# Maths Information Retrieval for Digital Libraries

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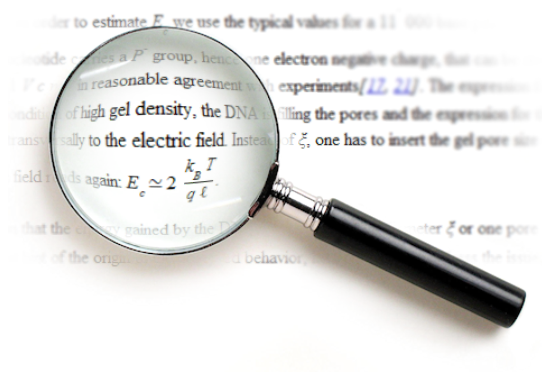
https://mir.fi.muni.cz/



Illustrations by Jiří Franek.

# Outline

# Motivation

# Motivation

- *Czech Digital Mathematics Library* (DML-CZ), http://www.dml.cz/
- *Centre de diffusion de revues académiques mathématiques* (CEDRAM), http://www.numdam.org/
- *Numérisation de documents anciens mathématiques* (NUMDAM), http://www.cedram.org/
- *Göttingen Göttinger Digitalisierungszentrum* (GDZ), http://gdz.sub.uni-goettingen.de/
- *Electronic Research Archive for Mathematics* (ERAM), http://www.emis.de/projects/JFM/
- *The Electronic Library of Mathematics* (ELibM), http://siba-sinmemis.unile.it/ELibM.html
- *Journal STORage* (JSTOR), http://www.jstor.org/
- *Project Euclid*, http://projecteuclid.org/
- *Russian Digital Mathematics Library* (RusDML), http://www.rusdml.de/
- *Polish Digital Mathematical Library* (DML-PL), http://pldml.icm.edu.pl/
- *Biblioteca Digital Española de Matemáticas* (DML-E), http://dmle.cindoc.csic.es/
- *Japanese Digital Mathematics Library* (DML-JP), http://sparc1.math.sci.hokudai.ac.jp/dmljp/
- *Riviste Elettroniche Italiane di Matematica* (REIM), http://siba2.unile.it/sinm/reim/
- *Biblioteca Digitale Italiana di Matematica* (bdim), http://www.bdim.eu/

# Motivation (cont.)

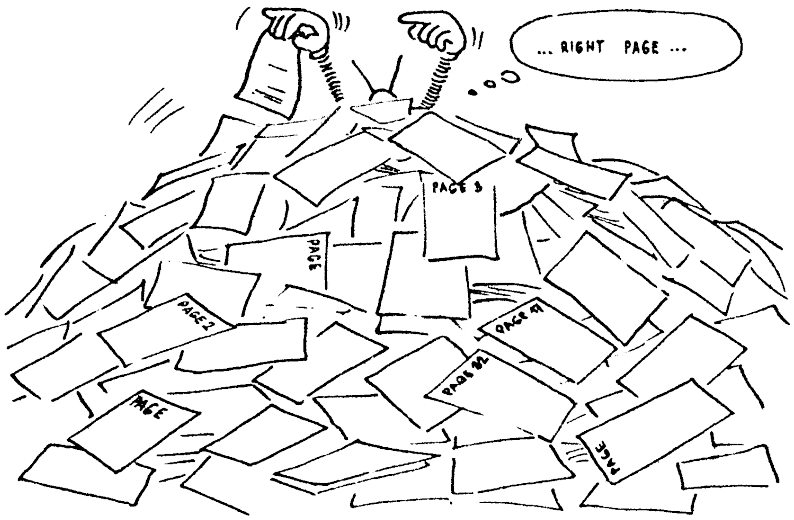
Q: 'What functionality and incentives would made a working mathematician to login and use a modern DML as EuDML?'

A: **'Math formulae search.'**

Prof. James Davenport, CEIC member, MKM 2011 PC chair, on panel at DML 2011 workshop in Bertinoro as a reply.

# Motivation (cont.)

- DML without maths-aware search support is an oxymoron.




- Simple search based on text keywords is not appropriate or sufficient for mathematical contents.

# Outline

# Sources of MathML in Digital Libraries

- 'Hand made'
- Tralics
- LaTeXML
- InftyReader
- MaxTract
- MATLAB
- Wolfram Alpha
- …

'Hand made' $x^2 + y^2$ MathML

```
<math xmlns='http://www.w3.org/1998/Math/MathML'>
    <msup>
        <mi>x</mi><mn>2</mn>
    </msup>
    <mo>+</mo>
    <msup>
        <mi>y</mi><mn>2</mn>
    </msup>
</math>
```

# Sources of MathML in Digital Libraries

- 'Hand made'
- Tralics
- LaTeXML
- InftyReader
- MaxTract
- MATLAB
- Wolfram Alpha
- …

## Matlab $x^2 + y^2$ MathML

```
generate::MathML(x^2 + y^2,
                 Content = FALSE, Annotation = FALSE)
<math xmlns='http://www.w3.org/1998/Math/MathML'>
  <mrow xref='No7'>
    <msup xref='No3'>
      <mi xref='No1'>x</mi>
      <mn xref='No2'>2</mn>
    </msup>
    <mo>+</mo>
    <msup xref='No6'>
      <mi xref='No4'>y</mi>
      <mn xref='No5'>2</mn>
    </msup>
  </mrow>
</math>
```

# Sources of MathML in Digital Libraries

- 'Hand made'
- Tralics
- LaTeXML
- InftyReader
- MaxTract
- MATLAB
- Wolfram Alpha
- …

LaTeXML $x^2 + y^2$ MathML

```
<math xmlns="http://www.w3.org/1998/Math/MathML"
    alttext="x^{2}+y^{2}" display="inline">
    <semantics>
        <mrow>
            <msup><mi>x</mi><mn>2</mn></msup>
            <mo>+</mo>
            <msup><mi>y</mi><mn>2</mn></msup>
        </mrow>
        <annotation encoding="application/x-tex">
            x^{2}+y^{2}
        </annotation>
    </semantics>
</math>
```

# Sources of MathML in Digital Libraries

- 'Hand made'
- Tralics
- LaTeXML
- InftyReader
- MaxTract
- MATLAB
- Wolfram Alpha
- …

## InftyReader $x^2 + y^2$ MathML

```
<math xmlns="http://www.w3.org/1998/Math/MathML">
    <msup>
        <mi mathvariant="italic">x</mi>
        <mrow>
            <mn mathvariant="normal">2</mn>
        </mrow>
    </msup>
    <mo mathvariant="normal">+</mo>
    <msup>
        <mi mathvariant="italic">y</mi>
        <mrow>
            <mn mathvariant="normal">2</mn>
        </mrow>
    </msup>
</math>
```

# MathML Canonicalizer

- Our own MathML canonicalization tool.
- The main design imperatives:
  - Modularity,
  - simplicity,
  - extensibility, and
  - flexibility.
- The speed of the canonicalization application is also a critical parameter.
  - In our MREC corpora there is 168,000,000 formulae to canonicalize.

# MathML Canonicalizer Use Cases

## <mphantom> Omission

```
<mfrac>
  <mrow>
    <mi> x </mi>
    <mo> + </mo>
    <mi> y </mi>
    <mo> + </mo>
    <mi> z </mi>
  </mrow>
  <mrow>
    <mi> x </mi>
    <mphantom>
      <mo> + </mo>
      <mi> y </mi>
    </mphantom>
    <mo> + </mo>
    <mi> z </mi>
  </mrow>
</mfrac>
```

```
<mfrac>
  <mrow>
    <mi> x </mi>
    <mo> + </mo>
    <mi> y </mi>
    <mo> + </mo>
    <mi> z </mi>
  </mrow>
  <mrow>
    <mi> x </mi>

    <mo> + </mo>
    <mi> z </mi>
  </mrow>
</mfrac>
```

# MathML Canonicalizer Use Cases

## Unnecessary Attributes

```
<mfrac linethickness="2"
       bevelled="true">
  <mi> a </mi>
  <mi> b </mi>
</mfrac>
```

```
<mfrac>
  <mi> a </mi>
  <mi> b </mi>
</mfrac>
```

# MathML Canonicalizer Use Cases

## <mrow> Minimizing

```
<msqrt>
  <mrow>
    <mo> - </mo>
    <mn> 1 </mn>
  </mrow>
</msqrt>
```

```
<msqrt>

  <mo> - </mo>
  <mn> 1 </mn>

</msqrt>
```

# MathML Canonicalizer Use Cases

## Unifying Fences

```
<mfenced open="[">
  <mi> x </mi>
  <mi> y </mi>
</mfenced>
```

```
<mrow>
  <mo> [ </mo>
  <mrow>
    <mi> x </mi>
    <mo> , </mo>
    <mi> y </mi>
  <mrow>
  <mo> ) </mo>
</mrow>
```

# MathML Canonicalizer Use Cases

## Sub-/Superscripts Handling

```
<msubsup>
  <mi> x </mi>

  <mn> 1 </mn>

  <mn> 2 </mn>
</msubsup>
```

```
<msup>
  <msub>
    <mi> x </mi>
    <mn> 1 </mn>
  </msub>
  <mn> 2 </mn>
</msup>
```

# MathML Canonicalizer Use Cases

## Applying Functions

```
<mi> f </mi>
<mo> &#x2061; </mo>
<mrow>
  <mo> ( </mo>
  <mi> x </mi>
  <mo> ) </mo>
</mrow>
```

```
<mi> f </mi>
<mrow>
  <mo> ( </mo>
  <mi> x </mi>
  <mo> ) </mo>
</mrow>
```

# MathML Canonicalizer Use Cases

## Applying Functions

```
<mi> sin </mi>

<mo> &#x2061; </mo>

<mi> x </mi>
```

```
<mi>sin</mi>
<mrow>
  <mo>(</mo>
  <mi>x</mi>
  <mo>)</mo>
</mrow>
```

# MathML Canonicalizer Web Evaluation Application

- JUnit testing seems not to be enough.
- Collaboration-enabled evaluation system needed:
  - Visualization of test data collection.
  - History of canonicalization results on the same data with different version of the Canonicalizer.
  - Annotations on the results.
  - Statistics.
  - Coverage of all the mark-up of the MathML standard.

# MathML Canonicalizer Web Evaluation Application

MathMLCanEval | Jmeno | Heslo | Prihlasit

## Vzorec

**Detaily vzorce**

| | |
|---|---|
| ID | 7519 |
| Uzivatel | admin |
| Zdrojovy dokument | ntcir-10 |
| Konverzni program | LaTeXML |
| Poznamky | |

**MathML kod**

```
<?xml version="1.0"?>
<math xmlns="http://www.w3.org/1998/Math/MathML" xmlns:dct="
  <semantics id="idp3882624">
    <mfrac id="idp3882752">
      <mrow id="idp3882880">
        <msup id="idp3883008">
          <mi id="idp3883136">e</mi>
          <mo id="idp3883392">+</mo>
        </msup>
        <mo id="idp3883648">+</mo>
        <msup id="idp3883904">
          <mi id="idp3884032">e</mi>
          <mo id="idp3884288">-</mo>
        </msup>
      </mrow>
      <mn id="idp3884544">2</mn>
    </mfrac>
    <annotation-xml id="idp3884800" encoding="MathML-Content
      <apply id="idp3885168">
        <divide id="idp3885296"/>
        <apply id="idp3885424">
          <plus id="idp3885552"/>
          <apply id="idp3885680">
            <csymbol id="idp3885808" cd="ambiguous">superscr
            <ci id="idp3886368">e</ci>
            <plus id="idp3886624"/>
          </apply>
          <apply id="idp3886752">
            <csymbol id="idp3886880" cd="ambiguous">superscr
            <ci id="idp3887440">e</ci>
            <minus id="idp3887696"/>
          </apply>
        </apply>
        <cn id="idp3887824" type="integer">2</cn>
      </apply>
    </annotation-xml>
    <annotation id="idp3888352" encoding="application/x-tex"
  </semantics>
</math>
```

$$\frac{e^{+}+e^{-}}{2}$$

**Provedene kanonikalizace**

| Cas | ID | Hash | Konfigurace | Doba behu |
|---|---|---|---|---|
| 2014-06-02T19:27:24.358+02:00 | 6568 | 7065b77e57410ff12fd2911015b7c178fea6bdeb | 1 | 2 |

**Ekvivaletni formule**



MathMLCanEval | Jmeno | Heslo | Prihlasit

## Kanonikalizovany vzorec

Najit podobne

**Podrobnosti**

| | |
|---|---|
| ID | 6568 |
| Puvodni vzorce | 7519 |
| Doba behu | 2 |

**Anotace**

**MathML kod**

Kanonizovany kod | Puvodni kod | Rozdil

```
1  <math display="inline" alttext="\frac{e^{+}+e^{-}}{2}" id="idp3881904"
   xmlns:acm="http://alpha.planetmath.org/onto/acm"
   xmlns:msc="http://alpha.planetmath.org/onto/msc"
   xmlns:arx="http://arxmliv.kwarc.info/ns/" xmlns:dct="http://purl.org/dc/terms/"
   xmlns="http://www.w3.org/1998/Math/MathML">
2   <semantics id="idp3882624">
3    <mfrac id="idp3882752">
4     <mrow id="idp3882880">
5      <msup id="idp3883008">
6       <mi id="idp3883136">e</mi>
7       <mo id="idp3883392">+</mo>
8      </msup>
9      <mo id="idp3883648">+</mo>
10     <msup id="idp3883904">
11      <mi id="idp3884032">e</mi>
12      <mo id="idp3884288">-</mo>
13     </msup>
14    </mrow>
15    <mn id="idp3884544">2</mn>
16   </mfrac>
17   <annotation-xml encoding="MathML-Content" id="idp3884800">
18    <apply id="idp3885168">
19     <divide id="idp3885296"></divide>
20     <apply id="idp3885424">
21      <plus id="idp3885552"></plus>
22      <apply id="idp3885680">
23       <csymbol cd="ambiguous" id="idp3885808">superscript</csymbol>
24       <ci id="idp3886368">e</ci>
25       <plus id="idp3886624"></plus>
26      </apply>
27      <apply id="idp3886752">
28       <csymbol cd="ambiguous" id="idp3886880">superscript</csymbol>
29       <ci id="idp3887440">e</ci>
30       <minus id="idp3887696"></minus>
31      </apply>
32     </apply>
33     <cn type="integer" id="idp3887824">2</cn>
34    </apply>
35   </annotation-xml>
36   <annotation encoding="application/x-tex" id="idp3888352">\frac{e^{+}+e^{-}}
     {2}</annotation>
37  </semantics>
38 </math>
```

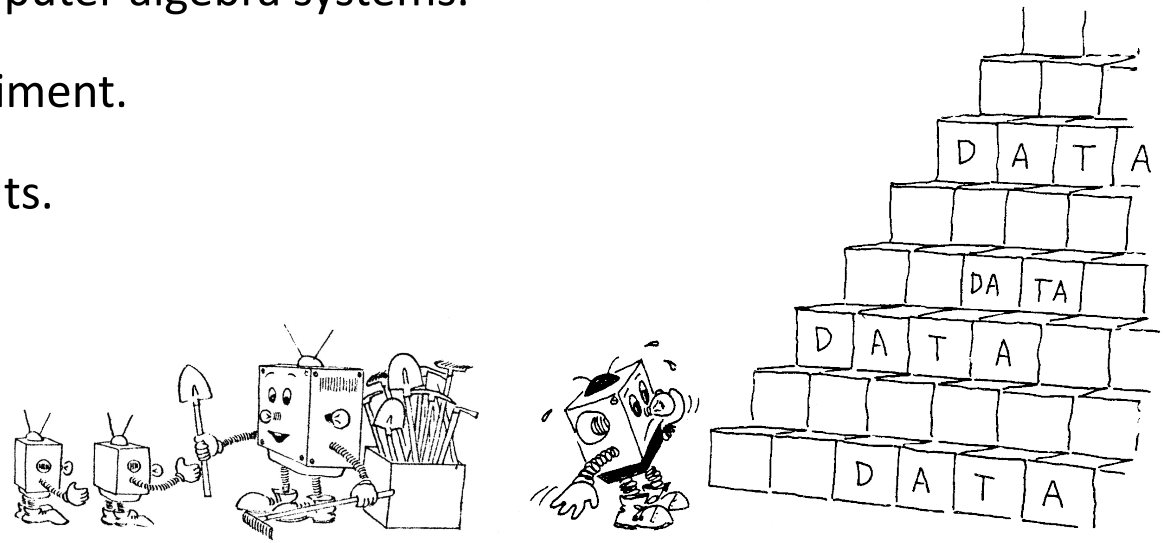
```
1  <math xmlns:msc="http://alpha.planetmath.org/onto/msc"
   xmlns:dct="http://purl.org/dc/terms/"
   xmlns:arx="http://arxmliv.kwarc.info/ns/"
   xmlns:acm="http://alpha.planetmath.org/onto/acm"
   xmlns="http://www.w3.org/1998/Math/MathML">
2   <semantics>
3    <mfrac>
4     <mrow>
5      <msup>
6       <mi>e</mi>
7       <mo>+</mo>
8      </msup>
9      <mo>+</mo>
10     <msup>
11      <mi>e</mi>
12      <mo>-</mo>
13     </msup>
14    </mrow>
15    <mn>2</mn>
16   </mfrac>
17   <annotation-xml encoding="MathML-Content">
18    <apply>
19     <divide></divide>
20     <apply>
21      <plus></plus>
22      <apply>
23       <csymbol>superscript</csymbol>
24       <ci>e</ci>
25       <plus></plus>
26      </apply>
27      <apply>
28       <csymbol>superscript</csymbol>
29       <ci>e</ci>
30       <minus></minus>
31      </apply>
32     </apply>
33     <cn type="integer">2</cn>
34    </apply>
35   </annotation-xml>
36   <annotation encoding="application/x-tex">\frac{e^{+}+e^{-}}
     {2}</annotation>
37  </semantics>
38 </math>
```

diff view generated by jsdifflib

# Outline

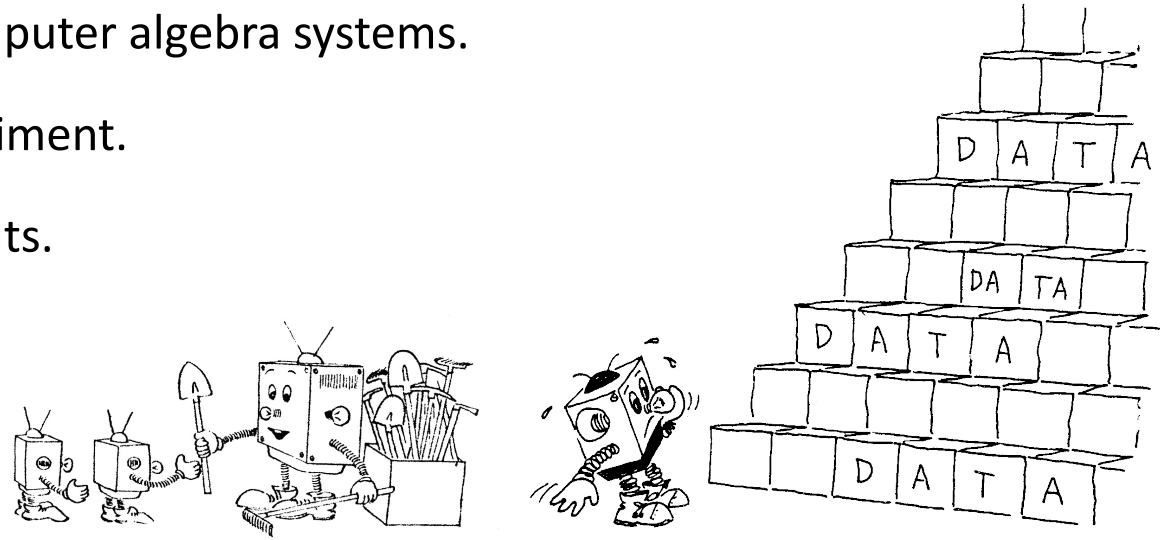
# Objectives

- Improvements of the relevance of the results of our math-aware search engine.
  - MathML Normalization.
  - Classification of identifiers.
  - Context driven search.
  - Involvement of computer algebra systems.
  - Image search experiment.
  - Ranking of the results.



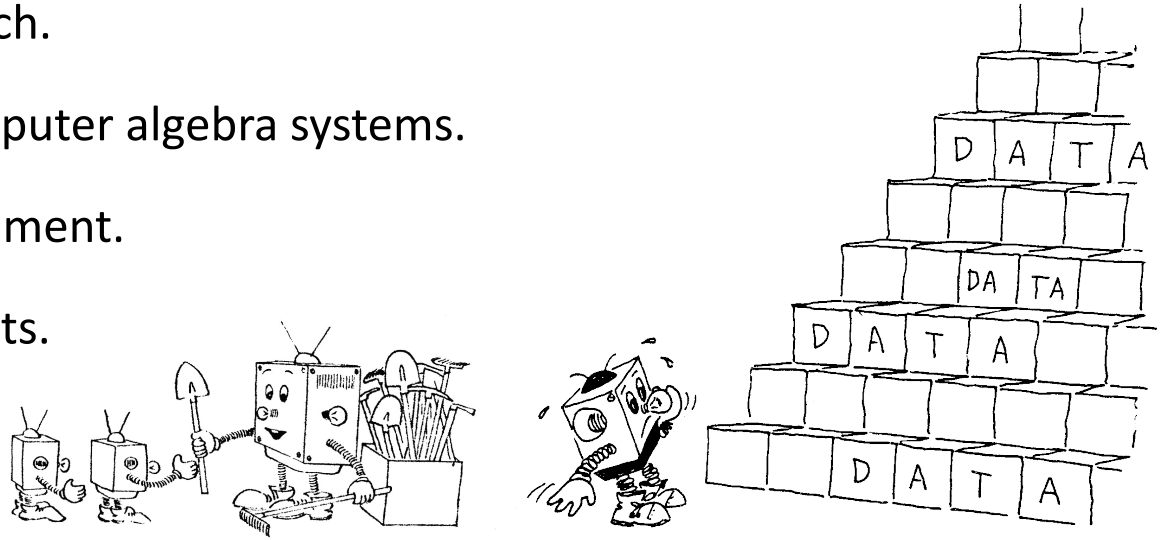
# Objectives

- Improvements of the relevance of the results of our math-aware search engine.
  - MathML Normalization.
    - Canonicalization of both Presentation and Content MathML.
  - Classification of identifiers.
  - Context driven search.
  - Involvement of computer algebra systems.
  - Image search experiment.
  - Ranking of the results.



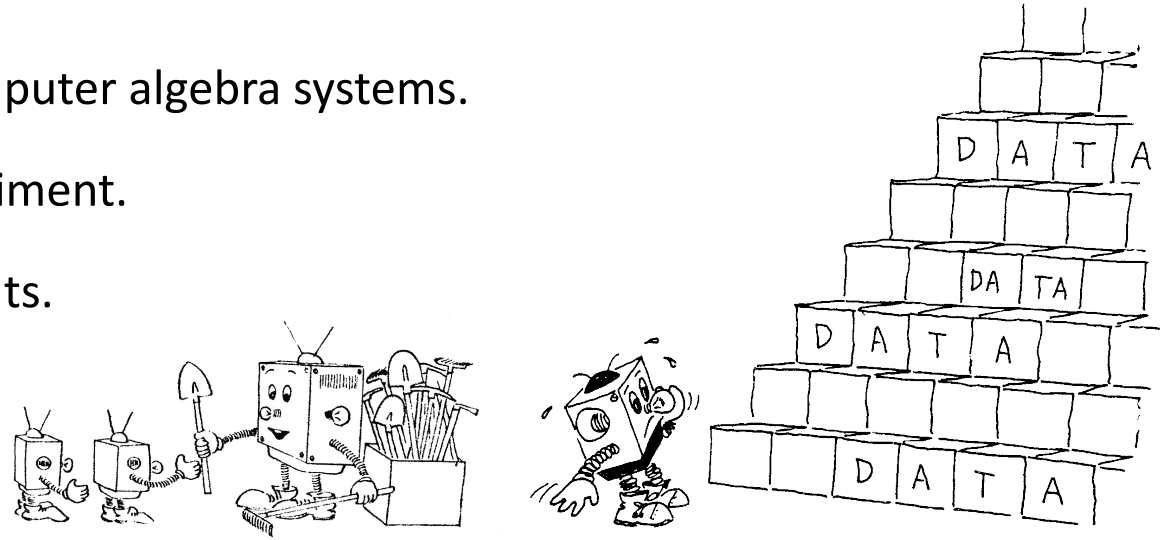
# Objectives

- Improvements of the relevance of the results of our math-aware search engine.
  - MathML Normalization.
  - Classification of identifiers.
    - To mark particular identifiers as variable name, function name, and so on.
    - Start from the metadata available for the documents.
  - Context driven search.
  - Involvement of computer algebra systems.
  - Image search experiment.
  - Ranking of the results.



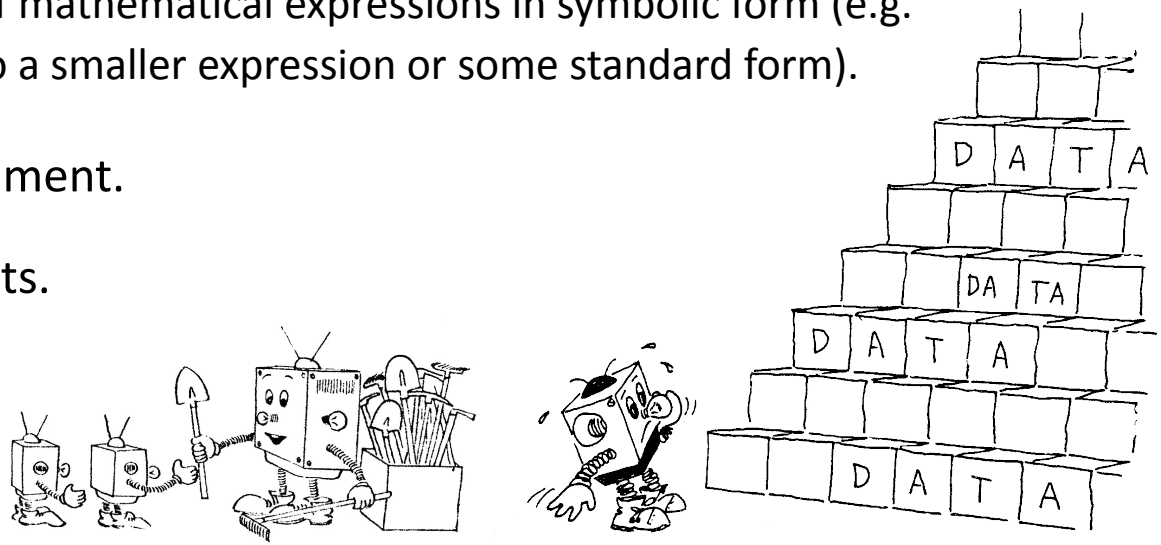
# Objectives

- Improvements of the relevance of the results of our math-aware search engine.
  - MathML Normalization.
  - Classification of identifiers.
  - Context driven search.
    - Exploitation of the metadata available for the documents.
    - Exploitation of the users' inputs.
  - Involvement of computer algebra systems.
  - Image search experiment.
  - Ranking of the results.



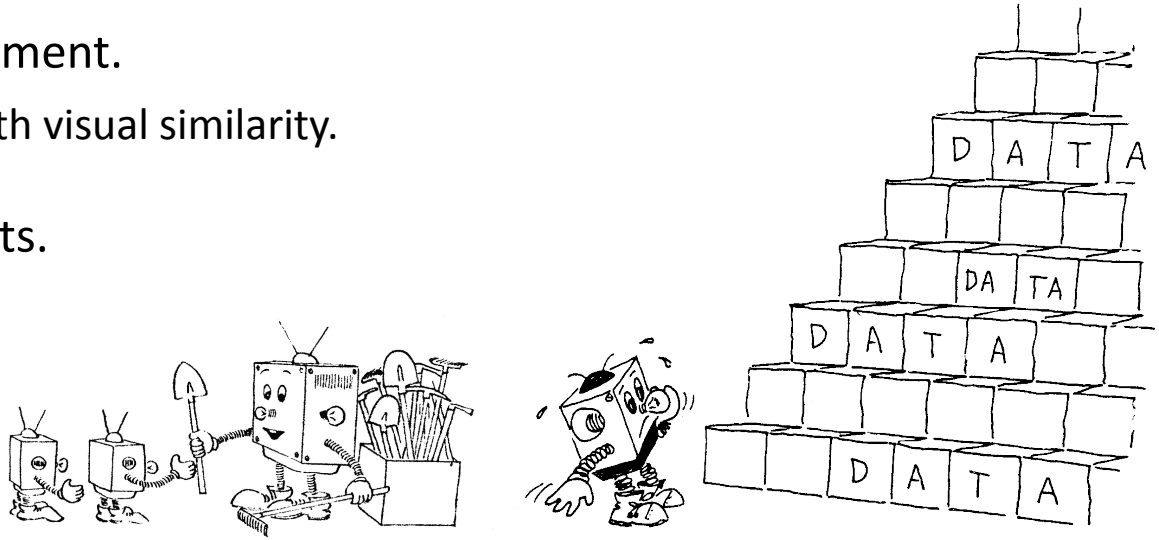
# Objectives

- Improvements of the relevance of the results of our math-aware search engine.
  - MathML Normalization.
  - Classification of identifiers.
  - Context driven search.
  - Involvement of computer algebra systems.
    - Manipulation of mathematical expressions in symbolic form (e.g. simplification to a smaller expression or some standard form).
  - Image search experiment.
  - Ranking of the results.



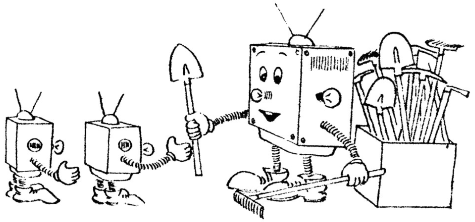
# Objectives

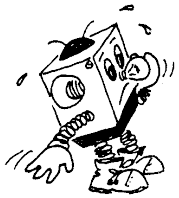
- Improvements of the relevance of the results of our math-aware search engine.
  - MathML Normalization.
  - Classification of identifiers.
  - Context driven search.
  - Involvement of computer algebra systems.
  - Image search experiment.
    - Experiments with visual similarity.
  - Ranking of the results.

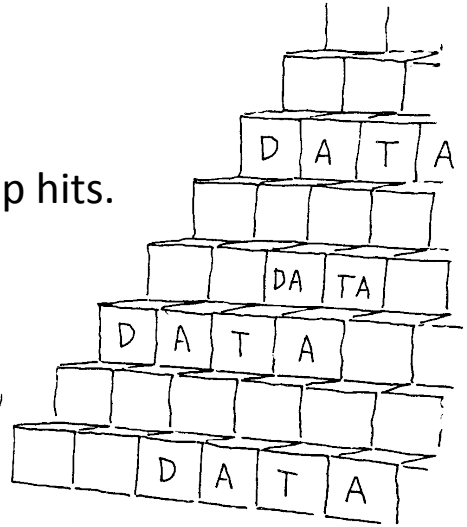


# Objectives

- Improvements of the relevance of the results of our math-aware search engine.
  - MathML Normalization.
  - Classification of identifiers.
  - Context driven search.
  - Involvement of computer algebra systems.
  - Image search experiment.
  - Ranking of the results.
    - Score bonus for documents to be known similar to top hits.
    - Internal subqueries for a single user's query.







# Outline

# NTCIR-10 Math Task

- The fist (pilot) year of the math task event last year (i.e. 2013).
- Formula search and Full-text search.
  - 4 runs submitted – differ in query language.
    - PMath – Run #1.
    - CMath – Run #2.
    - PCMath – Run #3.
    - TEX – Run #4.
- Open Information Retrieval.
  - 1 run submitted – TEX + text mixed queries.

# NTCIR-10 Math Task Results

Table 1: Result metrics for submitted runs in Formula Search with Relevance Level $\geq 3$ (Relevant)

| Metric | Run 1 | Run 2 | Run 4 |
|---|---|---|---|
| P-10 avg | 0.105 | 0.191 | **0.219** |
| P-5 avg | 0.133 | 0.229 | **0.276** |
| MAP avg | 0.060 | 0.112 | **0.127** |
| Precision | 0.109 (64/589) | **0.185** (92/496) | 0.123 (96/778) |

Table 2: Result metrics for submitted runs in Formula Search with Relevance Level $\geq 1$ (Partially Relevant)

| Metric | Run 1 | Run 2 | Run 4 |
|---|---|---|---|
| P-10 avg | 0.143 | 0.214 | **0.267** |
| P-5 avg | 0.181 | 0.267 | **0.343** |
| MAP avg | 0.066 | 0.081 | **0.100** |
| Precision | 0.148 (87/589) | **0.232** (115/496) | 0.161 (125/778) |

# NTCIR-11 Math Task

- A greater number of participants.
  - Increase from 6 to 8.
- Only one type of queries.
  - 50 queries, each
    - 1–4 formulae,
    - 1–4 keyphrases.
- Our results submitted for judgement in June 2014.

# NTCIR-11 Math Task Approach

- Query expansion & strip-merging of subresults.
  - Query expansion.

| | | | | | |
|---|---|---|---|---|---|
| query 1 (the original query): | $f_1$ | $f_2$ | $k_1$ | $k_2$ | $k_3$ |
| query 2: | $f_1$ | $f_2$ | $k_1$ | $k_2$ | |
| query 3: | $f_1$ | $f_2$ | $k_1$ | | |
| query 4: | $f_1$ | $f_2$ | | | |
| query 5: | $f_1$ | | $k_1$ | $k_2$ | $k_3$ |
| query 6: | | | $k_1$ | $k_2$ | $k_3$ |

# NTCIR-11 Math Task Approach

- Strip-merging of subresults.
  - Example on three subqueries (the original one and two derived subqueries).

*Results of the original query:*

1: $r1_{\text{original}}$
2: $r2_{\text{original}}$
3: $r3_{\text{original}}$
4: $r4_{\text{original}}$
5: $r5_{\text{original}}$
6: $r6_{\text{original}}$
7: $r7_{\text{original}}$
8: $r8_{\text{original}}$
9: $r9_{\text{original}}$
10: $r10_{\text{original}}$
11: $r11_{\text{original}}$

*Results of the subquery 1:*

1: $r1_{\text{subquery 1}}$
2: $r2_{\text{subquery 1}}$
3: $r3_{\text{subquery 1}}$
4: $r4_{\text{subquery 1}}$
5: $r5_{\text{subquery 1}}$

*Results of the subquery 2:*

1: $r1_{\text{subquery 2}}$
2: $r2_{\text{subquery 2}}$
3: $r3_{\text{subquery 2}}$
4: $r4_{\text{subquery 2}}$
5: $r5_{\text{subquery 2}}$

*The final result list:*

1: $r1_{\text{original}}$
2: $r2_{\text{original}}$
3: $r3_{\text{original}}$
4: $r1_{\text{subquery 1}}$
5: $r2_{\text{subquery 1}}$
6: $r1_{\text{subquery 2}}$
7: $r4_{\text{original}}$
8: $r5_{\text{original}}$
9: $r6_{\text{original}}$
10: $r3_{\text{subquery 1}}$
11: $r4_{\text{subquery 1}}$
12: $r2_{\text{subquery 2}}$
13: $r7_{\text{original}}$
14: $r8_{\text{original}}$
15: $r9_{\text{original}}$
16: $r5_{\text{subquery 1}}$
No more results from subquery 1.
17: $r3_{\text{subquery 2}}$
18: $r10_{\text{original}}$
19: $r11_{\text{original}}$
No more results from the original query.
20: $r4_{\text{subquery 2}}$
21: $r5_{\text{subquery 2}}$
No more results from subquery 2.
22: $r1_{\text{random}}$
23: $r2_{\text{random}}$
…
1000: $r979_{\text{random}}$

# NTCIR-11 Math Task Results

Table: Formulae count statistics

| Documents | Formulae | |
|---|---|---|
| | Original | Indexed |
| 8,301,545 | 59,647,566 | 3,021,865,236 |

Table: Index statistics

| Indexing times [min] | | Index size [GiB] |
|---|---|---|
| Wall Clock | CPU | |
| 1940.0 | 3413.55 | 68 |

# NTCIR-11 Math Task Results (cont.)

Table: Results of submitted runs with Relevance Level $\geq 3$ (Relevant)

| | PMath | CMath | PCMath | TEX |
|---|---|---|---|---|
| **MAP avg** | 0.3073 | **0.3630** | 0.3594 | 0.3357 |
| **P-10 avg** | 0.3040 | **0.3520** | 0.3480 | 0.3380 |
| **P-5 avg** | 0.5120 | 0.**5680** | 0.5560 | 0.5400 |

Table: Results of submitted runs with Relevance Level $\geq 1$ (Partially Relevant)

| | PMath | CMath | PCMath | TEX |
|---|---|---|---|---|
| **MAP avg** | 0.2557 | 0.2807 | 0.2799 | 0.2747 |
| **P-10 avg** | 0.5020 | 0.5440 | **0.5520** | 0.5400 |
| **P-5 avg** | 0.8440 | 0.8720 | 0.8640 | 0.8480 |

# NTCIR-11 Math Task: Our Investigation of Our Results

## Improper query conversion

Index: `\operatorname{Im}P^{+}_{\Gamma}=C_{\mu}^{+}(\Gamma)`

Query: `ImP^{+}_{\gamma}=C^{+}_{\mu}(\gamma)`

Index

```
...
<mrow>
 <mo>Im</mo>
 <mo></mo>
 <msup>
...
```

Query

```
...
<mrow>
 <mi>I</mi>
 <mi>m</mi>
 <msup>
...
```

# NTCIR-11 Math Task: Our Investigation of Our Results

## Substructure difference tolerance should be improved

```
...
  <mrow>
    QUERY-FORMULA-SUBPART-1
    [[ INDEX
        <mrow>
          <mo>∫</mo>
          <mrow>
    || QUERY
        <mi>o</mi>
    ]]
    QUERY-FORMULA-SUBPART-2
    INDEX-FORMULA-SUPPLEMENT
        </mrow>
      </mrow>
    </mrow>
  </mrow>
...
```

# NTCIR-11 Math Task: Our Investigation of Our Results

## \qvar{} handling

Original task query:

```
\qvar{S}=-\qvar{T}_{\qvar{p}}\int\qvar{d}^{\qvar{p}+1}
  \qvar{x}\sqrt{\qvar{g}}
```

Index: `S=-T_{p}\int d^{p+1}x\sqrt{-g}`

Query: `S=-T_{p}\int d^{p+1}x\sqrt{g}`

`\sqrt{g}` does not match `\sqrt{-g}`.

# NTCIR-11 Math Task: Our Investigation of Our Results

## Unification would be helpful

Query:

```
\qvar{x}\frac{\qvar{y}}{\qvar{z}}-\qvar{u}\frac{\qvar{v}}{\qvar{w}}
```

$$x\frac{y}{z} - u\frac{v}{w}$$

Matches:

$$\begin{aligned}\{q_s, q_r\} &= \int dx \int dy\, \{A(x,\mu)^p, A(y,\nu)^q\} \Big|_{\mu^{s+1}\nu^{r+1}} \\ &= pq\,\mu\nu \int dx\, A(\mu)^p (A(\nu)^q)' \left[\left\{\frac{s}{p}\nu - \frac{r}{q}\mu\right\}\frac{1}{\mu-\nu} + \frac{1}{h}\frac{rs}{pq}\right] \Big|_{\mu^{s+1}\nu^{r+1}}\end{aligned}$$

Does not match:

$$\zeta \sim c_1 \frac{\delta\rho_\sigma}{\rho_\sigma} - c_2 \frac{\delta H_{\mathrm{osc}}}{H_{\mathrm{osc}}}$$

# NTCIR-11 Math Task: Our Investigation of Our Results

- Combination of both formulae and text keywords in one query is important.
- Multiple subqueries derived from the original query with result lists merging turned out to be very useful.
  - One-by-one removal of the keywords and formulae.
  - "Strip-merging" of the results of the subqueries.
  - Further investigation of the best strategies needed.
    - Subqueries with subformulae?
    - Different strategy for merging of results?

# Outline

# Future Works

- Long-term goals:
  - All the objectives mentioned earlier. ☺
  - Whole arXiv indexing for MIaS search.
  - Evaluation.
- Short-term goals:
  - Improved strategies for MIaS internal subqueries derived from a single user's query.
  - Integration of MIaS with DML-CZ DSpace.
  - Exploitation of Gensim-Math-computed document similarities to improve of ranking results in MIaS.
  - Evaluation, Evaluation, Evaluation.

# Future Works – Indexing-Time Simple Unification

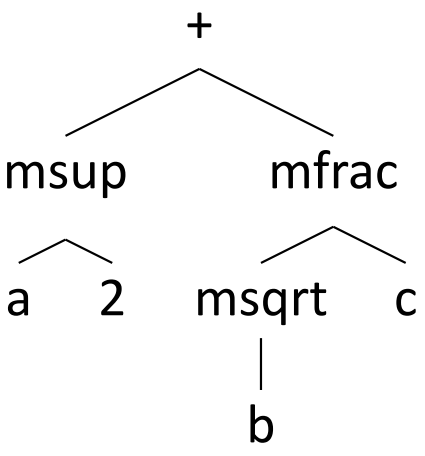
- The core idea is to implement a special identifier, let denote it $\boxed{\underline{\mathrm{U}}}$, working as a single universal unifying element through the whole index.
- The symbol $\boxed{\underline{\mathrm{U}}}$ would be used to derive a set of unified versions of formulae from the original formula.
  The derived versions are generated 'layer-by-layer' according to the MathML tree structure by substituting subtrees for $\boxed{\underline{\mathrm{U}}}$. For example:

# Future Works – Indexing-Time Simple Unification (cont.)

- Original formula:

```
a^2+\frac{\sqrt{b}}{c}
```

$$a^2 + \frac{\sqrt{b}}{c}$$

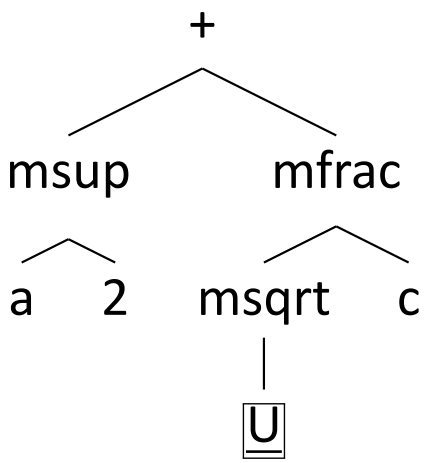


# Future Works – Indexing-Time Simple Unification (cont.)

- Sequence of the unified formulae derivation – step 1:

```
a^2+\frac{\sqrt{\unificator}}{c}
```

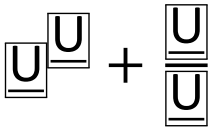
$$a^2 + \frac{\sqrt{\boxed{\underline{\mathrm{U}}}}}{c}$$

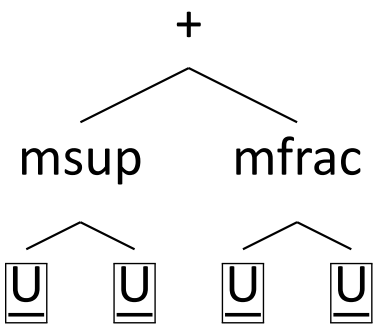


# Future Works – Indexing-Time Simple Unification (cont.)

- Sequence of the unified formulae derivation – step 2:

```
\unificator^\unificator
        +\frac{\unificator}{\unificator}
```



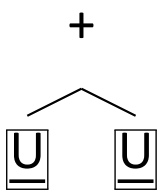


# Future Works – Indexing-Time Simple Unification (cont.)

- Sequence of the unified formulae derivation – step 3:

```
\unificator+\unificator
```

$\boxed{\underline{U}} + \boxed{\underline{U}}$

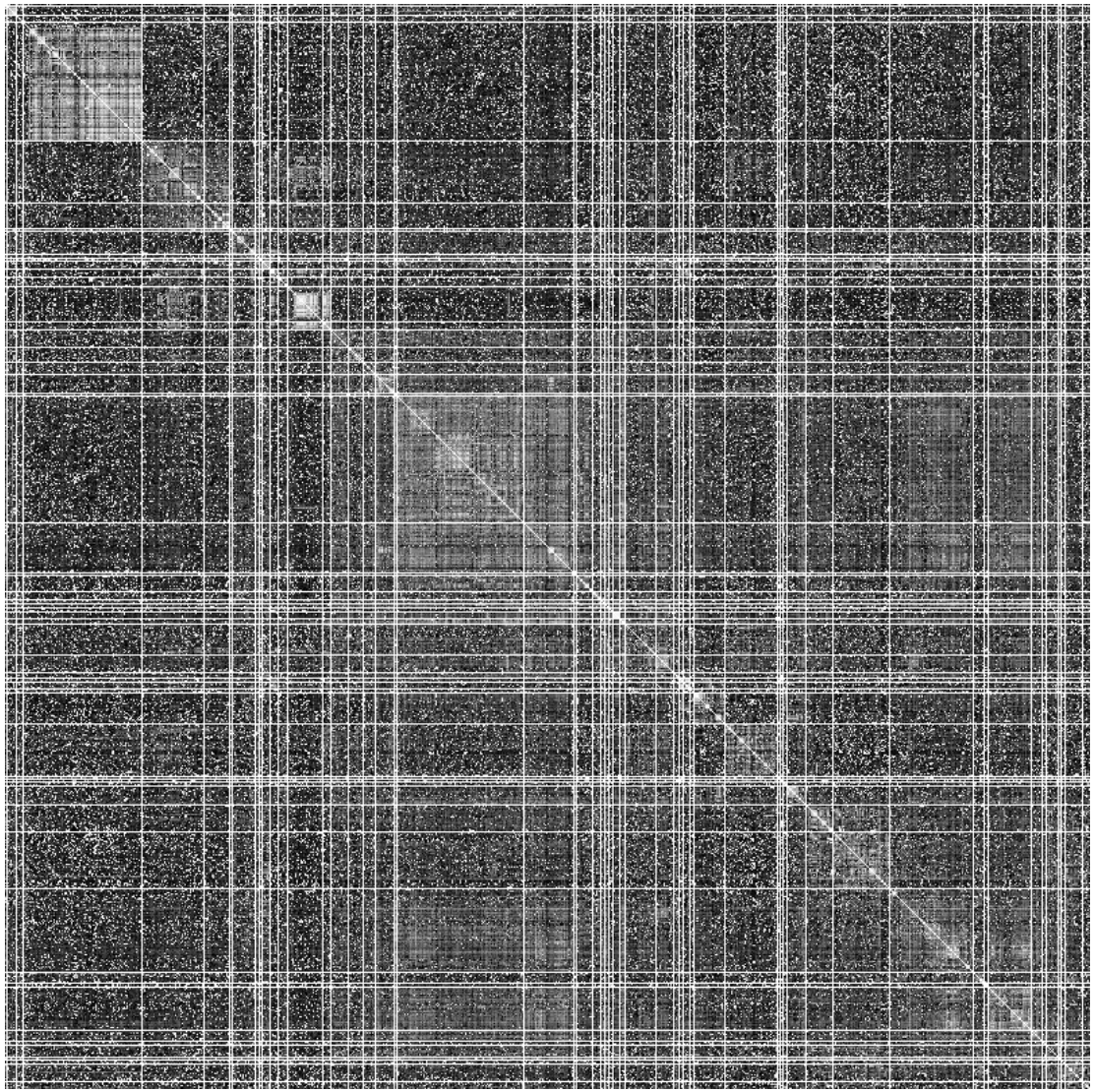



This expansion of the original formula would be applied to every formula during the indexing of the database of documents. The same method would also be used to expand every formula in the user's query to extend the original query. Hits on unified formulae would be rated with gradually decreased score according to the unification level of the formula.

# Future Works – Gensim Math Document Similarities

- Gensim by Radim Řehůřek is “the most robust, efficient and hassle-free piece of software to realize unsupervised semantic modelling from plain text”: `http://radimrehurek.com/gensim/`
- We are experimenting with correlation of document similarities based on Mathematics Subject Classification (MSC) vs. document similarities based on formulae and other prominent parts (title, authors, abstract…) of the documents.
- Visualized similarity matrices.

# Future Works – Gensim Math Document Similarities



Method: TfIdf-LSI; Weighted MTerms: true; MTerm Weight Conversion: 1

# Future Works – Gensim Math Document Similarities

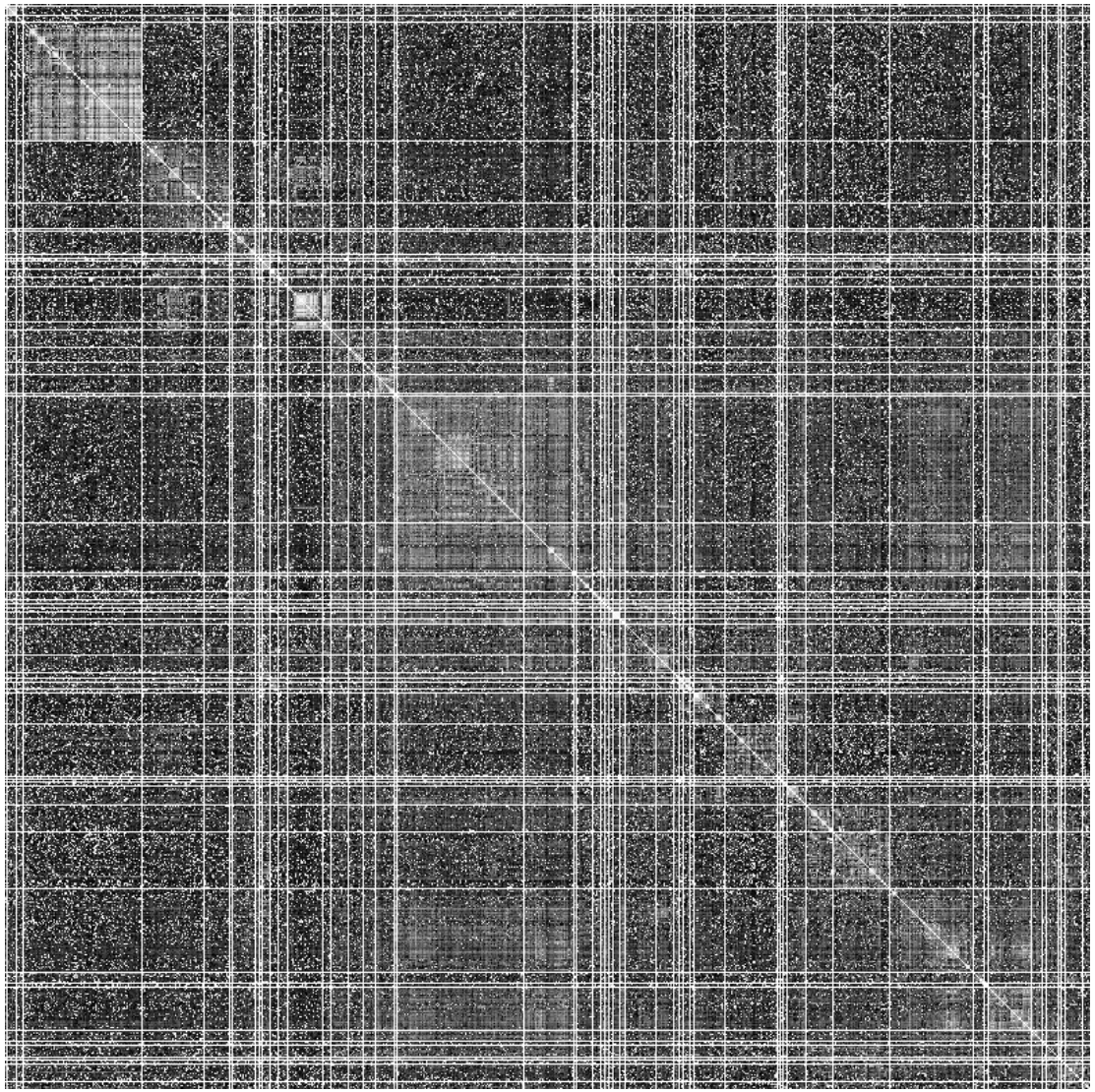
- MSC sorted documents in columns/rows, white lines separate MSC codes with different two characters (top category).
- All the documents compared each other.
  - Grayscale level indicates simarity of the document on the row to the document in the column.

    | | |
    |---|---|
    | white | Very similar. |
    | black | Very different. |

  - Different weighting (or even omitting) of tokens from various metadata fields.
  - Vector space model transformation method:

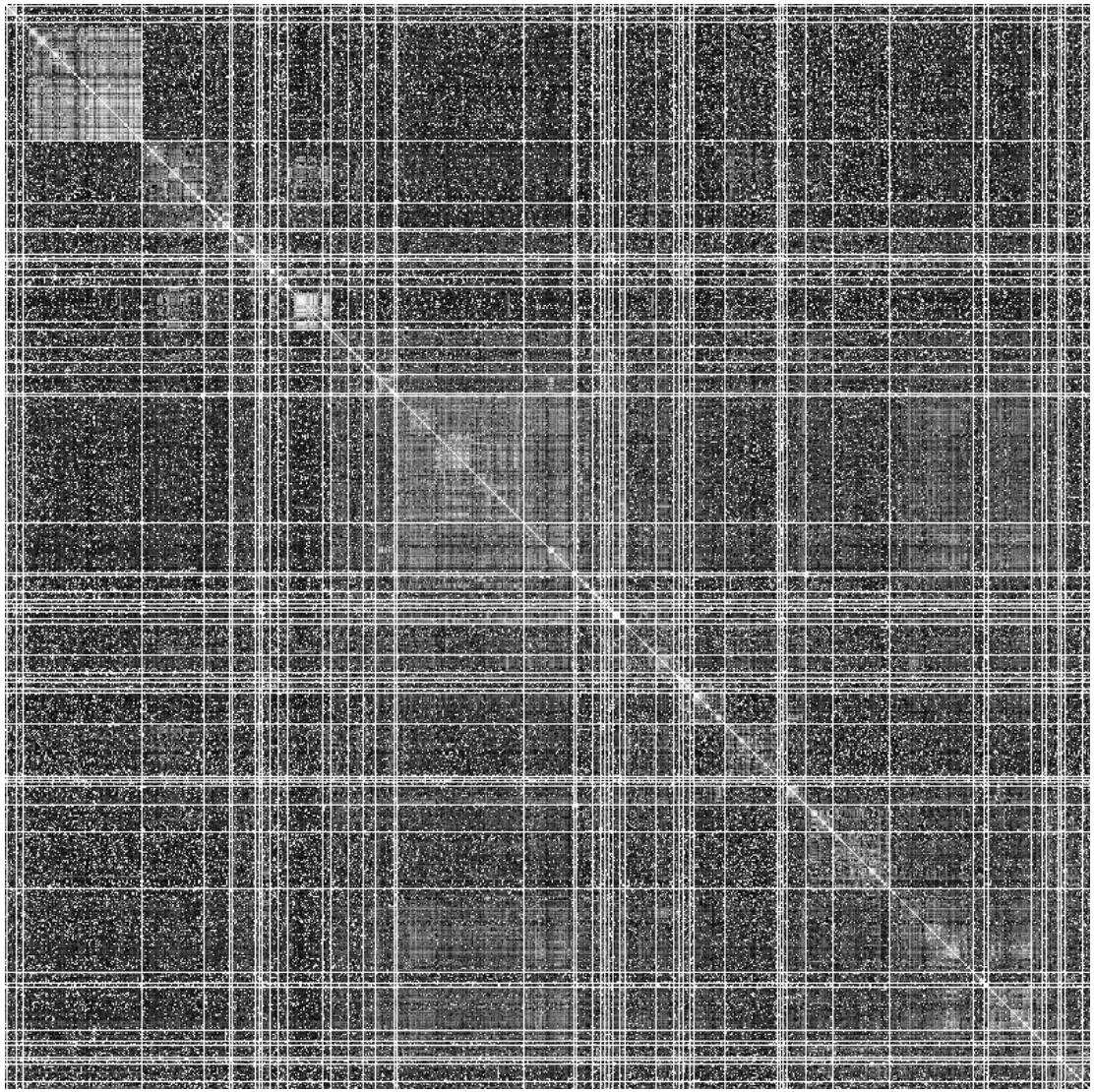
    | | |
    |---|---|
    | TfIdF-LSI | Inverse Document Frequency wrapped by Latent Semantic Indexing |
    | LDA | Latent Dirichlet Allocation |
    | ... | ... |

# Future Works – Gensim Math Document Similarities



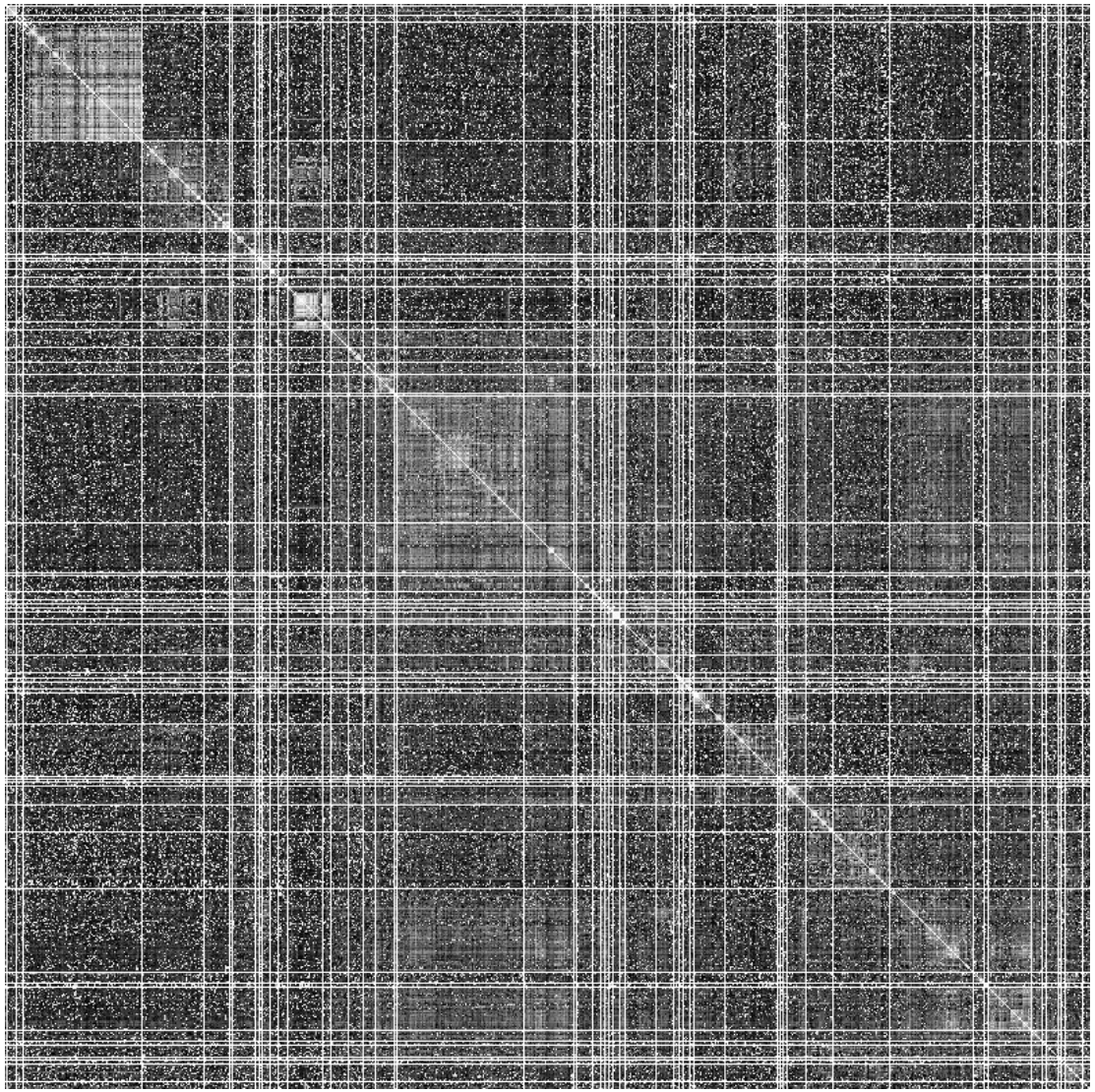
Method: TfIdf-LSI; Weighted MTerms: true; MTerm Weight Conversion: 1

# Future Works – Gensim Math Document Similarities



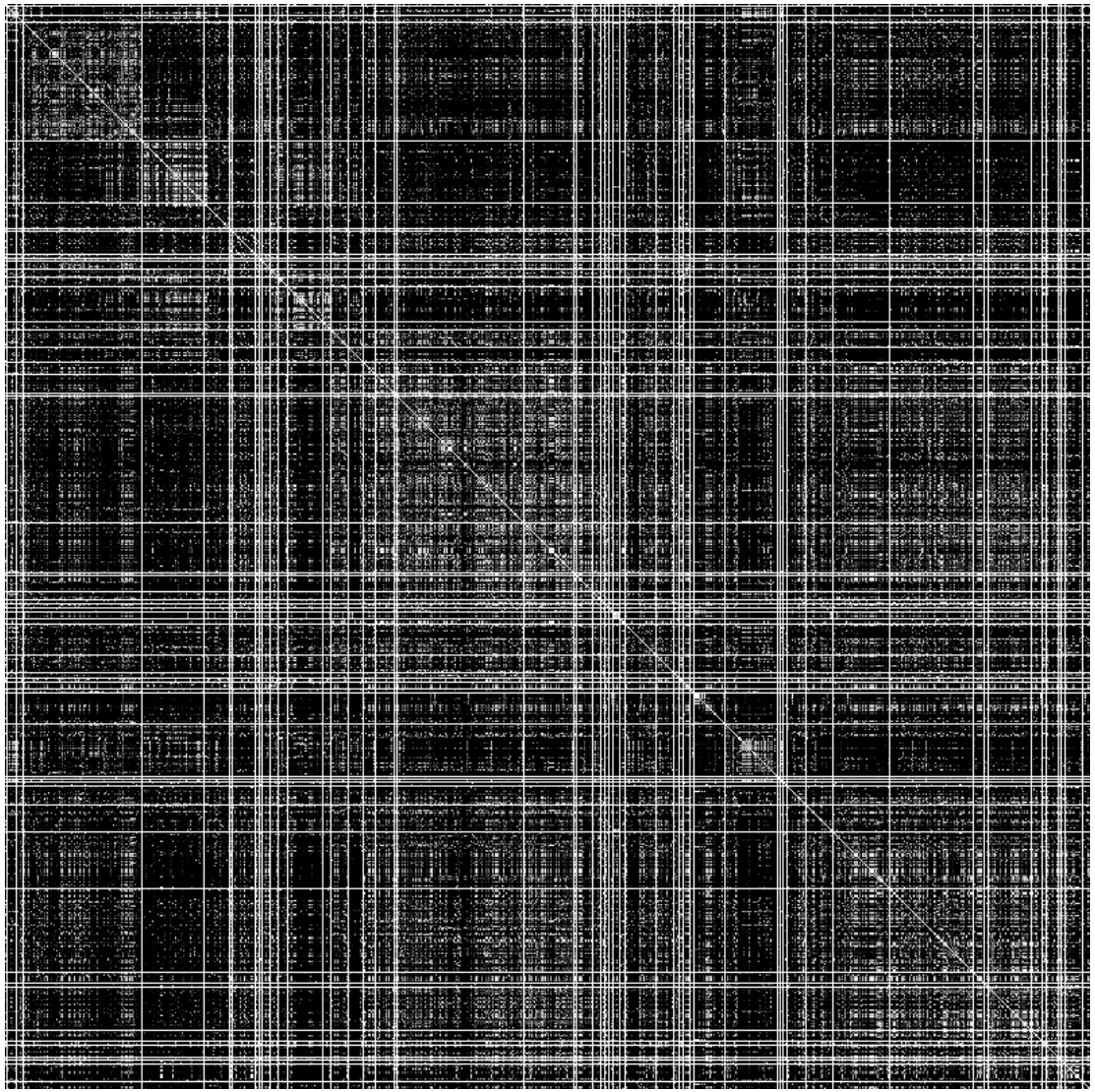
Method: TfIdf-LSI; Weighted MTerms: true; MTerm Weight Conversion: trunc(3.9 * mtermWeight)

# Future Works – Gensim Math Document Similarities



Method: TfIdf-LSI; Weighted MTerms: false

# Future Works – Gensim Math Document Similarities



Method: LDA; Weighted MTerms: false

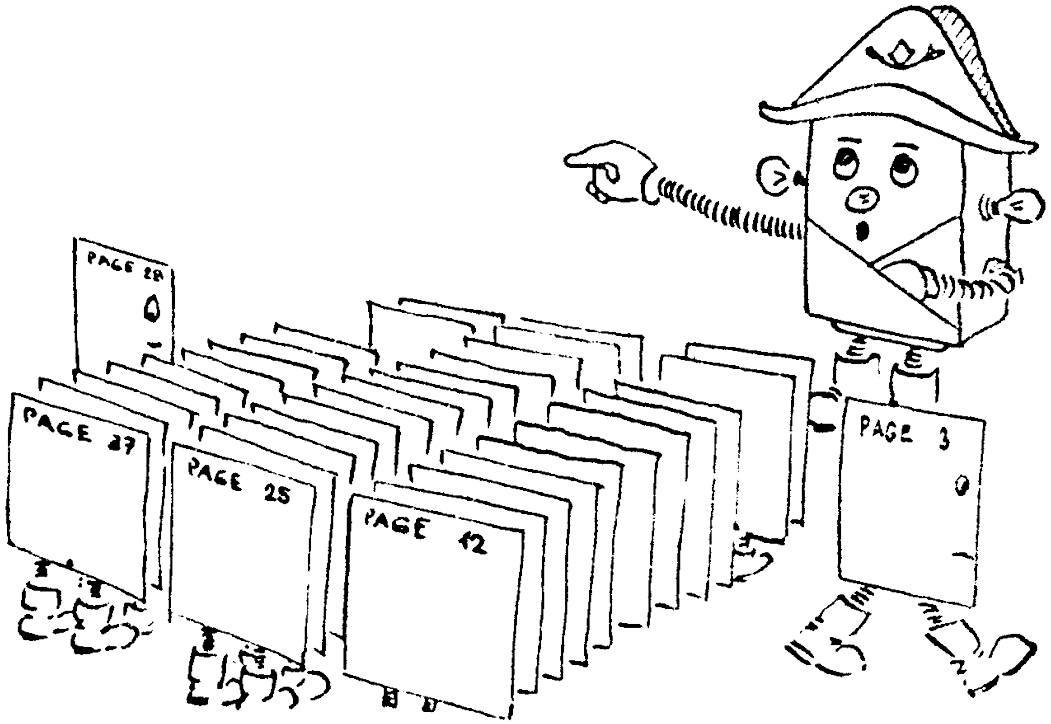
# Future Works – Gensim Math Document Similarities

- Gensim by Radim Řehůřek is "the most robust, efficient and hassle-free piece of software to realize unsupervised semantic modelling from plain text": `http://radimrehurek.com/gensim/`
- We are experimenting with correlation of document similarities based on Mathematics Subject Classification (MSC) vs. document similarities based on formulae and other prominent parts (title, authors, abstract…) of the documents.
- Visualized similarity matrices.
  - How to compute similarity of these matricies rigorously?
    - Variance of the normalized similarity inside each of the MSC regions + weighted average over the matrix?

# Summary

- We have our own math-aware search engine.
- We have a lot of possible improvements in our minds.
- We are interested in evaluation a lot.

# Questions?



Illustrations by Jiří Franek.

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