Wissenschaftliches Programmieren

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julia LaTeX

Text mode vs. math mode

```
The solution is $x = 42$.

text: f(x) = a + b - c, ax

math: $f(x) = a + b - c$, $ax$
```

The solution is $x = 42$.
text: f(x) = a + b - c, ax
math: $f(x) = a + b - c$, ax

- math mode: letters (variables) are *italic*,
- spaces in the source are ignored – the spacing follows math rules
- `$ # % & ~ ^ _ \ { }` are special characters
- in math mode `^` and `_` make super- and subscripts
- LaTeX math syntax is a de-facto standard: Markdown, Jupyter, Obsidian
- always load `mathtools` (it loads `amsmath`)

Inline vs. display math

```
The golden ratio
$\varphi = \frac{1+\sqrt5}{2}$ satisfies
$1/\varphi = \varphi - 1$ and
\[
\varphi = \frac{1+\sqrt5}{2}.
\]
Numbered:
\begin{equation}\label{eq:phi}
  \varphi^2 = \varphi + 1,
\end{equation}
see \eqref{eq:phi}.
```

The golden ratio $\varphi = \frac{1+\sqrt5}{2}$ satisfies $1/\varphi = \varphi - 1$ and

$$\varphi = \frac{1+\sqrt5}{2}.$$

Numbered:

$$\varphi^2 = \varphi + 1, \tag{1}$$

see (1).

- inline `$...$` keeps the line height: fractions are small
- display `\[...\]` is centered, full size, with space above and below; `equation` adds a number

Superscripts, subscripts, roots, accents

`$x_i$, $x_{ij}$, $x_i^2$, $e^{-x^2}$`	x_i, x_{ij}, x_i^2, e^{-x^2}
`$x^{2^n}$, ${(x^2)}^n$, $f'(x)$, $f''(x)$`	x^{2^n}, $(x^2)^n$, $f'(x)$, $f''(x)$
`$\sqrt{2}$, $\sqrt[3]{x}$, $\sqrt{1+\sqrt{x}}$`	$\sqrt{2}$, $\sqrt[3]{x}$, $\sqrt{1+\sqrt{x}}$
`$\hat x$, $\tilde x$, $\dot x$, $\vec v$`	$\hat{x}$, $\tilde{x}$, $\dot{x}$, $\vec{v}$
`$\bar z$, $\overline{z+w}$, $\widehat{xyz}$`	$\bar{z}$, $\overline{z+w}$, $\widehat{xyz}$

- `^` and `_` take *one* token, use brackets for longer sub/superscripts: `e^{-x^2}`
- the prime `'` is a superscript; `f''` is fine
- `\hat`, `\tilde`, `\bar`: single letters; `\widehat`, `\widetilde`, `\overline`: longer expressions

Fractions and binomial coefficients

```
inline $\frac{1}{2}$, forced $\dfrac{1}{2}$
\[
\frac{1}{2} \quad \tfrac{1}{2} \quad
   \binom{n}{k} = \frac{n!}{k!\,(n-k)!}
\]
\[
\frac{1}{2+\frac{1}{3+\frac{1}{4}}}
   \qquad
   \cfrac{1}{2+\cfrac{1}{3+\cfrac{1}{4}}}
\]
```

inline $\frac{1}{2}$, forced $\dfrac{1}{2}$

$$\frac{1}{2} \quad \tfrac{1}{2} \quad \binom{n}{k} = \frac{n!}{k!\,(n-k)!}$$

$$\frac{1}{2+\frac{1}{3+\frac{1}{4}}} \qquad \cfrac{1}{2+\cfrac{1}{3+\cfrac{1}{4}}}$$

- `\frac` chooses the size from the context; `\dfrac` is always display size
- nested `\frac` gets smaller and smaller; `\cfrac` keeps *every* level in display size
- in running text, complicated fractions are often better written as $a/(b+c)$

Greek letters

α \alpha	β \beta	γ \gamma	δ \delta	ϵ \epsilon
ε \varepsilon	ζ \zeta	η \eta	θ \theta	ϑ \vartheta
ι \iota	κ \kappa	λ \lambda	μ \mu	ν \nu
ξ \xi	π \pi	ρ \rho	ϱ \varrho	σ \sigma
τ \tau	υ \upsilon	ϕ \phi	φ \varphi	χ \chi
ψ \psi	ω \omega			
Γ \Gamma	Δ \Delta	Θ \Theta	Λ \Lambda	Ξ \Xi
Π \Pi	Σ \Sigma	Υ \Upsilon	Φ \Phi	Ψ \Psi
Ω \Omega				

- no `\Alpha`, `\Beta`, `\omicron`, …: these look like Latin letters, write `A`, `B`, `o`
- shape variants: `\epsilon` vs. `\varepsilon`, `\theta` vs. `\vartheta`, `\rho` vs. `\varrho`, `\phi` vs. `\varphi`

Relations, operators, arrows

$\le$ \le	$\ge$ \ge	$\neq$ \ne	$\approx$ \approx	$\equiv$ \equiv
$\sim$ \sim	$\simeq$ \simeq	$\ll$ \ll	$\gg$ \gg	$\propto$ \propto
$\in$ \in	$\notin$ \notin	$\subset$ \subset	$\subseteq$ \subseteq	$\mid$ \mid
$\pm$ \pm	$\cdot$ \cdot	$\times$ \times	$\circ$ \circ	$\setminus$ \setminus
$\cup$ \cup	$\cap$ \cap	$\otimes$ \otimes	∇ \nabla	∂ \partial
$\forall$ \forall	$\exists$ \exists	$\emptyset$ \emptyset	$\varnothing$ \varnothing	∞ \infty
$\to$ \to	$\mapsto$ \mapsto	$\Rightarrow$ \Rightarrow	$\iff$ \iff	$\implies$ \implies
$\langle$ \langle	$\rangle$ \rangle	$\ldots$ \ldots	$\cdots$ \cdots	$\ddots$ \ddots

- write `\cdot` or `\times`, never `*`;
- write `\langle x,y\rangle`, not `<x,y>`
- `a_1+\dots+a_n` and `x_1,\dots,x_n`: `\dots` chooses the height itself

Sums, integrals, limits

```
inline: $\sum_{i=1}^n a_i$,
$\int_0^1 f(x)\,\mathrm{d}x$
\[
   \sum_{i=1}^{n} a_i \quad \prod_{k\ge1} p_k
   \quad \int_0^\infty f(x)\,\mathrm{d}x
\]
\[
   \lim_{n\to\infty} \Bigl(1+\frac1n\Bigr)^n
   \quad
   \sum_{\substack{1\le i\le n\\ i\ne j}}
   a_{ij}
\]
```

inline: $\sum_{i=1}^n a_i$, $\int_0^1 f(x)\,\mathrm{d}x$

$$\sum_{i=1}^{n} a_i \quad \prod_{k\ge1} p_k \quad \int_0^\infty f(x)\,\mathrm{d}x$$

$$\lim_{n\to\infty} \Bigl(1+\frac1n\Bigr)^n \quad \sum_{\substack{1\le i\le n\\ i\ne j}} a_{ij}$$

- limits are *below/above* in display math and *beside* inline
- `\substack{..\\..}`: several lines under a sum
- a thin space `\,` before the differential: `f(x)\,\mathrm{d}x`

Function names and operators

```
wrong: $sin x$ \quad right: $\sin x$

$\log_2 n$, $\exp(x)$, $\det A$, $\max_i a_i$

$\operatorname{sgn}(x)$, $\operatorname{rank} A$

% in the preamble:
% \DeclareMathOperator{\tr}{tr}
% \DeclareMathOperator*{\argmax}{arg\,max}
$\tr A$
\[ \argmax_{x\in[0,1]} f(x) \]
```

wrong: $sinx$ right: $\sin x$

$\log_2 n$, $\exp(x)$, $\det A$, $\max_i a_i$

$\operatorname{sgn}(x)$, $\operatorname{rank} A$

$\tr A$

$$\argmax_{x\in[0,1]} f(x)$$

- function names are *upright* with correct spacing: `\sin`, `\log`, `\det`, `\gcd`, …
- once: `\operatorname{sgn}`; repeatedly: `\DeclareMathOperator` in the preamble
- the `*` form puts limits below, like `\max` and `\lim`

Spacing in math mode

source	ab	a\!b	a\,b	a\:b	a\;b	a\quad b	a\qquad b
width	0	$-\frac{3}{18}$ em	$\frac{3}{18}$ em	$\frac{4}{18}$ em	$\frac{5}{18}$ em	1 em	2 em
result	ab	ab	$a\,b$	$a\,b$	$a\,b$	$a\quad b$	$a\qquad b$

```
$\int_0^1 f(x)\,\mathrm{d}x$, $\sqrt{2}\,x$

$\Gamma_{\!2}$ vs.\ $\Gamma_2$, $n/\!\log n$

$x\in A,\; y\in B$

$f(x) = 0 \quad \text{for all } x>0$
```

$\int_0^1 f(x)\,\mathrm{d}x$, $\sqrt{2}\,x$

$\Gamma_{\!2}$ vs.\ Γ_2, $n/\!\log n$

$x\in A,\; y\in B$

$f(x) = 0 \quad \text{for all } x>0$

- spacing is automatic – add spaces only where LaTeX cannot know the meaning
- `\,` before differentials and after roots, `\quad` before text conditions, `\!` to pull things together

Math alphabets

```
$\mathbb{N} \subset \mathbb{Z} \subset
 \mathbb{Q} \subset \mathbb{R}$

$\mathcal{O}(n^2)$, $\mathcal{L}(V,W)$

$\mathrm{d}x$, $\mathrm{e}$,
$x_{\mathrm{max}}$ vs.\ $x_{max}$

$\mathbf{A}x$, $\symbf{Ax}$, $\symbf{\alpha}$

$\{x \mid x > 0 \text{ and } x \ne 1\}$
```

$\mathbb{N} \subset \mathbb{Z} \subset \mathbb{Q} \subset \mathbb{R}$

$\mathcal{O}(n^2)$, $\mathcal{L}(V,W)$

$\mathrm{d}x$, e, x_{max} vs. x_{max}

$\mathbf{A}x$, $\symbf{Ax}$, $\symbf{\alpha}$

$\{x \mid x > 0 \text{ and } x \ne 1\}$

- `\mathbb` for number sets, `\mathcal` for e.g. $\mathcal{O}$-notation
- `\mathrm` for upright *symbols* (constants, differentials, indices that are words); `\text{...}` for *words* in formulas
- bold: `\mathbf` (upright, Latin only); with `unicode-math` `\symbf` (also Greek)

Delimiters and their sizes

```
\[
   (\frac{a}{b}) \quad
   \left(\frac{a}{b}\right) \quad
   \bigl(\tfrac{a}{b}\bigr)
\]
\[
   \Bigl[\sum_i x_i\Bigr]^2 \quad
   \bigl\lvert x \bigr\rvert \quad
   \langle x, y \rangle
\]
\[
   \bigl\{ x \in \mathbb{R} \bigm| x > 0 \bigr\}
   \quad
   \left.\frac{\partial f}{\partial x}
   \right|_{x=0}
\]
```

$$\left(\frac{a}{b}\right) \quad \left(\frac{a}{b}\right) \quad \left(\frac{a}{b}\right)$$

$$\left[\sum_i x_i\right]^2 \quad |x| \quad \langle x, y \rangle$$

$$\left\{ x \in \mathbb{R} \,\middle|\, x > 0 \right\} \quad \left.\frac{\partial f}{\partial x}\right|_{x=0}$$

- manual sizes `\big`, `\Big`, `\bigg`, `\Bigg`; with `l`, `r`, `m` (`\bigl(`, `\bigm|`) for correct spacing
- `\left(...\right)` sizes automatically, `\left.` is an invisible delimiter

Matrices

```
\[    A = \begin{pmatrix} a & b \\ c & d
        \end{pmatrix}, \quad
     \det A = \begin{vmatrix} a & b \\ c & d
              \end{vmatrix}
\]
\[ \begin{bmatrix}
     a_{11} & \cdots & a_{1n} \\
     \vdots & \ddots & \vdots \\
     a_{m1} & \cdots & a_{mn}
   \end{bmatrix} \quad
   \begin{bmatrix*}[r] 1 & -1 \\ -10 & 2
   \end{bmatrix*}
\]
inline: $\begin{psmallmatrix} 1 & 0 \\ 0 & 1
         \end{psmallmatrix}$
```

$$A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}, \quad \det A = \begin{vmatrix} a & b \\ c & d \end{vmatrix}$$

$$\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \quad \begin{bmatrix*}[r] 1 & -1 \\ -10 & 2 \end{bmatrix*}$$

inline: $\begin{psmallmatrix} 1 & 0 \\ 0 & 1 \end{psmallmatrix}$

- `&` separates columns, `\\` ends a row; columns are centered;
  `matrix` (no brackets), `pmatrix` `()`, `bmatrix` `[]`, `Bmatrix` `{}`, `vmatrix` `||`, `Vmatrix` `||||`
- `mathtools`: `bmatrix*[r]` aligns columns right; `psmallmatrix` etc. for inline math

align

```
\begin{align}
  x   &= y+1  &  w   &= z        \\
  2x  &= -y   &  3w  &= z+1  \nonumber \\
  x+y &= 3    &  w+z &= 1   \label{eq:sys}
\end{align}
```

$$
\begin{aligned}
x &= y+1 & w &= z && (2)\\
2x &= -y & 3w &= z+1 \\
x+y &= 3 & w+z &= 1 && (3)
\end{aligned}
$$

- `&` before the relation; further `&` start the next column pair
- one number per line; `\nonumber` removes it, `\tag{*}` sets your own; `align*`: no numbers

gather and multline

```
\begin{gather}
  a^2 + b^2 = c^2 \\
  e^{i\pi} + 1 = 0
\end{gather}
\begin{multline}
  (a+b)^4 = a^4 + 4a^3b + 6a^2b^2 \\
    + 4ab^3 + b^4
\end{multline}
```

$$a^2 + b^2 = c^2 \tag{4}$$

$$e^{i\pi} + 1 = 0 \tag{5}$$

$$(a+b)^4 = a^4 + 4a^3b + 6a^2b^2 + 4ab^3 + b^4 \tag{6}$$

- `gather`: several centered equations, *no* alignment, one number each
- `multline`: *one* equation that is too long for a line; first line flush left, last line flush right, one number
- break long formulas *before* a binary operator ($+$, $-$) and repeat nothing

split, aligned, \shortintertext

```
\begin{equation}\label{eq:binom}
\begin{split}
  (a+b)^2 &= (a+b)(a+b) \\
          &= a^2 + 2ab + b^2
\end{split}
\end{equation}
\begin{align}
  f(x)  &= x^3 - x \\
\shortintertext{and therefore}
  f'(x) &= 3x^2 - 1
\end{align}
\[ \left.\begin{aligned}
     x + y &= 1 \\  x - y &= 0
   \end{aligned}\right\}
   \implies x = y = \tfrac12 \]
```

$$\begin{aligned}(a+b)^2 &= (a+b)(a+b)\\ &= a^2+2ab+b^2\end{aligned} \tag{7}$$

$$f(x) = x^3 - x \tag{8}$$

and therefore

$$f'(x) = 3x^2 - 1 \tag{9}$$

$$\left.\begin{aligned} x+y &= 1\\ x-y &= 0\end{aligned}\right\} \implies x = y = \tfrac{1}{2}$$

- `split` inside `equation`: aligned lines, *one* number; `aligned`: an aligned block as a part of a larger formula
- `\intertext`, `\shortintertext` (`mathtools`): text that keeps the alignment

Piecewise functions: cases and dcases

```
\[ \operatorname{sgn}(x) =
   \begin{cases}
     -1, & x < 0, \\
      0, & x = 0, \\
      1, & x > 0.
   \end{cases}
\]
\[ f(x) = \begin{cases}
     \frac{1}{x}, & x \ne 0, \\
     0,           & \text{otherwise}
   \end{cases}
\]
\[ f(x) = \begin{dcases}
     \frac{1}{x}, & x \ne 0, \\
     0,           & \text{otherwise}
   \end{dcases} \]
```

$$\operatorname{sgn}(x) = \begin{cases} -1, & x < 0, \\ 0, & x = 0, \\ 1, & x > 0. \end{cases}$$

$$f(x) = \begin{cases} \frac{1}{x}, & x \ne 0, \\ 0, & \text{otherwise} \end{cases}$$

$$f(x) = \begin{cases} \dfrac{1}{x}, & x \ne 0, \\ 0, & \text{otherwise} \end{cases}$$

- two columns `value & condition`, both flush left; words with `\text{...}`
- `cases` sets the entries in *text* size; `dcases` (`mathtools`) in display size
- `cases*` (`mathtools`): the condition column is text mode

mathtools: amsmath and more

```
% preamble:
% \DeclarePairedDelimiter\abs{\lvert}{\rvert}
% \DeclarePairedDelimiter\norm{\lVert}{\rVert}

$\abs{x}$, $\norm{v}$, $\abs[\big]{\sin x}$
\[ \
   norm*{\frac{x}{2}} \qquad
   a \coloneqq b \qquad a := b
\]
\[
  A \xrightarrow[\text{below}]{f\circ g} B
\]
```

$|x|$, $\|v\|$, $\left|\sin x\right|$

$$norm * \frac{x}{2} \qquad a \coloneqq b \qquad a := b$$

$$A \xrightarrow[\text{below}]{f \circ g} B$$

- `\usepackage{mathtools}` loads `amsmath`, fixes some of its problems and adds more
- `\DeclarePairedDelimiter`: your own bracket pair; `\norm*{..}` sizes automatically, `\norm[\big]{..}` manually
- `\coloneqq`: colon centered on the =; extensible arrows `\xrightarrow`, `\xleftrightarrow`

Typical mistakes

wrong		right	
`$sin x$`	$sinx$	`$\sin x$`	$\sin x$
`$x_max$`	x_max	`$x_{\max}$`	$x_{\max}$
`$e^-x^2$`	e^-x^2	`$e^{-x^2}$`	e^{-x^2}
`$\int f(x) dx$`	$\int f(x) dx$	`$\int f(x)\,\mathrm{d}x$`	$\int f(x)\,\mathrm{d}x$
`$f:A->B$`	$f:A->B$	`$f\colon A\to B$`	$f\colon A\to B$
`$a<<b$, $a*b$`	$a << b$, $a * b$	`$a\ll b$, $a\cdot b$`	$a \ll b$, $a \cdot b$
`$<x,y>$`	$<x,y>$	`$\langle x,y\rangle$`	$\langle x,y\rangle$
`$x_1,...,x_n$`	$x_1,...,x_n$	`$x_1,\dots,x_n$`	$x_1,\dots,x_n$

- obsolete: `$$...$$`, `eqnarray`, `{a \over b}` – use `\[...\]`, `align`, `\frac`

Unicode input and Julia

```
% unicode-math (LuaLaTeX, XeLaTeX)
\[ ∑_{k=0}^{∞} \frac{x^k}{k!} = e^x,
   \quad α ∈ ℝ \]
$∀ ε > 0 \; ∃ δ > 0\colon
 |x-y| < δ ⇒ |f(x)-f(y)| < ε$
```

$$\sum_{k=0}^{\infty} \frac{x^k}{k!} = e^x, \quad \alpha \in \mathbb{R}$$

$$\forall \varepsilon > 0\ \exists \delta > 0\colon |x-y| < \delta \Rightarrow |f(x)-f(y)| < \varepsilon$$

```
julia> α = 0.5      # \alpha<TAB>, same names as in LaTeX
julia> using Latexify, LaTeXStrings
julia> latexify(:(x^2/(1+y)))
L"$\frac{x^{2}}{1 + y}$"
julia> plot(x -> sin(α*x); label = L"\sin(\alpha x)")
```

- `unicode-math` accepts Unicode symbols directly — typed in the editor or in the Julia REPL as `\alpha<TAB>`
- `Latexify.jl`: Julia expressions, arrays, tables → LaTeX; `LaTeXStrings.jl`: `L"..."` without doubled backslashes