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It is a well known fact that \TeX can do a pretty good job on typesetting math. This is one reason why many scientific articles, papers and books are typeset using \TeX. However, in these days of triumphing angle brackets, coding in \TeX looks more and more out of place.

From the point of view of an author, coding in \TeX is quite natural, given that some time is spent on reading the manuals. This is because not only the natural flow of the definition suits the way mathematicians think, but also because the author has quite some control over the way his thoughts end up on paper. It will be no surprise that switching to a more restricted way of coding, which also demands more keystrokes, is not beforehand considered to be better.

There are however circumstances that one wants to share formulas (or formula-like specifications) between several applications, one of which is a typesetting engine. In that case, a bit more work now, later saves you some headaches due to keeping the different source documents in sync.

The moment coding math in xml is discussed, those in favour stress that coding can be eased by using appropriate editors. Here we encounter a dilemma. For optimal usage, one should code in terms of content, that is, the principles that are expressed in a formula. Editors are not that strong in this area, and if they would be, editing would be not that much different from traditionally editing formulas: just keying in ideas using code that at first sight looks obscure. A more graphical oriented editor can help authors to compose formulas, but the underlaying coding will mainly be in terms of placing glyphs and boxes, and as a result the code will hardly be usable in other applications.

So either we code in terms of concepts, which permits sharing code among applications, and poses strong limitations on the influence of authors on the visual appearance. Or we use an interactive editor to fine tune the appearance of a formula and take for granted that reuse will be minimal or suboptimal.

In the following chapters we will discuss the mathematical language MathML in the perspective of typography. As a typesetting vehicle, we have used \LaTeX. However, the principles introduced here and the examples that we provide are independent of \LaTeX. For a more formal exploration we recommend the MathML specification.

This document is dedicated to all those \LaTeX users who like typesetting math. I'm sure that my father, who was a math teacher, would have liked proofreading this document. His absence was compensated by Tobias Burnus, Wang Lei, Ton Otten, and later members of the \LaTeX mailing list who carefully read the text, corrected the errors in my math, tested the functionality, and made suggestions. Any remaining errors are mine.

When we started supporting MathML we were under the impression that it would be accepted and take of fast, but we were wrong. It toke much more than a decade for instance to see browsers support rendering. Being involved in typesetting educational content from xml files, we could use this subsystem ourselves, and this was useful in the sense that we ran into lots of contradicting and suboptimal MathML code. However, the most interesting application has always been in the math4all project, where we went from \TeX math, via content MathML and open math to presentational MathML. Nowadays web usage drives the coding and limitations in other programs (and rendering) are sometimes compensated by coding and our renderer then has to be able to recover nicely. Thanks to the enormous productivity of the main math4all author Frits Spijkers and the careful checking by my colleague Ton Otten, we could always keep op well. Development and support of the \LaTeX typesetting system is mostly done without any commercial
benefits and the amount of free time that we spend on it and especially its more obscure properties like MathML is compensated by flexible and tolerant users like them.

One problem is that our own usage of MathML changes over time. Some of our projects demand the use of this standard but at the same time the used sources need to satisfy other needs, for instance rendering on the web. For some 15 years now the changing demands and quality have made us oscillate between (often suboptimal) solutions that deal with the suboptimal code that comes from compromises. For instance the mentioned project is now using a mixture of MathML and so called asciimath because that is the only way the enormous amount of math code can be rendered on the web. And even there we need to bend the rules, for instance to compensate for missing features or cultural differences. Eventually I will rewrite the rendering from scratch but I need time and a very good reason for that.

This version of the manual is produced by ConTeXt MkIV and is also used as testcase. The version rendered at PRAGMA ADE uses the Lucida Bright fonts. These can be bought at www.tug.org for a reasonable low price and are really worth the money.

Hans Hagen
PRAGMA ADE
Hasselt NL
2001 — 2016
What is MATHML

1.1 backgrounds

MATHML showed up in the evolving vacuum between structural SGML markup and presentational HTML. Both SGML and HTML can be recognized by angle brackets. The disadvantage of SGML was that it was so open ended, that general tools could hardly be developed. HTML on the other hand was easy to use and became extremely popular and users as well as software vendors quickly spoiled the original ideas and created a mess. SGML never became really popular, but thanks to HTML people became accustomed to that kind of notation. So, when XML came around as a more restricted cousin of SGML, the world was kind of ready for it. It cannot be denied that by some clever marketing many of today’s users think that they use something new and modern, while we are actually dealing with something from the early days of computing. A main benefit of XML is that it brought the ideas behind SGML (and medium neutral coding in general) to the users and at the same time made a major cleanup of HTML possible.

About the same time, MATHML was defined, both to bring math to the WWW, and to provide a way of coding math that will stimulate sharing the same code between different applications. At the end of 2000, the MATHML version 2 draft became a recommendation. In the process of rewriting the interpreter for ConTeXt MkIV mid 2008 a draft of MATHML version 3 has been used.

Now, imagine that we want to present a document on the internet using a format like HTML, either for viewing or for being spoken. Converting text and graphics is, given proper source coding, seldom a problem, but converting formulas into some angle bracket representation is more tricky. A way out of this is MATHML’s presentational markup.

\[ a + b = c \]

This simple formula, when coded in \TeX, looks like:

$$ a + b = c $$

In presentational MATHML, we get:

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0"
      <mrow>
        <mi> a </mi>
        <mo> + </mo>
        <mi> b </mi>
        <mo> = </mo>
        <mi> c </mi>
      </mrow>
</math>
```

In presentational MATHML, we use mostly begintags \(<\texttt{mi}>\) and end tags \(</\texttt{mi}>\). The \texttt{mrow} element is the basic building block of a formula. The \texttt{mi} element specifies a math identifier and \texttt{mo} is used for
operators. In the process of typesetting, both are subjected to interpretation in order to get the best visualization.

Converting \TeX code directly or indirectly, using printable output or even in-memory produced math lists, has been one of the driving forces behind presentational MathML and other math related DTD’s like EUROMATH. One may wonder if there are sound and valid reasons for going the opposite way. You can imagine that a converter from \TeX to MathML produces menclose, mspace, mstyle and other elements that can have many spacing related attributes, but I wonder if any author is willing to think in those quantities. Visual editors of course are good candidates for producing presentational MathML.

But wouldn’t it be more efficient if we could express ideas and concepts in such a way that they could be handled by a broad range of applications, including a typesetting engine? This is why, in addition to presentational MathML, there is also content MathML. The previous formula, when coded in such a way, looks like:

```xml
<math xmlns="http://www.w3.org/1998/Math/MathML"
 xmlns:mml="http://www.w3.org/1998/Math/MathML"
 xmlns:xlink="http://www.w3.org/1998/xlink"
 version="2.0">
  <apply>
    <eq/>
    <apply>
      <plus/>
      <ci>a</ci>
      <ci>b</ci>
    </apply>
    <ci>c</ci>
  </apply>
</math>
```

This way of defining a formula resembles the so called polish (or stackwise) notation. Opposite to presentational markup, here a typesetting engine has to find out in what order and what way the content has to be presented. This may seem a disadvantage, but in practice implementing content markup is not that complicated. The big advantage is that, once we know how to typeset a concept, \TeX can do a good job, while in presentational markup much hard coded spacing can spoil everything. One can of course ignore specific elements, but it is more safe to start from less and enhance, than to leave away something with unknown quantities.

Instead of using hard coded operators as in presentational MathML, content markup uses empty elements like `<plus/>`. Many operators and functions are predefined but one can also define his own; in MathML 3 this is further extended by adopting OpenMath as variant.

Of course the main question to be answered now is to what extent the author can influence the appearance of a formula defined in content markup. Content markup has the advantage that the results can be more consistent, but taking away all control is counterproductive. The MathML level 2 draft mentions that this level covers most of the pre university math. If so, that is a proper starting point, but especially educational math often has to be typeset in such ways that it serves its purpose. Also, (re)using the formulas in other applications (simulators and alike) is useful in an educational setting, so content markup is quite suitable.

How do we combine the advantages of content markup with the wish of an author to control the visual output and at the same time get an as high as possible typeset result. There are several ways to accomplish this. One is to include in the document source both the content markup and the \TeX specific code.

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <semantics>
    <mrow>
      <mspace/>
      <mi>a</mi>
      <mspace/>
      <mi>b</mi>
    </mrow>
  </semantics>
</math>
```
What is MathML

\[ a + b = c \]

The \textit{annotation} element is one of the few that is permitted inside the \textit{math} element. In this example, we embed pure \TeX code, which, when enabled is typeset in math mode. It will be clear that for a simple formula like this one, such redundant coding is not needed, but one can imagine more complicated formulas. Because we want to limit the amount of work, we prefer just content markup.

\textit{Remark: Some characters, fillers or whatever may not show up. This is due to the fact that the relevant tables for Con\TeX\ MkIV are defined stepwise. In due time most relevant symbols will be accessible.}

\section*{1.2 \textit{two methods} \rightarrow}

The best way to learn MathML is to key in formulas, so that is what we did as soon as we started adding MathML support to Con\TeX. In some areas, MathML provides much detail (many functions are represented by elements) while in other areas one has to fall back on the more generic function element or a full description. Compare the following definitions:

\begin{verbatim}
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <sin/> <ci> x </ci> </apply>
</math>

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mrow> <mi> sin </mi> <mi> x </mi> </mrow>
</math>
\end{verbatim}

We prefer the first definition because it is more structured and gives more control over the result. There is only one 'unknown' quantity, \( x \), and from the encapsulating element \textit{ci} we know that it is an identifier.

\[ \sin x \]

\[ \sin x \]

In the content example, from the \textit{apply sin} we can deduce that the following argument is an operand, either an \textit{apply}, or a \textit{ci} or \textit{cn}. In the presentational alternative, the following elements can be braces, a math identifier, a row, a sequence of identifiers and operators, etc. There, the look and feel is hard coded.
This directive, either issued in the XML file, or set in the style file, changes the appearance of the function, but only in content markup. It is because of this feature, that we favour content markup.

\[ \sin(x) \]
\[ \sin x \]

Does this mean that we can cover everything with content markup? The answer to this is still unclear. Consider the following definition.

\[
\int \left( \frac{1}{\cos(ax)(1 \pm \sin(ax))} \right) dx = \left( \frac{1}{2a(1 \pm \sin(ax))} \right) + \frac{1}{2a} \log\tan\left(\frac{\pi}{4} + \frac{ax}{2}\right)
\]

Here we combine several cases in one formula by using \( \pm \) and \( \mp \) symbols. Because we only have plus and minus elements, we have to revert to the generic function element \( fn \). We show the complete definition of this formula.

<math xmlns='http://www.w3c.org/mathml' version='2.0'>
  <apply> <eq/>
    <apply> <int/>
      <bvar> <ci> x </ci> </bvar>
      <apply> <divide/> <cn> 1 </cn> <apply> <times/> <apply> <cos/> <apply> <times/> <ci> a </ci> <ci> x </ci> </apply> <apply> <fn> <ci> &plusminus; </ci> </fn> <cn> 1 </cn> <apply> <sin/> <apply> <times/> <ci> a </ci> <ci> x </ci> </apply> </apply> </apply> <apply> <plus/> <apply> <fn> <ci> &minusplus; </ci> </fn> <cn> 1 </cn> <apply> <divide/> <cn> 2 </cn> </apply> </apply> </apply> </apply> </apply> </apply> </apply></math>
The MathML parser and typesetting engine have to know how to handle these special cases, because the visualization depends on the function (or operator). Here both composed signs are treated like the plus and minus signs, but in other cases an embraced argument may be needed.
What is MathML
Presentational markup

<- 2.1 Introduction ->

If a document contains presentational MathML, there is a good chance that the code is output by an editor. Here we will discuss the presentation elements that make sense for users when they want to manually code presentational MathML. In this chapter we show the default rendering, later we will discuss options.

Although much is permitted, we advise to keep the code as simple as possible, because then \( \text{T}_{\text{E}}X \) can do a rather good job on interpreting and typesetting it. Just let \( \text{T}_{\text{E}}X \) take care of the spacing.

<- 2.2 \( \text{mi} \), \( \text{mn} \), \( \text{mo} \) ->

Presentational markup comes down to pasting boxes together in math specific ways. The basic building blocks are these three character elements.

\[
x = 5
\]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mrow>
    <mi>x</mi> <mo>=</mo> <mn>5</mn>
  </mrow>
</math>

| \( \text{mi} \) | identifier | normally typeset in an italic font |
| \( \text{mn} \) | number | normally typeset in a normal font |
| \( \text{mo} \) | operator | surrounded by specific spacing |

Because numbers are taken from an upright font, special numbers are taken care of automatically. Here are some from the MathML specification:

2 0.123 0,000,000 2.1e10 0xFFeF MCMLXIX twentyone

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mrow>
    <mn>2</mn> <mtext>&nbsp;&nbsp;</mtext> <mn>0.123</mn> <mtext>&nbsp;&nbsp;</mtext> <mn>0,000,000</mn> <mtext>&nbsp;&nbsp;</mtext> <mn>2.1e10</mn> <mtext>&nbsp;&nbsp;</mtext> <mn>0xFFeF</mn> <mtext>&nbsp;&nbsp;</mtext> <mn>MCMLXIX</mn> <mtext>&nbsp;&nbsp;</mtext> <mn>twenty one</mn> 
  </mrow>
</math>
Special characters can be accessed by their Unicode point or by a corresponding entity. For some reason there is quite some duplication in entities, but we don't bother too much about it because after all Unicode math (which has its own peculiarities) is the way to go. The specification has this somewhat strange formula definition:

\[ 2 + 3?? \frac{1}{2} \pi? \]

```
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mrow>
    <mn>2</mn> <mo>+</mo> <mrow>
      <mn>3</mn> <mo>&InvisibleTimes;</mo> <mi>&ImaginaryI;</mi>
    </mrow>
  </mrow>
  <mfrac>
    <mn>1</mn> <mn>2</mn>
  </mfrac>
  <mi>&pi;</mi> <mi>&ExponentialE;</mi>
</math>
```

And:

\[ \frac{?}{?x} \]

```
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mfrac>
    <mo>&DifferentialD;</mo> <mrow>
      <mo>&DifferentialD;</mo> <mi>x</mi>
    </mrow>
  </mfrac>
</math>
```

Visualizing the mo element involved some heuristics. For instance the size of fences depends on what they fence. In the following case you see how we can influence this. For practical purposes we only support size 1.

\[(x)\text{ or } (x)\text{ or } \left(\frac{1}{2}\right)\]

```
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mfrac>
    <mi>x</mi> <mi>x</mi>
  </mfrac>
</math>
```

Presentational markup
<math>
  <mrow>
    <mo> ( </mo> <mi> x </mi> <mo> ) </mo>
  </mrow>
</math>

### mi, mn

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>class, id, style</td>
<td>-</td>
</tr>
<tr>
<td>dir</td>
<td>-</td>
</tr>
<tr>
<td>href</td>
<td>-</td>
</tr>
<tr>
<td>mathbackground</td>
<td>-</td>
</tr>
<tr>
<td>mathcolor</td>
<td>-</td>
</tr>
<tr>
<td>mathsize</td>
<td>-</td>
</tr>
<tr>
<td>mathvariant</td>
<td>-</td>
</tr>
</tbody>
</table>

### mo

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>accent</td>
<td>-</td>
</tr>
<tr>
<td>class, id, style</td>
<td>-</td>
</tr>
<tr>
<td>dir</td>
<td>-</td>
</tr>
<tr>
<td>fence</td>
<td>-</td>
</tr>
<tr>
<td>form</td>
<td>-</td>
</tr>
<tr>
<td>href</td>
<td>-</td>
</tr>
<tr>
<td>largeop</td>
<td>-</td>
</tr>
<tr>
<td>lspace</td>
<td>-</td>
</tr>
<tr>
<td>mathbackground</td>
<td>-</td>
</tr>
<tr>
<td>mathcolor</td>
<td>-</td>
</tr>
<tr>
<td>mathsize</td>
<td>-</td>
</tr>
<tr>
<td>mathvariant</td>
<td>-</td>
</tr>
<tr>
<td>maxsize</td>
<td>+</td>
</tr>
<tr>
<td>minsize</td>
<td>-</td>
</tr>
<tr>
<td>movablelimits</td>
<td>-</td>
</tr>
<tr>
<td>rspace</td>
<td>-</td>
</tr>
<tr>
<td>separator</td>
<td>-</td>
</tr>
<tr>
<td>stretchy</td>
<td>-</td>
</tr>
<tr>
<td>symmetric</td>
<td>-</td>
</tr>
</tbody>
</table>

**If stretchy is true, this attribute specifies the maximum size of the operator. Allowed values are: ‘infinity’ or an arbitrary length.**
2.3 \textit{mrow} \\

The previous example demonstrated the use of \textit{mrow}, the element that is used to communicate the larger building blocks. Although this element from the perspective of typesetting is not always needed, by using it, the structure of the formula in the document source is more clear. There is some messy magic going on when we try to fake fenced expressions.

\[
x \geq 2
\]

\[
\begin{aligned}
\text{<math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<mrow>}
\text{<mi> x </mi> <mo> \&geq; </mo> <mn> 2 </mn> </mrow>}
\text{</math>}
\end{aligned}
\]

\[
y > 4
\]

\[
\begin{aligned}
\text{<math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<mrow>}
\text{<mi> y </mi> <mo> \&gt; </mo> <mn> 4 </mn> </mrow>}
\text{</math>}
\end{aligned}
\]

\[
\text{< x >}
\]

\[
\begin{aligned}
\text{<math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<mrow>}
\text{<mo> \&lt; </mo> <mi> x </mi> <mo> \&gt; </mo> </mrow>}
\text{</math>}
\end{aligned}
\]

\[
a < b < c
\]

\[
\begin{aligned}
\text{<math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<mrow>}
\text{<mi> a </mi> <mo> \&lt; </mo> <mi> b </mi> <mo> \&lt; </mo> <mi> c </mi> </mrow>}
\text{</math>}
\end{aligned}
\]

Spacing between a sign and the following token is taken care of automatically by \TeX:

\[
\text{\text{-} 1 \text{-} 1}
\]

\[
\begin{aligned}
\text{<math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<mrow>}
\text{<mo> \text{-} </mo>}
\text{<mn> 1 </mn>}
\text{<mo> \text{-} </mo>}
\text{<mn> 1 </mn>}
\text{</mrow>}
\text{</math>}
\end{aligned}
\]

\textit{mrow} class, id, style -

\textit{dir} -

\textit{Presentational markup}
Where in content markup super and subscript are absent and derived from the context, in presentational markup they are quite present.

\[ x_{1}^{2} \]

\[ \chi_{i}^{2} \]

Watch the difference between both definitions and appearances. You can influence the default behaviour with processing instructions.

---

**Presentational markup**

---
Addition, subtraction and multiplication is hard coded using the \texttt{mo} element with +, −, and × (or nothing). You can use / for division, but for more complicated formulas you have to fall back on fraction building. This is why \LaTeX{} provides the \texttt{mfrac}.

\[
\frac{x + 1}{y + 1}
\]

You can change the width of the rule, but this is generally a bad idea. For special purposes you can set the line thickness to zero.

\[
\begin{array}{c}
\frac{x \geq 2}{y \leq 4} \\
\end{array}
\]

A different kind of rendering is also possible, as shown in the following example.

\[
\frac{\frac{x}{2}}{\frac{x}{2}}
\]
<table>
<thead>
<tr>
<th>mfrac</th>
<th>bevelled</th>
<th>+</th>
<th>Specifies the way the fraction is displayed. If true, the fraction line is bevelled, which means that numerator and denominator are displayed side by side and separated by a slash (/).</th>
</tr>
</thead>
<tbody>
<tr>
<td>class, id, style</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>denomalign</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>href</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>linethickness</td>
<td>+</td>
<td></td>
<td>The thickness of the horizontal fraction line. The default value is medium, but thin, thick, and other values can be set.</td>
</tr>
<tr>
<td>mathbackground</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mathcolor</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>numalign</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**<- 2.6 mfenced ->**

Braces are used to visually group sub-expressions. In presentational MathML you can either hard code braces, or use the `mfenced` element to generate delimiters automatically. In ConTeXt, as much as possible, the operators and identifiers are interpreted, and when recognized treated according to their nature.

\[(a,b,1)\]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mfenced> <mi> a </mi> <mi> b </mi> <mn> 1 </mn> </mfenced>
</math>
```

The fencing symbols adapt their size to the content. Their dimensions also depend on the way math fonts are defined. The standard \(\text{\TeX}\) fonts will give the same height of braces around \(x\) and \(y\), but in other fonts the \(y\) may invoke slightly larger ones.

\([0,1)\]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mfenced open="[" close=")" separators="",">
    <mn> 0 </mn> <mn> 1 </mn>
  </mfenced>
</math>
```

The separators adapt their size to the fenced content too, just like the fences.

\[
\begin{bmatrix}
  1 & 1 & 1 \\
  x & y & z
\end{bmatrix}
\]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mfenced open="[" close="]" separators="|">
    <mfrac> <mn> 1 </mn> <mi> x </mi> </mfrac>
    <mfrac> <mn> 1 </mn> <mi> y </mi> </mfrac>
    <mfrac> <mn> 1 </mn> <mi> z </mi> </mfrac>
  </mfenced>
</math>
```

**Presentational markup**
\[(1 + x)\]

\[
\begin{align*}
\{1\}2 + 3 - 4 \\
\text{a}1b2c3d4e
\end{align*}
\]

**mfenced**

- class, id, style
- close
- href
- mathbackground
- mathcolor
- open
- separators

- A string for the closing delimiter. The default value is \)' and any white space is trimmed.
- A string for the opening delimiter. The default value is \('(' and any white space is trimmed.
- A sequence of zero or more characters to be used for different separators, optionally divided by white space, which is ignored.

---

### 2.7 msqrt, mroot

The shape and size of roots, integrals, sums and products can depend on the size of the content.

\[\sqrt{b}\]

\[
\begin{align*}
\text{msqrt} \\
\text{mi} b \text{ mi}
\end{align*}
\]
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mroot>
    <mi>b</mi>
    <mn>2</mn>
  </mroot>
</math>

\sqrt[2]{b}

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mroot>
    <mfrac>1</mfrac>
    <mi>b</mi>
  </mroot>
</math>

\sqrt[\frac{1}{b}]{1}

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mroot>
    <mfrac>
      <mn>1</mn>
      <mrow>a + b</mrow>
    </mfrac>
    <mn>3</mn>
  </mroot>
</math>

\sqrt[3]{\frac{1}{a + b}}

---

**msqrt, mroot**

class, id, style -

href -

mathbackground -

mathcolor -

---

**2.8 mtext**

If you put text in a *mi* element, it will come out rather ugly. This is due to the fact that identifiers are (at least in \TeX) not subjected to the kerning that is normally used in text. Therefore, when you want to add some text to a formula, you should use the *mtext* element.

\[
\text{SomeText}
\]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mtext>Some Text</mtext>
</math>

*Presentational markup*
<mfrac>
  <mi> Some Text </mi>
  <mtext> Some Text </mtext>
</mfrac>
</math>

As with all elements, leading and trailing spaces are ignored. If you really want a space in front or at
the end, you should use one of the space tokens other than the ascii spacing tokens. You can also use
entities like &nbsp;.

---

**mtext**

- class, id, style
- dir
- href
- mathbackground
- mathcolor
- mathsize
- mathvariant

\[ \begin{array}{c}
\text{munder, mover, munderover} \\
\end{array} \]

Not all formulas are math and spacing and font rules may differ per discipline. The following formula reflects a chemical reaction.

\[
2 \text{H}_2 + \text{O}_2 \rightarrow \text{explosion} \rightarrow 2 \text{H}_2 \text{O}
\]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mrow>
    <mrow>
      <mn>2</mn>
      <msub>
        <mtext>H</mtext>
        <mn>2</mn>
      </msub>
    </mrow>
    <mo>+</mo>
    <munder>
      <mtext>&RightArrow;</mtext>
      <mtext>explosion</mtext>
    </munder>
    <mrow>
      <mn>2</mn>
      <msub>
        <mtext>H</mtext>
        <mn>2</mn>
      </msub>
      <mtext>O</mtext>
    </mrow>
  </mrow>
</math>

The *munder*, *mover* and *munderover* elements can be used to put symbols and text or formulas on top
of each other. When applicable, the symbols will stretch themselves to span the natural size of the text or

*Presentational markup*
The following examples demonstrate how the relevant components of this threesome are defined.

\[
x \rightarrow\text{ maps to } y
\]
<mover>
  <mo> &RightArrow; </mo>
  <mtext> maps to </mtext>
</mover>

<mi> y </mi>
</mrow>
</math>

\[ \int_{1}^{\infty} \hat{x} + \ddot{x} \]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mrow>
    <munderover>
      <mi> &int; </mi>
      <mn> 1 </mn>
      <mi> &infin; </mi>
    </munderover>
    \hat{x} + \ddot{x}
  </mrow>
</math>

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mrow>
    <mover> <mi> x </mi> <mo> &#x2C6; </mo> </mover> <mo>+</mo>
    <mover> <mi> x </mi> <mo> &#x5E; </mo> </mover> <mo>+</mo>
    <mover> <mi> x </mi> <mo> &Hat; </mo> </mover>
  </mrow>
</math>

--

<table>
<thead>
<tr>
<th>munder</th>
<th>accentunder</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>align</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>class, id, style</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>href</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>mathbackground</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>mathcolor</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>mover</th>
<th>accent</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>align</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>class, id, style</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>href</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>mathbackground</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>mathcolor</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>munderover</th>
<th>accent</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>accentunder</td>
<td>-</td>
</tr>
</tbody>
</table>
This is a bit weird element. It behaves like \textit{mtext} but puts quotes around the text.

\begin{verbatim}
" Some Text "
\textit{Some Text}
\end{verbatim}

You can specify the left and right boundary characters, either directly or (preferably) using entities like &quot;:

\begin{verbatim}
+ A Famous Quotation +
\end{verbatim}

This element is implemented but it is such a weird element that it’s probably seldom used.

\begin{verbatim}
\[123\]
\end{verbatim}
A bit more complex example (taken from the specification) demonstrates where those somewhat strange rendering options are good for:

$$\begin{array}{rl}
10 & 1413 \\
131 & 103
\end{array}$$
In MathML 3 a few more notations showed up and to some extend we support them. We assume that the previously mentioned variants are always applied to the content first.

```xml
<menclose notation="box downdiagonalstrike">
  <mtext>whatever</mtext>
</menclose>

<menclose notation="roundedbox updiagonalstrike">
  <mtext>whatever</mtext>
</menclose>

<menclose notation="circle verticalstrike horizontalstrike">
  <mtext>whatever</mtext>
</menclose>

<menclose notation="left top verticalstrike">
  <mtext>whatever</mtext>
</menclose>

<menclose notation="right bottom horizontalstrike">
  <mtext>whatever</mtext>
</menclose>
```
The graphics are drawn at runtime by MetaPost. Currently we don’t combine them into one which would be more efficient in terms of output (not so much in runtime). You can define additional variants; as an example we show one of the solutions:

\startuseMPgraphic{mml:enclose:box}
  draw OverlayBox
  withpen pencircle scaled (ExHeight/10);
\stopuseMPgraphic

\defineoverlay [mml:enclose:box] [\useMPgraphic{mml:enclose:box}]

You can roll out your own:

\startuseMPgraphic{mml:enclose:mybox}
  draw OverlayBox enlarged (ExHeight/5)
  withpen pencircle scaled (ExHeight/10);
\stopuseMPgraphic

\defineoverlay [mml:enclose:mybox] [\useMPgraphic{mml:enclose:mybox}]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <menclose notation="mybox">
    <mtext>whatever</mtext>
  </menclose>
</math>
Presentational markup

- `mathbackground`
- `mathcolor`
- `notation` + A list of notations, separated by white space, to apply to the child elements. The symbols are each drawn as if the others are not present, and therefore may overlap. Supported values are: `longdiv`, `actuarial`, `radical`, `box downdiagonalstrike`, `roundedbox updiagonalstrike`, `circle verticalstrike horizontalstrike`, `right bottom horizontalstrike`, etc.

<- 2.12 `merror` ->

There is not much chance that this element will end up in a math textbook, unless the typeset output of programs is part of the story.

\[
\text{Are you kidding? } \frac{1+x}{0}
\]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <merror>
    <mtext> Are you kidding? &ThinSpace; </mtext>
    <mfrac>
      <mrow> <mn> 1 </mn> <mo> + </mo> <mi> x </mi> </mrow>
      <mn> 0 </mn>
    </mfrac>
  </merror>
</math>
```

<- 2.13 `mmultiscripts`, `mprescripts` ->

This element is one of the less obvious ones. The next two examples are taken from the specification. The `multiscripts` element takes an odd number of arguments. The second and successive child elements alternate between sub- and superscript. The empty element `none` —a dedicated element `mnone` would have been a better choice— serves as a placeholder.

\[
R_{i/j}
\]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mmultiscripts>
    <mi> R </mi>
    <mi> i </mi>
    <none/>
  </mmultiscripts>
</math>
```

Presentational markup
The `mmultiscripts` element can also be used to attach prescripts to a symbol. The next example demonstrates this. The empty `prescripts` element signals the start of the prescripts section.

\[ \mathbf{Q}_{b_4} \]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mmultiscripts>
    <mi> Qb </mi>
    <mn> 4 </mn>
    <none/>
    <mprescripts/>
    <mn> 427 </mn>
    <none/>
  </mmultiscripts>
</math>
```

**mmultiscripts** class, id, style -
  href -
  mathbackground -
  mathcolor -
  subscriptshift -
  superscriptshift -

### 2.14 `mspace` ->

Currently not all functionality of the `mspace` element is implemented. Over time we will see what support is needed and makes sense, especially since this command can spoil things. We only support the units that make sense, so units in terms of pixels—a rather persistent oversight in drafts—are kindly ignored.

\[
\begin{array}{c|c|c|c|c}
\text{use} & \text{me} & \text{with} & \text{care} \\
\hline
1em & 1ex & 10pt \\
\end{array}
\]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <?context-mathml-directive mspace option test ?>
  <mrow>
    <mtext> use </mtext> <mspace width="1em"/>
    <mtext> me </mtext> <mspace width="1ex"/>
    <mtext> with </mtext> <mspace width="10pt"/>
  </mrow>
</math>
```

*Presentational markup*
<mtext> care </mtext>
</mrow>
</math>

As you can see here, spaces inside a mtext matter too! The next example is more tight.

\[
\begin{align*}
\text{use} & \quad \text{me} \quad \text{with} \quad \text{care} \\
\text{use} & \quad \text{me} \quad \text{with} \quad \text{care}
\end{align*}
\]

You can also pass a sample text:

\[
\frac{44}{11 22 33} = \frac{11}{33}
\]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mfrac>
    <mi> 44 </mi>
    <mfrac>
      <mn> 11 </mn> <mn> 22 </mn> <mn> 33 </mn>
    </mfrac>
    <mfrac>
      <mn> 11 </mn> <mspace spacing="22"/> <mn> 33 </mn>
    </mfrac>
  </mfrac>
</math>

**mspace**
- class, id, style
- depth
- height
- linebreak
- mathbackground
- spacing - The desired width of the space.
- width - The desired width of the space.

*Presentational markup*
<2.15 mphantom ->

A phantom element hides its content but still takes its space. A phantom element can contain other elements.

\[
\text{who is afraid of elements}
\]

\[
<\text{math xmlns="http://www.w3c.org/mathml" version="2.0">}
<\text{mrow}>
<\text{mtext}> who is afraid of </text>
<\mspace width=".5em" />
<\text{mphantom}> phantom </mphantom>
<\mspace width=".5em" />
<\text{mtext}> elements </text>
</mrow>
</math>

mphantom class, id, style -
mathbackground -

<2.16 mpadded ->

As with a few other elements, we first have to see some practical usage for this, before we could implement the functionality needed.

mpadded class, id, style -
depth -
height -
href -
lspace -
mathbackground -
mathcolor -
voffset -
width -

<2.17 mtable, mtr, mtd, mlabeledtr ->

As soon as you want to represent a matrix or other more complicated composed constructs, you end up with spacing problems. This is when tables come into view. Because presentational elements have no deep knowledge about their content, tables made with presentational MATHML will in most cases look worse than those that result from content markup.

We have implemented tables on top of the normal XML (HTML) based table support in CONTĚXT, also known as natural tables. Depending on the needs, support for the mtable element will be extended.

The mtable element takes a lot of attributes. When no attributes are given, we assume that a matrix is wanted, and typeset the content accordingly.

\[
\begin{pmatrix}
x_{1,1} & 1 & 0 \\
0 & x_{2,2} & 1 \\
0 & 1 & x_{3,3}
\end{pmatrix}
\]

**Presentational markup**
\[
\begin{bmatrix}
1 & 1 & 0 \\
0 & 1 & 2 \\
0 & 3 & 3
\end{bmatrix}
\]

\[
\begin{bmatrix}
100 & 0 & 1 \\
0 & 10 & 1 \\
1 & 1 & 1
\end{bmatrix}
\]
A special case is the labeled row \texttt{mlabeledtr}. This one is meant for numbering equations. However, in a properly formatted document there is probably some encapsulating structure that takes care of this. Therefore we discard the first child element. We show an example taken from the specification.

\[
E = mc^2
\]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mtable>
    <mlabeledtr>
      <mtd>crap</mtd>
      <mtd>
        <mrow>
          <mi>E</mi>
          <mo>=</mo>
          <mrow>
            <mi>m</mi>
            <mi>&lt;</mi>
            <msup>
              <mi>c</mi>
              <mn>2</mn>
            </msup>
          </mrow>
        </mrow>
      </mtd>
    </mlabeledtr>
  </mtable>
</math>
```

Although the underlying table mechanism can provide all the support needed (and even more), not all attributes are yet implemented. We will make a useful selection.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>columnalign</td>
<td>keyword: left center (middle) right</td>
</tr>
<tr>
<td>columnspsacing</td>
<td>a meaningful dimension</td>
</tr>
<tr>
<td>rowspacing</td>
<td>a meaningful dimension</td>
</tr>
<tr>
<td>frame</td>
<td>keyword: none (off) solid (on)</td>
</tr>
<tr>
<td>color</td>
<td>a named color identifier</td>
</tr>
<tr>
<td>background</td>
<td>a named color identifier</td>
</tr>
</tbody>
</table>

We only support properly named colors as back- and foreground colors. The normal \texttt{ConTExT} color mapping mechanism can be used to remap colors. This permits (read: forces) a consistent usage of colors. If you use named backgrounds ... the sky is the limit.

```
<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>mtable</td>
<td>align</td>
</tr>
<tr>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>alignmentscope</td>
</tr>
<tr>
<td></td>
<td>class, id, style</td>
</tr>
</tbody>
</table>
```

\texttt{Presentational markup}
columnalign + Specifies the horizontal alignment of the cells. Multiple values separated by space are allowed and apply to the corresponding columns (e.g. columnalign="left right center"). Possible values are: left, center (default) and right.

columnlines -
columnspacing + Specifies the space between table columns.
columnwidth -
displaystyle -
equalcolumns -
equalrows -
frame -
framespacing -
groupalign -
href -
mathbackground + The background color.
mathcolor + The text color.
minlabelspacing -
rowalign -
rowlines -
rowspacing + Specifies the space between table rows.
side -
width -

mtd class, id, style -
columnalign -
columnspan -
frame - Specifies whether the cell gets a frame.
groupalign -
href -
mathbackground -
mathcolor -
rowalign -
rowspan -

mtr, labeledtr class, id, style -
columnalign + Overrides the horizontal alignment of cells specified by <mtable> for this row.
groupalign -
href -
mathbackground + The background color.
mathcolor + The text color.
rowalign -

Presentational markup
This element is new in MathML 3 and is kind of special in the sense that the content is analyzed. It would have made more sense just to provide some proper structure instead since it’s intended use is rather well defined.

Because it is not much fun to implement such a messy element we only support it partially and add what comes on our way. Here are a few examples (more or less taken from the reference).

\[
\begin{array}{c}
12 \\
\times 12 \\
24 \\
12 \\
144
\end{array}
\]

\[
\begin{array}{c}
123 \\
456+ \\
579
\end{array}
\]
<mline spacing="0,00+"/>
<mn>5,79</mn>
</mcolumn>
</math>

52
−7
45

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mcolumn>
    <mstyle mathsize="71%">
      <menclose notation="bottom"> <mn>10</mn> </menclose>
    </mstyle>
    <mn>52</mn><mrow> <mo>&minus;</mo> <mn>7</mn> </mrow>
    <mline spacing="45"/>
    <mn>45</mn>
  </mcolumn>
</math>

Similar effects can be accomplished with the mtable element.

<- 2.19 malignmark, maligngroup ->

This element is used in tables and is not yet implemented, first because I still have to unravel its exact usage, but second, because it is about the ugliest piece of MATHML markup you will encounter.

malignmark class, id, style edge

<- 2.20 mglyph ->

This element is for those who want to violate the ideas of general markup by popping in his or her own glyphs. Of course one should use entities, even if they have to be defined.

\[ A + B = C \]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <mrow>
    <mi> <mglyph fontfamily="Serif" index="65" alt="The Letter A"/> </mi>
    <mo> + </mo>
    <mi> <mglyph fontfamily="Serif" index="66" alt="The Letter B"/> </mi>
    <mo> = </mo>
    <mi> <mglyph fontfamily="Serif" index="67" alt="The Letter C"/> </mi>
  </mrow>
</math>

Presentational markup
Presentational markup

mglyph

alt + This attribute defines the alternative text describing the image.
class, id, style -
height -
href -
mathbackground -
src -
valign -
width -

<- 2.21 mstyle ->

This element is implemented but not yet discussed since we want more control over its misuse.

mstyle

dir -
decimalpoint -
displaystyle -
infixlinebreakstyle -
scriptlevel + Controls mostly the font-size. The higher the scriptlevel, the smaller the font size. This attribute accepts a non-negative integer, as well as a ‘+’ or a ‘−’ sign, which increments or decrements the current value.

scriptminsize -
scriptsizemultiplier -

<- 2.22 afterword ->

You may have noticed that we prefer content MathML over presentational MathML. So, unless you’re already tired of any math coded in angle brackets, we invite you to read the next chapter too.
In this chapter we will discuss the MathML elements from the point of view of typesetting. We will not pay attention to other rendering techniques, like speech generation. Some elements take attributes and those often make more sense for other applications than for a typesetting engine like \TeX, which has a strong math engine that knows how to handle math.

One of the most prominent changes in MathML 3 is support for an OpenMath like coding. Here the \texttt{csymbol} takes the place of the empty element as first argument of an \texttt{apply}. There are more symbols in OpenMath then we supported in the interpreter, but in due time (depending on demand) we will add more. At the time of writing this the draft was really a draft which made it hard to grasp all the implications for rendering so we probably need to overhaul the code sometime in the future.

Another change is the usage of \texttt{apply} that has been delegated to \texttt{bind}. One may wonder why this hadn’t happen before. For the moment we treat the \texttt{bind} as if it were an \texttt{apply}.

If you are dealing with rather ordinary math, you will only need a subset of content MathML. For this reason we will start with the most common elements. When you key in XML directly, you will encounter the \texttt{apply} element quite often, even in a relatively short formula like the following.

\[ -1 \]

\[
\begin{math}
<apply>
  <minus/>
  <cn> 1 </cn>
</apply>
\end{math}
\]

In most cases the \texttt{apply} element is followed by a specification disguised as an empty element. Later we will see more complex examples but here we already show the different ways of encoding. First we show the traditional MathML 2 method:

\[
\forall_x: x \geq 4
\]

\[
\begin{math}
<apply>
  <forall/>
  <bvar> <ci>x</ci> </bvar>
  <apply> <geq/> 
    <ci>x</ci>
    <cn>4</cn>
  </apply>
</apply>
\end{math}
\]
This is now called 'pragmatic' MathML. Using symbols and \textit{bind} this becomes 'strict' MathML:

$$\forall x : x \geq 4$$

\[
\text{<math xmlns="http://www.w3c.org/mathml" version="3.0">}
\text{<bind>}
\text{ <csymbol cd="quant1">forall</csymbol>}
\text{ <bvar>}
\text{ <ci>x</ci> }
\text{ </bvar>}
\text{ <apply>}
\text{ <csymbol cd="relation1">geq</csymbol>}
\text{ <ci>x</ci>}
\text{ <cn>4</cn>}
\text{ </apply>}
\text{ </bind>}
\text{ </math>}

\[\text{<- 3.3  ci, cn, sep ->}\]

These elements are used to specify identifiers and numbers. Both elements can be made more explicit by using attributes.

<table>
<thead>
<tr>
<th>type</th>
<th>set</th>
<th>vector</th>
<th>function</th>
<th>fn</th>
<th>idem</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>use a representation appropriate for sets</td>
<td>mark this element as vector</td>
<td>consider this element to be a function</td>
<td>idem</td>
<td></td>
</tr>
</tbody>
</table>

When \textit{set} is specified, a blackboard symbol is used when available.

$$x \in \mathbb{N}$$

\[
\text{<math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<apply>}
\text{ <in/>}
\text{ <ci> x </ci>}
\text{ <ci type="set"> N </ci>}
\text{ </apply>}
\text{ </math>}

The \textit{function} specification makes sense when the \textit{ci} element is used in for instance a differential equation.

<table>
<thead>
<tr>
<th>type</th>
<th>integer</th>
<th>a whole number with an optional base</th>
<th>logical</th>
<th>a boolean constant</th>
<th>rational</th>
<th>a real number</th>
<th>complex-cartesian</th>
<th>a complex number in ( x + iy ) notation</th>
<th>complex</th>
<th>idem</th>
<th>complex-polar</th>
<th>a complex number in polar notation ...</th>
</tr>
</thead>
</table>

\textit{Content markup}
You’re lucky when your document uses decimal notation, otherwise you will end up with long specs if you want to be clear in what numbers are used.

\[ 1A2C_{16} + 0101_{16} = 1B2D_{16} \]

Complex numbers have two components. These are separated by the `sep` element. In the following example we see that instead of using a `ci` with set specifier, the empty element `complexes` can be used. We will see some more of those later.

\[(+i) \in \mathbb{C}\]

Expressions, and especially those with `eq` are typical for math. Because such expressions can be quite large, there are provisions for proper alignment.

\[
\begin{array}{cccc}
\text{lt} & a < b & \text{leq} & a \leq b \\
\text{eq} & a = b & \text{neq} & a \neq b \\
\text{gt} & a > b & \text{geq} & a \geq b \\
\end{array}
\]

\[ a \leq b \leq c \]

Equivalence, approximations, and implications are handled like `eq` and alike and have their own symbols.
Content markup

\[ a + b \equiv b + a \]

\[
\begin{align*}
\text{This document is typeset with \textsc{LuaLaTeX} built upon \TeX{} version 3.14159, and given that \TeX{} is written by a mathematician, it will be no surprise that:} \\
3.14159 \approx \pi \\
x + 4 = 9 \Rightarrow x = 5
\end{align*}
\]

\[
\begin{align*}
\text{Addition and subtraction are main building blocks of math so you will meet them often.} \\
37 - x
\end{align*}
\]
In most cases there will be more than one argument to take care of, but especially \textit{minus} will be used with one argument too. Although \texttt{<cn> -37 </cn>} is valid, using \textit{minus} is sometimes more clear.

\[-37\]

\[
\text{You should pay attention to combinations of } plus \text{ and } minus. \text{ Opposite to presentational MATHML, in content markup you don't think and code sequential.}
\]

\[-x + 37\]

\[
\text{In MATHML 3 we can also be more vebose:}
\]

\[
a + x
\]

\[
\text{\texttt{<- 3.7 \texttt{times} ->}}
\]

\[
\text{Multiplication is another top ten element. Although 3p as content of the } ci \text{ element would have rendered the next example as well, you really should split off the number and mark it as } cn. \text{ When this is done consistently, we can comfortably change the font of numbers independent of the font used for displaying identifiers.}
\]

\[
3p
\]
In a following chapter we will see how we can add multiplication signs between variables and constants.

3
p

\[
\frac{-b - b - \sqrt{a}}{(b - b) - b - \sqrt{a}}
\]

\textit{3.8 divide ->}

When typeset, a division is characterized by a horizontal rule. Some elements, like the differential element \textit{diff}, generate their own division.

\[
1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \cdots = \frac{\pi}{4}
\]

This example also demonstrates how to mix \textit{plus} and \textit{minus}.

\begin{verbatim}
<math xmlns='http://www.w3c.org/mathml' version='2.0'>
  <apply> <eq/>
    <apply> <plus/>
      <cn> 1 </cn>
      <apply> <minus/>
        <apply> <divide/>
          <cn> 1 </cn>
          <cn> 3 </cn>
        </apply>
        <apply> <divide/>
          <cn> 1 </cn>
          <cn> 5 </cn>
        </apply>
      </apply>
      <apply> <minus/>
        <apply> <divide/>
          <cn> 1 </cn>
          <cn> 7 </cn>
        </apply>
        <ci> \cdots \end{ci}
      </apply>
    </apply>
    <apply> <divide/>
      <ci> \pi </ci>
      <cn> 4 </cn>
    </apply>
  </apply>
</math>
\end{verbatim}
In presentational MathML you think in super- and subscripts, but in content MathML these elements are not available. There you need to think in terms of *power*.

\[ x^2 + \sin^2 x \]

The *power* element is clever enough to determine where the superscript should go. In the case of the sinus function, by default it will go after the function identifier.

### 3.10 root, degree ->

If you study math related DTD's — these are the formal descriptions for SGML or XML element collections — you will notice that there are not that many elements that demand a special kind of typography: differential equations, limits, integrals and roots are the most distinctive ones.

\[ \sqrt[3]{64} = 4 \]
Contrary to power, the root element uses a specialized child element to denote the degree. The positive consequence of this is that there cannot be a misunderstanding about what role the child element plays, while in for instance power you need to know that the second child element denotes the degree.

\[ \sqrt[3]{64} = 4 \]

All members of the family of goniometric functions are available as empty element. When needed, their argument is surrounded by braces. They all behave the same.

\[
\sin, \arcsin, \sinh, \arcsinh, \\cos, \arccos, \cosh, \arccosh, \\
tan, \arctan, \tanh, \arctanh, \\
cot, \arccot, \coth, \arccoth, \\
csc, \arccsc, \csch, \arccsch, \\
sec, \arcsec, \sech, \arcsech
\]

These functions are normally typeset in a non italic (often roman) font shape.

\[
\sin(x + y) = \sin x \cos y + \cos x \sin y
\]

By default the typesetting engine will minimize the number of braces that surrounds the argument of a function.
You can specify π as an entity \&pi; or as empty element \textit{pi}. In many cases it is up to your taste which one you use. There are many symbols that are only available as entity, so in some respect there is no real reason to treat π different.

\[
\cos \pi = -1
\]

\[
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <eq/>
    <apply> <cos/> <pi/> </apply>
    <apply> <minus/> <cn> 1 </cn> </apply>
  </apply>
</math>
\]

\(- 3.12 \text{ log, ln, exp } \rightarrow \)

The \textit{log} and \textit{ln} are typeset similar to the previously discussed goniometric functions. The \textit{exp} element is a special case of \textit{power}. The constant \(e\) can be specified with \textit{exponentiale}.

\[
\ln (e + 2) \approx 1.55
\]

\[
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <approx/>
    <apply> <ln/> <apply> <plus/> <exponentiale/> <cn> 2 </cn> </apply> </apply>
  </apply>
</math>
\]
\[ e^2 = 7.3890560989307 \]

\[
\begin{align*}
\frac{a}{b} & \text{ quotient, rem } \\
\frac{5}{4} & \text{ is equivalent to } 1.25 \text{ and } 1.25 \times 4 \text{ gives } 5. \text{ An integer division will give 1 with a remainder } 2. \text{ Many computer languages provide a div and mod function, and since MathML is also meant for computation, it provides similar concepts, represented by the elements quotient and rem. The representation of quotient is rather undefined, but the next one is among the recommended alternatives.}
\end{align*}
\]

\[
\left\lfloor \frac{a}{b} \right\rfloor
\]

\[
\begin{math}
\text{\textbackslash{lt} 3.13 quotient, rem \textbackslash{gt}}
\end{math}
\]

The result of a division can be a rational number, so \( \frac{3}{4} \) is equivalent to 1.25 and 1.25 \( \times 4 \) gives 5. An integer division will give 1 with a remainder 2. Many computer languages provide a div and mod function, and since MathML is also meant for computation, it provides similar concepts, represented by the elements quotient and rem. The representation of quotient is rather undefined, but the next one is among the recommended alternatives.

\[
\left\lfloor \frac{a}{b} \right\rfloor
\]

\[
\begin{math}
\text{\textbackslash{lt} 3.14 factorial \textbackslash{gt}}
\end{math}
\]

Showing the representation of a factorial is rather dull, so we will use a few more elements as well as a processing instruction to illustrate the usage of factorial.

\[ n! = n \times (n - 1) \times (n - 2) \times \cdots \times 1 \]
The processing instruction is responsible for the placement of the \times symbols.

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply>
    <eq/>
    <ci> z </ci>
    <apply>
      <min/>
      <apply>
        <plus/> <ci> x </ci> <ci> y </ci>
      </apply>
      <apply>
        <times/> <cn> 2 </cn> <ci> x </ci>
      </apply>
      <apply>
        <divide/> <cn> 1 </cn> <ci> y </ci>
      </apply>
    </apply>
  </apply>
</math>

Logical expressions can be defined using these elements. The operations are represented by symbols and braces are applied when needed.

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply>
    <eq/>
    <apply>
      <and/>
      <cn type="integer" base="2"> 1001 </cn>
      <cn type="integer" base="2"> 0101 </cn>
    </apply>
    <cn type="integer" base="2"> 0001 </cn>
  </apply>
</math>
The appearance of a set depends on the presence of the child element bvar. In its simplest form, a set is represented as a list.

\[ \{1,4,8\} \neq ? \]

A set can be distinguished from a vector by its curly braces. The simplest case is just a comma separated list. The next example demonstrates the declarative case. Without doubt, there will be other alternatives.

\[ \{x \mid 2 < x < 8\} \]

This element is used in different contexts. When used as a top level element, a list is typeset as follows.

\[ [1,1,3] \]
When used in a context like `partialdiff`, the list specification becomes a subscript.

\[ D_{1,1,3}f \]

The function specification in this formula (which is taken from the specs) can also be specified as `<fn>` `<ci> f </ci>` `</fn>` (which is more clear).

### 3.19 union, intersect, ... ->

There is a large number of set operators, each represented by a distinctive symbol.

<table>
<thead>
<tr>
<th>operator</th>
<th>symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>union</td>
<td>( U \cup V )</td>
</tr>
<tr>
<td>intersect</td>
<td>( U \cap V )</td>
</tr>
<tr>
<td>in</td>
<td>( U \in V )</td>
</tr>
<tr>
<td>notin</td>
<td>( U \notin V )</td>
</tr>
<tr>
<td>subset</td>
<td>( U \subseteq V )</td>
</tr>
<tr>
<td>notsubset</td>
<td>( U \nsubseteq V )</td>
</tr>
<tr>
<td>prsubset</td>
<td>( U \subset V )</td>
</tr>
<tr>
<td>notprsubset</td>
<td>( U \nsubset V )</td>
</tr>
<tr>
<td>setdiff</td>
<td>( U \setminus V )</td>
</tr>
</tbody>
</table>

These operators are applied as follows:

\[ U \cup V \]

The visual representation of `conjugate` is a horizontal bar with a width matching the width of the expression.

\[ \overline{x + y} \]
The \textit{arg}, \textit{real} and \textit{imaginary} elements trigger the following appearance.

\[
\text{arg}(x + iy) \\
\Re(x + iy) \\
i
\]

\section*{3.21 \textit{abs}, \textit{floor}, \textit{ceiling} ->}

There are a couple of functions that turn numbers into positive or rounded ones. In computer languages names are used, but in math we use special boundary characters.

\[|-5| = 5\]

\[
\begin{align*}
\text{abs}(-5) & = 5 \\
\text{floor}(5.5) & = 5 \\
\text{ceiling}(5.5) & = 6
\end{align*}
\]
An interval is visualized as: \([1,10]\). The \textit{interval} element is a container element and has a begin and end tag. You can specify the closure as attribute:

\[(a, b] \]

The following closures are supported:

<table>
<thead>
<tr>
<th>Closure</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>open</td>
<td>((a, b))</td>
</tr>
<tr>
<td>closed</td>
<td>([a, b])</td>
</tr>
<tr>
<td>open-closed</td>
<td>((a, b])</td>
</tr>
<tr>
<td>closed-open</td>
<td>([a, b))</td>
</tr>
</tbody>
</table>

In strict MathML we use symbols instead of attributes to define the openness:

\[(a, x)\]

\([a, x]\)

This operator is applied to a function. The following example demonstrates that this is one of the few cases (if not the only one) where the first element following an \textit{apply} begintag is an \textit{apply} itself.

\(\sin^{-1} x\)
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply>
    <apply> <inverse/> <sin/> </apply>
    <ci> x </ci>
  </apply>
</math>

<-- 3.24 reln ->

This element is a left-over from the first MathML specification and its usage is no longer advocated. Its current functionality matches the functionality of apply.

<-- 3.25 cartesianproduct, vectorproduct, scalarproduct, outerproduct ->

The context of the formula will often provide information of what kind of multiplication is meant, but using different symbols to represent the kind of product certainly helps.

\[ a \times b \]

We have:

<table>
<thead>
<tr>
<th>Format</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>cartesian</td>
<td>( a \times b )</td>
</tr>
<tr>
<td>vector</td>
<td>( a \times b )</td>
</tr>
<tr>
<td>scalar</td>
<td>( a \cdot b )</td>
</tr>
<tr>
<td>outer</td>
<td>( a \otimes b )</td>
</tr>
</tbody>
</table>

<-- 3.26 sum, product, limit, lowlimit, uplimit, bvar ->

Sums, products and limits have a distinctive look, especially when they have upper and lower limits attached. Unfortunately there is no way to specify the \( x_i \) in content MathML. In the next chapter we will see how we can handle that.

\[ \sum_{i=1}^{n} \frac{1}{x} \]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <sum/> 
    <bvar> <ci> i </ci> </bvar>
    <lowlimit> <cn> 1 </cn> </lowlimit>
  </apply>
</math>

Content markup
When we omit the limits, the bvar is still typeset.

\[ \prod_{i} \frac{1}{x} \]

You can specify the condition under which the function is applied.

\[ \prod_{x \in \mathbb{R}} f(x) \]

\[ \lim_{x \to 0} \sin x \]

Content markup
These elements reach a high level of abstraction. The best way to learn how to use them is to carefully study some examples.

The \( bvar \) element is essential, since it is used to automatically generate some of the components that make up the visual appearance of the formula. If you look at the formal specification of these elements, you will notice that the appearance may depend on your definition. How the formula shows up, depends not only on the \( bvar \) element, but also on the optional \( degree \) element within.
\[
\frac{d^2 f(x)}{dx^2}
\]

\[
\frac{d^4 f}{xdy^2}
\]

\[
\frac{d^k f(x,y)}{xdy^k}
\]
Content markup

\[ \frac{d^{m+n}f(x,y)}{x \, df(x,y)} \]

When a degree is not specified, it is deduced from the context, but since this is not 100% robust, you can best be complete in your specification.

These examples are taken from the MathML specification. In the example document that comes with this manual you can find a couple more.

\texttt{<- 3.28 fn ->}

There are a lot of predefined functions and operators. If you want to introduce a new one, the \texttt{fn} element can be used. In the following example we have turned the ± and \(\mp\) symbols into (coupled) operators.

\[(x \pm 1)(x \mp 1) = x^2 - 1\]
The typeset result depends on the presence of a handler, which in this case happens to be true.

\(-3.29\) \textit{matrix, matrixrow ->}

A matrix is one of the building blocks of linear algebra and therefore both presentational and content MathML have dedicated elements for defining it.

\[
\begin{pmatrix}
23 & 87 & c \\
41 & b & 33 \\
a & 65 & 16
\end{pmatrix}
\]

\(<\text{math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<matrix>}
\text{<matrixrow> <cn> 23 </cn> <cn> 87 </cn> <ci> c </ci> </matrixrow>}
\text{<matrixrow> <cn> 41 </cn> <ci> b </ci> <cn> 33 </cn> </matrixrow>}
\text{<matrixrow> <ci> a </ci> <cn> 65 </cn> <cn> 16 </cn> </matrixrow>}
\text{</matrix>}
\text{</math>}

\(-3.30\) \textit{vector ->}

We make a difference between a vector specification and a vector variable. A specification is presented as a list:

\[
(x, y)
\]

\(<\text{math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<vector>}
\text{<ci> x </ci>}
\text{<ci> y </ci>}
\text{</vector>}
\text{</math>}

When the vector element has one child element, we use a right arrow to identify the variable as vector.

\[
\vec{A} \times \vec{B}
\]
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <vectorproduct/> 
    <vector> <ci> A </ci> </vector> 
    <vector> <ci> B </ci> </vector> 
  </apply>
</math>

<- 3.31 grad, curl, ident, divergence ->

These elements expand into named functions, but we can imagine that in the future a more appropriate visualization will be provided as an option.

\[ \nabla A \neq \nabla \times B \neq \text{id} \neq \text{div} D \n\]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <neq/> 
    <apply> <grad/> <ci> A </ci> </apply> 
    <apply> <curl/> <ci> B </ci> </apply> 
    <apply> <ident/> <ci> C </ci> </apply> 
    <apply> <divergence/> <ci> D </ci> </apply> 
  </apply>
</math>

<- 3.32 lambda, bvar ->

The lambda specification of a function needs a \text{bvar} element. The visualization can be influenced with processing instructions as described in a later chapter.

\[ x \mapsto \sin \left( x - \frac{x^2}{2} \right) \n\]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <lambda> 
    <bvar> <ci> x </ci> </bvar> 
    <apply> <sin/> 
      <apply> <minus/> 
        <ci> x </ci> 
      </apply> 
      <apply> <divide/> 
        <ci> x </ci> 
        <cn> 2 </cn> 
      </apply> 
    </apply>
  </lambda>
</math>

Content markup
There are not so many elements that deal with combinations of formulas or conditions. The piecewise is the only real selector available. The following example defines how the state of \( n \) depends on the state of \( x \).

\[
\begin{align*}
n &= \begin{cases} 
-1 & x < 0 \\
1 & x > 0 \\
0 & \text{otherwise}
\end{cases}
\end{align*}
\]

We could have used a third piece instead of (optional) otherwise.

Conditions are often used in combination with elements like forall. There are several ways to convert and combine them in formulas and environments, so you may expect more alternatives in the future.

\[
\forall x \quad x < 9 \; \text{or} \; x < 10
\]
The next example is taken from the specifications with a few small changes.

\[ \forall x \in \mathbb{N} \mid \exists p, q \in \mathbb{P} \land p + q = 2x \]
The *factorof* element is applied to its two child elements and contrary to most functions, the symbol is placed between the elements instead of in front.

\[ a \mid b \]

\[ \text{<math xmlns="http://www.w3c.org/mathml" version="2.0">} \]
\[ \text{<apply>} \text{<factorof/>} \]
\[ \text{<ci>} a \text{</ci>} \]
\[ \text{<ci>} b \text{</ci>} \]
\[ \text{</apply>} \]
\[ \text{</math>} \]

The same is true for the *tendsto* element.

\[ a \rightarrow b \]

\[ \text{<math xmlns="http://www.w3c.org/mathml" version="2.0">} \]
\[ \text{<apply>} \text{<tendsto/>} \]
\[ \text{<ci>} a \text{</ci>} \]
\[ \text{<ci>} b \text{</ci>} \]
\[ \text{</apply>} \]
\[ \text{</math>} \]

This is a nasty element since it has to take care of braces in special ways and therefore has to analyse its child elements.

\[ (f \circ g \circ h) \]

\[ \text{<math xmlns="http://www.w3c.org/mathml" version="2.0">} \]
\[ \text{<apply>} \text{<compose/>} \]
\[ \text{<ci type="fn">} f \text{</ci>} \]
\[ \text{<ci type="fn">} g \text{</ci>} \]
\[ \text{<ci type="fn">} h \text{</ci>} \]
\[ \text{</apply>} \]
\[ \text{</math>} \]

\[ (f \circ g) \times \]

\[ \text{<math xmlns="http://www.w3c.org/mathml" version="2.0">} \]
\[ \text{<apply>} \text{<compose/>} \]
\[ \text{</apply>} \]
\[ \text{</math>} \]
A laplacian function is typeset using a $\nabla$ (nabla) symbol.

\[ \nabla^2 x \]

When statistics shows up in math textbooks, the sum element is likely to show up, probably in combination with the for statistics meaningful symbolic representation of variables. The mean value of a series of observations is defined as:

\[ \bar{x} = \frac{\sum x}{n} \]
Of course this definition is not that perfect, but we will present a better alternative in the chapter on combined markup. The definition of the standard deviation is more complicated:

$$\sigma(x) \approx \sqrt{\frac{\sum(x - \bar{x})^2}{n-1}}$$
The next example demonstrates the usage of the variance in its own definition.

\[ \sigma(x) = \frac{(x - \bar{x})^2}{n - 1} \approx \frac{1}{n - 1} \sum (x - \bar{x}) \]

<math xmlns="http://www.w3.org/mathml" version="2.0">
  <apply>
    <eq/>
    <apply>
      <variance/>
      <ci>x</ci>
    </apply>
    <apply>
      <approx/>
      <apply>
        <mean/>
        <apply>
          <power/>
          <apply>
            <minus/>
            <ci>x</ci>
            <apply>
              <mean/>
              <ci>x</ci>
            </apply>
          </apply>
          <cn>2</cn>
        </apply>
        <apply>
          <times/>
          <apply>
            <divide/>
            <cn>1</cn>
            <apply>
              <minus/>
              <ci>n</ci>
              <cn>1</cn>
            </apply>
          </apply>
          <apply>
            <sum/>
            <apply>
              <power/>
              <apply>
                <minus/>
                <ci>x</ci>
                <apply>
                  <mean/>
                  <ci>x</ci>
                </apply>
              </apply>
              <cn>2</cn>
            </apply>
          </apply>
        </apply>
      </apply>
    </apply>
  </apply>
</math>
The *median* and *mode* of a series of observations have no special symbols and are presented as is.

<-- 3.39  *moment, momentabout, degree* -->

Because MathML is used for a wide range of applications, there can be information in a definition that does not end up in print but is only used in some cases. This is illustrated in the next example.

\[ \langle X^3 \rangle \]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply>
    <moment/>
    <degree><cn>3</cn></degree>
    <momentabout><ci>p</ci></momentabout>
    <ci>X</ci>
  </apply>
</math>
```

<-- 3.40  *determinant, transpose* -->

These two (and the following) are used to manipulate matrices, either or not in a symbolic way. A simple determinant or transpose looks like:

\[ |A| \]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply>
    <determinant/><ci type="matrix"> A </ci>
  </apply>
</math>
```

\[ A^T \]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply>
    <transpose/><ci type="matrix"> A </ci>
  </apply>
</math>
```

When the *determinant* element is applied to a full blown matrix, the braces are omitted and replaced by the vertical bars.

\[ |I| = \begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix} = 1 \]

```xml
<math xmlns='http://www.w3c.org/mathml' version='2.0'>
  |I| = \begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix} = 1
</math>
```
The selector element can be used to index a matrix cell or variable. This element honors the braces.

\[
\begin{pmatrix}
1 & 2 \\
3 & 4
\end{pmatrix}
\]

A more common usage of the selector is the following:

\[x_i\]

It is possible to pass a comma separated list of indices:

\[x_{1,2}\]
If you want to have a more verbose index, you can use the `csymbol` element, flagged with text encoding.

\[ x_{\text{max}} \]

\[
\begin{math}
<\text{apply}>
<\text{selector}/>
<\text{ci} x</\text{ci}>
<\text{csymbol encoding="text"}>\text{max}</\text{csymbol}>
</\text{apply}>
</math>
\]

\[- 3.42 \text{ card } -\]

A cardinality is visualized using vertical bars.

\[ |A| = 5 \]

\[
<\text{apply}>
<\text{eq}/>
<\text{apply}>
<\text{eq}/>
<\text{apply}>
<\text{csymbol encoding="text"}>
</\text{apply}>
</math>
\]

\[- 3.43 \text{ domain, codomain, image } -\]

The next couple of examples are taken from the MathML specification and demonstrate the usage of the not that spectacular domain related elements.

\[ \text{domain} f = \mathbb{R} \]

\[
<\text{apply}>
<\text{eq}/>
<\text{domain}/>
<\text{fn} f</\text{fn}>
</\text{apply}>
</math>
\]

These are typically situations where the `fn` element may show up.

\[ \text{codomain} f = \mathbb{Q} \]

\[ Content \ markup \]
This example from the MATHML specification demonstrates a typical usage of the \textit{image} element. As with the previous two, it is applied to a function, in this case the predefined \textit{sin}.

\[
\text{image}(\text{sin}) = [-1, 1]
\]

This is another seldom used element. Actually, this element is a further specification of the outer level applied function.

\[
\int_{C} f
\]

We will never know what Albert Einstein would have thought about MATHML. But we do know for sure that coding one of his famous findings in XML takes much more tokens that it takes in \LaTeX.
Within a `semantics` element there can be many `annotation` elements. When using CONTeXt, the elements that can be identified as being encoded in TEX will be treated as such. Currently, the related `annotation-xml` element is ignored.

\[ e = mc^2 \]

Another variant that we support is called ‘calcmath’ which is an efficient way to enter school math. The syntax resembles the one used in advanced calculators.

\[ x = \sqrt{\sin(x) + \cos(c)} \]

Sets of numbers are characterized with special (often blackboard) symbols. These symbols are not always available.

<table>
<thead>
<tr>
<th>Set</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>integers</td>
<td>( \mathbb{Z} )</td>
</tr>
<tr>
<td>reals</td>
<td>( \mathbb{R} )</td>
</tr>
<tr>
<td>rationals</td>
<td>( \mathbb{Q} )</td>
</tr>
<tr>
<td>natural numbers</td>
<td>( \mathbb{N} )</td>
</tr>
</tbody>
</table>
complexes \( \mathbb{C} \)
primes \( \mathbb{P} \)

\(<- 3.47 \) **π, imaginaryi, exponentiale ->**

Being a greek character, \( \pi \) is a distinctive character. In most math documents the imaginary \( i \) and exponential \( e \) are typeset as any math identifier.

\[
\text{π} \quad \text{i} \quad \text{e}
\]

\(<- 3.48 \) **eulergamma, infinity, emptyset ->**

There are a couple of more special tokens. As with the other ones, they can be changed by reassigning the corresponding entities.

\[
\text{𝛾} \quad \infty \quad ?
\]

\(<- 3.49 \) **notanumber ->**

Because MathML is used for more purposes than typesetting, there are a couple of elements that do not make much sense in print. One of these is *notanumber*, which is issued by programs as error code or string.

\[
\frac{x}{0} = \text{NaN}
\]

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <eq/> 
    <apply> <divide/> 
      <ci> x </ci> 
      <cn> 0 </cn> 
    </apply> 
    <notanumber/> 
  </apply>
</math>

\(<- 3.50 \) **true, false ->**

When assigning to a boolean variable, or in boolean expressions one can use 0 or 1 to identify the states, but if you want to be more verbose, you can use these elements.

Content markup
$l_2 \equiv \text{true}$

\[
\text{<math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<apply> <equivalent/>}
\text{ <cn type="integer" base="2"> 1 </cn>}
\text{ <true/>}
\text{ </apply>}
\text{ </math>}
\]

\text{<- 3.51 declare ->}

Reusing definitions would be a nice feature, but for the moment the formal specification of this element does not give us the freedom to use it the way we want.

\[
\text{declare } A \text{ as } (a, b, c)
\]

\[
\text{<math xmlns="http://www.w3c.org/mathml" version="2.0">}
\text{<declare>}
\text{ <ci> A </ci>}
\text{ <vector>}
\text{ <ci> a </ci>}
\text{ <ci> b </ci>}
\text{ <ci> c </ci>}
\text{ </vector>}
\text{ </declare>}
\text{ </math>}
\]

\text{<- 3.52 csymbol ->}

This element will be implemented as soon as we have an application for it.
The advantage of presentational markup is that you can build complicated formulas using super- and subscripts and other elements. The drawback is that the look and feel is rather fixed and cannot easily be adapted to the purpose that the document serves. Take for instance the difference between

\[ \log_2 x \]

and

\[ 2^{\log x} \]

Both formulas were defined in content MathML, so no explicit super- and subscripts were used. In the next chapter we will see how to achieve such different appearances.

There are situations where content MathML is not rich enough to achieve the desired output. This omission in content MathML forces us to fall back on presentational markup.

\[ P_1 = P_2 = 1.01 \approx 1 \]

Here we used presentational elements inside a content \texttt{ci} element. We could have omitted the outer \texttt{ci} element, but since the content MathML parser may base its decisions on the content elements it finds, it is best to keep the outer element there.

\[
\begin{equation}
\begin{array}{c}
\text{def}
\end{array}
\end{equation}
\]

The lack of an index element can be quite prominent. For instance, when in an expose about rendering we want to explore the mapping from coordinates in user space to those in device space, we use the following formula.

\[
(D_x, D_y, 1) = (U_x, U_y, 1) \begin{pmatrix}
    s_x & r_x & 0 \\
    r_y & s_y & 0 \\
    t_x & t_y & 1
\end{pmatrix}
\]

\[
(\text{def})
\]
\[
\begin{pmatrix}
\frac{1}{n} \sum x
\end{pmatrix}
\]
Mixed markup

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i
\]
You can also use a selector for indexing, so in practice we can avoid the mixed mode:

\[
(D_x, D_y, 1) \begin{pmatrix} s_x & r_x & 0 \\ s_y & r_y & 0 \\ t_x & t_y & 1 \end{pmatrix}
\]
Directives

Some elements can be tuned by changing their attributes. Especially when formulas are defined by a team of people or when they are taken from a repository, there is a good chance that inconsistencies will show up.

In ConTeXt, you can influence the appearance by setting the typesetting parameters of (classes of) elements. You can do this either by adding processing instructions, or by using the ConTeXt command `\setupMMLappearance`. Although the first method is more in the spirit of XML, the second method is more efficient and consistent. As a processing instruction, a directive looks like:

```xml
<?context-mathml-directive element key value ?>
```

This is equivalent to the ConTeXt command:

```
\setupMMLappearance [element] [key=value]
```

Some settings concern a group of elements, in which case a group classification (like `sign`) is used.

### 5.1 scripts

By default, nested super- and subscripts are kind of isolated from each other. If you want a combined script, there is the `msubsup`. You can however force combinations with a directive.

\[
\chi_i^2
\]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <msup>
    <msub> <mi> x </mi> <mn> 1 </mn> </msub>
    <mn> 2 </mn>
  </msup>
</math>
```

```xml
<?context-mathml-directive scripts alternative b ?>
```

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <msup>
    <msub> <mi> x </mi> <mn> 1 </mn> </msub>
    <mn> 2 </mn>
  </msup>
</math>
```
The core element of MATHML is apply. Even simple formulas will often have more than one (nested) apply. The most robust way to handle nested formulas is to use braces around each sub formula. No matter how robust this is, when presented in print we want to use as less braces as possible. The next example shows addition as well as subtraction.

\[ 7 + 5 - 3 \]

\[
\begin{math}
\begin{align*}
\text{7} & \plus \text{5} \minus \text{3} \\
\end{align*}
\end{math}
\]

In principle subtraction is adding negated numbers, so it would have been natural to have just an addition (plus) and negation operator. However, MATHML provides both a plus and minus operator, where the latter can be used as a negation. So in fact we have:

\[ 7 + 5 + (\neg 3) \]

Now imagine that a teacher wants to stress this negation in the way presented here, using parentheses. Since all the examples shown here are typeset directly from the MATHML source, you may expect a solution, so here it is:

\[
\begin{math}
\begin{align*}
\text{7} & \plus \text{5} \plus \neg \text{3} \\
\end{align*}
\end{math}
\]

By default signs are reduced, but one can disable that at the document and/or formula level using a processing instruction at the top of the formula. There are of course circumstances where the parentheses cannot be left out.

\[ a + (b + c) + d \]

\[
\begin{math}
\begin{align*}
a & \plus (b \plus c) \plus d \\
\end{align*}
\end{math}
\]
Another place where parentheses are not needed is the following:

\[-e^3\]

This means that the interpreter of this kind of MathML has to analyze child elements in order to choose the right way to typeset the formula. The output will look like:
By default, as less braces as possible are used. As demonstrated, a special case is when *plus* and *minus* have one sub element to deal with. If you really want many braces there, you can turn off sign reduction.

<table>
<thead>
<tr>
<th>sign reduction</th>
<th>use as less braces as possible</th>
<th>no</th>
<th>always use braces</th>
</tr>
</thead>
</table>

We will demonstrate these alternatives with an example.

\[ a + \sin b + c^5 + \sin^2 d + e \]

We need quite some code to encode this formula.

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <plus/>
    <ci> a </ci>
    <apply> <sin/>
      <ci> b </ci>
    </apply>
    <apply> <power/>
      <ci> c </ci>
      <cn> 5 </cn>
    </apply>
    <apply> <power/>
      <apply> <sin/>
        <ci> d </ci>
      </apply>
      <cn> 2 </cn>
    </apply>
    <ci> e </ci>
  </apply>
</math>
```

With power reduction turned off, we get:

\[ a + \sin b + c^5 + (\sin d) + e \]

As directive we used:

```xml
<?context-mathml-directive power reduction no ?>
```

The following example illustrates that we should be careful in coding such formulas; here the *power* is applied to the argument of *sin*.

\[ a + \sin b + c^5 + \sin(d^2) + e \]

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <plus/>
    <ci> a </ci>
    <apply> <sin/>
      <ci> d </ci>
    </apply>
  </apply>
</math>
```

**Directives**
Divisions can be very space consuming but there is a way out: using a forward slash symbol. You can set the level at which this will take place. By default, fractions are typeset in the traditional way.

\[ \frac{1}{1 + \frac{1}{x}} \]

\[ \frac{1}{1 + \frac{1}{1 + \frac{1}{x}}} \]
1 \over 1 + 1/x

1 \over 1 + 1/(1 + 1/x)

\(1 \over 1 + 1/x\)

\(1 + 1/x\)

\(1 + 1/(1 + 1/x)\)

5.4 relation

You should keep in mind that (at least level 2) content MathML is not that rich in terms of presenting your ideas in a visually attractive way. On the other hand, because the content is highly structured, some intelligence can be applied when typesetting them. By default, a relation is not vertically aligned but typeset horizontally.

If an application just needs raw formulas, definitions like the following are all right.

```xml
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <eq/>
    <apply> <plus/>
      <ci> a </ci>
      <ci> b </ci>
      <ci> c </ci>
    </apply>
    <apply> <plus/>
      <ci> d </ci>
      <ci> e </ci>
    </apply>
  </apply>
</math>
```
The typeset result will bring no surprises:

\[ a + b + c = d + e = f + g + h + i = 123 \]

But, do we want to show a formula that way? And what happens with much longer formulas? You can influence the appearance with processing instructions.

<table>
<thead>
<tr>
<th>relation</th>
<th>align no</th>
<th>don't align relations</th>
</tr>
</thead>
<tbody>
<tr>
<td>left</td>
<td>align all relations left</td>
<td></td>
</tr>
<tr>
<td>right</td>
<td>align all relations right</td>
<td></td>
</tr>
<tr>
<td>first</td>
<td>place the leftmost relation left</td>
<td></td>
</tr>
<tr>
<td>last</td>
<td>place the rightmost relation right</td>
<td></td>
</tr>
</tbody>
</table>

The next couple of formulas demonstrate in what way the previously defined formula is influenced by the processing instructions.

\[
\begin{align*}
  a + b + c &= \\
  d + e &= \\
  f + g + h + i &= 123
\end{align*}
\]

<?context-mathml-directive relation align left ?>

\[
\begin{align*}
  a + b + c &= \\
  &= d + e \\
  &= f + g + h + i \\
  &= 123
\end{align*}
\]

<?context-mathml-directive relation align right ?>

\[
\begin{align*}
  a + b + c &= d + e \\
  &= f + g + h + i \\
  &= 123
\end{align*}
\]

<?context-mathml-directive relation align first ?>

\[
\begin{align*}
  a + b + c &= \\
  d + e &= \\
  f + g + h + i &= 123
\end{align*}
\]

Directives
When in a document several number systems are used, it can make sense to mention the base of the number. There are several ways to identify the base.

<table>
<thead>
<tr>
<th>base symbol</th>
<th>numbers</th>
<th>a (decimal) number</th>
</tr>
</thead>
<tbody>
<tr>
<td>characters</td>
<td>one character</td>
<td></td>
</tr>
<tr>
<td>text</td>
<td>a mnemonic</td>
<td></td>
</tr>
<tr>
<td>no</td>
<td>no symbol</td>
<td></td>
</tr>
</tbody>
</table>

By default, when specified, a base is identified as number.

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <cn type="integer" base="8"> 1427 </cn>
</math>

There is a whole bunch of functions available as empty element, like \( \sin \) and \( \log \). When a function is applied to a function, braces make not much sense and placement is therefore disabled.

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <sin/> <ci> x </ci> </apply>
</math>

\( \sin x \)
<-- 5.7 limits -->

When limits are placed on top of the limitation symbol, this generally looks better than when they are placed alongside. You can also influence limit placement per element. This feature is available for \textit{int}, \textit{sum}, \textit{product} and \textit{limit}.

<table>
<thead>
<tr>
<th>limit location</th>
<th>top</th>
<th>place limits on top of the symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>right</td>
<td></td>
<td>attached limits as super/subscripts</td>
</tr>
</tbody>
</table>

\[
\int_{0}^{1} dx
\]

<?context-mathml-directive int location top ?>

\[
\int_{0}^{1} dx
\]

<?context-mathml-directive int location right ?>

<-- 5.8 declare -->

Currently declarations are not supposed to end up in print. By default we typeset a message, but you can as well completely hide declarations.

<table>
<thead>
<tr>
<th>declare state</th>
<th>start</th>
<th>show declarations</th>
</tr>
</thead>
<tbody>
<tr>
<td>stop</td>
<td></td>
<td>ignore (hide) declarations</td>
</tr>
</tbody>
</table>

<-- 5.9 lambda -->

There is more than one way to visualize a lambda function. As with some other settings, changing the appearance can best take place at the document level.

<table>
<thead>
<tr>
<th>lambda alternative</th>
<th>b</th>
<th>show lambda as arrow</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td></td>
<td>show lambda as set</td>
</tr>
</tbody>
</table>

\[
\lambda x \rightarrow \text{function}(x)
\]

<?context-mathml-directive lambda alternative b ?>

\[
\lambda x \rightarrow \text{function}(x)
\]

<?context-mathml-directive lambda alternative a ?>

\[
\lambda x \rightarrow \text{function}(x)
\]

\textit{Directives}
Taking the power of a function looks clumsy when braces are put around the function. Therefore, by default, the power is applied to the function symbol instead of the whole function.

<table>
<thead>
<tr>
<th>power reduction</th>
<th>yes</th>
<th>attach symbol to function symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>no</td>
<td>attach symbol to function argument</td>
</tr>
</tbody>
</table>

\[ \ln^3 x \]

Covering all kind of differential formulas is not trivial. Currently we support two locations for the operand (function). By default the operand is placed above the division line.

<table>
<thead>
<tr>
<th>diff location</th>
<th>top</th>
<th>put the operand in the fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>right</td>
<td>put the operand after the fraction</td>
</tr>
</tbody>
</table>

\[ \text{Directives} \]
Depending on the complication of a vector or on the available space, you may wish to typeset a vector horizontally or vertically. By default a vector is typeset horizontally.

---

\[
\frac{d^2f(2x+1)}{dx^2}
\]

\[
\frac{d^2}{dx^2}(f(2x+1))
\]

---

### 5.12 vector →

A vector is a sequence of elements that are typically used to represent quantities with both magnitude and direction. Vectors can be represented in both horizontal and vertical formats.

<table>
<thead>
<tr>
<th>vector direction</th>
<th>horizontal</th>
<th>vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>put vector elements alongside</td>
<td>stack vector elements</td>
</tr>
</tbody>
</table>

---

\[
\begin{align*}
\langle x, y, z \rangle &= \begin{pmatrix} 1 \\ 0 \\ 1 \end{pmatrix} \\
\end{align*}
\]
(x, y, z) = (1, 0, 1)

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply>
    <plus/>
    <ci>x</ci>
    <apply>
      <times/>
      <cn>2</cn>
      <ci>x</ci>
    </apply>
  </apply>
</math>

x + 2x

<math>
  \text{x + 2x}
</math>

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply>
    <times/>
    <ci>x</ci>
    <ci>x</ci>
  </apply>
</math>

x + 2\times x

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply>
    <times/>
    <ci>x</ci>
    <ci>x</ci>
  </apply>
</math>

x + 2\cdot x

The location of a logbase depends on tradition and/or preference, which is why we offer a few alternatives: as pre superscript (in the right top corner before the symbol) or as post subscript (in the lower left corner after the symbol).
log \_location \_right place logbase at the right top

log \_base at the right top

log \_location \_left place logbase at the lower left

<math xmlns="http://www.w3c.org/mathml" version="2.0">
<apply>
  <log/>
  <logbase>
    <ci> 3 </ci>
  </logbase>
  <apply>
    <plus/>
    <ci> x </ci>
    <cn> 1 </cn>
  </apply>
</apply>
</math>

\[
\log_3 (x + 1)
\]

<?context-mathml-directive log location right ?>

\[
3 \log (x + 1)
\]

<?context-mathml-directive log location left ?>

<- 5.15 polar ->

For polar notation we provide several renderings:

polar alternative a explicit polar notation

b exponential power notation
c exponential function notation

<math xmlns="http://www.w3c.org/mathml" version="2.0">
<cn type="polar"> 2 <sep/> <pi/> </cn>
</math>

\[
Polar (2, \pi)
\]

<?context-mathml-directive polar alternative a ?>

\[
e^{+i}
\]

<?context-mathml-directive polar alternative b ?>

\[
\exp (+i)
\]

<?context-mathml-directive polar alternative c ?>

<- 5.16 e-notation ->

Depending on the context, you may want to typeset the number 1.23e4 not as this sequence, but using a multiplier construct. As with the \textit{times}, we support both multiplication symbols.

\textit{Directives}
<table>
<thead>
<tr>
<th>enotation symbol</th>
<th>no</th>
<th>no interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>split exponent, using ( \times )</td>
<td></td>
</tr>
<tr>
<td>dot</td>
<td>split exponent, using ( \cdot )</td>
<td></td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\text{\(10^{-23}\)} & \quad \text{\(\text{enotation symbol no}\)} \\
\text{\(e \times 10\)} & \quad \text{\(\text{enotation symbol yes}\)} \\
\text{\(e \cdot 10\)} & \quad \text{\(\text{enotation symbol dot}\)}
\end{align*}
\]
Math can be typeset inline or display. In order not to widen up the text of a paragraph too much, inline math is typeset more cramped. Since MATHML does provide just a general purpose math element we have to provide the information needed using other elements. Consider the following text.

To what extent is math supposed to reflect the truth and nothing but the truth? Consider the simple expression $10 = 3 + 7$. Many readers will consider this the truth, but then, can we assume that the decimal notation is used?

$$10 = 3 + x$$

In many elementary math books, you can find expressions like the previous. Because in our daily life we use the decimal numbering system, we can safely assume that $x = 7$. But, without explicitly mentioning this boundary condition, more solutions are correct.

$$10 = 3 + 5$$ \hfill (1.a)

In formula 1.a we see an at first sight wrong formula. But, if we tell you that octal numbers are used, your opinion may change instantly. A rather clean way out of this confusion is to extend the notation of numbers by explicitly mentioning the base.

$$10_8 = 3_8 + 5_8$$ \hfill (2.b)

Of course, when a whole document is in octal notation, a proper introduction is better than annotated numbers as used in formula 2.a.

In terms of XML this can look like:

```xml
<document>
To what extent is math supposed to reflect the truth and nothing but the truth? Consider the simple expression

<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <eq/> 
  <cn> 10 </cn>
  <apply> <plus/> 
  <cn> 3 </cn>
  <cn> 7 </cn>
  </apply>
</apply>
</math>. Many readers will consider this the truth, but then, can we assume that the decimal notation is used?
</document>
```

```xml
<formula>
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <!-- Octal notation -->
</math>
</formula>
```
In many elementary math books, you can find expressions like the previous. Because in our daily life we use the decimal numbering system, we can safely assume that

$$x = 7$$

But, without explicitly mentioning this boundary condition, more solutions are correct.

In the formula we see an at first sight wrong formula. But, if we tell you that octal numbers are used, your opinion may change instantly. A rather clean way out of this confusion is to extend the notation of numbers by explicitly mentioning the base.

$$10 + 3 + 5$$
Of course, when a whole document is in octal notation, a proper introduction is better than annotated numbers as used in <textref label="octal base">formula</textref>.

Math that is part of the text flow is automatically handled as inline math. If needed you can encapsulate the code in an imath environment. Display math is recognized as such when it is a separate paragraph, but since this is more a \TeX feature than an XML one, you should encapsulate display math either in a dmath element or in a formula or subformula element.

For a while you can use attribute mode with values display or inline. Recent MathML specifications provide the display attribute with values block or inline. We support both.
Typesetting modes
Getting started

A comfortable way to get accustomed to MATHML is to make small documents of the following form:

\usemodule[mathml]
\starttext
\startbuffer
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <cos/>  
    <ci> x </ci>
  </apply>
</math>
\stopbuffer
\processxmlbuffer
\stoptext

As you see, we can mix MATHML with normal \TeX code. A document like this is processed in the normal way using the context command. If you also want to see the original code, you can say:

\usemodule[mathml]
\starttext
\startbuffer
<math xmlns="http://www.w3c.org/mathml" version="2.0">
  <apply> <cos/>  
    <ci> x </ci>
  </apply>
</math>
\stopbuffer
\processxmlbuffer
\typebuffer
\stoptext

Like \TeX and METAPOST code, buffers can contain MATHML code. The advantage of this method is that we only have to key in the data once. It also permits you to experiment with processing instructions.
If you like coding your documents in \TeX but want to experiment with MathML, combining both languages in the way demonstrated here may be an option. When you provide enough structure in your \TeX code, converting a document to xml is then not that hard to do. Where coding directly in xml is kind of annoying, coding MathML is less cumbersome, because you can structure your formulas pretty well, especially since the fragments are small so that proper indentation is possible.
Support for bidirectional math is not entirely trivial as it demands a font that supports it. When they were released, the stix fonts were not that useable and Khaled Hosny turned them into the xits fonts that are now quite complete and useable in an OpenType and Unicode environment. He also added support for right to left math.

Normally you will only use that in a right to left typeset document, in which case you have a setup like this:

```latex
\setuptobodyfont [xitsbidi]
\setupalign [r2l]
\setupmathematics [align=r2l]
\starttext
Some text.
\startformula \sqrt{^2\over 4} \stopformula
Some more text
\stoptext
```

As MathML has no global settings you need to control it specifically. At some point we might decide to provide some global flags but that depends on how the general bidi layout machinery evolves. Here we just stick to an example:

```xml
<math xmlns="http://www.w3.org/1998/Math/MathML" dir="rtl">
  <msqrt>
    <mfrac>
      <msup><mi></mi><mn>2</mn></sup>
      <mrow><mn>4</mn><mi></mi></mrow>
    </mfrac>
  </msqrt>
</math>
```

The order of input is still rather left to right which makes sense as we’re sort of structuring the math input.
Because OpenMath is now a subset of MathML we can to some extend also support this coding. We do a straightforward remapping to content MathML so any rendering that is supported there is also supported in the equivalent OpenMath code.

\[ y = f(x) - f(x-1) \]

Because in practice we may use a mixture of math encodings this can come in handy because it saves conversion of the XML source.
We support two types of annotation markup: \( \text{T}_{\text{E}}\!\!\!\!\!\!\!\!\!\text{X} \) (\text{tex}) and what we call 'calculator math' (\text{calcmath}). The second type is also available directly. Inline calcmath is coded using the \text{icm} element.

This is an inline formula \( \sin(x^2 + \frac{1}{x}) \) just to demonstrate the idea of calculator math.

\begin{document}
    This is an inline formula \text{icm}\sin(x^2+1/x)\text{icm} just to demonstrate the idea of calculator math.
\end{document}

If one edits the \text{XML} file directly this can type quite some coding. For more complex formulas one can revert to content \text{MATHML}, or when interactivity is needed to \text{OPENMATH}.

The argument that one should use a dedicated editor for math instead is not that convincing for authors who have to key on lots of small snippets of math. And one can always transform this code in its more bloated variant. The calcmath converter is dedicated to Frits Spijkers, author of Dutch math schoolbooks and fluent in all those math encodings methods we force upon him. The code resembles that used in the calculators at schools and we used it in projects with computer aided feedback where students had to key in math. When there is demand for this input method we will provide more details.
A few years back we included some basic support for AsciiMath as a proof of concept not knowing that one day we were forced to fully support it in a project. In one of our projects ConTExt is the backend for generating math books for high school math. Input is XML and math is coded in presentational MathML. We should say “was coded”, because in the Spring of 2014 another party in the project (the one responsible for the web part) converted the MathML into AsciiMath on behalf of their web authoring tool.

Where we would have chosen to use the MathML annotation attribute, they had chosen to flatten the structured MathML into less structured AsciiMath. And there was no way back. We're talking of tens of thousands of files here.¹

On the web AsciiMath is mostly interpreted by MathJax’s JavaScript in combination with CSS. Since we didn’t want to depend on a JavaScript conversion in ConTExt we started to completely rewrite our AsciiMath module. We also needed a bit more control in order to meet specific demands of the publisher, like formatting numbers, support for characters not in the normal repertoire, checking and tracing, and the speed of rendering had not to be affected.

If you invoke the AsciiMath module with \usemodule[asciimath] the command \asciimath{...} is available for testing purposes. Within the curly brackets you can type an AsciiMath expression.

Normally an AsciiMath expression in XML/HTML is enclosed by back-quotes:

```
x^2
```

But we rather stick to the XML like coding:

```am
x^2</am>
```

This is equivalent to the TeX command:

\[ x^2 \]

The interpretation of such a formula is no problem. But let’s give a few examples where AsciiMath lacks structure or needs a (sometimes bizar) interpretation to obtain adequate rendering:

Behaviour of superscripts and subscripts depends on operator that precedes a number or variable:

- `\sin^-1(x)` → \( \sin^{-1}(x) \)
- `\sin^+1(x)` → \( \sin^{+1}(x) \)
- `\int_a^b f(x)` → \( \int_a^b f(x) \)
- `\int_a^aa f(x)` → \( \int_a^a f(x) \)
- `\int_1000^2000 f(x)` → \( \int_{1000}^{2000} f(x) \)

A script can be either one character or a number made from more characters:

- `\int_a^b f(x)` → \( \int_a^b f(x) \)
- `\int_a^aa^bb f(x)` → \( \int_a^a a^bb f(x) \)
- `\int_1000^2000 f(x)` → \( \int_{1000}^{2000} f(x) \)

Behaviour of operator depends on character, where some characters have special meaning:

¹ Around the same time Google decided to drop native MathML support from Chrome so one might wonder why MathML was developed in the first place.
Behaviour of the curly brackets is somewhat peculiar because at times they are not used for grouping anymore:

\[
\begin{align*}
\{a/b\}/\{d/c\} & \quad \frac{a}{b} \div \frac{d}{c} \\
\{a/b\}/\{d/c\} & \quad \frac{\{a\}}{\{d\}} \div \{\{\}}
\end{align*}
\]

Behaviour depends on sequence of scripts (solved in ConTEXt):

\[
\begin{align*}
\text{int}_0^1 f(x)dx & \quad \int_0^1 f(x) dx \\
\text{int}^0_1 f(x)dx & \quad \int^1_0 f(x) dx \\
\sqrt{-3ax} & \quad \sqrt{-3ax} \\
n\sqrt{(-3ax)} & \quad \sqrt{-3ax} \\
\sqrt[3]{ax} & \quad \sqrt[3]{ax} \\
x^2+y_1+z_{12}^3 & \quad x^2 + y_1 + z_{12}^3 \\
\sin^{-1}(x) & \quad \sin^{-1}(x) \\
d/dx f(x)=\lim_{h->0} (f(x+h)-f(x))/h & \quad \frac{d}{dx} f(x) = \lim_{h \to 0} \frac{f(x+h)-f(x)}{h} \\
f(x)=\sum_{n=0}^{\infty} f^n((n))(a)/(n!)(x-a)^n & \quad f(x) = \sum_{n=0}^{\infty} \frac{f^n(a)}{n!} (x-a)^n \\
\text{int}_0^1 f(x)dx & \quad \int_0^1 f(x) dx \\
\text{int}^1_0 f(x)dx & \quad \int^1_0 f(x) dx \\
a//b & \quad a/b \\
a//\alpha & \quad a/\alpha \\
(a/b)/(d/c) & \quad \frac{a/b}{d/c} \\
((a*b))/(d/c) & \quad \frac{(a*b)}{d/c} \\
(a/b)/(c/d) & \quad \{(a)/(bd)\}/\{(bc)/(bd)\} = (a)/(bc) = (ad)/(bc)
\end{align*}
\]
\[ \frac{a}{c} \div \frac{b}{d} = \frac{ad}{bc} \]

\[ \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{pmatrix} n \\ k \end{pmatrix} \]

\[ \frac{1}{x} = \begin{cases} 1 & \text{if } x \neq 0 \\ \text{undefined} & \text{if } x = 0 \end{cases} \]

\[ \langle a, b \rangle \quad \text{and} \quad \langle x, y, u, v \rangle \]

\[ \langle larr; 0,4 \rangle \quad \langle ; 0,4 \rangle \quad \langle 0, rarr; \rangle \]

\[ \frac{5}{|CD|} = \frac{8}{5} \]

\[ \frac{|MD|}{|CD|} = \frac{|AD|}{|MD|} \]

\[ x \lt 4 \lor x \gt 1 \]

\[ \lim_{x \to \infty} \frac{1}{x} = 0 \]

\[ D_{f} \]

\[ p \perp q \]

\[ g \cdots \text{stackrel}(\text{n times}) \cdots g \]

\[ \text{stackrel(+)}(\rightarrow ) \quad \rightarrow \]

\[ \text{stackrel(+)}(\rightarrow ) \quad \rightarrow \]

\[ ((a_{(11)}, \cdots, a_{(1n)}), (vdots, ddots, vdots), (a_{(m1)}, \cdots, a_{(mn)})) \]

Unfortunately AsciiMath can be unpredictable which is a side effect of the fact that a high degree of tolerance is built in. We strongly advice to use spaces to make your results predictable.
One of the properties is that \TeX{} commands are supported, that is, with a few exceptions: P and S

don't produce \¶ and §. Also, don't confuse these symbols with the entities supported by MathML: in
\texttt{AsciiMath} \texttt{circ} is circle and not a circumflex. Also, \&lt; and \&gt; are converted into < and >
while \& becomes \&\textsuperscript{a}. As usual with input formats that start out simple, in the end they become so complex that
one can wonder why to use them. It is the usual problem of using one system for everything.

The following examples are similar to the once shown elsewhere in this document.

<derivatives ?>

\[(da)/(dx) = 0 \quad \frac{da}{dx} = 0\]

\[dx/dx = 0 \quad \frac{dx}{dx} = 0\]

\[(d(au))/(dx) = a (du)/(dx) \quad \frac{d(au)}{dx} = a \frac{du}{dx}\]

\[(d(u+v+w))/(dx) = (du)/(dx) + (dv)/(dx) + (dw)/(dx) \quad \frac{d(u+v+w)}{dx} = \frac{du}{dx} + \frac{dv}{dx} + \frac{dw}{dx}\]

\[(d(uv))/(dx) = u (dv)/(dx) + v (dv)/(dx) \quad \frac{d(uv)}{dx} = u \frac{dv}{dx} + v \frac{dv}{dx}\]

\[(d(uvw))/(dx) = vw(du)/(dx) + uw(dv)/(dx) + uv(dw)/(dx) \quad \frac{d(uvw)}{dx} = \frac{vw}{dx} \frac{du}{dx} + \frac{uw}{dx} \frac{dv}{dx} + \frac{uv}{dx} \frac{dw}{dx}\]

\[(d(u/v))/(dx) = (v(du)/(dx) - u(dv)/(dx) ) / (v^2) = 1/v (du)/(dx) - u/v^2 (dv)/(dx) \quad \frac{d(u/v)}{dx} = \frac{v \frac{du}{dx} - u \frac{dv}{dx}}{v^2} = \frac{1}{v} \frac{du}{dx} - \frac{u}{v^2} \frac{dv}{dx}\]

\[(d(u^n))/(dx) = n(u)^(n-1) (dv)/(dx) \quad \frac{d(u^n)}{dx} = n(u)^{n-1} \frac{dv}{dx}\]

\[(d \sqrt{u})/(dx) = 1/(2 \sqrt{u}) (du)/(dx) \quad \frac{d \sqrt{u}}{dx} = \frac{1}{2 \sqrt{u}} \frac{du}{dx}\]

\[(d(1/u))/(dx) = - 1/u^2 (du)/(dx) \quad \frac{d(1/u)}{dx} = - \frac{1}{u^2} \frac{du}{dx}\]

\[(d(1/(u^n)))/(dx) = - n/u^n (du)/(dx) \quad \frac{d(1/(u^n))}{dx} = - \frac{n}{u^n} \frac{du}{dx}\]

\[(d log (u + sqrt(u^2+1)))/(dx) = 1/(sqrt(u^2+1)) (du)/(dx) \quad \frac{d log (u + \sqrt{u^2+1})}{dx} = \frac{1}{\sqrt{u^2+1}} \frac{du}{dx}\]

<integral ?>

\[\int (1 / (x sqrt(a^2 + x^2))) dx = - 1/a log (a + sqrt(a^2 + x^2)) / x \quad \int \left( \frac{1}{x \sqrt{a^2 + x^2}} \right) dx = \]

\[- \frac{1}{a} log \left( \frac{a + \sqrt{a^2 + x^2}}{x} \right) \]

\texttt{AsciiMath}
\[
\int \left( \frac{1}{a + bx^2} \right) \log \left( a + x \sqrt{-ab} \right) / \log \left( a - x \sqrt{-ab} \right) = \int \left( \frac{1}{a + bx^2} \right) \log \left( a + x \frac{\sqrt{-ab}}{a} \right) / \log \left( a - x \frac{\sqrt{-ab}}{a} \right)
\]

\[
\int \frac{1}{\sqrt{-ab}} \tanh^{-1} \left( x \sqrt{-ab} \right) / a \]

\[
\int 1 \left( \frac{1}{\cos(ax) (1 \pm \sin(ax))} \right) dx = \left( \frac{1}{2a(1 \pm \sin(ax))} + \frac{1}{2a} \log \tan \left( \frac{\pi}{2} + \frac{ax}{2} \right) \right)
\]

\[
\sum_{n=1}^{\infty} \left( \frac{1}{2n-1} - \frac{1}{2n+1} \right) = \frac{\pi}{4}
\]

\[
\sum_{n=1}^{\infty} \left( \frac{1}{2n} \right)^2 + \frac{1}{3^2} + \frac{1}{4^2} + \cdots = \frac{\pi^2}{6}
\]

\[
\sum_{n=1}^{\infty} \left( \frac{1}{2n-1} \right)^2 - \frac{1}{2^2} + \frac{1}{3^2} - \frac{1}{4^2} + \cdots = \frac{\pi^2}{12}
\]

\[
\forall x \in \mathbb{R} \mid e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots + \frac{x^n}{n!}
\]

\[
\forall a > 0 \land b > 0 \mid \log_a a + \log_b b
\]

\[
\forall a > 0 \land b > 0 \mid \log_a a - \log_b b
\]

\[
\forall b \in \mathbb{R} \land a > 0 \mid b \log_a a
\]

\[
\forall a > 0 \mid a = \frac{\log_a a}{\log_a a}
\]

\[
\sin(x+y) = \sin x \cos y + \cos x \sin y
\]

\[
\sin(x-y) = \sin x \cos y - \cos x \sin y
\]

\[
\cos(x+y) = \cos x \cos y - \sin x \sin y
\]

\[
\cos(x-y) = \cos x \cos y + \sin x \sin y
\]

\[
\tan(x+y) = \frac{\tan x + \tan y}{1 - \tan x \tan y}
\]

\[
\tan(x-y) = \frac{\tan x - \tan y}{1 + \tan x \tan y}
\]

\[
\sin p + \sin q = 2 \sin \left( \frac{p+q}{2} \right) \cos \left( \frac{p-q}{2} \right)
\]

\[
\sin p - \sin q = 2 \cos \left( \frac{p+q}{2} \right) \sin \left( \frac{p-q}{2} \right)
\]

\[
\text{Asciimath}
\]
\[
cos p + \cos q = 2 \cos \frac{p+q}{2} \cos \frac{p-q}{2}
\]

\[
2 \cos \alpha \cos \beta = \cos(\alpha + \beta) + \cos(\alpha - \beta)
\]

\[
-2 \sin \alpha \cos \beta = \sin(\alpha + \beta) - \sin(\alpha - \beta)
\]

\[
\forall \Delta ABC \mid \frac{a}{\sin \alpha} + \frac{b}{\sin \beta} + \frac{c}{\sin \gamma}
\]

\[
\forall \Delta ABC \mid \begin{align*}
\begin{cases}
a^2 = b^2 + c^2 - 2bc \cos \alpha \\
b^2 = a^2 + c^2 - 2ac \cos \beta \\
c^2 = a^2 + b^2 - 2ab \cos \gamma
\end{cases}
\end{align*}
\]

\[\text{bar } x = \frac{1}{n} \sum x_i
\]

\[\sigma(x) \approx \sqrt{\frac{1}{n-1} \sum (x_i - \bar{x})^2}
\]

\[\sigma(x)^2 \approx \frac{1}{n-1} \sum (x_i - \bar{x})^2
\]

\[\text{[I]} = \begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix} = 1
\]
A few examples

<- 12.1 derivatives ->

derivate 12.1
\[ \frac{da}{dx} = 0 \]

\[
\text{<math xmlns='http://www.w3c.org/mathml' version='2.0'>}
\text{<apply> <eq/>}
\text{<apply> <diff/>}
\text{<bvar> <ci> x </ci> </bvar>}
\text{<ci> a </ci>}
\text{</apply>}
\text{<ci> 0 </ci>}
\text{</apply>}
\text{</math>}

derivate 12.2
\[ \frac{dx}{dx} = 1 \]

\[
\text{<math xmlns='http://www.w3c.org/mathml' version='2.0'>}
\text{<apply> <eq/>}
\text{<apply> <diff/>}
\text{<bvar> <ci> x </ci> </bvar>}
\text{<ci> x </ci>}
\text{</apply>}
\text{<cn> 1 </cn>}
\text{</apply>}
\text{</math>}

derivate 12.3
\[ \frac{d (au)}{dx} = a \frac{du}{dx} \]

\[
\text{<math xmlns='http://www.w3c.org/mathml' version='2.0'>}
\text{<apply> <eq/>}
\text{<apply> <diff/>}
\text{<bvar> <ci> x </ci> </bvar>}
\text{<apply> <times/>}
\text{<ci> a </ci>}
\text{<ci> u </ci>}
\text{</apply>}
\text{</apply>}
\text{<apply> <times/>}
\text{<ci> a </ci>}
\text{</apply>}
\text{</math>}

111
A few examples

**Derivate 12.4**
\[
\frac{d(u + v + w)}{dx} = \frac{du}{dx} + \frac{dv}{dx} + \frac{dw}{dx}
\]

**Derivate 12.5**
\[
\frac{d(uy)}{dx} = u\frac{dy}{dx} + v\frac{du}{dx}
\]
A few examples

\[ \frac{d(uvw)}{dx} = vw \frac{du}{dx} + uw \frac{dv}{dx} + uv \frac{dw}{dx} \]
A few examples

\[ \frac{d}{dx} \left( \frac{u}{v} \right) = \frac{\frac{d}{dx} u - \frac{d}{dx} v}{v^2} = \frac{1}{v^2} \left( \frac{du}{dx} - \frac{u}{v} \frac{dv}{dx} \right) \]
A few examples

\[
\frac{d}{dx} u^n = n(u) \frac{du}{dx}
\]

\[\text{Derivate 12.8}\]
A few examples

\[ \frac{d\sqrt{u}}{dx} = \frac{1}{2\sqrt{u}} \frac{du}{dx} \]
A few examples

**derivate 12.10**

\[ \frac{d \left( \frac{1}{u} \right)}{dx} = -\frac{1}{u^2} \frac{du}{dx} \]

**derivate 12.11**

\[ \frac{d \left( \frac{1}{u^n} \right)}{dx} = -\frac{n}{(u)^{n+1}} \frac{du}{dx} \]
A few examples

\[ \frac{d}{dx} \left( \frac{n}{u^{n+1}} \right) = \frac{d}{dx} \left( \frac{1}{u^{n+1}} \right) \]
A few examples

\[ \int \left( \frac{1}{x \sqrt{a^2 \pm x^2}} \right) \, dx = -\frac{1}{a} \log \frac{a + \sqrt{a^2 \pm x^2}}{x} \]
A few examples

\[
\int \left( \frac{1}{a + bx^2} \right) dx = \frac{1}{\sqrt{ab}} \log \frac{a + x\sqrt{-ab}}{a - x\sqrt{-ab}} \sqrt{\frac{1}{ab}} \tanh^{-1} \frac{x\sqrt{-ab}}{a}
\]
A few examples
A few examples
A few examples

\[
\int \frac{1}{\cos(ax)(1 \pm \sin(ax))} \, dx = \left( \frac{1}{2a(1 \pm \sin(ax))} \right) + \frac{1}{2a} \log \tan \left( \frac{\pi}{4} + \frac{ax}{2} \right)
\]
A few examples

\[
\sin(a \times x)\frac{1}{2a \times x} \log(\tan(\frac{\pi}{4} - \frac{1}{2a \times x} - \frac{1}{2c}))
\]

\[
1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \ldots = \frac{\pi}{4}
\]
A few examples:

\[ 1 + \frac{1}{2^2} + \frac{1}{3^2} + \frac{1}{4^2} + \cdots = \frac{\pi^2}{6} \]
A few examples

\[
1 - \frac{1}{2^2} + \frac{1}{3^2} - \frac{1}{4^2} + \cdots = \frac{\pi^2}{12}
\]
A few examples

\[ \forall x \in \mathbb{R} \mid e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots + \frac{x^n}{n!} + \ldots \]
A few examples
A few examples
<- 12.4 logs ->

log 12.1 \[ \forall a > 0 \land b > 0 \mid \log_{g} a b = \log_{g} a + \log_{g} b \]

A few examples
\[ \forall a > 0 \land b > 0 \mid \log_{g} \frac{a}{b} = \log_{g} a - \log_{g} b \]

<math xmlns='http://www.w3c.org/mathml' version='2.0'>
  <apply> <forall/>
    <condition>
      <apply> <and/>
        <apply> <gt/> <ci> a </ci> <cn> 0 </cn> 
        <apply> <gt/> <ci> b </ci> <cn> 0 </cn> 
      </apply>
    </condition>
    <apply> <eq/> 
      <apply> <log/> <logbase> <ci> g </ci> </logbase> 
        <apply> <divide/> <ci> a </ci> <ci> b </ci> 
      </apply>
      <apply> <minus/> 
        <apply> <log/> <logbase> <ci> g </ci> </logbase> <ci> a </ci> 
        <apply> <log/> <logbase> <ci> g </ci> </logbase> <ci> b </ci> 
      </apply>
    </apply>
  </apply>
</math>

\[ \forall b \in \mathbb{R} \land a > 0 \mid \log_{g} a^{b} = b \log_{g} a \]

<math xmlns='http://www.w3c.org/mathml' version='2.0'>
  <apply> <forall/> 
    <condition>
      <apply> <and/> 
        <apply> <in/> <ci> b </ci> <ci> \mathbb{R} </ci> 
        <apply> <gt/> <ci> a </ci> <cn> 0 </cn> 
      </apply>
    </condition>
    <apply> <eq/> 
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\textit{A few examples}
A few examples

\(|a > 0| \log_{g}a = \frac{\log_{p}a}{\log_{p}g}\)

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<- 12.5 goniometrics ->

gonio 12.1 \sin (x + y) = \sin x \cos y + \cos x \sin y

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A few examples
gonio 12.2
\[ \sin(x - y) = \sin x \cos y - \cos x \sin y \]

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gonio 12.3
\[ \cos(x + y) = \cos x \cos y - \sin x \sin y \]

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  </apply>
</math>

A few examples
A few examples

\[
\cos(x - y) = \cos x \cos y + \sin x \sin y
\]
A few examples

\[
\tan(x + y) = \frac{\tan x + \tan y}{1 - \tan x \tan y}
\]

\[
\tan(x - y) = \frac{\tan x - \tan y}{1 + \tan x \tan y}
\]
A few examples

\[
\begin{align*}
\sin p + \sin q &= 2 \sin \frac{p + q}{2} \cos \frac{p - q}{2}
\end{align*}
\]
A few examples

\[
\sin p - \sin q = 2\cos \frac{p + q}{2} \sin \frac{p - q}{2}
\]
A few examples

\[ \cos p + \cos q = 2 \cos \frac{p + q}{2} \cos \frac{p - q}{2} \]

\[ \cos p - \cos q = -2 \sin \frac{p + q}{2} \sin \frac{p - q}{2} \]
A few examples

\[2 \sin \alpha \cos \beta = \sin (\alpha + \beta) + \sin (\alpha - \beta)\]
A few examples

\[\sin (\alpha + \beta) - \sin (\alpha - \beta)\]
 gonio 12.13 

\[2 \cos \alpha \cos \beta = \cos (\alpha + \beta) + \cos (\alpha - \beta)\]

\[
\begin{align*}
&\text{2} \times \cos \alpha \times \cos \beta = \\
&\cos (\alpha + \beta) + \\
&\cos (\alpha - \beta)
\end{align*}
\]

 gonio 12.14 

\[-2 \sin \alpha \cos \beta = \sin (\alpha + \beta) - \sin (\alpha - \beta)\]

\[
\begin{align*}
&-\text{2} \times \sin \alpha \times \cos \beta = \\
&\sin (\alpha + \beta) - \\
&\sin (\alpha - \beta)
\end{align*}
\]

A few examples
A few examples
A few examples

∀ \bigtriangleup ABC
\begin{align*}
a^2 &= b^2 + c^2 - 2bc \cos \alpha \\
b^2 &= a^2 + c^2 - 2ac \cos \beta \\
c^2 &= a^2 + b^2 - 2ab \cos \gamma
\end{align*}
A few examples

\[
\begin{align*}
\text{apply} & \text{ eq/} \\
\text{apply} & \text{ power/} \\
\text{ci} & b \text{ ci} \\
\text{cn} & 2 \text{ cn} \\
\text{apply} & \text{ plus/} \\
\text{apply} & \text{ power/} \\
\text{ci} & a \text{ ci} \\
\text{cn} & 2 \text{ cn} \\
\text{apply} & \text{ power/} \\
\text{ci} & c \text{ ci} \\
\text{cn} & 2 \text{ cn} \\
\text{apply} & \text{ minus/} \\
\text{apply} & \text{ times/} \\
\text{cn} & 2 \text{ cn} \\
\text{ci} & a \text{ ci} \\
\text{ci} & c \text{ ci} \\
\text{apply} & \text{ cos/} \\
\text{ci} & \beta \text{ ci} \\
\end{align*}
\]
A few examples

\[ \cos(\gamma) \]

\[ \frac{1}{n} \sum x_i \]

\[ \sigma(x) \approx \sqrt{\frac{\sum (x_i - \bar{x}) n - 1}{n}} \]
A few examples

\[
\sigma(x) \approx \frac{1}{n-1} \sum (x_i - \bar{x})
\]

\[\sigma^2(x) \approx \frac{1}{n-1} \sum (x_i - \bar{x})^2\]
A few examples

\[ \sum \text{mean} \]

\[
\begin{vmatrix}
\sin \alpha & \cos \alpha \\
\sin \beta & \cos \beta
\end{vmatrix} = \sin (\alpha - \beta)
\]
matrix 12.2

\[ |I| = \begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix} = 1 \]

\[
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A few examples
A few examples
Support for MathML showed up in ConTeXt by the end of second millenium. The first more or less complete version of this manual dates from the end of 1999. At that time Unicode math was no fact yet and entities were the way to get special symbols done. Mapping the names of symbols onto something that could be rendered was up to the XML processors and typesetting engine.

Nowadays we can use Unicode directly although it has the drawback that not all editing applications show the corresponding shapes. It is for this reason that entities will have their use for a while. In the next table we see the official ones. The table is actually larger, but we only show the shapes that have a math property in the ConTeXt character database. The full list is supported and can be found in the following documents:

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Unicode Math
Unicode Math
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**Unicode Math**
A different way to look at this is Unicode itself. Here’s the list of characters that have a math related property in ConTeXt.
Unicode Math
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<th>Description</th>
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<td>binary</td>
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<tr>
<td>02057</td>
<td>(\cdots)</td>
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</table>
Unicode Math
Unicode Math

\[021F5 \uparrow \uparrow \text{ relation} \quad 02229 \cap \text{ binary}\]
\[021F6 \equiv \text{ relation} \quad 0222A \cup \text{ binary}\]
\[021F7 \rightarrow \text{ relation} \quad 0222B \setminus \text{ limop nothing}\]
\[021F8 \leftarrow \text{ relation} \quad 0222C \sslash \text{ limop nothing}\]
\[021F9 \leftrightarrow \text{ relation} \quad 0222D \smallsetminus \text{ limop nothing}\]
\[021FA \Rightarrow \text{ relation} \quad 0222E \frown \text{ limop}\]
\[021FB \Leftarrow \text{ relation} \quad 0222F \smallfrown \text{ limop}\]
\[021FC \leftrightarrow \text{ relation} \quad 02230 \smallsmile \text{ limop}\]
\[021FD \Leftrightarrow \text{ relation} \quad 02231 \smile \text{ limop}\]
\[021FE \Rightarrow \text{ relation} \quad 02232 \frown \text{ limop}\]
\[021FF \Leftarrow \text{ relation} \quad 02233 \smallfrown \text{ limop}\]
\[02200 \forall \text{ ordinary} \quad 02234 \vdots \text{ relation}\]
\[02201 \exists \text{ ordinary} \quad 02235 \ddots \text{ relation}\]
\[02202 \partial \text{ default} \quad 02236 \vdash \text{ punctuation}\]
\[02203 \exists \text{ ordinary} \quad 02237 \varnothing \text{ relation}\]
\[02204 \emptyset \text{ ordinary} \quad 02238 \vdash \text{ binary}\]
\[02205 \varnothing \text{ default} \quad 02239 \varnothing \text{ relation}\]
\[02206 \nabla \text{ default} \quad 0223C \smallsmile \text{ relation}\]
\[02207 \in \text{ relation} \quad 0223D \smile \text{ relation}\]
\[02208 \notin \text{ relation} \quad 02240 \smallfrown \text{ binary}\]
\[02209 \ni \text{ relation} \quad 02241 \frown \text{ relation}\]
\[0220A \exists \text{ relation} \quad 02242 \equiv \text{ relation}\]
\[0220B \Pi \text{ limop} \quad 02243 \equiv \text{ relation}\]
\[0220C \varnothing \text{ limop} \quad 02244 \varnothing \text{ relation}\]
\[0220D \sum \text{ limop} \quad 02245 \equiv \text{ relation}\]
\[0220E \cap \text{ binary relation} \quad 02246 \equiv \text{ relation}\]
\[0220F \cup \text{ binary} \quad 02247 \equiv \text{ relation}\]
\[02210 \div \text{ binary} \quad 02248 \equiv \text{ relation}\]
\[02211 \backslash \text{ binary} \quad 02249 \equiv \text{ relation}\]
\[02212 \ast \text{ binary} \quad 0224A \equiv \text{ relation}\]
\[02213 \sqrt[\text{ ordinary}] \text{ radical root} \quad 0224B \equiv \text{ relation}\]
\[02214 \% \text{ relation} \quad 02250 \equiv \text{ relation}\]
\[02215 \% \text{ default} \quad 02251 \equiv \text{ relation}\]
\[02216 \% \text{ ordinary} \quad 02252 \equiv \text{ relation}\]
\[02217 \% \text{ ordinary} \quad 02253 \equiv \text{ relation}\]
\[02218 \% \text{ ordinary} \quad 02254 \equiv \text{ relation}\]
\[02219 \% \text{ ordinary} \quad 02255 \equiv \text{ relation}\]
\[02220 \% \text{ binary} \quad 02256 \equiv \text{ relation}\]
\[02221 \% \text{ binary} \quad 02257 \equiv \text{ relation}\]
\[02222 \% \text{ relation} \quad 02258 \equiv \text{ relation}\]
\[02223 \% \text{ relation} \quad 02259 \equiv \text{ relation}\]
\[02224 \% \text{ relation} \quad 0225A \equiv \text{ relation}\]
\[02225 \% \text{ relation} \quad 0225B \equiv \text{ relation}\]
\[02226 \% \text{ relation} \quad 0225C \equiv \text{ relation}\]
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<td>⊬</td>
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</tr>
</tbody>
</table>

Unicode Math
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022C4 ◊ binary 02308 | open
022C5 · binary punctuation 02309 | close
022C6 ★ binary 0230A | open
022C7 ※ binary 0230B | close
022C8 ▼ relation 0231C open
022C9 △ binary 0231D close
022CA ▲ binary 0231E open
022CB ▽ binary 0231F close
022CC ▼ binary 02322 ~ relation
022CE ▴ binary 02323 ~ relation
022CF ▵ binary 023B0 open
022D0 ⊑ relation 023B1 close
022D1 ⊏ relation 023B4 topaccent
022D2 ⊒ binary 023B5 botaccent
022D3 ⊓ binary 023DC ~ topaccent
022D4 ⊔ relation 023DD botaccent
022D6 ⊕ binary 023DE ~ topaccent
022D7 ⊗ binary 023DF ~ botaccent
022D8 ⊔ relation 023E0 topaccent
022D9 ⊕ relation 023E1 botaccent
022DA ⊙ relation 024C7 ordinary
022DB ⊠ relation 024C8 ⊃ ordinary
022DC ⊴ relation 025A0 ■ ordinary
022DD ⊵ relation 025A1 □ ordinary
022DE ⊵ relation 025A2 □ ordinary
022DF ⊴ relation 025B2 ▲ binary
022E0 ⊢ relation 025B3 △ binary ordinary
022E1 ⊣ relation 025B6 ▶ binary
022E2 ⊤ relation 025B7 ▶ binary
022E3 ⊥ relation 025BC ▼ binary
022E4 ⊥ relation 025BD ▼ binary
022E5 ⊬ relation 025CO ▲ binary
022E6 ⊭ relation 025C1 ▲ binary
022E7 ⊮ relation 025CA ◊ ordinary
022E8 ⊮ relation 025EF ◊ binary
022E9 ⊮ relation 02605 ordinary
022EA ⊮ relation 02660 ♠ default
022EB ⊮ relation 02661 default
022EC ⊮ relation 02662 default
022ED ⊮ relation 02663 ♠ default
022EE : inner 02666 ♦ ordinary
022EF : inner 0266D ♦ default
022F0 : inner 0266E ♦ default
022F1 : inner 0266F ♦ default
02300 ord 02713 ✓ nothing
Unicode Math
Traditionally (in TeX) one enters ASCII characters to represent identifiers and use a font switch to get for instance a bold rendering. In Unicode it is more natural to use code points that represent the meaning. So, instead if entering byte U+0058 for a bold x one will use an utf sequence representing U+1D431.

Because there are not than many editors that show all those Unicode characters it still makes sense to use regular latin and greek alphabets combined with directives that tell what real alphabet is used. For ConTeXt it does not matter what approach is chosen: both work ok and internally characters are mapped onto the right slot. When a font does not provide a shape a fallback is chosen. Technically one can construct a complete math font by combining all kind of fonts, but this is normally not needed.

Here we show the combinations of styles and alternatives. Not all combinations are present in Unicode. Actually, as Unicode math is rather agnostic of cultural determined math rendering, at some point ConTeXt could provide more.\(^2\) Also, modern OpenType fonts can have alternatives, for instance variants of script, blackboard or fraktur. This is not related to Unicode and it makes no sense to encode that in MathML, but a setup of the rendering.

\begin{verbatim}
regular normal 0123456789 00034 - 00035
regular normal αβγδεζηθικλμνξοπρστυφχψωθφΩπερ[αβγδεζηθικλμνξοπρστυφχψωθφΩ
regular normal abcdefghijklmnopqrstuvwxyz 00039 - 00031
regular normal ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩ 00039 - 00031
regular normal ABCDEFGHIJKLMNOPQRSTUVWXYZ 00036 - 00039
0123456789 1D7CE - 1D7D7
sansserif normal 0123456789 1D7E2 - 1D7EB
\end{verbatim}

\(^2\) An example is the German handwriting style Suetterlin that is still used for vectors.
$$\alpha \beta \gamma \delta \varepsilon \zeta \theta \iota \kappa \lambda \mu \nu \xi \omicron \pi \rho \sigma \tau \upsilon \chi \psi \omega \varphi \vartheta \varkappa \rho \varsigma \varpi \varrho \varphi \psi \omega$$

$$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$$

$$\text{script normal}$$

$$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$$

$$\text{blackboard normal}$$

$$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$$
Glyphs (traditionally) come in three sizes. The script and scriptscript sizes can be downscaled from text size but most math fonts have additional glyphs tuned for smaller sizes. The next table shows some of this.

<table>
<thead>
<tr>
<th>Unicode Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
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<td>feminine ordinal indicator</td>
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<tr>
<td>000B2</td>
<td>superscript two</td>
</tr>
<tr>
<td>000B3</td>
<td>superscript three</td>
</tr>
<tr>
<td>000B9</td>
<td>superscript one</td>
</tr>
<tr>
<td>000BA</td>
<td>masculine ordinal indicator</td>
</tr>
<tr>
<td>002B0</td>
<td>modifier letter small h</td>
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<tr>
<td>002B1</td>
<td>modifier letter small h with hook</td>
</tr>
<tr>
<td>002B2</td>
<td>modifier letter small j</td>
</tr>
<tr>
<td>002B3</td>
<td>modifier letter small r</td>
</tr>
<tr>
<td>002B4</td>
<td>modifier letter small turned r</td>
</tr>
<tr>
<td>002B5</td>
<td>modifier letter small turned r with hook</td>
</tr>
<tr>
<td>002B6</td>
<td>modifier letter small capital inverted r</td>
</tr>
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02074 00034  4  \( x^4 = x^4 \) \( x^4 = x^4 \) superscript four
02075 00035  5  \( x^5 = x^5 \) \( x^5 = x^5 \) superscript five
02076 00036  6  \( x^6 = x^6 \) \( x^6 = x^6 \) superscript six
02077 00037  7  \( x^7 = x^7 \) \( x^7 = x^7 \) superscript seven
02078 00038  8  \( x^8 = x^8 \) \( x^8 = x^8 \) superscript eight
02079 00039  9  \( x^9 = x^9 \) \( x^9 = x^9 \) superscript nine
0207A 0002B  +  \( x^+ = x^+ \) \( x^+ = x^+ \) superscript plus sign
0207B 22122  −  \( x^- = x^- \) \( x^- = x^- \) superscript minus
0207C 0003D  =  \( x^n = x^n \) \( x^n = x^n \) superscript equals sign
0207D 00028  (  \( x^i = x^i \) \( x^i = x^i \) superscript left parenthesis
0207E 00029  )  \( x^i = x^i \) \( x^i = x^i \) superscript right parenthesis
0207F 0006E  n  \( x^n = x^n \) \( x^n = x^n \) superscript latin small letter n
02080 00030  0  \( x_0 = x_0 \) \( x_0 = x_0 \) subscript zero
02081 00031  1  \( x_1 = x_1 \) \( x_1 = x_1 \) subscript one
02082 00032  2  \( x_2 = x_2 \) \( x_2 = x_2 \) subscript two
02083 00033  3  \( x_3 = x_3 \) \( x_3 = x_3 \) subscript three
02084 00034  4  \( x_4 = x_4 \) \( x_4 = x_4 \) subscript four
02085 00035  5  \( x_5 = x_5 \) \( x_5 = x_5 \) subscript five
02086 00036  6  \( x_6 = x_6 \) \( x_6 = x_6 \) subscript six
02087 00037  7  \( x_7 = x_7 \) \( x_7 = x_7 \) subscript seven
02088 00038  8  \( x_8 = x_8 \) \( x_8 = x_8 \) subscript eight
02089 00039  9  \( x_9 = x_9 \) \( x_9 = x_9 \) subscript nine
0208A 0002B  +  \( x_+ = x_+ \) \( x_+ = x_+ \) subscript plus sign
0208B 22122  −  \( x_- = x_- \) \( x_- = x_- \) subscript minus
0208C 0003D  =  \( x_\equiv = x_\equiv \) \( x_\equiv = x_\equiv \) subscript equals sign
0208D 00028  (  \( x_i = x_i \) \( x_i = x_i \) subscript left parenthesis
0208E 00029  )  \( x_i = x_i \) \( x_i = x_i \) subscript right parenthesis
02090 00066  a  \( x_a = x_a \) \( x_a = x_a \) latin subscript small letter a
02091 00065  e  \( x_e = x_e \) \( x_e = x_e \) latin subscript small letter e
02092 0006F  o  \( x_o = x_o \) \( x_o = x_o \) latin subscript small letter o
02093 00078  x  \( x_x = x_x \) \( x_x = x_x \) latin subscript small letter x
02094 00259  x  \( x_x = x_x \) \( x_x = x_x \) latin subscript small letter schwa
02095 00068  h  \( x_h = x_h \) \( x_h = x_h \) latin subscript small letter h
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0209C 00074  t  \( x_t = x_t \) \( x_t = x_t \) latin subscript small letter t
0209D 0006A  j  \( x_j = x_j \) \( x_j = x_j \) latin subscript small letter j
0209E 00056  V  \( x^V = x^V \) \( x^V = x^V \) modifier letter capital v
0209F 02D61  x^V = x^V \( x^V = x^V \) tifinagh modifier letter labialization mark
03192 04E00  x^V = x^V \( x^V = x^V \) ideographic annotation one mark

Unicode Math
There are two ways to look at bold math. First there are bold alphabets and bold symbols and these have some meaning. Then there is what we can best call boldened math that is used in section titles and such. The normal bold then becomes heavy. The next table shows (for the font used here) what bold shapes are available.
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Unicode Math
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U+1D68A  𝛈  U+1D5EE  𝛈  MATHEMATICAL MONOSPACE SMALL A
Unicode Math

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