

# Querying

*"Papers about group theory that have theorems mentioning rational numbers"*

```
# prefix declarations omitted for conciseness
```

```
SELECT DISTINCT ?paper WHERE {
```

```
  # make sure that ?paper is about group theory
```

```
  ?paper sb:isBasedOn/^oa:hasTarget/oa:hasBody/rdf:value arxivcat:math\..GR
```

```
  # find theorems in ?paper and look up their offsets
```

```
  ?theorem_anno oa:hasBody/rdf:value sbp:Theorem .
```

```
  ?theorem_anno oa:hasTarget [
```

```
    oa:hasSource ?paper ;
```

```
    oa:hasSelector [ a sb:OffsetSelector ; oa:start ?t_start ; oa:end ?t_end
```

```
  ] .
```

```
  # Same with mentions of rational numbers (offsets ?q_start, ?q_end)
```

```
  ?q_anno oa:hasBody/rdf:value <http://www.wikidata.org/entity/Q1244890> .
```

```
  ?q_anno oa:hasTarget [
```

```
    oa:hasSource ?paper ;
```

```
    oa:hasSelector [ a sb:OffsetSelector ; oa:start ?q_start ; oa:end ?q_end
```

```
  ] .
```

```
  # make sure that mention is inside theorem
```

```
  FILTER (?t_start < ?q_start && ?t_end > ?q_end)
```

# Manual annotation AnnoTize

**Theorem 1.** Let  $G$  be a graph with  $m$  edges and no isolated vertices. Then, for  $k \geq 3$  it holds

$$r_k(G) \leq k^{3 \cdot 2^{-1/3} m^{2/3} + k(2m)^{1/3}} 8m.$$

Occurrence

Further we study the case when  $G$  is bipartite and show an upper bound  $r_k(G) \leq k^{(1+o(1))2\sqrt{mk}}$ .

**Theorem 2.** Let  $G$  be a bipartite graph with  $m$  edges and no isolated vertices. Then, for  $k \geq 2$  it holds

$$r_k(G) \leq 2^6 m^{3/2} k^{2\sqrt{km} + 1/2}.$$

Note that in the case  $k = 2$ , Theorem 2 is an improvement of the above mentioned result of

$k$

IdentifierOccurrence:

Identifier:

<http://127.0.0.1:5000//document.html/#b88755c4-fcbc-4c7b-9088-9e50256fb31f.anno.3>



Code (open source) for

<https://github.com/jfschaefer/spotterbase>

- Normalizing annotations
- Generating different types of plaintext
- Importing/exporting annotations as JSON
- ...

*Linked to original sources!*



- Implement a simple example spotter together
- Develop more interesting spotters
- Discuss what annotations would be useful

**Proposition 2.1.** *Let  $K$  be a number field. Let  $\mathcal{W}_K$  be any set of primes of  $K$ . Let  $\mathcal{S}_K \subseteq \mathcal{W}_K$  be a finite set. Let  $\mathcal{V}_K = \mathcal{W}_K \setminus \mathcal{S}_K$ . Then  $O_{K, \mathcal{V}_K}$  has a Diophantine definition over  $O_{K, \mathcal{W}_K}$ . (See, for example, [24].)*

“Infinite” versions of this proposition are more complicated. Before stating some of them below we introduce new terminology.

An annotation standard for STEM documents

- based on semantic web technologies *RDF, SPARQL, Web Annotation Standard*
- compatible with a wide range of annotation tasks
- to create diverse, re-usable annotation datasets and benchmarks
- to develop an ecosystem of tools around that standard
- to ultimately enable the development of semantic services

*active documents, formula search, ...*

# References I

- [AMA22] Takuto Asakura, Yusuke Miyao, and Akiko Aizawa. “Building Dataset for Grounding of Formulae — Annotating Coreference Relations Among Math Identifiers”. In: *Proceedings of the Language Resources and Evaluation Conference*. Marseille, France: European Language Resources Association, 2022, pp. 4851–4858. URL: <https://aclanthology.org/2022.lrec-1.519>.
- [Gin20] Deyan Ginev. *arXMLiv:2020 dataset, an HTML5 conversion of arXiv.org*. SIGMathLing – Special Interest Group on Math Linguistics. 2020. URL: <https://sigmathling.kwarc.info/resources/arxmliv-dataset-2020/>.

## References II

- [GM20] Deyan Ginev and Bruce R Miller. “Scientific Statement Classification over arXiv.org”. English. In: *Proceedings of the Twelfth Language Resources and Evaluation Conference*. Marseille, France: European Language Resources Association, May 2020, pp. 1219–1226. ISBN: 979-10-95546-34-4. URL: <https://aclanthology.org/2020.lrec-1.153>.
- [JP13] Kathleen Johst and Yury Person. *On the multicolor Ramsey number of a graph with  $m$  edges*. 2013. arXiv: 1311.5471 [math.CO].
- [Kri22] Kevin Krisciunas. *Including Atmospheric Extinction in a Performance Evaluation of a Fixed Grid of Solar Panels*. 2022. arXiv: 2107.02876 [astro-ph.IM].

## References III

- [Rab17] Ullrich Rabenstein. “Meaning Extraction and Semantic Services in STEM-Documents – A case study on Quantity Expressions and Units”. Master’s Thesis. Informatik, FAU Erlangen-Nürnberg, 2017. URL: <https://gl.kwarc.info/supervision/MSc-archive/blob/master/2017/urabenstein/Rabenstein.pdf>.
- [SML] *SIGMathLing – Special Interest Group on Maths Linguistics*. URL: <http://sigmathling.kwarc.info> (visited on 12/07/2018).