INFO1 – Mathematical formulas in LaTeX-ben

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Inline and display style formulas

- $e^{i\pi}+1=0$ is an *inline formula*, while

$$\sum_{n=0}^{\infty} \frac{f^{(n)}(x_0)}{n!}(x-x_0)^n$$

  is *display style*.

- `$e^{i\pi}+1=0$ is an \emph{inline formula}, while`
  `\[`
  `\sum_{n=0}^\infty \frac{f^{(n)}(x_0)}{n!}(x-x_0)^n`
  `\]`
  `is \emph{display style}.`

- To ensure math mode in a macro: = `\ensuremath`: Let $\mathbb{R}$ be the set of real numbers and $x \in \mathbb{R}$.

- `\newcommand*{\R}{\ensuremath{\mathbb{R}}}`
  `Let \R\ be the set of real numbers and $x\in\R$.`

Inline and display style formulas

- Inline
  - `$formula$`
  - `\(formula\)`
  - `\begin{math}formula\end{math}`
- Single line display style formula
  - `\[ formula \]`
  - `\begin{equation*} formula \end{equation*}` $\in$ amsmath package
  - `$$ formula $$` (original TEX command, don't use in LATEX)
  - `\begin{displaymath} formula \end{displaymath}`
- Single line display style formula with numbering
  - `\begin{equation}\label{eq:...} formula \end{equation}`
- Display style formulas are centered by default, if we want to align them to the left use `\documentclass[fleqn]{article}`
- The number appears on the right side by default, to change that use `\documentclass[leqno]{article}`

Display style multi-line formulas (amsmath package)

Environment name	Short description
\[\], \begin{equation*}	single line formula, no numbering
\begin{equation}	single line formula, numbered
\begin{multline*}	single line formula, wrapped
\begin{gather*}	multiple formulas below each other
\begin{align*}	equations in multiple lines and columns
\begin{alignat*}	same as the previous one, but with column width
\begin{flalign*}	same as align, but fit to width
\begin{gathered}	same as gather, for partial formulas
\begin{aligned}	same as align, for partial formulas
\begin{alignedat}	same as alignat, for partial formulas
\begin{split}	separating a single line formula into multiple lines
\begin{subequations}	multiple numbered formulas

Line break – single line formula into multiple lines

- In display style

$$\begin{aligned} 100 &= 1+8+27+64 = \\ &= 1+3+5+7+9+ \\ &\quad +11+13+15+17+19 \end{aligned} \tag{1}$$

- ```
  \begin{equation}\label{eq:split}
    \begin{split}
      100 &= 1+8+27+64 = {}\\
          &= 1+3+5+7+9+{}\\
          &\quad+11+13+15+17+19
    \end{split}
  \end{equation}
  ```
  ```

Multiple formulas without aligning

- Display style

$$x + y, \tag{2}$$

$$x^2 + xy + y^2. \tag{3}$$

- ```
  \begin{gather}
    x+y, \\
    x^2+xy+y^2.
  \end{gather}
  ```
- Inside a display style

$$x + y,$$

$$x^2 + xy + y^2.$$

- ```
  \[
    \begin{gathered}
      x+y, \\  x^2+xy+y^2.
    \end{gathered}
  \]
  ```

Multiple formulas aligned, separated

- With right align

$$
\begin{aligned}
x &= y + z && (1)\\
&= bd + bc && \text{since } ac = bd\\
&= 1000 && \text{substituted}
\end{aligned}
$$

- ```
  \begin{align*}
    x&=y+z    && (\ref{eq:split}) \\
     &=bd+bc  && \text{since }ac=bd \\
     &=1000   && \text{substituted}
  \end{align*}
  ```
  ```

Multiple formulas aligned

- Right-left align

$$\begin{aligned} 13x + 4y &= 9 \\ 3x - 12y + 23z &= 14 \end{aligned}$$

- ```
  \begin{alignat*}{4}
    13x &+{} &  4y &    &      & ={} & 9\\
     3x &-{} & 12y &+{} & 23z  & ={} &14
  \end{alignat*}
  ```
- what is the error?

$$\begin{aligned} 13x+ 4y &= 9 \\ 3x-12y+23z &=14 \end{aligned}$$
  ```

System of equations with the systeme package

- $$\begin{aligned} 13x + \ \ 4y \qquad\quad &= 9 \\ 3x - 12y + 23z &= 14 \end{aligned}$$
- ```
  \usepackage{systeme}
  \sysdelim..  %% two kinds of parenthesis can be used
  \systeme{13x+4y=9, 3x-12y+23z=14}
  ```
- Default: `\sysdelim\{.`

$$\begin{cases} 13x + \ \ 4y \qquad\quad = 9 \\ \ \ 3x - 12y + 23z = 14 \end{cases}$$
  ```

Forbidden to use!

- wrong:

$$\begin{aligned} 1+3 &= 4 \\ 1+3+5 &= 9 \end{aligned}$$

- right:

$$\begin{aligned} 1+3 &= 4 \\ 1+3+5 &= 9 \end{aligned}$$

-
```
\begin{eqnarray*} %% DO NOT USE
    1+3 & = & 4\\
  1+3+5 & = & 9
\end{eqnarray*}
```

-
```
\begin{align*} %% THIS IS RIGHT
    1+3 & = 4\\
  1+3+5 & = 9
\end{align*}
```

Referencing equations

- The inequality (5) follows from the equation (4).

$$x = ac + bc \tag{4}$$

$$y > dc \tag{5}$$

- ```
  The inequality \eqref{eq:2} follows
  from the equation (\ref{eq:1}).
  \begin{gather}
      x=ac+bc \label{eq:1}\\
      y>dc \label{eq:2}
  \end{gather}
  ```
  ```

Referencing subequations

- The inequality (6b) follows from the equation (6a).

$$x = ac + bc \tag{6a}$$

$$y > dc \tag{6b}$$

- The inequality \eqref{eq:sub2} follows from the equation (\ref{eq:sub1}).

```
\begin{subequations}
  \begin{gather}
      x=ac+bc \label{eq:sub1}\\
      y>dc \label{eq:sub2}
  \end{gather}
\end{subequations}
```

Formula fonts

- Boldface: \mathbf, Blackboard bold: \mathbb
- $\mathbb{R}$, $\mathbf{a}+\mathbf{b}$, $\sum_{i=1}^{n} \boldsymbol{a_i}+\boldsymbol{\eta}$
- ```
  \newcommand*{\R}{\ensuremath{\mathbb{R}}}
  \newcommand*{\vkt}{\mathbf}
  \R, $\vkt{a}+\vkt{b}$,
  $\bm{\sum_{i=1}^n a_i+\eta}$  %%% \usepackage{bm}
  ```
- $x(t)+\dot{x}(t)+\ddot{x}(t)$, $\tilde{z}=\hat{z}$
- `$x(t)+\dot{x}(t)+\ddot{x}(t)$, $\tilde{z}=\hat{z}$`
- α, ξ, ψ, Θ, Ω, $\aleph$
- `$\alpha$, $\xi$, $\psi$, $\Theta$, $\Omega$, $\aleph$`
- ϵ, ε, θ, ϑ, ϕ, φ, ρ, ϱ
- `$\epsilon$, $\varepsilon$, $\theta$, $\vartheta$, $\phi$, $\varphi$, $\rho$, $\varrho$`
  ```

Operators, operations

- $A \setminus (B \cup C) = A \cap D$,
  $\lnot(b\lor c) = \lnot b\land\lnot c$,
  $x^3\pm y^3 = (x\pm y)(x^2\mp xy+y^2)$,
  $\mathfrak A \oplus \mathfrak B$.
- `$A \setminus ( B \cup C ) = A \cap D$,\\`
  `$\lnot(b\lor c) = \lnot b\land\lnot c$,\\`
  `$x^3\pm y^3 = (x\pm y)(x^2\mp xy+y^2)$,\\`
  `$\mathfrak A \oplus \mathfrak B$. %% eufrak package`
- a^b, a^{b^c}, a_b, a_{b^c}
- `$a^b$, $a^{b^c}$, $a_b$, $a_{b^c}$`
- $\frac{a}{b}$, $\binom{a}{b}$,
- `$\frac ab$, $\binom ab$`

Operators, functions

- Inline: $\sum_{i=1}^{n} a_i$, $\int_a^b f$. Display style:

$$\sum_{i=1}^{n} a_i, \int_a^b f, \int\limits_a^b f.$$

- Inline:
  `$\sum_{i=1}^{n}a_i$, $\int_a^b f$. Display style:`
  `\[\sum_{i=1}^{n}a_i,\ \int_a^b f,\ \int\limits_a^b f.\]`
- Trace:

$$\operatorname*{Trace}_K F.$$

- `\DeclareMathOperator*{\Trace}{Trace} % in the preamble`
  `\[`
  `  \Trace_KF.`
  `\]`

Differential operator

- The differential operator is a curios one in typography, from the left it is an operator, but from the right it is a mathematical symbol:

$$\mathrm{d}x, \frac{\mathrm{d}y}{\mathrm{d}x}, \int_0^\infty \varphi(x)\,\mathrm{d}x$$

- ```
  \newcommand*\diff{\mathop{}\!\mathrm{d}}
  \[
    \diff x, \frac{\diff y}{\diff x},
    \int_0^\infty \varphi(x)\diff x
  \]
  ```
- For an integral, without macro definition:

  ```
  \int_0^\infty \varphi(x)\,\mathrm dx  %% or \mathrm{d}x
  ```
- Explanation: The `\,` leaves exactly as much space as needed before an operator. The `\!` is the same length, but negative.
  ```

Relation symbols

- $a < b$, $a \neq c$, $a \geq d$, $a \gg c$, $x := a + 1$,
- `$a<b$, $a\ne c$, $a\ge d$, $a\gg c$, $x:=a+1$,`
- $2 \mid n$, $2 \nmid n$, $e \parallel f$, $x \in \mathbb{R}^+$, $y \notin \mathrm{Z}$, $A \subset B$, $B \supseteq C$.
- `$2\mid n$, $2\nmid n$, $e\parallel f$, $x\in \mathbb{R}^+$, $y\notin\mathrm{Z}$, $A\subset B$, $B\supseteq C$.`
- $a\rho b$ is the product of three symbols, $a \rho b$ is a relation.
- `\newcommand*{\RO}{\mathrel{\rho}}`
  `$a\rho b$ is the product of three symbols, $a\RO b$ is a relation.`
- $A \xrightarrow{f} B$, $f(x) \overset{\text{def}}{=} x^2 - 1$.
- `$A \xrightarrow{f} B$, $f(x) \overset{\text{def}}{=} x^2-1$`

Brackets

- `\left`, `\right`: $|-x| = |+x|$, $|-x| = |+x|$
- `$|-x|=|+x|$`, `$\left|-x\right|=\left|+x\right|$`
- $\left(1+\left(1+\left(1+x\right)^2\right)^2\right)^2$
- `$\left(1+\left(1+\left(1+x\right)^2\right)^2\right)^2$`
- $\langle a, b\rangle$ (this isn't right: $< a, b >$)
- `$\left<a,b\right>$`
- an important example:

$$\int_a^b x^n \,\mathrm{d}x = \frac{x^{n+1}}{n+1}\bigg|_a^b$$

- ```
  \newcommand*\diff{\mathop{}\!\mathrm{d}}
  \int_a^b x^n \diff x =
  \left. \frac{x^{n+1}}{n+1} \right|_a^b
  ```
  ```

Cases

$$f(x) = \begin{cases} 0 & \text{if } x \text{ is rational,} \\ 1 & \text{if } x \text{ irrational.} \end{cases}$$

```
\[
  f(x) =
   \begin{cases}
     0 & \text{if $x$ is rational,}\\
     1 & \text{if $x$ irrational.}
   \end{cases}
\]
```

Misc. symbols

- Root: $\sqrt[3]{\alpha}$,

$$\sqrt{2+\sqrt{2+\sqrt{2+\sqrt{2}}}}.$$

- `\sqrt[3]{\alpha}, \sqrt{ 2+\sqrt{ 2+\sqrt{ 2+\sqrt{2}}}}`
- dots: $\ldots$, $\ldots$, $\cdots$, $\vdots$, $\ddots$.
- `\dots`, in math mode: `\ldots`, `\cdots`, `\vdots`, `\ddots`
- multiple line subscript:

$$\sum_{\substack{1\le i<j\\ j\in J}} a_{ij},$$

- `\sum_{\substack{ 1\le i < j\\ j\in J }} a_{ij},`

Arrays, matrices

- The `array` environment:

$$\left[\begin{array}{@{}ccc@{}} 1-\lambda & 3 & 10 \\ 13 & 2-\lambda & 13-2b \\ -7 & 2 & 16-\lambda \end{array}\right]$$

- ```
  \left[
  \begin{array}{@{}ccc@{}}
    1-\lambda & 3 & 10 \\
    13 & 2-\lambda & 13-2b \\
    -7 & 2 & 16-\lambda
  \end{array}
  \right]
  ```
  ```

Arrays, matrices

- In the `array` environment numbers can be aligned to the right:

$$\left[\begin{array}{@{}rrrr@{}} 1 & -1 & \dots & -1 \\ 0 & 1 & \dots & -1 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 1 \end{array}\right]$$

```
\left[
  \begin{array}{@{}rrrr@{}}
    1 & -1 & \dots & -1 \\
    0 &  1 & \dots & -1 \\
    \vdots&\vdots&\ddots&\vdots\\
    0 &  0 & \dots &  1
  \end{array}
\right]
```

Arrays, matrices – using amsmath

- `matrix`, `pmatrix` (), `bmatrix` [], `vmatrix` ||.

$$\begin{bmatrix} 1-\lambda & 3 & 10 \\ 13 & 2-\lambda & 13-2b \\ -7 & 2 & 16-\lambda \end{bmatrix}$$

-
```
\begin{bmatrix}
  1-\lambda & 3 & 10 \\
  13 & 2-\lambda & 13-2b \\
  -7 & 2 & 16-\lambda
\end{bmatrix}
```

Theorems, definitions,...

- Defining a theorem styled environment (the name of the environment can not be def).

```
\newtheorem{Theorem}{Theorem}
\newtheorem{Defin}{Definition}
```

- Using a theorem:

```
\begin{Theorem}
  There are infinitely many prime numbers.
\end{Theorem}
\begin{Theorem}[Euclid]
  There are infinitely many prime numbers.
\end{Theorem}
```

- Independent and shared numbering

```
\newtheorem{Theorem}{Theorem}[chapter]
\newtheorem{Defin}[Theorem]{Definition}
```

Proofs

Tétel (Euclid)

There are infinitely many prime numbers.

Proof.

Proof goes here. □

```
\usepackage{amsthm}
\newtheorem{te}{Theorem}

\begin{te}[Euclid]
  There are infinitely many prime numbers.
\end{te}
\begin{proof}
  Proof goes here.
\end{proof}
```

Styles of the amsthm package

There are three styles of theorem environments in amsthm:

- \theoremstyle{plain} the default style
- \theoremstyle{definition} less emphasized style
- \theoremstyle{remark} even less emphasized
- ```
  \newtheorem{theorem}{theorem}[section]  % plain
  \theoremstyle{definition}               % definition style
  \newtheorem{defin}[theorem]{definition}
  \theoremstyle{remark}                   % remark style
  \newtheorem{remark}[theorem]{remark}
  \theoremstyle{plain}                    % plain again
  \newtheorem{lemma}{lemma}
  ```
  ```

Questions (*the answers should include examples*)

1. How do we use inline formulas, display style formulas, single line, multi-line, numbered and not numbered formulas?
2. What effect does the optional parameters `fleqn` and `leqno` of `\documentclass` have on the formulas of the document.
3. Which environment can be used for systems of equations? Which packages helps to simplify their use?
4. Which commands are used to reference the number of the formula labeled by `\label{eq:Euler}`?
5. What does the `\DeclareMathOperator` and the `\DeclareMathOperator*` command do?
6. How can we define a relation symbol from any other symbol?

Questions 2 (*the answers should include examples*)

7. What does the `\stackrel{f}{\longrightarrow}` command do?
8. How can we ensure that brackets are the right size?
9. How do we print the differential operator at the end of integrals?
10. Which environment can be used for cases?
11. What does the `\substack` command do?
12. Write the latex code of a 2×2 matrix with the `array` and the `bmatrix` environment.
13. When defining theorem styled environments, how can we modify the independent and the shared number?

Questions 3 (*the answers should include examples*)

14. a^{b^c}, $\varepsilon > 0$, $\langle a, b \rangle$, $|-x|$, $\sqrt[3]{\alpha}$
15. $a < b$, $a \neq c$, $a \geq d$, $a \leq b$, $2 \mid n$, $2 \nmid n$, $a \in A$, $a \notin B$, $A \subset B$, $B \supseteq C$.
16. $\begin{bmatrix} 1 & -1 & -1 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{bmatrix}$ $\left[\begin{array}{cc|c} 1 & 1 & 4 \\ 2 & 1 & 6 \end{array}\right]$
17. Define the command `\C` that writes the symbol a $\mathbb{C}$.
18. Reference formula a 7 where

$$\int_1^\infty \frac{1}{x}\,\mathrm{d}x \tag{7}$$

19. $\lim\limits_{x \to 0} (1+x)^{\frac{1}{x}} = \mathrm{e}$, $x_{12} = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$, $\displaystyle\sum_{n=0}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{6}$
20. $\operatorname{ctg} \dfrac{3\pi}{4}$ (`\DeclareMathOperator`)
21. $\dfrac{x_1 + x_2 + \cdots + x_n}{n} \geq \sqrt[n]{x_1 x_2 \cdots x_n}$