

# Generating T<sub>E</sub>X from mathematical content with respect to notational settings

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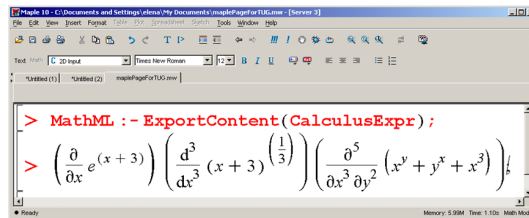
## Abstract

We describe how to obtain client-preferred notations in T<sub>E</sub>X generated from the output of mathematical software environments. Our approach is based on the fact that most packages can produce MathML or other XML-based formats for mathematical content. Generating T<sub>E</sub>X from these allows notational choices to be applied during the translation process. The particular choices of notation can be made either at the time T<sub>E</sub>X is generated or later, by the use of T<sub>E</sub>X macros. We show how this approach may be applied to the generation of T<sub>E</sub>X from both *presentationally*- and *conceptually*-oriented mathematical content and how MathML may be used in the process. Our implementation conserves the implicit high-level semantics of macro use in both T<sub>E</sub>X and MathML. Since the expressions generated by mathematical software may be quite lengthy, we also discuss issues that arise in line-breaking.

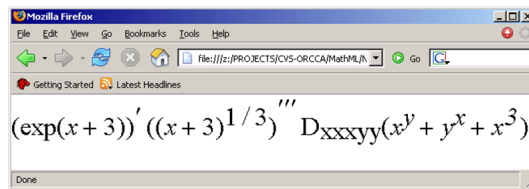
## 1 Introduction

Most mathematical software systems allow one to export expressions in T<sub>E</sub>X format. For many mathematical ideas there are several choices of notation, and typically the T<sub>E</sub>X formulae generated by software systems use the notational conventions selected by the system designers. These choices might be quite different from what would be selected by the client of the package, if a choice were offered.

We are interested in the problem of generating T<sub>E</sub>X that respects the notational conventions that are preferred by the client. To see the difference between a default and a customized rendering of an expression, compare the formulae of Figure 1a and Figure 1b. In most cases it is not possible for a user to obtain T<sub>E</sub>X output that uses their preferred notation. If the user of a computer algebra system or other mathematical software package wishes to publish the results of a computation, he or she must either accept the presentation offered by the system, or rewrite the T<sub>E</sub>X content. In this paper we present



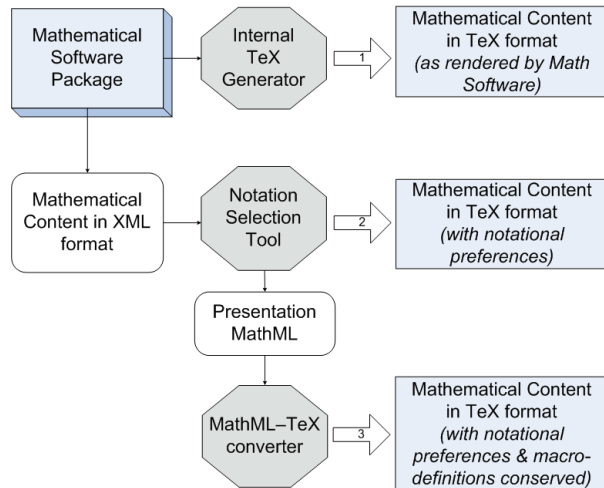
(a) Default rendering by Maple



(b) Customized rendering via Mozilla

Figure 1: Two renderings of the same expression.

an alternative approach, based on adding notation preferences to mathematical T<sub>E</sub>X converters.



**Figure 2:** Three ways to generate  $\text{\TeX}$  from a mathematical software system

There are several ways in which  $\text{\TeX}$  for mathematical expressions may be generated from a software package such as Maple [1], Mathematica [2], Axiom [3], Aldor [4], *etc.* One approach is to make a direct translation to  $\text{\TeX}$  from the internal expression representation of the software system. Exporting it to  $\text{\TeX}$  directly from the system will then produce package-specific presentation of this content (Figure 2, arrow 1). Another approach may be taken if the mathematical object has been created in a web-oriented mathematical environment, such as with the MONET web-services [5, 6]. In this situation the expression will most likely be encoded using some XML-based standard, such as OpenMath [7] or Content MathML [8]. These formats are supported by most computer algebra systems as well as many web browsers and other packages. The objective of this paper is to demonstrate a flexible technique to generate of  $\text{\TeX}$  presentation from these XML-based, semantically-oriented formats.

We explore two manners of producing  $\text{\TeX}$  from XML formats: The first is to do so directly from mathematical content, taking into account notational settings (Figure 2, arrow 2). The second approach is to use a two-stage conversion (Figure 2, arrow 3). In this case, MathML—combined with elements using some extended set of tags—is first generated from the mathematical content. This extended MathML is then translated into  $\text{\TeX}$  with corresponding  $\text{\TeX}$  macros. In this case, high-level mathematical constructs may be mapped directly to  $\text{\TeX}$  macros. This ensures that the semantics of the original expression are conserved in the output  $\text{\TeX}$  content.

This paper is organized as follows: Section 2 describes how presentation of mathematical content can be customized using a Notation Selection Tool. Section 3 describes a MathML to  $\text{\TeX}$  translator that is used in multi-stage conversion. Section 4 provides some details of how line breaking is achieved in the generated  $\text{\TeX}$ . Section 5 presents our conclusions and outlines some possible directions for future work in this area.

## 2 Generating presentation from content using notational preferences

Anyone with more than a passing familiarity with the subject understands that there is no universal notation for mathematics. There are mathematical concepts for which there are several different notations, and there are notations for which there are several different mathematical concepts. Figure 3 shows how the choice of different notation can affect the appearance of mathematical content. This choice of notation is certainly the major determining factor in how an expression will appear.

### 2.1 A notation selection tool

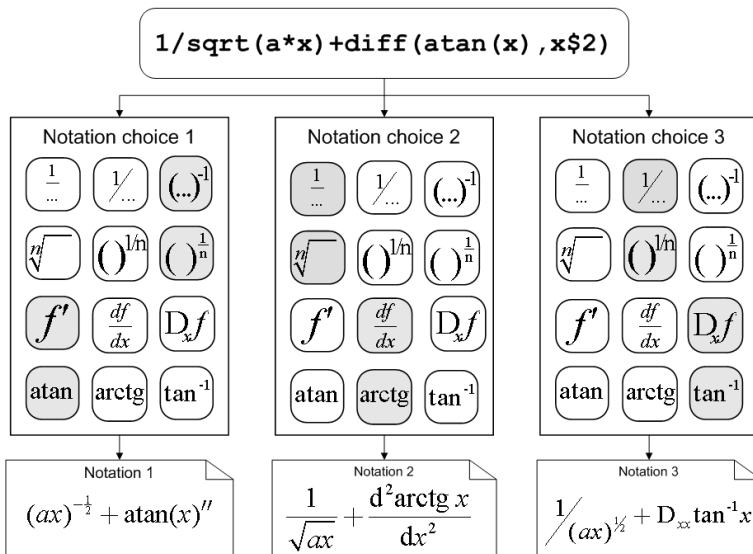
In earlier work we described a Notation Selection Tool [9, 10] designed to control conversion of mathematical expressions in XML format. The original purpose of this tool was to provide a graphical user interface (Figure 4) for notation selection. The tool generates an XSLT stylesheet used to transform Content MathML to Presentation MathML using the desired notational conventions. The stylesheet and the generated Presentation MathML are determined by the user’s choice of notation settings.

### 2.2 Extending the tool for direct conversion to $\text{\TeX}$

In the present work we use a key feature of the Notation Selection Tool: Its extensible design allows one to add new translation directions without modifying the software implementation. In particular, we can add direct conversion of OpenMath and Content MathML to  $\text{\TeX}$ .

We described in [9] how the Notation Selection Tool is initialized by a configuration file. This file is the only component in the design that provides information about the mathematical concepts that the converter can handle. It also stores the transformation rules to be applied for the selected notations.

Because all knowledge of the MathML conversion is contained in this configuration file, it may also be used to specify conversions involving other XML formats for input and other XML or text formats for output. Updating the configuration file



**Figure 3:** Generating different notations for the same mathematical content

with new conversion rules, such as with OpenMath as source and T<sub>E</sub>X as target, allows the Notation Selection Tool to perform new conversions according to desired rules:

```

<catalog>
  <name> CALCULUS </name>
  <itemlist>
    <item>
      <keyword> PARTIAL DERIVATIVE </keyword>
      <content>
        OpenMath encoding for mathematical
        concept PARTIAL DERIVATIVE
      </content>
      <choicelist>
        <choice>
          <!-- The first notation choice for -->
          <image src = "pd_1.gif"/>
          <keyvalue> 1 </keyvalue>
          <presentation>
            <converter input = "OpenMath" output="LaTeX">
              XSLT template for OpenMath
              to LATEX for this notation
            </converter>
            ...
          </presentation>
        </choice>
        ...
      </choicelist>
    </item>
    ...
  </itemlist>
</catalog>
    
```

If the user selects the notation  $D_x$  for partial differentiation and  $f'$  for ordinary differentiation, then, instead of obtaining the default output, the Maple expression shown in Figure 1a will be converted to

```

$$$({\left(\mathop{\exp}\left\{\left\{\left(x+3\right)\right\}\right\}}^{\prime}\right)\,
\left(\left\{\left\{\left(x+3\right)\right\}\right\}^{\left\{\left\{\prime\prime\prime\right\}\right\}}\right)\,
\left\{\left\{\mathop{D}\right\}\left\{\left\{x^y\right\}+\left\{y^x\right\}+\left\{x^3\right\}\right\}\right)}$$$
    
```

which renders as

$$(exp(x+3))' ((x+3)^{1/3})''' D_{xxxy} (x^y + y^x + x^3).$$

The configuration file may define more than one output format, for example both L<sup>A</sup>T<sub>E</sub>X and MathML. In this case, the conversion rules are selected according to the target format specified by the user (see Figure 4). This approach is a special case of that described in [11] for the conversion of mathematical documents into multiple forms.

### 2.3 The notation selection tool as a front-end in multi-stage conversion

We have discussed extension of the Notation Selection Tool by modifying the configuration file to provide new conversions *directly* to T<sub>E</sub>X. We can, instead, do the translation in a *series of stages* to increase flexibility.

We can use the Notation Selection Tool as an intermediate translation stage generating MathML. This MathML can then be further processed to produce T<sub>E</sub>X. This multi-stage mode of generating T<sub>E</sub>X from Content MathML or OpenMath can be specified by a menu selection in the Notation Selection Tool. In this mode, the Notation Selection Tool first generates MathML and then passes it to our configurable MathML to T<sub>E</sub>X converter [12].

This multi-stage process allows the Notation Selection Tool to generate extended markup (*i.e.* MathML and other XML) that may then later be transformed. To do this, the desired extended markup is placed in the output rules of the configuration file. This extended markup can use new tags to capture the semantics of new mathematical concepts or complex combinations of OpenMath or MathML constructs. For example, one might use a new XML

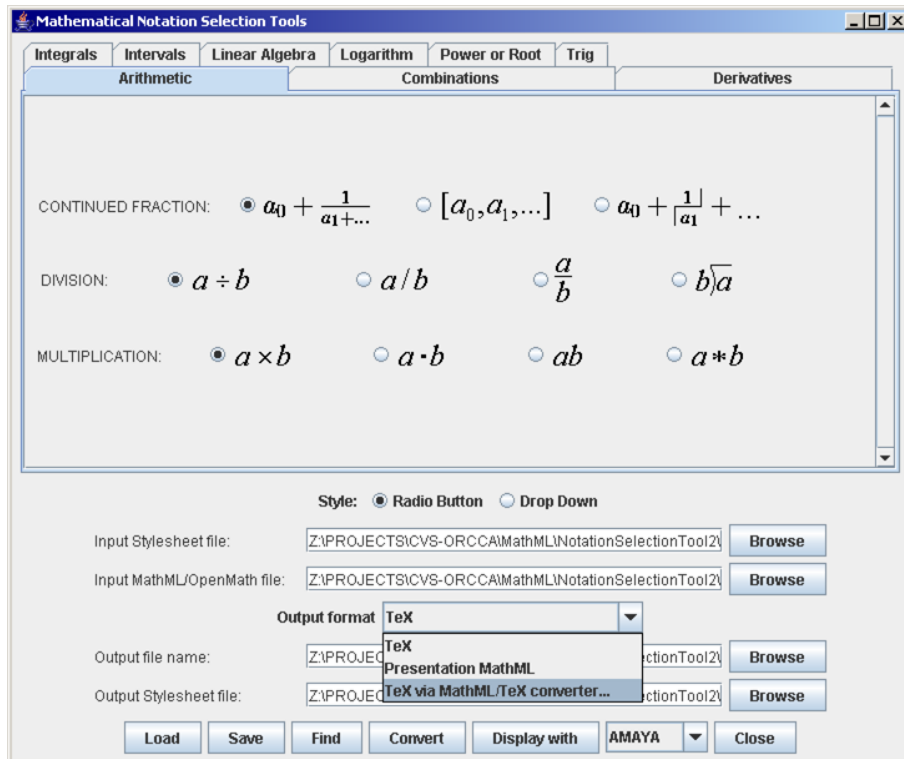


Figure 4: The Notation Selection Tool, stand-alone application interface

element to capture the semantics of binomial coefficients or continued fractions, which do not appear in standard MathML. In such a case, a new transformation rule can be added directly to the configuration file of the Notation Selection Tool:

```
<converter input = "Content \MathML{" output="LaTeX">
  <xsl:template match = "apply/mmlx:choose[position()=1]
    [count(child::*)=2]">
    <mmlx:binomial>
      <xsl:for-each select = 'mmlx:choose/child::*'>
        <xsl:copy-of select='.'/>
      </xsl:for-each>
    </mmlx:binomial>
  </xsl:template>
</converter>
```

The output of the XSLT transformation in the above example will contain Presentation MathML extended with the new tag `mmlx:binomial`. The prefix “mmlx” is defined at the beginning of the generated XML, and indicates that this element belongs to a different namespace than the standard MathML elements. The resulting element can be either expanded immediately after the conversion to obtain a combination of appropriate presentation markup and semantic annotation (possibly using a `<csymbol>` element). Alternatively, it may be carried on to the next step of the translation to  $\text{\TeX}$ , as described in the next section.

### 3 MathML to $\text{\TeX}$ conversion

In earlier work we have explored the question of conversion between  $\text{\TeX}$  and MathML, using a set of bidirectional transformation rules [13, 14, 15]. Here we summarize the aspects of the converter that are used in notation selection for  $\text{\TeX}$  via MathML.

#### 3.1 Modes of Conversion

In [15] we presented a MathML to  $\text{\TeX}$  translator that converts expressions in MathML representation to equivalent  $\text{\TeX}$  expressions. The translator supports conversion at three different levels of content granularity: (1) entire files, (2) individual expressions and (3) separate objects. The last option allows the user to manipulate stand-alone MathML and  $\text{\TeX}$ -objects obtained from sources other than the usual MathML or  $\text{\TeX}$  documents.

For the file-level conversion, the translator processes an entire MathML file and produces a complete  $\text{\TeX}$  document. The converter can also handle other XML files containing MathML and replace the MathML elements with their  $\text{\TeX}$  equivalents, embedded as CDATA sections, as shown on Figure 5. This option is useful when our converter is used as a pre-processor for HTML to  $\text{\LaTeX}$  translators such as `html2latex` [16]. Thus, from a sequence of two

translations we can produce T<sub>E</sub>X documents from HTML web pages containing mathematics.

### 3.2 Implementation

Even though the most natural choice for implementing a converter for XML-based languages such as MathML is via XSLT stylesheets, we have taken another approach. The main argument against using XSLT for this converter was our desire to provide a symmetric path for the inverse conversion from T<sub>E</sub>X to MathML. We chose to organize both of the translators based on *bidirectional* mappings between MathML and T<sub>E</sub>X constructs. Mapping rules describe the correspondence between T<sub>E</sub>X and MathML patterns in the following format:

```
<pat:template>
  <!-- TeX command with parameters -->
  <pat:tex op="\frac" params="\patVAR!{num}\patVAR!{den}"/>

  <!-- Corresponding \MathML{} tree -->
  <pat:mml op="mfrac">
    <mfrac>
      <pat:variable name="num"/>
      <pat:variable name="den"/>
    </mfrac>
  </pat:mml>
</pat:template>
```

Templates, such as the above, are organized into mapping files. The same file can be used both for converting from T<sub>E</sub>X to MathML and *vice versa*. The converter tools are implemented in Java and read one or more mapping files as they are initialized. The converter may be run as a stand-alone application (Figure 6) or as a web service [12]. The same configuration file is used to control a transformer in the reverse direction [17], from T<sub>E</sub>X to MathML. While it is the core Java program that is carrying out the actual conversion, its *behavior* is defined by the selection of mapping files.

This approach provides the converter with the desired flexibility: none of the conversion rules are hard-coded and any of them may be updated by editing the corresponding templates in the mapping files. The consistency between the two directions of conversion is preserved, since any of the mapping files can be used by either of the converters.

New mappings can be added in a similar way. Whenever a new pattern, such as a T<sub>E</sub>X macro or XML template, is introduced, a new template can be added to a mapping file. This immediately enables the conversion using a new transformation rule.

### 3.3 Conserving high-level semantics in translation

In [13] and in Section 2.3 we have described how new mathematical constructs can be described with T<sub>E</sub>X macros or XSLT template definitions.

Macros are usually used as abbreviations for lengthy expressions, expressions that are particularly notable, or that appear more than once. These expressions typically have some meaning that makes them natural choices for expression by macros. When converting a mathematical document between formats, we wish to conserve whatever implicit semantics is captured by the macro markup. Expanding macros and then converting loses this information.

In [13] and [18] we showed that rather than expanding all macros to low-level formatting instructions, in many cases it is possible to map high-level markup in one setting to corresponding markup in another, thus conserving implied semantics. We may arrange that each T<sub>E</sub>X style or class file have a counterpart XSLT stylesheet for use with Presentation MathML, and each T<sub>E</sub>X macro have a corresponding XSLT template definition.

We now give a complete example: Suppose we are working with documents that involve the Lambert “W” function of two arguments  $k$  and  $z$ , denoted  $W_k(z)$ . It would be possible to denote this explicitly as  $W\_k(x)$  everywhere in a T<sub>E</sub>X document, and as corresponding presentation markup in a MathML document. We prefer, however, to define a T<sub>E</sub>X macro, such as

```
\newcommand{\LambertW}[2]{W_{#1}\left( #2 \right)}
```

and a corresponding XSLT template

```
<xsl:template match="mmlx:LambertW">
  <mrow>
    <msub>
      <mo> W </mo>
      <xsl:apply-templates
        select = 'mmlx:LambertW/child::*[1]"/>
    </msub>
    <mfenced>
      <xsl:apply-templates
        select = 'mmlx:LambertW/child::*[2]"/>
    </mfenced>
  </mrow>
</xsl:template>
```

We also add a direct mapping rule for `\LambertW` and `<mmlx:LambertW>` to one of the translator mapping files:

```
<pat:template>
  <!-- TeX command -->
  <pat:tex op="\LambertW"
    params="\patVAR!{k} \patVAR!{z}"/>
  <!-- \MathML{} element -->
  <pat:mml op="mmlx:LambertW">
    <mmxl:LambertW>
      <pat:variable name="k"/>
      <pat:variable name="z"/>
    </mmxl:LambertW>
  </pat:mml>
</pat:template>
```

Using this mapping, a MathML expression

```
<mmxl:LambertW>
  <mn> 1 </mn>
  <mi> z </mi>
</mmxl:LambertW>
```

```

<?xml version='1.0' encoding='utf-8'?>
<html>
  <h1> XHTML + \MathML{} </h1>
  <ol>
    <li>
      <math>          \Leftarrow Expression 1
        <msup>
          <mi>x</mi>
          <mn>2</mn>
        </msup>
        <mo>+</mo>
        <mn>1</mn>
      </math>
    </li>
    <li>
      <math>          \Leftarrow Expression 2
        <msubsup>
          <mi> A </mi>
          <mi> i </mi>
          <mi> j </mi>
        </msubsup>
      </math>
    </li>
  </ol>
</html>

```

```

<?xml version='1.0' encoding='UTF-8' ?>
<html>
  <h1> \HTML{} + \MathML{} </h1>
  <ol>
    <li>
      <LaTeX xmlns='orcca.on.ca'> \Leftarrow Expression 1
      <![CDATA[ $x^2+1$ ]]>
    </LaTeX>
    </li>
    <li>
      <LaTeX xmlns='orcca.on.ca'> \Leftarrow Expression 2
      <![CDATA[ $A_{i^j}$ ]]>
    </LaTeX>
    </li>
  </ol>
</html>

```

Figure 5: Example of conversion from XHTML with MathML to T<sub>E</sub>X

will be translated to T<sub>E</sub>X as  $\backslash\text{LambertW}\{1\}\{z\}$  instead of  $W_{-1}\left(z\right)$ .

This approach, converting from MathML to T<sub>E</sub>X driven by high-level rules, allows a concept-level translation of user-defined macros. This preserves mathematical semantics implied by the markup of the original expression and, most importantly for the present paper, allows user-preferred notations to be given by alternative definitions of the target T<sub>E</sub>X macros.

#### 4 Automated line breaking

A secondary benefit of using a non-XSLT approach for conversion from MathML to T<sub>E</sub>X is that it makes automated line breaking of long expressions easier.

##### 4.1 Motivation

MathML browsers, such as those of the Netscape family, Amaya, and MathPlayer, perform line breaking in mathematical formulas according to their own logic, but T<sub>E</sub>X does not. Therefore long T<sub>E</sub>X formulas, generated from MathML may not fit in the text area of the document. Very often composing a mathematical paper with long formulae will give results as shown in Figure 7.

Manual line breaking in T<sub>E</sub>X formulae is viable only when the size of the expression is relatively small. However, when MathML content is generated

as output from a mathematical software package, or when numerous documents are to be converted, this approach is not sufficient. One solution would be to use the `breqn` package [19] to display generated T<sub>E</sub>X formulae. There are a number of reasons, however, why we have elected to provide line-breaking as part of the T<sub>E</sub>X generation:

- Generated T<sub>E</sub>X formulae can be very large, so a number of line breaking (and page breaking) issues arise that do not arise with handwritten equations. We can handle these situations better than a human-oriented package such as `breqn`.
- Generated T<sub>E</sub>X formulae can be idiosyncratic, so providing our own line breaking of equations gives finer control.
- As part of the T<sub>E</sub>X generation we have already performed much of the analysis that is required for line breaking.
- As a purely practical consideration, not all T<sub>E</sub>X environments support the `breqn` package.

##### 4.2 Algorithm overview

The subject of line-breaking for mathematical formulae is complex, and a full description of our approach is beyond the scope of this paper. For the purpose of this article, we highlight only some of the important aspects.

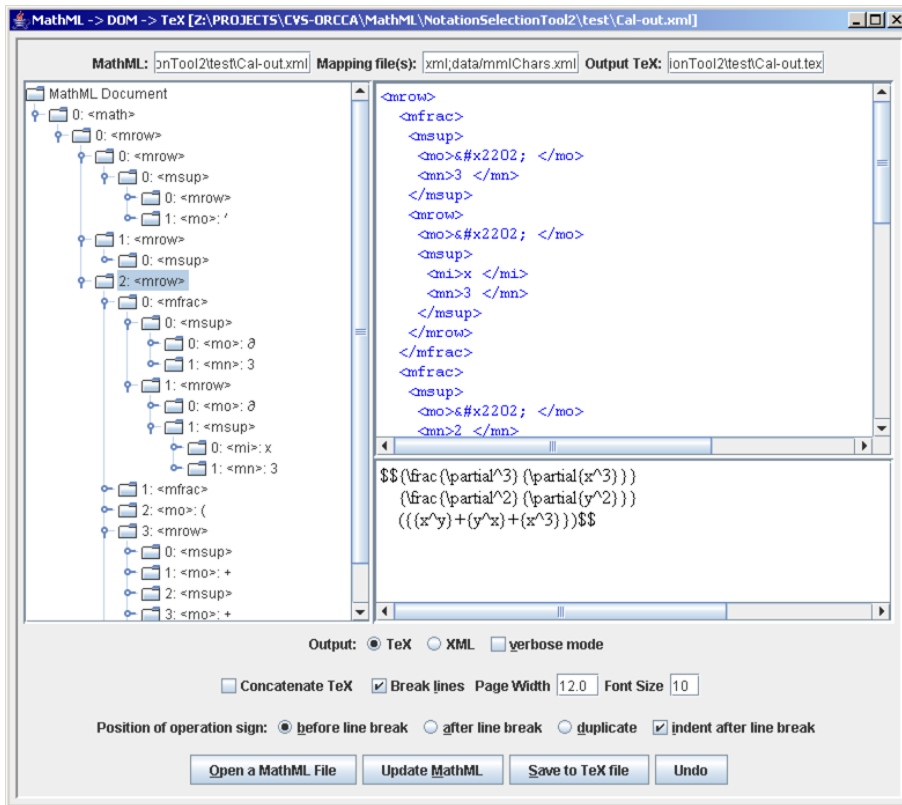


Figure 6: The MathML to T<sub>E</sub>X converter, stand-alone application interface

In a manner similar to the *total-fit* approach to line breaking implemented for T<sub>E</sub>X paragraphs by Knuth and Plass [20], our algorithm searches for all possible breakpoints in a formula and tries to find the combination of line breaks that will produce the best global arrangement.

In addition to splitting linear text, the method must take into account the two-dimensional nature of mathematical content and also consider the implicit semantics of expressions.

This leads to a number of constraints. For example, script sub-expressions may not be separated from their base expressions. Another common case is that of juxtaposition: Immediate function arguments should not be separated from the name of the function, e.g. we must avoid

$$p(x - y, z) \sin(2x + 1) ,$$

but implicit multiplication can be split between the factors

$$p(x - y, z) \times \sin(2x + 1) .$$

Juxtaposition is difficult to distinguish, since function application and implicit multiplication often

have no explicit indication which operation is intended (even though MathML provides invisible operators for this purpose).

In general, every possible breakpoint is assigned a “penalty” value, so for example, signs and relations, such as =, ⇒ etc, as well as + and − are usually given priority over division and multiplication. Preference is given to breaking a formula closer to the root of the expression tree than within a branch. This means that a product of sums will preferentially break at the multiplications, unless the other penalties make this an overwhelmingly bad choice.

### 4.3 Customization

In the previous example we saw that when multiplication is expressed implicitly, line breaking may force the addition of an explicit multiplication sign. This may be represented by a central dot ·, times ×, asterisk \* or other operator ⊗, ⊙, .... Our package allows the user to specify which is preferred.

Likewise, the positioning of the operator at a line break can be set to the upper line, the lower line, or repeated on both lines (see Figure 8). In addition various indentation styles may be desired for the multiple lines. These options reflect differ-



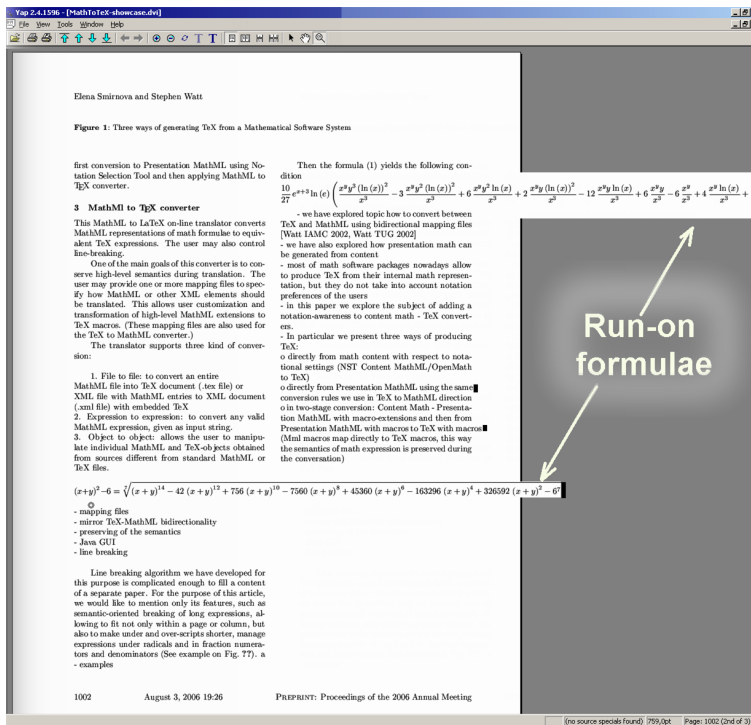


Figure 7: TeX article without line breaking in long formulae.

$$x_1 - y_2 + z_3 + \alpha - \beta^2 + \gamma^3 + f(1) + g(2)$$

(a) Before break

$$x_1 - y_2 + z_3 + \alpha - \beta^2 + \gamma^3 + f(1) + g(2)$$

(b) After break

$$x_1 - y_2 + z_3 + \alpha - \beta^2 + \gamma^3 + f(1) + g(2)$$

(c) Before and after break

Figure 8: Operator placement at line breaks

ent notational and cultural preferences, and can be customized by the user of the converter through the GUI interface or command line.

#### 4.4 Line breaking in sub-expressions

As well as allowing a formula to fit within a given page or column width, the line breaking algorithm also handles situations where certain sub-expressions are too large for conventional line-breaking. These

$$\sum_{(i,j) \in \{(\alpha, \beta) \mid ax^\alpha + bx^\beta = m, m \in R^+, \alpha \neq \beta, \gcd(a,b)=1\}}$$

Figure 9: Expression without line breaking does not fit in a text column

situations include long scripts (compare Figures 9 and 10), in fraction numerators and denominators (Figure 11), and expressions under radicals (Figure 12).

The sizes of the bounding boxes for the folded sub-expressions are normally calculated automatically, based on an optimal fit in the text area. If desired, they may instead be specified by the user. For example, for sub-scripts this is specified as a maximum ratio of the script width to the width of the base expression.

For large expressions, line breaking is a true two-dimensional problem involving box composition. In this setting, the height and width of individual terms depend on the choices made in displaying its sub-expressions. Examples of such nested line breaking are shown in Figures 10, 11 and 12.

As a practical implementation detail, we use the `array` environment to organize multi-line output in mathematical expressions. This is shown in



$$\sum_{(i,j) \in \left\{ (\alpha,\beta) \left| \begin{array}{l} ax^\alpha + bx^\beta = m, \\ m \in R^+, \alpha \neq \beta, \\ \gcd(a,b) = 1 \end{array} \right. \right\}} f(i)g^{-1}(j)\phi(i+j, i-j)$$

**Figure 10:** Adding line breaking in subscript allows the whole expression to fit in a column

$$\frac{10}{27} y^2 e^{(x+3)} \sqrt[3]{(x+3)} W_0(1.5 + 2.5 i) \times \left( \begin{array}{l} x^{(y-3)} \ln(x)^2 y^3 + 6 x^{(y-3)} \ln(x) y^2 + \\ 6 x^{(y-3)} y - 3 x^{(y-3)} \ln(x)^2 y^2 - \\ 12 x^{(y-3)} \ln(x) y - 6 x^{(y-3)} + \\ 2 x^{(y-3)} \ln(x)^2 y + 4 x^{(y-3)} \ln(x) + \\ y^{(x-2)} x^2 \ln(y)^3 - y^{(x-2)} x \ln(y)^3 + \\ 6 y^{(x-2)} x \ln(y)^2 + 6 y^{(x-2)} \ln(y) - \\ 3 y^{(x-2)} \ln(y)^2 - 14 y^{(x-2)} x \ln(y) \end{array} \right) / (x+3)^3$$

**Figure 11:** Line breaking in long fractions

$$(x+y)^2 - 6 = \sqrt[7]{\begin{array}{l} (x+y)^{14} - 42(x+y)^{12} + \\ 756(x+y)^{10} - 7560(x+y)^8 + \\ 45360(x+y)^6 - 163296 \times \\ (x+y)^4 + 326592(x+y)^2 - 6^7 \end{array}}$$

**Figure 12:** Line breaking in long sub-radical expressions

the code fragment of Figure 13. Note the command `\displaystyle` preceding every new line. This ensures rendering of fractions and scripts in display mode. To see the effect, compare the appearance of the formula with fractions of Figure 14a and Figure 14b.

#### 4.5 Open questions

One of the challenges in line breaking is to distinguish implicit multiplication and application of unspecified or user-defined functions. We may assume function application in the cases of explicit markup or known functions, such as `\mathop{\tg}` `\alpha` or `\tan x`. In general, however, we need either good heuristics, non-trivial semantic analysis, or explicit user markup.

Another challenge, this time from the aesthetic point of view, is how to arrange mixed expressions, such as shown in Figure 12, where we decide to maintain a single baseline for the overall expression and to align sub-expressions in place, instead

```


$$A \frac{x+y}{(a+b)^3} + 14m^{12} -$$


$$B \frac{a-b}{(x-y)^3} + 12n^{14}$$


```

**Figure 13:** Encoding of multi-line constructions

(a) In-line style

$$A \frac{x+y}{(a+b)^3} + 14m^{12} -$$

$$B \frac{a-b}{(x-y)^3} + 12n^{14}$$

(b) Display style

**Figure 14:** Array elements (a) without and (b) with explicit display style.

of moving them to separate lines and splitting them there.

The final issue we mention is the question of page breaking in the case of multi-page content. This situation frequently arises with output of computer algebra systems. We have implemented an approach that takes page size into account, but there remain a large number of questions with respect to handling of subexpressions and layout choices.

### 5 Conclusions and future work

We have explored an alternative approach to generating T<sub>E</sub>X expressions from mathematical content when the content is presented in a conceptually oriented format.

The main idea of our approach is to maintain the mathematical markup at a high level, either in T<sub>E</sub>X or MathML, allowing extended markup for new mathematical concepts. This allows higher-level transformations among the formats and allows late binding of user-specified notational choices.

We have shown how the rendering of mathematical content with T<sub>E</sub>X can be customized with our Notation Selection Tool. For this, we considered two methods of conversion to T<sub>E</sub>X: One as a direct translation using features of the Notation Selection Tool. The second method was to use MathML extended with new elements. We showed that the second approach offers a more fine-grained control over the conversion process. It allows implicit seman-

tics of mathematical expressions to be mapped from MathML template definitions to  $\text{T}_{\text{E}}\text{X}$  macros. Additionally, it allows a line breaking implementation suitable for large, generated mathematical expressions.

We continue investigating certain open problems in the the conversion between MathML and  $\text{T}_{\text{E}}\text{X}$ . These include automatic generation of templates for mapping rules and enhanced expression breaking methods. Another point of interest for our group in the MathML to  $\text{T}_{\text{E}}\text{X}$  conversion area is in automated generation of  $\text{T}_{\text{E}}\text{X}$  style files from XML cascading style sheets [21].

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