Mathematics in ConTEXt

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Introduction

This document

We discuss how to typeset mathematics with the ConTEXt (lmtx) typesetting system. Our main purpose is to provide general advice and assistance to ConTEXt users seeking to create beautiful, structured, and consistent documents with mathematical content (with these three criteria being interdependent). Although the focus will be on ConTEXt, we will also sometimes explore mathematical typesetting in a broader sense that applies to other systems.

The document contains material suitable both for beginners and for experts; our aim is that it shall cover all aspects of mathematical typesetting with ConTEXt. The beginner will hopefully not be overwhelmed by all the possible setups and tweaks that we show and discuss. We hope and believe that the default settings work well for most users. At the same time, we dare to claim that ConTEXt is the most advanced and capable system for typesetting mathematics today, in particular when it comes to Opentype mathematics. This does not mean that it is difficult to typeset mathematics in ConTEXt.

In Autumn 2021 we began to discuss mathematical typesetting in ConTEXt, starting on the ConTEXt mailing list. Given that ConTEXt is a modern system built upon Donald Knuth's classical typesetting system TEX, its mathematical typesetting capabilities were by that time already quite good. Mikael had previously used ConTEXt (mkii) to typeset his doctoral thesis in mathematics in 2008 and had coauthored a math book (first edition published in 2019) using ConTEXt (mkiv).

However, the situation was not optimal. ConTEXt was by default running on the LuaTEX engine, although the newer luametaTEX engine was also becoming available and mature. Additionally, several Opentype Unicode math fonts had been created. One problem was that the Opentype standard (or lack thereof) meant that formulas could appear quite different depending on the font and engine being used. To illustrate this, we consider the formula

$$\int_a^b f'(x)\,dx = [f(x)]_a^b$$

This formula was typeset with TEXGyre Bonum Math without any adjustments. Note that the bracket and the f are overlapping, the lower limit of the integral is not positioned correctly (we do not even try to place them correctly, but only raise and lower them according to the font parameters), and the integral sign appears too small (in traditional math fonts there were two sizes of the integral sign, in Opentype math fonts, there can be many, and therefore we just select the base glyph here). Although these weren't the exact issues we encountered (it's difficult to recall after all the changes, but it probably had to do with integrals or primes), the main problem was that adjusting one parameter to improve the appearance of one font often led to issues with another. It took us some time to address these discrepancies and inaccuracies, but we ultimately resolved them, sometimes by extending the luametaTEX engine, sometimes by working at the Lua and TEX end, combined with font-specific setups in “goodie files”. If we load the one for TEXGyre Bonum Math, the previous formula is set as

$$\int_a^b f'(x)\,dx = [f(x)]_a^b$$

Much better, indeed. The font issues were not the only problem, though. At that point, the math community had not widely adopted ConTEXt, and while there were many excellent examples of usage available, they were often somewhat concealed within the source (one exception was Aditya Mahajan's excellent manual [Mah06] on math alignments). This document shall fill in those gaps, and we hope that it will be useful as a rather complete math guide for all ConTEXt users.

When it comes to the advice on how to set mathematics, we claim no or little originality. Our main inspiration has been the old book [Lan61]. It was written as a typesetting guide for the Swedish publisher *Almqvist & Wiksell*, mainly for their mathematical publications, and particularly for the renowned journal *Acta Mathematica*. What sets this book apart is its explanation of the *why* behind the rules for consistent typesetting, rather than just the *how*. Some of the rules in that book are however outdated; one reason is that we now work digitally rather than with Monotype machines. You can find a lot in the literature about the typesetting of math, in particular in TEX. We mention [CBB54; DH21; Hag99; LS17; Mad11; Swa99], but the reader should also look in TUGBoat, MAPS and other places.

Writing and typesetting mathematics

Written mathematics can be very dense and it often contains symbols from different alphabets, set in different styles. Some symbols are raised or lowered. As a result, reading a mathematical text is challenging and time-consuming, and it is therefore important for the writer to make the suffer of the reader as small as possible. If we jump into the middle of a novel, we might be confused, but if we do it with a mathematical text, it might be completely incomprehensible, in particular if we are not acquainted with the notation. Consider the following paragraph, borrowed from Andrew Wiles' famous article where he among other things proves Fermat's last theorem [Wil95].

> Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then
>
> $$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$
>
> It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\bar{F}/F) \to \mathcal{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

The paragraph by Wiles above is not at all poorly written; it just happens to contain many formulas, use a rich set of symbols from various alphabets, and it is aimed at experts in the field. Taken out of its context, it is also difficult to read since we do not know the meaning of the different symbols (the authors of this document do not claim to understand the very advanced mathematics in Wiles' famous paper at all). Even if this document is about typesetting mathematics, perhaps the best advice we can give the writer is to use less math, or at least to think twice before introducing new notation, and not to complicate notation without a good reason.

When typesetting mathematics it is also very important that the spacing around symbols come out right. Luckily this is something that TEX usually handles perfectly well. Take a look at the following formula:

$$(\oplus_{\alpha=1}^{\ell}\mathfrak{q}_{\alpha}, \mathfrak{p}_s) \in C^*_{\max}(\Gamma, G)^+ \cong [C_0(\mathbb{R}^7) \otimes C_{\iota_*}]^+.$$

Thanks to the spacing and parentheses we readily recognize two verbs, $\in$ and $\cong$; the formula has the main structure

$$\rule{2em}{0.5em} \in \rule{2em}{0.5em} \cong \rule{2em}{0.5em}.$$

Thus, it says that the object $(\oplus_{\alpha=1}^{\ell}\mathfrak{q}_{\alpha}, \mathfrak{p}_s)$ (whatever that is) belongs to $C^*_{\max}(\Gamma, G)^+$, which in turn is isomorphic (small questionmark here since we do not know how the symbol $\cong$ is used) to $[C_0(\mathbb{R}^7) \otimes C_{\iota_*}]^+$. One reason that our eyes fell on those two symbols is that the spacing around them is slightly bigger than around the other symbols. If we take a new look at the same formula, but with these spaces removed,

$$(\oplus_{\alpha=1}^{\ell}\mathfrak{q}_{\alpha}{,}\mathfrak{p}_s){\in}C^*_{\max}(\Gamma{,}G)^+{\cong}[C_0(\mathbb{R}^7){\otimes}C_{\iota_*}]^+,$$

it is clearly much more difficult to get the structure of the formula. These spaces in formulas are indeed very important. TEX has classically divided the different symbols in a few atom classes, with spaces between them configured in a way that looks good. One of the new things in the luametaTEX engine is the possibility to define new classes and to set up the spacing between classes in a more flexible way. Even if there is a lot going on "behind the scene" this will likely go unnoticed to most users, since the default setup is hopefully well working. There will be a minimal amount of manual tweaking with spaces needed (if you find yourself doing lots of manual tweaks, you should suspect that there is a better way of doing what you are doing). At the same time, users have the opportunity to make very different setups, if needed.

Even though this document is about typesetting mathematics and there will be lots of formulas, and suggestions how to typeset them, we would like to stress a bit on the importance of the writing. Use complete sentences. Do not use unnecessarily complex notation, and think twice before introducing new. Do not overuse (displayed) formulas; it is often possible, and helps the reader, if you write a few extra words instead. The following quote from [Knu99] is good to have in mind:

> Many readers will skim over formulas on their first reading of your exposition. Therefore, your sentences should flow smoothly when all but the simplest formulas are replaced by "blah" or some other grunting noise.

A few notes about this document

This document is rather complex, with lots of code snippets and formulas. Almost all examples are done by adding the example code inside `\startbuffer` and `\stopbuffer`, and then showing the code with `\typebuffer` and the result with `\getbuffer`. Sometimes we have needed to add grouping and some local setup around the examples.

We have kept manual page break optimization at a minimum. This is for several reasons. One of them is that we consider this as a living, unfinished, document. Another is that we generate a screen and a print version from the same source (you are now reading the paper version). Still, we use some of the available mechanisms to obtain as good breaks as possible, such as club and widow penalties, also for code blocks. We flush the pages to the bottom of the text block, but limit the stretch in order to prohibit the stretch from becoming too large on problematic pages. We use a penalty of 5000 before displayed formulas since we prefer that they do not end up at the top of pages.

When it comes to the breaking of paragraphs, we use multiple (four) paragraph passes, where we enable and gradually increase the possible amount of expansion. This is mainly in order to avoid overful lines. We did not optimize line breaks manually. What you see here is essentially what we can do automatically.

Acknowledgements

We would like to thank all the ConTeXt users who have shared helpful suggestions and thoughts. Mikael would also like to thank the nice TeXies at the TeX Stack Exchange chat, as well as his colleagues, for valuable input and discussions.

Errors, misprints and questions

We hope that this document will serve the ConTeXt community well. It surely contains some errors and misprints, and even if we have tried to cover everything in ConTeXt that could be useful for people writing mathematics, we likely have missed a few things. Please write to us (`mickep@gmail.com` and `j.hagen@xs4all.nl`) if you find something that is wrong or that can be explained better, or if you miss something. Questions and discussions that could interest more people can better go to the ConTeXt mailing list.

1 Getting started

1.1 Two types of formulas

Formulas can either be typeset *inline* as $a^2 + b^2 = c^2$ or *displayed*, as

$$a^2 + b^2 = c^2.$$

Traditionally in TEX single dollars have been used to step into inline math mode, while double dollars enter displayed formulas. In ConTEXt it is still possible to use single dollars to enter inline math mode, but we suggest instead to use the dedicated macros. One advantage of that is the possibility to add optional settings. The inline formulas can, partly for historical reasons, be entered in several different ways. We can

- Use the traditional way and enclose the formula in a pair of dollar signs, as in `$a^2 + b^2 = c^2$`.
- Use the macro `\im`, as in `\im{a^2 + b^2 = c^2}`. This macro is a bit primitive, like the dollars, and no optional arguments are allowed. It is also accompanied with the `\dm` macro, that is a quick way to enter inline math, but in display style.
- Use the macro `\m`, as in `\m{a^2 + b^2 = c^2}`. This macro can be configured and a few optional arguments are allowed. For example, with `\m[color=C:3]{a^2 + b^2 = c^2}` we get a colored formula $a^2 + b^2 = c^2$. In fact, `\m` is only a short cut for the slightly longer `\math`.

Inline formulas are generally brief and should not take up too much vertical space in order to prevent excessive interline spacing; they are not labeled. We will discuss inline formulas to a larger extent in §4. In particular we will discuss line breaking and how to avoid line spreading due to “tall” formulas.

Displayed formulas are typeset separately from the surrounding text. Typically, they contain more complex formulas or those that are intended to be emphasized. If necessary, they may be labeled in the margin, as in the following example:

$$C_\alpha(x) = \Big\{ \prod_{i=1}^{k} T_{\alpha_i}^{n_i} x \;\Big|\; \alpha_i = \alpha,\ k = 1, 2, \dots;\ n_i = 0, \pm 1, \pm 2, \dots \Big\}. \tag{1.1}$$

The pairs `\startformula` and `\stopformula` give displayed formulas. The double dollars are not supported. The displayed formulas are by default centered horizontally, but it is possible to set them up, in particular to configure both the horizontal and vertical placement, and alignment.

We will discuss displayed math in detail in §5 and §3.6, and the numbering of equations in §6. Let us sum up with a small example snippet that contains both inline and displayed formulas.

```
The Pythagorean theorem: In a right triangle with legs \m{a} and \m{b} and
hypotenuse \m{c},

\startformula
  a^2 + b^2 = c^2.
\stopformula

There are many proofs of this equality.
```

This is the way we will show code snippets in this document. Usually we will then show the result of the code directly below. Here comes the result:

The Pythagorean theorem: In a right triangle with legs a and b and hypotenuse c,

$$a^2 + b^2 = c^2.$$

There are many proofs of this equality.

1.2 Some simple examples

Now we know how to enter math mode. To better understand how to input mathematical content, before going into more detail, we look next at some simple examples, gathered from various sources. Below each example, we give a few comments. More detailed information will be provided later, in particular in §2 when it comes to different constructions. In §12 we list the many Unicode symbols available, including the macros pointing to them.

```
\startformula
  \sin x = x \prod_{n=1}^{+\infty}
           \left( 1 - \frac{x^2}{n^2\pi^2} \right)
\stopformula
```

$$\sin x = x \prod_{n=1}^{+\infty} \left(1 - \frac{x^2}{n^2\pi^2} \right)$$

The fraction is set with `\frac`. The command takes two arguments, the first for the numerator and the second for the denominator. The `\left` and `\right` commands in front of the parentheses are used to automatically size them to fit the expression inside, ensuring that they are large enough to be easily readable.

```
\startformula
  f(\sigma_{ij}, \mathbf{F}) = F_{ij} \sigma_i \sigma_j = \bar{σ}^2
\stopformula
```

$$f(\sigma_{ij}, \mathbf{F}) = F_{ij} \sigma_i \sigma_j = \bar{\sigma}^2$$

To obtain bold letters, we use the `\mathbf` command, such as in the example **F**. Greek letters can be typeset using specific macros corresponding to their names. However, it is also possible to directly use the Unicode representation of a Greek letter, as shown with the last character, σ. The `\bar` command can be used to place a small macron accent (a bar) over its argument. If a wider bar accent is needed, the `\widebar` command can be used instead. But do read the section on accents before using that bar for complex conjugates.

```
\startformula
  \fenced[bar]{\mu(B) - \nu(B)}
  \leq
  C \fenced[bar][size=big]{\inf_E U^{\mu}}^{\frac{1}{2}}
\stopformula
```

$$|\mu(B) - \nu(B)| \leq C|\inf_E U^{\mu}|^{\frac{1}{2}}$$

Note that the command `\inf` produces “inf” in roman letters, with some space added before the U. The subscript is positioned below the word “inf”. We discuss more constructions like this in §2.4, where we will also see how to define our own. Absolute values are typeset using the `\fenced` command with the option `bar`. Alternatively, we can use the construction with `\left` and `\right`. We discuss delimiters in more detail, including how to define our own, in §2.5.

```
\startformula
  T_m(f,g)(x) = \int_{\reals^4} m(\xi, \eta) \hat{f}(\xi) \hat{g}(\eta)
                              e^{2\pi i x(\xi + \eta)} \dd \xi \dd \eta
\stopformula
```

$$T_m(f,g)(x) = \int_{\mathbb{R}^4} m(\xi,\eta)\hat{f}(\xi)\hat{g}(\eta)e^{2\pi i x(\xi+\eta)}\,d\xi\,d\eta$$

The `\hat` places a hat accent on top of its argument. However, it is designed to work best with single characters. For instance, using `\hat {fg}` to typeset $\hat{fg}$ is not recommended. In such cases, it is better to use the `\widehat` command, as in $\widehat{fg}$, or construct an appropriate accent with a construction like `fourier`, such as $(fg)^\frown$. More information on accents can be found in §2.9.

In the example, note the use of `\dd` to typeset the differential symbol with suitable spacing around the d. As we will see later, we can set it up to be upright instead of italic. Also, `\reals` is used to indicate the set of real numbers. To obtain other blackboard bold characters, use `\mathbb`.

```
\startformula
  \pi_1\colon U(\mathfrak{osp}(2p|2q))\to A_{p|q}^{+}
\stopformula
```

$$\pi_1\colon U(\mathfrak{osp}(2p|2q))\to A_{p|q}^{+}$$

The letters $\mathfrak{osp}$ are written in fraktur style, achieved with the command `\mathfrak{osp}`. Additionally, note the difference between using `\colon` and a regular colon in formulas. For example, using `\pi_1\colon U` yields the output $\pi_1\colon U$, while using `\pi_1:U` yields the output $\pi_1 : U$.

```
\startformula
  \mathbb{E}_{s\in S} \sum_{i = 1}^r
  g_i(s_1) g_i(s_2) \ldots g_i(s_k) \geq 2^{-(k + 1)} \beta
\stopformula
```

$$\mathbb{E}_{s\in S} \sum_{i = 1}^r g_i(s_1) g_i(s_2) \ldots g_i(s_k) \geq 2^{-(k + 1)} \beta$$

The `\ldots` command indicates that some terms are omitted in the product. Nowadays, it is common to use `\cdots` instead of `\ldots`, as in $g_i(s_1)g_i(s_2)\cdots g_i(s_k)$.

```
\startformula
  \frac{\partial f}{\partial t} + v\cdot\nabla_x f = Q(f,f)
\stopformula
```

$$\frac{\partial f}{\partial t} + v\cdot\nabla_x f = Q(f,f)$$

We can use `\partial` to obtain the stylized ∂ symbol for partial derivatives and `\nabla` to obtain the gradient symbol ∇. The centered dot, created by `\cdot`, is frequently used to indicate a scalar product.

```
\definemathfunction[Aut]
```

```
\startformula
  \integers_2
  \cong
  \Aut(\complexes) \subseteq \Aut(t_2)
  \cong
  \fenced
    [brace]
    [middle=`|]
    {(g_1,g_2,g_3) \in U(1)^3 \fence g_1g_2g_3=1}
  \times \integers_2
\stopformula
```

$$\mathbb{Z}_2 \cong \mathrm{Aut}(\mathbb{C}) \subseteq \mathrm{Aut}(t_2) \cong \left\{(g_1, g_2, g_3) \in U(1)^3 \,\middle|\, g_1g_2g_3 = 1\right\} \times \mathbb{Z}_2$$

The `\Aut` macro is not predefined in ConTEXt, but we defined it just before the formula using `\definemathfunction`. More about this can be found in §2.4. The `\fenced` construction is used to adjust the size of the braces (indicated by the `[brace]` option) to the content in between. In this example, the superscript 3 makes them too big, so we have to specify the size. Additionally, we use `middle=`|` to enable the use of `\fence` inside the fenced construction to get a vertical bar symbol (|) from the Unicode character set (the back tic needs to be there, to provide `middle` by the number of the glyph). More information on fences can be found in §2.5.

```
\startformula
  \frac{e^{-\lambda^2t}}{\sqrt{4\pi t}}
  \left\{ \exp\left[ -\frac{(u-v)^2}{4t} \right]
         -\exp\left[ -\frac{(u+v)^2}{4t} \right] \right\}
\stopformula
```

$$\frac{e^{-\lambda^2t}}{\sqrt{4\pi t}}\left\{ \exp\left[-\frac{(u-v)^2}{4t} \right] -\exp\left[-\frac{(u+v)^2}{4t} \right] \right\}$$

Here we have used nested delimiters, and we have used `\left` and `\right` instead of `\fenced`. Additionally, it is a good practice to use $\exp(x)$ instead of e^x when the argument x itself is large. Compare $e^{-\frac{(u-v)^2}{4t}}$ with what we have above. If we replace the fraction bar by a slash, $e^{-(u-v)^2/4t}$, we get something more acceptable. This is in particular true for inline formulas, as in this paragraph, where the `\frac` in the superscript forces some ugly line spread. We come back to that in §4.

```
\startformula
  0
  \longrightarrow
  E^0 \boxtimes F^0
  \mrightarrow{\phi}
  E^1 \boxtimes F^0 \oplus E^0 \boxtimes F^1
  \stackrel{\psi}{\longrightarrow}
  E^1 \boxtimes F^1
  \longrightarrow
  0
\stopformula
```

$$0 \longrightarrow E^0 \boxtimes F^0 \xrightarrow{\phi} E^1 \boxtimes F^0 \oplus E^0 \boxtimes F^1 \stackrel{\psi}{\longrightarrow} E^1 \boxtimes F^1 \longrightarrow 0$$

We used `\mrightarrow` to put the ϕ on top of the arrow and `\stackrel` to put the ψ (see §2.10). In §8 we will see some more examples of diagrams.

```
\startformula
  \mathfrak{D}_{\mathcal{A}}
  \colonequals
  \fenced
    [brace]
    [middle=`:]
    {d \in \naturalnumbers \fence \exists(b,d) = 1
     \text{ with } \frac{b}{d} \in \mathfrak{R}_{\mathcal{A}}}
\stopformula
```

$$\mathfrak{D}_{\mathcal{A}} \coloneqq \left\{ d \in \mathbb{N} : \exists(b,d) = 1 \text{ with } \frac{b}{d} \in \mathfrak{R}_{\mathcal{A}} \right\}$$

Note that `\mathcal` is meant to give a calligraphic A ($\mathcal{A}$), while `\mathscr` should give a script A ($\mathscr{A}$). In TEXGyre Pagella Math, as with many other fonts, there is no calligraphic alphabet, and in such cases the same alphabet is used in both cases. The symbol `\colonequals` is often used to denote a defining equality.

```
\startformula
  f(z)
  =
  \frac{1}{2\pi i}
  \aointc_{\partial \Omega}
    \frac{f(\zeta)}{\zeta - z} \dd \zeta
  - \frac{1}{\pi}
  \iint_{\Omega}
    \frac{\partial f}{\partial \conjugate{\zeta}}(\zeta)
    \frac{1}{\zeta - z} \dd \lambda(\zeta)
\stopformula
```

$$f(z) = \frac{1}{2\pi i} \ointctrclockwise_{\partial\Omega} \frac{f(\zeta)}{\zeta - z} d\zeta - \frac{1}{\pi} \iint_{\Omega} \frac{\partial f}{\partial \bar{\zeta}}(\zeta) \frac{1}{\zeta - z} d\lambda(\zeta)$$

There are several different types of integrals to choose from, see §2.13. Note also the `\conjugate{\zeta}`, giving the conjugate bar over the zeta, $\bar{\zeta}$.

1.3 A small note, with source

The aim of this document is to describe how to typeset mathematics with ConTEXt, not how to use ConTEXt in general. Below, however, we show a complete example (the `\starttext` and `\stoptext` are commented out, since we use it in this document). We first show the source, and then the typeset example. The enumerations defined for the theorem, lemma and proofs are described in detail in §7.

```
% language=en

\defineenumeration
  [Theorem]
  [alternative=serried,
   width=fit,
   distance=\emwidth,
```

```
   text=Theorem,
   style=italic,
   title=yes,
   titlestyle=normal,
   prefix=yes,
   headcommand=\groupedcommand{}{.}]

\defineenumeration
  [Lemma]
  [Theorem]
  [text=Lemma]

\defineenumeration
  [Proof]
  [alternative=serried,
   width=fit,
   distance=\emwidth,
   text=Proof,
   number=no,
   headstyle=italic,
   headcommand=\groupedcommand{}{.},
   title=yes,
   titlestyle=normal,
   closesymbol=\mathqed]

% \starttext

\startalignment[flushleft,tight]
  \bfb\setupinterlinespace We prove the l'Hospital rule directly from the
  Lagrange mean value theorem, without using the Cauchy mean value theorem.
\stopalignment

\blank[big]

\startlines
Anders Holst
Mikael P. Sundqvist
\stoplines

\blank[big]

\startnarrower[2*middle]
  \bold{Abstract.} At our first-year calculus course for engineers we
  discuss Lagrange's mean value theorem but not Cauchy's mean value
  theorem, and for this reason we usually give a weak form of l'Hospital's
  rule on limits. In this note we give a simple proof of the stronger
  version of l'Hospital's rule, using only Lagrange's mean value theorem
  and elementary results on limits and derivatives.
\stopnarrower
```

```
\blank[big]

We formulate and prove the l'Hospitals rule for one-sided limits. This in
fact strengthen the usual formulation slightly.

\startTheorem
  [title={l'Hospital's rule},
   reference={thm:lHospital}]
  Assume that the functions \m {f} and \m {g} are continuous in \m
  {\rightopeninterval {a,b}} and differentiable in \m {\openinterval
  {a,b}}. Assume further that \m {f(a) = g(a) = 0} and that \m {g'(x) \neq
  0} in \m {\openinterval {a,b}}. If \m {f'(x)/g'(x)\tendsto A} as \m {x
  \tendsto a^^{+}}, then \m {f(x)/g(x) \tendsto A} as \m {x \tendsto
  a^^{+}}.
\stopTheorem

A geometric interpretation of the l'Hospital rule goes as follow. In the \m
{uv}-plane, draw the curve parametrized by \m {u = g(x)} and \m {v = f(x)}.
Then the direction coefficient \m {f(x)/g(x)} of the secant (dotted in
\in{Figure}[fig:lHospital]) connecting \m {(g(x),f(x))} with \m
{(g(a),f(a)) = (0,0)} should approach the same value as the direction
coefficient \m {f'(x)/g'(x)} of the tangent to the curve at \m
{(g(x),f(x))} (dashed in \in {Figure}[fig:lHospital]) as \m {x} approaches
\m {a}. Our proof of the theorem uses that we can parametrize this curve
locally around the origin as a function graph \m {u = t} and \m {v =
f(\inverse{g}\of(t))}.

\startplacefloat
  [figure]
  [reference=fig:lHospital]
  \enabledirectives[metapost.text.fasttrack]
  \startMPcode[offset=1TS]
  numeric u ; u:=7.5ts ;
  path p,tangent,sekant ;

  p:=(0,0){dir 10}..(1.5,1){dir 50}..(3,2) ;
  z0 = point 1 of p ;
  tangent:=(((-1,0)--(1,0)) rotated 50) shifted z0 ;
  sekant:=origin--z0 ;

  drawarrow ((-0.25,0)--(3,0)) scaled u ;
  drawarrow ((0,-0.25)--(0,2)) scaled u ;

  pickup pencircle scaled 1 ;
  draw p scaled u ;
  draw tangent scaled u dashed evenly ;
  draw sekant scaled u dashed withdots ;
```

```
  dotlabel.ulft("\m{(g(x),f(x))}", z0 scaled u) ;
  dotlabel.lrt ("\m{(g(a),f(a))}", origin) ;
  label.bot("\m{u}", (2.9u,0)) ;
  label.lft("\m{v}", (0,1.9u)) ;
  \stopMPcode
  \disabledirectives[metapost.text.fasttrack]
\stopplacefloat

The only place in our proof where Lagrange's mean value theorem occurs is
in this useful property of right-hand side derivatives.

\startLemma
  [reference=lemma:rightderivative]
  Let \m {c > 0}. Assume that \m {\phi \maps \rightopeninterval {0,c} \to
  \reals} is continuous in \m {\rightopeninterval {0,c}} and differentiable
  in \m {\openinterval {0,c}}, and that \m {\lim_{t \tendsto 0^^{+}}
  \phi'(t)} exists and equals \m {A}. Then

  \startformula
    \lim_{h \tendsto 0^^{+}} \frac{\phi(0 + h) - \phi(0)}{h} = A.
  \stopformula
\stopLemma

\startProof
  For \m {h \in \openinterval {0,c}} the differential quotient \m {(\phi(0
  + h) - \phi(0))/h} equals \m {\phi'(\xi_h)} for some \m {\xi_h \in
  \openinterval {0,h}}, by Lagrange's mean value theorem. As \m {h\tendsto
  0^^{+}} we have \m {\xi_h \tendsto 0^^{+}}, and so

  \startformula
    \lim_{h\tendsto 0^^{+}}\frac{\phi(0+h)-\phi(0)}{h}
    = \lim_{h\tendsto 0^^{+}}\phi'(\xi_h)
    = A.
    \qedhere
  \stopformula
\stopProof

\startProof
  [title={of \in{Theorem}[thm:lHospital]}]
  Since \m {g'} is a Darboux function it will not change sign in \m
  {\openinterval {a,b}}, and for simplicity we assume that \m {g' > 0} in
  this interval. Lagrange's mean value theorem assures that \m {g} is
  strictly monotone in the interval \m {\rightopeninterval {a,b}} and thus
  that it has an inverse \m {\inverse{g}\maps \rightopeninterval {0,g(b)}
  \to \rightopeninterval {a,b}}.

  The composite function \m {\phi \mapsas t\mapsto f(\inverse{g}\of(t))},
  \m {t \in \rightopeninterval {0,g(b)}} is continuous at \m {t = 0} and
  differentiable for \m {t \in \openinterval {0, g(b)}}. By the
```

```
  substitution \m {t = g(x)} in the given limit, together with the chain
  rule and the rule of derivatives of inverse functions, we get

  \startformula
    A = \lim_{x\tendsto a^^{+}} \frac{f'(x)}{g'(x)}
      = \lim_{t\tendsto 0^^{+}} \frac{f'(\inverse{g}\of(t))}
                                     {g'(\inverse{g}\of(t))}
      = \lim_{t\tendsto 0^^{+}} \frac{\dd}{\dd t}f(\inverse{g}\of(t))
      = \lim_{t\tendsto 0^^{+}} \phi'(t).
  \stopformula

  By \in{Lemma}[lemma:rightderivative], and by substitution \m {t = g(x)}
  again, we conclude that

  \startformula
    A = \lim_{t\tendsto 0^^{+}} \frac{\phi(0+t) - \phi(0)}{t}
      = \lim_{t\tendsto 0^^{+}} \frac{f(\inverse{g}\of(t))}{t}
      = \lim_{x\tendsto a^^{+}} \frac{f(x)}{g(x)}.
  \stopformula

  This completes the proof.
\stopProof

% \stoptext
```

On the next few pages we show the result after compiling this small example. We added a `\switchtobodyfont[antykwa]`, to vary the look a little. More information on the use of fonts, as well as small examples of the available math fonts, can be found in §9.

We prove the l'Hospital rule directly from the Lagrange mean value theorem, without using the Cauchy mean value theorem.

Anders Holst
Mikael P. Sundqvist

Abstract. At our first-year calculus course for engineers we discuss Lagrange's mean value theorem but not Cauchy's mean value theorem, and for this reason we usually give a weak form of l'Hospital's rule on limits. In this note we give a simple proof of the stronger version of l'Hospital's rule, using only Lagrange's mean value theorem and elementary results on limits and derivatives.

We formulate and prove the l'Hospitals rule for one-sided limits. This in fact strengthen the usual formulation slightly.

Theorem 1.1 (l'Hospital's rule). *Assume that the functions f and g are continuous in $[a, b)$ and differentiable in (a, b). Assume further that $f(a) = g(a) = 0$ and that $g'(x) \neq 0$ in (a, b). If $f'(x)/g'(x) \to A$ as $x \to a^+$, then $f(x)/g(x) \to A$ as $x \to a^+$.*

A geometric interpretation of the l'Hospital rule goes as follow. In the uv-plane, draw the curve parametrized by $u = g(x)$ and $v = f(x)$. Then the direction coefficient $f(x)/g(x)$ of the secant (dotted in Figure 1.1) connecting $(g(x), f(x))$ with $(g(a), f(a)) = (0, 0)$ should approach the same value as the direction coefficient $f'(x)/g'(x)$ of the tangent to the curve at $(g(x), f(x))$ (dashed in Figure 1.1) as x approaches a. Our proof of the theorem uses that we can parametrize this curve locally around the origin as a function graph $u = t$ and $v = f(g^{-1}(t))$.

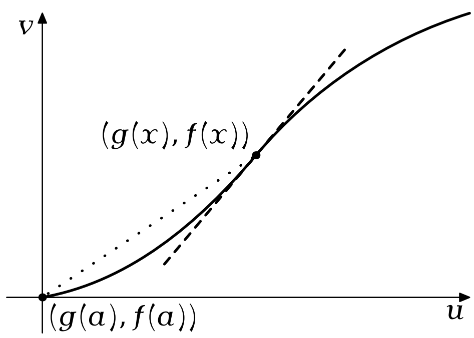


Figure 1.1

The only place in our proof where Lagrange's mean value theorem occurs is in this useful property of right-hand side derivatives.

Lemma 1.2. *Let $c > 0$. Assume that $\phi\colon [0, c) \to \mathbb{R}$ is continuous in $[0, c)$ and differentiable in $(0, c)$, and that $\lim_{t\to 0^+} \phi'(t)$ exists and equals A. Then*

$$\lim_{h\to 0^+} \frac{\phi(0 + h) - \phi(0)}{h} = A.$$

Proof. For $h \in (0,c)$ the differential quotient $(\phi(0+h)-\phi(0))/h$ equals $\phi'(\xi_h)$ for some $\xi_h \in (0,h)$, by Lagrange's mean value theorem. As $h \to 0^+$ we have $\xi_h \to 0^+$, and so

$$\lim_{h\to 0^+} \frac{\phi(0+h)-\phi(0)}{h} = \lim_{h\to 0^+} \phi'(\xi_h) = A. \qquad \square$$

Proof (of Theorem 1.1). Since g' is a Darboux function it will not change sign in (a,b), and for simplicity we assume that $g' > 0$ in this interval. Lagrange's mean value theorem assures that g is strictly monotone in the interval $[a,b)$ and thus that it has an inverse $g^{-1}\colon \bigl[0, g(b)\bigr) \to [a,b)$.

The composite function $\phi\colon t \mapsto f(g^{-1}(t))$, $t \in \bigl[0, g(b)\bigr)$ is continuous at $t=0$ and differentiable for $t \in \bigl(0, g(b)\bigr)$. By the substitution $t = g(x)$ in the given limit, together with the chain rule and the rule of derivatives of inverse functions, we get

$$A = \lim_{x\to a^+} \frac{f'(x)}{g'(x)} = \lim_{t\to 0^+} \frac{f'(g^{-1}(t))}{g'(g^{-1}(t))} = \lim_{t\to 0^+} \frac{d}{dt} f(g^{-1}(t)) = \lim_{t\to 0^+} \phi'(t).$$

By Lemma 1.2, and by substitution $t = g(x)$ again, we conclude that

$$A = \lim_{t\to 0^+} \frac{\phi(0+t)-\phi(0)}{t} = \lim_{t\to 0^+} \frac{f(g^{-1}(t))}{t} = \lim_{x\to a^+} \frac{f(x)}{g(x)}.$$

This completes the proof. $\square$

1.4 A bit more into the details

This section contains some more details about different math modes available, and since it is a bit technical, one could skip it at a first reading.

In traditional TEX there is really a difference between the inline formulas (what we end up in between single dollars) and displayed formulas (double dollars). With the recent development of math in ConTEXt, this difference is now gone. There is really only one math mode (inline), but we can enter it with different styles.

	display	text	script	scriptscript
uncramped	0	2	4	6
cramped	1	3	5	7

Intermezzo 1.1

We show below a formula, first set as a displayed formula and then as an inline formula. We use

```
\def\Styles{(\the\mathmainstyle,\the\mathparentstyle,\the\mathstyle)}
```

to show in what style we end up in the various positions in the formulas. The `\mathmainstyle` remembers the main style of the formula, the `\mathparentstyle` keeps track of the style of the parent and the `\mathstyle` controls the action at the current location. The user does not need to keep track of this, ConTEXt will automatically use the apropriate style.

We use the input

```
\Styles +
\sum_{\Styles}^{\Styles} \Styles_{\Styles} +
\int_{\Styles}^{\Styles} +
\frac{\Styles}{\Styles} +
\frac{\frac{\Styles}{\Styles}}{\frac{\Styles}{\Styles}} +
\Styles^{\Styles^{\Styles}}
```

First we look at the result when it is set as a displayed formula.

```
\startformula
  \getbuffer[styleformula]
\stopformula
```

$$(0,0,0) + \sum_{(0,0,5)}^{(0,0,4)} (0,0,0)_{(0,0,5)} + \int_{(0,0,5)}^{(0,0,4)} + \frac{(0,0,1)}{(0,0,1)} + \frac{\frac{(0,1,1)}{(0,1,1)}}{\frac{(0,1,1)}{(0,1,1)}} + (0,0,0)^{(0,0,4)^{(0,4,6)}}$$

Then we see how it comes out when it is set as an inline formula.

```
\m{\getbuffer[styleformula]}
```

$(2,2,2) + \sum_{(2,2,5)}^{(2,2,4)} (2,2,2)_{(2,2,5)} + \int_{(2,2,5)}^{(2,2,4)} + \frac{(2,2,5)}{(2,2,5)} + \frac{\frac{(2,5,7)}{(2,5,7)}}{\frac{(2,5,7)}{(2,5,7)}} + (2,2,2)^{(2,2,4)^{(2,4,6)}}$

The user can enforce a certain style, see the tables below. For the ones that start with `trigger` only the change imposed by the name is done. So, for example `\triggercrampedstyle` will enable cramped mode, without altering the display/tex/script/scriptscript style.

	uncramped	cramped
display	`\displaystyle`	`\crampeddisplaystyle`
text	`\textstyle`	`\crampedtextstyle`
script	`\scriptstyle`	`\crampedscriptstyle`
scriptscript	`\scriptscriptstyle`	`\crampedscriptscriptstyle`

Intermezzo 1.2

`\triggerdisplaystyle`	`\triggeruncrampedstyle`
`\triggertextstyle`	`\triggercrampedstyle`
`\triggerscriptstyle`	
`\triggerscriptscriptstyle`	

Intermezzo 1.3

`\triggersmallstyle`	`\triggerbigstyle`
`\triggeruncrampedsmallstyle`	`\triggeruncrampedbigstyle`
`\triggercrampedsmallstyle`	`\triggercrampedbigstyle`

Intermezzo 1.4

2 The building blocks of formulas

2.1 Alphabets and styles

By default, when we type Latin letters in math mode, we get italic Latin letters. For example, `\m{xyzXYZ}` gives $xyzXYZ$. However, in Unicode math, there are slots for several math alphabets with differently styled Latin letters. We show how to access them in Intermezzo 2.1. In fact, Unicode Math does only have a Script alphabet. A few fonts combine Calligraphic as a substitution, but TEXGyre Pagella, that we use here, does not. That is the reason we get the same output for both these alphabets. The macros we show can be used both as a grouped macro and as a macro with an argument. This means that, for example, both `{\mathfrak abcABC}` and `\mathfrak{abcABC}` give the same result, $\mathfrak{abcABC}$.

Serif	`\mathrm`	abcABC
Sans	`\mathss`	abcABC
Typewriter	`\mathtt`	$\mathtt{abcABC}$
Calligraphic	`\mathcal`	$\mathscr{abcABC}$
Script	`\mathscr`	$\mathscr{abcABC}$
Fraktur	`\mathfrak`	$\mathfrak{abcABC}$
Doublestruck bold	`\mathbb`	$\mathbb{abcABC}$

Intermezzo 2.1

Some alphabets are available in more than one style, as shown in Intermezzo 2.2. When entering math mode, the default style for the serif alphabet is italic.

Normal	`\mathtf`	abcABC
Italic	`\mathit`	$abcABC$
Bold	`\mathbf`	$\mathbf{abcABC}$
Bold italic	`\mathbi`	$\boldsymbol{abcABC}$

Intermezzo 2.2

When we change to a different alphabet, the font style is set to normal, but changing the font style does not automatically switch back to the default alphabet.

```
\startformula
  \mathss u + v \neq \mathit u + v \neq \mathrm u + v
\stopformula
```

$$\mathsf{u} + \mathsf{v} \neq \mathsf{u} + \mathsf{v} \neq \mathrm{u} + \mathrm{v}$$

Most fonts lack at least some alphabet. The Lucida Bright Math font, for example, lacks glyphs for the bold fraktur and the lowercase blackboard bold alphabets.

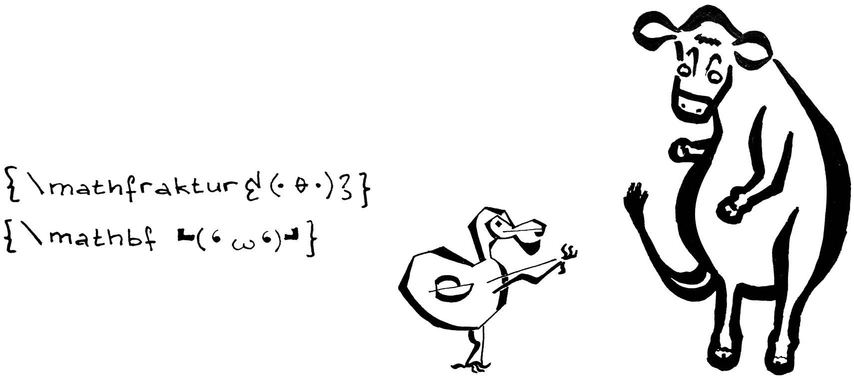
```
\startformula
  \mathbb   a + A \neq \mathfrak a + A \neq \mathbf   a + A
\stopformula
```

$$\mathrm{a} + \mathbb{A} \neq \mathfrak{a} + \mathfrak{A} \neq \mathfrak{a} + \mathfrak{A}$$

The same snippet in TEXGyre Pagella Math shows like this.

$$\mathbb{a} + \mathbb{A} \neq \mathfrak{a} + \mathfrak{A} \neq \boldsymbol{\mathfrak{a}} + \boldsymbol{\mathfrak{A}}$$

In fact, regarding the calligraphic and script alphabets, only the script has dedicated Unicode slots. Some fonts have a calligraphic alphabet in these slots, and others have script alphabets there. Only a few come with both, and then the other is given as a style alternative. In the configured math fonts, ConTEXt will give the correct results for `\mathcal` and `\mathscr` if both alphabets exist in the font. If only one of them exists, you will get that one in both cases. We show in §9 how to use the calligraphic and script alphabets (in fact, any alphabet) from a different font.



In addition to the Latin alphabets, the Greek alphabet is often used. Since most keyboards lack the greek letters, they are obtained via macros, such as `\im{\alpha\beta\gamma}` for $\alpha\beta\gamma$. Alternatively, if the user's keyboard or input method supports Unicode, they can directly input the Greek letters by typing `\im{αβγ}`. While it is possible to call for the correct Unicode slot for each letter directly, this can be rather cumbersome.

```
\startformula
  \alpha = α = \utfchar{"1D6FC} = \char"1D6FC
\stopformula
```

$$\alpha = \alpha = \alpha = \alpha$$

By convention, uppercase Greek letters are set upright while the default style for lowercase Greek letters is italic, and this convention is followed in ConTEXt. We can use `\setupmathematics` to alter this default. If we want to enforce an upright or italic style for Greek letters locally, we can use the `\mathgreekupright` and `\mathgreekitalic` commands.

```
\startformula
  \alpha\beta\Gamma \neq
  \mathgreekupright
  \alpha\beta\Gamma \neq
  \mathgreekitalic
  \alpha\beta\Gamma
\stopformula
```

$$\alpha\beta\Gamma \neq \upalpha\upbeta\Gamma \neq \alpha\beta\mathit{\Gamma}$$

The logic behind the decision on which alphabets have been included in Unicode can sometimes be difficult to understand. For serif Greek, there are four styles available: normal, italic, bold, and bold italic. However, for sans serif Greek, only bold and bold italic alphabets are available, with no normal or italic options.

```
\startformula
  \alpha\beta\Gamma \neq
  \mathbf
```

```
  \alpha\beta\Gamma \neq
  \mathss\mathbf
  \alpha\beta\Gamma \neq
  \mathgreekitalic
  \alpha\beta\Gamma \neq
  \mathgreekupright
  \alpha\beta\Gamma
\stopformula
```

$$\alpha\beta\Gamma \neq \boldsymbol{\alpha\beta}\Gamma \neq \boldsymbol{\alpha\beta\Gamma} \neq \boldsymbol{\alpha\beta\mathit{\Gamma}} \neq \boldsymbol{\alpha\beta\Gamma}$$

Do not use more styles or weights than you really need.

2.2 Non-alphabetic symbols

Symbols that are not part of the alphabet can be entered directly via the keyboard, such as the plus sign (`+`), minus sign (`-`), and equals sign (`=`). However, some symbols require the use of macros, like the wedge symbol (`\wedge`) in the example below.

```
\startformula
  u \wedge v + v \wedge u = 0
\stopformula
```

$$u \wedge v + v \wedge u = 0$$

See §12 for an extensive list of symbols and the macros connected with them, as well as how to define new symbols that you need.

2.3 Bold math

The techniques we have covered for changing the style of alphanumeric characters do not apply to non-alphanumeric symbols. Some math fonts include a bold weight that can be activated using the `\mb` command. As shown in the example below, this not only makes the characters bolder, but also affects the bar, plus, and equal signs, and so on. However, it's worth noting that in the fonts we've tested, the bold families are not complete. For that reason, faking bold is often used instead.

```
\startformula
          abc + 2592 = xyz + 2^5 \times 9^2 \breakhere
  \mathbi abc + 2592 = xyz + 2^5 \times 9^2 \breakhere
  \mb     abc + 2592 = xyz + 2^5 \times 9^2
\stopformula
```

$$abc + 2592 = xyz + 2^5 \times 9^2$$

$$\boldsymbol{abc} + \mathbf{2592} = \boldsymbol{xyz} + \mathbf{2}^{\mathbf{5}} \times \mathbf{9}^{\mathbf{2}}$$

$$\boldsymbol{abc + 2592 = xyz + 2^5 \times 9^2}$$

2.4 Mathematical expressions and functions

Mathematical expressions and functions that have a fixed meaning are typically set in an upright style, with additional space added around them. For example, to typeset the sine function, which is typically written in an upright style, we use the command `\sin(x)` instead of `sin(x)`, which would produce $sin(x)$. In the most common cases, the required commands for these functions are predefined, see Intermezzo 2.3.

\arccos	$\arccos(x)$	\arcsin	$\arcsin(x)$	\arctan	$\arctan(x)$
\arccosh	$\operatorname{arccosh}(x)$	\arcsinh	$\operatorname{arcsinh}(x)$	\arctanh	$\operatorname{arctanh}(x)$
\acos	$\arccos(x)$	\asin	$\arcsin(x)$	\atan	$\arctan(x)$
\arg	$\arg(x)$	\cos	$\cos(x)$	\cosh	$\cosh(x)$
\cot	$\cot(x)$	\coth	$\coth(x)$	\csc	$\csc(x)$
\deg	$\deg(x)$	\diff	$\mathrm{d}(x)$	\dim	$\dim(x)$
\exp	$\exp(x)$	\hom	$\hom(x)$	\ker	$\ker(x)$
\lg	$\lg(x)$	\ln	$\ln(x)$	\log	$\log(x)$
\sec	$\sec(x)$	\sin	$\sin(x)$	\sinh	$\sinh(x)$
\tan	$\tan(x)$	\tanh	$\tanh(x)$		

Intermezzo 2.3

These are defined with `\definemathfunction`, as for example

```
\definemathfunction[cos]
```

We often use subscripts for some of these constructions, which can be placed either inline or below (or above) the text.

```
We expect \im{\lim_{x\to+\infty} f(x)} in inline math,
but in a displayed math we prefer


\startformula
  \lim_{x\to+\infty} f(x).
\stopformula
```

We expect $\lim_{x\to+\infty} f(x)$ in inline math, but in a displayed math we prefer

$$\lim_{x\to+\infty} f(x).$$

The macro `\lim` is defined as

```
\definemathfunction
  [lim]
  [mathlimits=auto]
```

and the `mathlimits=auto` option places the subscripts below in displayed formulas. Below is a list of the math functions defined with this limit behavior (either `mathlimits=auto` or `mathlimits=yes`).

\det	$\det A$	\gcd	$\gcd(m, n)$	\inf	$\inf_{x\in\mathbb{R}} f(x)$
\inv	$\operatorname{inv} A$	\injlim	$\operatorname{inj\,lim}(A_i)$	\liminf	$\liminf a_n$
\limsup	$\limsup a_n$	\lim	$\lim_{x\to 0^+}(1+x)^{1/x}$	\median	$\operatorname{median} x$
\max	$\max(1, 2, 3)$	\min	$\min(1, 2, 3)$	\mod	$a \bmod b$
\projlim	$\operatorname{proj\,lim}^{(i)}$	\Pr	$\Pr(A \cap B)$	\sup	$\sup_{x\in\Omega} f(x)$

Intermezzo 2.4

We can use `\mfunction` to typeset a function that is not predefined.

If we plan to use the same function in multiple places, it is recommended to define a new instance with `\definemathfunction`.

```
\definemathfunction[hav]
```

```
\startformula
  \hav(\theta) = \frac{1 - \cos(\theta)}{2}
\stopformula
```

$$\operatorname{hav}(\theta) = \frac{1 - \cos(\theta)}{2}$$

Although we could have explicitly added `mathlimits=no` to the definition of `\hav`, we skipped it since it is already the default behavior.

Some math functions, like `\injlim` and `\projlim`, vary with the language. If we typeset `\im{\injlim^{(1)} = \projlim^{(1)}}` we get $\operatorname{inj\,lim}^{(1)} = \operatorname{proj\,lim}^{(1)}$. If we first switch to Spanish and typeset it, we get instead $\operatorname{lím\,iny}^{(1)} = \operatorname{lím\,proy}^{(1)}$. For the `\injlim` and `\projlim` some prefer a variant.

```
\setupmathlabeltext
  [en]
  [varprojlim={\wideunderleftarrow{\lim}}]

\setupmathlabeltext
  [en]
  [varinjlim={\wideunderrightarrow{\lim}}]

\definemathfunction
  [varprojlim]
  [mathlimits=no]

\definemathfunction
  [varinjlim]
  [mathlimits=no]

\startformula
  \varinjlim^{(1)} \bar{H}_{n+1}^{\gamma}
  \rightarrow
  \bar{H}_n(\varprojlim C_{\gamma}^{*}; G)
  \rightarrow
  \varinjlim \bar{H}_{n}^{\gamma}
\stopformula
```

$$\varinjlim^{(1)} \bar{H}_{n+1}^{\gamma} \rightarrow \bar{H}_n(\varprojlim C_{\gamma}^{*}; G) \rightarrow \varinjlim \bar{H}_{n}^{\gamma}$$

In the same spirit we can define variants of `\liminf` and `\limsup`.

```
\setupmathlabeltext
  [en]
  [varliminf={\underbar{\lim}}]

\setupmathlabeltext
  [en]
  [varlimsup={\overbar{\lim}}]

\definemathfunction
  [varliminf]
  [mathlimits=auto]
```

```
\definemathfunction
  [varlimsup]
  [mathlimits=auto]

\startformula
  \int_{\Omega} \varliminf_{n\to+\infty} f_n \dd\mu
  \leq
  \varliminf_{n\to+\infty} \int_{\Omega} f_n \dd\mu
  \mtp{,}
  \varlimsup_{n\to+\infty} \int_{\Omega} f_n \dd\mu
  \leq
  \int_{\Omega} \varlimsup_{n\to+\infty} f_n \dd\mu
\stopformula
```

$$\int_{\Omega} \varliminf_{n\to+\infty} f_n \, d\mu \leq \varliminf_{n\to+\infty} \int_{\Omega} f_n \, d\mu, \quad \varlimsup_{n\to+\infty} \int_{\Omega} f_n \, d\mu \leq \int_{\Omega} \varlimsup_{n\to+\infty} f_n \, d\mu$$

There are several ways to customize the style of math functions. For instance, if we want to typeset function names in a colored sans serif font, we can use `\setupmathfunctions`:

```
\setupmathfunctions
  [style=sans,
   color=C:3]

\startformula
  \sin^2\alpha + \cos^2\alpha = 1.
\stopformula
```

$$\sin^2\alpha + \cos^2\alpha = 1.$$

It is also possible to set the colors one by one when typing the formula. But please be a bit careful. Since for example $\cos[(x+y)(x-y)]$ is a valid formula, we do not want to activate the brackets here. For that reason you need to use the built-in `\mfunction` to apply the settings at one place.

When setting colors for individual functions, it is important to avoid inadvertently activating any special formatting. For example, the expression $\cos[(x+y)(x-y)]$ contains brackets that should not be considered as brackets for arguments. To ensure this, we use instead the `\mfunction` command.

```
\startformula
  \mfunction[color=C:3]{cos}[(x + y)(x - y)]
  \neq
  \mfunction[color=C:2][cos][(x + y)(x - y)]
  \neq
  \cos[color=C:1](\alpha)
\stopformula
```

$$\cos[(x+y)(x-y)] \neq \cos[(x+y)(x-y)] \neq \cos[color = C:1](\alpha)$$

The last example “fails” on purpose.

2.5 Fences

Fences, also known as paired delimiters, are a pair of symbols used to visually group parts of a formula. The most commonly used symbols for fences are parentheses ( ), brackets [ ], braces { }, angle brackets ⟨ ⟩, bars | |, and double vertical bars ‖ ‖. These paired symbols are often used when nested bracketing is needed, such as $3\{[f(x)+g(x)]+h(x)\}$.

In §1.2, you may have seen two ways to typeset fences: using `\fenced` or using `\left` and `\right` pairs. Let's take a look at a few more examples.

```
\startformula
  \fenced[parenthesis]       { 1 + \frac{a}{b} }      \mtp{}
  \fenced[bracket]           { F(x)^2          }_a^b \mtp{}
  \fenced[bracket][size=big] { F(x)^2          }_a^b \mtp{}
  \fenced[brace]             { \frac{x}{n}     }      \mtp{}
  \fenced[angle]             { f, g            }
\stopformula
```

$$\left(1+\frac{a}{b}\right) \quad [F(x)^2]_a^b \quad \big[F(x)^2\big]_a^b \quad \left\{\frac{x}{n}\right\} \quad \langle f,g\rangle$$

In the example above, the key `size=big` is used to specify a particular size for the bracket. The available options are `big`, `Big`, `bigg`, and `Bigg`, or alternatively, a number can be specified, such as 1, 2, 3, or 4. If you set `size=0`, the fence will not be scaled at all, and the base character will be used instead.

```
\startformula
  a(b + c)d =
  a\fenced[parenthesis]{b + c}d =
  a\left( b + c \right)d
\stopformula
```

$$a(b+c)d=a(b+c)d=a(b+c)d$$

If you use the system with `\left` and `\right`, you can also enforce different sizes with help of `\F`. For example, `\F1` gives the same as `big`. Note that these in fact change a state, so you have to group if you do not want them to spill over to the upcoming fences.

```
\startformula
  \left(        1 + \frac{a}{b} \right)        \mtp{}
  \left[        F(x)^2          \right]_a^b    \mtp{}
  {\F1\left[    F(x)^2          \right]_a^b}   \mtp{}
  \left\{       \frac{x}{n}     \right\}       \mtp{}
  \left\langle  f, g            \right\rangle
\stopformula
```

$$\left(1+\frac{a}{b}\right) \quad [F(x)^2]_a^b \quad \big[F(x)^2\big]_a^b \quad \left\{\frac{x}{n}\right\} \quad \langle f,g\rangle$$

The size of the fences can be calculated with different methods, and the result depends on the vertical variants that the font supports. Traditionally TEX provided the base size, four variants and extensibles. The four variants could be accessed with the help of `big`, `Big`, `bigg`, and `Bigg`. With Opentype math fonts, there can be many more variants. If we do not specify the size to the fence macro, we get the size that fits. We can specify the size explicitly, either with the keywords just mentioned or by using numbers. The variants that are used can be decided via the `\setupmathfence`. If `alternative=big` is used (default) the variants specified in the goodie file are used. If `alternative=small` is used, then for example `size=3` really gives the third variant.

```
\im{
  \fenced[parenthesis][size=7]{
```

```
  \fenced[parenthesis][size=6]{
  \fenced[parenthesis][size=5]{
  \fenced[parenthesis][size=4]{
  \fenced[parenthesis][size=3]{
  \fenced[parenthesis][size=2]{
  \fenced[parenthesis][size=1]{
  \fenced[parenthesis][size=0]{A}}}}}}}}
}
```

$$\Biggl(\Biggl(\biggl(\biggl(\Bigl(\bigl(((A))\bigr)\Bigr)\biggr)\biggr)\Biggr)\Biggr) \qquad \Biggl(\Biggl(\biggl(\biggl(\Bigl(\bigl(((A))\bigr)\Bigr)\biggr)\biggr)\Biggr)\Biggr)$$

`alternative=big` `alternative=small`

This is how it looks for Garamond Math.

$$\Biggl(\Biggl(\biggl(\biggl(\Bigl(\bigl(((A))\bigr)\Bigr)\biggr)\biggr)\Biggr)\Biggr) \qquad \Biggl(\Biggl(\biggl(\biggl(\Bigl(\bigl(((A))\bigr)\Bigr)\biggr)\biggr)\Biggr)\Biggr)$$

`alternative=big` `alternative=small`

This is how it looks for Lucida Bright Math.

$$\Biggl(\Biggl(\biggl(\biggl(\Bigl(\bigl(((A))\bigr)\Bigr)\biggr)\biggr)\Biggr)\Biggr) \qquad \Biggl(\Biggl(\biggl(\biggl(\Bigl(\bigl(((A))\bigr)\Bigr)\biggr)\biggr)\Biggr)\Biggr)$$

`alternative=big` `alternative=small`

And this is how it looks for TEXGyre Bonum Math.

$$\Biggl(\Biggl(\biggl(\biggl(\Bigl(\bigl(((A))\bigr)\Bigr)\biggr)\biggr)\Biggr)\Biggr) \qquad \Biggl(\Biggl(\biggl(\biggl(\Bigl(\bigl(((A))\bigr)\Bigr)\biggr)\biggr)\Biggr)\Biggr)$$

`alternative=big` `alternative=small`

As you can see, the fonts behave differently. Once you are aware of this, you can set the alternative you like best with `\setupmathfence`.

In formulas where you need no manual size tweaking, you can use `\autofences`. The result is that identified delimiter pairs will automatically scale to the size that would have been used if `\left` and `\right` had been used.

```
\startformula
  \autofences
  (       1 + \frac{a}{b}  )       \mtp{}
  [       F(x)^2           ]_a^b   \mtp{}
  \{      \frac{x}{n}      \}      \mtp{}
  \langle f, g             \rangle \mtp{}
  (       \sum_{k=1}^n a_k )
\stopformula
```

$$\left(1+\frac{a}{b}\right) \quad \left[F(x)^2\right]_a^b \quad \left\{\frac{x}{n}\right\} \quad \langle f,g\rangle \quad \left(\sum_{k=1}^n a_k\right)$$

As the parentheses around the sum shows, this might lead to larger sizes than one usually wants.

It is considered good style to define own fences for the ones that you use often. This gives you a consistent document, and it enables you to change all occurrences of a specific construction without touching the other ones. We define a paired delimiter `Set` intended to be used for sets (there is already `set` pre-defined for this purpose).

```
\definemathfence
  [Set]
  [brace]
  [define=yes,
   middle=`|]
```

We have defined `Set` as a copy of the `brace` fence. Thanks to `define=yes` the definition also creates a macro `\Set` that can be used instead of `\fenced[Set]`, and we also gave the bar to be used as a separator by using `\fence`. Note the backtic there to provide a number to the `middle` key. To prevent the extra creation of the macro, we can add `define=no`. We look at a few examples where the `\Set` fence is used.

```
\startformula
  \Set{ x\in\reals \fence \frac{x^2}{a^2} < 1 } =
  \Set{ x\in\reals \fence x^2 < a^2 } =
  \Set[size=1]{ x\in\reals \fence x^2 < a^2 }
\stopformula
```

$$\left\{x \in \mathbb{R} \,\middle|\, \frac{x^2}{a^2} < 1\right\} = \{x \in \mathbb{R} \mid x^2 < a^2\} = \{x \in \mathbb{R} \mid x^2 < a^2\}$$

We give one more example, where we use an empty left delimiter.

```
\definemathfence
  [evaluate]
  [define=yes,
   left=none,
   right=`|]
```

We use it like this.

```
\startformula
    \int_1^2 x^2 \dd x
  = \evaluate{\frac{x^3}{3}}_1^2
  = \frac{2^3}{3} - \frac{1^3}{3}
  = \frac{7}{3}
\stopformula
```

$$\int_1^2 x^2\, dx = \left.\frac{x^3}{3}\right|_1^2 = \frac{2^3}{3} - \frac{1^3}{3} = \frac{7}{3}$$

In Intermezzo 2.5 we list some predefined fences (the `moustache` is not present in TEXGyre Pagella Math, you have to use your imagination, perhaps you can picture Salvador Dalí). There are some more, you can try for example mirrored versions, as in `mirroredfloor`.

`parenthesis`	$\left(\frac{1+x}{1-x}\right)$	`bracket`	$\left[\frac{1+x}{1-x}\right]$	`brace`	$\left\{\frac{1+x}{1-x}\right\}$
`bar`	$\left\vert\frac{1+x}{1-x}\right\vert$	`doublebar`	$\left\Vert\frac{1+x}{1-x}\right\Vert$	`triplebar`	$\left\vert\left\Vert\frac{1+x}{1-x}\right\Vert\right\vert$
`angle`	$\left\langle\frac{1+x}{1-x}\right\rangle$	`doubleangle`	$\left\langle\!\left\langle\frac{1+x}{1-x}\right\rangle\!\right\rangle$	`solidus`	$\left/\frac{1+x}{1-x}\right/$
`ceiling`	$\left\lceil\frac{1+x}{1-x}\right\rceil$	`floor`	$\left\lfloor\frac{1+x}{1-x}\right\rfloor$	`moustache`	$\frac{1+x}{1-x}$
`uppercorner`	$\ulcorner\frac{1+x}{1-x}\urcorner$	`lowercorner`	$\llcorner\frac{1+x}{1-x}\lrcorner$	`group`	$\left\lgroup\frac{1+x}{1-x}\right\rgroup$
`openbracket`	$\left[\!\left[\frac{1+x}{1-x}\right]\!\right]$	`cases`	$\left\{\frac{1+x}{1-x}\right.$	`sesac`	$\left.\frac{1+x}{1-x}\right\}$

Intermezzo 2.5

We emphasize again that it is important to clearly define new instances that convey meaning. If you require angular brackets for the inner product and occasionally need a vertical bar in the middle, you can create a fence called `IP` that possesses the desired properties (again, there is a fence `innerproduct` pre-defined with these properties).

```
\definemathfence
  [IP]
  [angle]
  [define=yes,
   middle=`|]
```

Once defined, you can utilize `\IP` throughout your document with ease. Additionally, if you ever need to modify the notation for inner products, you can simply update the definition of `\IP`.

```
\startformula
  \IP{\phi \fence \psi} =
  \int_{\Omega} \conjugate{\phi(x)}\psi(x) \dd \mu(x)
\stopformula
```

$$\langle \phi \mid \psi \rangle = \int_{\Omega} \overline{\phi(x)}\psi(x)\, d\mu(x)$$

There are a few fences for intervals predefined (see Intermezzo 2.6).

`closedinterval`	$[a,b]$		
`openinterval`	(a,b)	`varopeninterval`	$]a,b[$
`leftopeninterval`	$(a,b]$	`varleftopeninterval`	$]a,b]$
`rightopeninterval`	$[a,b)$	`varrightopeninterval`	$[a,b[$

Intermezzo 2.6

In fact, all these intervals are inheriting from the `interval` fence, so we can setup all of them at once.

```
\setupmathfence
  [interval]
  [color=C:3,
   symbolcolor=C:2]
```

```
\startformula
  \fenced[openinterval]{a,b} = \fenced[varopeninterval]{a,b}
\stopformula
```

$$(a, b) =]a, b[$$

In a document, just as for the other fences, you typically define your own instances as the relevant copies.

```
\definemathfence
  [ooint]
  [varopeninterval]
  [define=yes]

\startformula
  A = \ooint{0,1} \cup \ooint{2,3} \breakhere
  A = ]0,1[ \cup ]2,3[
\stopformula
```

$$A =]0, 1[\cup]2, 3[$$

$$A =]0, 1[\cup]2, 3[$$

There is some bracket matching magic going on in the second line here that makes the spacing around the brackets to be good. In traditional TEX the input `]0,1[ \cup ]2,3[` in math would give very ugly spacing. It is more safe to use the fences mechanism, which automatically assigns the appropriate math atom type to the delimiters, ensuring proper spacing.

2.6 Sub- and superscripts

As we've seen in previous examples, superscripts are created using the caret symbol (`^`) and subscripts are created using the underscore symbol (`_`).

```
\startformula
  a_k = 2^k + 3^k
\stopformula
```

$$a_k = 2^k + 3^k$$

When setting more complicated expressions than single symbols as sub- or superscripts, it is necessary to use grouping.

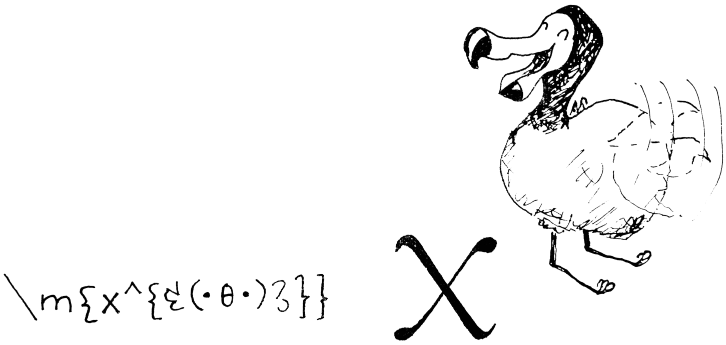
```
\startformula
  a_{k + 2} - 5a_{k + 1} + 6a_k = 0
\stopformula
```

$$a_{k+2} - 5a_{k+1} + 6a_k = 0$$

We have in fact so far only mentioned postscripts. It would be more correct to talk about postsubscripts and postsuperscripts. There is also native support for presubscripts and presuperscripts. They are accessed via triple carets or underscores.

```
\startformula
  a^2 b + 3F_1___2(a,b;c;z) - X_1^2___3^^^4
\stopformula
```

$$a^2b + 3{}_2F_1(a, b; c; z) - {}_3^4X_1^2$$



The mechanism of adding sub- and superscripts is slightly different for single characters and for larger constructions like big parentheses, or content put into boxes. We show an example below with a square of size 1cm. To the left it is considered as a single character, and the power two is placed on a certain height, as it would be on any character. To the right it is seen as a box, and the vertical placement of the power two is adapted.

$$\blacksquare^2 \quad \blacksquare^2$$

Here we have used the math atom option `single` to obtain the first case. One place where this is adapted is for functions like `\sin`, and it is done in order to have the superscripts placed at the same height in formulas like $\cos^2 \alpha + \sin^2 \alpha = 1$.

2.7 Tensors, multilevel sub- and superscripts

In some areas of mathematics and physics it is common to use several sub- and superscripts. We can meet expressions like Γ^n_{ki} but also more complicated constructions like ${\Gamma^n}_k{}^i$. The good news is that this can be done pretty simply with the help of multiple sets of sub- and superscripts. By this we mean that it is possible to bound several sub- and superscripts to one atom. We show how the formulas in this paragraph were input, with one additional formula.

```
\startformula
  \Gamma^n_{ki}
  \neq \Gamma^{n} \noscript _{k} \noscript ^{i}
  \neq \Gamma^{n} ^{}        _{k} _{}        ^{i}
\stopformula
```

$$\Gamma^n_{ki} \neq {\Gamma^n}_k{}^i \neq {\Gamma^n}_k{}^i$$

The first one has only one level; one subscript and one superscript. The second one has three levels. In the innermost we only have a superscript and in the next only a subscript, and in the third, finally, only a superscript. We have stepped to the next level via `\noscript`. We can also use empty sub- or superscripts to enforce going to the next level, as in the third expression.

It is possible to tweak a bit where the indices show up vertically by using the `align-scripts` key of `\setupmathematics`. Below we see `\getbuffer` set with the indicated value of `alignscripts`, with the following code.

```
\Gamma_{\nu}_{\mu}^{\kappa}_{\lambda}^{} + \Gamma_{\lambda}^{}
```

$\Gamma_{\nu\mu}{}^{\kappa}{}_{\lambda} + \Gamma_\lambda$	$\Gamma_{\nu\mu}{}^{\kappa}{}_{\lambda} + \Gamma_\lambda$	$\Gamma_{\nu\mu}{}^{\kappa}{}_{\lambda} + \Gamma_\lambda$	$\Gamma_{\nu\mu}{}^{\kappa}{}_{\lambda} + \Gamma_\lambda$
`yes`	`always`	`empty`	`no`

For horizontal spacing, it is a bit more complicated. Traditionally, TeX adds `\scriptspace` after sub- and superscripts. One reason is that the glyphs in traditional fonts lie about their widths. It is always added but in some cases it is not wanted. In luametaTeX we have more control over the inter atom spacing, which means that this space is no longer suitable for our needs.

In Unicode Math there is a font parameter `SpaceAfterScript`, that is trying to imitate the traditional TeX approach. We need support for multiscripts and we want to avoid the unwanted spaces, so we need a slightly more advanced model. In fact, the `SpaceAfterScript` is still listened to, and the space is always added, but we have an extra parameter `SpaceBetweenScript` that gets added instead between different levels of a multiscript. So, between multiscripts we use `SpaceBetweenScript` instead.

In fact, what is really added is `SpaceBetweenScript` multiplied by `interscriptfactor`. This means that a value of `0` will result in no space added. The default value of `interscriptfactor` is `1`.

```
\Gamma_{\nu}_{\mu}^{\kappa}_{\lambda}^{} +
\Gamma_{\lambda}\noscript^{\mu}^{\kappa}
```

$\Gamma_{\nu\mu\lambda}^{\kappa} + \Gamma_{\lambda}{}^{\mu\kappa}$	$\Gamma_{\nu\mu\lambda}^{\kappa} + \Gamma_{\lambda}{}^{\mu\kappa}$	$\Gamma_{\nu\mu\lambda}^{\kappa} + \Gamma_{\lambda}{}^{\mu\kappa}$	$\Gamma_{\nu\mu\lambda}^{\kappa} + \Gamma_{\lambda}{}^{\mu\kappa}$
`0`	`.5`	`1`	`2`

We give one more example. Since we by default ignore (regarding to vertical spacing) empty braces, we enter them for clarity.

```
\startformula
  h _{}        ^{\lambda}
   _{\kappa} ^{}
   _{\mu}    ^{}
   _{}       ^{\nu}
   _{\phi}   ^{}
  \in V \otimes V^{*} \otimes V^{*}
        \otimes V     \otimes V^{*}
\stopformula
```

$$h^{\lambda}{}_{\kappa\mu}{}^{\nu}{}_{\phi} \in V \otimes V^{*} \otimes V^{*} \otimes V \otimes V^{*}$$

Multiple prescripts are also possible, but perhaps of less usage. We show only one example. As you see, the ordering of the input is allowed to change.

```
\startformula
  X_{1}^{2}___{a}^^^{b}
   _{3}^{4}___{c}^^^{d}
   _{5}^{6}___{e}^^^{f}
  =
  X_{1}___{a}^^^{b}^{2}
   _{3}___{c}^^^{d}^{4}
   _{5}___{e}^^^{f}^{6}
\stopformula
```

$${}^{fdb}_{eca}X^{246}_{135} = {}^{fdb}_{eca}X^{246}_{135}$$

We give one nested example, found in some article.

```
\startformula
  a = a_   {b_{d}___{e}}
       ___{c_{f}___{g}}
\stopformula
```

$$a = {}_{{}_{g}c_{f}}a_{{}_{e}b_{d}}$$

We remind you once more to be nice to your readers regarding the choice of notation.

2.8 Prime time

Primes are a often used, in particular to denote derivatives. They indicate the number of times a function has been differentiated, with a single prime denoting the first derivative, a double prime denoting the second derivative, and so on.

```
\startformula
  f' + f'' + f''' + f''''
  =
  f\prime + f\prime\prime + f\prime\prime\prime +
  f\prime\prime\prime\prime
\stopformula
```

$$f' + f'' + f''' + f'''' = f' + f'' + f''' + f''''$$

Primes behave a bit like superscripts, but they are handled in their own way. If you just read the previous section, you know that we can have several levels of sub- and superscripts. This also applies to primes. In each level the primes are collected, and then put *outside* the superscript in that level, if present. If there happens to be a subscript only in the level, the primes are put on top of that. This means that if we want to type something like f'^{2} we need to type `f\prime\noscript^{2}` in order to push the superscript 2 into the next level. If you need to typeset the square of f', it is however likely nicer for the reader if you write $(f')^2$ rather than f'^{2}.

Additional primes are not starting new levels of sub/superscripts. Instead they are collected and joined into some multiprime construction. Look closely at the following example. All different terms use one level, only.

```
\startformula
  f_a^b' + f'_a^b + f_a'^b + f_a^b'' + f_a'^b'
  \neq
  f^b' + f'^b
  \neq
  f_a' + f'_a
\stopformula
```

$$f_a^{b\prime} + f_a^{b\prime} + f_a^{b\prime} + f_a^{b\prime\prime} + f_a^{b\prime\prime} \neq f^{b\prime} + f^{b\prime} \neq f_a' + f_a'$$

Compare that with the following examples where we use two levels. Look carefully on where the primes end up.

```
\startformula
  f_a^b'_a' + f'_a^b'^b + f_a^b''^b
\stopformula
```

$$f_{a\;a}^{b\prime\prime} + f_a^{b\prime\prime b} + f_a^{b\prime\prime b}$$

In the first part of the example the `_a^b'` make up one level, and then the `_a` forces the next level, and the prime there will then go above it, since there is no superscript in that level. In the second part of the example, the second prime is not starting a new group (remember, only sub- and superscripts do), but it is joined with the first prime into a double prime. The last `^b` starts a new level. The third example is just a more clear way to write the second example. Use `\\noscript` not only to force the next level, but also to make your code more clear.

The way primes are typeset can vary across different math fonts. Therefore, they are configured on a font-by-font basis in the goodie files. By using `\mathscriptbelow` we can visualize the line where the primes are anchored. (It also shows the lines where the sub- and superscripts are anchored.)

```
\startformula
  \mathscriptbelow
  f' \neq f^2
\stopformula
```

$$f' \neq f^2$$

If several levels are used, we run by default over the different levels and realign the primes so that all of them sit at the same height.

Let us also mention the `\primed` macro, that can be used to typeset primes in a different way (these types of constructions will be discussed again in §2.9 below).

```
\startformula
  (f')^2 = (\primed{f})^2 = \primed{f}^2 = f^{}\prime^2
  \neq
  (f^2)' = \primed{(f^2)} = \primed{f^2}
\stopformula
```

$$(f')^2 = (f')^2 = f'^2 = f'^2 \neq (f^2)' = (f^2)' = f^{2\prime}$$

Finally, it is not a good idea to write `f^{\prime}` or `f^{'}` since that will put the primes in the superscript, and the output will be different (and likely bad in many cases), $f^{\prime}$. We end with an example found on the preprint server arXiv, showing a creative use of pre- and postscripts, as well as primes:

```
\startformula
  \mathbf{D}_{t}^{\alpha}___{a}^^^{C} f(t) =
  \frac{1}{\Gamma(n - \alpha)}
  \int_{a}^{t} \frac{1}{(t - t')^{\alpha + 1 - n}}
             \frac{\dd^n}{\dd t^{}'^{n}} f(t') \dd t'
\stopformula
```

$${}_{a}^{C}\mathbf{D}_{t}^{\alpha} f(t) = \frac{1}{\Gamma(n - \alpha)} \int_{a}^{t} \frac{1}{(t - t')^{\alpha + 1 - n}} \frac{d^n}{dt'^{n}} f(t')\, dt'$$

2.9 Accents/embellishments

There are several predefined accents to put on characters. The accents below are meant for single characters, and do not stretch horizontally.

\grave	$\grave{x}$	\acute	$\acute{x}$	\hat	$\hat{x}$
\tilde	$\tilde{x}$	\bar	$\bar{x}$	\breve	$\breve{x}$
\dot	$\dot{x}$	\ddot	$\ddot{x}$	\ring	$\mathring{x}$
\check	$\check{x}$	\overleftharpoon	$\overleftharpoon{x}$	\overrightharpoon	$\overrightharpoon{x}$
\dddot	$\dddot{x}$	\ddddot	$\ddddot{x}$		

Intermezzo 2.7

To place accents over more than one character, we use the stretching variants available.

\widehat	$\widehat{x+y}$	\widetilde	$\widetilde{x+y}$
\widebar	$\overline{x+y}$	\widecheck	$\widecheck{x+y}$
\wideoverleftharpoon	$\overleftharpoon{x+y}$	\wideoverrightharpoon	$\overrightharpoon{x+y}$
\wideoverleftarrow	$\overleftarrow{x+y}$	\wideoverrightarrow	$\overrightarrow{x+y}$
\wideoverleftrightarrow	$\overleftrightarrow{x+y}$	\wideunderbar	$\underline{x+y}$
\wideunderleftrightarrow	$\underleftrightarrow{x+y}$	\wideunderrightharpoon	$\underrightharpoon{x+y}$
\wideunderleftharpoon	$\underleftharpoon{x+y}$	\wideunderleftarrow	$\underleftarrow{x+y}$
\wideunderrightarrow	$\underrightarrow{x+y}$		

Intermezzo 2.8

The notation $\vec{x}$ (typeset with `\vec{x}`) is often used to indicate vectors, but some may argue that it is not truly an accent, and that it is not suitable for vector notation. Instead, it might be better to use upright bold symbols such as $\mathbf{x}$ for vectors. Alternatively, if there is no risk of confusion, you can use ordinary italic letters.

Some math fonts provide several sizes of accents, and some accents have an extensible recipe. When an accent is not extensible, ConTEXt can scale the largest available piece horizontally to create the accent.

```
\startformula
  \check{u} + \widecheck{u} + \widecheck{uv} + \widecheck{uvw} +
  \widecheck{uvwx} + \widecheck{abcdefghijklmnopqrstuvwxyz}
  \breakhere
  \hat{u} + \widehat{u} + \widehat{uv} + \widehat{uvw} +
  \widehat{uvwx} + \widehat{abcdefghijklmnopqrstuvwxyz}
  \breakhere
  \tilde{u} + \widetilde{u} + \widetilde{uv} + \widetilde{uvw} +
  \widetilde{uvwx} + \widetilde{abcdefghijklmnopqrstuvwxyz}
\stopformula
```

$$\check{u} + \widecheck{u} + \widecheck{uv} + \widecheck{uvw} + \widecheck{uvwx} + \widecheck{abcdefghijklmnopqrstuvwxyz}$$

$$\hat{u} + \widehat{u} + \widehat{uv} + \widehat{uvw} + \widehat{uvwx} + \widehat{abcdefghijklmnopqrstuvwxyz}$$

$$\tilde{u} + \widetilde{u} + \widetilde{uv} + \widetilde{uvw} + \widetilde{uvwx} + \widetilde{abcdefghijklmnopqrstuvwxyz}$$

The extremely wide accents can sometimes look strange. A suggestion that we read about in [Swa99] is to enclose the content in parentheses and place the hat or tilde just to the right if the content is too wide. To achieve this, use the `marked` construction (see also below):

```
\startformula
  \widehat{f \ast g \ast h} =
  \hatmarked{(f \ast g \ast h)} =
  \hat{f} \hat{g} \hat{h}
\stopformula
```

$$\widehat{f \ast g \ast h} = (f \ast g \ast h)\widehat{} = \hat{f}\hat{g}\hat{h}$$

There are a few non-accent characters that come as `marked` versions (we have also seen `\primed` before). Judge for yourself which one you prefer.

```
\startformula
  \daggermarked{Q}Q  = Q^{\dagger}Q  \mtp{,}
  \ddaggermarked{Q}Q = Q^{\ddagger}Q \mtp{,}
  \starmarked{Q}Q    = Q^{\star}Q    \mtp{,}
  \astmarked{Q}Q     = Q^{\ast}Q
\stopformula
```

$$Q^{\dagger}Q = Q^{\dagger}Q, \quad Q^{\ddagger}Q = Q^{\ddagger}Q, \quad Q^{\star}Q = Q^{\star}Q, \quad Q^{\ast}Q = Q^{\ast}Q$$

We can put multiple accents on a letter, just by nesting the arguments. In Fourier analysis one might meet a formula like this one.

```
\startformula
  \hat{\hat{\hat{\hat{f}}}} =
  \check{\check{f}} = f
\stopformula
```

$$\hat{\hat{\hat{\hat{f}}}} = \check{\check{f}} = f$$

Instead of building towers, it might then be better to use some other notation, like $\mathcal{F}^4 f = \mathcal{P}^2 f = f$. It is, however, worth to mention that the first accent is placed on the letter according to the anchoring point, and the rest of the accents are placed centered above the first one.

```
\startformula
  \hat{\dot{u}} =
  \dot{\hat{u}}
\stopformula
```

$$\hat{\dot{u}} = \dot{\hat{u}}$$

There are several possible ways to create a longer bar or rule above an expression. These are sometimes used for closure or complex conjugation.

```
\startformula
  \bar{v} + \bar{w} =
  \widebar{v} + \widebar{w} =
  \widebar  {v + w} =
  \overbar  {v + w} =
  \overline {v + w} =
  (v + w)^*
\stopformula
```

$$\bar{v} + \bar{w} = \overline{v} + \overline{w} = \overline{v + w} = \overline{v + w} = \overline{v + w} = (v + w)^*$$

The differences in output are due to different mechanisms used. The `\bar` gives a non-stretching macron accent, while the `\widebar` provides a stretching one. The `\overbar` is in fact not an accent at all, but a stacker (see below). The `\overline` does not use the font, but draws a rule on top of the content. In older printing it was difficult (or, rather, it demanded some work) to draw horizontal lines.

In the case of complex conjugation, one shall be a bit careful. In general, when putting accents over i the dot is removed, as in $\hat{\imath}$. By using `\widebar` this is also the case. The instance `top:dot` of `mathaccent` is defined with option `i=`. It prevents the dot from being removed. The predefined accent `\conjugate` uses this.

```
\startformula
  \widebar{\cos(\theta) + \ii \sin(\theta)}
  = \cos(\theta) - \ii \sin(\theta)
  \breakhere
  \conjugate{\cos(\theta) + \ii \sin(\theta)}
  = \cos(\theta) - \ii \sin(\theta)
\stopformula
```

$$\overline{\cos(\theta) + \imath \sin(\theta)} = \cos(\theta) - i \sin(\theta)$$

$$\overline{\cos(\theta) + i \sin(\theta)} = \cos(\theta) - i \sin(\theta)$$

One could even consider alternative notations for conjugate, for example the asterisk.

Let us also add that a few Opentype fonts come with flattened accents, see the examples in Figure 2.1. Lucida does not have flattened accents, so the two hats look the same. Stix Two Math and Cambria Math have flattened accents. The effect is subtle, but the hat on the uppercase W has a slightly smaller height than the one on the lowercase w. This detail can sometimes save us from line to spread. In fonts where this is not supported, we can fake it with the `flattenaccents` tweak. This tweak is enabled in TEXGyre Bonum Math.

$$\hat{w} + \hat{W}$$

Lucida

$$\hat{w} + \hat{W}$$

Stix Two

$$\hat{w} + \hat{W}$$

Lucida (tweaked)

$$\hat{w} + \hat{W}$$

Bonum (tweaked)

Figure 2.1

2.10 Stackers and annotations

Stackers and extensibles are often used to add decorative elements above or below other content. Fortunately, a variety of these elements have already been predefined in ConTEXt. We start by discussing a type of stackers where we decorate formula snippets on the top or bottom with some brace, bracket or similar. These are a bit similar to accents, but their purpose is slightly different. See Intermezzos 2.9, 2.10 and 2.11 for some examples.

These are defined with `mathlimits=yes`, which means that we can put text or math above or below them. Thus, we can for example do

```
\startformula
  \underbrace{x + x + \ldots + x}_{= mx}
```

`\overleftrightarrow`	$\overleftrightarrow{x+y}$		
`\overleftarrow`	$\overleftarrow{x+y}$	`\overrightarrow`	$\overrightarrow{x+y}$
`\overtwoheadleftarrow`	$\overtwoheadleftarrow{x+y}$	`\overtwoheadrightarrow`	$\overtwoheadrightarrow{x+y}$
`\overlefttailarrow`	$\overlefttailarrow{x+y}$	`\overrighttailarrow`	$\overrighttailarrow{x+y}$
`\overlefttailarrow`	$\overlefttailarrow{x+y}$	`\overrighttailarrow`	$\overrighttailarrow{x+y}$
`\overlefthookarrow`	$\overlefthookarrow{x+y}$	`\overrighthookarrow`	$\overrighthookarrow{x+y}$
`\overleftharpoondown`	$\overleftharpoondown{x+y}$	`\overrightharpoondown`	$\overrightharpoondown{x+y}$
`\overleftharpoonup`	$\overleftharpoonup{x+y}$	`\overrightharpoonup`	$\overrightharpoonup{x+y}$
`\overLeftarrow`	$\overLeftarrow{x+y}$	`\overRightarrow`	$\overRightarrow{x+y}$
`\overLeftbararrow`	$\overLeftbararrow{x+y}$	`\overRightbararrow`	$\overRightbararrow{x+y}$
`\overLeftrightarrow`	$\overLeftrightarrow{x+y}$		

Intermezzo 2.9

`\underleftrightarrow`	$\underleftrightarrow{x+y}$		
`\underleftarrow`	$\underleftarrow{x+y}$	`\underrightarrow`	$\underrightarrow{x+y}$
`\undertwoheadleftarrow`	$\undertwoheadleftarrow{x+y}$	`\undertwoheadrightarrow`	$\undertwoheadrightarrow{x+y}$
`\underlefttailarrow`	$\underlefttailarrow{x+y}$	`\underrighttailarrow`	$\underrighttailarrow{x+y}$
`\underlefttailarrow`	$\underlefttailarrow{x+y}$	`\underrighttailarrow`	$\underrighttailarrow{x+y}$
`\underlefthookarrow`	$\underlefthookarrow{x+y}$	`\underrighthookarrow`	$\underrighthookarrow{x+y}$
`\underleftharpoondown`	$\underleftharpoondown{x+y}$	`\underrightharpoondown`	$\underrightharpoondown{x+y}$
`\underleftharpoonup`	$\underleftharpoonup{x+y}$	`\underrightharpoonup`	$\underrightharpoonup{x+y}$
`\underLeftarrow`	$\underLeftarrow{x+y}$	`\underRightarrow`	$\underRightarrow{x+y}$
`\underLeftbartarrow`	$\underLeftbararrow{x+y}$	`\underRightbararrow`	$\underRightbararrow{x+y}$
`\underLeftrightarrow`	$\underLeftrightarrow{x+y}$		

Intermezzo 2.10

```
  +
  \underbrace{y + y + \ldots + y}_{= ny}
  = mx + ny
\stopformula
```

$$\underbrace{x + x + \ldots + x}_{=mx} + \underbrace{y + y + \ldots + y}_{=ny} = mx + ny$$

As in many other situations, we can add struts to enforce a consistent vertical placement.

```
\startformula
```

`\overbar`	$\overline{x+y}$	`\underbar`	$\underline{x+y}$	`\doublebar`	$\underline{\overline{x+y}}$
`\overbrace`	$\overbrace{x+y}$	`\underbrace`	$\underbrace{x+y}$	`\doublebrace`	$\underbrace{\overbrace{x+y}}$
`\overbracket`	$\overbracket{x+y}$	`\underbracket`	$\underbracket{x+y}$	`\doublebracket`	$\underbracket{\overbracket{x+y}}$
`\overparent`	$\overparen{x+y}$	`\underparent`	$\underparen{x+y}$	`\doubleparent`	$\underparen{\overparen{x+y}}$

Intermezzo 2.11

```
  \underbrace[strut=yes]{x + x + \ldots + x}_{= mx}
  +
  \underbrace[strut=yes]{y + y + \ldots + y}_{= ny}
  = mx + ny
\stopformula
```

$$\underbrace{x+x+\ldots+x}_{=mx}+\underbrace{y+y+\ldots+y}_{=ny}=mx+ny$$

As an alternative, it is possible to use the `mathannotation` mechanism.

```
\startformula
  \mathannotation[bottom={= mx}]{\underbrace{x + x + \ldots + x}}
  +
  \mathannotation[bottom={= ny}]{\underbrace{y + y + \ldots + y}}
  = mx + ny
\stopformula
```

$$\underbrace{x+x+\ldots+x}_{\text{= mx}}+\underbrace{y+y+\ldots+y}_{\text{= ny}}=mx+ny$$

These over- and underdecorations are built with a base glyph, variants or an extensible recipe (if it exist), depending on the size of the content. This means that the size jumps in discrete steps, so the width might not fit the content perfectly. Let us look at one example. We locally show the glyphs for more clarity.

```
\startformula\showglyphs
  \overparent[shrink=no]{x} + \overparent[shrink=no]{xy} +
  \overparent[shrink=no]{x + y}\mtp{,}
  \overparent{x} + \overparent{xy} +
  \overparent{x + y}
\stopformula
```

$$\overparen{x}+\overparen{xy}+\overparen{x+y},\quad \overparen{x}+\overparen{xy}+\overparen{x+y}$$

Note that the parentheses in the right formula are scaled just slightly. In fact, they are not (yet) scaled if the extensible recipe is active (as it is for the parentheses on top of $x+y$). In Intermezzo 2.12 we show this example in some of the other fonts.

Be kind to your readers; do not overuse this type of constructions.

```
\startformula
\underbracket{
  \underbracket{
    \underbracket{
      \underbracket{
        \underbracket{
```

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

Antykwa

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

TEXGyre Bonum

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

Cambria Math

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

Dejavu Math

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

Erewhon Math

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

Garamond Math

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

Kepler Math

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

Latin Modern Math

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

Libertinus Math

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

TEXGyre Pagella Math

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

Stix Two Math

$$\overparent{x}+\overparent{xy}+\overparent{x+y},\quad \overparent{x}+\overparent{xy}+\overparent{x+y}$$

TEXGyre Termes Math

Intermezzo 2.12

```
        \underbracket{
          \underbracket{
            \underbracket{1}_1
            +1}_{2}
          +1}_{3}
        -1}_{2}
      +1}_{3}
    -1}_{2}
  -1}_{1}
-1}_{0}
\stopformula
```

$$\underbracket{\underbracket{\underbracket{\underbracket{\underbracket{\underbracket{\underbracket{\underbracket{1}_{1}+1}_{2}+1}_{3}-1}_{2}+1}_{3}-1}_{2}-1}_{1}-1}_{0}$$

The other type of stackers are decorated arrows and similar symbols, where content might be put on top or below.

```
\startformula
A \mrel{1+2}{a+b+c}                    B \mequal{1+2}{a+b+c}
C \mleftarrow{1+2}{a+b+c}              D \mrightarrow{1+2}{a+b+c}
E \mleftrightarrow{1+2}{a+b+c}         F \mLeftarrow{1+2}{a+b+c}
G \mRightarrow{1+2}{a+b+c}             H \mLeftrightarrow{1+2}{a+b+c}
I \mtwoheadleftarrow{1+2}{a+b+c}       J \mtwoheadrightarrow{1+2}{a+b+c}
K \mmapsto{1+2}{a+b+c}                 L \mhookleftarrow{1+2}{a+b+c}
M \mhookrightarrow{1+2}{a+b+c}         N \mleftharpoondown{1+2}{a+b+c}
O \mleftharpoonup{1+2}{a+b+c}          P \mrightharpoondown{1+2}{a+b+c}
Q \mrightharpoonup{1+2}{a+b+c}         R \mrightoverleftarrow{1+2}{a+b+c}
```

```
S \mleftoverrightarrow{1+2}{a+b+c}  T \mleftrightharpoons{1+2}{a+b+c}
U \mrightleftharpoons{1+2}{a+b+c}   V \mtriplerel{1+2}{a+b+c} W
\stopformula
```

$$A \overset{1+2}{\underset{a+b+c}{\rule{2em}{0.4pt}}} B \xlongequal[a+b+c]{1+2} C \xleftarrow[a+b+c]{1+2} D \xrightarrow[a+b+c]{1+2} E \xleftrightarrow[a+b+c]{1+2} F \xLeftarrow[a+b+c]{1+2} G \xRightarrow[a+b+c]{1+2} H \xLeftrightarrow[a+b+c]{1+2}$$
$$I \xtwoheadleftarrow[a+b+c]{1+2} J \xtwoheadrightarrow[a+b+c]{1+2} K \xmapsto[a+b+c]{1+2} L \xhookleftarrow[a+b+c]{1+2} M \xhookrightarrow[a+b+c]{1+2} N \xleftharpoondown[a+b+c]{1+2} O \xleftharpoonup[a+b+c]{1+2} P \xrightharpoondown[a+b+c]{1+2}$$
$$Q \xrightharpoonup[a+b+c]{1+2} R \xrightleftarrows[a+b+c]{1+2} S \xleftrightarrows[a+b+c]{1+2} T \xleftrightharpoons[a+b+c]{1+2} U \xrightleftharpoons[a+b+c]{1+2} V \overset{1+2}{\underset{a+b+c}{\equiv}} W$$

Some fonts lack some of these. In Stix Two Math we get the following.

$$A \overset{1+2}{\underset{a+b+c}{\rule{2em}{0.4pt}}} B \xlongequal[a+b+c]{1+2} C \xleftarrow[a+b+c]{1+2} D \xrightarrow[a+b+c]{1+2} E \xleftrightarrow[a+b+c]{1+2} F \xLeftarrow[a+b+c]{1+2} G \xRightarrow[a+b+c]{1+2}$$
$$H \xLeftrightarrow[a+b+c]{1+2} I \xtwoheadleftarrow[a+b+c]{1+2} J \xtwoheadrightarrow[a+b+c]{1+2} K \xmapsto[a+b+c]{1+2} L \xhookleftarrow[a+b+c]{1+2} M \xhookrightarrow[a+b+c]{1+2} N \xleftharpoondown[a+b+c]{1+2}$$
$$O \xleftharpoonup[a+b+c]{1+2} P \xrightharpoondown[a+b+c]{1+2} Q \xrightharpoonup[a+b+c]{1+2} R \overset{1+2}{\underset{a+b+c}{\rightleftarrows}} S \overset{1+2}{\underset{a+b+c}{\leftrightarrows}} T \overset{1+2}{\underset{a+b+c}{\leftrightharpoons}} U \overset{1+2}{\underset{a+b+c}{\rightleftharpoons}} V \overset{1+2}{\underset{a+b+c}{\equiv}} W$$

Additionally, there are variants that begin with “t” instead of “m”, that use text mode for the content above or below the extensible symbol. Below we provide two common ways to indicate that a function is an injection.

```
\startformula
  f \colon A \trightarrow{injection}                B \mtp{,}
  f \colon A \hookrightarrow                        B \mtp{,}
  f \colon A \mhookrightarrow[minwidth=2\emwidth] B \mtp{.}
\stopformula
```

$$f\colon A \xrightarrow{\text{injection}} B, \quad f\colon A \hookrightarrow B, \quad f\colon A \xhookrightarrow{\quad} B.$$

These extensible arrows are defined as stackers, but we can create our own as well. For example, we can put a small diamond symbol (⋄) (Unicode slot `0x022C4`) on top of something by defining a new type of stacker called `MyStacker`. While the predefined arrows come out as relations with corresponding spacing, our new stacker might not be well-suited for this class. Relations have too much space around them, while the usual spacing around characters might be too small. We can instead make use of the fraction class, which adds some additional spacing around our constructions (though not as much as for the relation class). Note that the choice of math class also might affect the possibility of line breaks.

```
\definemathstackers
  [MyStacker]
  [both]
  [mathclass=fraction]
```

We can now use `\mathover` to put the diamond on top of something. For spacing comparison, we also add an example that uses the predefined stacker `top`.

```
\startformula
  A \mathover[MyStacker]{"22C4}{B} C \mathover[top]{"22C4}{D} E
\stopformula
```

$$A \overset{\diamond}{B} C \overset{\diamond}{D} E$$

If we want to use this type of construction many times, it is convenient to define an instance.

```
\definemathover
  [MyStacker] % stacker
  [Diamonded] % name
  ["22C4]     % unicode slot
```

We can now use `\Diamonded` to put a small diamond on top of something.

```
\startformula
  \Diamonded{x} \Diamonded{y} + \Diamonded{A} =
  \Diamonded{1 + 11} + \Diamonded{\sum_{k=1}}
\stopformula
```

$$\overset{\diamond}{x}\,\overset{\diamond}{y} + \overset{\diamond}{A} = \overset{\diamond}{1 + 11} + \overset{\diamond}{\textstyle\sum_{k=1}}$$

Observe that the diamonds we put on the characters do not obey the anchoring that accents use, but are centered. This is more easily seen if we show some bounding boxes.

$$\overset{\diamond}{x}\,\overset{\diamond}{y} + \overset{\diamond}{A} = \overset{\diamond}{1 + 11} + \overset{\diamond}{\textstyle\sum_{k=1}}$$

There is also `\definemathunder` for stacking below and `\definemathdouble` to place content both above and below. We give an example of the latter, where we use the small star that sits in Unicode slot `0x022C6`.

```
\definemathdouble
  [MyStacker] % stacker
  [Adorned]   % name
  ["22C4]     % slot above
  ["22C6]     % slot below
```

We can now use `\Adorned`.

```
\startformula
  \Adorned{x} \Adorned{y} + \Adorned{A} =
  \Adorned{1+11} + \Adorned{\sum_a}
\stopformula
```

$$\overset{\diamond}{\underset{\star}{x}}\,\overset{\diamond}{\underset{\star}{y}} + \overset{\diamond}{\underset{\star}{A}} = \overset{\diamond}{\underset{\star}{1+11}} + \overset{\diamond}{\underset{\star}{\textstyle\sum_a}}$$

2.11 Factorials

One usually uses the notation $n! = \prod_{k=1}^{n} k$ (we only type the `!` where we want it). If one has a product of two factorials, $n!\,m!$ the situation can benefit from a small space. On the other hand, for double factorials, $n!!$ one does not want space between the exclamation marks. This is solved by giving the factorial (well, the exclamation mark) its own atom class.

An old notation for n-factorial is $\underline{\lvert n}$. Here we typed `\oldfactorial{n}`, after the definition

```
\definemathradical
  [oldfactorial]
  [lbannuity]
```

was given.

2.12 Punctuation

While the typesetting of common punctuation marks like periods, colons, semicolons, exclamation marks, and question marks may seem like a simple matter, as they are readily available on the keyboard, there are a few complications to consider. For example, in a vector like $(1, 2, 3)$, the comma is considered part of the mathematical expression, but in a text sentence like "$f(x) = x^2$, $x \in \mathbb{R}$", the comma functions as a punctuation mark. The same is true in a displayed formula.

$$f(x) = x^2, \quad x \in \mathbb{R}$$

Note that the formula above consists of two independent formulas: $f(x) = x^2$ and $x \in \mathbb{R}$. While one might argue that it doesn't matter whether the comma used to separate them comes from text or math, certain combinations of fonts can yield different outcomes. Additionally, if exporting to different formats, the structure may be affected.

Another question to consider is how much space should follow the comma in the displayed formula. Upon examining various TEX documents, we've observed that the space after the comma is typically either one quad or two quads.

```
\startformula
  f(x) = x^2,\quad  x \in \reals \breakhere
  f(x) = x^2,\qquad x \in \reals
\stopformula
```

$$f(x) = x^2,\quad x \in \mathbb{R}$$
$$f(x) = x^2,\qquad x \in \mathbb{R}$$

This is perfectly fine, and the most important thing to have in mind is to be consistent, but one should be aware that the commas in the formulas above are math commas, i.e., set with the math font. In our first displayed formula above we used `\mtp{,}` (mtp as in math text punctuation) to typeset the comma.

```
\startformula
  f(x) = x^2\mtp{,} x \in \reals
\stopformula
```

The comma is then taken from the text font. Note that we do not add a `\quad` or `\qquad`. The `\mtp{,}` will result in a comma that has class textpunctuation, and the space between this class and the ordinary class (that the following x belongs to) is configured to be `\mathinterwordmuskip`, which by default is defined as 18mu, a quad. We quote [Lan61] (translated into English) where the choice of a quad is supported:

> "A quad—nothing less, but also nothing more—is set between all independent formulas, independent of their length, height or character."

Instead of using a comma to separate formulas with conditions, some prefer to put the condition in parentheses. It is important to maintain consistency in the spacing between the main formula and the condition. One option is to use `\mtp{}` to add the space, while another is to use `\quad`.

```
\startformula
  f(x) = x^2 \mtp{} (x\in\reals)
\stopformula
```

$$f(x) = x^2 \quad (x \in \mathbb{R})$$

Default punctuation varies depending on the context and language. We first show how common punctuation marks look by default in ConTEXt.

```
\startformula
  3.14  \mtp{} 3,14  \mtp{} (a,b)  \mtp{} (a;b)  \breakhere
  3. 14 \mtp{} 3, 14 \mtp{} (a, b) \mtp{} (a; b)
\stopformula
```

$$3.14 \quad 3,14 \quad (a,b) \quad (a;b)$$

$$3.14 \quad 3,14 \quad (a,b) \quad (a;b)$$

As you can see, the spacing in the input did not have any effect. After the period, we get no space, while we get a small space after the comma and the semicolon. Punctuation usage can vary by context and language, with some languages using a comma instead of a period as the decimal separator. There are different ways to configure. We will first show a few different setups using the `autopunctuation` key, which is the oldest mechanism. The example code is exactly the same as above.

```
\setupmathematics
  [autopunctuation=all]
```

$$3.14 \quad 3{,}14 \quad (a{,}b) \quad (a;b)$$

$$3.\ 14 \quad 3,14 \quad (a,b) \quad (a;b)$$

```
\setupmathematics
  [autopunctuation={comma,semicolon}]
```

$$3.14 \quad 3{,}14 \quad (a{,}b) \quad (a{;}b)$$

$$3.14 \quad 3,14 \quad (a,b) \quad (a;b)$$

Our second method is to use the `autospacing` key. The colon is used in different meanings in mathematics, and the spacing around it should be different. When used for proportions there is an equal amount of spacing on each side, $1 : 2$. When used in function constructions, the macro `\colon` is used to get less spacing to the left of the colon, $f\colon \mathbb{R} \to \mathbb{R}$. We will use the following snippet.

```
\startformula
  f : \reals \to \reals \quad f \colon \reals \to \reals \breakhere
  f:  \reals \to \reals \quad f\colon  \reals \to \reals
\stopformula
```

Observe the different spacing around the colons in the code. By default that difference does not have an influence.

$$f : \mathbb{R} \to \mathbb{R} \quad f\colon \mathbb{R} \to \mathbb{R}$$

$$f : \mathbb{R} \to \mathbb{R} \quad f\colon \mathbb{R} \to \mathbb{R}$$

With `autospacing` set to `yes` the spacing will change the output.

```
\setupmathematics
  [autospacing=yes]
```

$$f : \mathbb{R} \to \mathbb{R} \quad f : \mathbb{R} \to \mathbb{R}$$

$$f\colon \mathbb{R} \to \mathbb{R} \quad f\colon \mathbb{R} \to \mathbb{R}$$

Finally, we show different ways to convert decimal periods and decimal commas in numbers with help of the `autonumbers` key. We use the following snippet.

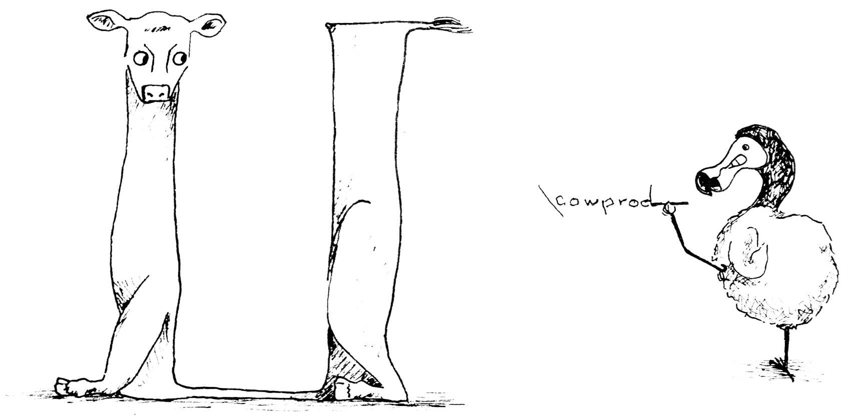
```
\im{1,222,333.44}    \par
\im{1.222.333,44}    \par
\im{1, 222, 333. 44} \par
\im{111 222}         \par
\im{(1.5,1.5)}       \par
\im{(1.5, 1.5)}      \par
\im{(1,5;1,5)}
```

Take a close look at Intermezzo 2.13 at the different outputs we get, depending on they value of `autonumbers`.

1, 222, 333.44	1,222,333.44	1.222.333,44	1 222 333.44
1.222.333, 44	1.222.333,44	1,222,333.44	1.222.333 44
1, 222, 333.44	1, 222, 333. 44	1. 222. 333, 44	1 222 333. 44
111222	111 222	111 222	111 222
(1.5, 1.5)	(1.5,1.5)	(1,5.1,5)	(1.5 1.5)
(1.5, 1.5)	(1.5, 1.5)	(1,5. 1,5)	(1.5 1.5)
(1, 5; 1, 5)	(1,5; 1,5)	(1.5; 1.5)	(1 5; 1 5)
`autonumbers=no`	`autonumbers=1`	`autonumbers=2`	`autonumbers=3`
	1 222 333,44	1.222.333 44	1,222,333 44
	1,222,333 44	1 222 333.44	1 222 333,44
	1 222 333, 44	1. 222. 333 44	1, 222, 333 44
	111 222	111 222	111 222
	(1,5 1,5)	(1 5.1 5)	(1 5,1 5)
	(1,5 1,5)	(1 5. 1 5)	(1 5, 1 5)
	(1 5; 1 5)	(1.5; 1.5)	(1,5; 1,5)
	`autonumbers=4`	`autonumbers=5`	`autonumbers=6`

Intermezzo 2.13

2.13 Big operators



There are four groups of big operators defined in ConTEXt: integrals, summations, products and operators. We start by listing the elements in each group.

```
\startformula
  \int \iint \iiint \iiiint \quad
  \oint \oiint \oiiint \intc \ointc \aointc \aodownintc
```

```
  \rectangularpoleintc \semicirclepoleintc  \circlepoleoutsideintc
  \circlepoleinsideintc \squareintc \quad
  \sumint \barint \doublebarint \slashint \hookleftarrowint
  \timesint \capint \cupint \upperint \lowerint
\stopformula
```

$$\int \iint \iiint \iiiint \quad \oint \oiint \oiiint ∱ ∲ ∳ ⨑$$

As you see, we do not get all of them in Latin Modern Math. With Stix Two Math we get

$$\int \iint \iiint \iiiint \quad \oint \oiint \oiiint ∱ ∲ ∳ ⨑ ⨒ ⨓ ⨔ ⨕ ⨖ \quad ⨋ ⨍ ⨎ ⨏ ⨐ ⨗ ⨘ ⨙ ⨚ ⨛ ⨜$$

```
\startformula
\sum \blackboardsum \modtwosum
\stopformula
```

$$\sum ⅀ ⨊$$

```
\startformula
\prod \coprod
\stopformula
```

$$\prod \coprod$$

```
\startformula
\bigwedge \bigvee \bigcap \bigcup \bigodot \bigoplus \bigotimes \quad
\bigudot \biguplus \bigsqcap \bigsqcup \bigtimes \bigdoublewedge
\bigdoublevee \quad \leftouterjoin \rightouterjoin \fullouterjoin
\bigbottom \bigtop \bigsolidus \bigreversesolidus
\stopformula
```

$$\bigwedge \bigvee \bigcap \bigcup \bigodot \bigoplus \bigotimes \quad ⨃ \biguplus ⨅ \bigsqcup ⨉ ⩕ ⩖ \quad ⟕ ⟖ ⟗ ⟘ ⟙ ⧸ ⧹$$

These operators can be typeset differently based on the group they belong to. For instance, the integral operator is typeset differently from the other operators by default due to the location of the limits.

```
\im{ \int_0^1 f(x) \dd x \neq \sum_{k=1}^n a_k \neq
     \prod_{k=1}^n a_k \neq \bigoplus_{k=1}^n a_k } \par
\dm{ \int_0^1 f(x) \dd x \neq \sum_{k=1}^n a_k \neq
     \prod_{k=1}^n a_k \neq \bigoplus_{k=1}^n a_k }
```

$\int_0^1 f(x)\,dx \neq \sum_{k=1}^n a_k \neq \prod_{k=1}^n a_k \neq \bigoplus_{k=1}^n a_k$

$$\int_0^1 f(x)\,dx \neq \sum_{k=1}^n a_k \neq \prod_{k=1}^n a_k \neq \bigoplus_{k=1}^n a_k$$

As you can see, all the big operators have their limits positioned to the right in inline formulas. In displayed formulas, the integral operator remains consistent with this convention, while the other operators have their limits positioned above and below. This layout makes sense since the different operators have similar heights. However, some people prefer to have the limits positioned below and above the integral sign in displayed formulas.

```
\setupmathoperators
  [integrals]
  [method=auto]
```

With this setup, the previous example looks like this.

$\int_0^1 f(x)\,dx \neq \sum_{k=1}^n a_k \neq \prod_{k=1}^n a_k \neq \bigoplus_{k=1}^n a_k$

$$\int\limits_0^1 f(x)\,dx \neq \sum_{k=1}^n a_k \neq \prod_{k=1}^n a_k \neq \bigoplus_{k=1}^n a_k$$

Some fonts, like TEXGyre Bonum Math, come with an extensible integral. We can use it by giving the integrand as an argument to `\int`. Note the placement of the limits.

```
\startformula
  \int_a^b \frac{\blackrule[width=1cm,height=1cm]}
               {\blackrule[width=1cm,height=1cm]} \dd x \neq
  \int { \frac{\blackrule[width=1cm,height=1cm]}
             {\blackrule[width=1cm,height=1cm]} }_a^b \dd x \neq
  \int[size=2cm,bottom=a,top=b,color=C:3]
    \frac{\blackrule[width=1cm,height=1cm]}
         {\blackrule[width=1cm,height=1cm]} \dd x
\stopformula
```

$$\int_a^b \frac{\rule{1cm}{1cm}}{\rule{1cm}{1cm}}\,dx \neq \int_a^b \frac{\rule{1cm}{1cm}}{\rule{1cm}{1cm}}\,dx \neq \int_a^b \frac{\rule{1cm}{1cm}}{\rule{1cm}{1cm}}\,dx$$

In the last example we used the keyword driven setup of integrals. (Here `C:3` is one of the colors in the color palette we use in this document.)

2.14 Radicals

Square roots are set with `\sqrt` or by raising to the power one-half. In the pre-digital time a surd sign √ was often used, since it was then complicated to set the horizontal bar. To get a nth root you either give an extra argument to `\sqrt` or use `\root`.

```
\startformula
  \sqrt{1 + x} = (1 + x)^{\frac{1}{2}} = \surd(1 + x)
             = \sqrt[rule=no]{(1 + x)} \breakhere
  \root[n=n]{1 + x} = \root[n]{1 + x} = \sqrt[n]{1 + x}
                  = (1 + x)^{1/n}
\stopformula
```

$$\sqrt{1+x} = (1+x)^{\frac{1}{2}} = \surd(1+x) = \surd(1+x)$$
$$\sqrt[n]{1+x} = \sqrt[n]{1+x} = \sqrt[n]{1+x} = (1+x)^{1/n}$$

In §4.5, we will address the apparent inconsistency between the exponents $\frac{1}{2}$ and $1/n$. When an equation contains multiple radicals, it may be preferable for them to have a consistent appearance. To achieve this, we can work with struts. We will use the following code.

```
\im{ \sqrt{e} + \sqrt{f} + \sqrt{g} + \sqrt{h} }
```

Below we show the output it gives with different struts applied. We do set up the strut with

```
\setupmathradical
  [sqrt]
  [strut=X]
```

where we let `X` be the value indicated below the formula (except for the first case where the key is not altered). We also use a helper to show the struts.

$\sqrt{e} + \sqrt{f} + \sqrt{g} + \sqrt{h}$	$\sqrt{e} + \sqrt{f} + \sqrt{g} + \sqrt{h}$	$\sqrt{e} + \sqrt{f} + \sqrt{g} + \sqrt{h}$
default	`yes`	`no`
$\sqrt{e} + \sqrt{f} + \sqrt{g} + \sqrt{h}$	$\sqrt{e} + \sqrt{f} + \sqrt{g} + \sqrt{h}$	$\sqrt{e} + \sqrt{f} + \sqrt{g} + \sqrt{h}$
`math`	`height`	`depth`

Another keyword that might come in handy is the `depth`. Let us look at an example

```
\startformula
  \sqrt{x} + \sqrt{y} + \sqrt{a_k^n}
\stopformula
```

$$\sqrt{x} + \sqrt{y} + \sqrt{a_k^n}$$

Observe how the size of the radical is adjusted based on the depth of the y. Similarly, the same size is applied to a_k^n, but since the k has a greater depth, the radical is shifted downwards. To avoid this, we can explicitly set the depth (`0pt` is not a valid option, `none` sets it to `1sp`).

```
\startformula
  \sqrt[depth=none]{x} + \sqrt[depth=none]{y} +
  \sqrt[depth=none]{a_k^n} = \sqrt[depth=10pt]{a_k^n}
\stopformula
```

$$\sqrt{x} + \sqrt{y} + \sqrt{a_k^n} = \sqrt{a_k^n}$$

If we plan on using square roots without any depth in multiple instances, it is a good practice to define a new instance.

```
\definemathradical
  [Sqrt]
  [depth=none]

\startformula
  \Sqrt{x} + \Sqrt{y} + \Sqrt{a_k^n}
\stopformula
```

$$\sqrt{x} + \sqrt{y} + \sqrt{a_k^n}$$

Another way to enforce uniform typesetting in formulas with several radicals is to set `height=\maxdimen` and `depth=\maxdimen`.

```
\setupmathradical
  [sqrt]
  [depth=\maxdimen,
   height=\maxdimen]
```

```
\startformula
  \sqrt{x} + \sqrt{y} + \sqrt{a_k^n}
\stopformula
```

$$\sqrt{x} + \sqrt{y} + \sqrt{a_k^n}$$

There is also a parameter `mindepth` that gives the minimum amount of depth for a radical. Compare the left-hand and right-hand sides below, where `mindepth` is inactive for the left-hand side, while the (default) value `.20\exheight` is used for the right-hand side.

$$\sqrt{1+x}\,\sqrt{1-x} \neq \sqrt{1+x}\,\sqrt{1-x}$$

At a first glance the two versions might look the same. But in the left-hand side the $\sqrt{1-x}$ has no depth, while the plus sign in the $\sqrt{1+x}$ forces some depth, making the radicals differently aligned vertically. In the right-hand side the `mindepth` prevents this. Its value depends on the font.

Finally, to honor an anonymous Italian user at Stack Exchange, we show how to define a radical with a small hook.

```
\definemathradical
  [italiansqrt]
  [rule=yes,
   left="221A,
   right=\delimitedrightannuityshortuc,
   rightmargin=.05\emwidth]

\startformula
  \italiansqrt{1 + x} + \italiansqrt{\frac{1 + x}{1 - x}}
\stopformula
```

$$\sqrt{1+x} + \sqrt{\frac{1+x}{1-x}}$$

2.15 Fractions

We can typeset fractions with the `\frac` macro. It takes two arguments, the numerator and the denominator.

```
\startformula
  \frac{1 + \frac{1}{x}}{1 - \frac{1}{x^2}} = \frac{x}{x - 1}
\stopformula
```

$$\frac{1 + \frac{1}{x}}{1 - \frac{1}{x^2}} = \frac{x}{x - 1}$$

This covers almost everything you need to know about fractions. However, if you want more details, keep reading. You'll likely use `\frac` most of the time, since it automatically adapts to the appropriate style in both displayed and inline formulas. But there are a few other options available, such as `\dfrac`, `\tfrac`, and `\sfrac`, which enforce display style math, text style math, and script style, respectively. Additionally, there's `\vfrac`, which can be thought of as a virgule fraction.

Vertical spacing in fractions is partly determined by struts. We'll demonstrate this using the following example, which sets different types of fractions in both display math and inline math.

```
\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \sfrac{a}{b} = \vfrac{a}{b}
```

In Intermezzo 2.14 we show the output with `\setupmathfractions[strut=X]`, where `X` is indicated below each example. To guide you we show the struts as bars.

$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$	$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$
default inline	default display
$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$	$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$
`yes` inline	`yes` display
$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$	$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$
`no` inline	`no` display
$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$	$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$
`math` inline	`math` display
$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$	$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$
`text` inline	`text` display
$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$	$\frac{a}{b} = \dfrac{a}{b} = \tfrac{a}{b} = \frac{\scriptscriptstyle a}{\scriptscriptstyle b} = a/b$
`tight` inline	`tight` display

Intermezzo 2.14

The usage of struts is mainly for consistency. One can argue that the spacing between the fraction bar and the g in the following fraction is too big.

$$\frac{f}{g}$$

But then one should also have in mind that there might be other fractions nearby. We show below a formula with one additional fraction, and different settings for the strut, for comparison.

$\frac{f}{g} = \frac{u}{h}$	$\frac{f}{g} = \frac{u}{h}$	$\frac{f}{g} = \frac{u}{h}$	$\frac{f}{g} = \frac{u}{h}$	$\frac{f}{g} = \frac{u}{h}$	$\frac{f}{g} = \frac{u}{h}$
default	`yes`	`no`	`math`	`text`	`tight`

It is also possible to configure the strut by giving an optional argument to `\frac`.

```
\startformula
  \frac[strut=no]{f}{g}
\stopformula
```

$$\frac{f}{g}$$

There are some more options possible to give. Instead of having a tall nested fraction one can use a slash.

```
\startformula
  \dfrac
    [method=line,
     vfactor=0]
    { \left( 1 + \frac{1}{x} \right) }
    { \left( 1 - \frac{1}{x} \right) }
  =
  \frac{x + 1}{x - 1}
\stopformula
```

$$\left(1 + \frac{1}{x}\right)\Big/\left(1 - \frac{1}{x}\right) = \frac{x+1}{x-1}$$

Note here the use of `\dfrac` instead of `\frac`. With `\frac`, the content of the inner fractions would be set in script style. Also compare with what we get if we use `\vfrac`.

```
\startformula
  \vfrac
    { \left( 1 + \frac{1}{x} \right) }
    { \left( 1 - \frac{1}{x} \right) }
  =
  \frac{x + 1}{x - 1}
\stopformula
```

$$\left(1 + \tfrac{1}{x}\right)\Big/\left(1 - \tfrac{1}{x}\right) = \frac{x+1}{x-1}$$

It is not only the size that is different, the numerator is raised a bit and the denominator is lowered a bit. The `\vfrac` is defined with `method=horizontal`, and is merely meant to be used for smaller numerical inline fractions, $^{7}/_{12}$.

Next, we show how to modify the fraction bar. This should in general not be necessary, but it gives a good example of the flexibility of ConTEXt.

```
\startformula
  \frac
    [margin=0.25\mathemwidth]
    {1 + \frac{1}{x}}
    {1 - \frac{1}{x}}
  =
  \frac[color=C:3]{x + 1}{x - 1}
\stopformula
```

$$\frac{1 + \frac{1}{x}}{1 - \frac{1}{x}} = \frac{x+1}{x-1}$$

If you are to use a different style many times is of course better to define a new instance.

```
\definemathfraction
  [widefrac]
  [rule=yes,
   rulethickness=2pt,
   symbolcolor=C:2,
   topcolor=C:3,
```

```
   bottomcolor=C:1,
   margin=0.5\mathemwidth,
   mathstyle=display]
```

```
\startformula
  \widefrac
    {1 + \frac{1}{x}}
    {1 - \frac{1}{x}}
  =
  \frac{x + 1}{x - 1}
\stopformula
```

$$\frac{1+\frac{1}{x}}{1-\frac{1}{x}} = \frac{x+1}{x-1}$$

We have complete control of the math styles used in the numerator and the denominator.

```
\startformula
  \frac{1 + \frac{1}{x}}
       {1 - \frac{1}{x}}
  =
  \frac[mathstyle=display]
       {1 + \frac{1}{x}}
       {1 - \frac{1}{x}}
  =
  \frac[mathnumeratorstyle=display]
       {1 + \frac{1}{x}}
       {1 - \frac{1}{x}}
  =
  \frac[mathdenominatorstyle=display]
       {1 + \frac{1}{x}}
       {1 - \frac{1}{x}}
\stopformula
```

$$\frac{1+\tfrac{1}{x}}{1-\tfrac{1}{x}} = \frac{1+\dfrac{1}{x}}{1-\dfrac{1}{x}} = \frac{1+\dfrac{1}{x}}{1-\tfrac{1}{x}} = \frac{1+\tfrac{1}{x}}{1-\dfrac{1}{x}}$$

Let's explore a perhaps unexpected example. The binomial coefficients $\binom{n}{k}$ are actually defined using the fraction mechanism. We will next demonstrate how to use `\definemathfraction` to define a Christoffel symbol of the second kind. This symbol resembles a binomial coefficient, but it uses curly braces instead of parentheses.

```
\definemathfraction
  [Christoffel]
  [left="7B,  % unicode for {
   right="7D, % unicode for }
   rule=no]   % no rule
```

```
\startformula
  \Christoffel{l}{jk} = \Gamma^{l}__{jk}(x)
\stopformula
```

$$\left\{ {l \atop jk} \right\} = \Gamma^{l}_{jk}(x)$$

We will next demonstrate several ways to typeset continued fractions. We begin by using the ordinary `\frac` macro.

```
\startformula
e = 2 +
  \frac
    {1}
    {1 + \frac
           {1}
           {2 + \frac
                  {1}
                  {1 + \frac
                         {1}
                         {1 + \frac
                                {1}
                                {4 + \frac
                                       {1}
                                       {1 + \frac
                                              {1}
                                              {1 + \frac
                                                     {1}
                                                     {6 + \ldots}}}}}}}}
\stopformula
```

$$e = 2 + \frac{1}{1 + \frac{1}{2 + \frac{1}{1 + \frac{1}{1 + \frac{1}{4 + \frac{1}{1 + \frac{1}{1 + \frac{1}{6 + \ldots}}}}}}}}$$

There is also a predefined `\cfrac` that can be used. It will set each piece in display style.

```
\startformula
a_0 + \cfrac
        {1}
        {a_1 + \cfrac
                 {1}
                 {a_2 + \cfrac
                          {1}
                          {a_3}}}
\stopformula
```

$$a_0 + \cfrac{1}{a_1 + \cfrac{1}{a_2 + \cfrac{1}{a_3}}}$$

Some like to have the numerators flush right. We can use `\setupmathfraction` to get that.

```
\setupmathfraction
  [cfrac]
  [topalign=flushright]
```

The same example as above now looks like this:

$$a_0 + \cfrac{1}{a_1 + \cfrac{1}{a_2 + \cfrac{1}{a_3}}}$$

Some mathematicians prefer to decrease the size of fractions progressively. This can be accomplished by using `\setmscale`, which scales all math starting from a specific point. By giving it a minus sign as argument, it will use the factor specified in the `\mathscale-factor` macro, which is set to 0.7 by default.

```
\startformula
  1 + \frac
        {1}
        {2 + \frac
               {1}
               {3 + \frac
                      {1}
                      {4 + \frac
                             {1}
                             {\setmscale{-}
                              5 + \frac
                                    {1}
                                    {\setmscale{-}
                                     6 + \frac
                                           {1}
                                           {\setmscale{-}
                                           7 + \ldots}}}}}}
\stopformula
```

$$1 + \frac{1}{2 + \frac{1}{3 + \frac{1}{4 + \frac{1}{5 + \frac{1}{6 + \frac{1}{7 + \ldots}}}}}}$$

Some argue that it's preferable to use alternative notation for continued fractions, such as $[1; 2, 3, 4, 5, 6, 7, \ldots]$, for the example above.

If the numerator or denominator of a fraction is lengthy, it's possible to split it using `\splitfrac`, which is a specific instance of a math fraction without a fraction bar.

```
\startformula
  \frac
    {\splitfrac{a+b+c+d}{+e+f+g}}
    {x+y+z}
  =
  \vfrac
    {\splitfrac{(a+b+c+d}{+e+f+g)}}
    {\xi}
\stopformula
```

$$\frac{\splitfrac{a+b+c+d}{+e+f+g}}{x+y+z} = \splitfrac{(a+b+c+d}{+e+f+g)} \Big/ \xi$$

In the right-hand side of the example, we used `\vfrac` to slash the outer fraction. If we had used `\frac`, it would have appeared unbalanced due to the very small denominator. It is worth noting that `\splitfrac` produces slightly skewed fractions. This is achieved with the keys `topalign=split:flushleft` and `bottomalign=split:flushright`, which flush the fraction to the left and right, respectively. Additionally, a minimum extra distance can be added to skew the fraction further using the `distance` key (default is 1em). We demonstrate two extreme usages.

```
\startformula
  \frac
    {\splitfrac[distance=3em]{a + b + c + d}{+ e + f + g}}
    {x + y + z}
  =
  \frac
    {\splitfrac[distance=0em]{a + b + c + d}{+ e + f + g}}
    {x + y + z}
\stopformula
```

$$\frac{\begin{array}{l}a+b+c+d\\ \qquad\qquad\quad +e+f+g\end{array}}{x+y+z} = \frac{\begin{array}{l}a+b+c+d\\ \quad +e+f+g\end{array}}{x+y+z}$$

We now have a good understanding of how to typeset fractions in ConTEXt. Fractions set with a fraction bar tend to be tall. In §4.5 we will provide some general advice on how to typeset fractions in inline formulas, to make them blend with the rest of the text.

2.16 Matrices

Matrices are defined and manipulated using the `mathmatrix` system in ConTEXt. To typeset a matrix without any delimiters, such as parentheses, we can use `startmathmatrix` and `stopmathmatrix`.

```
\startformula
  \startmathmatrix
    \NC a \NC b \NR
    \NC c \NC d \NR
  \stopmathmatrix
\stopformula
```

$$\begin{matrix} a & b \\ c & d \end{matrix}$$

New columns can be added to a matrix using `\NC` and new rows with `\NR`. To enclose the matrix with delimiters, such as brackets, we can use the `fences` keyword.

```
\startformula
  \startmathmatrix[fences=bracket]
    \NC a \NC b \NR
    \NC c \NC d \NR
  \stopmathmatrix
\stopformula
```

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

A few instances of `mathmatrix` are predefined. For example we can get brackets by invoking the `matrix:brackets` instance. We do that by using the `\startnamedmatrix` and `\stopnamedmatrix` pair, or by using its simple command `\bmatrix`. In the first case we use `\NC` for new columns and `\NR` for new rows. In the second, we separate columns by commas and rows by semicolons.

```
\startformula
  \startnamedmatrix[matrix:brackets]
    \NC a \NC b \NR
    \NC c \NC d \NR
  \stopnamedmatrix
  =
  \bmatrix{a,b;c,d}
\stopformula
```

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

We list other pre-defined instances, with their simple commands.

Instance	**Simple command**
`matrix:bars`	`vmatrix`
`matrix:braces`	`bracematrix`
`matrix:brackets`	`bmatrix`
`matrix:doublebar`	`vvmatrix`
`matrix:groups`	`gmatrix`
`matrix:none`	`matrix`
`matrix:parentheses`	`pmatrix`
`matrix:triplebar`	`vvvmatrix`

We show a small example of each case (here we use TEXGyre Pagella Math that comes with all the different delimiters).

$$\begin{vmatrix} 1 & 2 \\ 3 & 4 \end{vmatrix} + \begin{Bmatrix} 1 & 2 \\ 3 & 4 \end{Bmatrix} + \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} + \begin{Vmatrix} 1 & 2 \\ 3 & 4 \end{Vmatrix} + \left\lgroup\begin{matrix} 1 & 2 \\ 3 & 4 \end{matrix}\right\rgroup + \begin{matrix} 1 & 2 \\ 3 & 4 \end{matrix} + \begin{pmatrix} 1 & 2 \\ 3 & 4 \end{pmatrix} + \left\vert\kern-0.25ex\left\vert\kern-0.25ex\left\vert\begin{matrix} 1 & 2 \\ 3 & 4 \end{matrix}\right\vert\kern-0.25ex\right\vert\kern-0.25ex\right\vert$$

It is generally considered good style to avoid mixing different matrix types within a single document, unless there is a specific reason to do so. In linear algebra books, the `bmatrix` or `pmatrix` environments are often used for matrices, while the `vmatrix` environment is typically used for determinants.

If needed, we can define new matrix types using `\definemathmatrix`. The only required argument is the name of the new matrix. Once the matrix type is defined, we can use it either with `\startnamedmatrix` and `\stopnamedmatrix` as shown earlier, or directly with the matrix name.

```
\definemathmatrix
  [MyMatrix]
  [fences=openbracket,
   simplecommand=MyMatrix]

\startformula
  \startMyMatrix
    \NC -1 \NC  2 \NR
```

```
    \NC  4 \NC -5 \NR
  \stopMyMatrix
\stopformula
```

$$\left[\!\left[\begin{matrix} -1 & 2 \\ 4 & -5 \end{matrix}\right]\!\right]$$

We use `\setupmathmatrix` to configure `MyMatrix`. We can for example align the entries to the right instead of the default middle.

```
\setupmathmatrix
  [MyMatrix]
  [align={all:right}]
```

The `{all:right}` right-aligns all columns in the matrix. The example from above now looks like this.

$$\left[\!\left[\begin{matrix} -1 & 2 \\ 4 & -5 \end{matrix}\right]\!\right]$$

You can also specify the alignment of each column individually by using the `align` key with a comma-separated list of alignments. For instance, `align={all:right,1:left}` will set all columns right-aligned except the first one, which will be left-aligned. Observe the order.

As another example, suppose we want to define a matrix type for column vectors with comma-separated entries. We can achieve this by adding an `action` key to the definition, in this case we set it to `transpose` (another handy one is `negate`).

```
\definemathmatrix
  [colvec]
  [fences=bracket,
   action=transpose,
   simplecommand=colvec]

\startformula
  \colvec{1,2,3} + \colvec{4,5,6} = \colvec{5,7,9}
\stopformula
```

$$\begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix} + \begin{bmatrix} 4 \\ 5 \\ 6 \end{bmatrix} = \begin{bmatrix} 5 \\ 7 \\ 9 \end{bmatrix}$$

One could question if that was really necessary. After all, we could have obtained the same output by separating with semicolons. In other cases, the `action` can save some typing.

```
\startformula
  \pmatrix{1,2;3,4;5,6}^T =
  \pmatrix[action=transpose]{1,2;3,4;5,6}
\stopformula
```

$$\begin{pmatrix} 1 & 2 \\ 3 & 4 \\ 5 & 6 \end{pmatrix}^T = \begin{pmatrix} 1 & 3 & 5 \\ 2 & 4 & 6 \end{pmatrix}$$

Note here how we have avoided to retype the entries of the matrix, transposed.

There are different ways to emphasize the structure of a matrix. We can use `\HF` to indicate omitted rows with dot leaders, as shown in this example of a Vandermonde matrix.

```
\startformula
  \startnamedmatrix[matrix:bars]
    \NC 1 \NC x \NC x^2 \NC \ldots \NC x^{n-1} \NR
    \NC 1 \NC y \NC y^2 \NC \ldots \NC y^{n-1} \NR
    \HF                                       \NR
    \NC 1 \NC z \NC z^2 \NC \ldots \NC z^{n-1} \NR
  \stopnamedmatrix
\stopformula
```

$$\begin{vmatrix} 1 & x & x^2 & \ldots & x^{n-1} \\ 1 & y & y^2 & \ldots & y^{n-1} \\ . & . & . & . & . \\ 1 & z & z^2 & \ldots & z^{n-1} \end{vmatrix}$$

We can add horizontal and vertical lines to indicate the different blocks in a block matrix by using `\HL` and `\VL`, or even by `\VLT` and `\VLB` that adapt their height and depth a bit better.

```
\startformula
  \startnamedmatrix[matrix:brackets]
    \NC A \NC b \NR
    \NC c \NC 0 \NR
  \stopnamedmatrix
  =
  \startnamedmatrix[matrix:brackets]
    \NC A \VL b \NR
    \HL
    \NC c \VL 0 \NR
  \stopnamedmatrix
  =
  \startnamedmatrix[matrix:brackets]
    \NC A \VLT b \NR
    \HL
    \NC c \VLB 0 \NR
  \stopnamedmatrix
  =
  \startnamedmatrix[matrix:brackets]
    \NC A \VLT[2,C:2] b \NR
    \HL[4,C:3]       \NC c \VLB              0 \NR     \stopnamedmatrix
\stopformula
```

$$\begin{bmatrix} A & b \\ c & 0 \end{bmatrix} = \left[\begin{array}{c|c} A & b \\ \hline c & 0 \end{array}\right] = \left[\begin{array}{c|c} A & b \\ \hline c & 0 \end{array}\right] = \left[\begin{array}{c|c} A & b \\ \hline c & 0 \end{array}\right]$$

The `\VLT` and `\VLB` are in fact special examples of `\GL`, “graphics line”, that can be used to draw rules to and from arbitrary places. Below the first argument `[1]` is an identifier, while the second tells where to anchor. So, for example `[t]` means top of strut, `[d]` depth of strut and `[d,c]` means depth of strut and closing the path.

```
\startformula
  \startmatrix[fences=bracket,
               rulecolor=C:2,
               rulethickness=2pt]
    \NC  \GL[1][t] \NC \lambda \NC       1 \NC \GL[1][t]    \NC 0 \NR
    \NC  \GL[1][d] \NC       0 \NC \lambda \NC \GL[1][d,c] \NC 0 \NR
    \NC            \NC       0 \NC       0 \NC             \NC 1 \NR
  \stopmatrix
\stopformula
```

$$\begin{bmatrix} \boxed{\begin{matrix} \lambda & 1 \\ 0 & \lambda \end{matrix}} & \begin{matrix} 0 \\ 0 \end{matrix} \\ \begin{matrix} 0 & 0 \end{matrix} & 1 \end{bmatrix}$$

The `\GL` drawing macro is in fact an alias for `\graphicline`, that can also be used in text, where it works quite well for drawing lines from one point to another, as long as we stay on one page. You can probably guess how this was done in this paragraph, at least if you know that an `[x]` will align on the `exheight`. The last one also has an `e`, so we end with `[x,e]`.

Labels to rows and columns can be added with the column types `TT` (top), `BT` (bottom), `LT` (left) and `RT` (right).

```
\startformula
  \startnamedmatrix[matrix:brackets]
    \NC B                   \NC C                  \RT \scriptstyle n - r \NR
    \NC 0                   \NC D                  \RT \scriptstyle r     \NR
    \BT \scriptstyle n - r  \BT \scriptstyle r     \NC                    \NR
  \stopnamedmatrix
\stopformula
```

$$\begin{array}{cl} \begin{bmatrix} B & C \\ 0 & D \end{bmatrix} & \begin{matrix} \scriptstyle n-r \\ \scriptstyle r \end{matrix} \\ \begin{matrix} \scriptstyle n-r & \scriptstyle r \end{matrix} & \end{array}$$

We continue with one more example, with inspiration from the Wikipedia page on Jordan normal form. It is one big matrix consisting of several so-called Jordan blocks. Each block is set inside a rectangle.

$$\begin{bmatrix} \boxed{\begin{matrix} \lambda_1 & 1 & \\ & \lambda_1 & 1 \\ & & \lambda_1 \end{matrix}} & & & & \\ & \boxed{\begin{matrix} \lambda_2 & 1 \\ & \lambda_2 \end{matrix}} & & & \\ & & \boxed{\lambda_3} & & \\ & & & \ddots & \\ & & & & \boxed{\begin{matrix} \lambda_n & 1 \\ & \lambda_n \end{matrix}} \end{bmatrix}$$

Here, one could in principle use `\HL` and `\VL` to build blocks, but instead we used math frames, with the `\mcframed` with matrices inside. Thus, the building blocks were written as

```
\startbuffer[block1]
\mcframed{
  \startmathmatrix
    \NC \lambda_1 \NC 1         \NC           \NR
    \NC           \NC \lambda_1 \NC 1         \NR
    \NC           \NC           \NC \lambda_1 \NR
  \stopmathmatrix
}
\stopbuffer

\startbuffer[block2]
\mcframed{
  \startmathmatrix
    \NC \lambda_2 \NC 1          \NR
    \NC           \NC \lambda_2  \NR
  \stopmathmatrix
}
\stopbuffer

\startbuffer[block3]
\mcframed{
  \startmathmatrix
    \NC \lambda_3 \NR
  \stopmathmatrix
}
\stopbuffer

\startbuffer[block4]
\mcframed{
  \startmathmatrix
    \NC \lambda_n \NC 1          \NR
    \NC           \NC \lambda_n  \NR
  \stopmathmatrix
}
\stopbuffer
```

Once this was done, we made the bigger matrix by calling these buffers.

```
\startformula
  \bmatrix{\getbuffer[block1], , , , ;
          ,\getbuffer[block2], , , ;
          , ,\getbuffer[block3], , ;
          , , ,\ddots, ,           ;
          , , , ,\getbuffer[block4]}
\stopformula
```

This way of working with buffers is very convenient and it enforces some structure, that leads to improved readability of the code. We show one more example, where the matrices get nested.

```
\startbuffer[rmat]
  \bmatrix{0, 5; 6, 7}
\stopbuffer

\startformula
  \bmatrix{1, 2; 3, 4}
  \otimes
  \getbuffer[rmat]
  =
  \bmatrix
    {
      1 \getbuffer[rmat], 2 \getbuffer[rmat];
      3 \getbuffer[rmat], 4 \getbuffer[rmat]
    }
\stopformula
```

$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \otimes \begin{bmatrix} 0 & 5 \\ 6 & 7 \end{bmatrix} = \begin{bmatrix} 1\begin{bmatrix} 0 & 5 \\ 6 & 7 \end{bmatrix} & 2\begin{bmatrix} 0 & 5 \\ 6 & 7 \end{bmatrix} \\ 3\begin{bmatrix} 0 & 5 \\ 6 & 7 \end{bmatrix} & 4\begin{bmatrix} 0 & 5 \\ 6 & 7 \end{bmatrix} \end{bmatrix}$$

3 Keywords

3.1 Introduction

ConTEXt is built around mechanisms and we have in this document already seen many of them, but now it is time to discuss them a bit closer. By a mechanism we mean a general construction that is shared by several macros, so-called instances. It is easy to define new instances and to set them up. We give a fake example, where we work with the non-existing mechanism `X`. To define a new instance, we use `\defineX`. Keywords can be given, as in

```
\defineX
  [foo]
  [a=x,
   b=y]
```

Here the instance `foo` was defined, having the keywords `a` and `b` set to `x` and `y`, respectively. It is also possible to define a new instance as a copy of an existing one, as

```
\defineX
  [foo]
  [bar]
```

where the instance `foo` was defined as a copy of `bar`.

Once defined, it is possible to set up the instance `foo` with `\setupX`. Below we set the keyword `c` to `z`.

```
\setupX
  [foo]
  [c=z]
```

If we want to set a keyword at usage, that is also possible. So

```
\startX
  [foo]
  [c=z]
  ...
\stopX
```

if it is an environment, or even

```
\foo[c=z]
```

if it is a macro, typically works. Some keywords are better set up outside of usage, though.

To understand the different mathematical mechanisms, we will list the corresponding keywords and give examples of what they do.

3.2 Accents

We can define new accents with `\definemathaccent` and set them up with `\setupmath-accent`. The definitions are given in `math-acc.mklx`.

`alignsymbol` If set to `yes` then the accent is centered over the base character if the accent is wider than the base character.

```
\startformula\showglyphs
    \bar[alignsymbol=no]{i}
  = \bar[alignsymbol=yes]{i}
  = \bar[alignsymbol=yes,shrink=yes]{i}
\stopformula
```

$$\bar{\imath} = \bar{\imath} = \bar{\imath}$$

Note in the example above that when combined with `shrink` (see below), the centering is no longer active, since after the shrinking the condition is no longer matched.

`color/symbolcolor/textcolor` Set the color of accents. The `color` sets the color for the whole construction, `symbolcolor` sets the color of the accent and `textcolor` sets the color of the base character or construction.

```
\startformula
    \hat{A}
  = \hat[color=C:3]{A}
  = \hat[symbolcolor=C:3]{A}
  = \hat[textcolor=C:3]{A}
  = \hat[color=C:3,
         symbolcolor=C:1]{A}
  = \hat[color=C:3,
         textcolor=C:1]{A}
  = \hat[color=C:3,
         symbolcolor=C:2,
         textcolor=C:1]{A}
\stopformula
```

$$\hat{A} = \hat{A} = \hat{A} = \hat{A} = \hat{A} = \hat{A} = \hat{A}$$

By default no color change is applied.

`i` If set to `auto` the dot over i and j that have accent over them will be removed. This will not happen otherwise.

```
\startformula
  \hat{i} = \hat[i=]{i} \neq \bar{j} = \bar[i=]{j}
\stopformula
```

$$\hat{\imath} = \hat{i} \neq \bar{\jmath} = \bar{j}$$

There is a `conjugate` instance that is like `widebar` except that is defined with `i=`, so the dots over i and j are kept.

`scale` Can be set to `no` (no scaling), `yes` (use base, variants and extensible) and `keep` (use base, variants and extensible, but keep base).

```
\startformula
    \hat[scale=no]  {f + g}
  = \hat[scale=yes] {f + g}
  = \hat[scale=keep]{f + g}
\stopformula
```

$$\hat{f + g} = \widehat{f + g} = \widehat{f + g}$$

Some accents have this set to `yes` or `keep` (typically the wide ones), but default is `no`.

`stretch/shrink` It is possible to stretch and shrink accent glyphs. Possible values are `yes` and `no`. It depends also on how the `scale` is set.

```
\startformula
    \hat[scale=no,stretch=no]   {f + g}
  = \hat[scale=yes,stretch=no]  {f + g}
  = \hat[scale=keep,stretch=no] {f + g}
  = \hat[scale=no,stretch=yes]  {f + g}
  = \hat[scale=yes,stretch=yes] {f + g}
  = \hat[scale=keep,stretch=yes]{f + g}
\stopformula
```

$$f \hat{+} g = \widehat{f+g} = \widehat{f+g} = \widehat{f+g} = \widehat{f+g} = \widehat{f+g}$$

The `\widehat` and its friends have `scale` set to `keep` and both `stretch` and `shrink` enabled.

3.3 Alignments

See `math-ali.mkxl` and `strc-mat.mkxl` for details. For simple alignments, see the separate section below.

`align` Setup the alignment of different columns.

```
\startformula
  \startalign[n=4]
    \NC A       \NC = B      \NC + C      \NC + D      \NR
    \NC A' + 1  \NC = B' + 1 \NC + C' + 1 \NC + D' + 1 \NR
  \stopalign
\stopformula
\startformula
  \startalign[n=4,align={all:left,1:right}]
    \NC A       \NC = B      \NC + C      \NC + D      \NR
    \NC A' + 1  \NC = B' + 1 \NC + C' + 1 \NC + D' + 1 \NR
  \stopalign
\stopformula
\startformula
  \startalign[n=4,align=all:middle]
    \NC A       \NC = B      \NC + C      \NC + D      \NR
    \NC A' + 1  \NC = B' + 1 \NC + C' + 1 \NC + D' + 1 \NR
  \stopalign
\stopformula
```

$$\begin{array}{rlll} A & = B & + C & + D \\ A' + 1 & = B' + 1 & + C' + 1 & + D' + 1 \end{array}$$

$$\begin{array}{rlll} A & = B & + C & + D \\ A' + 1 & = B' + 1 & + C' + 1 & + D' + 1 \end{array}$$

$$\begin{array}{cccc} A & = B & + C & + D \\ A' + 1 & = B' + 1 & + C' + 1 & + D' + 1 \end{array}$$

`distance` Distance between alignment groups. By default set to `\emwidth`.

```
\startformula
  \startalign[m=2,n=2]
    \NC x \NC = 2
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
\startformula
  \startalign[m=2,n=2,distance=2\emwidth]
    \NC x \NC = 2
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
\startformula
  \startalign[m=2,n=2,distance=0pt plus 1fil]
    \NC x \NC = 2
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
```

$$x = 2 \quad y = 3$$

$$x = 2 \qquad y = 3$$

$$x = 2 \hfill y = 3$$

`grid` By default set to `math`. Only applicable if in grid mode.

`location` Determines where the alignments go. By default it is midaligned, but it can also be set to `left`, `right` or `packed`.

```
\startformula
  \startalign
    \NC x \NC = 2 \NR
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
\startformula
  \startalign[location=left]
    \NC x \NC = 2 \NR
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
\startformula
  \startalign[location=right]
    \NC x \NC = 2 \NR
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
```

$$x = 2$$

$$y = 3$$

$x = 2$

$y = 3$

$$x = 2$$
$$y = 3$$

In the case of `packed` it can be used as a part of a larger formula

```
\startformula
  \startalign
    [location=packed,
     fences=sesac]
    \NC A \EQ B \NR
    \NC C \EQ D \NR
    \NC E \EQ F \NR
  \stopalign
  \implies
  \startalign
    [location=packed,
     fences=cases]
    \NC G \EQ H \NR
    \NC I \EQ J \NR
  \stopalign
\stopformula
```

$$\left.\begin{aligned} A &= B \\ C &= D \\ E &= F \end{aligned}\right\} \implies \left\{\begin{aligned} G &= H \\ I &= J \end{aligned}\right.$$

`m/n` The `m` describes the number of alignment blocks and `n` describes the number of alignment points in each block.

```
\startformula
  \startalign[m=3,n=2]
    \NC x \NC = 2
    \NC y \NC = 3
    \NC z \NC = 1 \NR
  \stopalign
\stopformula
```

$$x = 2 \quad y = 3 \quad z = 1$$

`spaceinbetween` Space between lines in alignments. By default set to the same value as the space between lines in formulas (`\setupformula[spaceinbetween=...]`). The default value is `quarterline`.

```
\startformula
  \startalign
    \NC x \NC = 2 \NR
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
\startformula
```

```
  \startalign[spaceinbetween=\lineheight]
    \NC x \NC = 2 \NR
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
```

$$x = 2$$
$$y = 3$$
$$x = 2$$

$$y = 3$$

text Possibility to add text to the left margin. With just `text` all lines will have that text, with `text:n` only the `n`th line will get it.

```
\startformula
  \startalign[text=foo]
    \NC x \NC = 2 \NR
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
\startformula
  \startalign[text:1=foo,text:2=bar]
    \NC x \NC = 2 \NR
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
```

foo $x = 2$

foo $y = 3$

foo $x = 2$

bar $y = 3$

textcolor Possibility to add text to the left margin. As for `text`, with `textcolor` the color of all text comments will get the color, while with `textcolor:n` it will only apply to the one on line `n`.

```
\startformula
  \startalign[text:2=and,textcolor:2=C:3]
    \NC x \NC = 2 \NR
    \NC y \NC = 3 \NR
  \stopalign
\stopformula
```

$x = 2$

and $y = 3$

3.4 Cases

distance Specify the space between the columns.

```
\startformula
  f(x) =
  \startcases
    \NC  x \NC x \geq 0 \NR
    \NC -x \NC x <    0 \NR
  \stopcases
  \quad
  f(x) =
  \startcases
    [distance=2em]
    \NC  x \NC x \geq 0 \NR
    \NC -x \NC x <    0 \NR
  \stopcases
\stopformula
```

$$f(x) = \begin{cases} x & x \geq 0 \\ -x & x < 0 \end{cases} \quad f(x) = \begin{cases} x & \qquad x \geq 0 \\ -x & \qquad x < 0 \end{cases}$$

spaceinbetween Specify the space between lines. By default inherited from the same parameter for math alignments, where it is set to `quarterline`.

```
\startformula
  f(x) =
  \startcases
    \NC  x \NC x \geq 0 \NR
    \NC -x \NC x <    0 \NR
  \stopcases
  \quad
  f(x) =
  \startcases
    [spaceinbetween=1\lineheight]
    \NC  x \NC x \geq 0 \NR
    \NC -x \NC x <    0 \NR
  \stopcases
\stopformula
```

$$f(x) = \begin{cases} x & x \geq 0 \\ -x & x < 0 \end{cases} \quad f(x) = \begin{cases} x & x \geq 0 \\[1em] -x & x < 0 \end{cases}$$

strut If set to `yes` (default) struts will be added. If set to `no`, then not.

```
\startformula\showstruts
  f(x) =
  \startcases
    \NC  x \NC x \geq 0 \NR
    \NC -x \NC x <    0 \NR
  \stopcases
  \quad
  f(x) =
  \startcases
    [strut=no]
```

```
      \NC  x \NC x \geq 0 \NR
      \NC -x \NC x <    0 \NR
    \stopcases
  \stopformula
```

$$f(x) = \begin{cases} x & |x \geq 0 \\ -x & |x < 0 \end{cases} \quad f(x) = \begin{cases} x & x \geq 0 \\ -x & x < 0 \end{cases}$$

3.5 Fences

bottomspace/topspace These keywords can be used to fake the size of the contents of fences.

```
\startformula
    \fenced[parenthesis]                                 {1 + x^2}
  = \fenced[parenthesis][bottomspace=-2pt,topspace=-2pt]{1 + x^2}
  = \fenced[parenthesis][bottomspace=5pt, topspace=5pt] {1 + x^2}
\stopformula
```

$$\left(1 + x^2\right) = (1 + x^2) = \Bigl(1 + x^2\Bigr)$$

color/symbolcolor/middlecolor With these keys we add colors to the fences.

```
\startformula
    \innerproduct                {u \fence v}
  = \innerproduct[color=C:3]     {u \fence v}
  = \innerproduct[symbolcolor=C:3]{u \fence v}
  = \innerproduct[middlecolor=C:3]{u \fence v}
\stopformula
```

$$\langle u \mid v\rangle = \langle u \mid v\rangle = \langle u \mid v\rangle = \langle u \mid v\rangle$$

define When defining a new fence instance, one can set this keyword to yes in order to also define a shortcut macro with the name of the fence.

```
\definemathfence
  [MySet]
  [brace]
  [define=yes,
   middle=`|]

\startformula
  \fenced[MySet]{x \in \reals \fence x > 0}
  = \MySet{x \in \reals \fence x > 0}
\stopformula
```

$$\{x \in \mathbb{R} \mid x > 0\} = \{x \in \mathbb{R} \mid x > 0\}$$

distance This only applies if text is set to yes.

factor By default auto. It can be none, force (see below), or a numerical value.

```
\startformula
    \fenced[bracket]              {\frac{1 + x}{1 - x}}
  = \fenced[bracket][factor=auto] {\frac{1 + x}{1 - x}}
  = \fenced[bracket][factor=none] {\frac{1 + x}{1 - x}}
```

```
  = \fenced[bracket][factor=1]    {\frac{1 + x}{1 - x}}
  = \fenced[bracket][factor=2]    {\frac{1 + x}{1 - x}}
  = \fenced[bracket][factor=4]    {\frac{1 + x}{1 - x}}
\stopformula
```

$$\left[\frac{1+x}{1-x}\right] = \left[\frac{1+x}{1-x}\right] = [\frac{1+x}{1-x}] = [\frac{1+x}{1-x}] = \left[\frac{1+x}{1-x}\right] = \Bigg[\frac{1+x}{1-x}\Bigg]$$

`height/depth` Can be used together with `factor=force`. Note that the fence is not centered on the math axis anymore.

```
\startformula
    \fenced[bracket]
           {\frac{1 + x}{1 - x}}
  = \fenced[bracket]
           [factor=force,height=1cm,depth=.5cm]
           {\frac{1 + x}{1 - x}}
  = \fenced[bracket]
           [factor=force,height=.5cm,depth=1cm]
           {\frac{1 + x}{1 - x}}
\stopformula
```

$$\left[\frac{1+x}{1-x}\right] = \Bigg[\frac{1+x}{1-x}\Bigg] = \Bigg[\frac{1+x}{1-x}\Bigg]$$

`mathclass/leftclass/rightclass/middleclass` By default a fencing behaves as an open atom to the left and close atom to the right. This can be altered by setting either `mathclass` (both left and right) or `leftclass` and `rightclass`, independently.

```
\startformula\showmakeup[mathglue]
  x
  + \fenced[brace]                            {x}
  + \fenced[brace][mathclass=\mathordinarycode] {x}
  + \fenced[brace][leftclass=\mathordinarycode] {x}
  + \fenced[brace][rightclass=\mathordinarycode]{x}
  + x
\stopformula
```

$$x + \{x\} + \{x\} + \{x\} + \{x\} + x$$

It is also possible to set the class of the middle symbol, if used.

```
\startformula\showmakeup[mathglue]
    \fenced[brace]
           [middle=`|]
           {x \in \reals \fence x > 0}
  = \fenced[brace]
           [middle=`|,
            middleclass=\mathordinarycode]
```

```
            {x \in \reals \fence x > 0}
\stopformula
```

$$\{x \in \mathbb{R} \mid x > 0\} = \{x \in \mathbb{R} | x > 0\}$$

mathstyle With this parameter it is possible to enforce a certain style of a fence.

```
\startformula
    \fenced[brace]                                  {x^2}
  + \fenced[brace][mathstyle={scriptscript}]        {x^2}
  + \fenced[brace][mathstyle={cramped,scriptscript}]{x^2}
\stopformula
```

$$\left\{x^2\right\} + {\scriptscriptstyle \{x^2\}} + {\scriptscriptstyle \{x^2\}}$$

middle/right/left The symbols to be used can be specified. This is of course more often used when defining a new fence.

```
\startformula
  \fenced[nothing][left="27EE,right="27E7,middle=`:]{x \fence y}
\stopformula
```

$$\lgroup x : y \rrbracket$$

size Used to set the size of the fences manually. We can either set them by number

```
\startformula
    \fenced[bracket]          {\frac{1 + x}{1 - x}}
  = \fenced[bracket][size=0]  {\frac{1 + x}{1 - x}}
  = \fenced[bracket][size=1]  {\frac{1 + x}{1 - x}}
  = \fenced[bracket][size=2]  {\frac{1 + x}{1 - x}}
  = \fenced[bracket][size=3]  {\frac{1 + x}{1 - x}}
  = \fenced[bracket][size=4]  {\frac{1 + x}{1 - x}}
\stopformula
```

$$\left[\frac{1+x}{1-x}\right] = [\frac{1+x}{1-x}] = \bigl[\frac{1+x}{1-x}\bigr] = \Bigl[\frac{1+x}{1-x}\Bigr] = \biggl[\frac{1+x}{1-x}\biggr] = \Biggl[\frac{1+x}{1-x}\Biggr]$$

or by keyword

```
\startformula
    \fenced[bracket]          {\frac{1 + x}{1 - x}}
  = \fenced[bracket][size=big] {\frac{1 + x}{1 - x}}
  = \fenced[bracket][size=Big] {\frac{1 + x}{1 - x}}
  = \fenced[bracket][size=bigg]{\frac{1 + x}{1 - x}}
  = \fenced[bracket][size=Bigg]{\frac{1 + x}{1 - x}}
\stopformula
```

$$\left[\frac{1+x}{1-x}\right] = \bigl[\frac{1+x}{1-x}\bigr] = \Bigl[\frac{1+x}{1-x}\Bigr] = \biggl[\frac{1+x}{1-x}\biggr] = \Biggl[\frac{1+x}{1-x}\Biggr]$$

source/leftsource/rightsource/middlesource Can be used to decorate fences. We show one example.

```
\defineboxanchor[left]
\defineboxanchor[right]
```

```
\setboxanchor
  [left]
  [corner={left,bottom},location=height,xoffset=.5em,yoffset=-.25ex]
  \hbox to \zeropoint{\hss\mathindexfont open\hss}

\setboxanchor
  [right]
  [corner={right,bottom},location=height,xoffset=-.5em,yoffset=-.25ex]
  \hbox to \zeropoint{\hss\mathindexfont close\hss}

\startformula
  \fenced
    [parenthesis]
    [leftsource=left,rightsource=right]
    {1 + \frac{x}{n}}^{n}
\stopformula
```

$$\underset{\text{open}}{\left(}1+\frac{x}{n}\underset{\text{close}}{\right)}^{n}$$

snap About moving (snapping) exponents. By default set to no. With

```
\dm{\frac{1}{\left(1 + x^2\right)^2} + \frac{1}{(1 + x^2)^2}}
```

we get $\frac{1}{\left(1 + x^2\right)^2} + \frac{1}{(1 + x^2)^2}$. If set to yes we get $\frac{1}{(1 + x^2)^2} + \frac{1}{(1 + x^2)^2}$.

3.6 Formulas

align This controls the alignment of the formula. By default formulas are centered on the line, but they can also be flushleft, flushright or slanted. The last option means that the first line is flush left, the last flush right, and the rest centered.

```
\startformula
  1\breakhere
  1+2\breakhere
  1+2+3\breakhere
  1+2+3+4
\stopformula

\startformula
  [align=flushleft]
  1\breakhere
  1+2\breakhere
  1+2+3\breakhere
  1+2+3+4
\stopformula

\startformula
  [align=flushright]
  1\breakhere
  1+2\breakhere
```

```
  1+2+3\breakhere
  1+2+3+4
\stopformula

\startformula
  [align=middle]
  1\breakhere
  1+2\breakhere
  1+2+3\breakhere
  1+2+3+4
\stopformula

\startformula
  [align=slanted]
  1\breakhere
  1+2\breakhere
  1+2+3\breakhere
  1+2+3+4
\stopformula
```

$$
\begin{gathered}
1\\
1+2\\
1+2+3\\
1+2+3+4
\end{gathered}
$$

1

$1+2$

$1+2+3$

$1+2+3+4$

$$
\begin{array}{r}
1\\
1+2\\
1+2+3\\
1+2+3+4
\end{array}
$$

$$
\begin{gathered}
1\\
1+2\\
1+2+3\\
1+2+3+4
\end{gathered}
$$

1

$$1+2$$

$$1+2+3$$

$$\hfill 1+2+3+4$$

alternative Can be default, single or multi. Has to do with grid typesetting. See the details manual. Use on your own risk.

`expansion` By default disabled. Only active if expansion is enabled in the paragraph.

`grid` Has to do with grid typesetting. Do not use it with complex math.

`indentnext` Wether or not to indent the paragraph following the formula. Can be `yes`, `no` and `auto`, where `auto` indents if there is an extra line in the source after the formula, and otherwise not. Note that indenting has to be enabled for this to apply.

`interlinespace` This sets the space *between* the baselines (but if too small they will of course not clash). By default set to `1.125\lineheight`. It makes sense to have it slightly larger than the interline space.

```
\startformula
  A \breakhere B
\stopformula
\startformula[interlinespace=0pt]
  A \breakhere B
\stopformula
\startformula[interlinespace=2\lineheight]
  A \breakhere B
\stopformula
```

$$A$$

$$B$$

$$A$$

$$B$$

$$A$$

$$B$$

`left/right` To set up what goes around the equation number.

```
\startplaceformula
  \startformula
    A = B
  \stopformula
\stopplaceformula
\startplaceformula
  \startformula[left={[},right={]}]
    A = B
  \stopformula
\stopplaceformula
```

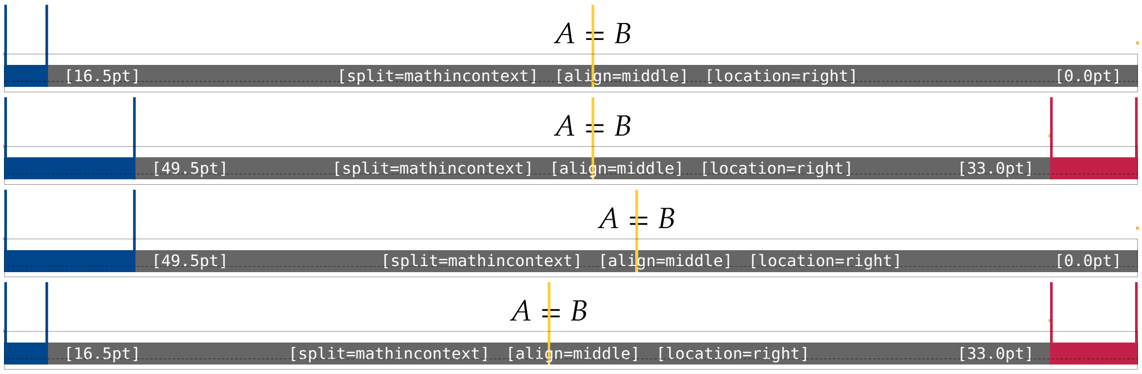
$$A = B \qquad (3.1)$$

$$A = B \qquad [3.2]$$

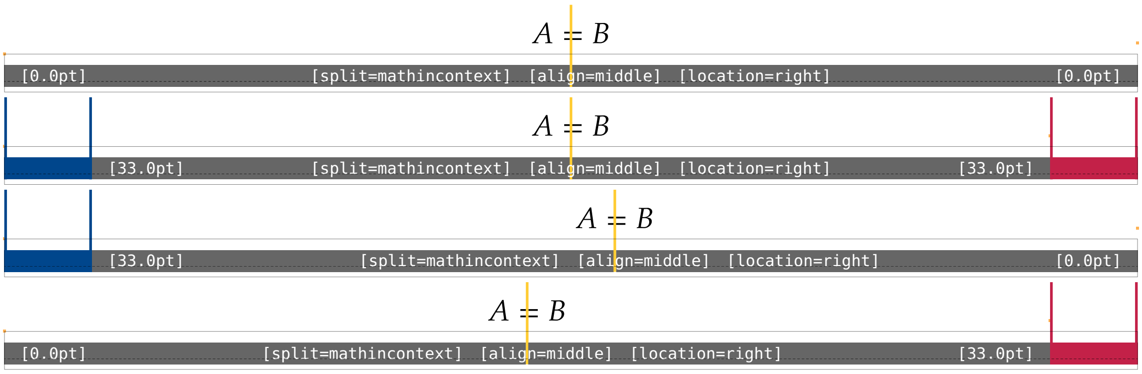
`margin/leftmargin/rightmargin` Set up margins for the formula. In the example below it looks a bit asymmetric due to the fact that we are in an environment with a positive left margin.

```
\enabletrackers[math.showmargins.less]
\startformula
  A = B
\stopformula
```

```
\startformula[margin=3\emwidth]
  A = B
\stopformula
\startformula[leftmargin=3\emwidth]
  A = B
\stopformula
\startformula[rightmargin=3\emwidth]
  A = B
\stopformula
\disabletrackers[math.showmargins.less]
```



This is how it shows outside that environment.



`margindistance/leftmargindistance/rightmargindistance` A bit like the `margin` keys, but see page 130.

`numberconversionset` Specify format for equation numbers. See page 126 for an example.

`numberdistance` The minimum space between formulas and equation numbers. See the discussion in §6.7.

`numberlocation` If `split` is set to `line` then setting `numberlocation` to `overlay` ensures that the number is not pushing the formula off-center.

```
\startplaceformula[eq:linea]
  \startformula[split=line]
    m(b-a)\leq\int_a^b f(x)\dd x\leq M(b-a).
  \stopformula
\stopplaceformula

\startplaceformula[eq:lineb]
  \startformula[split=line,numberlocation=overlay]
    m(b-a)\leq\int_a^b f(x)\dd x\leq M(b-a).
```

```
  \stopformula
\stopplaceformula
```

$$m(b-a) \leq \int_a^b f(x)\,dx \leq M(b-a)\,. \tag{3.3}$$

$$m(b-a) \leq \int_a^b f(x)\,dx \leq M(b-a)\,. \tag{3.4}$$

`numberstrut` If `yes` then use a strut for the equation number, if `no` then don't. The default is `yes`; `always` adds a strut even if there is no number.

`numberthreshold` Threshold for moving the equation number down (if at the right margin) in alignments.

`penalties` To set up penalties in formulas. For example there is

```
\startsetups[math:penalties:page]
  \shapingpenaltiesmode \zerocount            \widowpenalties \plusthree
\plustenthousand \plustenthousand \zerocount   \clubpenalties  \plusthree
\plustenthousand \plustenthousand \zerocount
\stopsetups
```

and the default is indeed this if `split` is set to `yes` (default).

`snap/snapstep` This is meant for typesetting with the grid. With `snap` set to `yes` high or low formulas will typically not cause spreading of lines. The `snapstep` can be `small`, `medium` or `big` and the `medium` is the default.

`spacebefore/spaceafter` Used to setup the space before and after formulas. By default it is `big`.

```
\samplefile{knuthmath}
\startformula
  A = B
\stopformula
\samplefile{knuthmath}
\startformula[spacebefore=small,spaceafter=small]
  A = B
\stopformula
\samplefile{knuthmath}
```

Many readers will skim over formulas on their first reading of your exposition. Therefore, your sentences should flow smoothly when all but the simplest formulas are replaced by “blah” or some other grunting noise.

$$A = B$$

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$$A = B$$

Many readers will skim over formulas on their first reading of your exposition. Therefore, your sentences should flow smoothly when all but the simplest formulas are replaced by “blah” or some other grunting noise.

In this manual we wanted to prevent page breaks just before displayed formulas. For that reason we did

```
\definevspacing[mathtoppenalty][penalty:4000]
```

and then

```
\setupformula
  [spacebefore={medium,mathtoppenalty},
   spaceafter=medium]
```

`spaceinbetween` This sets the extra space *between* the lines.

```
\startformula
  A \breakhere B
\stopformula
\startformula[spaceinbetween=0pt]
  A \breakhere B
\stopformula
\startformula[spaceinbetween=1\lineheight]
  A \breakhere B
\stopformula
\startformula[spaceinbetween=2\lineheight]
  A \breakhere B
\stopformula
```

$$A$$
$$B$$
$$A$$
$$B$$
$$A$$
$$B$$
$$A$$
$$B$$

`split` Set up how the formula can be split. If set to `line` then the formula does not break over lines at all. If `no` then the formula is split over lines, but penalties are set to prohibit a page break. The default is `yes`, which means that formulas both break over lines and over pages. For this manual we did the following setup:

```
\startsetups[math:penalties:mathincontext]
  \shapingpenaltiesmode \zerocount
  \widowpenalties 3 5000 250 100
  \clubpenalties  3 5000 250 100
\stopsetups
```

and then

```
    \setupformula
      [split=mathincontext]
```

`textdistance/textmargin` These are used to layout long formulas. See page 114 for a discussion and examples.

`width` This sets the width of the text block (think `\hsize`)

```
\enabletrackers[math.showmargins.less]
\startplaceformula
  \startformula
    A = B
  \stopformula
\stopplaceformula
\startplaceformula
  \startformula[width=10cm]
    A = B
  \stopformula
\stopplaceformula
\disabletrackers[math.showmargins.less]
```

$$A = B \tag{3.5}$$

[16.5pt] [split=mathincontext] [align=middle] [location=right] [0.0pt]

$$A = B \tag{3.6}$$

[16.5pt] [split=mathincontext] [align=middle] [location=right] [0.0pt]

3.7 Fractions

`alternative` Can be set to `inner`, `outer` or `both`, and it will reflect the style of the fraction. Here `inner` means that we listen to `mathnumeratorstyle` and `mathdenominatorstyle` (and these are by default set to the value of `mathstyle`). On the other hand, `outer` means that we listen to the `mathstyle`, but not the the `mathnumeratorstyle` or `mathdenominatorstyle`. Finally, `both` means that we listen to all parameters. We show some silly examples. Note that when we work in `outer` or `both` we might loose the vertical alignment with the math axis.

```
\startformula
    \frac[alternative=inner,mathnumeratorstyle=script]        {a}{b}
  = \frac[alternative=inner,mathdenominatorstyle=scriptscript]{a}{b}
  = \frac[alternative=inner,mathstyle=script]                 {a}{b}
  = \frac[alternative=outer,mathnumeratorstyle=script]        {a}{b}
  = \frac[alternative=outer,mathdenominatorstyle=scriptscript]{a}{b}
  = \frac[alternative=outer,mathstyle=script]                 {a}{b}
  = \frac[alternative=both, mathnumeratorstyle=script]        {a}{b}
  = \frac[alternative=both, mathdenominatorstyle=scriptscript]{a}{b}
  = \frac[alternative=both, mathstyle=script]                 {a}{b}
\stopformula
```

$$\frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b}$$

The third fraction above might look wrong, but it is not, since `mathnumeratorstyle` and `mathdenominatorstyle` inherit from `mathstyle`.

`color` It is possible to set the color of the fraction, the numerator, and the denominator independently.

```
\startformula
    \frac                     {a}{b}
  = {\color[C:3]     {\frac{a}{b}}}
```

```
  = \frac[color=C:3]      {a}{b}
  = \frac[topcolor=C:3]   {a}{b}
  = \frac[bottomcolor=C:3]{a}{b}
  = \frac[textcolor=C:3]  {a}{b}
  = \frac[symbolcolor=C:3]{a}{b}
\stopformula
```

$$\frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b} = \frac{a}{b}$$

By default the fraction is set in the current color.

`distance/bottomdistance/topdistance` To set the distance between the fraction bar and the numerator and/or denominator. It is currently only done at the outer setting, since it should probably be the same for the whole document.

```
\setupmathfractions
  [distance=bottom,
   bottomdistance=2ex]
\dm { \frac{a}{b} }
\setupmathfractions
  [distance=top,
   topdistance=2ex]
\dm { \frac{a}{b} }
\setupmathfractions
  [distance=both,
   topdistance=2ex,
   bottomdistance=2ex]
\dm { \frac{a}{b} }
\setupmathfractions
  [distance=none]
\dm { \frac{a}{b} }
```

$$\frac{a}{b}\frac{a}{b}\frac{a}{b}\frac{a}{b}$$

`hfactor/vfactor` These parameters are only active in skewed fractions (that is, if `method` is set to `horizontal` or `line`). There are two font parameters in the Opentype specification, `SkewedFractionHorizontalGap` and `SkewedFractionVerticalGap`, that are meant to control skewed fractions. They do not make sense (for us) so we do not use them.

The `hfactor/1000` is the fraction of the width of the slash glyph that the numerator and denominator are moved closer to each other horizontally.

The `vfactor/1000` is the fraction of the math axis used to move numerator and denominator apart. Note that if `method` is set to `horizontal`, then there is also a compensation for the math axis.

```
\startformula\showglyphs
    \frac[hfactor=0,    method=horizontal]{a}{b}
  = \frac[hfactor=250,  method=horizontal]{a}{b}
  = \frac[hfactor=500,  method=horizontal]{a}{b}
```

```
  = \frac[hfactor=1000, method=horizontal]{a}{b}
  = \frac[hfactor=-1000,method=horizontal]{a}{b}
\stopformula
```

$$a/b = a/b = a/b = a/b = a\ /\ b$$

```
\startformula\showglyphs
    \frac[vfactor=0,    method=horizontal]{a}{b}
  = \frac[vfactor=250,  method=horizontal]{a}{b}
  = \frac[vfactor=500,  method=horizontal]{a}{b}
  = \frac[vfactor=1000, method=horizontal]{a}{b}
  = \frac[vfactor=-1000,method=horizontal]{a}{b}
\stopformula
```

$$a/b = a/b = a/b = a/b = a/b$$

```
\startformula\showglyphs
    \frac[vfactor=0,    method=line]{a}{b}
  = \frac[vfactor=250,  method=line]{a}{b}
  = \frac[vfactor=500,  method=line]{a}{b}
  = \frac[vfactor=1000, method=line]{a}{b}
  = \frac[vfactor=-1000,method=line]{a}{b}
\stopformula
```

$$a/b = a/b = a/b = a/b = a/b$$

`left/right` The values should be numbers, typically corresponding to delimiters; see the example with the Christoffel symbol on page 55.

`margin` Can be used to insert margins around numerator and denominator.

```
\startformula
    \frac                 {a + b}{c}
  = \frac[margin=\emwidth]{a + b}{c}
\stopformula
```

$$\frac{a+b}{c} = \frac{\quad a+b \quad}{c}$$

The default `margin` is 0pt.

`mathclass` By default a fraction has the mathfraction class. But this can be changed if a fraction is used as something different. One could perhaps argue that the Christoffel symbol on page 55 is not really a fraction when it comes to spacing.

```
\startformula\showmakeup[mathglue]
  1 + \frac{a}{b}
  = \frac[mathclass=\mathordinarycode]{a}{b} + 1
\stopformula
```

$$1 + \frac{a}{b} = \frac{a}{b} + 1$$

`mathdenominatorstyle` The style of the denominator. See the `alternative` key for an example.

`mathnumeratorstyle` The style of the numerator. See the `alternative` key for an example.

`mathstyle` The style of the fraction. See the `alternative` key for an example.

`method` Possible values are `vertical` (default), `horizontal`, and `line`. The `vertical` uses `\Uatop`, `\Uatopwithdelims`, `\Uabove`, `\Uabovewithdelims`, `\Uover`, `\Uoverwithdelims`, `\Ustretched` or `\Ustretchedwithdelims`, depending on other parameters. The `horizontal` and `line` use `\Uskewed` or `\Uskewedwithdelims`.

With `vertical` we get the usual fractions with a horizontal fraction bar.

With `line`, the numerator and denominator start at the base line, and are then shifted up and down by half of `vfactor/1000`, multiplied by the size of the math axis font parameter.

The font parameters `SkewedFractionHorizontalGap` and `SkewedFractionVerticalGap` are not used, since they do not make sense for the model we use.

With `horizontal`, we get, in addition to the shifting in `line`, also a shift up and down with half the height of the math axis for the numerator and denominator, respectively.

```
\startformula
    \frac                   {a}{b}
  = \frac[method=vertical]  {a}{b}
  = \frac[method=horizontal]{a}{b}
  = \frac[method=line]      {a}{b}
\stopformula
```

$$\frac{a}{b} = \frac{a}{b} = {}^{a}/_{b} = a/b$$

`middle` A number describing the unicode slot of the fraction bar. Default is `"2F`. This does not have any effect if `method` is `vertical`.

```
\startformula
  \frac[method=horizontal]{5}{8}
  =
  \frac[method=horizontal,
        middle="2044]{5}{8}
  =
  \frac[method=horizontal,
        middle="2215]{5}{8}
  =
  \frac[method=horizontal,
        middle="7C]{5}{8}
\stopformula
```

$$^{5}/_{8} = {}^{5}/_{8} = {}^{5}/_{8} = {}^{5}|_{8}$$

`rule` This is by default set to `symbol` which means that some symbol in the font is used repeatedly. This symbol is set by the `symbol` key, that by default is `\fractionbarextenderuc`, pointing to a private Unicode slot. If set to `no` then there will be no rule, as in binomial coefficients. If set to `yes`, a rule will be used. Then `rulethickness` can be used to set the width of the rule.

`rulethickness` To set the width of the rule if `rule=yes` is used.

`source` One can use `source` to decorate formulas, probably mainly for educational purposes. See `anch-box.mkxl` for examples on how to define and setup your own.

```
\setupboxanchorcontent
  [top,left]
  [rulecolor=C:2]

\startformula
  \connectboxanchors[top][top]{one}{two}
  x + \frac[source=\namedboxanchor{one}]{1+x}{2-x} =
  z + \frac[source=\namedboxanchor{two}]{1+x^2}{2-x^3}
\stopformula
```

$$x + \frac{1+x}{2-x} = z + \frac{1+x^2}{2-x^3}$$

strut By default we have this key set to `yes`, which inserts struts in both the numerator and denominator. With `no` we get no struts.

symbol To set which symbol to use as a fraction bar if not using a rule. See the `rule` key.

3.8 Functions

color Color functions.

```
\startformula
        \cos(x)
  \quad \mfunction{cos}(x)
  \quad \mfunction[color=C:3]{cos}(x)
\stopformula
```

$$\cos(x) \quad \cos(x) \quad \cos(x)$$

Note that we cannot use `\cos[color=C:3](x)` since we want to be able to use brackets as delimiters for the argument of functions.

style Specify the style of functions.

```
\startformula
        \cos(x)
  \quad \mfunction{cos}(x)
  \quad \mfunction[style=bold]{cos}(x)
  \quad \mfunction[style=\mathfrak]{cos}(x)
\stopformula
```

$$\cos(x) \quad \cos(x) \quad \mathbf{cos}(x) \quad \mathfrak{cos}(x)$$

3.9 Matrices

The TeX code behind the matrix mechanism can be found in `math-ali.mkxl`.

align To align the columns. By default they are centered. The `all:right` will flush all columns to the right. Note that by adding `3:left` and `2:middle` the `all:right` is overwritten for these columns.

```
\startformula
    \startmathmatrix
      \NC  1 \NC  2 \NC -3 \NC 4 \NR
      \NC -5 \NC -6 \NC  7 \NC 8 \NR
    \stopmathmatrix
```

```
    \qquad
    \startmathmatrix
      [align={all:right}]
      \NC  1 \NC  2 \NC -3 \NC 4 \NR
      \NC -5 \NC -6 \NC  7 \NC 8 \NR
    \stopmathmatrix
    \qquad
    \startmathmatrix
      [align={all:right,3:left,2:middle}]
      \NC  1 \NC  2 \NC -3 \NC 4 \NR
      \NC -5 \NC -6 \NC  7 \NC 8 \NR
    \stopmathmatrix
\stopformula
```

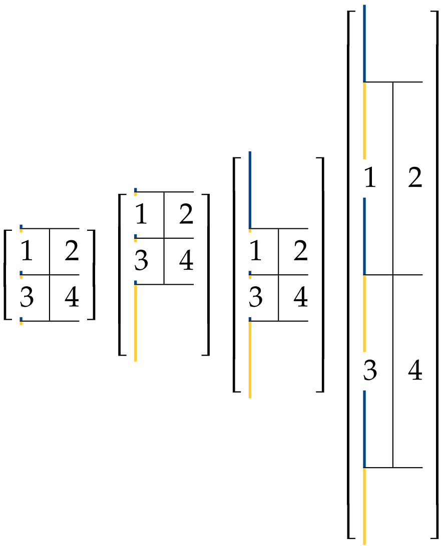
$$\begin{matrix} 1 & 2 & -3 & 4 \\ -5 & -6 & 7 & 8 \end{matrix} \qquad \begin{matrix} 1 & 2 & -3 & 4 \\ -5 & -6 & 7 & 8 \end{matrix} \qquad \begin{matrix} 1 & 2 & -3 & 4 \\ -5 & -6 & 7 & 8 \end{matrix}$$

`boffset/moffset/toffset` Offset in matrices. In the examples below, the `matrixoffset` buffer is given by

```
\dm {
  \startmathmatrix
    [fences=bracket]
    \HL
    \NC 1 \VL 2 \NR
    \HL
    \NC 3 \VL 4 \NR
    \HL
  \stopmathmatrix
}
```

We then use the following code, note that we first add a bottom offset with `boffset`, then a top offset with `toffset` and finally also a middle offset with `moffset`.

```
\enabletrackers[math.matrices.hl]
\getbuffer[matrixoffset]
\setupmathmatrix[boffset=2\lineheight]
\getbuffer[matrixoffset]
\setupmathmatrix[toffset=2\lineheight]
\getbuffer[matrixoffset]
\setupmathmatrix[moffset=2\lineheight]
\getbuffer[matrixoffset]
```



`distance` Control the distance between columns.

```
\startformula
    \startmathmatrix
      \NC 1 \NC 2 \NR
      \NC 3 \NC 4 \NR
    \stopmathmatrix
    \quad
    \startmathmatrix
      [distance=4\emwidth]
      \NC 1 \NC 2 \NR
      \NC 3 \NC 4 \NR
    \stopmathmatrix
\stopformula
```

$$\begin{matrix} 1 & 2 \\ 3 & 4 \end{matrix} \quad \begin{matrix} 1 & \qquad 2 \\ 3 & \qquad 4 \end{matrix}$$

`fences` Specify a set of fences to use.

```
\startformula
    \startmathmatrix
      \NC 1 \NC 2 \NR
      \NC 3 \NC 4 \NR
    \stopmathmatrix
    \quad
    \startmathmatrix
      [fences=bracket]
      \NC 1 \NC 2 \NR
      \NC 3 \NC 4 \NR
    \stopmathmatrix
\stopformula
```

$$\begin{matrix} 1 & 2 \\ 3 & 4 \end{matrix} \quad \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$$

`left/right` Set up something to the left and right of a matrix.

```
\startformula
    \startmathmatrix
      [left=\left(,right=\right)]
      \NC 1 \NC 2 \NR
      \NC 3 \NC 4 \NR
    \stopmathmatrix
    \quad
    \startmathmatrix
      [fences=parenthesis]
      \NC 1 \NC 2 \NR
      \NC 3 \NC 4 \NR
    \stopmathmatrix
\stopformula
```

$$\begin{pmatrix} 1 & 2 \\ 3 & 4 \end{pmatrix} \quad \begin{pmatrix} 1 & 2 \\ 3 & 4 \end{pmatrix}$$

The `left` and `right` content goes outside of the fences, if both are present.

`leftmargin/rightmargin` Add space between the content and the fences.

```
\startformula
    x +
    \startmathmatrix
      [fences=bracket,
       leftmargin=1\emwidth]
      \NC 1 \NC 2 \NR
      \NC 3 \NC 4 \NR
    \stopmathmatrix
    +
    \startmathmatrix
      [fences=bracket,
       rightmargin=1\emwidth]
      \NC 1 \NC 2 \NR
      \NC 3 \NC 4 \NR
    \stopmathmatrix
    + x
\stopformula
```

$$x + \quad \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} + \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \quad + x$$

`rulecolor` Setup the color of a possible rule.

```
\startformula
    \startmathmatrix
      [rulecolor=C:3]
      \NC 1 \VL 2 \NR
      \HL
      \NC 3 \VL 4 \NR
    \stopmathmatrix
\stopformula
```

$$\begin{array}{c|c} 1 & 2 \\ \hline 3 & 4 \end{array}$$

rulethickness Setup the width of a possible rule.

```
\startformula
    \startmathmatrix
      [rulethickness=6\linewidth]
      \NC 1 \VL 2 \NR
      \HL
      \NC 3 \VL 4 \NR
    \stopmathmatrix
\stopformula
```

$$\begin{array}{c|c} 1 & 2 \\ \hline 3 & 4 \end{array}$$

simplecommand This is only used when defining new instances of matrices. See page 60.

3.10 Operators

bottom/top Just another way to specify limits on big operators.

```
\startformula
        \int_a^b             f(x) \dd x
  \quad \int[bottom=a,top=b]{f(x) \dd x}
\stopformula
```

$$\int_a^b f(x)\,dx \quad \int_a^b f(x)\,dx$$

color/symbolcolor/bottomcolor/topcolor Color operators and their limits. Note that we need to use the `bottom` and `top` keys to place the limits.

```
\startformula
        \int                                {f(x) \dd x}_a^b
  \quad \int[color=C:3]                     {f(x) \dd x}_a^b
  \quad \int[symbolcolor=C:3]               {f(x) \dd x}_a^b
  \quad \int[color=C:3,bottom=a,top=b]      {f(x) \dd x}
  \quad \int[bottomcolor=C:3,bottom=a,top=b]{f(x) \dd x}
  \quad \int[topcolor=C:3,bottom=a,top=b]   {f(x) \dd x}
\stopformula
```

$$\int_a^b f(x)\,dx \quad \int_a^b f(x)\,dx \quad \int_a^b f(x)\,dx \quad \int_a^b f(x)\,dx \quad \int_a^b f(x)\,dx \quad \int_a^b f(x)\,dx$$

left Gives the actual symbol that is used.

```
\startformula
        \int            {f(x) \dd x}_a^b
  \quad \int[left="2211]{f(x) \dd x}_a^b
\stopformula
```

$$\int_a^b f(x)\,dx \quad \sum_a^b f(x)\,dx$$

mathclass The default class is `\mathoperatorcode` for general operators, but `\mathintegralcode` for integral type operators.

```
\startformula\showmakeup[mathglue]
        3\int                            {f(x) \dd x}_a^b
  \quad 3\int[mathclass=\mathrelationcode]{f(x) \dd x}_a^b
\stopformula
```

$$3\int_a^b f(x)\,dx \quad 3\int_a^b f(x)\,dx$$

`method` Different ways to place the limits. Here `horizontal` (and `nolimits`) put the limits beside (default for integral type operators), `vertical` (and `limits`) put them on top and below, while `auto` (default for other big operators) depend on the math style.

```
\startformula
        \int                   {f(x) \dd x}_{a}^{b}
  \quad \int[method=auto]      {f(x) \dd x}_{a}^{b}
  \quad \int[method=horizontal]{f(x) \dd x}_{a}^{b}
  \quad \int[method=vertical]  {f(x) \dd x}_{a}^{b}
  \breakhere\textstyle
        \int                   {f(x) \dd x}_{a}^{b}
  \quad \int[method=auto]      {f(x) \dd x}_{a}^{b}
  \quad \int[method=horizontal]{f(x) \dd x}_{a}^{b}
  \quad \int[method=vertical]  {f(x) \dd x}_{a}^{b}
\stopformula
```

$$\int_a^b f(x)\,dx \quad \int\limits_a^b f(x)\,dx \quad \int_a^b f(x)\,dx \quad \int\limits_a^b f(x)\,dx$$

$$\textstyle \int_a^b f(x)\,dx \quad \int_a^b f(x)\,dx \quad \int_a^b f(x)\,dx \quad \int\limits_a^b f(x)\,dx$$

```
\startformula
        \sum                   {a_k}_{1}^{+\infty}
  \quad \sum[method=auto]      {a_k}_{1}^{+\infty}
  \quad \sum[method=horizontal]{a_k}_{1}^{+\infty}
  \quad \sum[method=vertical]  {a_k}_{1}^{+\infty}
  \breakhere\textstyle
        \sum                   {a_k}_{1}^{+\infty}
  \quad \sum[method=auto]      {a_k}_{1}^{+\infty}
  \quad \sum[method=horizontal]{a_k}_{1}^{+\infty}
  \quad \sum[method=vertical]  {a_k}_{1}^{+\infty}
\stopformula
```

$$\sum_1^{+\infty} a_k \quad \sum_1^{+\infty} a_k \quad \sum\nolimits_1^{+\infty} a_k \quad \sum_1^{+\infty} a_k$$

$$\textstyle \sum_1^{+\infty} a_k \quad \sum_1^{+\infty} a_k \quad \sum_1^{+\infty} a_k \quad \sum\limits_1^{+\infty} a_k$$

`size` Some fonts come with extensible integrals. See the example on page 50.

3.11 Radicals

These keywords can either be used directly on a radical, or with `\setupmathradical` on a predefined or on your own radical instance. If you want to look into the source then start with the file `math-rad.mklx`.

`color/symbolcolor/textcolor` Color radicals.

```
\startformula
        \root[n=3]              {1 + x}
  \quad \root[n=3,color=C:3]      {1 + x}
  \quad \root[n=3,symbolcolor=C:3]{1 + x}
  \quad \root[n=3,textcolor=C:3]  {1 + x}
  \quad \root[n=3,numbercolor=C:3]{1 + x}
\stopformula
```

$$\sqrt[3]{1+x} \quad \sqrt[3]{1+x} \quad \sqrt[3]{1+x} \quad \sqrt[3]{1+x} \quad \sqrt[3]{1+x}$$

`depth/height` Set the depth and height explicitly.

```
\startformula
    \sqrt                    {\frac{a}{b}}
  = \sqrt[height=4\exheight]{\frac{a}{b}}
  = \sqrt[depth=4\exheight] {\frac{a}{b}}
\stopformula
```

$$\sqrt{\frac{a}{b}} = \sqrt{\frac{a}{b}} = \sqrt{\frac{a}{b}}$$

Both are by default set to 0pt and adapted to the actual content. See also the `mindepth` key and the discussion starting on page 51.

`left/right` Change radical symbol for something else.

```
\startformula
    \sqrt                           {a + b}
  = \sqrt[left="7B]                 {a + b}
  = \sqrt[left=\zerocount,right="7D]{a + b}
\stopformula
```

$$\sqrt{a+b} = \{\overline{a+b} = \overline{a+b}\}$$

A more natural example might be $\widehat{(f+g)}$.

`leftmargin/rightmargin` Margins for the content of the radical. By default these are set to `0pt`. For a few fonts we set up a small `leftmargin` in the typescript.

```
\startformula
    \sqrt                         {\frac{a}{b}}
  = \sqrt[leftmargin=\emwidth] {\frac{a}{b}}
  = \sqrt[rightmargin=\emwidth]{\frac{a}{b}}
\stopformula
```

$$\sqrt{\frac{a}{b}} = \sqrt{\quad\frac{a}{b}} = \sqrt{\frac{a}{b}\quad}$$

`mathstyle` Specifies the mathstyle of the content of the radical. By default it is cramped.

```
\startformula
      \sqrt                    {x^2}
  + A^{\sqrt                   {x^2}}
```

```
  =    \sqrt[mathstyle=uncramped]{x^2}
  + A^{\sqrt[mathstyle=uncramped]{x^2}}
\stopformula
```

$$\sqrt{x^2} + A^{\sqrt{x^2}} = \sqrt{x^2} + A^{\sqrt{x^2}}$$

mindepth This enforces a minimal depth of the expression. It is currently set to `.2\exheight`, but it might be needed to set by font. Compare with `depth` and `height` that enforces a certain depth and height.

source Can be used to anchor material.

```
\defineboxanchor
  [dodo]

\setboxanchor
  [dodo]
  [corner=depth,
   location=height,
   yoffset=-.25ex]
  \hbox to \zeropoint{\mathindexfont dodo}

\startformula
    \root[source=dodo][3]{b}
  = \root             [3]{b}
\stopformula
```

$$\sqrt[3]{b} = \sqrt[3]{b}$$

plugin By default unset. If set to `mp` then the radical symbol is drawn with MetaFun.

```
\startformula
    \sqrt{1 + x}
  = \sqrt[plugin=mp]{1 + x}
  = \sqrt[plugin=mp,symbolcolor=C:2]{1 + x}
\stopformula
```

$$\sqrt{1 + x} = \sqrt{1 + x} = \sqrt{1 + x}$$

strut By default set to `height`, which means that a strut with some height but no depth is added inside the radical. See the examples on page 51.

3.12 Simple alignments

Use `\definemathsimplealign` and `\setupmathsimplealign` to work with these alignments. We use the `SA` one below as an example.

```
\definemathsimplealign
  [SA]
```

align Specify the alignment of each column. The syntax is the same as the one for math alignments and matrices.

```
\startformula\showmakeup[mathglue]
  \startSA
    \NC A      \NC = B + B' \NR
    \NC C + C' \NC = D      \NR
```

```
  \stopSA
  \quad
  \startSA[align=all:right]
    \NC A       \NC = B + B' \NR
    \NC C + C' \NC = D       \NR
  \stopSA
  \quad
  \startSA[align={1:right,2:left}]
    \NC A       \NC = B + B' \NR
    \NC C + C' \NC = D       \NR
  \stopSA
\stopformula
```

$$\begin{array}{cc} A & = B + B' \\ C + C' & = D \end{array} \quad \begin{array}{rr} A & = B + B' \\ C + C' & = D \end{array} \quad \begin{array}{rl} A & = B + B' \\ C + C' & = D \end{array}$$

From this example, we see that by default all columns are aligned to the middle. We change that so that the first one is flush right, the second flush left.

```
\setupmathsimplealign
  [SA]
  [align={1:right,2:left}]
```

distance Determines the horizontal distance between the two columns. By default it is set to `math`, which means that it will use the proper interatom spacing.

```
\startformula\showmakeup[mathglue]
  \startSA
    \NC A       \NC = B + B' \NR
    \NC C + C' \NC = D       \NR
  \stopSA
  \quad
  \startSA[distance=math]
    \NC A       \NC = B + B' \NR
    \NC C + C' \NC = D       \NR
  \stopSA
  \quad
  \startSA[distance=0pt]
    \NC A       \NC = B + B' \NR
    \NC C + C' \NC = D       \NR
  \stopSA
\stopformula
```

$$\begin{array}{rl} A & = B + B' \\ C + C' & = D \end{array} \quad \begin{array}{rl} A & = B + B' \\ C + C' & = D \end{array} \quad \begin{array}{r@{}l} A & = B + B' \\ C + C' & = D \end{array}$$

left/right Add content, typically fences, around the simple align.

```
\startformula
  \startSA
    \NC A \NC = B \NR
    \NC C \NC = D \NR
  \stopSA
```

```
    \quad
    \startSA
      [left=\startmathfenced[cases],
       right=\stopmathfenced]
      \NC A \NC = B \NR
      \NC C \NC = D \NR
    \stopSA
    \quad
    \startSA
      [left=\left.,
       right=\right\rbracket]
      \NC A \NC = B \NR
      \NC C \NC = D \NR
    \stopSA
  \stopformula
```

$$\begin{matrix} A = B \\ C = D \end{matrix} \quad \begin{cases} A = B \\ C = D \end{cases} \quad \left. \begin{matrix} A = B \\ C = D \end{matrix} \right]$$

The period in `\left.` represent an empty slot and is needed for pairing.

`leftmargin/rightmargin` Set extra space before or after the simple align.

```
  \startformula
    f(x) +
    \startSA
      [left=\startmathfenced[doublebar],
       right=\stopmathfenced]
      \NC A \NC = B \NR
      \NC C \NC = D \NR
    \stopSA
    + g(x)
    \quad
    f(x) +
    \startSA
      [left=\startmathfenced[doublebar],
       right=\stopmathfenced,
       leftmargin=\emwidth,
       rightmargin=\emwidth]
      \NC A \NC = B \NR
      \NC C \NC = D \NR
    \stopSA
    + g(x)
  \stopformula
```

$$f(x) + \left\| \begin{matrix} A = B \\ C = D \end{matrix} \right\| + g(x) \quad f(x) + \quad \left\| \begin{matrix} A = B \\ C = D \end{matrix} \right\| \quad + g(x)$$

`location` Anchor the construction in different places.

```
  \startformula
    \mathaxisbelow
    \startSA
```

```
    \NC A \NC = B \NR
    \NC C \NC = D \NR
  \stopSA
  \quad
  \startSA[location=top]
    \NC A \NC = B \NR
    \NC C \NC = D \NR
  \stopSA
  \quad
  \startSA[location=bottom]
    \NC A \NC = B \NR
    \NC C \NC = D \NR
  \stopSA
\stopformula
```

$$\begin{array}{l} A = B \\ C = D \end{array} \quad \begin{array}{l} A = B \\ C = D \end{array} \quad \begin{array}{l} A = B \\ C = D \end{array}$$

simplecommand Specify a command to use. Then commas are used to separate columns and semicolons to separate lines. This is only meant to be used with systems of equations.

spaceinbetween Specify the space between rows.

```
\startformula
  \startSA
    \NC A \NC = B \NR
    \NC C \NC = D \NR
  \stopSA
  \quad
  \startSA[spaceinbetween=2\lineheight]
    \NC A \NC = B \NR
    \NC C \NC = D \NR
  \stopSA
\stopformula
```

$$\begin{array}{l} A = B \\ C = D \end{array} \quad \begin{array}{l} A = B \\[2em] C = D \end{array}$$

text/textdistance Add text comments to the simple align.

```
\startformula\showstruts
  \startSA[text=foo]
    \NC A \NC = B \NR
    \NC C \NC = D \NR
  \stopSA
  \quad
  \startSA[text=foo,textdistance=2\emwidth]
    \NC A \NC = B \NR
```

```
    \NC C \NC = D \NR
  \stopSA
\stopformula
```

$$\begin{aligned}&|A = B\\&|C = D\end{aligned}\ \text{foo}\quad \begin{aligned}&|A = B\\&|C = D\end{aligned}\qquad \text{foo}$$

3.13 Stackers

`alternative` It is possible to use alternative symbols for some stackers, with the `mat` library (see below how it is loaded). These are drawn in MetaPost.

```
\useMPlibrary[mat]
\startformula
        \overbrace                    {A + B}
  \quad \overbrace[alternative=normal]{A + B}
  \quad \overbrace[alternative=mp]    {A + B}
\stopformula
```

$$\overbrace{A+B}\quad\overbrace{A+B}\quad\overbrace{A+B}$$

`bottomcommand/middlecommand/topcommand` Possibility to add commands. Below we show an example where we add a frame, and then we need to use `\groupedcommand`.

```
\startformula
        A \mhookrightarrow                            {a}{b} B
  \quad A \mhookrightarrow[bottomcommand=\inmframed]{a}{b} B
  \quad A \mhookrightarrow[middlecommand=\inmframed]{a}{b} B
  \quad A \mhookrightarrow[topcommand=\inmframed]   {a}{b} B
\stopformula
```

$$A \xhookrightarrow[b]{a} B \quad A \xhookrightarrow[\boxed{b}]{a} B \quad A \xhookrightarrow[b]{a} B \quad A \xhookrightarrow[b]{\boxed{a}} B$$

In this particular case, the spacing is not optimal, some extra space between the framed content and the arrow can be inserted with help of the `voffset` key. You might notice that the `middlecommand` is not doing anything. That depends on the type of stacker. Below is an example where it has an effect.

```
\startformula
        \overbraceunderbrace                          {1 + 2 + 3}
  \quad \overbraceunderbrace[middlecommand=\inmframed]{1 + 2 + 3}
\stopformula
```

$$\overbrace{\underbrace{1+2+3}}\quad\overbrace{\underbrace{\boxed{1+2+3}}}$$

`color/bottomcolor/middlecolor/topcolor` Changes the color of the pieces.

```
\startformula
        A \mhookrightarrow                 {a}{b} B
  \quad A \mhookrightarrow[color=C:3]      {a}{b} B
  \quad A \mhookrightarrow[bottomcolor=C:3]{a}{b} B
  \quad A \mhookrightarrow[middlecolor=C:3]{a}{b} B
```

```
  \quad A \mhookrightarrow[topcolor=C:3]   {a}{b} B
\stopformula
```

$$A \xhookrightarrow[b]{a} B \quad A \xhookrightarrow[b]{a} B \quad A \xhookrightarrow[b]{a} B \quad A \xhookrightarrow[b]{a} B \quad A \xhookrightarrow[b]{a} B$$

The `middlecolor` does not do anything in the example above.

```
\startformula
        \overbraceunderbrace                    {1 + 2 + 3}
  \quad \overbraceunderbrace[middlecolor=C:3]{1 + 2 + 3}
\stopformula
```

$$\overbrace{\underbrace{1+2+3}} \quad \overbrace{\underbrace{1+2+3}}$$

`distance` Set distance for top/bottom extensibles.

```
\startformula
        \overbraceunderbrace                        {1 + 2 + 3}
  \quad \overbraceunderbrace[distance=1\exheight]{1 + 2 + 3}
\stopformula
```

$$\overbrace{\underbrace{1+2+3}} \quad \overbrace{\underbrace{1+2+3}}$$

`hoffset/voffset` Set horizontal and vertical offsets.

```
\startformula
        A \mhookrightarrow                      {a}{b} B
  \quad A \mhookrightarrow[voffset=4\exheight]{a}{b} B
  \quad A \mhookrightarrow[hoffset=4\exheight]{a}{b} B
\stopformula
```

$$A \xhookrightarrow[b]{a} B \quad A \xhookrightarrow[b]{a} B \quad A \xhookrightarrow[\quad b \quad]{\quad a \quad} B$$

`lb/lt/rb/rt` Corner offsets. By default set to 0pt.

```
\startformula
        \overbraceunderbrace              {1 + 2 + 3}
  \quad \overbraceunderbrace[lb=\emwidth]{1 + 2 + 3}
  \quad \overbraceunderbrace[lt=\emwidth]{1 + 2 + 3}
  \quad \overbraceunderbrace[rb=\emwidth]{1 + 2 + 3}
  \quad \overbraceunderbrace[rt=\emwidth]{1 + 2 + 3}
\stopformula
```

$$\overbrace{\underbrace{1+2+3}} \quad \overbrace{\underbrace{1+2+3}} \quad \overbrace{\underbrace{1+2+3}} \quad \overbrace{\underbrace{1+2+3}} \quad \overbrace{\underbrace{1+2+3}}$$

`left/right` It is possible to put content directly to the left or right of a top/bottom stacker.

```
\startformula
        \overbraceunderbrace          {1 + 2 + 3}
  \quad \overbraceunderbrace[left=A] {1 + 2 + 3}
  \quad \overbraceunderbrace[right=B]{1 + 2 + 3}
\stopformula
```

$$\overbrace{\underbrace{1+2+3}} \quad A\overbrace{\underbrace{1+2+3}} \quad \overbrace{\underbrace{1+2+3}}B$$

`location` When using a stacker consisting of a middle symbol, it is by default resting on the base line. That corresponds to `location` set to `top`. The other possible values move the symbol down, at a step of 25%.

```
\startformula
        A \mhookrightarrow                 {a}{b} B
  \quad A \mhookrightarrow[location=top]   {a}{b} B
  \quad A \mhookrightarrow[location=high]  {a}{b} B
  \quad A \mhookrightarrow[location=middle]{a}{b} B
  \quad A \mhookrightarrow[location=low]   {a}{b} B
  \quad A \mhookrightarrow[location=bottom]{a}{b} B
\stopformula
```

$$A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B$$

`mathclass` The atom class of the stacker can be set explicitly.

```
\startformula\showmakeup[mathglue]
        A \mhookrightarrow                               {a}{b} B
  \quad A \mhookrightarrow[mathclass=\mathbinarycode]{a}{b} B
\stopformula
```

$$A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B$$

`mindepth/minheight/minwidth` These will guarantee some minimal lengths.

```
\startformula
        A \mhookrightarrow                          {a}{b} B
  \quad A \mhookrightarrow[mindepth=2\exheight] {a}{b} B
  \quad A \mhookrightarrow[minheight=3\exheight]{a}{b} B
  \quad A \mhookrightarrow[minwidth=2\emwidth]  {a}{b} B
\stopformula
```

$$A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \xhookrightarrow[b]{a} B$$

`mp/mpheight/mpdepth/mpoffset` Parameters to use for MetaPost stackers (when using `alternative=mp`). See `meta-imp-mat.mkiv` for further details.

`offset` You can try `min`, `max` or `normal`, and then there is a challenge to explain what they do!

```
\startformula
             \overbraceunderbrace                 {1 + 2 + 3}
  \breakhere \overbraceunderbrace[offset=normal]{1 + 2 + 3}
  \breakhere \overbraceunderbrace[offset=min]   {1 + 2 + 3}
  \breakhere \overbraceunderbrace[offset=max]   {1 + 2 + 3}
  \breakhere
        \overbraceunderbrace[offset=normal,hoffset=3TS]{1 + 2 + 3}
  \breakhere
        \overbraceunderbrace[offset=min,hoffset=3TS]   {1 + 2 + 3}
```

```
  \breakhere
        \overbraceunderbrace[offset=max,hoffset=3TS]   {1 + 2 + 3}
\stopformula
```

$$\overbrace{\underbrace{1+2+3}}$$
$$\overbrace{\underbrace{1+2+3}}$$
$$\overbrace{\underbrace{1+2+3}}$$
$$\overbrace{\underbrace{1+2+3}}$$
$$\overbrace{\underbrace{1+2+3}}$$
$$\overbrace{\underbrace{1+2+3}}$$
$$\overbrace{\underbrace{1+2+3}}$$

order Due to different conventions it might be good to be able to swap the argument that goes above with the one that goes below. The order key can be normal (first argument above, second below) and reverse (first argument below, second above).

```
\startformula
        A \mhookrightarrow                {a}{b} B
  \quad A \mhookrightarrow[order=normal]  {a}{b} B
  \quad A \mhookrightarrow[order=reverse]{a}{b} B
\stopformula
```

$$A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{b}{\underset{a}{\hookrightarrow}} B$$

sample To use a character as a model for a group. Used for example for implications, where the $\Longleftrightarrow$ is used. See math-stc.mkxl for details.

shrink/stretch Stretch or shrink extensible stackers. Typically applies for variants of the glyph. We show one example where the brace is shrinked, the default behavior.

```
\startformula
        \overbrace           {12}
  \quad \overbrace[shrink=yes]{12}
  \quad \overbrace[shrink=no] {12}
\stopformula
```

$$\overbrace{12} \quad \overbrace{12} \quad \overbrace{12}$$

strut By default struts are used for consistency.

```
\startformula\showstruts
        A \mhookrightarrow              {a}{b} B
  \quad A \mhookrightarrow[strut=yes]   {a}{b} B
  \quad A \mhookrightarrow[strut=no]    {a}{b} B
\stopformula
```

$$A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B$$

style/bottomstyle/middlestyle/topstyle These are used to change the style of pieces. Note that it depends a bit on the type of the stacker if they are applicable or not.

```
\startformula
        A \mhookrightarrow                  {a}{b} B
  \quad A \mhookrightarrow[style=bold]      {a}{b} B
  \quad A \mhookrightarrow[bottomstyle=bold]{a}{b} B
  \quad A \mhookrightarrow[middlestyle=bold]{a}{b} B
  \quad A \mhookrightarrow[topstyle=bold]   {a}{b} B
\stopformula
```

$$A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{a}{\underset{\boldsymbol{b}}{\hookrightarrow}} B \quad A \overset{a}{\underset{b}{\hookrightarrow}} B \quad A \overset{\boldsymbol{a}}{\underset{b}{\hookrightarrow}} B$$

Just as for the command keys, the `middlestyle` is not doing anything in the example above.

```
\startformula
        \overbraceunderbrace                   {1 + 2 + 3}
  \quad \overbraceunderbrace[middlestyle=bold]{1 + 2 + 3}
\stopformula
```

$$\overbrace{\underbrace{1+2+3}} \quad \overbrace{\underbrace{\mathbf{1+2+3}}}$$

4 Inline math

4.1 Introduction

In the previous chapters we have discussed how to enter the different math modes and how to access various symbols, alphabets and other constructions. Now it is time to discuss typesetting of inline formulas in more detail. We will focus on how these formulas interplay with the surrounding text and paragraphs and how we can configure that, as well as some things to think about when typing inline formulas. This material covered in this chapter is complex, and the normal user can skip it (but §4.5 includes some general suggestions on setting inline fractions) and still be fine, since the default setups should work well.

We first discuss line breaking. The problem here is that for the rather advanced paragraph builder of TeX to succeed to typeset nice paragraphs when math is involved, we sometimes need to break these formulas. It is impossible to make a general set up that will always lead to good line breaks, the user should expect some rewriting or manual juggling. Line breaks in mathematics can be controlled via penalties, and we will show several possible ways to do so.

To prevent lines from spreading, one usually needs to prevent inline formulas from being too tall. We will present the profiling mechanism in ConTeXt that sometimes can prevent lines from spreading, even though the lines are slightly too tall, without a bad outcome. The user can also work to prevent the lines from spreading. One way to do so is to slash the fractions. This does not really have to do so much with ConTeXt but is rather some general advice.

4.2 Breaking paragraphs into lines

The algorithm used by TeX to break paragraphs into lines, the Knuth–Plass algorithm, is rather complex. We will not discuss it in detail here, but if we want to understand the math configurations that we will discuss below, it will be good to understand some aspects of it, in particular the ones that has to do with mathematics. We start, however, with a paragraph borrowed from [CBB54], without any mathematics. The vertical bars indicate all possible break points.

> The art of presenting printed mathematics has much in common with those of display advertising and window-dressing. Crowding is to be avoided; contrast can be used whether of formula against formula or of words against symbols; essential information ought not too often to be hidden away in the small type of inferiors and superiors.

Note that some of the possible breaking points are inside words, leading to hyphenation (`disc`) while others are before spaces (`glue`). Most of the breaks in the paragraph above will never happen; it would for example lead to a very underful first line if we broke after the first word. TeX calculates badness of possible breakpoints and deactivate them 'on-the-fly' if they are too bad. We end up with a tree of possible breakpoints. With a normal set up (not as above) this tree is not so big, and from it the optimal choice (least demerits) can be found. For completeness we show below the actual values for the example paragraph above. In order of appearance, the columns stand for the line, the index of the possible breaking point, the parent index in the tree, the demerit values, the classification (that in ConTEXt (lmtx) can be set up to be more granular) and finally the type of breaking point.

1	1	0	100000000	veryloose	glue
	2	0	100000000	veryloose	glue
	3	0	100000000	veryloose	glue
	4	0	100062500	veryloose	disc
	5	0	100062500	veryloose	disc
	6	0	100000000	veryloose	glue
	7	0	100000000	veryloose	glue
	8	0	100062500	veryloose	disc
	9	0	100062500	veryloose	disc
	10	0	100062500	veryloose	disc
	11	0	100000000	veryloose	glue
	12	0	100000000	veryloose	glue
	13	0	100000000	veryloose	glue
	14	0	100000000	veryloose	glue
	15	0	100062500	veryloose	disc
	16	0	100000000	veryloose	glue
	17	0	46036225	veryloose	glue
	18	0	352836	veryloose	glue
	19	0	6889	loose	glue
	20	0	67169	barelytight	disc
2	21	19	100006889	veryloose	glue
	22	2	100008069	loose	glue
	23	1	100004121	decent	glue
	24	19	100069389	veryloose	disc
	25	3	100065444	almostloose	disc
	26	2	100066621	decent	disc
	27	19	100069389	veryloose	disc
	28	3	100074529	almosttight	disc
	29	19	100069389	veryloose	disc
	30	19	100006889	veryloose	glue
	31	19	100006889	veryloose	glue
	32	6	100004100	decent	glue
	33	19	100069389	veryloose	disc
	34	19	100009389	veryloose	disc
	35	7	100009669	barelytight	disc
	36	19	100069389	veryloose	disc
	37	19	100006889	veryloose	glue

	38	19	100069389	veryloose	disc
	39	12	100069984	barelytight	disc
	40	19	100006889	veryloose	glue
	41	13	100003416	loose	glue
	42	19	100006889	veryloose	glue
	43	14	100006429	loose	glue
	44	13	100004100	decent	glue
	45	19	100006889	veryloose	glue
	46	14	100004100	decent	glue
	47	17	76606066	veryloose	glue
	48	18	6084072	veryloose	glue
	49	18	452972	veryloose	disc
	50	19	11930	loose	glue
	51	19	27305	tight	glue
	52	20	75965	almosttight	glue
3	53	50	100011930	veryloose	glue
	54	50	100011930	veryloose	glue
	55	30	100009585	barelyloose	glue
	56	50	100011930	veryloose	glue
	57	32	100008456	loose	glue
	58	50	100074430	veryloose	disc
	59	32	100066721	decent	disc
	60	50	100011930	veryloose	glue
	61	35	100014569	loose	glue
	62	50	100011930	veryloose	glue
	63	50	100074430	veryloose	disc
	64	37	100071514	almostloose	disc
	65	50	100011930	veryloose	glue
	66	50	100011930	veryloose	glue
	67	47	85546166	veryloose	glue
	68	48	46102348	veryloose	glue
	69	49	2613872	veryloose	glue
	70	49	532213	loose	disc
	71	50	44691	veryloose	glue
	72	50	78551	decent	disc
	73	51	90166	barelyloose	disc
	74	51	28394	almosttight	glue

	75	52	139194	almosttight	disc
4	76	53	100077291	barelyloose	disc
	77	74	100090894	veryloose	disc
	78	53	100097706	tight	disc
	79	74	100028394	veryloose	glue
	80	57	100012600	decent	glue
	81	74	100028394	veryloose	glue
	82	60	100016030	decent	glue
	83	74	100090894	veryloose	disc
	84	62	100016031	almostloose	glue
	85	62	100016030	decent	glue
	86	74	100028394	veryloose	glue
	87	67	86445891	veryloose	disc
	88	68	60127373	veryloose	glue
	89	69	44902881	veryloose	glue
	90	69	8268756	veryloose	glue
	91	69	2781153	veryloose	glue
	92	70	544757	veryloose	glue
	93	71	66300	veryloose	glue
	94	71	48072	barelyloose	penalty
	95	71	127640	barelytight	disc
	96	73	176520	almostloose	disc
	97	72	168872	barelytight	disc
	98	74	130915	veryloose	disc
	99	74	31218	barelyloose	penalty
	100	74	6298110	tight	penalty
5	101	99	107593718	veryloose	disc
	102	99	107593718	veryloose	disc
	103	79	107603058	loose	disc
	104	99	107593718	veryloose	disc
	105	79	107593619	almostloose	disc
	106	99	100031218	veryloose	glue
	107	79	100032494	decent	glue

98	74 51 19
99	74 51 19
100	74 51 19

The above paragraph was set with an infinite tolerance, which means that possible breakpoints are not discarded. Most of the possible breaking points indeed come with a very high demerits value. With the actual settings in this document, there are only a few breaking points left for the same paragraph:

> The art of presenting printed mathematics has much in common with those of display advertising and window-dressing. Crowding is to be avoided; contrast can be used whether of formula against formula or of words against symbols; essential information ought not too often to be hidden away in the small type of inferiors and superiors.

This leads in the end to a smaller tree to use for selecting the best solution.

1	1	0	6889	loose	glue	3	4	3	28394	almosttight	glue		4	3 1
2	2	1	11930	loose	glue	4	5	4	31218	barelyloose	penalty		5	4 3 1
	3	1	27305	tight	glue		6	4	6298110	tight	penalty		6	4 3 1

The example above does not involve any mathematics. Let us now consider one example (borrowed from the excellent book [Wei80]) that does.

```
If \m {z \in \rho(T)} then \m {z - T} is injective and \m {R(z,T)} is
continuous. If \m {z - T} is injective and \m {R(z,T)} is continuous, then
\m {z \nin \sigma_{p}(T)} and thus by Theorem 5.23(b) the set \m {D(R(z,T))
= R(z-T)} is dense in \m {H}; as \m {R(z,T)} is closed, we have \m {R(z -
T) = D(R(z,T)) = H}. If \m {R(z,T) = H} and \m {z \in \reals}, then \m {N(z
```

```
- T) = N(z^* - T^*) = R(z - T)^{\bot} = \{0\}}; therefore \m {z - T} is
bijective, i.e., \m {z \in \rho(T)}. If \m {\mfunction{Im} z \neq 0}, then
\m {z \in \rho(T)} by Theorem 5.23(a).\par
```

The output with the settings in this document is given below.

> If $z \in \rho(T)$ then $z - T$ is injective and $R(z, T)$ is continuous. If $z - T$ is injective and $R(z, T)$ is continuous, then $z \notin \sigma_p(T)$ and thus by Theorem 5.23(b) the set $D(R(z, T)) = R(z - T)$ is dense in H; as $R(z, T)$ is closed, we have $R(z - T) = D(R(z, T)) = H$. If $R(z, T) = H$ and $z \in \mathbb{R}$, then $N(z - T) = N(z^* - T^*) = R(z - T)^{\perp} = \{0\}$; therefore $z - T$ is bijective, i.e., $z \in \rho(T)$. If $\mathrm{Im} z \neq 0$, then $z \in \rho(T)$ by Theorem 5.23(a).

1	1	0	256	barelyloose	glue		6	4	1357761	decent	penalty	8	5 4 3 1
	2	0	4900	barelytight	glue	5	7	5	520161	veryloose	glue	9	5 4 3 1
2	3	1	985	almostloose	glue		8	5	760786	barelyloose	penalty	10	6 4 3 1
3	4	3	251661	almostloose	penalty		9	5	521707	almosttight	penalty		
4	5	4	508061	loose	penalty		10	6	1360361	decent	penalty		

We see a new type of line break, inside formulas (`penalty`). Automatic line breaks inside formulas have in TEX always been restricted to *after* relation and binary operator atoms; in contrast with text, line breaks in math are not permitted at glue. The penalties (`\relpenalty` and `\binoppenalty`) have usually been set to 500 and 700, respectively; a small preference for breaking after relations. Note that we do not only have a few possible breaks inside math, some of them are in fact realized, in spite of the added penalty. (Hyphenation breaks also come with a penalty, but we will not discuss that here.)

If we do not allow any breaks in mathematics (by setting the corresponding penalties to 10000), then TEX will in this example paragraph not find any good solution. This results in an overful hbox, with one of the longer formulas sticking out in the margin.

> If $z \in \rho(T)$ then $z - T$ is injective and $R(z, T)$ is continuous. If $z - T$ is injective and $R(z, T)$ is continuous, then $z \notin \sigma_p(T)$ and thus by Theorem 5.23(b) the set $D(R(z,T)) = R(z-T)$ is dense in H; as $R(z,T)$ is closed, we have $R(z-T) = D(R(z,T)) = H$. If $R(z,T) = H$ and $z \in \mathbb{R}$, then $N(z-T) = N(z^* - T^*) = R(z-T)^{\perp} = \{0\}$; therefore $z - T$ is bijective, i.e., $z \in \rho(T)$. If $\mathrm{Im} z \neq 0$, then $z \in \rho(T)$ by Theorem 5.23(a).

That looks bad; line breaking inside formulas is a “necessary evil”. The way to set it up is to use penalties. We will use the same paragraph to discuss and show a few settings we can do in ConTEXt. First we show the paragraph with the penalties attached, with the longstanding “default” setting of only allowing breaks after relations (with penalty 500) and binary operators (penalty 700).

> If $z \in \rho(T)$ then $z - T$ is injective and $R(z, T)$ is continuous. If $z - T$ is injective and $R(z, T)$ is continuous, then $z \notin \sigma_p(T)$ and thus by Theorem 5.23(b) the set $D(R(z, T)) = R(z - T)$ is dense in H; as $R(z, T)$ is closed, we have $R(z - T) = D(R(z, T)) = H$. If $R(z, T) = H$ and $z \in \mathbb{R}$, then $N(z - T) = N(z^* - T^*) = R(z-T)^{\perp} = \{0\}$; therefore $z - T$ is bijective, i.e., $z \in \rho(T)$. If $\mathrm{Im} z \neq 0$, then $z \in \rho(T)$ by Theorem 5.23(a).

The gray boxes show the penalties that are relevant for us (the other ones are connected with widows and orphans). We see that it is by default always a 0 penalty before and after a formula, and indeed a penalty of 500 after relations and 700 after binary operators. Before we continue the discussion, let us emphasize that after experimenting with different values (and in fact also different models for calculation of badness and demerits), we have concluded that the quality from the values used since plain TEX are not so easy to improve. But we believe that some flexibility, described below, might improve the situation slightly.

It is considered non-optimal to break a formula just before a one character formula. We find a lonely H in our example paragraph. One way to avoid having a line break before it is to insert what is called a tie, a non-breakable space just before the formula. This can be done with `\penalty10000`, but often also as `~`. The 10000 penalty will prohibit a line break. One can imagine situations where one has to choose between a line break before a singleton and a bad break inside a longer formula. For this reason, we believe that it is better to insert a smaller penalty, and to do it automatically. We can do that with `\preshortinlinepenalty`. By default it is set to 150.

> If $z \in \rho(T)$ then $z - T$ is injective and $R(z, T)$ is continuous. If $z - T$ is injective and $R(z, T)$ is continuous, then $z \notin \sigma_p(T)$ and thus by Theorem 5.23(b) the set $D(R(z, T)) = R(z - T)$ is dense in H; as $R(z, T)$ is closed, we have $R(z - T) = D(R(z, T)) = H$. If $R(z, T) = H$ and $z \in \mathbb{R}$, then $N(z - T) = N(z^* - T^*) = R(z - T)^\perp = \{0\}$; therefore $z - T$ is bijective, i.e., $z \in \rho(T)$. If $\operatorname{Im} z \neq 0$, then $z \in \rho(T)$ by Theorem 5.23(a).

Next, one could consider to open up and allow lines to break also before and after other atom classes than relation and binary operator. This is indeed possible to do for any atom class in ConTEXt. In a general setup it does not prove to be too useful. With

```
\setmathpostpenalty\mathvariablecode500
\setmathpostpenalty\mathordinarycode500
\setmathpostpenalty\mathdigitcode500
```

we allow breaks after variable, ordinary and digit atoms, adding a penalty of 500. This results in a very bad break.

> If $z \in \rho(T)$ then $z - T$ is injective and $R(z, T)$ is continuous. If $z - T$ is injective and $R(z, T)$ is continuous, then $z \notin \sigma_p(T)$ and thus by Theorem 5.23(b) the set $D(R(z, T$
> $)) = R(z - T)$ is dense in H; as $R(z, T)$ is closed, we have $R(z - T) = D(R(z, T)) = H$. If $R(z, T) = H$ and $z \in \mathbb{R}$, then $N(z - T) = N(z^* - T^*) = R(z - T)^\perp = \{0\}$; therefore $z - T$ is bijective, i.e., $z \in \rho(T)$. If $\operatorname{Im} z \neq 0$, then $z \in \rho(T)$ by Theorem 5.23(a).

To add a penalty before an atom class `\setmathpostpenalty` is used. By default, we follow the traditional setup, only the penalties after relations and binary operators are set to finite values. There is, however, a third class that has a value set, punctuation is set to 10000, which as we know can be seen as infinity. There is a finesse about this, though. Say that we want to define some macro that likely will involve several commas, like a tuple. If one use many such constructions in a paragraph, it might be difficult to find breakpoints, since in an expression like $(1, 2, 3, 4, 5, 6, 7, 8, 9)$ there is nowhere to break. It is then possible to use a so-called math nesting.

```
\definemathnesting[tuple][left=(,right=),inlinefactor=500]
```

Now `\m{ (a,b,c) + \tuple{1,2,3} + (p,q,r) }` gives $(a, b, c) + (1, 2, 3) + (p, q, r)$. Here the 10000 penalty after the commas have become 5000. Still not a wanted break point, but it might be better than nothing.

There is in fact yet another mechanism enabled that sometimes change the default penalties after relations and binary operators. There is a multiplier `\mathinlinepenaltyfactor`, by default set to 1500. It will keep control of fences and multiply the penalties inside them.

If $z \in \rho(T)$ then $z - T$ is injective and $R(z, T)$ is continuous. If $z - T$ is injective and $R(z, T)$ is continuous, then $z \notin \sigma_p(T)$ and thus by Theorem 5.23(b) the set $D(R(z, T)) = R(z - T)$ is dense in H; as $R(z, T)$ is closed, we have $R(z - T) = D(R(z, T)) = H$. If $R(z, T) = H$ and $z \in \mathbb{R}$, then $N(z - T) = N(z^* - T^*) = R(z - T)^\perp = \{0\}$; therefore $z - T$ is bijective, i.e., $z \in \rho(T)$. If $\operatorname{Im} z \neq 0$, then $z \in \rho(T)$ by Theorem 5.23(a).

The binary operator penalties appearing inside parentheses have been multiplied by 1.5, and are now $700 \times 1.5 = 1050$.

We mention one more method to control line breaks in math. In a long formula it might be considered better to break somewhere in the middle rather than at the very beginning or very end. This can be done with `\mathforwardpenalties` and `\mathbackwardpenalties`:

```
\mathforwardpenalties  3 200 100 50
\mathbackwardpenalties 3 200 100 50
```

This will add 200 to the outermost penalty, 100 to the next one and 50 to the third (if available). Since we add penalties at the boundaries of formulas, we lower the penalties after the relation and binary operators, and set them to 400 and 600, respectively.

If $z \in \rho(T)$ then $z - T$ is injective and $R(z, T)$ is continuous. If $z - T$ is injective and $R(z, T)$ is continuous, then $z \notin \sigma_p(T)$ and thus by Theorem 5.23(b) the set $D(R(z, T)) = R(z - T)$ is dense in H; as $R(z, T)$ is closed, we have $R(z - T) = D(R(z, T)) = H$. If $R(z, T) = H$ and $z \in \mathbb{R}$, then $N(z - T) = N(z^* - T^*) = R(z - T)^\perp = \{0\}$; therefore $z - T$ is bijective, i.e., $z \in \rho(T)$. If $\operatorname{Im} z \neq 0$, then $z \in \rho(T)$ by Theorem 5.23(a).

Note that now the penalty after the $\in$ in the first formula $z \in \rho(T)$ is $400 + 200 + 200 = 800$, while it for the minus in the second formula $z - T$ is $600 + 200 + 200 = 1000$. For the longer formulas, > in front of the penalty helper indicate that the forward penalty is applied, < that the backwards penalty is applied, and = that both are applied. Note the ordering of the different applications. For example we see in $N(z - T)$ at the beginning of a formula a 1100 after the minus. That comes from $600 \times 1.5 + 200$. So, the forward and backward penalties are added *after* we have compensated for being inside the parentheses.

4.3 What do others say on the breaking of inline formulas?

The breaking of inline formulas over several lines is an interesting and rather complex topic. In fact, it should not be something that the user should need to have in mind while typing, but it is good to know something about it. Let us therefore start with a small historical background.

The simplest rule is to be find in [CBB54]: "Undisplayed formulae (that is, formulae run in as part of the text) must never be broken at the end of a line."

In [Lan61] there is a discussion on the issue that runs over three pages, and except that it gives several examples, it can be summarized as follows. It is strongly suggested to change the wording or the word spacing locally to avoid line breaks in formulas. If that does not help it is suggested to display the formula that has to be broken, if it is not too short, or if it does not lead to an unbalanced emphasizing of the formula. If neither of these solutions are possible, it is suggested that one breaks the formula according to the priority below.

$$xxx,\overset{1}{|}xxx=\overset{2}{|}xxx+\overset{3}{|}xxx/\overset{4}{|}xxx(\overset{5}{|}xxx)\overset{6}{|}x(x,\overset{7}{|}xx)$$

Let us develop their reasoning a bit. The best place to divide the formula is after a comma or other punctuation where the formula is already naturally divided. In fact, it is even suggested that this is not a problem at all in cases as $f(x) = x^2, x \in \mathbb{R}$, where the comma is not really a part of one of the formulas, but one can assume that they do not want to break after the comma in $f(x, y)$. The next best solution is to divide the formula after a verb like the equal sign, the third best is after a binary operator like plus. Except for these, breaks are really considered to be bad, but it goes on. The fourth best is to divide after a multiplication or division. In case of a multiplication like $(a + b)(c + d)$ no multiplication sign should be printed, but in the case of division $(a + b)/(c + d)$ one should have $(a + b)/$ on the first line and $(c + d)$ on the second. The last three options are considered very bad.

If it is not possible to break the formula according to the list above, the manual also says it is forbidden to do so after functions like sin or after operators like $\sum$ or $\int$.

In [Swa99] the topic is covered in Sections 3.3 and 3.4. Seven rules are formulated. They are more or less in agreement with the rules given by Lansburgh, but they are not given any clear priority. Instead of formulating the rules in [Swa99], let us point out some differences between them and [Lan61]. A noticeable one is that line breaks are allowed not only after, but also *before* verbs like $=$ and conjunctions like $+$. Also, if breaking a product $(a + b)(c + d)$ into $(a + b)$ and $(c + d)$ (something that we usually do not allow), it is suggested that a multiplication sign ($\cdot$ or $\times$) is inserted on the second line. In the formulas $x(a + b + c)$, $(a + b - c)y$ and $\sum(a + b - c)$ it is written that no break should be allowed. Also, no breaks are allowed between the integral $\int$ and the differential dx.

4.4 Tall mathematics in paragraphs

Tall mathematical expressions in inline mathematics is a problem, since they will cause an uneven space between lines in paragraphs. One way to avoid the problem is to use smaller symbols when available, like $\int$ instead of $\displaystyle\int$ (this will automatically be the case if one starts inline math and uses `\int`). On the other hand, in some formulas the letters might become too small. We do not want to use a big fraction like $\dfrac{a}{b}$ in inline formulas, since that will spread the lines, but the $\frac{a}{b}$ (that we get from `\frac{a}{b}` in inline math mode) looks too cramped; the small letters will decrease the readability. That becomes even worse if we also add a superscript, $\frac{a^b}{c}$. Then we also risk the line to spread.

Some tall formulas might be transformed into displayed formulas, but when that happens too much, the text can become less readable. So, the question is what we should do? Tall formulas coming from fractions can be slashed, something that we will discuss in the next section. If we want to use too tall formulas, then there is not much to do. But for formulas that are just a bit too tall, we can sometimes still reduce the lines without getting a bad result. Let us look at a maybe not to obvious example, borrowed from the book [SS98] that contains lots of nice math problems.

> **Problem 4.1.18 (Fa78)** Let $M_{n\times n}$ be the vector space of real $n \times n$ matrices, identified with $\mathbb{R}^{n^2}$. Let $X \subset M_{n\times n}$ be a compact set. Let $S \subset \mathbb{C}$ be the set of all numbers that are eigenvalues of at least one element of X. Prove that S is compact.

> **Problem 4.1.18 (Fa78)** Let $M_{n\times n}$ be the vector space of real $n \times n$ matrices, identified with $\mathbb{R}^{n^2}$. Let $X \subset M_{n\times n}$ be a compact set. Let $S \subset \mathbb{C}$ be the set of all numbers that are eigenvalues of at least one element of X. Prove that S is compact.

Maybe it is difficult to see the difference between these paragraphs. The tallest formula, $\mathbb{R}^{n^2}$ introduces some extra space between the first two lines in the first paragraph. This space is, however, removed in the second. The mechanism behind this is *profiling*, which is enabled by invoking `\setupalign[profile]`. It will run over lines where extra line skip is needed, and look at the boxes. If the line skip can be reduced without the lines clashing, it will do so (one can set up the granularity). As often is the case in ConTEXt, it is possible to enable a tracker to visualize this (the `profiling.lines.show` tracker). The same two paragraphs are typeset below. In the first one, where profiling is off we show the lines. In the second we show lines where profiling kicks in.

Problem 4.1.18 (Fa78) Let $M_{n\times n}$ be the vector space of real $n \times n$ matrices, identified with $\mathbb{R}^{n^2}$. Let $X \subset M_{n\times n}$ be a compact set. Let $S \subset \mathbb{C}$ be the set of all numbers that are eigenvalues of at least one element of X. Prove that S is compact.

Problem 4.1.18 (Fa78) Let $M_{n\times n}$ be the vector space of real $n \times n$ matrices, identified with $\mathbb{R}^{n^2}$. Let $X \subset M_{n\times n}$ be a compact set. Let $S \subset \mathbb{C}$ be the set of all numbers that are eigenvalues of at least one element of X. Prove that S is compact.

4.5 Slashing fractions

Fractions in inline formulas are problematic simply because they are tall by construction. We will below give many examples with some general advice, partly inspired by the 29(!) pages long discussion on fractions in [Lan61]. We have in mind that we want to avoid tall formulas that introduces extra line spread. Below, we will only show the output of examples, together with comments. We give suggestions both for display and inline formulas. It is often more difficult to get the inline version correct, and, as mentioned, we will often use a fraction slash instead of a fraction bar, i.e. we will *slash the fractions*.

In our first example we have fractions with numbers only. In display style math these can be set slightly smaller with `\tfrac`. In text style math they will automatically get the correct smaller size with `\frac`.

Display: $\tfrac{11}{19} + \tfrac{3}{19}\sqrt{5} - \tfrac{1}{19}\sqrt{7} - \tfrac{2}{19}\sqrt{5}\sqrt{7}$

Inline: $\frac{11}{19} + \frac{3}{19}\sqrt{5} - \frac{1}{19}\sqrt{7} - \frac{2}{19}\sqrt{5}\sqrt{7}$

If there is a fraction with only numbers, we can still set it with `\tfrac`, as in the first example below. This also applies if there are more terms with numeric fractions, as in the polynomial in the second example. If, however, there are some non-numeric fractions, as in the third example, we suggest to set that fraction ($a/5$ in the example) in display style. Then it is also natural to set the other fraction ($\frac{1}{8}$ in the example) in display style. Note that we have slashed $a/5$ but not $\frac{1}{8}$ in the inline version. One could argue that it looks better with $1/8$ as well.

Display: $\tfrac{1}{24}(L^2 + 4\pi^2) \quad \tfrac{3}{5}x^2 + 2x + \tfrac{1}{8} \quad \dfrac{a}{5}x^2 + 2x + \dfrac{1}{8}$

Inline: $\frac{1}{24}(L^2 + 4\pi^2) \quad \frac{3}{5}x^2 + 2x + \frac{1}{8} \quad (a/5)x^2 + 2x + \frac{1}{8}$

With integer fractions in front of a big symbol, like an integral, big parentheses, or a sum, there is no meaning in keeping the fractions small in display math.

Display: $\dfrac{1}{2}\displaystyle\int_0^2 f(\theta)\,d\theta \quad \dfrac{3}{5}\left(\dfrac{a}{b} - 1\right) \quad \dfrac{1}{2}\displaystyle\sum_{k=1}^{+\infty}\dfrac{1}{k^2}, \quad \dfrac{1}{2}\log\left(\dfrac{x}{y}\right)$

Inline: $\frac{1}{2}\int_0^2 f(\theta)\,d\theta \quad \frac{3}{5}(a/b - 1) \quad \frac{1}{2}\sum_{k=1}^{+\infty} 1/k^2 \quad \frac{1}{2}\log(x/y)$

Here we have letter fractions that are simple in the sense that both numerator and denominator only has one term. Since there are letters, we shall not use a smaller style. This fixes the look in the display style. In text style, we must slash. The reason is that we do not want high fractions that forces a larger total line height, and we do not want to make the symbols smaller.

Display: $$\frac{1}{2\pi} \qquad x' = \frac{x}{|x|} \qquad \frac{dy}{dx} \qquad \left\lfloor \frac{n^2}{4} \right\rfloor$$

Inline: $1/2\pi$ $\quad x' = x/|x|$ $\quad dy/dx$ $\quad \lfloor n^2/4 \rfloor$ or $\lfloor \frac{1}{4} n^2 \rfloor$

In the first example we slash and get $1/2\pi$. Could this be mixed up with $\frac{1}{2}\pi$? Yes, probably. But, if we think about how we read the formula out, "one over two π", it makes sense to write $1/2\pi$. In cases where you want or need to, you can insert parentheses and write $1/(2\pi)$.

There is not much to say about the second and third examples. For the fourth, we can choose between $\lfloor n^2/4 \rfloor$ and $\lfloor \frac{1}{4} n^2 \rfloor$ (the fraction here is set with `\frac`). The important point is that the formulas do not change the height of the line.

Display: $$\frac{\Gamma(\beta_1)\Gamma(\beta_2) \dots \Gamma(\beta_n)}{\Gamma(\beta_1 + \beta_2 + \dots + \beta_n)} \qquad \frac{1}{\zeta(s)} \sum_{n=1}^{+\infty} \frac{\mu(n)}{n^s}$$

Inline: $\Gamma(\beta_1)\Gamma(\beta_2) \dots \Gamma(\beta_n)/\Gamma(\beta_1 + \beta_2 + \dots + \beta_n)$ $\quad [1/\zeta(s)] \sum_{n=1}^{+\infty} \mu(n)/n^s$

With the examples above we only want to emphasize that the same idea applies even if the expressions in the fractions are a bit more complicated. If they get too long, however, they should be displayed. These two formulas are border cases.

In the second example we have two fractions that are both slashed, independently of each other. Note the added square brackets in the first of them.

Display: $$\frac{1}{2\pi i}\frac{\partial f}{\partial x_j} \qquad \frac{\sin^2 tu}{u^2} \qquad \frac{1}{d_\chi}(\Lambda * \mathcal{M})$$

Inline: $(1/2\pi i)\,\partial f/\partial x_j$ $\quad (\sin^2 tu)/u^2$ $\quad (1/d_\chi)(\Lambda * \mathcal{M})$

In these examples we have inserted parentheses when slashing the fractions. We need no parentheses around the numerator (in the third example there are already parentheses, and we must not remove them!).

Display: $\frac{1}{2}(a + b)$ or $\dfrac{a+b}{2}$

Inline: $\frac{1}{2}(a + b)$ or $(a + b)/2$

In cases like these you have the freedom to choose, but be consistent throughout your document.

Display: $$\sqrt{\frac{v}{\sigma}\frac{dv}{\sigma}}$$

Inline: $\sqrt{v/\sigma\, dv/\sigma}$

Square roots work as parentheses, so you do not need to insert any when slashing.

Display: $$\frac{1}{n+1} \qquad w = \frac{az+b}{cz+d} \qquad \frac{F(t_i) - F(t_{i-1})}{t_i - t_{i-1}}$$

Inline: $1/(n+1)$ $w = (az+b)/(cz+d)$ $[F(t_i) - F(t_{i-1})]/(t_i - t_{i-1})$

When slashing fractions that are not simple (i.e. where the numerator and/or the denominator have more than one term), we will need to add parentheses. Note the square brackets in the third example above.

Display: $\frac{1}{n+1}B_{n+1}(x)$ $\frac{n!}{(n-2j)!(2j)!!}$ $\frac{B_1}{1+x} - \frac{B_2}{2(1+x)^2}$

Inline: $[1/(n+1)]B_{n+1}(x)$ $n!/[(n-2j)!(2j)!!]$ $B_1/(1+x) - B_2/[2(1+x)^2]$

In the first example the square brackets must be there. One could question them in the second example if one reads it as "n-factorial over ...". If hesitant, add parentheses. The third example consists of two terms, one where we only need ordinary parentheses, and one where we also need square brackets. The last term could equally well have been written as $-\frac{1}{2}B_2/(1+x)^2$.

Display: $\frac{1}{(2\pi i)^k}\int_{\nu+x} \varkappa\varphi$

Inline: $[1/(2\pi i)^k] \int_{\nu+x} \varkappa\varphi$ or $(2\pi i)^{-k} \int_{\nu+x} \varkappa\varphi$

The fraction above can be slashed as we first show, which leads to extra brackets. It is perhaps better in cases like this to simply get rid of the fraction by writing $1/(2\pi i)^k$ as $(2\pi i)^{-k}$.

Display: $a^{\frac{3}{5}}$ $a^{b/2} = a^{\frac{1}{2}b}$ $w^{(N+2)/(N-2)}$ $L^{Np/(N-2)}$ $\left(\int_\Omega |f|^p \, d\mu\right)^{1/p}$

Inline: $a^{3/5}$ $a^{b/2}$ $w^{(N+2)/(N-2)}$ $L^{Np/(N-2)}$ $(\int_\Omega |f|^p \, d\mu)^{1/p}$

Fractions in exponents and indices are set more or less as if they were set on the line, but with smaller sizes. This is taken care of automatically.

Bad: $e^{\frac{\ell_{\gamma_1}(X)+\ell_{\gamma_2}(X)}{2}}$ Better: $e^{\frac{1}{2}[\ell_{\gamma_1}(X)+\ell_{\gamma_2}(X)]}$ Better: $\exp\left\{\frac{1}{2}[\ell_{\gamma_1}(X)+\ell_{\gamma_2}(X)]\right\}$

The first example above is too cluttered. It gets slightly better if we take the $\frac{1}{2}$ out as a factor, but even better if we avoid the exponential form altogether and write the exponential function as exp. We end this long list with examples by reminding you that it is also possible to use a slash in display math.

Display: $\mathcal{M}_{g,n} = \mathcal{T}_{g,n}(L)/\mathrm{Mod}_{g,n}$ $\left(\frac{az+b}{cz+d}\right)\Big/\left(\frac{ez+f}{gz+h}\right)$

Inline: $\mathcal{M}_{g,n} = \mathcal{T}_{g,n}(L)/\mathrm{Mod}_{g,n}$ $[(az+b)/(cz+d)]/[(ez+f)/(gz+h)]$

5 Displayed math

5.1 Introduction

By displayed formulas we mean formulas that stand alone, broken out of the paragraph. One simple example is given by

$$f(x) = f(0) + \int_0^x f'(t)\,dt.$$

In contrast with inline formulas, that we just discussed, we have much more freedom when it comes to the displayed ones. If the formula is tall it is not a big problem, as long as it fits on the page. If it is long, we can break it across lines. For this reason it is very tempting to use displayed formulas a lot. But they can be overused. If every paragraph contains one, the text will easily look torn apart.

Nevertheless, displayed formulas are useful, and in this chapter we will discuss various ways of typesetting them. Their structure can vary, and that calls for different constructions in ConTEXt. Until recently, and in particular in traditional TEX, to typeset long formulas with several verbs (say equal signs), we were stuck with with alignment constructions that were based on `\halign`. Everything was put into boxes, and the parts were typeset in several different math formulas, and then put together. In ConTEXt(lmtx) we can in fact stay in paragraph mode, and format the paragraph according to our needs. We only need to enter and leave mathematics once. It has several positive consequences; we can more easily convert to other formats and make the code accessible.

5.2 Different types of displayed formulas

We follow [Lan61] and divide the types of formulas into three classes, depending on the structure they have. By this we mean the number of verbs (like $=$, $\leq$) but also how many formulas there are.

1. A *simple formula* is a formula with at most one verb, like $a = b + c/d$ and $a + b - c$.
2. A *chain formula* is a formula with several verbs, like $a = b + c \leq d + e$.
3. A *multiple formula* is a set of formulas (that can be simple or chain formulas) that are to be set together.

We will discuss these types one by one. We will often use a dummy command `\Snip` that prints some dummy math. This is merely to emphasize the structure of the formulas, not their content.

5.3 Simple formulas

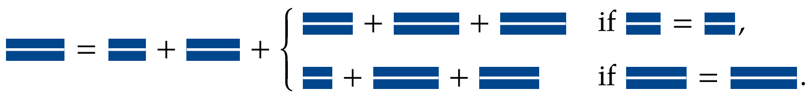
We start with the very simplest type of formula.

```
\startformula
  \Snip[1] \colonequals \Snip
\stopformula
```

```
\startformula
  \fenced[bar]{\Snip[4]}
  \leq
  \fenced[bar]{\Snip[2]} + \fenced[bar]{\Snip[2]}
\stopformula
```

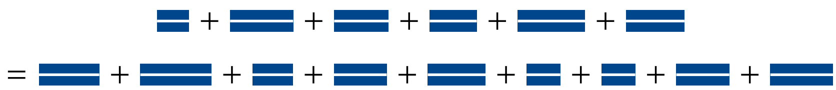
A simple formula might have complicated pieces.

```
\startformula
  \Snip[1] = \Snip[2] +
  \startcases
    \NC \Snip[3]  \TC if \im{\Snip[1] = \Snip[1]},\NR
    \NC \Snip[3]  \TC if \im{\Snip[1] = \Snip[1]}.\NR
  \stopcases
\stopformula
```



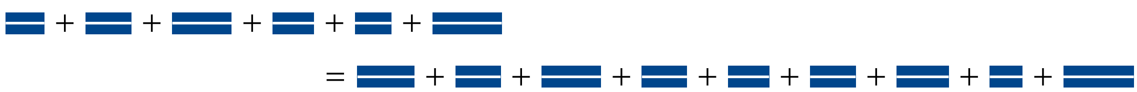
If the formula is too long to fit on the line, it will automatically be broken.

```
\startformula
  \Snip[6] = \Snip[9]
\stopformula
```

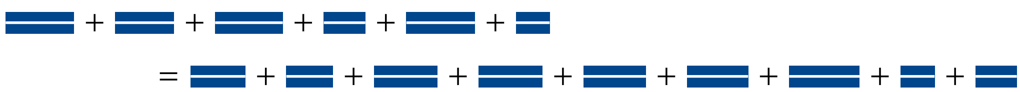


The rules on where to break the lines are driven by penalties. It is set up to prefer breaks just before the relation class, or, if that is not possible, just before the binary class. Note that both lines are mid-aligned. We can control both the breaking point and the alignment. In this particular case we use `align=slanted`, that flushes the first line left and the last line right, and align the rest of the lines, if there are any, to the middle.

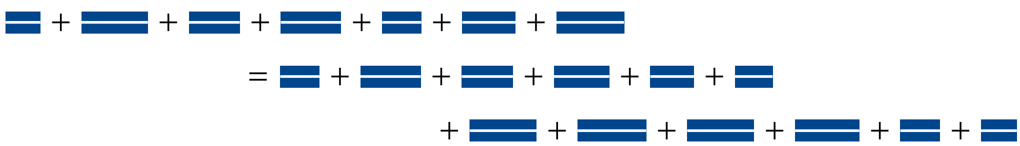
```
\startformula
  [align=slanted]
  \Snip[6] \breakhere = \Snip[9]
\stopformula
```



We tell where to have line breaks with `\breakhere`. In this specific case, the formula would look better with a margin. We get that by adding `margin=2em` as an option to `\startformula`.

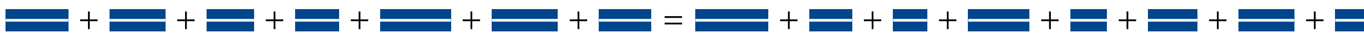


We show one example with slightly longer lines, split into three lines.



If we do not want to break the formula, we can use `split=line`. But then it will stick out in the margin if too long.

```
\startformula
  [split=line]
  \Snip[7] = \Snip[8]
\stopformula
```

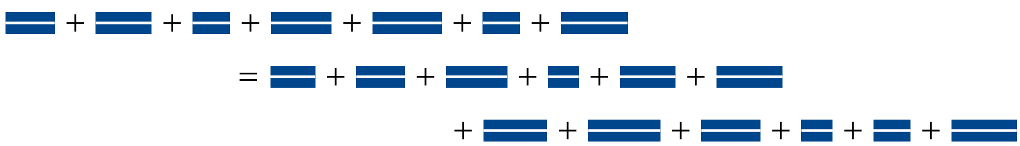


It is possible to define a new formula and set its align method and margin (and other parameters). This is preferable for consistency.

```
\defineformula
  [MySlanted]
  [align=slanted,
   margin=2em]
```

We can now use it with `\startnamedformula`. Note that the middle line is mid-aligned.

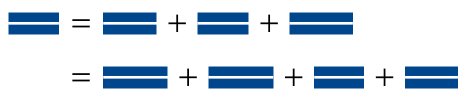
```
\startnamedformula
  [MySlanted]
  \Snip[7] \breakhere = \Snip[6] \breakhere + \Snip[6]
\stopnamedformula
```



5.4 Chain formulas

Chain formulas contain more than one verb. It is often a good idea to break the formula over several lines and align on the verbs. This is done by using `\alignhere` and `\breakhere`.

```
\startformula
  \Snip[1] \alignhere = \Snip
           \breakhere = \Snip
\stopformula
```

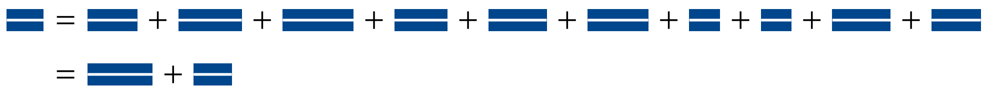


The same output can be obtained by using `\startalign` and `\stopalign`. There is, however, an important difference. When we use `\startalign` and `\stopalign` the formula is typeset with the `\halign` primitive. This means that we enter end leave math mode for every cell. With the method just shown, using `\alignhere`, the formula is in fact one long paragraph that is broken at the appropriate places, and we never leave math mode.

It might happen that one part of the formula is much longer than the others.

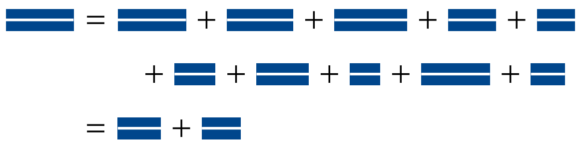
```
\startformula
  \Snip[1] \alignhere = \Snip[10]
```

```
          \breakhere = \Snip[2]
\stopformula
```



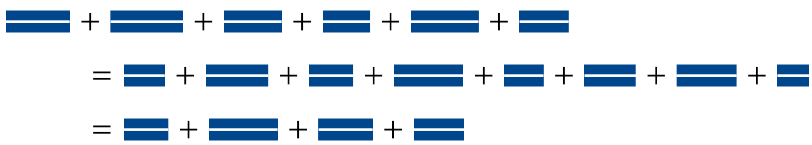
Such a formula might look a bit unbalanced, with the equal signs so far to the left, or you might be on a narrower text block. A remedy might be to break the right-hand side in the first line into two pieces. But then we should also indent the (new) second line a bit. This is done with `\skiphere`.

```
\startformula
  \Snip[1] \alignhere = \Snip[5]
          \breakhere \skiphere + \Snip[5]
          \breakhere = \Snip[2]
\stopformula
```



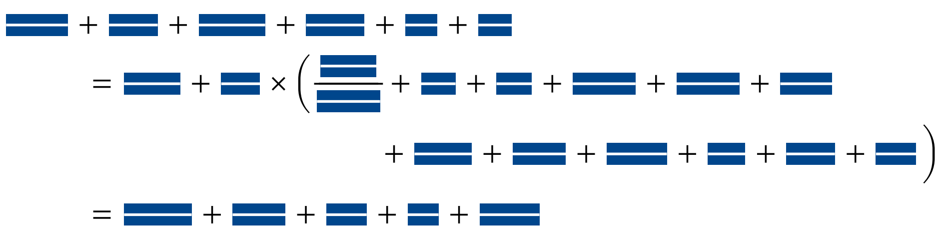
If you have a too long left-hand side, it is possible to add it on its own line. Then the `textdistance` key is useful. The `textdistance=3em` will add `3em` on all lines except the first.

```
\startformula
  [textdistance=3em]
  \alignhere \Snip[6]
  \breakhere = \Snip[8]
  \breakhere = \Snip[4]
\stopformula
```



We look at one more example.

```
\startformula
  [textdistance=3em]
  \alignhere \Snip[6]
  \breakhere = \Snip[2] \times
    \F3 \left( \frac{\Snip[1]}{\Snip[1]} + \Snip[5]
  \breakhere   \skiphere[5] + \Snip[6] \right)
  \breakhere = \Snip[5]
\stopformula
```



Some comments are needed. First, we used `\F3` to force the delimiters to be of the third available size. Notice also that we use a `\breakhere` inside the delimited part, so that is possible. We have used `\skiphere[5]` to emphasize that the broken pair of parentheses belong to each other. The 5 is a multiplier of the standard skip, that is set to `2em`, but it can be changed with the `textmargin` key. It is also possible to specify an explicit length, as in `\skiphere[4em]`.

5.5 Multiple formulas

We will here look at displayed content that in fact consist of several formulas. In inline mode, when we write `\im{f(x)=\sin x}, \im{x\in\reals}` we get $f(x) = \sin x$, $x \in \mathbb{R}$. The point here is that we use two formulas and the comma in-between them is taken from the text font (we remind you of §2.12 about punctuation in math). We separate formulas with `\mtp`, math text punctuation.

```
\startformula
  f(x) = \sin x \mtp{,}
  x \in \reals  \mtp{.}
\stopformula
```

$$f(x) = \sin x, \quad x \in \mathbb{R}.$$

We can, if we want to enforce the structure, put the formulas into the relevant math mode, but that is in general tedious.

```
\startformula
  \dm{f(x) = \sin x} \mtp{,}
  \dm{x \in \reals}  \mtp{.}
\stopformula
```

$$f(x) = \sin x, \quad x \in \mathbb{R}.$$

The `\mtp` puts it argument into an `hbox` and apply the `mathtextpunctuation` class; the extra space you see to the right of the comma is set up via the atom class `mathtextpunctuation`. One can omit the comma (some also omit the period) in the example above, and then it is customary to use parentheses for the domain of definition. We use `\mtp{}` to get the same amount of extra spacing,

```
\startformula
  f(x) = \sin x \mtp{}
  (x \in \reals)
\stopformula
```

$$f(x) = \sin x \quad (x \in \mathbb{R})$$

It is usually best to keep the formulas on one line if they fit. Add spacing (for example with `\mtp` or `\quad`) between them,

```
\startformula
  x = r \sin\theta \cos\phi \mtp{,}
  y = r \sin\theta \sin\phi \mtp{,}
  z = r \cos\theta          \mtp{.}
\stopformula
```

$$x = r \sin\theta \cos\phi, \quad y = r \sin\theta \sin\phi, \quad z = r \cos\theta.$$

Just as we broke longer formulas with `\breakhere`, we can use it to stack several formulas on top of each other.

```
\startformula
  \Snip[1] = \Snip[4] \breakhere \Snip[1] = \Snip[5]
\stopformula
```

$$\quad = \quad + \quad + \quad + \quad$$
$$\quad = \quad + \quad + \quad + \quad + \quad$$

If, as above, the formulas follow each other directly, only have one verb each, and if they have the same character, it might be a good idea to align them on the verb (the equal sign in the example). This is done by adding multiple `\alignhere`, at the relevant places.

```
\startformula
  \Snip[1] \alignhere = \Snip[4] \breakhere
  \Snip[1] \alignhere = \Snip[5]
\stopformula
```

$$\begin{aligned} \quad &= \quad + \quad + \quad + \quad \\ \quad &= \quad + \quad + \quad + \quad + \quad \end{aligned}$$

Here is another case where it makes sense to align on the equal signs, even though the third equation runs over two lines. We use `\skiphere` to indent the last line.

$$\begin{aligned}
\frac{\pi}{4} &= \arctan 1, \\
\frac{\pi}{4} &= \arctan \frac{1}{2} + \arctan \frac{1}{3}, \\
\frac{\pi}{4} &= 183 \arctan \frac{1}{239} + 32 \arctan \frac{1}{1023} - 68 \arctan \frac{1}{5832} \\
&\qquad + 12 \arctan \frac{1}{110443} - 12 \arctan \frac{1}{4841182} - 100 \arctan \frac{1}{6826318}.
\end{aligned}$$

It is not a problem if more than one (or all) equations do continue on the next line,

$$\begin{aligned}
\quad &= [\quad + \quad + \quad + \quad] \quad \\
&\qquad + [\quad + \quad + \quad + \quad] \quad, \\
\quad &= [\quad + \quad + \quad + \quad] \quad \\
&\qquad + [\quad + \quad + \quad + \quad] \quad.
\end{aligned}$$

The following three formulas all have two equal signs. We suggest not to align on any of the equal signs, since that will promote either one of them,

$$E = \langle \mathbf{x}_u, \mathbf{x}_u \rangle = r^2,$$
$$F = \langle \mathbf{x}_u, \mathbf{x}_v \rangle = 0,$$
$$G = \langle \mathbf{x}_v, \mathbf{x}_v \rangle = (a + r \cos u)^2.$$

If you want to enforce alignment, it is best to do so on the first equal sign,

$$\begin{aligned}
E &= \langle \mathbf{x}_u, \mathbf{x}_u \rangle = r^2, \\
F &= \langle \mathbf{x}_u, \mathbf{x}_v \rangle = 0, \\
G &= \langle \mathbf{x}_v, \mathbf{x}_v \rangle = (a + r \cos u)^2,
\end{aligned}$$

In the above case all terms fit nicely on our line, so that is a good option,

$$E = \langle \mathbf{x}_u, \mathbf{x}_u \rangle = r^2, \quad F = \langle \mathbf{x}_u, \mathbf{x}_v \rangle = 0, \quad G = \langle \mathbf{x}_v, \mathbf{x}_v \rangle = (a + r \cos u)^2.$$

The formulas

$$x^2 = \frac{c^2 \sin^2 \alpha \sin^2 \beta}{\sin^2 \alpha + \sin^2 \beta - 2 \sin \alpha \sin \beta \cos \gamma},$$
$$(\pi - 2\alpha) + (\pi - 2\beta) + (\pi - 2\gamma) = \pi,$$

do not have the same character (yes, in this case more aesthetically than mathematically), and are best centered independently, or not put in the same display at all,

$$x^2 = \frac{c^2 \sin^2 \alpha \sin^2 \beta}{\sin^2 \alpha + \sin^2 \beta - 2 \sin \alpha \sin \beta \cos \gamma},$$
$$(\pi - 2\alpha) + (\pi - 2\beta) + (\pi - 2\gamma) = \pi.$$

It is bad style to introduce alignments where they do not belong. Let us consider a few examples, found in math books, where either the alignment was non-optimal, or where it should not have been used. We start with an example where the first formula is a long chain formula that needs to be broken over two lines.

$$\begin{aligned} \mathcal{F}_x - \dot{\mathcal{F}}_{\dot{x}} &= \dot{x}\mathcal{F}_{x\dot{x}} + \dot{y}\mathcal{F}_{x\dot{y}} - \mathcal{F}_{\dot{x}x}\dot{x} - \mathcal{F}_{\dot{x}y}\dot{y} - \mathcal{F}_{\dot{x}\dot{x}}\ddot{x} - \mathcal{F}_{\dot{x}\dot{y}}\ddot{y} \\ &= \dot{y}[\mathcal{F}_{x\dot{y}} - \mathcal{F}_{\dot{x}y} - (\dot{x}\ddot{y} - \dot{y}\ddot{x})\mathcal{F}_1], \\ \mathcal{F}_y - \dot{\mathcal{F}}_{\dot{y}} &= -\dot{x}[\mathcal{F}_{x\dot{y}} - \mathcal{F}_{\dot{x}y} + (\dot{x}\ddot{y} - \ddot{x}\dot{y})\mathcal{F}_1]. \end{aligned}$$

Here one could consider to set it as two independent formulas, and then there is nothing wrong by aligning the first one on the equal signs,

$$\begin{aligned} \mathcal{F}_x - \dot{\mathcal{F}}_{\dot{x}} &= \dot{x}\mathcal{F}_{x\dot{x}} + \dot{y}\mathcal{F}_{x\dot{y}} - \mathcal{F}_{\dot{x}x}\dot{x} - \mathcal{F}_{\dot{x}y}\dot{y} - \mathcal{F}_{\dot{x}\dot{x}}\ddot{x} - \mathcal{F}_{\dot{x}\dot{y}}\ddot{y} \\ &= \dot{y}[\mathcal{F}_{x\dot{y}} - \mathcal{F}_{\dot{x}y} - (\dot{x}\ddot{y} - \dot{y}\ddot{x})\mathcal{F}_1], \end{aligned}$$

and

$$\mathcal{F}_y - \dot{\mathcal{F}}_{\dot{y}} = -\dot{x}[\mathcal{F}_{x\dot{y}} - \mathcal{F}_{\dot{x}y} + (\dot{x}\ddot{y} - \ddot{x}\dot{y})\mathcal{F}_1].$$

In the next example, the formula starting with b_2 indeed fits on the first line, but it becomes less emphasized than the other three formulas.

$$\begin{aligned} b_1 &= 1 - \frac{x^2}{2!}, \quad b_2 = 1 - \frac{x^2}{2} + \frac{x^4}{4!} - \frac{x^6}{6!}, \\ b_3 &= 1 - \frac{x^2}{2} + \frac{x^4}{4!} - \frac{x^6}{6!} + \frac{x^8}{8!} - \frac{x^{10}}{10!}, \\ b_4 &= 1 - \frac{x^2}{2} + \frac{x^4}{4!} - \frac{x^6}{6!} + \frac{x^8}{8!} - \frac{x^{10}}{10!} + \frac{x^{12}}{12!} - \frac{x^{14}}{14!}. \end{aligned}$$

Here, we better use one formula per line, if we want to align at all.

$$\begin{aligned} b_1 &= 1 - \frac{x^2}{2!}, \\ b_2 &= 1 - \frac{x^2}{2} + \frac{x^4}{4!} - \frac{x^6}{6!}, \\ b_3 &= 1 - \frac{x^2}{2} + \frac{x^4}{4!} - \frac{x^6}{6!} + \frac{x^8}{8!} - \frac{x^{10}}{10!}, \\ b_4 &= 1 - \frac{x^2}{2} + \frac{x^4}{4!} - \frac{x^6}{6!} + \frac{x^8}{8!} - \frac{x^{10}}{10!} + \frac{x^{12}}{12!} - \frac{x^{14}}{14!}. \end{aligned}$$

Sometimes it makes sense to group several equations with a brace.

```
\startformula
  \startalign
    [location=packed,
     fences=sesac]
```

```
    \NC x \EQ r \sin\theta \cos\phi \mtp{,} \NR
    \NC y \EQ r \sin\theta \sin\phi \mtp{,} \NR
    \NC z \EQ r \cos\theta          \mtp{.} \NR
  \stopalign
\stopformula
```

$$\left.\begin{aligned} x &= r\sin\theta\cos\phi, \\ y &= r\sin\theta\sin\phi, \\ z &= r\cos\theta. \end{aligned}\right\}$$

This can also be done with a `simplealign` construction.

```
\definemathsimplealign
  [collected]
  [left={\startmathfenced[sesac]},
   right=\stopmathfenced,
   align={1:right,2:left},
   strut=yes]
```

We can now do

```
\startformula
  \startcollected
    \NC x \EQ r \sin\theta \cos\phi \mtp{,} \NR
    \NC y \EQ r \sin\theta \sin\phi \mtp{,} \NR
    \NC z \EQ r \cos\theta          \mtp{.} \NR
  \stopcollected
\stopformula
```

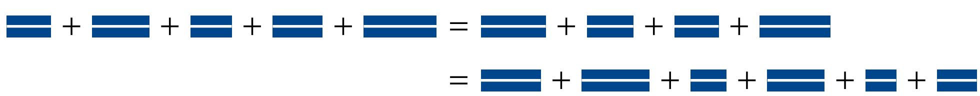
$$\left.\begin{aligned} x &= r\sin\theta\cos\phi, \\ y &= r\sin\theta\sin\phi, \\ z &= r\cos\theta. \end{aligned}\right\}$$

It might at first glance look weird with the brace on the right side, but that makes sense if we view the three equations as one unit and add an equation number to it. The `\EQ` is a shortcut for `\NC =`.

5.6 Alignments

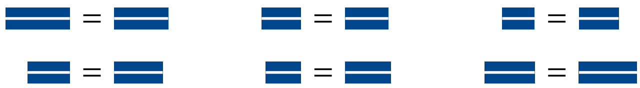
We mentioned before that it is also possible to use `\startalign` and `\stopalign` to align formulas. This has for a very long time been *the* way to do it, but now it is almost not needed in ConTEXt anymore. We show a few examples.

```
\startformula
  \startalign
    \NC \Snip \EQ \Snip[4] \NR
    \NC       \EQ \Snip[6] \NR
  \stopalign
\stopformula
```



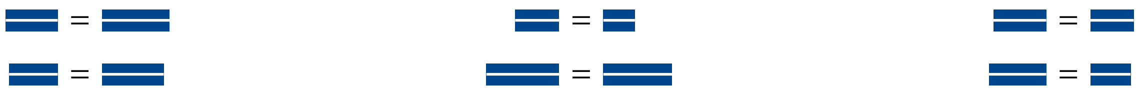
One occasion where an align can still be called for is when one has several formulas in a grid.

```
\startformula
  \startalign
    [m=3,distance=3em,align={1:right,2:left}]
    \NC \Snip[1] \EQ \Snip[1]
    \NC \Snip[1] \EQ \Snip[1]
    \NC \Snip[1] \EQ \Snip[1] \NR
    \NC \Snip[1] \EQ \Snip[1]
    \NC \Snip[1] \EQ \Snip[1]
    \NC \Snip[1] \EQ \Snip[1] \NR
  \stopalign
\stopformula
```

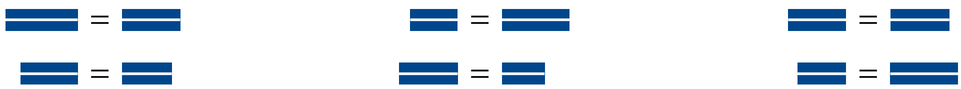


The result is three (since `m=3`) columns of formulas, and each formula has two points of alignment. The `distance=3em` sets `3em` of spacing between the columns.

```
\startformula
  \startalign
    [m=3,distance=3em plus 1fil,align={1:right,2:left}]
    \NC \Snip[1] \EQ \Snip[1]
    \NC \Snip[1] \EQ \Snip[1]
    \NC \Snip[1] \EQ \Snip[1] \NR
    \NC \Snip[1] \EQ \Snip[1]
    \NC \Snip[1] \EQ \Snip[1]
    \NC \Snip[1] \EQ \Snip[1] \NR
  \stopalign
\stopformula
```



We can add margins to the formula with the `margin` key. Below we show the same formula, but with `margin=3em`.



6 Equation labels

6.1 Introduction

There are different schools on which equations to number. Some people like to number precisely the equations that are referred to in the text, others like to label all equations, since the reader might need to refer to an equation that the author did not refer to in the text. In any case, to be able to refer to an equation, we need to label it somehow. The standard way to achieve equation numbering in ConTEXt has always been to wrap the formula in `\startplaceformula` and `\stopplaceformula`. With the new displayed formula mechanism we will see that new opportunities have appeared.

6.2 Numbering a simple formula

The number will by default be positioned to the right of the equation, flushed to the right side of the text block. We give an example.

```
\startplaceformula
  [reference=eq:Pythagoras]
  \startformula
    a^2 + b^2 = c^2.
  \stopformula
\stopplaceformula

From \in{Equation}[eq:Pythagoras] it follows\unknown
```

$$a^2 + b^2 = c^2. \tag{6.1}$$

From Equation 6.1 it follows...

Note how the equation number was referred to with `\in`. The label of the formula is enclosed in parentheses, but when we referred to it we only got the number. To get parentheses we define a new referencing command.

```
\definereferenceformat
  [eqref]
  [left=(,
   right=)]
```

We can now use `\eqref`.

```
From \eqref[eq:Pythagoras] it follows\unknown
```

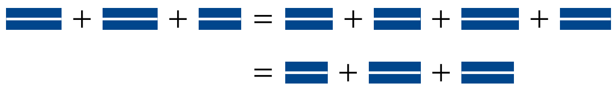
From (6.1) it follows...

6.3 One formula running over several lines

We recall that a chain formula, even if it runs over several lines, is still one formula, and therefore it should have (at most) one number attached to it. The number will by default be placed after the formula, flush right.

```
\startplaceformula
  \startformula
    \Snip \alignhere = \Snip
```

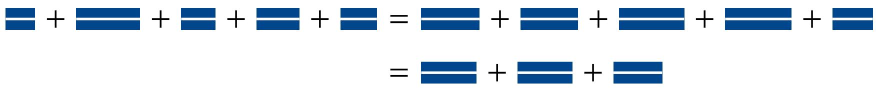
```
        \breakhere = \Snip
  \stopformula
\stopplaceformula
```



(6.2)

With the new formula mechanism we have `\numberhere` available. We can do

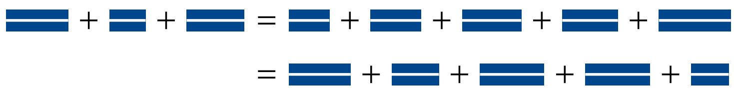
```
\startformula
  \Snip \alignhere = \Snip
        \breakhere = \Snip \numberhere
\stopformula
```



(6.3)

We can add the `\numberhere` on any line. By default it is put on the same size as the formula number (driven by the `location` key of the formula). Thus, if we put it before the `\breakhere` in the example above, we get this

```
\startformula
  \Snip \alignhere = \Snip \numberhere
        \breakhere = \Snip
\stopformula
```



(6.4)

6.4 Several equations on several lines

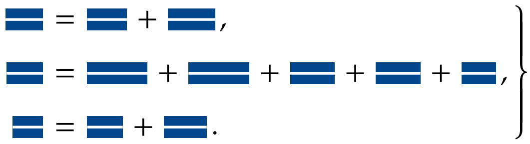
Sometimes several equations can be considered to be a group of equations, and then it can be natural to apply one number to the group. We can use the `collected` environment that we defined before.

```
\startplaceformula
  \startformula
    \startcollected
      \NC x \EQ r \sin\theta \cos\phi \mtp{,} \NR
      \NC y \EQ r \sin\theta \sin\phi \mtp{,} \NR
      \NC z \EQ r \cos\theta          \mtp{.} \NR
    \stopcollected
  \stopformula
\stopplaceformula
```

$$\left.\begin{aligned} x &= r\sin\theta\cos\phi,\\ y &= r\sin\theta\sin\phi,\\ z &= r\cos\theta. \end{aligned}\right\} \tag{6.5}$$

```
\startplaceformula
  \startformula
    \startcollected
      \NC \Snip[1] \EQ \Snip \mtp{,} \NR
      \NC \Snip[1] \EQ \Snip \mtp{,} \NR
```

```
      \NC \Snip[1] \EQ \Snip \mtp{.} \NR
    \stopcollected
  \stopformula
\stopplaceformula
```



(6.6)

Note that we did not give any reference to the equations above, so we cannot refer to it. If we really want to number each equation independently, we can either use several `\numberhere` or we can use `align` and add tags to `\NR`. In the first case it comes out as

```
\startformula
  x \alignhere = r \sin\theta \cos\phi \mtp{,}
  \numberhere[eq:x] \breakhere
  y \alignhere = r \sin\theta \sin\phi \mtp{,}
  \numberhere[eq:y] \breakhere
  z \alignhere = r \cos\theta          \mtp{.}
  \numberhere[eq:z]
\stopformula

In equations \eqref[eq:x], \eqref[eq:y] and \eqref[eq:z] we see \unknown
```

$$x = r \sin\theta \cos\phi, \tag{6.7}$$

$$y = r \sin\theta \sin\phi, \tag{6.8}$$

$$z = r \cos\theta. \tag{6.9}$$

In equations (6.7), (6.8) and (6.9) we see . . .

In the second case, with an align, we instead do

```
\startplaceformula
  \startformula
    \startalign
      \NC x \EQ r \sin\theta \cos\phi \mtp{,} \NR[eq:X]
      \NC y \EQ r \sin\theta \sin\phi \mtp{,} \NR[eq:Y]
      \NC z \EQ r \cos\theta          \mtp{.} \NR[eq:Z]
    \stopalign
  \stopformula
\stopplaceformula

In equations \eqref[eq:X], \eqref[eq:Y] and \eqref[eq:Z] we see \unknown
```

$$x = r \sin\theta \cos\phi, \tag{6.10}$$

$$y = r \sin\theta \sin\phi, \tag{6.11}$$

$$z = r \cos\theta. \tag{6.12}$$

In equations (6.10), (6.11) and (6.12) we see . . .

6.5 Sub-equations

For the example with spherical coordinates above, one might prefer to have one number and instead use sub-numbering with letters on the different equations. Again, we can use any of the mechanisms. With the new mechanism we need to add `\startsubnumberinghere` and `\stopsubnumberinghere` around the formula.

```
\startformula
  \startsubnumberinghere
    x \alignhere = r \sin\theta \cos\phi \mtp{,}
    \numberhere[eq:xx] \breakhere
    y \alignhere = r \sin\theta \sin\phi \mtp{,}
    \numberhere[eq:yy] \breakhere
    z \alignhere = r \cos\theta          \mtp{.}
    \numberhere[eq:zz]
  \stopsubnumberinghere
\stopformula

In equations \eqref[eq:xx], \eqref[eq:yy] and \eqref[eq:zz] we see \unknown
```

$$x = r\sin\theta\cos\phi, \tag{6.13.a}$$

$$y = r\sin\theta\sin\phi, \tag{6.13.b}$$

$$z = r\cos\theta. \tag{6.13.c}$$

In equations (6.13.a), (6.13.b) and (6.13.c) we see ...

If we prefer to use the align mechanism, we can obtain that by changing `\NR` into `\NR[+]`.

```
\startplaceformula[eq:spherical]
  \startformula
    \startalign
      \NC x \EQ r \sin\theta \cos\phi \mtp{,} \NR[+]
      \NC y \EQ r \sin\theta \sin\phi \mtp{,} \NR[+]
      \NC z \EQ r \cos\theta          \mtp{.} \NR[+]
    \stopalign
  \stopformula
\stopplaceformula

We see in \eqref[eq:spherical] \ldots
```

$$x = r\sin\theta\cos\phi, \tag{6.14.a}$$

$$y = r\sin\theta\sin\phi, \tag{6.14.b}$$

$$z = r\cos\theta. \tag{6.14.c}$$

We see in (6.14) ...

Note that when we refer back to the equation, we only get the main number. If we want to be able to refer to the different parts, we better use `\startsubformulas` and `\stopsupformulas`.

```
\startsubformulas
  \startplaceformula
    \startformula
      \startalign
        \NC x \EQ r \sin\theta \cos\phi \mtp{,} \NR[eq:sx]
        \NC y \EQ r \sin\theta \sin\phi \mtp{,} \NR[eq:sy]
        \NC z \EQ r \cos\theta          \mtp{.} \NR[eq:sz]
```

```
      \stopalign
    \stopformula
  \stopplaceformula
\stopsubformulas

We see in \eqref[eq:sx], \eqref[eq:sy] and \eqref[eq:sz] that \ldots
```

$$x = r \sin\theta \cos\phi, \tag{6.15.a}$$

$$y = r \sin\theta \sin\phi, \tag{6.15.b}$$

$$z = r \cos\theta. \tag{6.15.c}$$

We see in (6.15.a), (6.15.b) and (6.15.c) that …

We can get rid of the period between the number and sub-number by using the predefined separator set `none`.

```
\setupformula
  [numberseparatorset=none]
```

We use the same example code as above, but now the output is as follows.

$$x = r \sin\theta \cos\phi, \tag{6.16a}$$

$$y = r \sin\theta \sin\phi, \tag{6.16b}$$

$$z = r \cos\theta. \tag{6.16c}$$

We see in (6.16a), (6.16b) and (6.16c) that …

We show one additional example where we define our own separator set.

```
\defineseparatorset[Dash][][\endash]

\setupformula
  [numberseparatorset=Dash]
```

The same example code now gives the following output.

$$x = r \sin\theta \cos\phi, \tag{6.17–a}$$

$$y = r \sin\theta \sin\phi, \tag{6.17–b}$$

$$z = r \cos\theta. \tag{6.17–c}$$

We see in (6.17–a), (6.17–b) and (6.17–c) that …

6.6 Configuring equation numbers

So far, we have only used equation numbers on the right side of the equations. We can change this.

```
\setupformula
  [location=left]
```

With this setting, the equation numbers are placed flushed left instead.

```
\startplaceformula
  \startformula
    J_{3/2}(x)
    =
    x^{-1} J_{1/2}(x) - J_{-1/2}(x)
```

```
    =
    \left( \frac{2}{\pi x} \right)^{1/2}
    \left( \frac{\sin x}{x} - \cos x \right)
  \stopformula
\stopplaceformula
```

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right) \tag{6.18}$$

With longer formulas that run over several lines, the equation number is now put on the first line instead of the last.

```
\startplaceformula
  \startformula
    J_{3/2}(x)
    \alignhere
    =
    x^{-1} J_{1/2}(x) - J_{-1/2}(x)
    \breakhere
    =
    \left( \frac{2}{\pi x} \right)^{1/2}
    \left( \frac{\sin x}{x} - \cos x \right)
  \stopformula
\stopplaceformula
```

$$\begin{aligned} J_{3/2}(x) &= x^{-1}J_{1/2}(x) - J_{-1/2}(x) \\ &= \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right) \end{aligned} \tag{6.19}$$

There are more possibilities for the formula numbering. We will show a few, but we do not recommend anyone to use this format.

```
\setupformula
  [left={[},
   right={]},
   numberstyle=\bf,
   numbercolor=C:3]
```

With these setups we get a different bracketing, a lovely color, and bold style.

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right) \qquad \mathbf{[6.20]}$$

We can also get a different format on the numbering.

```
\defineconversionset
  [MyConversion]
  [Romannumerals,mathGreeknumerals]


\setupformula
  [numberconversionset=MyConversion]
```

This will give us roman uppercase numbers as the main formula number, and uppercase greek (math) for the sub-numbering. With `greeknumerals` we would have gotten the lowercase greek from the text font, if it exists. The same formula as earlier is now set like this,

$$x = r\sin\theta\cos\phi, \tag{[6.XXI.A]}$$

$$y = r\sin\theta\sin\phi, \tag{[6.XXI.B]}$$

$$z = r\cos\theta. \tag{[6.XXI.Γ]}$$

It is possible to give some explicit but arbitrary label to an equation. But doing so, it is not possible to refer to the equation.

```
\startplaceformula
  [title=\dagger]
\startformula
  \int u\dd v + \int v\dd u = uv
\stopformula
\stopplaceformula
```

$$\int u\,dv + \int v\,du = uv \tag{†}$$

6.7 Troubleshooting

The numbered equations we have been looking at so far have been rather unproblematic, in the sense that the formulas have been narrow enough so that there has always been space enough to put the equation number. If this is not the case, it is in general a complex task to get things right. In the best of worlds, we never have to think about these problems, but it is good to be aware of the default behavior, and to know what options are available. Also, in your project you should define your own formula with your chosen setting to get consistency throughout your document.

In the examples below we will use the same formulas several times but with different settings. In our default layout the formula fits on the line, with a number, but instead of changing the formula from example to example, we locally change the layout. We have also enabled a tracker (`math.showmargins.less`) that will guide us.

First, we look at a simple one-line formula. The result in the layout used in this document is not problematic, the formula number fits well on the same line as the formula.

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right) \tag{6.22}$$

[0.0pt] [split=mathincontext] [align=middle] [location=right] [0.0pt]

Note in particular that the equation number sits in a box of a certain width. It is there to ensure that we have at least a certain distance between the formula and the equation number (the `numberdistance` parameter). If we add a sufficiently large margin, the equation number is by default pushed down to the line below.

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right)$$

(6.23)

[27.5pt] [split=mathincontext] [align=middle] [location=right] [27.5pt]

One could argue that in this formula, it would look better with the number on the same line as the formula, and that can be achieved by decreasing the value of `numberdistance` from its default `2em`. In the formula below we set it to `1em`.

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right) \tag{6.24}$$

[27.5pt] [split=mathincontext] [align=middle] [location=right] [27.5pt]

Another option, if we are locally in a narrower mode, might be to put the number at the right margin, independent of the current `\leftskip` and `\rightskip`. This is done by setting `location` to `atrightmargin`. One shall then be aware that this also nils the `numberdistance`.

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right) \tag{6.25}$$

[27.5pt] [split=mathincontext] [align=middle] [location=atrightmargin] [27.5pt]

The situation is similar if we set `location=left`, but then the number by default appears on top of the formula.

(6.26)

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right)$$

[27.5pt] [split=mathincontext] [align=middle] [location=left] [27.5pt]

Here one can again play with the `numberdistance` or set `location=atleftmargin`. We emphasize that it is natural that the formula numbers sit above if flush left and below if flush right, in case there is not enough space. In a right-to-left document one could argue for the opposite, and it is indeed possible to change by invoking `order=reverse`.

(6.27)

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right)$$

[27.5pt] [split=mathincontext] [align=middle] [location=right] [27.5pt]

The situation is essentially the same when we flush formulas to the left, at least if the number is on the right.

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right) \tag{6.28}$$

[0.0pt] [split=mathincontext] [align=flushleft] [location=right] [0.0pt]

If one decides to flush the formulas to the left, one usually has a small margin to the left. Here we have used `leftmargin=3em`.

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right) \tag{6.29}$$

[33.0pt] [split=mathincontext] [align=flushleft] [location=right] [0.0pt]

If one in addition wants the number to the left, by invoking `location=left`, it will be forced to be on top of the formula, independent of the left margin.

(6.30)

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right)$$

[33.0pt] [split=mathincontext] [align=flushleft] [location=left] [0.0pt]

It is still possible to use `location=atleftmargin`, but then one has to watch out, since then `numberdistance` is reset.

$$(6.31)\quad J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right)$$

[33.0pt] [split=mathincontext] [align=flushleft] [location=atleftmargin] [0.0pt]

It is the responsibility of the author to use a sufficiently large left margin. If we set it to 4em we get the following.

$$J_{3/2}(x) = x^{-1}J_{1/2}(x) - J_{-1/2}(x) = \left(\frac{2}{\pi x}\right)^{1/2}\left(\frac{\sin x}{x} - \cos x\right) \tag{6.32}$$

[44.0pt] [split=mathincontext] [align=flushleft] [location=atleftmargin] [0.0pt]

The situation for equations that are flushed right is completely analog to the flush left equations, but since that is a very strange way of aligning equations, we do not discuss more examples on that. Instead we move on to the more complicated aligned and slanted equations. In fact, for aligned equations, the situation is very similar to the one for single line equations that we have just discussed, so we only show a few examples. First, if there is no issue with spacing, the equation number is placed on the first line if flush left and on the last line if flush right.

$$\begin{aligned} \max_{b_k=\pm 1} U(x_k + \sqrt{2}\varepsilon b_k v_k) &\geq U(x_k) + \varepsilon^2\langle D^2U(x_k)v_k, v_k\rangle + O(\varepsilon^2) \\ &= U(x_k) + \varepsilon^2\langle D^2U(x_*)v_k, v_k\rangle + O(\varepsilon^2) \\ &= U(x_k) - \varepsilon^2 + O(\varepsilon^2) \end{aligned} \tag{6.33}$$

[0.0pt] [split=no] [align=middle] [location=right] [0.0pt]

In a tighter layout, the number is still set on the last line if there is sufficient space (otherwise it goes to the line below).

$$\begin{aligned} \max_{b_k=\pm 1} U(x_k + \sqrt{2}\varepsilon b_k v_k) &\geq U(x_k) + \varepsilon^2\langle D^2U(x_k)v_k, v_k\rangle + O(\varepsilon^2) \\ &= U(x_k) + \varepsilon^2\langle D^2U(x_*)v_k, v_k\rangle + O(\varepsilon^2) \\ &= U(x_k) - \varepsilon^2 + O(\varepsilon^2) \end{aligned} \tag{6.34}$$

[55.0pt] [split=no] [align=middle] [location=right] [55.0pt]

This shall also work if we flush formulas to the left.

$$\begin{aligned} \max_{b_k=\pm 1} U(x_k + \sqrt{2}\varepsilon b_k v_k) &\geq U(x_k) + \varepsilon^2\langle D^2U(x_k)v_k, v_k\rangle + O(\varepsilon^2) \\ &= U(x_k) + \varepsilon^2\langle D^2U(x_*)v_k, v_k\rangle + O(\varepsilon^2) \\ &= U(x_k) - \varepsilon^2 + O(\varepsilon^2) \end{aligned} \tag{6.35}$$

[44.0pt] [split=no] [align=flushleft] [location=right] [0.0pt]

We turn to slanted formulas, where we will look at examples of a formula that is split over three lines. First, we look at the result in the layout used in this document. Note that the number is placed below the last line.

$$\begin{multlined} I(x) \sim \frac{1}{\sqrt{x}} e^{x\phi(c)} \int_{-\infty}^{+\infty} e^{s^2\phi''(c)/2} \\ \times \left(f(c) + \frac{1}{x}\left\{ \frac{1}{2}s^2 f''(c) + \frac{1}{24}s^4 f(c)\phi^{(4)}(c) + \frac{1}{6}s^4 f'(c)\phi'''(c) \right.\right. \\ \left.\left. + \frac{1}{72}s^6[\phi'''(c)]^2 f(c) \right\}\right) ds, \quad x \to +\infty. \end{multlined} \tag{6.36}$$

[0.0pt] [split=no] [align=slanted] [location=right] [0.0pt]

It is possible to use the `margin` and `location` keys to ensure space for the equation number at the last line.

$$\begin{aligned} I(x) \sim \frac{1}{\sqrt{x}} e^{x\phi(c)} \int_{-\infty}^{+\infty} & e^{s^2\phi''(c)/2} \\ & \times \biggl(f(c) + \frac{1}{x} \biggl\{ \frac{1}{2} s^2 f''(c) + \frac{1}{24} s^4 f(c) \phi^{(4)}(c) + \frac{1}{6} s^4 f'(c) \phi'''(c) \\ & \qquad + \frac{1}{72} s^6 [\phi'''(c)]^2 f(c) \biggr\} \biggr) \, ds, \quad x \to +\infty. \end{aligned} \tag{6.37}$$

[44.0pt] [split=no] [align=slanted] [location=atrightmargin] [44.0pt]

This will, however, also enforce the same margin for the mid-aligned lines. Here it is better to use the `margindistance` key. In the example we set it to `4em`, the same value as we set the margin to in the previous formula.

$$\begin{aligned} I(x) \sim \frac{1}{\sqrt{x}} e^{x\phi(c)} \int_{-\infty}^{+\infty} & e^{s^2\phi''(c)/2} \\ & \times \biggl(f(c) + \frac{1}{x} \biggl\{ \frac{1}{2} s^2 f''(c) + \frac{1}{24} s^4 f(c) \phi^{(4)}(c) + \frac{1}{6} s^4 f'(c) \phi'''(c) \\ & \qquad + \frac{1}{72} s^6 [\phi'''(c)]^2 f(c) \biggr\} \biggr) \, ds, \quad x \to +\infty. \end{aligned} \tag{6.38}$$

[0.0pt] [split=no] [align=slanted] [location=right] [0.0pt]

7 Enunciations

7.1 Introduction

If you write on mathematics you will most likely need some theorem-like environments. In ConTEXt they are best implemented via so-called enumerations. Enumerations have many configuration possibilities, and we won't show them all. We believe it is more instructive to define a theorem environment step-by-step, to see what some of the most useful keys do with the enumerations. We give two examples, one inspired by [LS17] and one by [The17].

7.2 AMS styled theorems, step by step

If you are impatient, you can have a look at page 133 for the final suggested definition of the AMS styled theorem environment.

First we define the theorem enumeration, without setting any further keys.

```
\defineenumeration[theorem]
```

Let us take a look how it comes out.

```
\starttheorem
Let \im {a} and \im {b} be the legs and let \im {c} be the hypotenuse in a
right triangle. Then

\startformula
  a^2 + b^2 = c^2.
\stopformula
\stoptheorem
```

theorem 1

Let a and b be the legs and let c be the hypotenuse in a right triangle. Then

$$a^2 + b^2 = c^2.$$

If you are familiar with AMS styled theorems, you see that there are several things to change. We start by using the `alternative` key to avoid heads to be written on its own line. In ConTEXt the terminology for that is that it should be serried.

```
\setupenumeration
  [theorem]
  [alternative=serried]
```

The same example as before now looks like this.

theorem 2 Let a and b be the legs and let c be the hypotenuse in a right triangle. Then

$$a^2 + b^2 = c^2.$$

There is too much space between the head and the body. The problem here is twofold; the width of the head is too big and the distance between the head and the body is too big. We use the `width` and `distance` keys.

```
\setupenumeration
  [theorem]
  [width=fit,
   distance=1em]
```

Now the example looks better.

theorem 3 Let a and b be the legs and let c be the hypotenuse in a right triangle. Then

$$a^2 + b^2 = c^2.$$

We next use the `text` key to redefine the text in the head. We change it into Theorem, with a capital T. In fact, it is possible to use any text in the head, independent of the name of the enumeration.

```
\setupenumeration
  [theorem]
  [text=Theorem]
```

The example now looks like this.

Theorem 4 Let a and b be the legs and let c be the hypotenuse in a right triangle. Then

$$a^2 + b^2 = c^2.$$

The body of the theorems are set in italic. We use the `style` key to fix that.

This is pretty much what we expect.

Theorem 5 *Let a and b be the legs and let c be the hypotenuse in a right triangle. Then*

$$a^2 + b^2 = c^2.$$

In this case we recognize the theorem as the Pythagorean theorem. We enable titles with the `title` key. The title should be set in normal text, not bold. This is ensured with the `titlestyle` key.

```
\setupenumeration
  [theorem]
  [title=yes,
   titlestyle=normal]
```

Note how the code changes below.

Theorem 6 (Pythagoras) *Let a and b be the legs and let c be the hypotenuse in a right triangle. Then*

$$a^2 + b^2 = c^2.$$

We include the chapter number as a prefix to the theorem number.

```
\setupenumeration
  [theorem]
  [prefix=yes,
   prefixsegments=chapter]
```

The theorem now looks like this.

Theorem 7.7 (Pythagoras) *Let a and b be the legs and let c be the hypotenuse in a right triangle. Then*

$$a^2 + b^2 = c^2.$$

In case you also want to include the section number into the number of the theorem, you can use `prefixsegments=chapter:section`.

Finally, in the AMS style the head ends with a period. We use a the key `headcommand` to add that period. The `headcommand` is supposed to have one argument (the head).

```
\starttexdefinition MyThmHeadCommand #1
#1.
\stoptexdefinition

\setupenumeration
  [theorem]
  [headcommand=\MyThmHeadCommand]
```

Here we have defined our own command `\MyThmHeadCommand` that just sets its argument together with a period. In cases like this one could simply use the neat `\groupedcommand`.

In any case, the code now generates a theorem where the head ends with a (intentionally bold) period.

Theorem 7.8 (Pythagoras)**.** *Let a and b be the legs and let c be the hypotenuse in a right triangle. Then*

$$a^2 + b^2 = c^2.$$

Before we continue, we emphasize that you do not need to set each of these keys one by one as we have done here. In your document, you typically add everything to the definition already.

```
\defineenumeration
  [theorem]
  [alternative=serried,
   width=fit,
   distance=1em,
   text=Theorem,
   style=italic,
   title=yes,
   titlestyle=normal,
   prefix=yes,
   headcommand=\groupedcommand{}{.}]
```

7.3 More AMS styled enunciations

It is suggested in [LS17] that the following enunciations share the style of Theorem: Algorithm, Assertion, Axiom, Conjecture, Corollary, Criterion, Hypothesis, Lemma, Proposition, Reduction and Sublemma. They all share the property that they usually require some kind of argument.

We do not need to start over and write all settings for each such enunciation we need; `defineenumeration` provides a second optional argument, where we can give another enumeration to copy the settings from. If we only want to change the name but keep the same counter, we only need to alter the text of the head.

```
\defineenumeration
  [lemma]
  [theorem]
  [text=Lemma]
```

Note in the example below that all the settings we had from the theorem environment are inherited by the lemma environment.

```
\startlemma[reference=lem:pyth]    The altitude of a right triangle from its
right angle to its hypotenuse splits    the triangle into two triangles that
are both similar to the original triangle.
\stoplemma
```

Lemma 7.9. *The altitude of a right triangle from its right angle to its hypotenuse splits the triangle into two triangles that are both similar to the original triangle.*

The `reference=lem:pyth` is here so that we can refer to this lemma later. We do this by typing `\in{Lemma}[lem:pyth]`, which gives us Lemma 7.9.

Proofs are set in roman with head in italic, ending with a period.

```
\defineenumeration
  [proof]
  [alternative=serried,
   width=fit,
   distance=1ex,
   text=Proof,
   number=no,
   headstyle=italic,
   headcommand=\groupedcommand{}{.}]
```

```
\startproof
By comparing the angles of the main triangle with the two subtriangles, we
find
that they are all similar according to the angle-angle rule.
\stopproof
```

Proof. By comparing the angles of the main triangle with the two subtriangles, we find that they are all similar according to the angle-angle rule.

Sometimes proofs are not written directly below the theorem-like environment. It might then be a good idea to do this in the title.

```
\setupenumeration
  [proof]
  [title=yes,
   titlestyle=normal]
```

This setting will set the title upright, and as for theorems, the titles are by default surrounded by parentheses.

```
\startproof[title={of \in{Lemma}[lem:pyth]}]
By comparing the angles of the main triangle with the two subtriangles, we
find
that they are all similar according to the angle-angle rule.
\stopproof
```

Proof (of Lemma 7.9). By comparing the angles of the main triangle with the two subtriangles, we find that they are all similar according to the angle-angle rule.

According to the AMS style we should write "*Proof of Lemma* 7.9.", all except the number in italic. To achieve this, we reset the title style (this means that it will have the same style as the rest of the head), and also disable the parentheses around the title by resetting the keys `titleleft` and `titleright`. In addition, we first reset the predefined distance before the title (which by default is larger than a space) with help of `titledistance` and then add a space with the `titlecommand` key. Finally, we also define a new reference style that should typeset the references in normal upright text.

```
\setupenumeration
  [proof]
  [titlestyle=,
   titleleft=,
   titleright=,
   titledistance=0pt,
   titlecommand=\groupedcommand{\space}{}]

\definereferenceformat
  [inhead]
  [in]
  [style=normal]
```

We need to adapt the code in the proof slightly.

```
\startproof[title={of Lemma \inhead[lem:pyth]}]
By comparing the angles of the main triangle with the two subtriangles, we
find
that they are all similar according to the angle-angle rule.
\stopproof
```

Proof of Lemma 7.9. By comparing the angles of the main triangle with the two subtriangles, we find that they are all similar according to the angle-angle rule.

It is a common practice to end proofs with a small box, for example □. This box is usually set flush right on the last line of the proof. It is said that one should not end proofs with displayed formulas, but if this is done, it can make sense to put the box to the right of the formula to save a line. We can use the `\closesymbol` for that.

```
\setupenumeration
  [proof]
  [closesymbol=\mathqed]
```

We run the last version of the example, and get this.

Proof of Lemma 7.9. By comparing the angles of the main triangle with the two subtriangles, we find that they are all similar according to the angle-angle rule. □

We show the output of an example where we have broken the general advice of not ending a proof with a displayed formula. The box is placed on the same line as the formula.

Proof. The height, drawn from the right angle, divides the hypotenuse into two parts. Let x be the length of the part adjacent to the leg with length a. Consequently, the length of the other part is $c - x$. From Lemma 7.9 it follows that

$$\frac{a}{c} = \frac{x}{a}, \quad \frac{b}{c} = \frac{c-x}{b}.$$

Rearranging,

$$a^2 + b^2 = cx + c(c - x) = c^2. \qquad \square$$

Note the `\qedhere` that automatically places the symbol where we want it. If you end with a more complicated formula you might encounter problems. It is then best to rewrite the proof and end it with text instead. If we prefer to have the symbol on the line after the formula, we need to use `\qed` instead. We give below the complete definition of the proof environment that we ended up with.

```
\defineenumeration
  [proof]
  [alternative=serried,
   width=fit,
   distance=1em,
   text=Proof,
   number=no,
   headstyle=italic,
   headcommand=\groupedcommand{}{.},
   title=yes,
   titlestyle=,
   titleleft=,
   titleright=,
   titledistance=0pt,
   titlecommand=\groupedcommand{\space}{},
   closesymbol=\mathqed]
```

If we want to use another symbol, we can for instance do

```
\definesymbol
  [mathqed]
  [{\blackrule[height=1.3333ex,width=0.6666ex]}]
```

According to [LS17] definition style enunciations include Affirmation, Application, Assumption, Condition, Convention, Definition, Discussion, Example, Exercise, Fact, Model, Problem, Property, Question, Scholium and Terminology.

They should be typeset like the theorems, but with normal (non-italic) body.

```
\defineenumeration
  [definition]
  [theorem]
  [text=Definition,
   style=normal]
```

```
\startdefinition
The \emph {Willmore energy} of a closed surface \im {\Sigma\subset S^3} is
given    by the quantity \im {\mathscr {W}(\Sigma)=\int_{\Sigma} (1+H^2) \dd
\Sigma}.
\stopdefinition
```

Definition 7.10. The *Willmore energy* of a closed surface $\Sigma \subset S^3$ is given by the quantity $\mathscr{W}(\Sigma) = \int_{\Sigma}(1 + H^2)\, d\Sigma$.

In [LS17] the following enunciations are set in the same style as remarks: Answer, Base, Case, Claim, Comment, Conclusion, Note, Notation, Observation, Subcase, Step and Summary.

Further, one can read that remarks are set with an italic head, roman number and body. We define the remark enumeration as a copy of the theorem enumeration, and do the relevant changes.

```
\defineenumeration
  [remark]
  [theorem]
  [text=Remark,
   style=normal,
   headstyle=italic,
   numberstyle=normal,
   title=no]
```

```
\startremark
It is not known who was first to prove the Pythagorean theorem.
\stopremark
```

Remark 7.11. It is not known who was first to prove the Pythagorean theorem.

7.4 Chicago-styled enunciations

According to [The17] most enunciations can be written in small caps (with a starting large cap)

```
\defineenumeration
  [theorem]
  [alternative=serried,
   width=fit,
   text=Theorem,
   style=italic,
   title=yes,
   prefix=yes,
   indenting=yes,
   headstyle=\sc,
   headindenting=yes,
   titlestyle=normal]
```

We show the output of the Pythagorean threorem again.

THEOREM 7.1 (Pythagoras) *Let a and b be the legs and let c be the hypotenuse in a right triangle. Then*

$$a^2 + b^2 = c^2.$$

7.5 Comments

In case we want an enumeration to inherit all the settings from another, but to let it have its own numbering, we can explicitly set the `counter`.

```
\defineenumeration
  [proposition]
  [theorem]
  [text=Proposition,
   counter=proposition]
```

```
\startproposition   The altitude of a right triangle from its right angle to
its hypotenuse split   the triangle into two triangles that are both similar
to the original triangle.
\stopproposition
```

Proposition 7.1. *The altitude of a right triangle from its right angle to its hypotenuse split the triangle into two triangles that are both similar to the original triangle.*

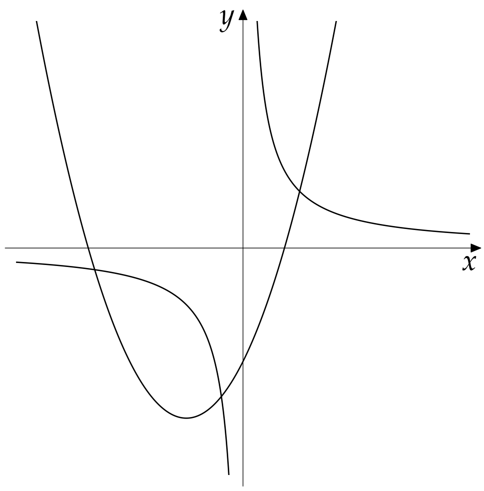
8 Illustrations

8.1 Introduction

The close interplay between ConTEXt and MetaPost (or the extension MetaFun) comes in very handy when simple figures are needed. We will not go into detail, since that would add too many pages on a somewhat peripheral topic. Instead we refer to the MetaFun manual, [Hag17], and show only a few examples, without comments. There are also other good tools, like Tikz and Asymptote, that can be used within ConTEXt, but we will not discuss them in this document.

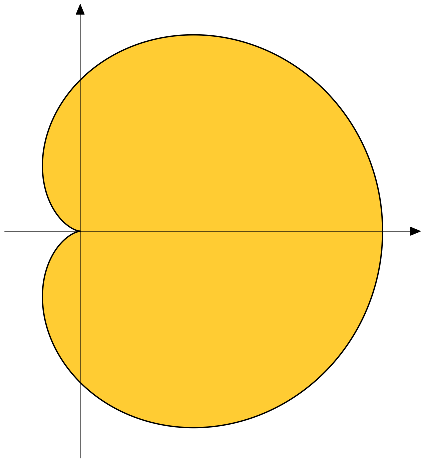
8.2 Function graphs

```
\startMPcode
numeric u ; u := .75cm ;

draw function(2, "x", "x*x+2*x-2", -4, 4, 1/100) scaled u ;
draw function(2, "x", "1/x", -4, -0.2, 1/100)    scaled u ;
draw function(2, "x", "1/x", 0.2, 4, 1/100)      scaled u ;

clip currentpicture to (fullsquare scaled 8u) ;

drawarrow ((-4.2,0) -- (4.2,0)) scaled u withpen pencircle scaled .25 ;
drawarrow ((0,-4.2) -- (0,4.2)) scaled u withpen pencircle scaled .25 ;
label.bot("\m{x}", (4u, 0)) ;
label.lft("\m{y}", (0, 4u)) ;
\stopMPcode
```



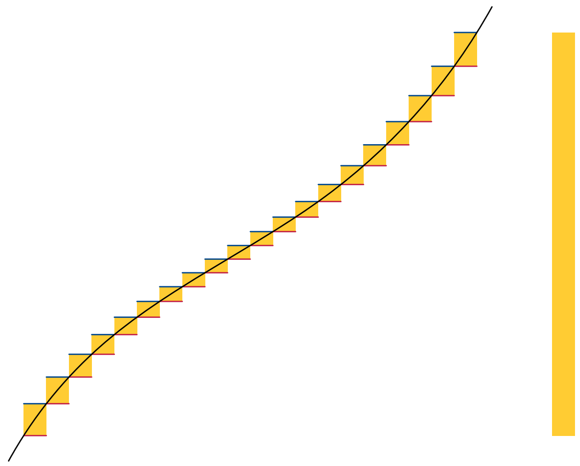

```
\startMPcode
numeric u ; u := 2cm ;

path pascal ;
pascal := (function(1,"(1 + cos(x))*cos(x)","(1 + cos(x))*sin(x)",
                   epsed(-pi+0.01),epsed(pi-0.01),0.01)
                   && cycle)
                   scaled u ;
```

```
fill pascal withcolor "C:2" ;
draw pascal ;

drawarrow ((-0.5,0) -- (2.25,0)) scaled u withpen pencircle scaled .25 ;
drawarrow ((0,-1.5) -- (0,1.5))  scaled u withpen pencircle scaled .25 ;
\stopMPcode
```



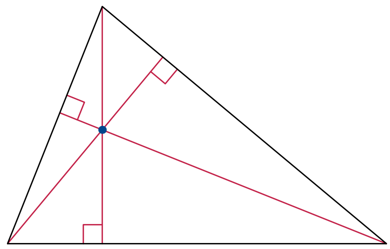
```
\startMPcode
numeric u ; u := 1cm ;
numeric n ; n := 20 ;
numeric startx ; startx := -3 ;
numeric stopx  ; stopx  :=  3 ;
numeric xx[],yy[];

path fun ; fun = (-3.2,-3)..(-2,-1.5)..(1,0.5)..(3.2,3);

for i = 0 upto n :
 xx[i] := (i/n)*stopx + (1 - i/n)*startx ;
 yy[i] := ypart (((xx[i],-5) -- (xx[i],5)) intersectionpoint fun) ;
 if i > 0 :
   fill ((xx[i - 1], yy[i]    ) --
         (xx[i],     yy[i]    ) --
         (xx[i],     yy[i - 1]) --
         (xx[i - 1], yy[i - 1]) -- cycle)
        scaled u withcolor "C:2" ;
   draw ((xx[i - 1], yy[i])     --
         (xx[i],     yy[i]))
        scaled u withcolor "C:1" ;
   draw ((xx[i - 1], yy[i - 1]) --
         (xx[i], yy[i - 1]))
        scaled u withcolor "C:3";
 fi;
endfor

draw fun scaled u ;
```

```
fill (unitsquare xyscaled ((6/n),yy[n] - yy[0])
                 shifted (4,yy[0]))
                 scaled u
                 withcolor "C:2" ;
\stopMPcode
```



8.3 Geometry

```
\startMPcode
u := 5ts ;
z0 = origin ;
z1 = (4u,0) ;
z2 = (u,2.5u) ;
z3 = whatever[z0,z1] = z2 + whatever*dir(angle(z1 - z0) - 90) ;
z4 = whatever[z1,z2] = z0 + whatever*dir(angle(z2 - z1) - 90) ;
z5 = whatever[z2,z0] = z1 + whatever*dir(angle(z0 - z2) - 90) ;
z6 = (z2 -- z3) intersectionpoint (z4--z0);

drawoptions(withcolor "C:3") ;

draw z2 -- z3 &&
     z0 -- z4 &&
     z1 -- z5 ;

anglemethod := 2;
anglelength := 0.2u;
draw anglebetween(z3 -- z2, z3 -- z0, "");
draw anglebetween(z4 -- z0, z4 -- z1, "");
draw anglebetween(z5 -- z1, z5 -- z2, "");

drawoptions() ;

draw z0 -- z1 -- z2 -- cycle withstacking 2 ;
drawpoints z6 withpen pencircle scaled 3pt
              withcolor "C:1" ;
\stopMPcode
```

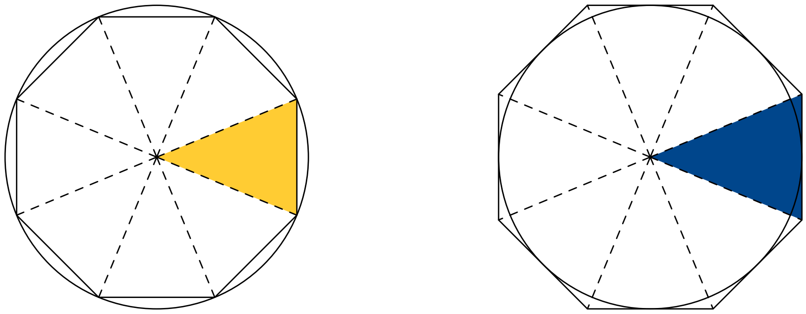


```
\startuseMPgraphic{circle-base}
u := 8ts ;
n := 8 ;
path c ; c = fullcircle scaled 2u;
pair iz[], oz[] ;

for i = 1 upto n :
 iz[i] = point ((i - 0.5)/8) along c;
 oz[i] = (1/cosd(180/n))*iz[i];
endfor;
\stopuseMPgraphic

\startuseMPgraphic{circle-inner}
\includeMPgraphic{circle-base}
fill (origin -- iz[1] -- iz[8] -- cycle) withcolor "C:2";

for i = 1 upto n :
  draw origin -- iz[i] dashed evenly ;
endfor;

draw c ;
draw for i = 1 upto n : iz[i] -- endfor cycle ;
\stopuseMPgraphic

\startuseMPgraphic{circle-outer}
\includeMPgraphic{circle-base}
fill (origin -- oz[1] -- oz[8] -- cycle) withcolor "C:1";

for i = 1 upto n :
  draw origin -- oz[i] dashed evenly;
endfor;

draw c ;
draw for i = 1 upto n : oz[i] -- endfor cycle ;
\stopuseMPgraphic
```

8.4 Diagrams

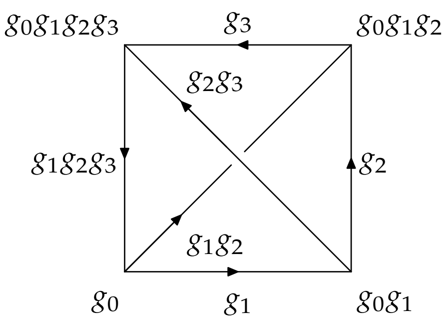
We show a few diagrams, but refer to Alan's nice module `/tex/texmf-context/doc/context/documents/general/manuals/nodes.pdf` for details.

```
\startMPcode
  numeric u ; u := 1cm ;
  crossingscale := .5u ;
  z1 = origin  ; z2 = (3u,0) ;
```



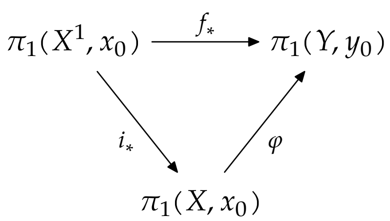
(a) (b)

```
  z3 = (3u,3u) ; z4 = (0,3u) ;
  z12 = .5[z1,z2] ; z23 = .5[z2,z3] ;
  z34 = .5[z3,z4] ; z41 = .5[z4,z1] ;
  z13 = .5[z1,z3] ;

  draw (z2 -- z4) ;
  draw (z1 -- z3) crossingunder (z2 -- z4) ;
  drawarrow (z1 -- z12) ; draw (z12 -- z2) ;
  drawarrow (z2 -- z23) ; draw (z23 -- z3) ;
  drawarrow (z3 -- z34) ; draw (z34 -- z4) ;
  drawarrow (z4 -- z41) ; draw (z41 -- z1) ;
  drawarrow (z1         -- .5[z1,z13]) ;
  drawarrow (.1[z13,z4] -- .5[z13,z4]) ;

  label.llft("\m{\strut g_0}",           z1) ;
  label.lrt ("\m{\strut g_0g_1}",        z2) ;
  label.urt ("\m{\strut g_0g_1g_2}",     z3) ;
  label.ulft("\m{\strut g_0g_1g_2g_3}",  z4) ;
  label.bot ("\m{\strut g_1}",          z12) ;
  label.rt  ("\m{\strut g_2}",           z23) ;
  label.top ("\m{\strut g_3}",           z34) ;
  label.lft ("\m{\strut g_1g_2g_3}",    z41) ;
  label.lrt ("\m{\strut g_1g_2}",.5[z1,z13]) ;
  label.urt ("\m{\strut g_2g_3}",.5[z13,z4]) ;
\stopMPcode
```




```
\setupframed
  [node]
  [offset=.5TS]
```

```
\setupframed
  [smallnode]
  [offset=.1TS]

\startMPcode
save nodepath ; save l ; l = 5ahlength ;
save A, B, C, D, E ;
pair A, B, C, D, E ;

A.i = 0 ; A = makenode(A.i, "\node{\im{\pi_1(X^1, x_0)}}") ;
B.i = 1 ; B = makenode(B.i, "\node{\im{\pi_1(Y,y_0)}}") ;
C.i = 2 ; C = makenode(C.i, "\node{\im{\pi_1(X,x_0)}}") ;

A = origin ;
B = A + betweennodes.rt(nodepath,A.i,nodepath,B.i) + (2l,0) ;
C = .5[A,B] + (0,-3l) ;

for i = A.i, B.i, C.i :
  draw node(i) ;
endfor

drawarrow fromto.llft ( 0,A.i,C.i,"\smallnode{\im{i_{*}}}") ;
drawarrow fromto.top  ( 0,A.i,B.i,"\smallnode{\im{f_{*}}}") ;
drawarrow fromto.lrt  ( 0,C.i,B.i,"\smallnode{\im{\varphi}}") ;
\stopMPcode
```




```
\startformula
  \startnodes [dx=3cm,dy=2cm,rotation=75]
    \placenode [0,0] {\node{\im{G(X)}}}
    \placenode [1,0] {\node{\im{G(Y)}}}
    \placenode [1,1] {\node{\im{F(Y)}}}
    \placenode [0,1] {\node{\im{F(X)}}}
    \connectnodes [0,1] [alternative=arrow,
    label={\smallnode{\im{G(f)}}},position=bottom]
    \connectnodes [3,2] [alternative=arrow,
    label={\smallnode{\im{F(f)}}},position=top]
    \connectnodes [2,1] [alternative=arrow,
    label={\smallnode{\im{η_Y}}}, position=right]
    \connectnodes [3,0] [alternative=arrow,
    label={\smallnode{\im{η_X}}}, position=left]
```

```
  \stopnodes
\stopformula
```

$$\begin{tikzcd} F(X) \arrow[r, "F(f)"] \arrow[d, "\eta_X"'] & F(Y) \arrow[d, "\eta_Y"] \\ G(X) \arrow[r, "G(f)"'] & G(Y) \end{tikzcd}$$

9 Math fonts

9.1 Selecting a font

The default font in ConTEXt is the Computer Modern based Latin Modern, with Latin Modern Math as math font. By running `\setupbodyfont` with the right arguments the font setup can be changed. For example,

```
\setupbodyfont[pagella]
```

will change the font into TEXGyre Pagella (with the corresponding math font TEXGyre Pagella Math), that is used in this document.

Several fonts with math support follow with an installation of ConTEXt, and the aim here is to show a small sample of all of them (see Intermezzo 9.1). In addition to the fonts that are shipped with the installation, there is also support (read: ready-made type scripts) for some commercial fonts, such as Cambria and Lucida Bright. We do not own any copy of the commercial Minion Math font, and hence we do not support it.

Users shall be aware that the coverage of symbols in math font varies. Some might be done by tweaking an existing glyph. If you miss some glyph you can write to us, but please also add an example of real usage.

antykwa**	bonum	cambria	concrete
dejavu	ebgaramond	erewhon	iwona**
kpfonts*	kurier**	libertinus	lucida
modern	pagella	schola	stixtwo
termes	xcharter		

Intermezzo 9.1 Fonts with support in ConTEXt. The kpfonts is marked with *. It comes in more than one weight and style. The fonts marked with ** are the only ones that have math fonts in Type1 format (they also come in several weights). All the other fonts are Opentype fonts.

There are some more free fonts that are not shipped with ConTEXt. We have not yet written any complete setup for the fonts `Fira Math`, `GFS Neohellenic`, `Lete Sans Math`, `New Computer Modern Math`, `Noto Sans Math` or `Plex Math`, since they still seem to be under development or are incomplete.

It is also possible to mix fonts in different ways than the ones mentioned here. This is typically done with the help of typescript files, and is discussed elsewhere. It can be good to have in mind, though, to enable the loading of existing goodie files if you use a supported math font. The best way to see how this is done is probably by studying some existing typescript file.

In a document like this one where we do several fontswitches, one shall not use `setupbodyfont` everywhere. For Antykwa, for example, one shall have `\usebodyfont[antykwa]` before `\starttext` and then switch to it with `\switchtobodyfont[antykwa]`.

9.2 antykwa

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\overline{F}/F) \to \mathcal{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\ldots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\left\{t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j}\right\}.$$

A few alphabets:

`\mathit`	$\mathit{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathrm`	$\mathrm{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathss`	$\mathsf{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathtt`	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathcal`	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathscr`	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathfrak`	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathbb`	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$\mathit{A B \Gamma \Delta E Z H \Theta I K \Lambda M N \Xi O \Pi P \Theta \Sigma T \Upsilon \Phi X \Psi \Omega}$

9.3 antykwa-light

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbb{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbb{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\overline{F}/F) \to \mathcal{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\ldots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\Big\{ t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j} \Big\}.$$

A few alphabets:

`\mathit`	$\mathit{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathrm`	$\mathrm{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathss`	$\mathsf{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathtt`	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathcal`	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathscr`	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathfrak`	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathbb`	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$ABΓΔEZHΘIKΛMNΞOΠPΘΣTΥΦXΨΩ$

9.4 antykwa-cond

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_\mathfrak{p}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\overline{F}/F) \to \mathcal{O}_\mathfrak{p}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\ldots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\Big\{t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j}\Big\}.$$

A few alphabets:

`\mathit`	$\mathit{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathrm`	$\mathrm{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathss`	$\mathsf{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathtt`	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathcal`	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathscr`	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathfrak`	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathbb`	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$\mathit{AB\Gamma\Delta EZH\Theta IK\Lambda MN\Xi O\Pi P\Theta\Sigma TY\Phi X\Psi\Omega}$

9.5 bonum

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{p}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{p}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{p}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{p}}$ ($k \geq 1$) in this case was then

$$\delta_{k,\mathfrak{p}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{p}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{p}} \to \mathcal{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{p}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{p}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\overline{F}/F) \to \mathcal{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\dots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\left\{t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j}\right\}.$$

A few alphabets:

\mathit	$\mathit{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathrm	$\mathrm{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathss	$\mathsf{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathtt	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathcal	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathscr	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathfrak	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathbb	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$\mathit{AB\Gamma\Delta EZH\Theta IK\Lambda MN\Xi O\Pi P\Theta\Sigma T\Upsilon\Phi X\Psi\Omega}$

9.6 cambria

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \lim\limits_{?} u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\overline{F}/F) \to \mathcal{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\ldots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\left\{t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j}\right\}.$$

A few alphabets:

\mathit	$ABCDEFGHIJKLMNOPQRSTUVWXYZ$
\mathrm	$\mathrm{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathss	$\mathsf{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathtt	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathcal	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathscr	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathfrak	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathbb	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$ABΓΔEZHΘIKΛMNΞOΠPΘΣTΥΦXΨΩ$

9.7 concrete

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbb{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbb{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_\mathfrak{p}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\overline{F}/F) \to \mathcal{O}_\mathfrak{p}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\ldots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\{t < t_n : |\xi(t)-\xi(t_n)| = 2^{-j}\}.$$

A few alphabets:

\mathit	$\mathit{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathrm	$\mathrm{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathss	$\mathsf{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathtt	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathcal	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathscr	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathfrak	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathbb	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$\mathit{AB\Gamma\Delta EZH\Theta IK\Lambda MN\Xi O\Pi P\Theta\Sigma T\Upsilon\Phi X\Psi\Omega}$

9.8 dejavu

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\Big|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\overline{F}/F) \to \mathcal{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\ldots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\left\{t < t_n : |\xi(t)-\xi(t_n)| = 2^{-j}\right\}.$$

A few alphabets:

\mathit	$\mathit{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathrm	$\mathrm{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathss	$\mathsf{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathtt	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathcal	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathscr	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathfrak	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
\mathbb	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$\mathit{A B \Gamma \Delta E Z H \Theta I K \Lambda M N \Xi O \Pi P \Theta \Sigma T \Upsilon \Phi X \Psi \Omega}$

9.9 ebgaramond

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\bar{F}/F) \to \mathcal{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\dots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\{t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j}\}.$$

A few alphabets:

`\mathit`	$\mathit{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathrm`	$\mathrm{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathss`	$\mathsf{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathtt`	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathcal`	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathscr`	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathfrak`	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathbb`	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$\mathit{AB\Gamma\Delta EZH\Theta IK\Lambda MN\Xi O\Pi P\Theta\Sigma T\Upsilon\Phi X\Psi\Omega}$

9.10 erewhon

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\Big|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathscr{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where θ: $\mathrm{Gal}(\overline{F}/F) \to \mathscr{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\dots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\bigl\{t < t_n : |\xi(t)-\xi(t_n)| = 2^{-j}\bigr\}.$$

A few alphabets:

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\mathrm	$\mathrm{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
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lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$AB\Gamma\Delta EZH\Theta IK\Lambda MN\Xi O\Pi P\Theta\Sigma T\Upsilon\Phi X\Psi\Omega$

9.11 iwona

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbb{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbb{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ ($k \geq 1$) in this case was then

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A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\dots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\bigl\{t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j}\bigr\}.$$

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`\mathtt`	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathcal`	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathscr`	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
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uppercase greek	$\mathit{AB\Gamma\Delta EZH\Theta IK\Lambda MN\Xi O\Pi P\Theta\Sigma T\Upsilon\Phi X\Psi\Omega}$

9.12 iwona-light

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbb{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbb{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ ($k \geq 1$) in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k\,\delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\overline{F}/F) \to \mathcal{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\dots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\Big\{t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j}\Big\}.$$

A few alphabets:

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`\mathbb`	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$ABΓΔEZHΘIKΛMNΞOΠPΘΣTΥΦXΨΩ$

9.13 KOEIELETTERS

A PARAGRAPH FROM [WIL95]:

ASSUME FOR THE MOMENT THAT $F_{?}$ IS $Q_{?}$. IN THIS CASE $\mathcal{E}_{?}$ IS ISOMORPHIC TO THE LUBIN–TATE GROUP ASSOCIATED TO $?X + X^{?}$ WHERE $? = ?(?)$. THEN LETTING $?_{N}$ BE NONTRIVIAL ROOTS OF $[?^{N}](X) = 0$ CHOSEN SO THAT $[?](?_{N}) = ?_{N-1}$, IT WAS SHOWN IN [CW] THAT TO EACH ELEMENT $U = \lim_{?} U_{N} ? U_{\infty,?}$ THERE CORRESPONDED A UNIQUE POWER SERIES $F_{U}(T) ? Z_{?}T^{\times}$ SUCH THAT $F_{U}(?_{N}) = U_{N}$ FOR $N ? 1$. THE DEFINITION OF $?_{K,?}$ $(K ? 1)$ IN THIS CASE WAS THEN

$$?_{K,?}(U) = \left(\frac{1}{?'(T)}\frac{?}{?T}\right)^{K} \log F_{U}(T)\Big|_{T=0}.$$

IT IS EASY TO SEE THAT $?_{K,?}$ GIVES A HOMOMORPHISM: $U_{\infty} \to U_{\infty,?} \to O_{?}$ SATISFYING $?_{K,?}(?^{?}) = ?(?)^{K}?_{K,?}(?)$ WHERE $??\,\mathrm{GAL}(F/F) \to O_{?}^{\times}$ IS THE CHARACTER GIVING THE ACTION ON $E[?^{\infty}]$.

A FEW FORMULAS:

$$\int_0^{?/2} \ln(\sin x)\,?x = -\frac{?}{2}\ln 2, \quad \frac{1}{\prod_{P=2}(1-1/P^{2})} = \prod_{P=2} \sum_{K=0}^{+\infty} \frac{1}{P^{2K}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+?}}} = 2, \quad \frac{1-x^{2}}{(1+x)^{2}} = \frac{1-x}{1+x},$$

$$\binom{N}{4} = \frac{N(N-1)(N-2)(N-3)}{1 ? 2 ? 3 ? 4}, \quad T_{N+1} ? \sup\left\{T < T_{N} : \left|?(T) - ?(T_{N})\right| = 2^{-J}\right\}.$$

A FEW ALPHABETS:

\mathit	ABCDEFGHIJKLMNOPQRSTUVWXYZ
\mathrm	ABCDEFGHIJKLMNOPQRSTUVWXYZ
\mathss	ABCDEFGHIJKLMNOPQRSTUVWXYZ
\mathtt	ABCDEFGHIJKLMNOPQRSTUVWXYZ
\mathcal	ABCDEFGHIJKLMNOPQRSTUVWXYZ
\mathscr	ABCDEFGHIJKLMNOPQRSTUVWXYZ
\mathfrak	ABCDEFGHIJKLMNOPQRSTUVWXYZ
\mathbb	ABCDEFGHIJKLMNOPQRSTUVWXYZ
LOWERCASE GREEK	????????????????????????
UPPERCASE GREEK	????????????????????????

9.14 kpfonts

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{p}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{p}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{p}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[[T]]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{p}}$ $(k \geq 1)$ in this case was then

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A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

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`\mathscr`	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
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lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
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9.15 kurier

A paragraph from [Wil95]:

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A few formulas:

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9.16 kurier-light

A paragraph from [Wil95]:

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A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

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9.17 libertinus

A paragraph from [Wil95]:

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A few formulas:

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`\mathscr`	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
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lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$\mathit{AB\Gamma\Delta EZH\Theta IK\Lambda MN\Xi O\Pi P\Theta\Sigma TY\Phi X\Psi\Omega}$

9.18 lucida

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{p}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{p}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{p}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{p}}$ ($k \geq 1$) in this case was then

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A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\ldots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} \coloneqq \sup\Big\{t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j}\Big\}.$$

A few alphabets:

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`\mathfrak`	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathbb`	$\mathbb{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
lowercase greek	$\alpha\beta\gamma\delta\varepsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\varsigma\sigma\tau\upsilon\varphi\chi\psi\omega$
uppercase greek	$AB\Gamma\Delta EZH\Theta IK\Lambda MN\Xi O\Pi P?\Sigma TY\Phi X\Psi\Omega$

9.19 modern

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

$$\delta_{k,\mathfrak{P}}(u) = \left(\frac{1}{\lambda'(T)}\frac{d}{dT}\right)^k \log f_u(T)\bigg|_{T=0}.$$

It is easy to see that $\delta_{k,\mathfrak{P}}$ gives a homomorphism: $U_\infty \to U_{\infty,\mathfrak{P}} \to \mathcal{O}_{\mathfrak{p}}$ satisfying $\delta_{k,\mathfrak{P}}(\varepsilon^\sigma) = \theta(\sigma)^k \delta_{k,\mathfrak{P}}(\varepsilon)$ where $\theta\colon \mathrm{Gal}(\bar{F}/F) \to \mathcal{O}_{\mathfrak{p}}^\times$ is the character giving the action on $E[\mathfrak{p}^\infty]$.

A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod\limits_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

$$\sqrt{2+\sqrt{2+\sqrt{2+\ldots}}} = 2, \quad \frac{1-x^2}{(1+x)^2} = \frac{1-x}{1+x},$$

$$\binom{n}{4} = \frac{n(n-1)(n-2)(n-3)}{1\cdot 2\cdot 3\cdot 4}, \quad t_{n+1} := \sup\bigl\{t < t_n : |\xi(t) - \xi(t_n)| = 2^{-j}\bigr\}.$$

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`\mathtt`	$\mathtt{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathcal`	$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathscr`	$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
`\mathfrak`	$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$
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uppercase greek	$ABΓΔEZHΘIKΛMNΞOΠPΘΣTΥΦXΨΩ$

9.20 pagella

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

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A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

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9.21 schola

A paragraph from [Wil95]:

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A few formulas:

$$\int_0^{\pi/2} \ln(\sin x)\,dx = -\frac{\pi}{2}\ln 2, \quad \frac{1}{\prod_{p=2}^{p_m}(1-1/p^2)} = \prod_{p=2}^{p_m}\sum_{k=0}^{+\infty}\frac{1}{p^{2k}},$$

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9.22 stixtwo

A paragraph from [Wil95]:

Assume for the moment that $F_{\mathfrak{P}}$ is $\mathbf{Q}_p$. In this case $\hat{E}_{\mathfrak{P}}$ is isomorphic to the Lubin–Tate group associated to $\pi x + x^p$ where $\pi = \varphi(\mathfrak{p})$. Then letting ω_n be nontrivial roots of $[\pi^n](x) = 0$ chosen so that $[\pi](\omega_n) = \omega_{n-1}$, it was shown in [CW] that to each element $u = \varprojlim u_n \in U_{\infty,\mathfrak{P}}$ there corresponded a unique power series $f_u(T) \in \mathbf{Z}_p[\![T]\!]^\times$ such that $f_u(\omega_n) = u_n$ for $n \geq 1$. The definition of $\delta_{k,\mathfrak{P}}$ $(k \geq 1)$ in this case was then

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uppercase greek	$\mathit{ABΓΔEZHΘIKΛMNΞOΠPΘΣTΥΦXΨΩ}$

9.23 termes

A paragraph from [Wil95]:

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9.24 xcharter

A paragraph from [Wil95]:

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\setupbodyfont[drontfont]

10 Meaningful mathematics

10.1 Introduction

We have so far focused mainly on how to typeset mathematics; we have not discussed so much about the meaning of the formulas. It should be clear that $\sqrt{x}$ stands for the square root of x, but many other symbols are used with more than one meaning. When we see a formula, we can often guess the intended meaning from the context, in particular if the author has used standard notation, introduced new notation, not used the same notation to mean several things, and kept the notation as simple as possible. There are, however, ambiguous cases.

We give one example where the situation might not be completely clear. If, in a manuscript on complex analysis, we meet the formula $\bar{z} \in \overline{U}$, we will likely interpret the first bar as the complex conjugate of the complex number z. But the meaning of $\overline{U}$ is perhaps less clear. The $\in$ hints that it should be a set. One standard notation implies that it denotes the closure of the set U. But it could also, in principle, mean the set of complex conjugate of the elements in the set U. Even if the bars over these characters look the same in the pdf file, it would be good if it was possible also to carry the meaning somehow.

If somebody who copies the formula from the pdf they shall get something sensible out of it when pasting it elsewhere. It is therefore important to work with the symbols predefined in Unicode math, and not to come up with own weird symbols by clipping, rotating, or in other problematic ways combining symbols and perhaps also rules.

Unicode math contains a lot of symbols. Many of them are described with a name that rather say something about the shape than about how they are supposed to be used. Given that we are free to use whatever symbol to denote antything, this is perhaps natural. But it is also problematic. Take $\otimes$ (its official name is CIRCLED TIMES), for example. It comes with two synonyms that tell a bit how it can be used “tensor product” and “vector pointing into page”. For the first usage the macro name `\otimes` has traditionally in TEX been attached to the symbol. But, as the synonym says, sometimes it also denotes a vector pointing into the page, and then one can question both the macro name and the binary operation class that is attached to it. If one wants to use this symbol in the latter meaning it is natural to define a new macro that typesets the symbol, with a matching class. Observe, however, that such a construct will not change the meaning for someone copying the symbol from the pdf. It will still be CIRCLED TIMES.

10.2 Accessibility, tagging

When it comes to accessibility, the situation becomes even more interesting. How shall a screen reader read the symbol $\otimes$? As “CIRCLED TIMES”, as “tensor product” or as “points into the page”? Or perhaps as “otimes”? ConTEXt has for a long time been able to tag documents that include mathematics and also export them to MathML. As of now, the formulas are transformed into some core MathML and included as attachments in the pdf file. Meaning easily gets lost in this conversion, so one can question how accessible the result actually is for a person who needs to have it read aloud. Moreover, the MathML itself, or the flavor of it, sometimes changes. For example, the `mfenced` element recently got deprecated, leading to compatibility issues for a lot of existing documents. This lack of stability makes it both difficult and demotivating to support tagging.

It can be useful to have the MathML if one wants to export and show the output on a web site. One shall remember, though, that the typeset math from ConTEXt that one gets in a pdf file is not in general equivalent (features differ) to the MathML produced, so it will not be perfect.

The example $\bar{z} \in \overline{U}$, discussed in the introduction comes out like this (we have replaced the math italic z and U so that they show below since they are not present in the monotype font we use)

```
<math>
 <mrow>
  <mover>
   <mi>z</mi>
   <mo>‾</mo>
  </mover>
  <mo>∈</mo>
  <mover>
   <mi>U</mi>
   <mo>‾</mo>
  </mover>
 </mrow>
</math>
```

Let us also mention that it is not easy to verify that the tagging actually works. At Lund university, where Mikael is working, the tool Ally (as a plugin to the Canvas LMS) is used to check the tagged pdf files, and it does usually mark tagged pdf files from ConTEXt as being perfectly tagged. But even here, things do change. At some point it was changed so that formulas were seen as attached images, and then it complained about lacking alternative texts. It is also an interesting fact that exporting a claimed perfectly tagged pdf file into sound (also possible in Canvas LMS), it does not read the formulas correctly, if at all.

10.3 Dictionaries

With the right mark up and choice of notation from the writer, it should be possible to have it read different things, depending on the context. We therefore came up with dictionaries. They make it possible for symbols to carry a meaning and context, in addition to the atom class. In fact, we shall think of it as something that is independent of the atom class. A Unicode character can thus have several instances, where different instances might belong to different groups. Of course the math class can also vary. Thus, for ⊗ it could be like this:

Symbol	Macro	Class	Group	Meaning
⊗	`\tensorproduct`	binary operator	binary operator	tensor product
⊗	`\pointsintopage`	ordinary	unary arithmetic	points into the page

The idea is then that the user can specify the groups used in a document. If one typesets a document on mathematical logic, one can load the groups that are attached to logic, and one will have these macros predefined, likely with the intended meaning. One can of course add or change the setup as well.

10.4 Formulas converted into text

One reason to introduce dictionaries with groups, in addition to atom classes, is that we can now use the label system in ConTEXt to attach to each symbol also a label that tells how it could be read out. The same has been done for various macros, and as a result we can convert formulas into "spoken mathematics", something that will be easily read by screen readers, since it is only text. Of course, given the amount of symbols and macros, we are not complete. In fact, we do not want to be complete either, and the reason is simple: We cannot know how various authors wants their formulas to be spoken. So, what we have is merely a proof of concept, with a set of interpretations that covers many basic usages of commonly used symbols.

To get a hold of it, let us look at a few simple examples, where we after each formula show how it is interpreted in text.

```
\startformula
  1 + 2 = 3
\stopformula
```

$$1 + 2 = 3$$ [1] 2359 en

[1] 1 plus 2 equals 3

```
\startformula
  3^2 + 4^2 = 5^2
\stopformula
```

$$3^2 + 4^2 = 5^2$$ [2] 2360 en

[2] 3 squared plus 4 squared equals 5 squared

```
\startformula
  \frac{3}{6} = \frac{1}{2} = 1/2
\stopformula
```

$$\frac{3}{6} = \frac{1}{2} = 1/2$$ [3] 2361 en

[3] the fraction of 3 and 6 equals the fraction of 1 and 2 equals 1 divided by 2

```
\startformula
  \sqrt{9} = 3
\stopformula
```

$$\sqrt{9} = 3$$ [4] 2362 en

[4] the square root of 9 equals 3

```
\startformula
  \sin \left(\frac{\pi}{6}\right) = \frac{1}{2}
\stopformula
```

$$\sin\left(\frac{\pi}{6}\right) = \frac{1}{2}$$ [5] 2363 en

[5] sin fenced the fraction of π and 6 end fenced equals the fraction of 1 and 2

```
\startformula
  \conjugate{1 + 2\ii} = 1 - 2\ii
\stopformula
```

$$\overline{1 + 2i} = 1 - 2i$$ [6] 2364 en

[6] the conjugate of 1 plus 2 *i* equals 1 minus 2 *i*

```
\startformula
  \frac{1 + 2}{3 + 4} = \frac{3}{7}
\stopformula
```

$$\frac{1+2}{3+4} = \frac{3}{7}$$ [7]

[7] the fraction of 1 plus 2 and denominator 3 plus 4 end denominator equals the fraction of 3 and 7

10.5 Some difficulties and comments

The process has really been trial and error. There is for sure space for improvements and variations, but we believe that the main structure is there. Different areas of mathematics come with different notation and different ways to interpret. So, if for example a logician wants to take this up, there is for sure some basic tuning before it works as expected.

One of the difficulties we encountered along the way was how to work with parentheses. When we write $a(b+c)$ we likely read it as "a times b plus c". But we cannot read it like that, since that could equally well be interpreted as $ab + c$. We need the parentheses to be interpreted as some group:

```
\startformula
  a(b + c)
\stopformula
```

$$a(b+c)$$ [8]

[8] *a* times group *b* plus *c* end group

On the other hand, when we write $f(x)$ it is likely that it shall be interpreted as "f of x" rather than "f times x".

```
\startformula
  f(x) \neq f\of(x)
\stopformula
```

$$f(x) \neq f(x)$$ [9]

[9] *f* times group *x* end group is not equal to *f* of group *x* end group

In addition to the `\of` to handle this case, we also introduced the possibility to declare glyphs as being functions. So, it is possible to do

```
  \registermathfunction[]
```

and then leave out the `\of`. In fact, one of the main difficulties has been to control when the explicit "times" shall be there and when it shall not. There are several special cases; we have likely missed a few.

It is also possible to declare whole alphabets as being for example vectors or matrices. We can do

```
\registermathsymbol[default][en][lowercasebold][the vector]
```

and then use them as follows:

```
\startformula
  (\alpha + \beta) \mathbf{u} = \alpha \mathbf{u} + \beta \mathbf{u}
\stopformula
```

$$(\alpha+\beta)\mathbf{u} = \alpha\mathbf{u} + \beta\mathbf{u}$$ [10]

[10] group α plus β end group times the vector **u** equals α times the vector **u** plus β times the vector **u**

10.6 A few more examples

We give a few more examples for you to ponder.

```
\startformula
  a__1(1 + x) + (1 + y)b__1 - a_2(1 + z) - (1 + u)b_2
\stopformula
```

$$a_1(1+x)+(1+y)b_1-a_2(1+z)-(1+u)b_2$$ [11]

[11] a with lower index 1 times group 1 plus x end group plus group 1 plus y end group times b with lower index 1 minus a with lower index 2 times group 1 plus z end group minus group 1 plus u end group times b with lower index 2

```
\startformula
  a__{0}.a__{1}\notimes a__{2} \ldots a__{n} \ldots
\stopformula
```

$$a_0.a_1a_2\ldots a_n\ldots$$ [12]

[12] a with lower index 0 . a with lower index 1 , a with lower index 2 , and so on, a with lower index n , and so on,

```
\startformula
  h'\of(x) \neq h'(x)
\stopformula
```

$$h'(x)\neq h'(x)$$ [13]

[13] h prime of group x end group is not equal to h prime of group x end group

```
\startformula
  s\of(1) = s\of(\set{0}) = \set{0} \cup \set{\set{0}}
\stopformula
```

$$s(1)=s(\{0\})=\{0\}\cup\{\{0\}\}$$ [14]

[14] s of group 1 end group equals s of group the set 0 end the set end group equals the set 0 end the set union the set the set 0 end the set end the set

```
\startformula
  a\sqrt{x} = ax^{1/2} \neq ax^{1/3} = a\root[3]{x}
\stopformula
```

$$a\sqrt{x}=ax^{1/2}\neq ax^{1/3}=a\sqrt[3]{x}$$ [15]

[15] a times the square root of x equals a times x to the power of group 1 divided by 2 end group is not equal to a times x to the power of group 1 divided by 3 end group equals a times the root with degree 3 of x

```
\startformula
  \rationals = \set{\frac{p}{q} \fence p,q \in \integers \land q \neq 0}
\stopformula
```

$$\mathbb{Q}=\left\{\frac{p}{q}\;\middle|\;p,q\in\mathbb{Z}\wedge q\neq 0\right\}$$ [16]

[16] the rational numbers equals the set the fraction of p and q such that p comma q belongs to the integers and q is not equal to 0 end the set

```
\startformula
  f \mapsas x \mapsto x + \exp(x)
\stopformula
```

$$f\colon x \mapsto x + \exp(x)$$ [17] 2385 en

[17] f is defined so that x maps to x plus exp of x

```
\startformula
  \lim_{k \tendsto +\infty} \frac{A__k}{B__k}
\stopformula
```

$$\lim_{k \to +\infty} \frac{A_k}{B_k}$$ [18] 2386 en

[18] the limit as group k tends to plus infinity end group , of the fraction of numerator A with lower index k end numerator and denominator B with lower index k end denominator

```
\startformula
  \Gamma__1^^2__3^^4 \neq \Gamma__1^^2^^{}__3^^4
\stopformula
```

$$\Gamma_{13}^{24} \neq \Gamma_{13}^{2\ \ 4}$$ [19] 2387 en

[19] Γ postscripts sub 1 super 2 sub 3 super 4 end scripts is not equal to Γ postscripts sub 1 super 2 sub 3 super 4 end scripts

```
\startformula
  \int_{a}^{b} f'(x) \dd x = f(b) - f(a)
\stopformula
```

$$\int_a^b f'(x)\,dx = f(b) - f(a)$$ [20] 2388 en

[20] integral from a to b , of f prime of group x end group d x equals f times group b end group minus f times group a end group

```
\startformula
  \int_{\Omega} f \dd \mu = 0
\stopformula
```

$$\int_\Omega f\,d\mu = 0$$ [21] 2389 en

[21] integral over Ω , of f d μ equals 0

```
\startformula
  \sigma \of (A \transpose{A}) \setminus \set{0}
  =
  \sigma \of (\transpose{A} A) \setminus \set{0}
\stopformula
```

$$\sigma(AA^T) \setminus \{0\} = \sigma(A^T A) \setminus \{0\}$$ [22] 2390 en

[22] σ of group A times the transpose of A end group set minus the set 0 end the set equals σ of group the transpose of A times A end group set minus the set 0 end the set

```
\startformula
  \frac{\partial^3 u}{\partial x^2 \partial y}
\stopformula
```

$$\frac{\partial^3 u}{\partial x^2\, \partial y}$$ [23] 2391 en

[23] the partial derivative partial d cubed u over partial d x squared partial d y end derivative

10.7 A longer example, revisited

We show below again the example from the introduction, this time with the math interpretations written out. To get some variation, we use here TEXGyre Bonum.

We prove the l'Hospital rule directly from the Lagrange mean value theorem, without using the Cauchy mean value theorem.

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Abstract. At our first-year calculus course for engineers we discuss Lagrange's mean value theorem but not Cauchy's mean value theorem, and for this reason we usually give a weak form of l'Hospital's rule on limits. In this note we give a simple proof of the stronger version of l'Hospital's rule, using only Lagrange's mean value theorem and elementary results on limits and derivatives.

We formulate and prove the l'Hospitals rule for one-sided limits. This in fact strengthen the usual formulation slightly.

Theorem 10.3 (l'Hospital's rule). *Assume that the functions* f[24] *and* g[25] *are continuous in* $[a, b)$[26] *and differentiable in* (a, b).[27] *Assume further that* $f(a) = g(a) = 0$[28] *and that* $g'(x) \neq 0$[29] *in* (a, b).[30] *If* $f'(x)/g'(x) \to A$[31] *as* $x \to a^+$[32] *then* $f(x)/g(x) \to A$[33] *as* $x \to a^+$.[34]

A geometric interpretation of the l'Hospital rule goes as follow. In the uv[35] plane, draw the curve parametrized by $u = g(x)$[36] and $v = f(x)$.[37] Then the direction coefficient $f(x)/g(x)$[38] of the secant (dotted in Figure 10.1) connecting $(g(x), f(x))$[39] with $(g(a), f(a)) = (0, 0)$[40] should approach the same value as the direction coefficient $f'(x)/g'(x)$[41] of the tangent to the curve at $(g(x), f(x))$[42] (dashed in Figure 10.1) as x[43] approaches a.[44] Our proof of the theorem uses that we can

[24] the function f
[25] the function g
[26] the right open interval a comma b end the right open interval
[27] the open interval a comma b end the open interval
[28] the function f of a equals the function g of a equals 0
[29] the function g prime of x is not equal to 0
[30] the open interval a comma b end the open interval
[31] the function f prime of x divided by the function g prime of x tends to A
[32] x tends to a with upper index plus
[33] the function f of x divided by the function g of x tends to A
[34] x tends to a with upper index plus
[35] u times v
[36] u equals the function g of x
[37] v equals the function f of x
[38] the function f of x divided by the function g of x
[39] group the function g of x comma the function f of x end group
[40] group the function g of a comma the function f of a end group equals group 0 comma 0 end group
[41] the function f prime of x divided by the function g prime of x
[42] group the function g of x comma the function f of x end group
[43] x
[44] a

parametrize this curve locally around the origin as a function graph $u = t$[45] and $v = f(g^{-1}(t))$[46].

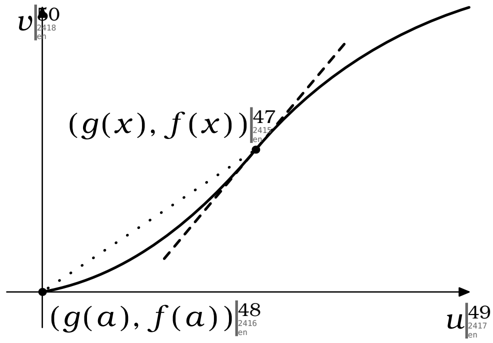

Figure 10.1

The only place in our proof where Lagrange's mean value theorem occurs is in this useful property of right-hand side derivatives.

Lemma 10.4. *Let $c > 0$[51]. Assume that $\phi\colon [0, c) \to \mathbb{R}$[52] is continuous in $[0, c)$[53] and differentiable in $(0, c)$[54], and that $\lim_{t\to 0^+} \phi'(t)$[55] exists and equals A[56]. Then*

$$\lim_{h\to 0^+} \frac{\phi(0+h) - \phi(0)}{h} = A.$$ [57]

Proof. For $h \in (0, c)$[58] the differential quotient $(\phi(0+h) - \phi(0))/h$[59] equals $\phi'(\xi_h)$[60] for some $\xi_h \in (0, h)$[61], by Lagrange's mean value theorem. As $h \to 0^+$[62] we have $\xi_h \to 0^+$[63], and so

$$\lim_{h\to 0^+} \frac{\phi(0+h) - \phi(0)}{h} = \lim_{h\to 0^+} \phi'(\xi_h) = A.$$ [64] □

Proof (of Theorem 10.3). Since g'[65] is a Darboux function it will not change sign

[45] u equals t
[46] v equals the function f of group the inverse of the function g of group t end group end group
[47] group the function g of x comma the function f of x end group
[48] group the function g of a comma the function f of a end group
[49] u
[50] v
[51] c is greater than 0
[52] ϕ maps the right open interval 0 comma c end the right open interval to the real numbers
[53] the right open interval 0 comma c end the right open interval
[54] the open interval 0 comma c end the open interval
[55] the limit as group t tends to 0 with upper index plus end group , of ϕ prime of group t end group
[56] A
[57] the limit as group h tends to 0 with upper index plus end group , of the fraction of numerator ϕ group 0 plus h end group minus ϕ group 0 end group end numerator and h equals A
[58] h belongs to the open interval 0 comma c end the open interval
[59] group ϕ group 0 plus h end group minus ϕ group 0 end group end group divided by h
[60] ϕ prime of group ξ with lower index h end group
[61] ξ with lower index h belongs to the open interval 0 comma h end the open interval
[62] h tends to 0 with upper index plus
[63] ξ with lower index h tends to 0 with upper index plus
[64] the limit as group h tends to 0 with upper index plus end group , of the fraction of numerator ϕ group 0 plus h end group minus ϕ group 0 end group end numerator and h equals the limit as group h tends to 0 with upper index plus end group , of ϕ prime of group ξ with lower index h end group equals A
[65] the function g prime

in (a, b),[66] and for simplicity we assume that $g' > 0$[67] in this interval. Lagrange's mean value theorem assures that g[68] is strictly monotone in the interval $[a, b)$[69] and thus that it has an inverse $g^{-1}\colon [0, g(b)) \to [a, b)$.[70]

The composite function $\phi\colon t \mapsto f(g^{-1}(t))$,[71] $t \in [0, g(b))$[72] is continuous at $t = 0$[73] and differentiable for $t \in (0, g(b))$.[74] By the substitution $t = g(x)$[75] in the given limit, together with the chain rule and the rule of derivatives of inverse functions, we get

$$A = \lim_{x\to a^+} \frac{f'(x)}{g'(x)} = \lim_{t\to 0^+} \frac{f'(g^{-1}(t))}{g'(g^{-1}(t))} = \lim_{t\to 0^+} \frac{d}{dt} f(g^{-1}(t)) = \lim_{t\to 0^+} \phi'(t)\,.$$ [76]

By Lemma 10.4, and by substitution $t = g(x)$[77] again, we conclude that

$$A = \lim_{t\to 0^+} \frac{\phi(0+t) - \phi(0)}{t} = \lim_{t\to 0^+} \frac{f(g^{-1}(t))}{t} = \lim_{x\to a^+} \frac{f(x)}{g(x)}\,.$$ [78]

This completes the proof. □

---

66 the open interval a comma b end the open interval
67 the function g prime is greater than 0
68 the function g
69 the right open interval a comma b end the right open interval
70 the inverse of the function g maps the right open interval 0 comma the function g of b end the right open interval to the right open interval a comma b end the right open interval
71 ϕ is defined so that t maps to the function f of group the inverse of the function g of group t end group end group
72 t belongs to the right open interval 0 comma the function g of b end the right open interval
73 t equals 0
74 t belongs to the open interval 0 comma the function g of b end the open interval
75 t equals the function g of x
76 A equals the limit as group x tends to a with upper index plus end group , of the fraction of numerator the function f prime of group x end group end numerator and denominator the function g prime of group x end group end denominator equals the limit as group t tends to 0 with upper index plus end group , of the fraction of numerator the function f prime of group the inverse of the function g of group t end group end group end numerator and denominator the function g prime of group the inverse of the function g of group t end group end group end denominator equals the limit as group t tends to 0 with upper index plus end group , of the derivative d over d t end derivative times the function f of group the inverse of the function g of group t end group end group equals the limit as group t tends to 0 with upper index plus end group , of ϕ prime of group t end group times
77 t equals the function g of x
78 A equals the limit as group t tends to 0 with upper index plus end group , of the fraction of numerator ϕ group 0 plus t end group minus ϕ group 0 end group end numerator and t equals the limit as group t tends to 0 with upper index plus end group , of the fraction of numerator the function f of group the inverse of the function g of group t end group end group end numerator and t equals the limit as group x tends to a with upper index plus end group , of the fraction of numerator the function f of group x end group end numerator and denominator the function g of group x end group end denominator

11 Miscellaneous

11.1 Introduction

In this section we collected some topics that we felt did not really fit elsewhere. The content here will likely change, and is not really part of the base material.

11.2 Manipulating matrices

If you want to show both a matrix and its transpose, you do not need to rewrite the matrix again. There is an `action` key that lets you do some simple manipulations of the matrix.

```
\startformula
\bmatrix{-1, 2, 3; 4,-5, 6; 7, 8,-9}^T =
\bmatrix
  [action=transpose]
  {-1, 2, 3; 4,-5, 6; 7, 8,-9}
\stopformula
```

$$\begin{bmatrix} -1 & 2 & 3 \\ 4 & -5 & 6 \\ 7 & 8 & -9 \end{bmatrix}^T = \begin{bmatrix} -1 & 4 & 7 \\ 2 & -5 & 8 \\ 3 & 6 & -9 \end{bmatrix}$$

In addition to transposing one can also scale the matrix with the `action` key. If you use `action=negate` you scale by -1.

```
\startformula
  -3 \bmatrix{-1, 2, 3; 4,-5, 6; 7, 8,-9} =
     \bmatrix
       [action={{scale,-3}}]
       {-1, 2, 3; 4,-5, 6; 7, 8,-9}
\stopformula
```

$$-3\begin{bmatrix} -1 & 2 & 3 \\ 4 & -5 & 6 \\ 7 & 8 & -9 \end{bmatrix} = \begin{bmatrix} 3 & -6 & -9 \\ -12 & 15 & -18 \\ -21 & -24 & 27 \end{bmatrix}$$

It is possible to both transpose and scale. If you need more advanced printing and calculations with matrices, you can load the matrix module.

```
\usemodule[matrix]
```

Once this is loaded we can for example typeset a general matrix with

```
\startformula
\ctxmodulematrix{
  typeset(moduledata.matrix.symbolic("a", "m", "n"))}
\stopformula
```

$$\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}$$

We can also define some matrices and do some math with them.

```
\startluacode
  document.matA = {{ 1, 2, 2}, { 2, 1, -2}, { -2, 2, -1}}
  document.matB = {{ 1,  2}, { 2,  4}, { 3, -3}}
  matrixoption = {fences = "brackets"}
\stopluacode
```

First we typeset them. By adding `matrixoption` as en extra argument to `typeset` we get the matrix with brackets instead of parentheses. Here `brackets` can be changed into `parentheses` or `bars`.

```
\startformula
  A = \directlua{moduledata.matrix.typeset(document.matA)}\mtp{,}
  B = \directlua{moduledata.matrix.typeset(document.matB,matrixoption)}
\stopformula
```

$$A = \begin{pmatrix} 1 & 2 & 2 \\ 2 & 1 & -2 \\ -2 & 2 & -1 \end{pmatrix}, \quad B = \begin{bmatrix} 1 & 2 \\ 2 & 4 \\ 3 & -3 \end{bmatrix}$$

The module supports the calculation of inverses, transposes and determinants of matrices.

```
\startformula
AB = \directlua{
  moduledata.matrix.typeset(
    moduledata.matrix.product(
      document.matA,
      document.matB),
    matrixoption)}
\stopformula
```

$$AB = \begin{bmatrix} 11 & 4 \\ -2 & 14 \\ -1 & 7 \end{bmatrix}$$

It is also possible to perform row operations, write a matrix in row echelon form, as well as to solve linear equations. You can find examples by looking in (and compiling) `m-matrix.mkiv`.

11.3 Systems of equations

We have emphasized simplicity. Thus, with a system of equations, we have suggested to either write them in the same line if possible,

$$x^2 + y^2 = 1, \quad y + 2x = 1,$$

or put on top of each other, aligned on the equal sign,

$$\begin{aligned} x^2 + y^2 &= 1, \\ y + 2x &= 1. \end{aligned}$$

We have emphasized that it does not make sense to align more terms in the equations. In linear algebra books, one often see alignments on more terms (that mess up the spacing in the equations, but that is usually not seen as an issue). In ConTEXt we can use the `simplealign` mechanism for this, and in particular there is implemented a parser (a bit like `simplecommand` for matrices) that will let us type the equations in a natural way without lots of alignment characters. We give a few examples.

```
\startformula
  \equationsystem {
      x -  y -     z =    2,
  {-2}x - 3y + {3a}z =   12,
               4z = {-3},
  }
\stopformula
```

$$\begin{aligned} x - \quad y - \quad z &= \ 2 \\ -2x - 3y + 3az &= \ 12 \\ + \ 4z &= -3 \end{aligned}$$

```
\startformula
  \lequationsystem{x - y - z = 2, -5y + {(3a-5)}z = 16, 4z = {-3}}
  \iff
  \lequationsystem{x - y - z = 2, -5y + {(3a-5)}z = 16, 4z = {-3}}
\stopformula
```

$$\left\{\begin{aligned} x - \quad y - \qquad\qquad z &= \ 2 \\ -5y + (3a-5)\,z &= \ 16 \\ + \qquad\quad 4z &= -3 \end{aligned}\right. \iff \left\{\begin{aligned} x - \quad y - \qquad\qquad z &= \ 2 \\ -5y + (3a-5)\,z &= \ 16 \\ + \qquad\quad 4z &= -3 \end{aligned}\right.$$

11.4 Polynomial long division

Polynomial long division is usually taught in highschool. It can be a tiresome task to type, and there are several ways to do this. We will show below how to do this in ConTEXt with the `\polynomial*` macros, and we will do it by one example. First, we can obtain the result by just typing (in math mode)

```
\startformula
  \polynomial
    [7, -5,  0, 3, 2]
    [3,  0,  1]
\stopformula
```

to get

$$\begin{aligned} \frac{2x^4 + 3x^3 - 5x + 7}{x^2 + 3} &= 2x^2 + \frac{3x^3 - 6x^2 - 5x + 7}{x^2 + 3} \\ &= 2x^2 + 3x + \frac{-6x^2 - 14x + 7}{x^2 + 3} \\ &= 2x^2 + 3x - 6 + \frac{-14x + 25}{x^2 + 3} \end{aligned}$$

With `alternative=complete` we get all steps twice, first by adding and subtracting the term, and then by simplification.

```
\startformula
  \polynomial
    [alternative=complete]
    [7, -5,  0, 3, 2]
```

```
  [3,  0,  1]
\stopformula
```

$$\begin{aligned}\frac{2x^4+3x^3-5x+7}{x^2+3} &= \frac{2x^2(x^2+3)+2x^4+3x^3-5x+7-2x^2(x^2+3)}{x^2+3}\\ &= 2x^2+\frac{3x^3-6x^2-5x+7}{x^2+3}\\ &= 2x^2+\frac{3x(x^2+3)+3x^3-6x^2-5x+7-3x(x^2+3)}{x^2+3}\\ &= 2x^2+3x+\frac{-6x^2-14x+7}{x^2+3}\\ &= 2x^2+3x+\frac{-6(x^2+3)-6x^2-14x+7+6(x^2+3)}{x^2+3}\\ &= 2x^2+3x-6+\frac{-14x+25}{x^2+3}\end{aligned}$$

By running `\polynomial` a few macros also get defined. They give us access to the various parts in the polynomial division. If we want to play with them, it might also be handy to use the option `alternative=none`. Then no output is given. Thus, if we do

```
\polynomial
  [alternative=none]
  [7, -5,  0, 3, 2]
  [3,  0,  1]
```

then we will have access to everything in Intermezzo 11.1.

`\polynomialnumerator`	$2x^4+3x^3-5x+7$
`\polynomialdenominator`	x^2+3
`\polynomialnumerator[1]`	$3x^3-6x^2-5x+7$
`\polynomialnumerator[2]`	$-6x^2-14x+7$
`\polynomialnumerator[3]`	$-14x+25$
`\polynomialquotient[1]`	$2x^2$
`\polynomialquotient[2]`	$2x^2+3x$
`\polynomialquotient[3]`	$2x^2+3x-6$
`\polynomialquotientstep[1]`	$2x^2$
`\polynomialquotientstep[2]`	$3x$
`\polynomialquotientstep[3]`	-6
`\polynomialsteps`	3

Intermezzo 11.1

This means that we can for do the typesetting a bit as we wish. For instance, if we type

```
\startformula
  \frac{\polynomialnumerator}{\polynomialdenominator}
  =
  \frac{\polynomialnumerator
        + \polynomialquotientstep[1](\polynomialdenominator)
        - \polynomialquotientstep[1](\polynomialdenominator)}
       {\polynomialdenominator}
\stopformula
```

then we do the adding and subtracting after the current numerator instead of before it,

$$\frac{2x^4+3x^3-5x+7}{x^2+3}=\frac{2x^4+3x^3-5x+7+2x^2(x^2+3)-2x^2(x^2+3)}{x^2+3}$$

It is also possible to use a different name of the variable.

```
\startformula
  \polynomial
    [symbol=z]
    [7, -5,  0, 3, 2]
    [3,  0,  1]
\stopformula
```

$$\begin{aligned}\frac{2z^4+3z^3-5z+7}{z^2+3} &= 2z^2+\frac{3z^3-6z^2-5z+7}{z^2+3}\\ &= 2z^2+3z+\frac{-6z^2-14z+7}{z^2+3}\\ &= 2z^2+3z-6+\frac{-14z+25}{z^2+3}\end{aligned}$$

It is also possible to use colors.

```
\startformula
  \polynomial
    [color={1={n=C:1,d=C:2,q=C:3},2={n=C:3,d=C:2,q=C:1}}]
    [7, -5,  0, 3, 2]
    [3,  0,  1]
\stopformula
```

$$\begin{aligned}\frac{2x^4+3x^3-5x+7}{x^2+3} &= 2x^2+\frac{3x^3-6x^2-5x+7}{x^2+3}\\ &= 2x^2+3x+\frac{-6x^2-14x+7}{x^2+3}\\ &= 2x^2+3x-6+\frac{-14x+25}{x^2+3}\end{aligned}$$

If we use non-integers, we might get surprised.

```
\startformula
  \polynomial
    [7, -5,  2, 3]
    [3,  0,  2.7]
\stopformula
```

$$\begin{aligned}\frac{3x^3+2x^2-5x+7}{2.7x^2+3} &\approx 1.111x+\frac{2x^2-8.333x+7}{2.7x^2+3}\\ &\approx 1.111x+0.741+\frac{-8.333x+4.778}{2.7x^2+3}\end{aligned}$$

11.5 Frames and decorations of formulas

It is possible to frame formulas.

```
\startformula
  \mframed{ \int_0^x f'(t) \dd t = f(x) - f(0) }
\stopformula
```

$$\boxed{\int_0^x f'(t)\,dt = f(x) - f(0)}$$

This mechanism uses the frame mechanism and therefore it is possible to use various keywords.

```
\startformula
  \mframed
    [offset=1ex,
     frame=no,
     foregroundcolor=C:1,
     background=color,
     backgroundcolor=C:2]
    { f(x) = f(0) + \int_0^x f'(t) \dd t}
\stopformula
```

$$f(x) = f(0) + \int_0^x f'(t)\,dt$$

It is also possible to set backgrounds using the bar mechanism. With the definition

```
\definebar
  [foobar]
  [mathbackground]
  [height=\strutht,
   depth=\strutdp,
   offset=.5ex,
   color=C:2]
```

we can set the background of the same formula as before as

```
\startformula
  \foobar { f(x) = f(0) + \int_0^x f'(t) \dd t}
\stopformula
```

$$f(x) = f(0) + \int_0^x f'(t)\,dt$$

The bar approach also works for formulas that break over a line.

```
\startformula
  \foobar {
    f(x)
    \alignhere = f(0) + \int_0^x f'(t) \dd t
    \breakhere = \frac{\dd}{\dd x}\int_0^x f(t) \dd t
    }
\stopformula
```

$$\begin{aligned} f(x) &= f(0) + \int_0^x f'(t)\,dt \\ &= \frac{d}{dx}\int_0^x f(t)\,dt \end{aligned}$$

There are, of course, limitations to this approach.

```
\definebar
  [Foobar]
  [foobar]
  [offset=1ex,
   color=C:3]

\definebar
  [FooBar]
  [Foobar]
  [color=C:1]

\startformula
  \foobar { a \alignhere = \Foobar {b} \breakhere
   = c \breakhere = \FooBar {d} + e }
\stopformula
```

$$
\begin{aligned}
a &= b \\
&= c \\
&= d + e
\end{aligned}
$$

Maybe it is more useful for emphasizing a few terms, rather than the whole equation.

```
\startformula
  f(x) = \frac{\dd}{\dd x}\int_0^x f(t) \dd t
       = \foobar{f(0)} + \int_0^x f'(t) \dd t
\stopformula
```

$$f(x) = \frac{d}{dx}\int_0^x f(t)\,dt = f(0) + \int_0^x f'(t)\,dt$$

12 Unicode symbols

12.1 Introduction

Unicode comes with several blocks that contain mathematical symbols. Below we list the symbols in the math blocks. The structure of the tables is the following (with one example):

Unicode slot	Symbol	Macro	Math class	Description
U+02200	∀	\forall	ordinary	for all

Many of the symbols are indeed defined in ConTEXt via some macro, but not all. One of the reasons is that we simply do not know how many of the symbols are meant to be used, and there are so many of them, so the names would just become silly. You can define macros for the additional symbols that you need.

```
\definemathsymbol[similar][relation]["02243]
```

Once that is done you can use `\m{a \similar b}` to get $a \simeq b$. Some other Unicode slots do have several macro definitions attached to them, often with different math class. Use the appropriate one that fits with your intended use case. We give one example with `\divides` and `\mid` that are both attached to the vertical bar `0x02223`. Note the difference in spacing around the vertical bar.

```
\startformula
  3\divides 15 \mtp{} \{x \in \reals \mid x > 0\}
\stopformula
```

$$3|15 \quad \{x \in \mathbb{R} \mid x > 0\}$$

You may also have noticed that we have switched font in this chapter. We use Stix Two Math since it has a lot more symbols than TEXGyre Pagella Math. If you want to generate lists like the ones below, you can do:

```
\usemodule[math-characters]
\showmathfontcharacters[list=mathematicaloperators,method=manual]
```

Possible values for the `list` key can be found in `char-ini.lua`.

12.2 Basic latin block

This is not a true math block.

U+0002B	+		binary	plus sign
U+0003C	<	\lt	relation	less-than sign
U+0003D	=	\Relbar	relation	equals sign
		\eq	relation	
U+0003E	>	\gt	relation	greater-than sign
U+0005E	^		ordinary	circumflex accent
U+0007C	|		ordinary	vertical line
		\lvert	open	
		\mvert	middle	
		\rvert	close	
		\singleverticalbar	delimiter	

		\vert	delimiter	
U+0007E	~		relation	tilde

12.3 Latin-1 Supplement block

This is not a true math block.

U+000AC	¬	\lnot	ordinary	not sign
U+000B0	°		ordinary	degree sign
U+000B1	±	\pm	binary	plus-minus sign
U+000D7	×		binary	multiplication sign
		\crossproduct	binary	
		\times	binary	
U+000F7	÷	\div	binary	division sign

12.4 Mathematical operators

U+02200	∀	\forall	ordinary	for all
U+02201	∁	\complement	ordinary	complement
U+02202	∂	\partial	differential	partial differential
U+02203	∃	\exists	ordinary	there exists
U+02204	∄	\nexists	ordinary	there does not exist
U+02205	∅	\emptyset	ordinary	empty set
U+02206	∆	\laplace	differential	increment
U+02207	∇	\gradient	differential	nabla
		\nabla	differential	
U+02208	∈	\in	relation	element of
U+02209	∉	\nin	relation	not an element of
		\notin	relation	
U+0220A	∊		ordinary	small element of
U+0220B	∋	\ni	relation	contains as member
		\owns	relation	
U+0220C	∌	\nni	relation	does not contain as member
		\nowns	relation	
U+0220D	∍		ordinary	small contains as member
U+0220E	∎		ordinary	end of proof
U+0220F	∏	\prod	operator	n-ary product
U+02210	∐	\coprod	operator	n-ary coproduct
U+02211	∑	\sum	operator	n-ary summation
U+02212	−	\minus	binary	minus sign
		\relbar	relation	
U+02213	∓	\mp	binary	minus-or-plus sign
U+02214	∔	\dotplus	binary	dot plus
U+02215	∕		ordinary	division slash
U+02216	∖	\setminus	binary	set minus
U+02217	∗	\adjointsymbol	prime	asterisk operator
		\ast	binary	
		\convolve	binary	

U+02218	∘	\circ	binary	ring operator
U+02219	∙		binary	bullet operator
U+0221A	√	\rootradical	root	square root
		\surd	ordinary	
		\surdradical	radical	
U+0221B	∛		ordinary	cube root
U+0221C	∜		ordinary	fourth root
U+0221D	∝	\propto	relation	proportional to
U+0221E	∞	\infty	ordinary	infinity
U+0221F	∟	\rightangle	ordinary	right angle
U+02220	∠	\angle	ordinary	angle
U+02221	∡	\measuredangle	ordinary	measured angle
U+02222	∢	\sphericalangle	ordinary	spherical angle
U+02223	∣	\divides	ordinary	divides
		\mid	relation	
U+02224	∤		relation	does not divide
		\ndivides	ordinary	
		\nmid	relation	
U+02225	∥		relation	parallel to
		\parallel	relation	
U+02226	∦	\nparallel	relation	not parallel to
U+02227	∧	\land	binary	logical and
		\wedge	binary	
U+02228	∨	\lor	binary	logical or
		\vee	binary	
U+02229	∩	\cap	binary	intersection
U+0222A	∪	\cup	binary	union
U+0222B	∫		integral	integral
		\int	integral	
		\intop	ordinary	
U+0222C	∬		integral	double integral
		\iint	integral	
		\iintop	ordinary	
U+0222D	∭		integral	triple integral
		\iiint	integral	
		\iiintop	ordinary	
U+0222E	∮	\oint	integral	contour integral
U+0222F	∯	\oiint	integral	surface integral
U+02230	∰	\oiiint	integral	volume integral
U+02231	∱	\intclockwise	integral	clockwise integral
U+02232	∲	\ointclockwise	integral	clockwise contour integral
U+02233	∳	\ointctrclockwise	integral	anticlockwise contour integral
U+02234	∴	\therefore	ellipsis	therefore
U+02235	∵	\because	ellipsis	because
U+02236	∶		punctuation	ratio
		\colon	punctuation	

		\maps	punctuation	
		\mapsas	punctuation	
U+02237	∷	\squaredots	relation	proportion
U+02238	∸	\dotminus	binary	dot minus
U+02239	∹	\minuscolon	relation	excess
U+0223A	∺		ordinary	geometric proportion
U+0223B	∻		ordinary	homothetic
U+0223C	∼	\sim	relation	tilde operator
U+0223D	∽	\backsim	relation	reversed tilde
U+0223E	∾		ordinary	inverted lazy s
U+0223F	∿		ordinary	sine wave
U+02240	≀	\wr	binary	wreath product
U+02241	≁	\nsim	relation	not tilde
U+02242	≂	\eqsim	relation	minus tilde
U+02243	≃	\simeq	relation	asymptotically equal to
U+02244	≄	\nsimeq	relation	not asymptotically equal to
U+02245	≅	\approxEq	relation	approximately equal to
		\cong	relation	
U+02246	≆	\napproxEq	relation	approximately but not actually equal to
		\ncong	relation	
U+02247	≇	\approxnEq	relation	neither approximately nor actually equal to
U+02248	≈	\approx	relation	almost equal to
U+02249	≉	\napprox	relation	not almost equal to
U+0224A	≊	\approxeq	relation	almost equal or equal to
U+0224B	≋		relation	triple tilde
U+0224C	≌		relation	all equal to
U+0224D	≍	\asymp	relation	equivalent to
U+0224E	≎	\Bumpeq	relation	geometrically equivalent to
U+0224F	≏		ordinary	difference between
U+02250	≐	\doteq	relation	approaches the limit
U+02251	≑	\Doteq	relation	geometrically equal to
		\doteqdot	relation	
U+02252	≒	\fallingdotseq	relation	approximately equal to or the image of
U+02253	≓	\risingdotseq	relation	image of or approximately equal to
U+02254	≔	\colonequals	relation	colon equals
U+02255	≕	\equalscolon	relation	equals colon
U+02256	≖	\eqcirc	relation	ring in equal to
U+02257	≗	\circeq	relation	ring equal to
U+02258	≘		ordinary	corresponds to
U+02259	≙	\wedgeeq	relation	estimates
U+0225A	≚	\veeeq	relation	equiangular to
U+0225B	≛	\stareq	relation	star equals

U+0225C	≜	\triangleq	relation	delta equal to
U+0225D	≝	\definedeq	relation	equal to by definition
U+0225E	≞	\measuredeq	relation	measured by
U+0225F	≟	\questionedeq	relation	questioned equal to
U+02260	≠	\ne	relation	not equal to
		\neq	relation	
U+02261	≡	\equiv	relation	identical to
U+02262	≢	\nequiv	relation	not identical to
U+02263	≣		relation	strictly equivalent to
U+02264	≤	\le	relation	less-than or equal to
		\leq	relation	
U+02265	≥	\ge	relation	greater-than or equal to
		\geq	relation	
U+02266	≦	\leqq	relation	less-than over equal to
U+02267	≧	\geqq	relation	greater-than over equal to
U+02268	≨	\lneqq	relation	less-than but not equal to
U+02269	≩	\gneqq	relation	greater-than but not equal to
U+0226A	≪	\ll	relation	much less-than
U+0226B	≫	\gg	relation	much greater-than
U+0226C	≬	\between	relation	between
U+0226D	≭	\nasymp	relation	not equivalent to
U+0226E	≮	\nless	relation	not less-than
U+0226F	≯	\ngtr	relation	not greater-than
U+02270	≰	\nleq	relation	neither less-than nor equal to
U+02271	≱	\ngeq	relation	neither greater-than nor equal to
U+02272	≲	\lesssim	relation	less-than or equivalent to
U+02273	≳	\gtrsim	relation	greater-than or equivalent to
U+02274	≴	\nlesssim	relation	neither less-than nor equivalent to
U+02275	≵	\ngtrsim	relation	neither greater-than nor equivalent to
U+02276	≶	\lessgtr	relation	less-than or greater-than
U+02277	≷	\gtrless	relation	greater-than or less-than
U+02278	≸	\nlessgtr	relation	neither less-than nor greater-than
U+02279	≹	\ngtrless	relation	neither greater-than nor less-than
U+0227A	≺	\prec	relation	precedes
U+0227B	≻	\succ	relation	succeeds
U+0227C	≼	\preccurlyeq	relation	precedes or equal to
U+0227D	≽	\succcurlyeq	relation	succeeds or equal to
U+0227E	≾	\precsim	relation	precedes or equivalent to
U+0227F	≿	\succsim	relation	succeeds or equivalent to

U+02280	⊀	\nprec	relation	does not precede
U+02281	⊁	\nsucc	relation	does not succeed
U+02282	⊂	\subset	relation	subset of
U+02283	⊃	\supset	relation	superset of
U+02284	⊄	\nsubset	relation	not a subset of
U+02285	⊅	\nsupset	relation	not a superset of
U+02286	⊆	\subseteq	relation	subset of or equal to
U+02287	⊇	\supseteq	relation	superset of or equal to
U+02288	⊈	\nsubseteq	relation	neither a subset of nor equal to
U+02289	⊉	\nsupseteq	relation	neither a superset of nor equal to
U+0228A	⊊	\subsetneq	relation	subset of with not equal to
U+0228B	⊋	\supsetneq	relation	superset of with not equal to
U+0228C	⊌		ordinary	multiset
U+0228D	⊍		ordinary	multiset multiplication
U+0228E	⊎	\uplus	binary	multiset union
U+0228F	⊏	\sqsubset	relation	square image of
U+02290	⊐	\sqsupset	relation	square original of
U+02291	⊑	\sqsubseteq	binary	square image of or equal to
U+02292	⊒	\sqsupseteq	binary	square original of or equal to
U+02293	⊓	\sqcap	binary	square cap
U+02294	⊔	\sqcup	binary	square cup
U+02295	⊕	\oplus	binary	circled plus
U+02296	⊖	\ominus	binary	circled minus
U+02297	⊗	\otimes	binary	circled times
U+02298	⊘	\oslash	binary	circled division slash
U+02299	⊙	\odot	binary	circled dot operator
U+0229A	⊚	\circledcirc	binary	circled ring operator
U+0229B	⊛	\circledast	binary	circled asterisk operator
U+0229C	⊜	\circledequals	binary	circled equals
U+0229D	⊝	\circleddash	binary	circled dash
U+0229E	⊞	\boxplus	binary	squared plus
U+0229F	⊟	\boxminus	binary	squared minus
U+022A0	⊠	\boxtimes	binary	squared times
U+022A1	⊡	\boxdot	binary	squared dot operator
U+022A2	⊢	\vdash	relation	right tack
U+022A3	⊣	\dashv	relation	left tack
U+022A4	⊤	\top	ordinary	down tack
U+022A5	⊥	\bot	ordinary	up tack
		\orthogonalcomplementsymbol	prime	
		\perp	relation	
U+022A6	⊦		ordinary	assertion
U+022A7	⊧	\models	relation	models

U+022A8	⊨	\vDash	relation	true
U+022A9	⊩	\Vdash	relation	forces
U+022AA	⊪	\Vvdash	relation	triple vertical bar right turnstile
U+022AB	⊫	\VDash	relation	double vertical bar double right turnstile
U+022AC	⊬	\nvdash	relation	does not prove
U+022AD	⊭	\nvDash	relation	not true
U+022AE	⊮	\nVdash	relation	does not force
U+022AF	⊯	\nVDash	relation	negated double vertical bar double right turnstile
U+022B0	⊰		ordinary	precedes under relation
U+022B1	⊱		ordinary	succeeds under relation
U+022B2	⊲		binary	normal subgroup of
U+022B3	⊳		binary	contains as normal subgroup
U+022B4	⊴		ordinary	normal subgroup of or equal to
U+022B5	⊵		ordinary	contains as normal subgroup or equal to
U+022B6	⊶		relation	original of
U+022B7	⊷		relation	image of
U+022B8	⊸	\multimap	relation	multimap
U+022B9	⊹		ordinary	hermitian conjugate matrix
U+022BA	⊺	\intercal	binary	intercalate
U+022BB	⊻	\veebar	binary	xor
U+022BC	⊼	\barwedge	binary	nand
U+022BD	⊽		ordinary	nor
U+022BE	⊾		ordinary	right angle with arc
U+022BF	⊿		ordinary	right triangle
U+022C0	⋀	\bigwedge	operator	n-ary logical and
U+022C1	⋁	\bigvee	operator	n-ary logical or
U+022C2	⋂	\bigcap	operator	n-ary intersection
U+022C3	⋃	\bigcup	operator	n-ary union
U+022C4	⋄	\diamond	binary	diamond operator
U+022C5	⋅		binary	dot operator
		\cdot	binary	
		\cdotp	punctuation	
		\scalarproduct	binary	
U+022C6	⋆	\star	binary	star operator
U+022C7	⋇	\divideontimes	binary	division times
U+022C8	⋈	\Join	relation	bowtie
		\bowtie	relation	
U+022C9	⋉	\ltimes	binary	left normal factor semidirect product
U+022CA	⋊	\rtimes	binary	right normal factor semidirect product

U+022CB	⋋	\leftthreetimes	binary	left semidirect product
U+022CC	⋌	\rightthreetimes	binary	right semidirect product
U+022CD	⋍		ordinary	reversed tilde equals
U+022CE	⋎	\curlyvee	binary	curly logical or
U+022CF	⋏	\curlywedge	binary	curly logical and
U+022D0	⋐	\Subset	relation	double subset
U+022D1	⋑	\Supset	relation	double superset
U+022D2	⋒	\Cap	binary	double intersection
		\doublecap	binary	
U+022D3	⋓	\Cup	binary	double union
		\doublecup	binary	
U+022D4	⋔	\pitchfork	relation	pitchfork
U+022D5	⋕		ordinary	equal and parallel to
U+022D6	⋖	\lessdot	binary	less-than with dot
U+022D7	⋗	\gtrdot	binary	greater-than with dot
U+022D8	⋘	\lll	relation	very much less-than
		\llless	relation	
U+022D9	⋙	\ggg	relation	very much greater-than
		\gggtr	relation	
U+022DA	⋚	\lesseqgtr	relation	less-than equal to or greater-than
U+022DB	⋛	\gtreqless	relation	greater-than equal to or less-than
U+022DC	⋜	\eqless	relation	equal to or less-than
U+022DD	⋝	\eqgtr	relation	equal to or greater-than
U+022DE	⋞	\curlyeqprec	relation	equal to or precedes
U+022DF	⋟	\curlyeqsucc	relation	equal to or succeeds
U+022E0	⋠	\npreccurlyeq	relation	does not precede or equal
U+022E1	⋡	\nsucccurlyeq	relation	does not succeed or equal
U+022E2	⋢	\nsqsubseteq	relation	not square image of or equal to
U+022E3	⋣	\nsqsupseteq	relation	not square original of or equal to
U+022E4	⋤	\sqsubsetneq	relation	square image of or not equal to
U+022E5	⋥	\sqsupsetneq	relation	square original of or not equal to
U+022E6	⋦	\lnsim	relation	less-than but not equivalent to
U+022E7	⋧	\gnsim	relation	greater-than but not equivalent to
U+022E8	⋨	\precnsim	relation	precedes but not equivalent to
U+022E9	⋩	\succnsim	relation	succeeds but not equivalent to
U+022EA	⋪	\ntriangleright	relation	not normal subgroup of
U+022EB	⋫	\ntriangleleft	relation	does not contain as normal subgroup

U+022EC	⋬	\ntrianglelefteq	relation	not normal subgroup of or equal to
U+022ED	⋭	\ntrianglerighteq	relation	does not contain as normal subgroup or equal
U+022EE	⋮	\vdots	ellipsis	vertical ellipsis
U+022EF	⋯	\cdots	ellipsis	midline horizontal ellipsis
U+022F0	⋰	\udots	ellipsis	up right diagonal ellipsis
U+022F1	⋱	\ddots	ellipsis	down right diagonal ellipsis
U+022F2	⋲		ordinary	element of with long horizontal stroke
U+022F3	⋳		ordinary	element of with vertical bar at end of horizontal stroke
U+022F4	⋴		ordinary	small element of with vertical bar at end of horizontal stroke
U+022F5	⋵		ordinary	element of with dot above
U+022F6	⋶		ordinary	element of with overbar
U+022F7	⋷		ordinary	small element of with overbar
U+022F8	⋸		ordinary	element of with underbar
U+022F9	⋹		ordinary	element of with two horizontal strokes
U+022FA	⋺		ordinary	contains with long horizontal stroke
U+022FB	⋻		ordinary	contains with vertical bar at end of horizontal stroke
U+022FC	⋼		ordinary	small contains with vertical bar at end of horizontal stroke
U+022FD	⋽		ordinary	contains with overbar
U+022FE	⋾		ordinary	small contains with overbar
U+022FF	⋿		ordinary	z notation bag membership

12.5 Miscellaneous Mathematical Symbols-A

U+027C0	⟀	ordinary	three dimensional angle
U+027C1	⟁	ordinary	white triangle containing small white triangle
U+027C2	⟂	ordinary	perpendicular
U+027C3	⟃	ordinary	open subset
U+027C4	⟄	ordinary	open superset
U+027C5	⟅	ordinary	left s-shaped bag delimiter
U+027C6	⟆	ordinary	right s-shaped bag delimiter

U+027C7	⟇		ordinary	or with dot inside
U+027C8	⟈		ordinary	reverse solidus preceding subset
U+027C9	⟉		ordinary	superset preceding solidus
U+027CB	⟋		ordinary	mathematical rising diagonal
U+027CC	⟌		ordinary	long division
U+027CD	⟍		ordinary	mathematical falling diagonal
U+027D0	⟐		ordinary	white diamond with centred dot
U+027D1	⟑		ordinary	and with dot
U+027D2	⟒		ordinary	element of opening upwards
U+027D3	⟓		ordinary	lower right corner with dot
U+027D4	⟔		ordinary	upper left corner with dot
U+027D5	⟕		ordinary	left outer join
U+027D6	⟖		ordinary	right outer join
U+027D7	⟗		ordinary	full outer join
U+027D8	⟘		ordinary	large up tack
U+027D9	⟙		ordinary	large down tack
U+027DA	⟚		ordinary	left and right double turnstile
U+027DB	⟛		ordinary	left and right tack
U+027DC	⟜		ordinary	left multimap
U+027DD	⟝		ordinary	long right tack
U+027DE	⟞		ordinary	long left tack
U+027DF	⟟		ordinary	up tack with circle above
U+027E0	⟠		ordinary	lozenge divided by horizontal rule
U+027E1	⟡		ordinary	white concave-sided diamond
U+027E2	⟢		ordinary	white concave-sided diamond with leftwards tick
U+027E3	⟣		ordinary	white concave-sided diamond with rightwards tick
U+027E4	⟤		ordinary	white square with leftwards tick
U+027E5	⟥		ordinary	white square with rightwards tick
U+027E6	⟦	\llbracket	open	mathematical left white square bracket
U+027E7	⟧	\rrbracket	close	mathematical right white square bracket
U+027E8	⟨	\langle	open	mathematical left angle bracket
U+027E9	⟩	\rangle	close	mathematical right angle bracket
U+027EA	⟪	\llangle	open	mathematical left double angle bracket
U+027EB	⟫	\rrangle	close	mathematical right double angle bracket
U+027EC	⟬		ordinary	mathematical left white tortoise shell bracket
U+027ED	⟭		ordinary	mathematical right white tortoise shell bracket
U+027EE	⟮	\lgroup	open	mathematical left flattened parenthesis
U+027EF	⟯	\rgroup	close	mathematical right flattened parenthesis

12.6 Miscellaneous Mathematical Symbols-B

U+02980	⦀	\tripleverticalbar	delimiter	triple vertical bar delimiter
U+02981	⦁		ordinary	z notation spot
U+02982	⦂		ordinary	z notation type colon
U+02983	⦃		ordinary	left white curly bracket
U+02984	⦄		ordinary	right white curly bracket
U+02985	⦅		ordinary	left white parenthesis
U+02986	⦆		ordinary	right white parenthesis

U+02987	⦇		ordinary	z notation left image bracket
U+02988	⦈		ordinary	z notation right image bracket
U+02989	⦉		ordinary	z notation left binding bracket
U+0298A	⦊		ordinary	z notation right binding bracket
U+0298B	⦋		ordinary	left square bracket with underbar
U+0298C	⦌		ordinary	right square bracket with underbar
U+0298D	⦍		ordinary	left square bracket with tick in top corner
U+0298E	⦎		ordinary	right square bracket with tick in bottom corner
U+0298F	⦏		ordinary	left square bracket with tick in bottom corner
U+02990	⦐		ordinary	right square bracket with tick in top corner
U+02991	⦑		ordinary	left angle bracket with dot
U+02992	⦒		ordinary	right angle bracket with dot
U+02993	⦓		ordinary	left arc less-than bracket
U+02994	⦔		ordinary	right arc greater-than bracket
U+02995	⦕		ordinary	double left arc greater-than bracket
U+02996	⦖		ordinary	double right arc less-than bracket
U+02997	⦗	\linterval	open	left black tortoise shell bracket
		\llointerval	open	
		\rlointerval	close	
		\rointerval	close	
U+02998	⦘	\lointerval	open	right black tortoise shell bracket
		\lrointerval	open	
		\rinterval	close	
		\rrointerval	close	
U+02999	⦙		ordinary	dotted fence
U+0299A	⦚		ordinary	vertical zigzag line
U+0299B	⦛		ordinary	measured angle opening left
U+0299C	⦜		ordinary	right angle variant with square
U+0299D	⦝		ordinary	measured right angle with dot
U+0299E	⦞		ordinary	angle with s inside
U+0299F	⦟		ordinary	acute angle
U+029A0	⦠		ordinary	spherical angle opening left
U+029A1	⦡		ordinary	spherical angle opening up
U+029A2	⦢		ordinary	turned angle
U+029A3	⦣		ordinary	reversed angle
U+029A4	⦤		ordinary	angle with underbar
U+029A5	⦥		ordinary	reversed angle with underbar
U+029A6	⦦		ordinary	oblique angle opening up
U+029A7	⦧		ordinary	oblique angle opening down
U+029A8	⦨		ordinary	measured angle with open arm ending in arrow pointing up and right
U+029A9	⦩		ordinary	measured angle with open arm ending in arrow pointing up and left
U+029AA	⦪		ordinary	measured angle with open arm ending

			in arrow pointing down and right
U+029AB	⦫	ordinary	measured angle with open arm ending in arrow pointing down and left
U+029AC	⦬	ordinary	measured angle with open arm ending in arrow pointing right and up
U+029AD	⦭	ordinary	measured angle with open arm ending in arrow pointing left and up
U+029AE	⦮	ordinary	measured angle with open arm ending in arrow pointing right and down
U+029AF	⦯	ordinary	measured angle with open arm ending in arrow pointing left and down
U+029B0	⦰	ordinary	reversed empty set
U+029B1	⦱	ordinary	empty set with overbar
U+029B2	⦲	ordinary	empty set with small circle above
U+029B3	⦳	ordinary	empty set with right arrow above
U+029B4	⦴	ordinary	empty set with left arrow above
U+029B5	⦵	ordinary	circle with horizontal bar
U+029B6	⦶	ordinary	circled vertical bar
U+029B7	⦷	ordinary	circled parallel
U+029B8	⦸	ordinary	circled reverse solidus
U+029B9	⦹	ordinary	circled perpendicular
U+029BA	⦺	ordinary	circle divided by horizontal bar and top half divided by vertical bar
U+029BB	⦻	ordinary	circle with superimposed x
U+029BC	⦼	ordinary	circled anticlockwise-rotated division sign
U+029BD	⦽	ordinary	up arrow through circle
U+029BE	⦾	ordinary	circled white bullet
U+029BF	⦿	ordinary	circled bullet
U+029C0	⧀	ordinary	circled less-than
U+029C1	⧁	ordinary	circled greater-than
U+029C2	⧂	ordinary	circle with small circle to the right
U+029C3	⧃	ordinary	circle with two horizontal strokes to the right
U+029C4	⧄	ordinary	squared rising diagonal slash
U+029C5	⧅	ordinary	squared falling diagonal slash
U+029C6	⧆	ordinary	squared asterisk
U+029C7	⧇	ordinary	squared small circle
U+029C8	⧈	ordinary	squared square
U+029C9	⧉	ordinary	two joined squares
U+029CA	⧊	ordinary	triangle with dot above
U+029CB	⧋	ordinary	triangle with underbar
U+029CC	⧌	ordinary	s in triangle
U+029CD	⧍	ordinary	triangle with serifs at bottom
U+029CE	⧎	ordinary	right triangle above left triangle
U+029CF	⧏	ordinary	left triangle beside vertical bar
U+029D0	⧐	ordinary	vertical bar beside right triangle
U+029D1	⧑	ordinary	bowtie with left half black

U+029D2	⧒	ordinary	bowtie with right half black
U+029D3	⧓	ordinary	black bowtie
U+029D4	⧔	ordinary	times with left half black
U+029D5	⧕	ordinary	times with right half black
U+029D6	⧖	ordinary	white hourglass
U+029D7	⧗	ordinary	black hourglass
U+029D8	⧘	ordinary	left wiggly fence
U+029D9	⧙	ordinary	right wiggly fence
U+029DA	⧚	ordinary	left double wiggly fence
U+029DB	⧛	ordinary	right double wiggly fence
U+029DC	⧜	ordinary	incomplete infinity
U+029DD	⧝	ordinary	tie over infinity
U+029DE	⧞	ordinary	infinity negated with vertical bar
U+029DF	⧟	ordinary	double-ended multimap
U+029E0	⧠	ordinary	square with contoured outline
U+029E1	⧡	ordinary	increases as
U+029E2	⧢	ordinary	shuffle product
U+029E3	⧣	ordinary	equals sign and slanted parallel
U+029E4	⧤	ordinary	equals sign and slanted parallel with tilde above
U+029E5	⧥	ordinary	identical to and slanted parallel
U+029E6	⧦	ordinary	gleich stark
U+029E7	⧧	ordinary	thermodynamic
U+029E8	⧨	ordinary	down-pointing triangle with left half black
U+029E9	⧩	ordinary	down-pointing triangle with right half black
U+029EA	⧪	ordinary	black diamond with down arrow
U+029EB	⧫	ordinary	black lozenge
U+029EC	⧬	ordinary	white circle with down arrow
U+029ED	⧭	ordinary	black circle with down arrow
U+029EE	⧮	ordinary	error-barred white square
U+029EF	⧯	ordinary	error-barred black square
U+029F0	⧰	ordinary	error-barred white diamond
U+029F1	⧱	ordinary	error-barred black diamond
U+029F2	⧲	ordinary	error-barred white circle
U+029F3	⧳	ordinary	error-barred black circle
U+029F4	⧴	ordinary	rule-delayed
U+029F5	⧵	ordinary	reverse solidus operator
U+029F6	⧶	ordinary	solidus with overbar
U+029F7	⧷	ordinary	reverse solidus with horizontal stroke
U+029F8	⧸	ordinary	big solidus
U+029F9	⧹	ordinary	big reverse solidus
U+029FA	⧺	ordinary	double plus
U+029FB	⧻	ordinary	triple plus
U+029FC	⧼	ordinary	left-pointing curved angle bracket
U+029FD	⧽	ordinary	right-pointing curved angle bracket

U+029FE	⧾		ordinary	tiny
U+029FF	⧿		ordinary	miny

12.7 Supplemental Mathematical Operators

U+02A00	⨀	\bigodot	operator	n-ary circled dot operator
U+02A01	⨁	\bigoplus	operator	n-ary circled plus operator
U+02A02	⨂	\bigotimes	operator	n-ary circled times operator
U+02A03	⨃	\bigudot	operator	n-ary union operator with dot
U+02A04	⨄	\biguplus	operator	n-ary union operator with plus
U+02A05	⨅	\bigsqcap	operator	n-ary square intersection operator
U+02A06	⨆	\bigsqcup	operator	n-ary square union operator
U+02A07	⨇		ordinary	two logical and operator
U+02A08	⨈		ordinary	two logical or operator
U+02A09	⨉	\bigtimes	operator	n-ary times operator
U+02A0A	⨊		ordinary	modulo two sum
U+02A0B	⨋		ordinary	summation with integral
U+02A0C	⨌		integral	quadruple integral operator
		\iiiint	integral	
		\iiiintop	ordinary	
U+02A0D	⨍		ordinary	finite part integral
U+02A0E	⨎		ordinary	integral with double stroke
U+02A0F	⨏		ordinary	integral average with slash
U+02A10	⨐		ordinary	circulation function
U+02A11	⨑		ordinary	anticlockwise integration
U+02A12	⨒		ordinary	line integration with rectangular path around pole
U+02A13	⨓		ordinary	line integration with semicircular path around pole
U+02A14	⨔		ordinary	line integration not including the pole
U+02A15	⨕		ordinary	integral around a point operator
U+02A16	⨖		ordinary	quaternion integral operator
U+02A17	⨗		ordinary	integral with leftwards arrow with hook
U+02A18	⨘		ordinary	integral with times sign
U+02A19	⨙		ordinary	integral with intersection
U+02A1A	⨚		ordinary	integral with union
U+02A1B	⨛		ordinary	integral with overbar
U+02A1C	⨜		ordinary	integral with underbar
U+02A1D	⨝		ordinary	join
U+02A1E	⨞		ordinary	large left triangle operator
U+02A1F	⨟		ordinary	z notation schema composition
U+02A20	⨠		ordinary	z notation schema piping
U+02A21	⨡		ordinary	z notation schema projection
U+02A22	⨢		ordinary	plus sign with small circle above
U+02A23	⨣		ordinary	plus sign with circumflex accent above
U+02A24	⨤		ordinary	plus sign with tilde above
U+02A25	⨥		ordinary	plus sign with dot below
U+02A26	⨦		ordinary	plus sign with tilde below

U+02A27	⨧		ordinary	plus sign with subscript two
U+02A28	⨨		ordinary	plus sign with black triangle
U+02A29	⨩		ordinary	minus sign with comma above
U+02A2A	⨪		ordinary	minus sign with dot below
U+02A2B	⨫		ordinary	minus sign with falling dots
U+02A2C	⨬		ordinary	minus sign with rising dots
U+02A2D	⨭		ordinary	plus sign in left half circle
U+02A2E	⨮		ordinary	plus sign in right half circle
U+02A2F	⨯		ordinary	vector or cross product
U+02A30	⨰		ordinary	multiplication sign with dot above
U+02A31	⨱		ordinary	multiplication sign with underbar
U+02A32	⨲		ordinary	semidirect product with bottom closed
U+02A33	⨳		ordinary	smash product
U+02A34	⨴		ordinary	multiplication sign in left half circle
U+02A35	⨵		ordinary	multiplication sign in right half circle
U+02A36	⨶		ordinary	circled multiplication sign with circumflex accent
U+02A37	⨷		ordinary	multiplication sign in double circle
U+02A38	⨸		ordinary	circled division sign
U+02A39	⨹		ordinary	plus sign in triangle
U+02A3A	⨺		ordinary	minus sign in triangle
U+02A3B	⨻		ordinary	multiplication sign in triangle
U+02A3C	⨼		ordinary	interior product
U+02A3D	⨽		ordinary	righthand interior product
U+02A3E	⨾		ordinary	z notation relational composition
U+02A3F	⨿	\amalg	binary	amalgamation or coproduct
U+02A40	⩀		ordinary	intersection with dot
U+02A41	⩁		ordinary	union with minus sign
U+02A42	⩂		ordinary	union with overbar
U+02A43	⩃		ordinary	intersection with overbar
U+02A44	⩄		ordinary	intersection with logical and
U+02A45	⩅		ordinary	union with logical or
U+02A46	⩆		ordinary	union above intersection
U+02A47	⩇		ordinary	intersection above union
U+02A48	⩈		ordinary	union above bar above intersection
U+02A49	⩉		ordinary	intersection above bar above union
U+02A4A	⩊		ordinary	union beside and joined with union
U+02A4B	⩋		ordinary	intersection beside and joined with intersection
U+02A4C	⩌		ordinary	closed union with serifs
U+02A4D	⩍		ordinary	closed intersection with serifs
U+02A4E	⩎		ordinary	double square intersection
U+02A4F	⩏		ordinary	double square union
U+02A50	⩐		ordinary	closed union with serifs and smash product
U+02A51	⩑		ordinary	logical and with dot above
U+02A52	⩒		ordinary	logical or with dot above
U+02A53	⩓		ordinary	double logical and

U+02A54	⩔		ordinary	double logical or
U+02A55	⩕		ordinary	two intersecting logical and
U+02A56	⩖		ordinary	two intersecting logical or
U+02A57	⩗		ordinary	sloping large or
U+02A58	⩘		ordinary	sloping large and
U+02A59	⩙		ordinary	logical or overlapping logical and
U+02A5A	⩚		ordinary	logical and with middle stem
U+02A5B	⩛		ordinary	logical or with middle stem
U+02A5C	⩜		ordinary	logical and with horizontal dash
U+02A5D	⩝		ordinary	logical or with horizontal dash
U+02A5E	⩞		ordinary	logical and with double overbar
U+02A5F	⩟		ordinary	logical and with underbar
U+02A60	⩠		ordinary	logical and with double underbar
U+02A61	⩡		ordinary	small vee with underbar
U+02A62	⩢		ordinary	logical or with double overbar
U+02A63	⩣		ordinary	logical or with double underbar
U+02A64	⩤		ordinary	z notation domain antirestriction
U+02A65	⩥		ordinary	z notation range antirestriction
U+02A66	⩦		ordinary	equals sign with dot below
U+02A67	⩧		ordinary	identical with dot above
U+02A68	⩨		ordinary	triple horizontal bar with double vertical stroke
U+02A69	⩩		ordinary	triple horizontal bar with triple vertical stroke
U+02A6A	⩪		ordinary	tilde operator with dot above
U+02A6B	⩫		ordinary	tilde operator with rising dots
U+02A6C	⩬		ordinary	similar minus similar
U+02A6D	⩭		ordinary	congruent with dot above
U+02A6E	⩮		ordinary	equals with asterisk
U+02A6F	⩯		ordinary	almost equal to with circumflex accent
U+02A70	⩰		ordinary	approximately equal or equal to
U+02A71	⩱		ordinary	equals sign above plus sign
U+02A72	⩲		ordinary	plus sign above equals sign
U+02A73	⩳		ordinary	equals sign above tilde operator
U+02A74	⩴	\coloncolonequals	relation	double colon equal
U+02A75	⩵	\eqeq	relation	two consecutive equals signs
U+02A76	⩶	\eqeqeq	relation	three consecutive equals signs
U+02A77	⩷		ordinary	equals sign with two dots above and two dots below
U+02A78	⩸		ordinary	equivalent with four dots above
U+02A79	⩹		ordinary	less-than with circle inside
U+02A7A	⩺		ordinary	greater-than with circle inside
U+02A7B	⩻		ordinary	less-than with question mark above
U+02A7C	⩼		ordinary	greater-than with question mark above
U+02A7D	⩽	\leqslant	relation	less-than or slanted equal to
U+02A7E	⩾	\geqslant	relation	greater-than or slanted equal to
U+02A7F	⩿		ordinary	less-than or slanted equal to with dot inside

U+02A80	⪀		ordinary	greater-than or slanted equal to with dot inside
U+02A81	⪁		ordinary	less-than or slanted equal to with dot above
U+02A82	⪂		ordinary	greater-than or slanted equal to with dot above
U+02A83	⪃		ordinary	less-than or slanted equal to with dot above right
U+02A84	⪄		ordinary	greater-than or slanted equal to with dot above left
U+02A85	⪅	\lessapprox	relation	less-than or approximate
U+02A86	⪆	\gtrapprox	relation	greater-than or approximate
U+02A87	⪇	\lneq	relation	less-than and single-line not equal to
U+02A88	⪈	\rneq	relation	greater-than and single-line not equal to
U+02A89	⪉	\lnapprox	relation	less-than and not approximate
U+02A8A	⪊	\gnapprox	relation	greater-than and not approximate
U+02A8B	⪋	\lesseqqgtr	relation	less-than above double-line equal above greater-than
U+02A8C	⪌	\gtreqqless	relation	greater-than above double-line equal above less-than
U+02A8D	⪍		ordinary	less-than above similar or equal
U+02A8E	⪎		ordinary	greater-than above similar or equal
U+02A8F	⪏		ordinary	less-than above similar above greater-than
U+02A90	⪐		ordinary	greater-than above similar above less-than
U+02A91	⪑		ordinary	less-than above greater-than above double-line equal
U+02A92	⪒		ordinary	greater-than above less-than above double-line equal
U+02A93	⪓		ordinary	less-than above slanted equal above greater-than above slanted equal
U+02A94	⪔		ordinary	greater-than above slanted equal above less-than above slanted equal
U+02A95	⪕	\eqslantless	relation	slanted equal to or less-than
U+02A96	⪖	\eqslantgtr	relation	slanted equal to or greater-than
U+02A97	⪗		ordinary	slanted equal to or less-than with dot inside
U+02A98	⪘		ordinary	slanted equal to or greater-than with dot inside
U+02A99	⪙		ordinary	double-line equal to or less-than
U+02A9A	⪚		ordinary	double-line equal to or greater-than
U+02A9B	⪛		ordinary	double-line slanted equal to or less-than
U+02A9C	⪜		ordinary	double-line slanted equal to or greater-than
U+02A9D	⪝		ordinary	similar or less-than
U+02A9E	⪞		ordinary	similar or greater-than
U+02A9F	⪟		ordinary	similar above less-than above equals

				sign
U+02AA0	⪠		ordinary	similar above greater-than above equals sign
U+02AA1	⪡		ordinary	double nested less-than
U+02AA2	⪢		ordinary	double nested greater-than
U+02AA3	⪣		ordinary	double nested less-than with underbar
U+02AA4	⪤		ordinary	greater-than overlapping less-than
U+02AA5	⪥		ordinary	greater-than beside less-than
U+02AA6	⪦		ordinary	less-than closed by curve
U+02AA7	⪧		ordinary	greater-than closed by curve
U+02AA8	⪨		ordinary	less-than closed by curve above slanted equal
U+02AA9	⪩		ordinary	greater-than closed by curve above slanted equal
U+02AAA	⪪		ordinary	smaller than
U+02AAB	⪫		ordinary	larger than
U+02AAC	⪬		ordinary	smaller than or equal to
U+02AAD	⪭		ordinary	larger than or equal to
U+02AAE	⪮		ordinary	equals sign with bumpy above
U+02AAF	⪯	\preceq	relation	precedes above single-line equals sign
U+02AB0	⪰	\succeq	relation	succeeds above single-line equals sign
U+02AB1	⪱	\precneq	relation	precedes above single-line not equal to
U+02AB2	⪲	\succneq	relation	succeeds above single-line not equal to
U+02AB3	⪳	\preceqq	relation	precedes above equals sign
U+02AB4	⪴	\succeqq	relation	succeeds above equals sign
U+02AB5	⪵	\precneqq	relation	precedes above not equal to
U+02AB6	⪶	\succneqq	relation	succeeds above not equal to
U+02AB7	⪷	\precapprox	relation	precedes above almost equal to
U+02AB8	⪸	\succapprox	relation	succeeds above almost equal to
U+02AB9	⪹	\precnapprox	relation	precedes above not almost equal to
U+02ABA	⪺	\succnapprox	relation	succeeds above not almost equal to
U+02ABB	⪻		ordinary	double precedes
U+02ABC	⪼		ordinary	double succeeds
U+02ABD	⪽		ordinary	subset with dot
U+02ABE	⪾		ordinary	superset with dot
U+02ABF	⪿		ordinary	subset with plus sign below
U+02AC0	⫀		ordinary	superset with plus sign below
U+02AC1	⫁		ordinary	subset with multiplication sign below
U+02AC2	⫂		ordinary	superset with multiplication sign below
U+02AC3	⫃		ordinary	subset of or equal to with dot above
U+02AC4	⫄		ordinary	superset of or equal to with dot above
U+02AC5	⫅	\subseteqq	relation	subset of above equals sign
U+02AC6	⫆	\supseteqq	relation	superset of above equals sign
U+02AC7	⫇		ordinary	subset of above tilde operator
U+02AC8	⫈		ordinary	superset of above tilde operator
U+02AC9	⫉		ordinary	subset of above almost equal to
U+02ACA	⫊		ordinary	superset of above almost equal to
U+02ACB	⫋	\subsetneqq	relation	subset of above not equal to

U+02ACC	⫌	\supsetneqq	relation	superset of above not equal to
U+02ACD	⫍		ordinary	square left open box operator
U+02ACE	⫎		ordinary	square right open box operator
U+02ACF	⫏		ordinary	closed subset
U+02AD0	⫐		ordinary	closed superset
U+02AD1	⫑		ordinary	closed subset or equal to
U+02AD2	⫒		ordinary	closed superset or equal to
U+02AD3	⫓		ordinary	subset above superset
U+02AD4	⫔		ordinary	superset above subset
U+02AD5	⫕		ordinary	subset above subset
U+02AD6	⫖		ordinary	superset above superset
U+02AD7	⫗		ordinary	superset beside subset
U+02AD8	⫘		ordinary	superset beside and joined by dash with subset
U+02AD9	⫙		ordinary	element of opening downwards
U+02ADA	⫚		ordinary	pitchfork with tee top
U+02ADB	⫛		ordinary	transversal intersection
U+02ADC	⫝̸		ordinary	forking
U+02ADD	⫝		ordinary	nonforking
U+02ADE	⫞		ordinary	short left tack
U+02ADF	⫟		ordinary	short down tack
U+02AE0	⫠		ordinary	short up tack
U+02AE1	⫡		ordinary	perpendicular with s
U+02AE2	⫢		ordinary	vertical bar triple right turnstile
U+02AE3	⫣		ordinary	double vertical bar left turnstile
U+02AE4	⫤		ordinary	vertical bar double left turnstile
U+02AE5	⫥		ordinary	double vertical bar double left turnstile
U+02AE6	⫦		ordinary	long dash from left member of double vertical
U+02AE7	⫧		ordinary	short down tack with overbar
U+02AE8	⫨		ordinary	short up tack with underbar
U+02AE9	⫩		ordinary	short up tack above short down tack
U+02AEA	⫪		ordinary	double down tack
U+02AEB	⫫		ordinary	double up tack
U+02AEC	⫬		ordinary	double stroke not sign
U+02AED	⫭		ordinary	reversed double stroke not sign
U+02AEE	⫮		ordinary	does not divide with reversed negation slash
U+02AEF	⫯		ordinary	vertical line with circle above
U+02AF0	⫰		ordinary	vertical line with circle below
U+02AF1	⫱		ordinary	down tack with circle below
U+02AF2	⫲		ordinary	parallel with horizontal stroke
U+02AF3	⫳		ordinary	parallel with tilde operator
U+02AF4	⫴		ordinary	triple vertical bar binary relation
U+02AF5	⫵		ordinary	triple vertical bar with horizontal stroke
U+02AF6	⫶		ordinary	triple colon operator
U+02AF7	⫷		ordinary	triple nested less-than
U+02AF8	⫸		ordinary	triple nested greater-than

U+02AF9	⫹	ordinary	double-line slanted less-than or equal to
U+02AFA	⫺	ordinary	double-line slanted greater-than or equal to
U+02AFB	⫻	ordinary	triple solidus binary relation
U+02AFC	⫼	ordinary	large triple vertical bar operator
U+02AFD	⫽	ordinary	double solidus operator
U+02AFE	⫾	ordinary	white vertical bar
U+02AFF	⫿	ordinary	n-ary white vertical bar

12.8 Miscellaneous Symbols and Arrows

U+02B12	⬒	ordinary	square with top half black
U+02B13	⬓	ordinary	square with bottom half black
U+02B14	⬔	ordinary	square with upper right diagonal half black
U+02B15	⬕	ordinary	square with lower left diagonal half black
U+02B16	⬖	ordinary	diamond with left half black
U+02B17	⬗	ordinary	diamond with right half black
U+02B18	⬘	ordinary	diamond with top half black
U+02B19	⬙	ordinary	diamond with bottom half black
U+02B1A	⬚	ordinary	dotted square
U+02B1B	⬛	ordinary	black large square
U+02B1C	⬜	ordinary	white large square
U+02B1D	⬝	ordinary	black very small square
U+02B1E	⬞	ordinary	white very small square
U+02B1F	⬟	ordinary	black pentagon
U+02B20	⬠	ordinary	white pentagon
U+02B21	⬡	ordinary	white hexagon
U+02B22	⬢	ordinary	black hexagon
U+02B23	⬣	ordinary	horizontal black hexagon
U+02B24	⬤	ordinary	black large circle
U+02B25	⬥	ordinary	black medium diamond
U+02B26	⬦	ordinary	white medium diamond
U+02B27	⬧	ordinary	black medium lozenge
U+02B28	⬨	ordinary	white medium lozenge
U+02B29	⬩	ordinary	black small diamond
U+02B2A	⬪	ordinary	black small lozenge
U+02B2B	⬫	ordinary	white small lozenge
U+02B2C	⬬	ordinary	black horizontal ellipse
U+02B2D	⬭	ordinary	white horizontal ellipse
U+02B2E	⬮	ordinary	black vertical ellipse
U+02B2F	⬯	ordinary	white vertical ellipse
U+02B30	⬰	ordinary	left arrow with small circle
U+02B31	⬱	ordinary	three leftwards arrows
U+02B32	⬲	ordinary	left arrow with circled plus
U+02B33	⬳	ordinary	long leftwards squiggle arrow
U+02B34	⬴	ordinary	leftwards two-headed arrow with vertical stroke
U+02B35	⬵	ordinary	leftwards two-headed arrow with double vertical stroke
U+02B36	⬶	ordinary	leftwards two-headed arrow from bar
U+02B37	⬷	ordinary	leftwards two-headed triple dash arrow

U+02B38	⬸	ordinary	leftwards arrow with dotted stem
U+02B39	⬹	ordinary	leftwards arrow with tail with vertical stroke
U+02B3A	⬺	ordinary	leftwards arrow with tail with double vertical stroke
U+02B3B	⬻	ordinary	leftwards two-headed arrow with tail
U+02B3C	⬼	ordinary	leftwards two-headed arrow with tail with vertical stroke
U+02B3D	⬽	ordinary	leftwards two-headed arrow with tail with double vertical stroke
U+02B3E	⬾	ordinary	leftwards arrow through x
U+02B3F	⬿	ordinary	wave arrow pointing directly left
U+02B40	⭀	ordinary	equals sign above leftwards arrow
U+02B41	⭁	ordinary	reverse tilde operator above leftwards arrow
U+02B42	⭂	ordinary	leftwards arrow above reverse almost equal to
U+02B43	⭃	ordinary	rightwards arrow through greater-than
U+02B44	⭄	ordinary	rightwards arrow through superset
U+02B45	⭅	ordinary	leftwards quadruple arrow
U+02B46	⭆	ordinary	rightwards quadruple arrow
U+02B47	⭇	ordinary	reverse tilde operator above rightwards arrow
U+02B48	⭈	ordinary	rightwards arrow above reverse almost equal to
U+02B49	⭉	ordinary	tilde operator above leftwards arrow
U+02B4A	⭊	ordinary	leftwards arrow above almost equal to
U+02B4B	⭋	ordinary	leftwards arrow above reverse tilde operator
U+02B4C	⭌	ordinary	rightwards arrow above reverse tilde operator
U+02B50	⭐	ordinary	white medium star
U+02B51	⭑	ordinary	black small star
U+02B52	⭒	ordinary	white small star
U+02B53	⭓	ordinary	black right-pointing pentagon
U+02B54	⭔	ordinary	white right-pointing pentagon

12.9 Supplemental Arrows-A

U+027F0	⟰		ordinary	upwards quadruple arrow
U+027F1	⟱		ordinary	downwards quadruple arrow
U+027F2	⟲		ordinary	anticlockwise gapped circle arrow
U+027F3	⟳		ordinary	clockwise gapped circle arrow
U+027F4	⟴		ordinary	right arrow with circled plus
U+027F5	⟵	\longleftarrow	relation	long leftwards arrow
U+027F6	⟶	\longrightarrow	relation	long rightwards arrow
U+027F7	⟷	\longleftrightarrow	relation	long left right arrow
U+027F8	⟸	\Longleftarrow	relation	long leftwards double arrow
U+027F9	⟹	\Longrightarrow	relation	long rightwards double arrow
U+027FA	⟺	\Longleftrightarrow	relation	long left right double arrow
U+027FB	⟻	\longmapsfrom	relation	long leftwards arrow from bar
U+027FC	⟼	\longmapsto	relation	long rightwards arrow from bar
U+027FD	⟽	\Longmapsfrom	relation	long leftwards double arrow from bar
U+027FE	⟾	\Longmapsto	relation	long rightwards double arrow from bar
U+027FF	⟿	\longrightsquigarrow	relation	long rightwards squiggle arrow

12.10 Supplemental Arrows-B

U+02900	⤀		ordinary	rightwards two-headed arrow with vertical stroke
U+02901	⤁		ordinary	rightwards two-headed arrow with double vertical stroke
U+02902	⤂		ordinary	leftwards double arrow with vertical stroke
U+02903	⤃		ordinary	rightwards double arrow with vertical stroke
U+02904	⤄		ordinary	left right double arrow with vertical stroke
U+02905	⤅		ordinary	rightwards two-headed arrow from bar
U+02906	⤆	\Mapsfrom	relation	leftwards double arrow from bar
U+02907	⤇	\Mapsto	relation	rightwards double arrow from bar
U+02908	⤈		ordinary	downwards arrow with horizontal stroke
U+02909	⤉		ordinary	upwards arrow with horizontal stroke
U+0290A	⤊	\Uuparrow	relation	upwards triple arrow
U+0290B	⤋	\Ddownarrow	relation	downwards triple arrow
U+0290C	⤌	\dashedleftarrow	relation	leftwards double dash arrow
U+0290D	⤍	\dashedrightarrow	relation	rightwards double dash arrow
U+0290E	⤎		ordinary	leftwards triple dash arrow
U+0290F	⤏		ordinary	rightwards triple dash arrow
U+02910	⤐		ordinary	rightwards two-headed triple dash arrow
U+02911	⤑	\dottedrightarrow	relation	rightwards arrow with dotted stem
U+02912	⤒		ordinary	upwards arrow to bar
U+02913	⤓		ordinary	downwards arrow to bar
U+02914	⤔		ordinary	rightwards arrow with tail with vertical stroke
U+02915	⤕		ordinary	rightwards arrow with tail with double vertical stroke
U+02916	⤖	\twoheadrightarrowtail	relation	rightwards two-headed arrow with tail
U+02917	⤗		relation	rightwards two-headed arrow with tail with vertical stroke
U+02918	⤘		ordinary	rightwards two-headed arrow with tail with double vertical stroke
U+02919	⤙		ordinary	leftwards arrow-tail
U+0291A	⤚		ordinary	rightwards arrow-tail
U+0291B	⤛		ordinary	leftwards double arrow-tail
U+0291C	⤜		ordinary	rightwards double arrow-tail
U+0291D	⤝		ordinary	leftwards arrow to black diamond
U+0291E	⤞		ordinary	rightwards arrow to black diamond

U+0291F	⤟		ordinary	leftwards arrow from bar to black diamond
U+02920	⤠		ordinary	rightwards arrow from bar to black diamond
U+02921	⤡	\nwsearrow	relation	north west and south east arrow
U+02922	⤢	\neswarrow	relation	north east and south west arrow
U+02923	⤣	\lhooknwarrow	relation	north west arrow with hook
U+02924	⤤	\rhooknearrow	relation	north east arrow with hook
U+02925	⤥	\lhooksearrow	relation	south east arrow with hook
U+02926	⤦	\rhookswarrow	relation	south west arrow with hook
U+02927	⤧		ordinary	north west arrow and north east arrow
U+02928	⤨		ordinary	north east arrow and south east arrow
U+02929	⤩		ordinary	south east arrow and south west arrow
U+0292A	⤪		ordinary	south west arrow and north west arrow
U+0292B	⤫		ordinary	rising diagonal crossing falling diagonal
U+0292C	⤬		ordinary	falling diagonal crossing rising diagonal
U+0292D	⤭		ordinary	south east arrow crossing north east arrow
U+0292E	⤮		ordinary	north east arrow crossing south east arrow
U+0292F	⤯		ordinary	falling diagonal crossing north east arrow
U+02930	⤰		ordinary	rising diagonal crossing south east arrow
U+02931	⤱		ordinary	north east arrow crossing north west arrow
U+02932	⤲		ordinary	north west arrow crossing north east arrow
U+02933	⤳		ordinary	wave arrow pointing directly right
U+02934	⤴		ordinary	arrow pointing rightwards then curving upwards
U+02935	⤵		ordinary	arrow pointing rightwards then curving downwards
U+02936	⤶		ordinary	arrow pointing downwards then curving leftwards
U+02937	⤷		ordinary	arrow pointing downwards then curving rightwards
U+02938	⤸		ordinary	right-side arc clockwise arrow
U+02939	⤹		ordinary	left-side arc anticlockwise arrow
U+0293A	⤺		ordinary	top arc anticlockwise arrow
U+0293B	⤻		ordinary	bottom arc anticlockwise arrow
U+0293C	⤼		ordinary	top arc clockwise arrow

			with minus
U+0293D	⤽	ordinary	top arc anticlockwise arrow with plus
U+0293E	⤾	ordinary	lower right semicircular clockwise arrow
U+0293F	⤿	ordinary	lower left semicircular anticlock-wise arrow
U+02940	⥀	ordinary	anticlockwise closed circle arrow
U+02941	⥁	ordinary	clockwise closed circle arrow
U+02942	⥂	ordinary	rightwards arrow above short leftwards arrow
U+02943	⥃	ordinary	leftwards arrow above short right-wards arrow
U+02944	⥄	ordinary	short rightwards arrow above leftwards arrow
U+02945	⥅	ordinary	rightwards arrow with plus below
U+02946	⥆	ordinary	leftwards arrow with plus below
U+02947	⥇	ordinary	rightwards arrow through x
U+02948	⥈	ordinary	left right arrow through small circle
U+02949	⥉	ordinary	upwards two-headed arrow from small circle
U+0294A	⥊	ordinary	left barb up right barb down harpoon
U+0294B	⥋	ordinary	left barb down right barb up harpoon
U+0294C	⥌	ordinary	up barb right down barb left harpoon
U+0294D	⥍	ordinary	up barb left down barb right harpoon
U+0294E	⥎	ordinary	left barb up right barb up harpoon
U+0294F	⥏	ordinary	up barb right down barb right harpoon
U+02950	⥐	ordinary	left barb down right barb down harpoon
U+02951	⥑	ordinary	up barb left down barb left harpoon
U+02952	⥒	ordinary	leftwards harpoon with barb up to bar
U+02953	⥓	ordinary	rightwards harpoon with barb up to bar
U+02954	⥔	ordinary	upwards harpoon with barb right to bar
U+02955	⥕	ordinary	downwards harpoon with barb right to bar
U+02956	⥖	ordinary	leftwards harpoon with barb down to bar
U+02957	⥗	ordinary	rightwards harpoon with barb

			down to bar
U+02958	⥘	ordinary	upwards harpoon with barb left to bar
U+02959	⥙	ordinary	downwards harpoon with barb left to bar
U+0295A	⥚	ordinary	leftwards harpoon with barb up from bar
U+0295B	⥛	ordinary	rightwards harpoon with barb up from bar
U+0295C	⥜	ordinary	upwards harpoon with barb right from bar
U+0295D	⥝	ordinary	downwards harpoon with barb right from bar
U+0295E	⥞	ordinary	leftwards harpoon with barb down from bar
U+0295F	⥟	ordinary	rightwards harpoon with barb down from bar
U+02960	⥠	ordinary	upwards harpoon with barb left from bar
U+02961	⥡	ordinary	downwards harpoon with barb left from bar
U+02962	⥢	ordinary	leftwards harpoon with barb up above leftwards harpoon with barb down
U+02963	⥣	ordinary	upwards harpoon with barb left beside upwards harpoon with barb right
U+02964	⥤	ordinary	rightwards harpoon with barb up above rightwards harpoon with barb down
U+02965	⥥	ordinary	downwards harpoon with barb left beside downwards harpoon with barb right
U+02966	⥦	ordinary	leftwards harpoon with barb up above rightwards harpoon with barb up
U+02967	⥧	ordinary	leftwards harpoon with barb down above rightwards harpoon with barb down
U+02968	⥨	ordinary	rightwards harpoon with barb up above leftwards harpoon with barb up
U+02969	⥩	ordinary	rightwards harpoon with barb down above leftwards harpoon with barb down
U+0296A	⥪	ordinary	leftwards harpoon with barb up above long dash
U+0296B	⥫	ordinary	leftwards harpoon with barb down

				below long dash
U+0296C	⥬		ordinary	rightwards harpoon with barb up above long dash
U+0296D	⥭		ordinary	rightwards harpoon with barb down below long dash
U+0296E	⥮		ordinary	upwards harpoon with barb left beside downwards harpoon with barb right
U+0296F	⥯		ordinary	downwards harpoon with barb left beside upwards harpoon with barb right
U+02970	⥰		ordinary	right double arrow with rounded head
U+02971	⥱		ordinary	equals sign above right-wards arrow
U+02972	⥲		ordinary	tilde operator above rightwards arrow
U+02973	⥳		ordinary	leftwards arrow above tilde operator
U+02974	⥴		ordinary	rightwards arrow above tilde operator
U+02975	⥵		ordinary	rightwards arrow above almost equal to
U+02976	⥶		ordinary	less-than above leftwards arrow
U+02977	⥷		ordinary	leftwards arrow through less-than
U+02978	⥸		ordinary	greater-than above right-wards arrow
U+02979	⥹		ordinary	subset above rightwards arrow
U+0297A	⥺		ordinary	leftwards arrow through subset
U+0297B	⥻		ordinary	superset above leftwards arrow
U+0297C	⥼		ordinary	left fish tail
U+0297D	⥽		ordinary	right fish tail
U+0297E	⥾		ordinary	up fish tail
U+0297F	⥿		ordinary	down fish tail

12.11 Mathematical Alphanumeric Symbols

U+003B1	α	\alpha	variable	greek small letter alpha
U+003B2	β	\beta	variable	greek small letter beta
U+003B3	γ	\gamma	variable	greek small letter gamma
U+003B4	δ	\delta	variable	greek small letter delta
U+003B5	ε	\varepsilon	variable	greek small letter epsilon
U+003B6	ζ	\zeta	variable	greek small letter zeta
U+003B7	η	\eta	variable	greek small letter eta
U+003B8	θ	\theta	variable	greek small letter theta
U+003B9	ι	\iota	variable	greek small letter iota
U+003BA	κ	\kappa	variable	greek small letter kappa
U+003BB	λ	\lambda	variable	greek small letter lamda
U+003BC	μ	\mu	variable	greek small letter mu

U+003BD	ν	\nu	variable	greek small letter nu
U+003BE	ξ	\xi	variable	greek small letter xi
U+003BF	ο	\omicron	variable	greek small letter omicron
U+003C0	π	\pi	variable	greek small letter pi
U+003C1	ρ	\rho	variable	greek small letter rho
U+003C2	ς	\varsigma	variable	greek small letter final sigma
U+003C3	σ	\sigma	variable	greek small letter sigma
U+003C4	τ	\tau	variable	greek small letter tau
U+003C5	υ	\upsilon	variable	greek small letter upsilon
U+003C6	φ	\varphi	variable	greek small letter phi
U+003C7	χ	\chi	variable	greek small letter chi
U+003C8	ψ	\psi	variable	greek small letter psi
U+003C9	ω	\omega	variable	greek small letter omega

U+00391	Α	\Alpha	variable	greek capital letter alpha
U+00392	Β	\Beta	variable	greek capital letter beta
U+00393	Γ	\Gamma	variable	greek capital letter gamma
U+00394	Δ	\Delta	variable	greek capital letter delta
U+00395	Ε	\Epsilon	variable	greek capital letter epsilon
U+00396	Ζ	\Zeta	variable	greek capital letter zeta
U+00397	Η	\Eta	variable	greek capital letter eta
U+00398	Θ	\Theta	variable	greek capital letter theta
U+00399	Ι	\Iota	variable	greek capital letter iota
U+0039A	Κ	\Kappa	variable	greek capital letter kappa
U+0039B	Λ	\Lambda	variable	greek capital letter lamda
U+0039C	Μ	\Mu	variable	greek capital letter mu
U+0039D	Ν	\Nu	variable	greek capital letter nu
U+0039E	Ξ	\Xi	variable	greek capital letter xi
U+0039F	Ο	\Omicron	variable	greek capital letter omicron
U+003A0	Π	\Pi	variable	greek capital letter pi
U+003A1	Ρ	\Rho	variable	greek capital letter rho
U+003A3	Σ	\Sigma	variable	greek capital letter sigma
U+003A4	Τ	\Tau	variable	greek capital letter tau
U+003A5	Υ	\Upsilon	variable	greek capital letter upsilon
U+003A6	Φ	\Phi	variable	greek capital letter phi
U+003A7	Χ	\Chi	variable	greek capital letter chi
U+003A8	Ψ	\Psi	variable	greek capital letter psi
U+003A9	Ω	\Omega	variable	greek capital letter omega
U+003AA	Ϊ		variable	greek capital letter iota with dialytika

U+1D400	𝐀		variable	mathematical bold capital a
U+1D401	𝐁		variable	mathematical bold capital b
U+1D402	𝐂		variable	mathematical bold capital c
U+1D403	𝐃		variable	mathematical bold capital d
U+1D404	𝐄		variable	mathematical bold capital e
U+1D405	𝐅		variable	mathematical bold capital f
U+1D406	𝐆		variable	mathematical bold capital g
U+1D407	𝐇		variable	mathematical bold capital h
U+1D408	𝐈		variable	mathematical bold capital i

U+1D409	**J**		variable	mathematical bold capital j
U+1D40A	**K**		variable	mathematical bold capital k
U+1D40B	**L**		variable	mathematical bold capital l
U+1D40C	**M**		variable	mathematical bold capital m
U+1D40D	**N**		variable	mathematical bold capital n
U+1D40E	**O**		variable	mathematical bold capital o
U+1D40F	**P**		variable	mathematical bold capital p
U+1D410	**Q**		variable	mathematical bold capital q
U+1D411	**R**		variable	mathematical bold capital r
U+1D412	**S**		variable	mathematical bold capital s
U+1D413	**T**		variable	mathematical bold capital t
U+1D414	**U**		variable	mathematical bold capital u
U+1D415	**V**		variable	mathematical bold capital v
U+1D416	**W**		variable	mathematical bold capital w
U+1D417	**X**		variable	mathematical bold capital x
U+1D418	**Y**		variable	mathematical bold capital y
U+1D419	**Z**		variable	mathematical bold capital z
U+1D41A	**a**		variable	mathematical bold small a
U+1D41B	**b**		variable	mathematical bold small b
U+1D41C	**c**		variable	mathematical bold small c
U+1D41D	**d**		variable	mathematical bold small d
U+1D41E	**e**		variable	mathematical bold small e
U+1D41F	**f**		variable	mathematical bold small f
U+1D420	**g**		variable	mathematical bold small g
U+1D421	**h**		variable	mathematical bold small h
U+1D422	**i**		variable	mathematical bold small i
U+1D423	**j**		variable	mathematical bold small j
U+1D424	**k**		variable	mathematical bold small k
U+1D425	**l**		variable	mathematical bold small l
U+1D426	**m**		variable	mathematical bold small m
U+1D427	**n**		variable	mathematical bold small n
U+1D428	**o**		variable	mathematical bold small o
U+1D429	**p**		variable	mathematical bold small p
U+1D42A	**q**		variable	mathematical bold small q
U+1D42B	**r**		variable	mathematical bold small r
U+1D42C	**s**		variable	mathematical bold small s
U+1D42D	**t**		variable	mathematical bold small t
U+1D42E	**u**		variable	mathematical bold small u
U+1D42F	**v**		variable	mathematical bold small v
U+1D430	**w**		variable	mathematical bold small w
U+1D431	**x**		variable	mathematical bold small x
U+1D432	**y**		variable	mathematical bold small y
U+1D433	**z**		variable	mathematical bold small z
U+1D434	*A*		variable	mathematical italic capital a
U+1D435	*B*		variable	mathematical italic capital b
U+1D436	*C*		variable	mathematical italic capital c
U+1D437	*D*		variable	mathematical italic capital d
		\mathDitalicshape	differential	

U+1D438	E		variable	mathematical italic capital e
U+1D439	F		variable	mathematical italic capital f
U+1D43A	G		variable	mathematical italic capital g
U+1D43B	H		variable	mathematical italic capital h
U+1D43C	I		variable	mathematical italic capital i
U+1D43D	J		variable	mathematical italic capital j
U+1D43E	K		variable	mathematical italic capital k
U+1D43F	L		variable	mathematical italic capital l
U+1D440	M		variable	mathematical italic capital m
U+1D441	N		variable	mathematical italic capital n
U+1D442	O		variable	mathematical italic capital o
U+1D443	P		variable	mathematical italic capital p
U+1D444	Q		variable	mathematical italic capital q
U+1D445	R		variable	mathematical italic capital r
U+1D446	S		variable	mathematical italic capital s
U+1D447	T		variable	mathematical italic capital t
		\transposesymbol	prime	
U+1D448	U		variable	mathematical italic capital u
U+1D449	V		variable	mathematical italic capital v
U+1D44A	W		variable	mathematical italic capital w
U+1D44B	X		variable	mathematical italic capital x
U+1D44C	Y		variable	mathematical italic capital y
U+1D44D	Z		variable	mathematical italic capital z
U+1D44E	a		variable	mathematical italic small a
U+1D44F	b		variable	mathematical italic small b
U+1D450	c		variable	mathematical italic small c
U+1D451	d		variable	mathematical italic small d
		\mathditalicshape	differential	
U+1D452	e		variable	mathematical italic small e
		\ee	exponential	
U+1D453	f		variable	mathematical italic small f
U+1D454	g		variable	mathematical italic small g
U+0210E	h	\Planckconst	variable	planck constant
U+1D456	i		variable	mathematical italic small i
		\ii	imaginary	
U+1D457	j		variable	mathematical italic small j
		\ji	imaginary	
U+1D458	k		variable	mathematical italic small k
U+1D459	l		variable	mathematical italic small l
U+1D45A	m		variable	mathematical italic small m
U+1D45B	n		variable	mathematical italic small n
U+1D45C	o		variable	mathematical italic small o
U+1D45D	p		variable	mathematical italic small p
U+1D45E	q		variable	mathematical italic small q
U+1D45F	r		variable	mathematical italic small r
U+1D460	s		variable	mathematical italic small s
U+1D461	t		variable	mathematical italic small t
U+1D462	u		variable	mathematical italic small u

U+1D463	v	variable	mathematical italic small v
U+1D464	w	variable	mathematical italic small w
U+1D465	x	variable	mathematical italic small x
U+1D466	y	variable	mathematical italic small y
U+1D467	z	variable	mathematical italic small z
U+1D468	$\boldsymbol{A}$	variable	mathematical bold italic capital a
U+1D469	$\boldsymbol{B}$	variable	mathematical bold italic capital b
U+1D46A	$\boldsymbol{C}$	variable	mathematical bold italic capital c
U+1D46B	$\boldsymbol{D}$	variable	mathematical bold italic capital d
U+1D46C	$\boldsymbol{E}$	variable	mathematical bold italic capital e
U+1D46D	$\boldsymbol{F}$	variable	mathematical bold italic capital f
U+1D46E	$\boldsymbol{G}$	variable	mathematical bold italic capital g
U+1D46F	$\boldsymbol{H}$	variable	mathematical bold italic capital h
U+1D470	$\boldsymbol{I}$	variable	mathematical bold italic capital i
U+1D471	$\boldsymbol{J}$	variable	mathematical bold italic capital j
U+1D472	$\boldsymbol{K}$	variable	mathematical bold italic capital k
U+1D473	$\boldsymbol{L}$	variable	mathematical bold italic capital l
U+1D474	$\boldsymbol{M}$	variable	mathematical bold italic capital m
U+1D475	$\boldsymbol{N}$	variable	mathematical bold italic capital n
U+1D476	$\boldsymbol{O}$	variable	mathematical bold italic capital o
U+1D477	$\boldsymbol{P}$	variable	mathematical bold italic capital p
U+1D478	$\boldsymbol{Q}$	variable	mathematical bold italic capital q
U+1D479	$\boldsymbol{R}$	variable	mathematical bold italic capital r
U+1D47A	$\boldsymbol{S}$	variable	mathematical bold italic capital s
U+1D47B	$\boldsymbol{T}$	variable	mathematical bold italic capital t
U+1D47C	$\boldsymbol{U}$	variable	mathematical bold italic capital u
U+1D47D	$\boldsymbol{V}$	variable	mathematical bold italic capital v
U+1D47E	$\boldsymbol{W}$	variable	mathematical bold italic capital w
U+1D47F	$\boldsymbol{X}$	variable	mathematical bold italic capital x
U+1D480	$\boldsymbol{Y}$	variable	mathematical bold italic capital y
U+1D481	$\boldsymbol{Z}$	variable	mathematical bold italic capital z
U+1D482	$\boldsymbol{a}$	variable	mathematical bold italic small a
U+1D483	$\boldsymbol{b}$	variable	mathematical bold italic small b
U+1D484	$\boldsymbol{c}$	variable	mathematical bold italic small c
U+1D485	$\boldsymbol{d}$	variable	mathematical bold italic small d
U+1D486	$\boldsymbol{e}$	variable	mathematical bold italic small e
U+1D487	$\boldsymbol{f}$	variable	mathematical bold italic small f
U+1D488	$\boldsymbol{g}$	variable	mathematical bold italic small g
U+1D489	$\boldsymbol{h}$	variable	mathematical bold italic small h
U+1D48A	$\boldsymbol{i}$	variable	mathematical bold italic small i
U+1D48B	$\boldsymbol{j}$	variable	mathematical bold italic small j
U+1D48C	$\boldsymbol{k}$	variable	mathematical bold italic small k
U+1D48D	$\boldsymbol{l}$	variable	mathematical bold italic small l
U+1D48E	$\boldsymbol{m}$	variable	mathematical bold italic small m
U+1D48F	$\boldsymbol{n}$	variable	mathematical bold italic small n
U+1D490	$\boldsymbol{o}$	variable	mathematical bold italic small o
U+1D491	$\boldsymbol{p}$	variable	mathematical bold italic small p
U+1D492	$\boldsymbol{q}$	variable	mathematical bold italic small q

U+1D493	𝒓	variable	mathematical bold italic small r
U+1D494	𝒔	variable	mathematical bold italic small s
U+1D495	𝒕	variable	mathematical bold italic small t
U+1D496	𝒖	variable	mathematical bold italic small u
U+1D497	𝒗	variable	mathematical bold italic small v
U+1D498	𝒘	variable	mathematical bold italic small w
U+1D499	𝒙	variable	mathematical bold italic small x
U+1D49A	𝒚	variable	mathematical bold italic small y
U+1D49B	𝒛	variable	mathematical bold italic small z
U+1D49C	𝒜	variable	mathematical script capital a
U+0212C	ℬ	variable	script capital b
U+1D49E	𝒞	variable	mathematical script capital c
U+1D49F	𝒟	variable	mathematical script capital d
U+02130	ℰ	variable	script capital e
U+02131	ℱ	variable	script capital f
U+1D4A2	𝒢	variable	mathematical script capital g
U+0210B	ℋ	variable	script capital h
U+02110	ℐ	variable	script capital i
U+1D4A5	𝒥	variable	mathematical script capital j
U+1D4A6	𝒦	variable	mathematical script capital k
U+02112	ℒ	variable	script capital l
U+02133	ℳ	variable	script capital m
U+1D4A9	𝒩	variable	mathematical script capital n
U+1D4AA	𝒪	variable	mathematical script capital o
U+1D4AB	𝒫	variable	mathematical script capital p
U+1D4AC	𝒬	variable	mathematical script capital q
U+0211B	ℛ	variable	script capital r
U+1D4AE	𝒮	variable	mathematical script capital s
U+1D4AF	𝒯	variable	mathematical script capital t
U+1D4B0	𝒰	variable	mathematical script capital u
U+1D4B1	𝒱	variable	mathematical script capital v
U+1D4B2	𝒲	variable	mathematical script capital w
U+1D4B3	𝒳	variable	mathematical script capital x
U+1D4B4	𝒴	variable	mathematical script capital y
U+1D4B5	𝒵	variable	mathematical script capital z
U+1D4B6	𝒶	variable	mathematical script small a
U+1D4B7	𝒷	variable	mathematical script small b
U+1D4B8	𝒸	variable	mathematical script small c
U+1D4B9	𝒹	variable	mathematical script small d
U+0212F	ℯ	variable	script small e
U+1D4BB	𝒻	variable	mathematical script small f
U+0210A	ℊ	variable	script small g
U+1D4BD	𝒽	variable	mathematical script small h
U+1D4BE	𝒾	variable	mathematical script small i
U+1D4BF	𝒿	variable	mathematical script small j
U+1D4C0	𝓀	variable	mathematical script small k
U+1D4C1	𝓁	variable	mathematical script small l
U+1D4C2	𝓂	variable	mathematical script small m

U+1D4C3	𝓃	variable	mathematical script small n
U+02134	ℴ	variable	script small o
U+1D4C5	𝓅	variable	mathematical script small p
U+1D4C6	𝓆	variable	mathematical script small q
U+1D4C7	𝓇	variable	mathematical script small r
U+1D4C8	𝓈	variable	mathematical script small s
U+1D4C9	𝓉	variable	mathematical script small t
U+1D4CA	𝓊	variable	mathematical script small u
U+1D4CB	𝓋	variable	mathematical script small v
U+1D4CC	𝓌	variable	mathematical script small w
U+1D4CD	𝓍	variable	mathematical script small x
U+1D4CE	𝓎	variable	mathematical script small y
U+1D4CF	𝓏	variable	mathematical script small z
U+1D4D0	𝓐	variable	mathematical bold script capital a
U+1D4D1	𝓑	variable	mathematical bold script capital b
U+1D4D2	𝓒	variable	mathematical bold script capital c
U+1D4D3	𝓓	variable	mathematical bold script capital d
U+1D4D4	𝓔	variable	mathematical bold script capital e
U+1D4D5	𝓕	variable	mathematical bold script capital f
U+1D4D6	𝓖	variable	mathematical bold script capital g
U+1D4D7	𝓗	variable	mathematical bold script capital h
U+1D4D8	𝓘	variable	mathematical bold script capital i
U+1D4D9	𝓙	variable	mathematical bold script capital j
U+1D4DA	𝓚	variable	mathematical bold script capital k
U+1D4DB	𝓛	variable	mathematical bold script capital l
U+1D4DC	𝓜	variable	mathematical bold script capital m
U+1D4DD	𝓝	variable	mathematical bold script capital n
U+1D4DE	𝓞	variable	mathematical bold script capital o
U+1D4DF	𝓟	variable	mathematical bold script capital p
U+1D4E0	𝓠	variable	mathematical bold script capital q
U+1D4E1	𝓡	variable	mathematical bold script capital r
U+1D4E2	𝓢	variable	mathematical bold script capital s
U+1D4E3	𝓣	variable	mathematical bold script capital t
U+1D4E4	𝓤	variable	mathematical bold script capital u
U+1D4E5	𝓥	variable	mathematical bold script capital v
U+1D4E6	𝓦	variable	mathematical bold script capital w
U+1D4E7	𝓧	variable	mathematical bold script capital x
U+1D4E8	𝓨	variable	mathematical bold script capital y
U+1D4E9	𝓩	variable	mathematical bold script capital z
U+1D4EA	𝓪	variable	mathematical bold script small a
U+1D4EB	𝓫	variable	mathematical bold script small b
U+1D4EC	𝓬	variable	mathematical bold script small c
U+1D4ED	𝓭	variable	mathematical bold script small d
U+1D4EE	𝓮	variable	mathematical bold script small e
U+1D4EF	𝓯	variable	mathematical bold script small f
U+1D4F0	𝓰	variable	mathematical bold script small g
U+1D4F1	𝓱	variable	mathematical bold script small h
U+1D4F2	𝓲	variable	mathematical bold script small i

U+1D4F3	𝓳		variable	mathematical bold script small j
U+1D4F4	𝓴		variable	mathematical bold script small k
U+1D4F5	𝓵		variable	mathematical bold script small l
U+1D4F6	𝓶		variable	mathematical bold script small m
U+1D4F7	𝓷		variable	mathematical bold script small n
U+1D4F8	𝓸		variable	mathematical bold script small o
U+1D4F9	𝓹		variable	mathematical bold script small p
U+1D4FA	𝓺		variable	mathematical bold script small q
U+1D4FB	𝓻		variable	mathematical bold script small r
U+1D4FC	𝓼		variable	mathematical bold script small s
U+1D4FD	𝓽		variable	mathematical bold script small t
U+1D4FE	𝓾		variable	mathematical bold script small u
U+1D4FF	𝓿		variable	mathematical bold script small v
U+1D500	𝔀		variable	mathematical bold script small w
U+1D501	𝔁		variable	mathematical bold script small x
U+1D502	𝔂		variable	mathematical bold script small y
U+1D503	𝔃		variable	mathematical bold script small z
U+1D504	𝔄		variable	mathematical fraktur capital a
U+1D505	𝔅		variable	mathematical fraktur capital b
U+0212D	ℭ		variable	black-letter capital c
U+1D507	𝔇		variable	mathematical fraktur capital d
U+1D508	𝔈		variable	mathematical fraktur capital e
U+1D509	𝔉		variable	mathematical fraktur capital f
U+1D50A	𝔊		variable	mathematical fraktur capital g
U+0210C	ℌ		variable	black-letter capital h
U+02111	ℑ	\Im	variable	black-letter capital i
U+1D50D	𝔍		variable	mathematical fraktur capital j
U+1D50E	𝔎		variable	mathematical fraktur capital k
U+1D50F	𝔏		variable	mathematical fraktur capital l
U+1D510	𝔐		variable	mathematical fraktur capital m
U+1D511	𝔑		variable	mathematical fraktur capital n
U+1D512	𝔒		variable	mathematical fraktur capital o
U+1D513	𝔓		variable	mathematical fraktur capital p
U+1D514	𝔔		variable	mathematical fraktur capital q
U+0211C	ℜ	\Re	variable	black-letter capital r
U+1D516	𝔖		variable	mathematical fraktur capital s
U+1D517	𝔗		variable	mathematical fraktur capital t
U+1D518	𝔘		variable	mathematical fraktur capital u
U+1D519	𝔙		variable	mathematical fraktur capital v
U+1D51A	𝔚		variable	mathematical fraktur capital w
U+1D51B	𝔛		variable	mathematical fraktur capital x
U+1D51C	𝔜		variable	mathematical fraktur capital y
U+02128	ℨ		variable	black-letter capital z
U+1D51E	𝔞		variable	mathematical fraktur small a
U+1D51F	𝔟		variable	mathematical fraktur small b
U+1D520	𝔠		variable	mathematical fraktur small c
U+1D521	𝔡		variable	mathematical fraktur small d
U+1D522	𝔢		variable	mathematical fraktur small e

U+1D523	𝔣		variable	mathematical fraktur small f
U+1D524	𝔤		variable	mathematical fraktur small g
U+1D525	𝔥		variable	mathematical fraktur small h
U+1D526	𝔦		variable	mathematical fraktur small i
U+1D527	𝔧		variable	mathematical fraktur small j
U+1D528	𝔨		variable	mathematical fraktur small k
U+1D529	𝔩		variable	mathematical fraktur small l
U+1D52A	𝔪		variable	mathematical fraktur small m
U+1D52B	𝔫		variable	mathematical fraktur small n
U+1D52C	𝔬		variable	mathematical fraktur small o
U+1D52D	𝔭		variable	mathematical fraktur small p
U+1D52E	𝔮		variable	mathematical fraktur small q
U+1D52F	𝔯		variable	mathematical fraktur small r
U+1D530	𝔰		variable	mathematical fraktur small s
U+1D531	𝔱		variable	mathematical fraktur small t
U+1D532	𝔲		variable	mathematical fraktur small u
U+1D533	𝔳		variable	mathematical fraktur small v
U+1D534	𝔴		variable	mathematical fraktur small w
U+1D535	𝔵		variable	mathematical fraktur small x
U+1D536	𝔶		variable	mathematical fraktur small y
U+1D537	𝔷		variable	mathematical fraktur small z
U+1D538	𝔸		variable	mathematical double-struck capital a
U+1D539	𝔹		variable	mathematical double-struck capital b
U+02102	ℂ		variable	double-struck capital c
		\complexes	ordinary	
U+1D53B	𝔻		variable	mathematical double-struck capital d
U+1D53C	𝔼		variable	mathematical double-struck capital e
U+1D53D	𝔽		variable	mathematical double-struck capital f
U+1D53E	𝔾		variable	mathematical double-struck capital g
U+0210D	ℍ		variable	double-struck capital h
U+1D540	𝕀		variable	mathematical double-struck capital i
U+1D541	𝕁		variable	mathematical double-struck capital j
U+1D542	𝕂		variable	mathematical double-struck capital k
U+1D543	𝕃		variable	mathematical double-struck capital l
U+1D544	𝕄		variable	mathematical double-struck capital m
U+02115	ℕ	\naturalnumbers	variable	double-struck capital n
U+1D546	𝕆		variable	mathematical double-struck capital o
U+02119	ℙ	\primes	variable	double-struck capital p
U+0211A	ℚ	\rationals	variable	double-struck capital q
U+0211D	ℝ	\reals	variable	double-struck capital r
U+1D54A	𝕊		variable	mathematical double-struck capital s
U+1D54B	𝕋		variable	mathematical double-struck capital t
U+1D54C	𝕌		variable	mathematical double-struck capital u
U+1D54D	𝕍		variable	mathematical double-struck capital v
U+1D54E	𝕎		variable	mathematical double-struck capital w
U+1D54F	𝕏		variable	mathematical double-struck capital x
U+1D550	𝕐		variable	mathematical double-struck capital y
U+02124	ℤ	\integers	variable	double-struck capital z

U+1D552	𝕒	variable	mathematical double-struck small a
U+1D553	𝕓	variable	mathematical double-struck small b
U+1D554	𝕔	variable	mathematical double-struck small c
U+1D555	𝕕	variable	mathematical double-struck small d
U+1D556	𝕖	variable	mathematical double-struck small e
U+1D557	𝕗	variable	mathematical double-struck small f
U+1D558	𝕘	variable	mathematical double-struck small g
U+1D559	𝕙	variable	mathematical double-struck small h
U+1D55A	𝕚	variable	mathematical double-struck small i
U+1D55B	𝕛	variable	mathematical double-struck small j
U+1D55C	𝕜	variable	mathematical double-struck small k
U+1D55D	𝕝	variable	mathematical double-struck small l
U+1D55E	𝕞	variable	mathematical double-struck small m
U+1D55F	𝕟	variable	mathematical double-struck small n
U+1D560	𝕠	variable	mathematical double-struck small o
U+1D561	𝕡	variable	mathematical double-struck small p
U+1D562	𝕢	variable	mathematical double-struck small q
U+1D563	𝕣	variable	mathematical double-struck small r
U+1D564	𝕤	variable	mathematical double-struck small s
U+1D565	𝕥	variable	mathematical double-struck small t
U+1D566	𝕦	variable	mathematical double-struck small u
U+1D567	𝕧	variable	mathematical double-struck small v
U+1D568	𝕨	variable	mathematical double-struck small w
U+1D569	𝕩	variable	mathematical double-struck small x
U+1D56A	𝕪	variable	mathematical double-struck small y
U+1D56B	𝕫	variable	mathematical double-struck small z
U+1D56C	𝕬	variable	mathematical bold fraktur capital a
U+1D56D	𝕭	variable	mathematical bold fraktur capital b
U+1D56E	𝕮	variable	mathematical bold fraktur capital c
U+1D56F	𝕯	variable	mathematical bold fraktur capital d
U+1D570	𝕰	variable	mathematical bold fraktur capital e
U+1D571	𝕱	variable	mathematical bold fraktur capital f
U+1D572	𝕲	variable	mathematical bold fraktur capital g
U+1D573	𝕳	variable	mathematical bold fraktur capital h
U+1D574	𝕴	variable	mathematical bold fraktur capital i
U+1D575	𝕵	variable	mathematical bold fraktur capital j
U+1D576	𝕶	variable	mathematical bold fraktur capital k
U+1D577	𝕷	variable	mathematical bold fraktur capital l
U+1D578	𝕸	variable	mathematical bold fraktur capital m
U+1D579	𝕹	variable	mathematical bold fraktur capital n
U+1D57A	𝕺	variable	mathematical bold fraktur capital o
U+1D57B	𝕻	variable	mathematical bold fraktur capital p
U+1D57C	𝕼	variable	mathematical bold fraktur capital q
U+1D57D	𝕽	variable	mathematical bold fraktur capital r
U+1D57E	𝕾	variable	mathematical bold fraktur capital s
U+1D57F	𝕿	variable	mathematical bold fraktur capital t
U+1D580	𝖀	variable	mathematical bold fraktur capital u
U+1D581	𝖁	variable	mathematical bold fraktur capital v

U+1D582	𝖂	variable	mathematical bold fraktur capital w
U+1D583	𝖃	variable	mathematical bold fraktur capital x
U+1D584	𝖄	variable	mathematical bold fraktur capital y
U+1D585	𝖅	variable	mathematical bold fraktur capital z
U+1D586	𝖆	variable	mathematical bold fraktur small a
U+1D587	𝖇	variable	mathematical bold fraktur small b
U+1D588	𝖈	variable	mathematical bold fraktur small c
U+1D589	𝖉	variable	mathematical bold fraktur small d
U+1D58A	𝖊	variable	mathematical bold fraktur small e
U+1D58B	𝖋	variable	mathematical bold fraktur small f
U+1D58C	𝖌	variable	mathematical bold fraktur small g
U+1D58D	𝖍	variable	mathematical bold fraktur small h
U+1D58E	𝖎	variable	mathematical bold fraktur small i
U+1D58F	𝖏	variable	mathematical bold fraktur small j
U+1D590	𝖐	variable	mathematical bold fraktur small k
U+1D591	𝖑	variable	mathematical bold fraktur small l
U+1D592	𝖒	variable	mathematical bold fraktur small m
U+1D593	𝖓	variable	mathematical bold fraktur small n
U+1D594	𝖔	variable	mathematical bold fraktur small o
U+1D595	𝖕	variable	mathematical bold fraktur small p
U+1D596	𝖖	variable	mathematical bold fraktur small q
U+1D597	𝖗	variable	mathematical bold fraktur small r
U+1D598	𝖘	variable	mathematical bold fraktur small s
U+1D599	𝖙	variable	mathematical bold fraktur small t
U+1D59A	𝖚	variable	mathematical bold fraktur small u
U+1D59B	𝖛	variable	mathematical bold fraktur small v
U+1D59C	𝖜	variable	mathematical bold fraktur small w
U+1D59D	𝖝	variable	mathematical bold fraktur small x
U+1D59E	𝖞	variable	mathematical bold fraktur small y
U+1D59F	𝖟	variable	mathematical bold fraktur small z
U+1D5A0	𝖠	variable	mathematical sans-serif capital a
U+1D5A1	𝖡	variable	mathematical sans-serif capital b
U+1D5A2	𝖢	variable	mathematical sans-serif capital c
U+1D5A3	𝖣	variable	mathematical sans-serif capital d
U+1D5A4	𝖤	variable	mathematical sans-serif capital e
U+1D5A5	𝖥	variable	mathematical sans-serif capital f
U+1D5A6	𝖦	variable	mathematical sans-serif capital g
U+1D5A7	𝖧	variable	mathematical sans-serif capital h
U+1D5A8	𝖨	variable	mathematical sans-serif capital i
U+1D5A9	𝖩	variable	mathematical sans-serif capital j
U+1D5AA	𝖪	variable	mathematical sans-serif capital k
U+1D5AB	𝖫	variable	mathematical sans-serif capital l
U+1D5AC	𝖬	variable	mathematical sans-serif capital m
U+1D5AD	𝖭	variable	mathematical sans-serif capital n
U+1D5AE	𝖮	variable	mathematical sans-serif capital o
U+1D5AF	𝖯	variable	mathematical sans-serif capital p
U+1D5B0	𝖰	variable	mathematical sans-serif capital q
U+1D5B1	𝖱	variable	mathematical sans-serif capital r

U+1D5B2	S	variable	mathematical sans-serif capital s
U+1D5B3	T	variable	mathematical sans-serif capital t
U+1D5B4	U	variable	mathematical sans-serif capital u
U+1D5B5	V	variable	mathematical sans-serif capital v
U+1D5B6	W	variable	mathematical sans-serif capital w
U+1D5B7	X	variable	mathematical sans-serif capital x
U+1D5B8	Y	variable	mathematical sans-serif capital y
U+1D5B9	Z	variable	mathematical sans-serif capital z
U+1D5BA	a	variable	mathematical sans-serif small a
U+1D5BB	b	variable	mathematical sans-serif small b
U+1D5BC	c	variable	mathematical sans-serif small c
U+1D5BD	d	variable	mathematical sans-serif small d
U+1D5BE	e	variable	mathematical sans-serif small e
U+1D5BF	f	variable	mathematical sans-serif small f
U+1D5C0	g	variable	mathematical sans-serif small g
U+1D5C1	h	variable	mathematical sans-serif small h
U+1D5C2	i	variable	mathematical sans-serif small i
U+1D5C3	j	variable	mathematical sans-serif small j
U+1D5C4	k	variable	mathematical sans-serif small k
U+1D5C5	l	variable	mathematical sans-serif small l
U+1D5C6	m	variable	mathematical sans-serif small m
U+1D5C7	n	variable	mathematical sans-serif small n
U+1D5C8	o	variable	mathematical sans-serif small o
U+1D5C9	p	variable	mathematical sans-serif small p
U+1D5CA	q	variable	mathematical sans-serif small q
U+1D5CB	r	variable	mathematical sans-serif small r
U+1D5CC	s	variable	mathematical sans-serif small s
U+1D5CD	t	variable	mathematical sans-serif small t
U+1D5CE	u	variable	mathematical sans-serif small u
U+1D5CF	v	variable	mathematical sans-serif small v
U+1D5D0	w	variable	mathematical sans-serif small w
U+1D5D1	x	variable	mathematical sans-serif small x
U+1D5D2	y	variable	mathematical sans-serif small y
U+1D5D3	z	variable	mathematical sans-serif small z
U+1D5D4	**A**	variable	mathematical sans-serif bold capital a
U+1D5D5	**B**	variable	mathematical sans-serif bold capital b
U+1D5D6	**C**	variable	mathematical sans-serif bold capital c
U+1D5D7	**D**	variable	mathematical sans-serif bold capital d
U+1D5D8	**E**	variable	mathematical sans-serif bold capital e
U+1D5D9	**F**	variable	mathematical sans-serif bold capital f
U+1D5DA	**G**	variable	mathematical sans-serif bold capital g
U+1D5DB	**H**	variable	mathematical sans-serif bold capital h
U+1D5DC	**I**	variable	mathematical sans-serif bold capital i
U+1D5DD	**J**	variable	mathematical sans-serif bold capital j
U+1D5DE	**K**	variable	mathematical sans-serif bold capital k
U+1D5DF	**L**	variable	mathematical sans-serif bold capital l
U+1D5E0	**M**	variable	mathematical sans-serif bold capital m

U+1D5E1	𝗡	variable	mathematical sans-serif bold capital n
U+1D5E2	𝗢	variable	mathematical sans-serif bold capital o
U+1D5E3	𝗣	variable	mathematical sans-serif bold capital p
U+1D5E4	𝗤	variable	mathematical sans-serif bold capital q
U+1D5E5	𝗥	variable	mathematical sans-serif bold capital r
U+1D5E6	𝗦	variable	mathematical sans-serif bold capital s
U+1D5E7	𝗧	variable	mathematical sans-serif bold capital t
U+1D5E8	𝗨	variable	mathematical sans-serif bold capital u
U+1D5E9	𝗩	variable	mathematical sans-serif bold capital v
U+1D5EA	𝗪	variable	mathematical sans-serif bold capital w
U+1D5EB	𝗫	variable	mathematical sans-serif bold capital x
U+1D5EC	𝗬	variable	mathematical sans-serif bold capital y
U+1D5ED	𝗭	variable	mathematical sans-serif bold capital z
U+1D5EE	𝗮	variable	mathematical sans-serif bold small a
U+1D5EF	𝗯	variable	mathematical sans-serif bold small b
U+1D5F0	𝗰	variable	mathematical sans-serif bold small c
U+1D5F1	𝗱	variable	mathematical sans-serif bold small d
U+1D5F2	𝗲	variable	mathematical sans-serif bold small e
U+1D5F3	𝗳	variable	mathematical sans-serif bold small f
U+1D5F4	𝗴	variable	mathematical sans-serif bold small g
U+1D5F5	𝗵	variable	mathematical sans-serif bold small h
U+1D5F6	𝗶	variable	mathematical sans-serif bold small i
U+1D5F7	𝗷	variable	mathematical sans-serif bold small j
U+1D5F8	𝗸	variable	mathematical sans-serif bold small k
U+1D5F9	𝗹	variable	mathematical sans-serif bold small l
U+1D5FA	𝗺	variable	mathematical sans-serif bold small m
U+1D5FB	𝗻	variable	mathematical sans-serif bold small n
U+1D5FC	𝗼	variable	mathematical sans-serif bold small o
U+1D5FD	𝗽	variable	mathematical sans-serif bold small p
U+1D5FE	𝗾	variable	mathematical sans-serif bold small q
U+1D5FF	𝗿	variable	mathematical sans-serif bold small r
U+1D600	𝘀	variable	mathematical sans-serif bold small s
U+1D601	𝘁	variable	mathematical sans-serif bold small t
U+1D602	𝘂	variable	mathematical sans-serif bold small u
U+1D603	𝘃	variable	mathematical sans-serif bold small v
U+1D604	𝘄	variable	mathematical sans-serif bold small w
U+1D605	𝘅	variable	mathematical sans-serif bold small x
U+1D606	𝘆	variable	mathematical sans-serif bold small y
U+1D607	𝘇	variable	mathematical sans-serif bold small z
U+1D608	𝘈	variable	mathematical sans-serif italic capital a
U+1D609	𝘉	variable	mathematical sans-serif italic capital b
U+1D60A	𝘊	variable	mathematical sans-serif italic capital c
U+1D60B	𝘋	variable	mathematical sans-serif italic capital d

U+1D60C	*E*	variable	mathematical sans-serif italic capital e
U+1D60D	*F*	variable	mathematical sans-serif italic capital f
U+1D60E	*G*	variable	mathematical sans-serif italic capital g
U+1D60F	*H*	variable	mathematical sans-serif italic capital h
U+1D610	*I*	variable	mathematical sans-serif italic capital i
U+1D611	*J*	variable	mathematical sans-serif italic capital j
U+1D612	*K*	variable	mathematical sans-serif italic capital k
U+1D613	*L*	variable	mathematical sans-serif italic capital l
U+1D614	*M*	variable	mathematical sans-serif italic capital m
U+1D615	*N*	variable	mathematical sans-serif italic capital n
U+1D616	*O*	variable	mathematical sans-serif italic capital o
U+1D617	*P*	variable	mathematical sans-serif italic capital p
U+1D618	*Q*	variable	mathematical sans-serif italic capital q
U+1D619	*R*	variable	mathematical sans-serif italic capital r
U+1D61A	*S*	variable	mathematical sans-serif italic capital s
U+1D61B	*T*	variable	mathematical sans-serif italic capital t
U+1D61C	*U*	variable	mathematical sans-serif italic capital u
U+1D61D	*V*	variable	mathematical sans-serif italic capital v
U+1D61E	*W*	variable	mathematical sans-serif italic capital w
U+1D61F	*X*	variable	mathematical sans-serif italic capital x
U+1D620	*Y*	variable	mathematical sans-serif italic capital y
U+1D621	*Z*	variable	mathematical sans-serif italic capital z
U+1D622	*a*	variable	mathematical sans-serif italic small a
U+1D623	*b*	variable	mathematical sans-serif italic small b
U+1D624	*c*	variable	mathematical sans-serif italic small c
U+1D625	*d*	variable	mathematical sans-serif italic small d
U+1D626	*e*	variable	mathematical sans-serif italic small e
U+1D627	*f*	variable	mathematical sans-serif italic small f
U+1D628	*g*	variable	mathematical sans-serif italic small g
U+1D629	*h*	variable	mathematical sans-serif italic small h
U+1D62A	*i*	variable	mathematical sans-serif italic small i
U+1D62B	*j*	variable	mathematical sans-serif italic small j
U+1D62C	*k*	variable	mathematical sans-serif italic small k

U+1D62D	*l*	variable	mathematical sans-serif italic small l
U+1D62E	*m*	variable	mathematical sans-serif italic small m
U+1D62F	*n*	variable	mathematical sans-serif italic small n
U+1D630	*o*	variable	mathematical sans-serif italic small o
U+1D631	*p*	variable	mathematical sans-serif italic small p
U+1D632	*q*	variable	mathematical sans-serif italic small q
U+1D633	*r*	variable	mathematical sans-serif italic small r
U+1D634	*s*	variable	mathematical sans-serif italic small s
U+1D635	*t*	variable	mathematical sans-serif italic small t
U+1D636	*u*	variable	mathematical sans-serif italic small u
U+1D637	*v*	variable	mathematical sans-serif italic small v
U+1D638	*w*	variable	mathematical sans-serif italic small w
U+1D639	*x*	variable	mathematical sans-serif italic small x
U+1D63A	*y*	variable	mathematical sans-serif italic small y
U+1D63B	*z*	variable	mathematical sans-serif italic small z
U+1D63C	***A***	variable	mathematical sans-serif bold italic capital a
U+1D63D	***B***	variable	mathematical sans-serif bold italic capital b
U+1D63E	***C***	variable	mathematical sans-serif bold italic capital c
U+1D63F	***D***	variable	mathematical sans-serif bold italic capital d
U+1D640	***E***	variable	mathematical sans-serif bold italic capital e
U+1D641	***F***	variable	mathematical sans-serif bold italic capital f
U+1D642	***G***	variable	mathematical sans-serif bold italic capital g
U+1D643	***H***	variable	mathematical sans-serif bold italic capital h
U+1D644	***I***	variable	mathematical sans-serif bold italic capital i
U+1D645	***J***	variable	mathematical sans-serif bold italic capital j
U+1D646	***K***	variable	mathematical sans-serif bold italic capital k
U+1D647	***L***	variable	mathematical sans-serif bold italic capital l
U+1D648	***M***	variable	mathematical sans-serif bold italic capital m
U+1D649	***N***	variable	mathematical sans-serif bold italic capital n
U+1D64A	***O***	variable	mathematical sans-serif bold italic capital o
U+1D64B	***P***	variable	mathematical sans-serif bold italic capital p
U+1D64C	***Q***	variable	mathematical sans-serif bold italic

			capital q
U+1D64D	***R***	variable	mathematical sans-serif bold italic capital r
U+1D64E	***S***	variable	mathematical sans-serif bold italic capital s
U+1D64F	***T***	variable	mathematical sans-serif bold italic capital t
U+1D650	***U***	variable	mathematical sans-serif bold italic capital u
U+1D651	***V***	variable	mathematical sans-serif bold italic capital v
U+1D652	***W***	variable	mathematical sans-serif bold italic capital w
U+1D653	***X***	variable	mathematical sans-serif bold italic capital x
U+1D654	***Y***	variable	mathematical sans-serif bold italic capital y
U+1D655	***Z***	variable	mathematical sans-serif bold italic capital z
U+1D656	***a***	variable	mathematical sans-serif bold italic small a
U+1D657	***b***	variable	mathematical sans-serif bold italic small b
U+1D658	***c***	variable	mathematical sans-serif bold italic small c
U+1D659	***d***	variable	mathematical sans-serif bold italic small d
U+1D65A	***e***	variable	mathematical sans-serif bold italic small e
U+1D65B	***f***	variable	mathematical sans-serif bold italic small f
U+1D65C	***g***	variable	mathematical sans-serif bold italic small g
U+1D65D	***h***	variable	mathematical sans-serif bold italic small h
U+1D65E	***i***	variable	mathematical sans-serif bold italic small i
U+1D65F	***j***	variable	mathematical sans-serif bold italic small j
U+1D660	***k***	variable	mathematical sans-serif bold italic small k
U+1D661	***l***	variable	mathematical sans-serif bold italic small l
U+1D662	***m***	variable	mathematical sans-serif bold italic small m
U+1D663	***n***	variable	mathematical sans-serif bold italic small n
U+1D664	***o***	variable	mathematical sans-serif bold italic

			small o
U+1D665	***p***	variable	mathematical sans-serif bold italic small p
U+1D666	***q***	variable	mathematical sans-serif bold italic small q
U+1D667	***r***	variable	mathematical sans-serif bold italic small r
U+1D668	***s***	variable	mathematical sans-serif bold italic small s
U+1D669	***t***	variable	mathematical sans-serif bold italic small t
U+1D66A	***u***	variable	mathematical sans-serif bold italic small u
U+1D66B	***v***	variable	mathematical sans-serif bold italic small v
U+1D66C	***w***	variable	mathematical sans-serif bold italic small w
U+1D66D	***x***	variable	mathematical sans-serif bold italic small x
U+1D66E	***y***	variable	mathematical sans-serif bold italic small y
U+1D66F	***z***	variable	mathematical sans-serif bold italic small z
U+1D670	A	variable	mathematical monospace capital a
U+1D671	B	variable	mathematical monospace capital b
U+1D672	C	variable	mathematical monospace capital c
U+1D673	D	variable	mathematical monospace capital d
U+1D674	E	variable	mathematical monospace capital e
U+1D675	F	variable	mathematical monospace capital f
U+1D676	G	variable	mathematical monospace capital g
U+1D677	H	variable	mathematical monospace capital h
U+1D678	I	variable	mathematical monospace capital i
U+1D679	J	variable	mathematical monospace capital j
U+1D67A	K	variable	mathematical monospace capital k
U+1D67B	L	variable	mathematical monospace capital l
U+1D67C	M	variable	mathematical monospace capital m
U+1D67D	N	variable	mathematical monospace capital n
U+1D67E	O	variable	mathematical monospace capital o
U+1D67F	P	variable	mathematical monospace capital p
U+1D680	Q	variable	mathematical monospace capital q
U+1D681	R	variable	mathematical monospace capital r
U+1D682	S	variable	mathematical monospace capital s
U+1D683	T	variable	mathematical monospace capital t
U+1D684	U	variable	mathematical monospace capital u
U+1D685	V	variable	mathematical monospace capital v
U+1D686	W	variable	mathematical monospace capital w
U+1D687	X	variable	mathematical monospace capital x
U+1D688	Y	variable	mathematical monospace capital y

U+1D689	𝚉		variable	mathematical monospace capital z
U+1D68A	𝚊		variable	mathematical monospace small a
U+1D68B	𝚋		variable	mathematical monospace small b
U+1D68C	𝚌		variable	mathematical monospace small c
U+1D68D	𝚍		variable	mathematical monospace small d
U+1D68E	𝚎		variable	mathematical monospace small e
U+1D68F	𝚏		variable	mathematical monospace small f
U+1D690	𝚐		variable	mathematical monospace small g
U+1D691	𝚑		variable	mathematical monospace small h
U+1D692	𝚒		variable	mathematical monospace small i
U+1D693	𝚓		variable	mathematical monospace small j
U+1D694	𝚔		variable	mathematical monospace small k
U+1D695	𝚕		variable	mathematical monospace small l
U+1D696	𝚖		variable	mathematical monospace small m
U+1D697	𝚗		variable	mathematical monospace small n
U+1D698	𝚘		variable	mathematical monospace small o
U+1D699	𝚙		variable	mathematical monospace small p
U+1D69A	𝚚		variable	mathematical monospace small q
U+1D69B	𝚛		variable	mathematical monospace small r
U+1D69C	𝚜		variable	mathematical monospace small s
U+1D69D	𝚝		variable	mathematical monospace small t
U+1D69E	𝚞		variable	mathematical monospace small u
U+1D69F	𝚟		variable	mathematical monospace small v
U+1D6A0	𝚠		variable	mathematical monospace small w
U+1D6A1	𝚡		variable	mathematical monospace small x
U+1D6A2	𝚢		variable	mathematical monospace small y
U+1D6A3	𝚣		variable	mathematical monospace small z
U+1D6A4	𝚤	\imath	ordinary	mathematical italic small dotless i
U+1D6A5	𝚥	\jmath	ordinary	mathematical italic small dotless j
U+1D6A8	𝚨		variable	mathematical bold capital alpha
U+1D6A9	𝚩		variable	mathematical bold capital beta
U+1D6AA	𝚪		variable	mathematical bold capital gamma
U+1D6AB	𝚫		variable	mathematical bold capital delta
U+1D6AC	𝚬		variable	mathematical bold capital epsilon
U+1D6AD	𝚭		variable	mathematical bold capital zeta
U+1D6AE	𝚮		variable	mathematical bold capital eta
U+1D6AF	𝚯		variable	mathematical bold capital theta
U+1D6B0	𝚰		variable	mathematical bold capital iota
U+1D6B1	𝚱		variable	mathematical bold capital kappa
U+1D6B2	𝚲		variable	mathematical bold capital lamda
U+1D6B3	𝚳		variable	mathematical bold capital mu
U+1D6B4	𝚴		variable	mathematical bold capital nu
U+1D6B5	𝚵		variable	mathematical bold capital xi
U+1D6B6	𝚶		variable	mathematical bold capital omicron
U+1D6B7	𝚷		variable	mathematical bold capital pi
U+1D6B8	𝚸		variable	mathematical bold capital rho
U+1D6B9	𝚹		variable	mathematical bold capital theta symbol

U+1D6BA	𝚺	variable	mathematical bold capital sigma
U+1D6BB	𝚻	variable	mathematical bold capital tau
U+1D6BC	𝚼	variable	mathematical bold capital upsilon
U+1D6BD	𝚽	variable	mathematical bold capital phi
U+1D6BE	𝚾	variable	mathematical bold capital chi
U+1D6BF	𝚿	variable	mathematical bold capital psi
U+1D6C0	𝛀	variable	mathematical bold capital omega
U+1D6C1	𝛁	differential	mathematical bold nabla
U+1D6C2	𝛂	variable	mathematical bold small alpha
U+1D6C3	𝛃	variable	mathematical bold small beta
U+1D6C4	𝛄	variable	mathematical bold small gamma
U+1D6C5	𝛅	variable	mathematical bold small delta
U+1D6C6	𝛆	variable	mathematical bold small epsilon
U+1D6C7	𝛇	variable	mathematical bold small zeta
U+1D6C8	𝛈	variable	mathematical bold small eta
U+1D6C9	𝛉	variable	mathematical bold small theta
U+1D6CA	𝛊	variable	mathematical bold small iota
U+1D6CB	𝛋	variable	mathematical bold small kappa
U+1D6CC	𝛌	variable	mathematical bold small lamda
U+1D6CD	𝛍	variable	mathematical bold small mu
U+1D6CE	𝛎	variable	mathematical bold small nu
U+1D6CF	𝛏	variable	mathematical bold small xi
U+1D6D0	𝛐	variable	mathematical bold small omicron
U+1D6D1	𝛑	variable	mathematical bold small pi
U+1D6D2	𝛒	variable	mathematical bold small rho
U+1D6D3	𝛓	variable	mathematical bold small final sigma
U+1D6D4	𝛔	variable	mathematical bold small sigma
U+1D6D5	𝛕	variable	mathematical bold small tau
U+1D6D6	𝛖	variable	mathematical bold small upsilon
U+1D6D7	𝛗	variable	mathematical bold small phi
U+1D6D8	𝛘	variable	mathematical bold small chi
U+1D6D9	𝛙	variable	mathematical bold small psi
U+1D6DA	𝛚	variable	mathematical bold small omega
U+1D6DB	𝛛	differential	mathematical bold partial differential
U+1D6DC	𝛜	variable	mathematical bold epsilon symbol
U+1D6DD	𝛝	variable	mathematical bold theta symbol
U+1D6DE	𝛞	variable	mathematical bold kappa symbol
U+1D6DF	𝛟	variable	mathematical bold phi symbol
U+1D6E0	𝛠	variable	mathematical bold rho symbol
U+1D6E1	𝛡	variable	mathematical bold pi symbol
U+1D6E2	𝛢	variable	mathematical italic capital alpha
U+1D6E3	𝛣	variable	mathematical italic capital beta
U+1D6E4	𝛤	variable	mathematical italic capital gamma
U+1D6E5	𝛥	variable	mathematical italic capital delta
U+1D6E6	𝛦	variable	mathematical italic capital epsilon
U+1D6E7	𝛧	variable	mathematical italic capital zeta
U+1D6E8	𝛨	variable	mathematical italic capital eta
U+1D6E9	𝛩	variable	mathematical italic capital theta

U+1D6EA	I		variable	mathematical italic capital iota
U+1D6EB	K		variable	mathematical italic capital kappa
U+1D6EC	Λ		variable	mathematical italic capital lamda
U+1D6ED	M		variable	mathematical italic capital mu
U+1D6EE	N		variable	mathematical italic capital nu
U+1D6EF	Ξ		variable	mathematical italic capital xi
U+1D6F0	O		variable	mathematical italic capital omicron
U+1D6F1	Π		variable	mathematical italic capital pi
U+1D6F2	P		variable	mathematical italic capital rho
U+1D6F3	$\varTheta$		variable	mathematical italic capital theta symbol
U+1D6F4	Σ		variable	mathematical italic capital sigma
U+1D6F5	T		variable	mathematical italic capital tau
U+1D6F6	Υ		variable	mathematical italic capital upsilon
U+1D6F7	Φ		variable	mathematical italic capital phi
U+1D6F8	X		variable	mathematical italic capital chi
U+1D6F9	Ψ		variable	mathematical italic capital psi
U+1D6FA	Ω		variable	mathematical italic capital omega
U+1D6FB	∇		differential	mathematical italic nabla
U+1D6FC	α		variable	mathematical italic small alpha
U+1D6FD	β		variable	mathematical italic small beta
U+1D6FE	γ		variable	mathematical italic small gamma
U+1D6FF	δ		variable	mathematical italic small delta
U+1D700	ε		variable	mathematical italic small epsilon
U+1D701	ζ		variable	mathematical italic small zeta
U+1D702	η		variable	mathematical italic small eta
U+1D703	θ		variable	mathematical italic small theta
U+1D704	ι		variable	mathematical italic small iota
U+1D705	κ		variable	mathematical italic small kappa
U+1D706	λ		variable	mathematical italic small lamda
U+1D707	μ		variable	mathematical italic small mu
U+1D708	ν		variable	mathematical italic small nu
U+1D709	ξ		variable	mathematical italic small xi
U+1D70A	o		variable	mathematical italic small omicron
U+1D70B	π		variable	mathematical italic small pi
U+1D70C	ρ		variable	mathematical italic small rho
U+1D70D	ς		variable	mathematical italic small final sigma
U+1D70E	σ		variable	mathematical italic small sigma
U+1D70F	τ		variable	mathematical italic small tau
U+1D710	υ		variable	mathematical italic small upsilon
U+1D711	φ		variable	mathematical italic small phi
U+1D712	χ		variable	mathematical italic small chi
U+1D713	ψ		variable	mathematical italic small psi
U+1D714	ω		variable	mathematical italic small omega
U+1D715	∂		differential	mathematical italic partial differential
U+1D716	ϵ		variable	mathematical italic epsilon symbol
U+1D717	ϑ	\vartheta	variable	mathematical italic theta symbol
U+1D718	$\varkappa$	\varkappa	variable	mathematical italic kappa symbol

U+1D719	𝜙		variable	mathematical italic phi symbol
U+1D71A	𝜚	\varrho	variable	mathematical italic rho symbol
U+1D71B	𝜛		ordinary	mathematical italic pi symbol
U+1D71C	𝜜		variable	mathematical bold italic capital alpha
U+1D71D	𝜝		variable	mathematical bold italic capital beta
U+1D71E	𝜞		variable	mathematical bold italic capital gamma
U+1D71F	𝜟		variable	mathematical bold italic capital delta
U+1D720	𝜠		variable	mathematical bold italic capital epsilon
U+1D721	𝜡		variable	mathematical bold italic capital zeta
U+1D722	𝜢		variable	mathematical bold italic capital eta
U+1D723	𝜣		variable	mathematical bold italic capital theta
U+1D724	𝜤		variable	mathematical bold italic capital iota
U+1D725	𝜥		variable	mathematical bold italic capital kappa
U+1D726	𝜦		variable	mathematical bold italic capital lamda
U+1D727	𝜧		variable	mathematical bold italic capital mu
U+1D728	𝜨		variable	mathematical bold italic capital nu
U+1D729	𝜩		variable	mathematical bold italic capital xi
U+1D72A	𝜪		variable	mathematical bold italic capital omicron
U+1D72B	𝜫		variable	mathematical bold italic capital pi
U+1D72C	𝜬		variable	mathematical bold italic capital rho
U+1D72D	𝜭		variable	mathematical bold italic capital theta symbol
U+1D72E	𝜮		variable	mathematical bold italic capital sigma
U+1D72F	𝜯		variable	mathematical bold italic capital tau
U+1D730	𝜰		variable	mathematical bold italic capital upsilon
U+1D731	𝜱		variable	mathematical bold italic capital phi
U+1D732	𝜲		variable	mathematical bold italic capital chi
U+1D733	𝜳		variable	mathematical bold italic capital psi
U+1D734	𝜴		variable	mathematical bold italic capital omega
U+1D735	𝜵		differential	mathematical bold italic nabla
U+1D736	𝜶		variable	mathematical bold italic small alpha
U+1D737	𝜷		variable	mathematical bold italic small beta
U+1D738	𝜸		variable	mathematical bold italic small gamma
U+1D739	𝜹		variable	mathematical bold italic small delta
U+1D73A	𝜺		variable	mathematical bold italic small epsilon
U+1D73B	𝜻		variable	mathematical bold italic small zeta
U+1D73C	𝜼		variable	mathematical bold italic small eta
U+1D73D	𝜽		variable	mathematical bold italic small theta
U+1D73E	𝜾		variable	mathematical bold italic small iota
U+1D73F	𝜿		variable	mathematical bold italic small kappa

U+1D740	𝝀	variable	mathematical bold italic small lamda
U+1D741	𝝁	variable	mathematical bold italic small mu
U+1D742	𝝂	variable	mathematical bold italic small nu
U+1D743	𝝃	variable	mathematical bold italic small xi
U+1D744	𝝄	variable	mathematical bold italic small omicron
U+1D745	𝝅	variable	mathematical bold italic small pi
U+1D746	𝝆	variable	mathematical bold italic small rho
U+1D747	𝝇	variable	mathematical bold italic small final sigma
U+1D748	𝝈	variable	mathematical bold italic small sigma
U+1D749	𝝉	variable	mathematical bold italic small tau
U+1D74A	𝝊	variable	mathematical bold italic small upsilon
U+1D74B	𝝋	variable	mathematical bold italic small phi
U+1D74C	𝝌	variable	mathematical bold italic small chi
U+1D74D	𝝍	variable	mathematical bold italic small psi
U+1D74E	𝝎	variable	mathematical bold italic small omega
U+1D74F	𝝏	differential	mathematical bold italic partial differential
U+1D750	𝝐	variable	mathematical bold italic epsilon symbol
U+1D751	𝝑	variable	mathematical bold italic theta symbol
U+1D752	𝝒	variable	mathematical bold italic kappa symbol
U+1D753	𝝓	variable	mathematical bold italic phi symbol
U+1D754	𝝔	variable	mathematical bold italic rho symbol
U+1D755	𝝕	variable	mathematical bold italic pi symbol
U+1D756	𝝖	variable	mathematical sans-serif bold capital alpha
U+1D757	𝝗	variable	mathematical sans-serif bold capital beta
U+1D758	𝝘	variable	mathematical sans-serif bold capital gamma
U+1D759	𝝙	variable	mathematical sans-serif bold capital delta
U+1D75A	𝝚	variable	mathematical sans-serif bold capital epsilon
U+1D75B	𝝛	variable	mathematical sans-serif bold capital zeta
U+1D75C	𝝜	variable	mathematical sans-serif bold capital eta
U+1D75D	𝝝	variable	mathematical sans-serif bold capital theta
U+1D75E	𝝞	variable	mathematical sans-serif bold capital iota
U+1D75F	𝝟	variable	mathematical sans-serif bold capital kappa

U+1D760	𝝠	variable	mathematical sans-serif bold capital lamda
U+1D761	𝝡	variable	mathematical sans-serif bold capital mu
U+1D762	𝝢	variable	mathematical sans-serif bold capital nu
U+1D763	𝝣	variable	mathematical sans-serif bold capital xi
U+1D764	𝝤	variable	mathematical sans-serif bold capital omicron
U+1D765	𝝥	variable	mathematical sans-serif bold capital pi
U+1D766	𝝦	variable	mathematical sans-serif bold capital rho
U+1D767	𝝧	variable	mathematical sans-serif bold capital theta symbol
U+1D768	𝝨	variable	mathematical sans-serif bold capital sigma
U+1D769	𝝩	variable	mathematical sans-serif bold capital tau
U+1D76A	𝝪	variable	mathematical sans-serif bold capital upsilon
U+1D76B	𝝫	variable	mathematical sans-serif bold capital phi
U+1D76C	𝝬	variable	mathematical sans-serif bold capital chi
U+1D76D	𝝭	variable	mathematical sans-serif bold capital psi
U+1D76E	𝝮	variable	mathematical sans-serif bold capital omega
U+1D76F	𝝯	differential	mathematical sans-serif bold nabla
U+1D770	𝝰	variable	mathematical sans-serif bold small alpha
U+1D771	𝝱	variable	mathematical sans-serif bold small beta
U+1D772	𝝲	variable	mathematical sans-serif bold small gamma
U+1D773	𝝳	variable	mathematical sans-serif bold small delta
U+1D774	𝝴	variable	mathematical sans-serif bold small epsilon
U+1D775	𝝵	variable	mathematical sans-serif bold small zeta
U+1D776	𝝶	variable	mathematical sans-serif bold small eta
U+1D777	𝝷	variable	mathematical sans-serif bold small theta
U+1D778	𝝸	variable	mathematical sans-serif bold small

			iota
U+1D779	𝝹	variable	mathematical sans-serif bold small kappa
U+1D77A	𝝺	variable	mathematical sans-serif bold small lamda
U+1D77B	𝝻	variable	mathematical sans-serif bold small mu
U+1D77C	𝝼	variable	mathematical sans-serif bold small nu
U+1D77D	𝝽	variable	mathematical sans-serif bold small xi
U+1D77E	𝝾	variable	mathematical sans-serif bold small omicron
U+1D77F	𝝿	variable	mathematical sans-serif bold small pi
U+1D780	𝞀	variable	mathematical sans-serif bold small rho
U+1D781	𝞁	variable	mathematical sans-serif bold small final sigma
U+1D782	𝞂	variable	mathematical sans-serif bold small sigma
U+1D783	𝞃	variable	mathematical sans-serif bold small tau
U+1D784	𝞄	variable	mathematical sans-serif bold small upsilon
U+1D785	𝞅	variable	mathematical sans-serif bold small phi
U+1D786	𝞆	variable	mathematical sans-serif bold small chi
U+1D787	𝞇	variable	mathematical sans-serif bold small psi
U+1D788	𝞈	variable	mathematical sans-serif bold small omega
U+1D789	𝞉	differential	mathematical sans-serif bold partial differential
U+1D78A	𝞊	variable	mathematical sans-serif bold epsilon symbol
U+1D78B	𝞋	variable	mathematical sans-serif bold theta symbol
U+1D78C	𝞌	variable	mathematical sans-serif bold kappa symbol
U+1D78D	𝞍	variable	mathematical sans-serif bold phi symbol
U+1D78E	𝞎	variable	mathematical sans-serif bold rho symbol
U+1D78F	𝞏	variable	mathematical sans-serif bold pi symbol
U+1D790	𝞐	variable	mathematical sans-serif bold italic capital alpha
U+1D791	𝞑	variable	mathematical sans-serif bold italic capital beta

U+1D792	𝞒	variable	mathematical sans-serif bold italic capital gamma
U+1D793	𝞓	variable	mathematical sans-serif bold italic capital delta
U+1D794	𝞔	variable	mathematical sans-serif bold italic capital epsilon
U+1D795	𝞕	variable	mathematical sans-serif bold italic capital zeta
U+1D796	𝞖	variable	mathematical sans-serif bold italic capital eta
U+1D797	𝞗	variable	mathematical sans-serif bold italic capital theta
U+1D798	𝞘	variable	mathematical sans-serif bold italic capital iota
U+1D799	𝞙	variable	mathematical sans-serif bold italic capital kappa
U+1D79A	𝞚	variable	mathematical sans-serif bold italic capital lamda
U+1D79B	𝞛	variable	mathematical sans-serif bold italic capital mu
U+1D79C	𝞜	variable	mathematical sans-serif bold italic capital nu
U+1D79D	𝞝	variable	mathematical sans-serif bold italic capital xi
U+1D79E	𝞞	variable	mathematical sans-serif bold italic capital omicron
U+1D79F	𝞟	variable	mathematical sans-serif bold italic capital pi
U+1D7A0	𝞠	variable	mathematical sans-serif bold italic capital rho
U+1D7A1	𝞡	variable	mathematical sans-serif bold italic capital theta symbol
U+1D7A2	𝞢	variable	mathematical sans-serif bold italic capital sigma
U+1D7A3	𝞣	variable	mathematical sans-serif bold italic capital tau
U+1D7A4	𝞤	variable	mathematical sans-serif bold italic capital upsilon
U+1D7A5	𝞥	variable	mathematical sans-serif bold italic capital phi
U+1D7A6	𝞦	variable	mathematical sans-serif bold italic capital chi
U+1D7A7	𝞧	variable	mathematical sans-serif bold italic capital psi
U+1D7A8	𝞨	variable	mathematical sans-serif bold italic capital omega
U+1D7A9	𝞩	differential	mathematical sans-serif bold italic nabla

U+1D7AA	𝞪	variable	mathematical sans-serif bold italic small alpha
U+1D7AB	𝞫	variable	mathematical sans-serif bold italic small beta
U+1D7AC	𝞬	variable	mathematical sans-serif bold italic small gamma
U+1D7AD	𝞭	variable	mathematical sans-serif bold italic small delta
U+1D7AE	𝞮	variable	mathematical sans-serif bold italic small epsilon
U+1D7AF	𝞯	variable	mathematical sans-serif bold italic small zeta
U+1D7B0	𝞰	variable	mathematical sans-serif bold italic small eta
U+1D7B1	𝞱	variable	mathematical sans-serif bold italic small theta
U+1D7B2	𝞲	variable	mathematical sans-serif bold italic small iota
U+1D7B3	𝞳	variable	mathematical sans-serif bold italic small kappa
U+1D7B4	𝞴	variable	mathematical sans-serif bold italic small lamda
U+1D7B5	𝞵	variable	mathematical sans-serif bold italic small mu
U+1D7B6	𝞶	variable	mathematical sans-serif bold italic small nu
U+1D7B7	𝞷	variable	mathematical sans-serif bold italic small xi
U+1D7B8	𝞸	variable	mathematical sans-serif bold italic small omicron
U+1D7B9	𝞹	variable	mathematical sans-serif bold italic small pi
U+1D7BA	𝞺	variable	mathematical sans-serif bold italic small rho
U+1D7BB	𝞻	variable	mathematical sans-serif bold italic small final sigma
U+1D7BC	𝞼	variable	mathematical sans-serif bold italic small sigma
U+1D7BD	𝞽	variable	mathematical sans-serif bold italic small tau
U+1D7BE	𝞾	variable	mathematical sans-serif bold italic small upsilon
U+1D7BF	𝞿	variable	mathematical sans-serif bold italic small phi
U+1D7C0	𝟀	variable	mathematical sans-serif bold italic small chi
U+1D7C1	𝟁	variable	mathematical sans-serif bold italic small psi

U+1D7C2	𝟂	variable	mathematical sans-serif bold italic small omega
U+1D7C3	𝟃	differential	mathematical sans-serif bold italic partial differential
U+1D7C4	𝟄	variable	mathematical sans-serif bold italic epsilon symbol
U+1D7C5	𝟅	variable	mathematical sans-serif bold italic theta symbol
U+1D7C6	𝟆	variable	mathematical sans-serif bold italic kappa symbol
U+1D7C7	𝟇	variable	mathematical sans-serif bold italic phi symbol
U+1D7C8	𝟈	variable	mathematical sans-serif bold italic rho symbol
U+1D7C9	𝟉	variable	mathematical sans-serif bold italic pi symbol
U+1D7CA	𝟊	variable	mathematical bold capital digamma
U+1D7CB	𝟋	variable	mathematical bold small digamma
U+1D7CE	𝟎	digit	mathematical bold digit zero
U+1D7CF	𝟏	digit	mathematical bold digit one
U+1D7D0	𝟐	digit	mathematical bold digit two
U+1D7D1	𝟑	digit	mathematical bold digit three
U+1D7D2	𝟒	digit	mathematical bold digit four
U+1D7D3	𝟓	digit	mathematical bold digit five
U+1D7D4	𝟔	digit	mathematical bold digit six
U+1D7D5	𝟕	digit	mathematical bold digit seven
U+1D7D6	𝟖	digit	mathematical bold digit eight
U+1D7D7	𝟗	digit	mathematical bold digit nine
U+1D7D8	𝟘	digit	mathematical double-struck digit zero
U+1D7D9	𝟙	digit	mathematical double-struck digit one
U+1D7DA	𝟚	digit	mathematical double-struck digit two
U+1D7DB	𝟛	digit	mathematical double-struck digit three
U+1D7DC	𝟜	digit	mathematical double-struck digit four
U+1D7DD	𝟝	digit	mathematical double-struck digit five
U+1D7DE	𝟞	digit	mathematical double-struck digit six
U+1D7DF	𝟟	digit	mathematical double-struck digit seven
U+1D7E0	𝟠	digit	mathematical double-struck digit eight
U+1D7E1	𝟡	digit	mathematical double-struck digit nine
U+1D7E2	𝟢	digit	mathematical sans-serif digit zero
U+1D7E3	𝟣	digit	mathematical sans-serif digit one
U+1D7E4	𝟤	digit	mathematical sans-serif digit two
U+1D7E5	𝟥	digit	mathematical sans-serif digit three
U+1D7E6	𝟦	digit	mathematical sans-serif digit four

U+1D7E7	𝟧		digit	mathematical sans-serif digit five
U+1D7E8	𝟨		digit	mathematical sans-serif digit six
U+1D7E9	𝟩		digit	mathematical sans-serif digit seven
U+1D7EA	𝟪		digit	mathematical sans-serif digit eight
U+1D7EB	𝟫		digit	mathematical sans-serif digit nine
U+1D7EC	𝟬		digit	mathematical sans-serif bold digit zero
U+1D7ED	𝟭		digit	mathematical sans-serif bold digit one
U+1D7EE	𝟮		digit	mathematical sans-serif bold digit two
U+1D7EF	𝟯		digit	mathematical sans-serif bold digit three
U+1D7F0	𝟰		digit	mathematical sans-serif bold digit four
U+1D7F1	𝟱		digit	mathematical sans-serif bold digit five
U+1D7F2	𝟲		digit	mathematical sans-serif bold digit six
U+1D7F3	𝟳		digit	mathematical sans-serif bold digit seven
U+1D7F4	𝟴		digit	mathematical sans-serif bold digit eight
U+1D7F5	𝟵		digit	mathematical sans-serif bold digit nine
U+1D7F6	𝟶		digit	mathematical monospace digit zero
U+1D7F7	𝟷		digit	mathematical monospace digit one
U+1D7F8	𝟸		digit	mathematical monospace digit two
U+1D7F9	𝟹		digit	mathematical monospace digit three
U+1D7FA	𝟺		digit	mathematical monospace digit four
U+1D7FB	𝟻		digit	mathematical monospace digit five
U+1D7FC	𝟼		digit	mathematical monospace digit six
U+1D7FD	𝟽		digit	mathematical monospace digit seven
U+1D7FE	𝟾		digit	mathematical monospace digit eight
U+1D7FF	𝟿		digit	mathematical monospace digit nine

12.12 Letterlike Symbols

U+02102	ℂ		variable	double-struck capital c
		\complexes	ordinary	
U+02107	ℇ	\Eulerconst	variable	euler constant
U+0210A	ℊ		variable	script small g
U+0210B	ℋ		variable	script capital h
U+0210C	ℌ		variable	black-letter capital h
U+0210D	ℍ		variable	double-struck capital h
U+0210E	ℎ	\Planckconst	variable	planck constant
U+0210F	ℏ		variable	planck constant over two pi
		\hbar	variable	
		\hslash	variable	
U+02110	ℐ		variable	script capital i
U+02111	ℑ	\Im	variable	black-letter capital i
U+02112	ℒ		variable	script capital l

U+02113	ℓ	\ell	variable	script small l
U+02115	ℕ	\naturalnumbers	variable	double-struck capital n
U+02118	℘	\wp	variable	script capital p
U+02119	ℙ	\primes	variable	double-struck capital p
U+0211A	ℚ	\rationals	variable	double-struck capital q
U+0211B	ℛ		variable	script capital r
U+0211C	ℜ	\Re	variable	black-letter capital r
U+0211D	ℝ	\reals	variable	double-struck capital r
U+02124	ℤ	\integers	variable	double-struck capital z
U+02128	ℨ		variable	black-letter capital z
U+02129	℩	\turnediota	variable	turned greek small letter iota
U+0212C	ℬ		variable	script capital b
U+0212D	ℭ		variable	black-letter capital c
U+0212F	ℯ		variable	script small e
U+02130	ℰ		variable	script capital e
U+02131	ℱ		variable	script capital f
U+02133	ℳ		variable	script capital m
U+02134	ℴ		variable	script small o
U+02135	ℵ	\aleph	variable	alef symbol
U+02136	ℶ	\beth	variable	bet symbol
U+02137	ℷ	\gimel	variable	gimel symbol
U+02138	ℸ	\daleth	variable	dalet symbol
U+0213C	ℼ		variable	double-struck small pi
U+0213D	ℽ		variable	double-struck small gamma
U+0213E	ℾ		variable	double-struck capital gamma
U+0213F	ℿ		variable	double-struck capital pi
U+02140	⅀		variable	double-struck n-ary summation
U+02141	⅁	\Game	variable	turned sans-serif capital g
U+02142	⅂		variable	turned sans-serif capital l
U+02143	⅃		variable	reversed sans-serif capital l
U+02144	⅄		variable	turned sans-serif capital y
U+02145	ⅅ		variable	double-struck italic capital d
		\differentialD	differential	
U+02146	ⅆ		variable	double-struck italic small d
		\differentiald	differential	
U+02147	ⅇ		variable	double-struck italic small e
		\exponentiale	exponential	
U+02148	ⅈ		variable	double-struck italic small i
		\imaginaryi	imaginary	
U+02149	ⅉ		variable	double-struck italic small j
		\imaginaryj	imaginary	
U+0214B	⅋	\upand	binary	turned ampersand

12.13 Miscellaneous Technical

U+02308	⌈	\lceil	open	left ceiling
U+02309	⌉	\rceil	close	right ceiling
U+0230A	⌊	\lfloor	open	left floor
U+0230B	⌋	\rfloor	close	right floor

U+02320	⌠		ordinary	top half integral
U+02321	⌡		ordinary	bottom half integral
U+0237C	⍼		ordinary	right angle with downwards zigzag arrow
U+0239B	⎛		ordinary	left parenthesis upper hook
U+0239C	⎜		ordinary	left parenthesis extension
U+0239D	⎝		ordinary	left parenthesis lower hook
U+0239E	⎞		ordinary	right parenthesis upper hook
U+0239F	⎟		ordinary	right parenthesis extension
U+023A0	⎠		ordinary	right parenthesis lower hook
U+023A1	⎡		ordinary	left square bracket upper corner
U+023A2	⎢		ordinary	left square bracket extension
U+023A3	⎣		ordinary	left square bracket lower corner
U+023A4	⎤		ordinary	right square bracket upper corner
U+023A5	⎥		ordinary	right square bracket extension
U+023A6	⎦		ordinary	right square bracket lower corner
U+023A7	⎧		ordinary	left curly bracket upper hook
U+023A8	⎨		ordinary	left curly bracket middle piece
U+023A9	⎩		ordinary	left curly bracket lower hook
U+023AA	⎪		ordinary	curly bracket extension
U+023AB	⎫		ordinary	right curly bracket upper hook
U+023AC	⎬		ordinary	right curly bracket middle piece
U+023AD	⎭		ordinary	right curly bracket lower hook
U+023AE	⎮		ordinary	integral extension
U+023AF	⎯		ordinary	horizontal line extension
U+023B0	⎰	\lmoustache	open	upper left or lower right curly bracket section
U+023B1	⎱	\rmoustache	close	upper right or lower left curly bracket section
U+023B2	⎲		ordinary	summation top
U+023B3	⎳		ordinary	summation bottom
U+023B4	⎴	\overbracket	topaccent	top square bracket
U+023B5	⎵	\underbracket	botaccent	bottom square bracket
U+023B7	⎷		ordinary	radical symbol bottom
U+023D0	⏐		ordinary	vertical line extension
U+023DC	⏜	\overparent	topaccent	top parenthesis
U+023DD	⏝	\underparent	botaccent	bottom parenthesis
U+023DE	⏞	\overbrace	topaccent	top curly bracket
U+023DF	⏟	\underbrace	botaccent	bottom curly bracket
U+023E0	⏠		topaccent	top tortoise shell bracket

U+023E1	⏡	botaccent	bottom tortoise shell bracket
U+023E2	⏢	ordinary	white trapezium

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