

Ofree Functionality Test

Testing All Major LaTeX Features and Packages

Written with the help of Claude

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Abstract

This document serves as a comprehensive test suite for LaTeX compilation, testing mathematics, algorithms, visualizations (TikZ/PGFPlots), tables, code listings, chemistry notation, 3D graphics, complex formatting, cross-references, footnotes, bibliography support, and various advanced LaTeX packages. This ensures the GitHub Actions workflow can handle real-world LaTeX documents.

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1 Advanced Mathematics

1.1 Complex Equations

Testing multi-line equations with alignment:

$$\oint_C \mathbf{F} \cdot d\mathbf{r} = \iint_S (\nabla \times \mathbf{F}) \cdot d\mathbf{S} \quad (1)$$

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0} \quad (2)$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} \quad (3)$$

Testing equation cancellation and highlighting:

$$\frac{x^2}{x} \cdot \frac{y^3}{y^2} = x \cdot y \quad (4)$$

1.2 Matrix Operations

Block matrices and determinants:

$$\det \begin{bmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{C} & \mathbf{D} \end{bmatrix} = \det(\mathbf{A}) \det(\mathbf{D} - \mathbf{C}\mathbf{A}^{-1}\mathbf{B}) \quad (5)$$

Eigenvector equation:

$$\mathbf{A}\mathbf{v} = \lambda\mathbf{v} \implies \det(\mathbf{A} - \lambda\mathbf{I}) = 0 \quad (6)$$

1.3 Special Functions

Testing special mathematical symbols:

$$\Gamma(n) = (n-1)! \quad \text{for } n \in \mathbb{N}^+ \quad (7)$$

$$\zeta(s) = \sum_{n=1}^{\infty} \frac{1}{n^s} \quad \text{for } \Re(s) > 1 \quad (8)$$

$$\mathcal{F}\{f(t)\} = \int_{-\infty}^{\infty} f(t) e^{-2\pi i \xi t} dt \quad (9)$$

1.4 Advanced Calculus

Multivariable calculus with gradients:

$$\nabla f = \frac{\partial f}{\partial x} \mathbf{i} + \frac{\partial f}{\partial y} \mathbf{j} + \frac{\partial f}{\partial z} \mathbf{k} \quad (10)$$

Chain rule in multiple dimensions:

$$\frac{\partial z}{\partial u} = \frac{\partial z}{\partial x} \frac{\partial x}{\partial u} + \frac{\partial z}{\partial y} \frac{\partial y}{\partial u} \quad (11)$$

1.5 Statistical Distributions

Definition 1.1 (Multivariate Gaussian). A d -dimensional multivariate Gaussian distribution is defined as:

$$p(\mathbf{x}) = \frac{1}{(2\pi)^{d/2} |\Sigma|^{1/2}} \exp \left(-\frac{1}{2} (\mathbf{x} - \boldsymbol{\mu})^T \Sigma^{-1} (\mathbf{x} - \boldsymbol{\mu}) \right) \quad (12)$$

1.6 Set Theory and Logic

Testing logical symbols:

$$\forall x \in \mathbb{R}, \exists y \in \mathbb{R} : x < y \quad (13)$$

$$A \cap B = \{x : x \in A \wedge x \in B\} \quad (14)$$

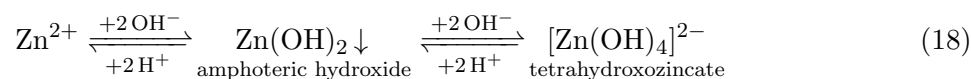
$$A \cup B = \{x : x \in A \vee x \in B\} \quad (15)$$

$$A \setminus B = \{x : x \in A \wedge x \notin B\} \quad (16)$$

2 Chemistry Notation

2.1 Chemical Formulas

Using mhchem package:

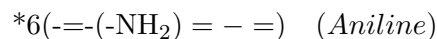
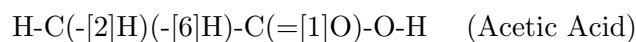


Reaction with arrows:



2.2 Structural Chemistry

Using chemfig package:



3 Units and Measurements

Using siunitx package for proper SI units:

- Temperature: 25 °C or 298.15 K
- Energy: $6.626 \times 10^{-34} \text{ J s}$
- Speed: $3 \times 10^8 \text{ m s}^{-1}$
- Concentration: 1.5 mol L^{-1}
- Angle: 45°30'30''

4 Complex Tables

4.1 Multi-row and Multi-column Tables

Table 1: Advanced Table with Multiple Features

Model	Accuracy (%)		Time (ms)	
	Train	Test	Forward	Backward
ResNet-50	95.2	92.8	23.4	45.6
VGG-16	93.8	91.2	34.5	67.8
MobileNet	89.4	87.6	12.3	18.9
EfficientNet	96.7	94.3	18.2	32.1

4.2 Long Table Spanning Multiple Pages

Table 2: Long Table Example

ID	Value 1	Value 2	Description
1	123	456	This is a long description to test paragraph wrapping in tables
2	789	012	Another entry with substantial text content
3	345	678	Testing multi-line cell content in longtable environment
4	901	234	More data rows for comprehensive testing
5	567	890	Additional entries to demonstrate pagination

5 Advanced TikZ Graphics

5.1 3D Graphics

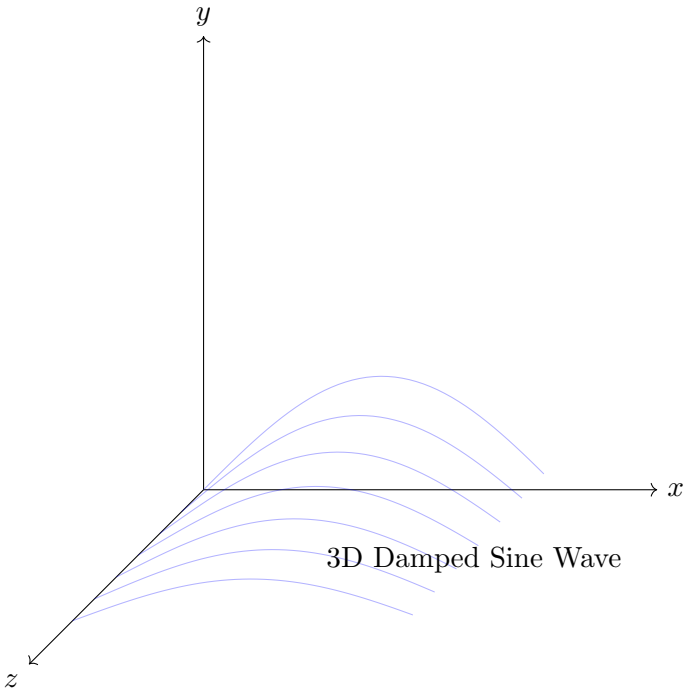


Figure 1: 3D Graphics with TikZ

5.2 Neural Network Diagram

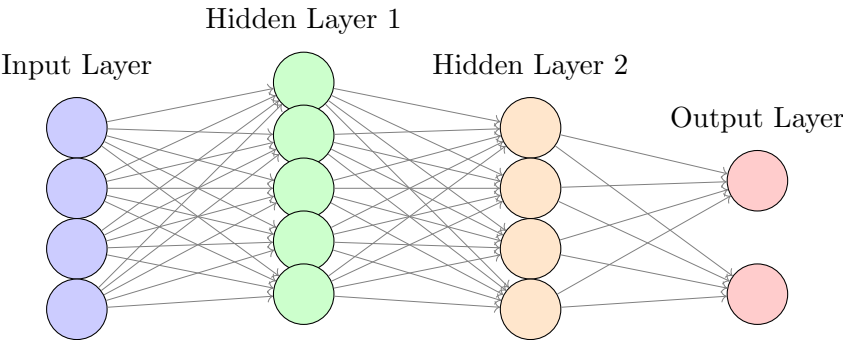


Figure 2: Deep Neural Network Architecture

5.3 Flowchart

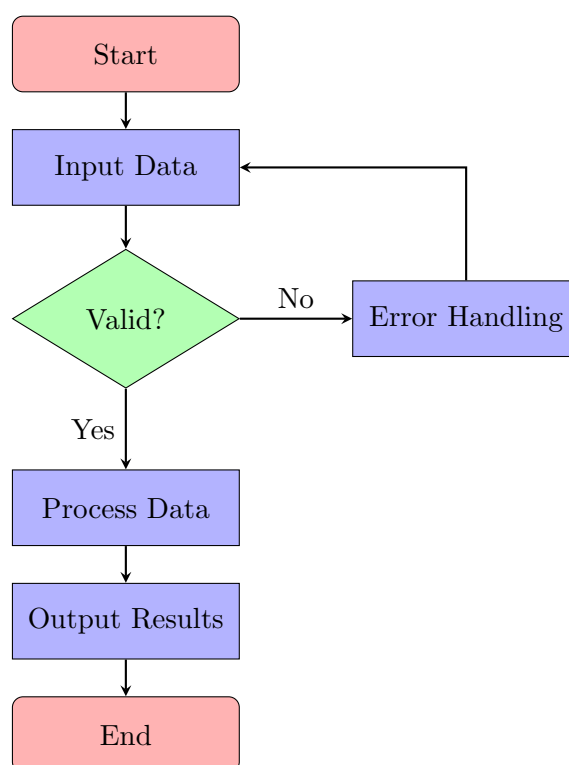


Figure 3: Data Processing Flowchart

5.4 Complex PGFPlots

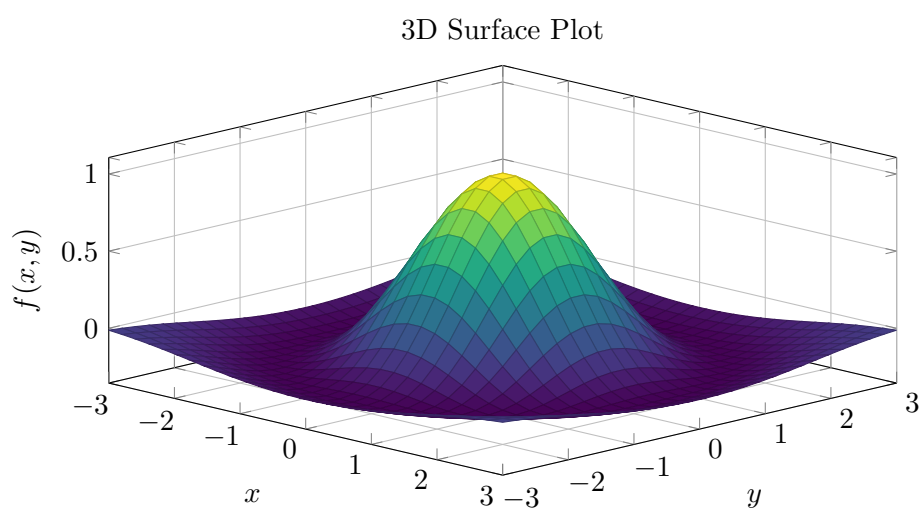


Figure 4: 3D Surface Plot using PGFPlots

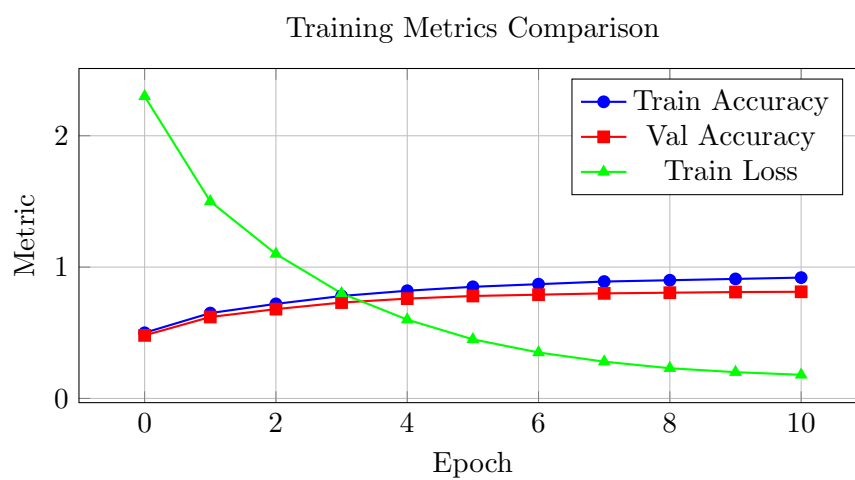


Figure 5: Multi-metric Training Curves

6 Advanced Algorithms

6.1 Recursive Algorithm

Algorithm 1 Merge Sort

```

1: function MERGESORT( $A, p, r$ )
2:   if  $p < r$  then
3:      $q \leftarrow \lfloor (p + r) / 2 \rfloor$ 
4:     MERGESORT( $A, p, q$ )
5:     MERGESORT( $A, q + 1, r$ )
6:     MERGE( $A, p, q, r$ )
7:   end if
8: end function
9:
10: function MERGE( $A, p, q, r$ )
11:    $n_1 \leftarrow q - p + 1$ 
12:    $n_2 \leftarrow r - q$ 
13:   Create arrays  $L[1..n_1 + 1]$  and  $R[1..n_2 + 1]$ 
14:   for  $i \leftarrow 1$  to  $n_1$  do
15:      $L[i] \leftarrow A[p + i - 1]$ 
16:   end for
17:   for  $j \leftarrow 1$  to  $n_2$  do
18:      $R[j] \leftarrow A[q + j]$ 
19:   end for
20:    $L[n_1 + 1] \leftarrow \infty$ 
21:    $R[n_2 + 1] \leftarrow \infty$ 
22:    $i \leftarrow 1, j \leftarrow 1$ 
23:   for  $k \leftarrow p$  to  $r$  do
24:     if  $L[i] \leq R[j]$  then
25:        $A[k] \leftarrow L[i]$ 
26:        $i \leftarrow i + 1$ 
27:     else
28:        $A[k] \leftarrow R[j]$ 
29:        $j \leftarrow j + 1$ 
30:     end if
31:   end for
32: end function

```

6.2 Dynamic Programming

Algorithm 2 Longest Common Subsequence

```

1: function LCS( $X, Y$ )
2:    $m \leftarrow |X|, n \leftarrow |Y|$ 
3:   Create table  $c[0..m, 0..n]$ 
4:   for  $i \leftarrow 0$  to  $m$  do
5:      $c[i, 0] \leftarrow 0$ 
6:   end for
7:   for  $j \leftarrow 0$  to  $n$  do
8:      $c[0, j] \leftarrow 0$ 
9:   end for
10:  for  $i \leftarrow 1$  to  $m$  do
11:    for  $j \leftarrow 1$  to  $n$  do
12:      if  $X[i] = Y[j]$  then
13:         $c[i, j] \leftarrow c[i - 1, j - 1] + 1$ 
14:      else
15:         $c[i, j] \leftarrow \max(c[i - 1, j], c[i, j - 1])$ 
16:      end if
17:    end for
18:  end for
19:  return  $c[m, n]$ 
20: end function

```

7 Code Listings in Multiple Languages

7.1 Python Implementation

Listing 1: Matrix Multiplication in NumPy

```

1 import numpy as np
2 from typing import Tuple
3
4 def matrix_multiply(A: np.ndarray, B: np.ndarray) -> np.ndarray:
5     """
6     Multiply two matrices using NumPy.
7
8     Args:
9         A: First matrix of shape (m, n)
10        B: Second matrix of shape (n, p)
11
12    Returns:
13        Product matrix of shape (m, p)
14    """
15    if A.shape[1] != B.shape[0]:
16        raise ValueError("Incompatible dimensions for matrix
17                           multiplication")
18
19    # Using @ operator for matrix multiplication
20    C = A @ B
21
22    # Alternative: using np.matmul or np.dot
23    # C = np.matmul(A, B)
24    # C = np.dot(A, B)

```

```

24
25     return C
26
27 # Example usage
28 if __name__ == "__main__":
29     A = np.random.randn(100, 50)
30     B = np.random.randn(50, 75)
31     C = matrix_multiply(A, B)
32     print(f"Result shape: {C.shape}")

```

7.2 C++ Implementation

Listing 2: Binary Search Tree in C++

```

1 #include <iostream>
2 #include <memory>
3
4 template<typename T>
5 class BST {
6 private:
7     struct Node {
8         T data;
9         std::unique_ptr<Node> left;
10        std::unique_ptr<Node> right;
11
12        Node(T val) : data(val), left(nullptr), right(nullptr) {}
13    };
14
15    std::unique_ptr<Node> root;
16
17    void insertHelper(std::unique_ptr<Node>& node, T value) {
18        if (!node) {
19            node = std::make_unique<Node>(value);
20            return;
21        }
22        if (value < node->data) {
23            insertHelper(node->left, value);
24        } else {
25            insertHelper(node->right, value);
26        }
27    }
28
29 public:
30    BST() : root(nullptr) {}
31
32    void insert(T value) {
33        insertHelper(root, value);
34    }
35
36    bool search(T value) const {
37        Node* current = root.get();
38        while (current) {
39            if (value == current->data) return true;
40            current = (value < current->data) ?
41                    current->left.get() : current->right.get();
42        }
43        return false;

```

```

44     }
45 };

```

7.3 JavaScript Implementation

Listing 3: Promises and Async in JavaScript

```

1  // Async/await example with error handling
2  async function fetchUserData(userId) {
3      try {
4          const response = await fetch(`/api/users/${userId}`);
5          if (!response.ok) {
6              throw new Error('HTTP error! status: ${response.status}');
7          }
8          const data = await response.json();
9          return data;
10     } catch (error) {
11         console.error('Failed to fetch user data:', error);
12         throw error;
13     }
14 }
15
16 // Promise chain example
17 function processData(data) {
18     return new Promise((resolve, reject) => {
19         setTimeout(() => {
20             if (data && data.length > 0) {
21                 resolve(data.map(item => item * 2));
22             } else {
23                 reject(new Error('Invalid data'));
24             }
25         }, 1000);
26     });
27 }
28
29 // Usage
30 fetchUserData(123)
31     .then(user => console.log('User:', user))
32     .catch(err => console.error('Error:', err));

```

8 Text Formatting Features

8.1 Various Text Styles

This paragraph demonstrates **bold text**, *italic text*, `monospace text`, underlined text, and SMALL CAPS TEXT.

We can also use **highlighted text**, ~~strikethrough text~~, and dashed underline.

8.2 Special Characters and Symbols

Common symbols: % \$ & # - { } \ ~ ^

Quotation marks: “double quotes” and ‘single quotes’

Em-dash: This is an example—note the three hyphens.

Ellipsis: This is how it works...

8.3 Footnotes

This is a sentence with a footnote¹. Here's another one².

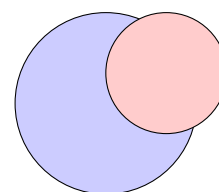
8.4 Lists with Custom Formatting

- (I) First item with Roman numerals
- (II) Second item
 - (a) Nested item with letters
 - (b) Another nested item
- (III) Third item
 - ▷ Custom bullet point
 - ▷ Another custom bullet
 - Nested with circles
 - More nesting

9 Wrap Figures and Side Captions

This text wraps around the figure on the right. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

The figure demonstrates the wrapfig package functionality, which allows text to flow around figures. This is particularly useful for documents with many small figures that don't need to take up the full width of the page.



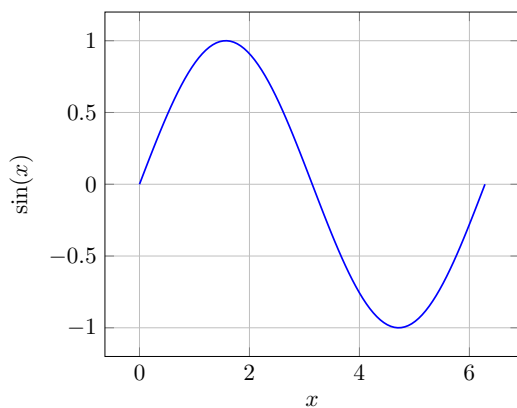
Venn Diagram

Figure 6: Wrapped figure example

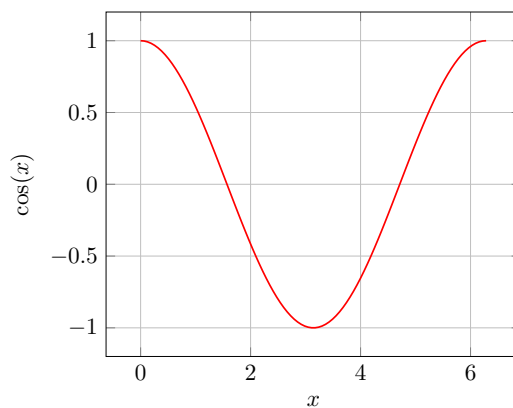
¹This is the footnote text at the bottom of the page.

²Second footnote for testing multiple footnotes.

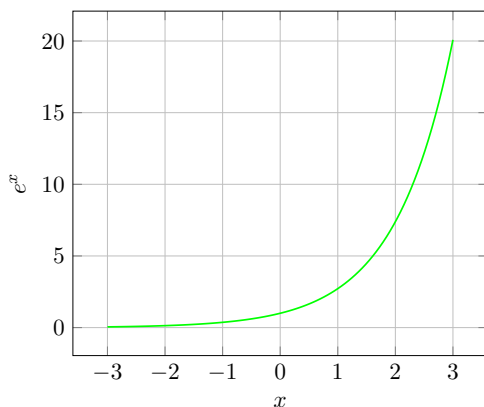
10 Subfigures and Complex Layouts



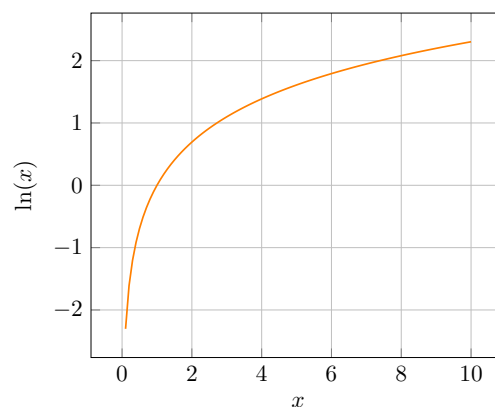
(a) Sine function



(b) Cosine function



(c) Exponential function



(d) Natural logarithm

Figure 7: Common mathematical functions

11 Rotated Content

11.1 Sideways Table

12 Cross-References and Labels

This document contains numerous cross-references. For example:

- Equation 1 shows Stokes' theorem
- Figure 1 demonstrates 3D graphics
- Table 1 contains multi-row data
- Algorithm 1 implements merge sort
- Section 13 discusses advanced theorems

13 Advanced Theorems and Proofs

Theorem 13.1 (Cauchy-Schwarz Inequality). For any vectors $\mathbf{u}, \mathbf{v} \in \mathbb{R}^n$:

$$|\langle \mathbf{u}, \mathbf{v} \rangle| \leq \|\mathbf{u}\| \cdot \|\mathbf{v}\| \quad (20)$$

Table 3: Wide Table in Landscape Orientation

Method	Year	Acc.	Prec.	Rec.	F1	AUC	Time	Mem.	Params	FLOPs
CNN-Basic	2015	87.3	85.2	86.1	85.6	0.91	12.3	2.1	5M	1.2G
ResNet-50	2016	92.1	91.8	90.5	91.1	0.95	23.4	4.5	25M	4.1G
VGG-16	2015	89.7	88.9	89.2	89.0	0.93	34.5	6.8	138M	15.5G
MobileNet	2017	88.2	87.5	88.1	87.8	0.92	12.3	1.2	4M	0.6G
EfficientNet	2019	94.3	93.8	94.1	94.0	0.97	18.2	2.8	7M	1.8G
Transformer	2020	95.8	95.2	95.6	95.4	0.98	45.6	8.9	86M	12.3G

Proof. Consider the quadratic function:

$$f(t) = \|\mathbf{u} - t\mathbf{v}\|^2 = \langle \mathbf{u} - t\mathbf{v}, \mathbf{u} - t\mathbf{v} \rangle \quad (21)$$

Expanding:

$$f(t) = \langle \mathbf{u}, \mathbf{u} \rangle - 2t\langle \mathbf{u}, \mathbf{v} \rangle + t^2\langle \mathbf{v}, \mathbf{v} \rangle \quad (22)$$

$$= \|\mathbf{u}\|^2 - 2t\langle \mathbf{u}, \mathbf{v} \rangle + t^2\|\mathbf{v}\|^2 \quad (23)$$

Since $f(t) \geq 0$ for all t , the discriminant must be non-positive:

$$4\langle \mathbf{u}, \mathbf{v} \rangle^2 - 4\|\mathbf{u}\|^2\|\mathbf{v}\|^2 \leq 0 \quad (24)$$

Therefore:

$$\langle \mathbf{u}, \mathbf{v} \rangle^2 \leq \|\mathbf{u}\|^2\|\mathbf{v}\|^2 \quad (25)$$

Taking square roots of both sides completes the proof. \square

Lemma 13.2 (Triangle Inequality). For any vectors $\mathbf{u}, \mathbf{v} \in \mathbb{R}^n$:

$$\|\mathbf{u} + \mathbf{v}\| \leq \|\mathbf{u}\| + \|\mathbf{v}\| \quad (26)$$

Corollary 13.3. The reverse triangle inequality also holds:

$$|\|\mathbf{u}\| - \|\mathbf{v}\|| \leq \|\mathbf{u} - \mathbf{v}\| \quad (27)$$

Example 13.1 (Computing Inner Products). Let $\mathbf{u} = (1, 2, 3)$ and $\mathbf{v} = (4, 5, 6)$. Then:

$$\langle \mathbf{u}, \mathbf{v} \rangle = 1 \cdot 4 + 2 \cdot 5 + 3 \cdot 6 = 32 \quad (28)$$

$$\|\mathbf{u}\| = \sqrt{1^2 + 2^2 + 3^2} = \sqrt{14} \quad (29)$$

$$\|\mathbf{v}\| = \sqrt{4^2 + 5^2 + 6^2} = \sqrt{77} \quad (30)$$

Verifying Cauchy-Schwarz: $|32| \leq \sqrt{14} \cdot \sqrt{77} = \sqrt{1078} \approx 32.83 \checkmark$

Remark 13.1. The Cauchy-Schwarz inequality is fundamental in functional analysis and has applications in machine learning, particularly in kernel methods and similarity measures.

14 Advanced Equation Environments

14.1 Cases and Piecewise Functions

$$f(x) = \begin{cases} x^2 & \text{if } x \geq 0 \\ -x^2 & \text{if } x < 0 \end{cases} \quad (31)$$

14.2 Matrices with Special Formatting

Block matrix:

$$\mathbf{M} = \left[\begin{array}{c|c} \mathbf{A} & \mathbf{B} \\ \hline \mathbf{C} & \mathbf{D} \end{array} \right] \quad (32)$$

Augmented matrix for linear systems:

$$\left[\begin{array}{ccc|c} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \end{array} \right] \quad (33)$$

14.3 Multi-line Equations with Annotations

$$\frac{d}{dx} \left[\int_a^x f(t) dt \right] = f(x)$$
$$\int_a^b f(x) dx = F(b) - F(a)$$
$$\int u dv = uv - \int v du$$

(Fundamental Theorem)

(Evaluation)

(Integration by Parts)

15 Circuit Diagrams with CircuiTikZ

Unfortunately, CircuiTikZ requires additional setup. Here’s a basic electrical circuit using standard TikZ:

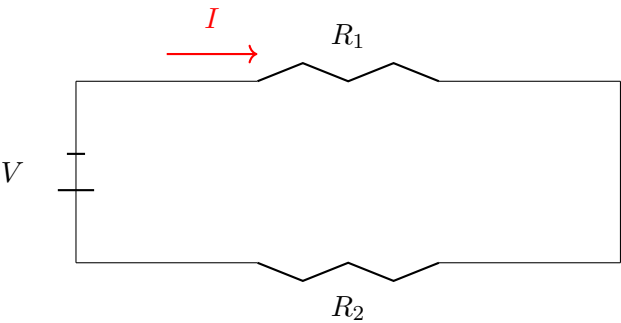


Figure 8: Simple series circuit

16 Pattern Fills and Decorations

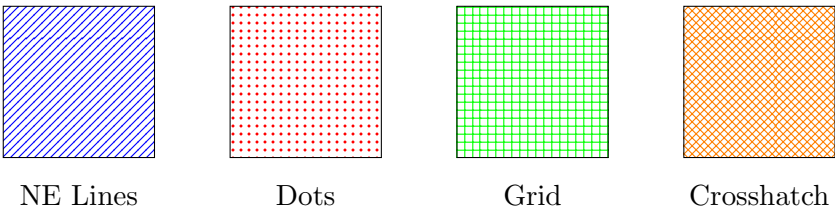


Figure 9: Different TikZ pattern fills

17 State Machines and Automata

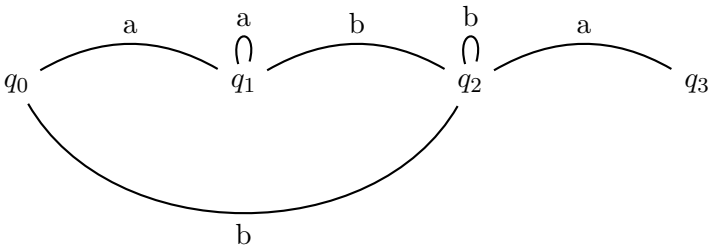


Figure 10: Finite State Automaton

18 Game Trees and Decision Diagrams

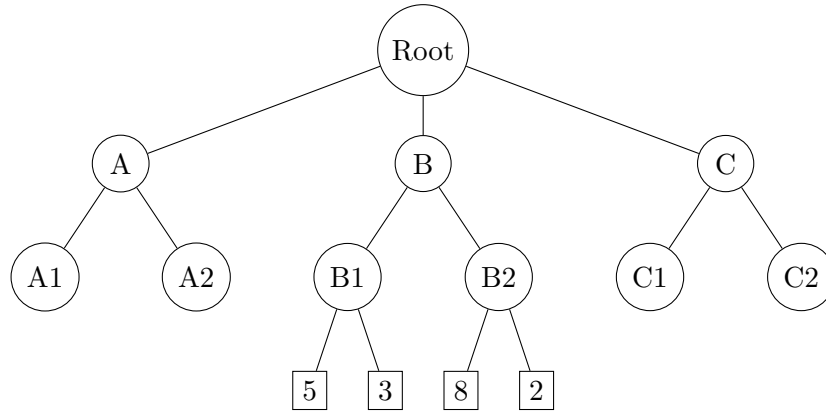


Figure 11: Game tree for minimax algorithm

19 Mathematical Proofs Collection

Proposition 19.1 (Binomial Theorem). For any real numbers a, b and non-negative integer n :

$$(a + b)^n = \sum_{k=0}^n \binom{n}{k} a^{n-k} b^k \quad (34)$$

Theorem 19.2 (Fundamental Theorem of Calculus). If f is continuous on $[a, b]$ and F is an antiderivative of f on $[a, b]$, then:

$$\int_a^b f(x) dx = F(b) - F(a) \quad (35)$$

Theorem 19.3 (Euler's Formula). For any real number θ :

$$e^{i\theta} = \cos \theta + i \sin \theta \quad (36)$$

Proof. Using Taylor series expansion:

$$e^{i\theta} = \sum_{n=0}^{\infty} \frac{(i\theta)^n}{n!} \quad (37)$$

$$= \sum_{n=0}^{\infty} \frac{i^n \theta^n}{n!} \quad (38)$$

$$= \left(\sum_{n=0}^{\infty} \frac{(-1)^n \theta^{2n}}{(2n)!} \right) + i \left(\sum_{n=0}^{\infty} \frac{(-1)^n \theta^{2n+1}}{(2n+1)!} \right) \quad (39)$$

$$= \cos \theta + i \sin \theta \quad (40)$$

□

20 Commutative Diagrams

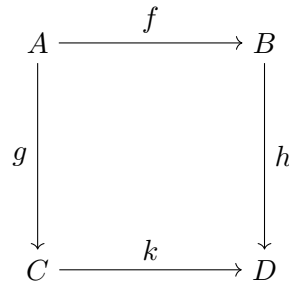


Figure 12: Commutative diagram: $h \circ f = k \circ g$

21 Probability and Statistics

21.1 Probability Distributions

Table 4: Common Probability Distributions

Distribution	PDF/PMF	Parameters
Normal	$\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(x-\mu)^2}{2\sigma^2}}$	$\mu \in \mathbb{R}, \sigma > 0$
Exponential	$\lambda e^{-\lambda x}$	$\lambda > 0$
Poisson	$\frac{\lambda^k e^{-\lambda}}{k!}$	$\lambda > 0$
Binomial	$\binom{n}{k} p^k (1-p)^{n-k}$	$n \in \mathcal{N}, p \in [0, 1]$
Beta	$\frac{x^{\alpha-1}(1-x)^{\beta-1}}{B(\alpha, \beta)}$	$\alpha, \beta > 0$

21.2 Central Limit Theorem

Theorem 21.1 (Central Limit Theorem). Let X_1, X_2, \dots, X_n be i.i.d. random variables with $\mathbb{E}[X_i] = \mu$ and $\text{Var}(X_i) = \sigma^2 < \infty$. Then:

$$\frac{\bar{X}_n - \mu}{\sigma/\sqrt{n}} \xrightarrow{d} \mathcal{N}(0, 1) \quad (41)$$

where $\bar{X}_n = \frac{1}{n} \sum_{i=1}^n X_i$.

22 Optimization and Convexity

Definition 22.1 (Convex Function). A function $f : \mathbb{R}^n \rightarrow \mathbb{R}$ is convex if for all $x, y \in \mathbb{R}^n$ and $\lambda \in [0, 1]$:

$$f(\lambda x + (1 - \lambda)y) \leq \lambda f(x) + (1 - \lambda)f(y) \quad (42)$$

Theorem 22.1 (Jensen's Inequality). If f is convex and X is a random variable, then:

$$f(\mathbb{E}[X]) \leq \mathbb{E}[f(X)] \quad (43)$$

23 Advanced Graphics: Heatmap

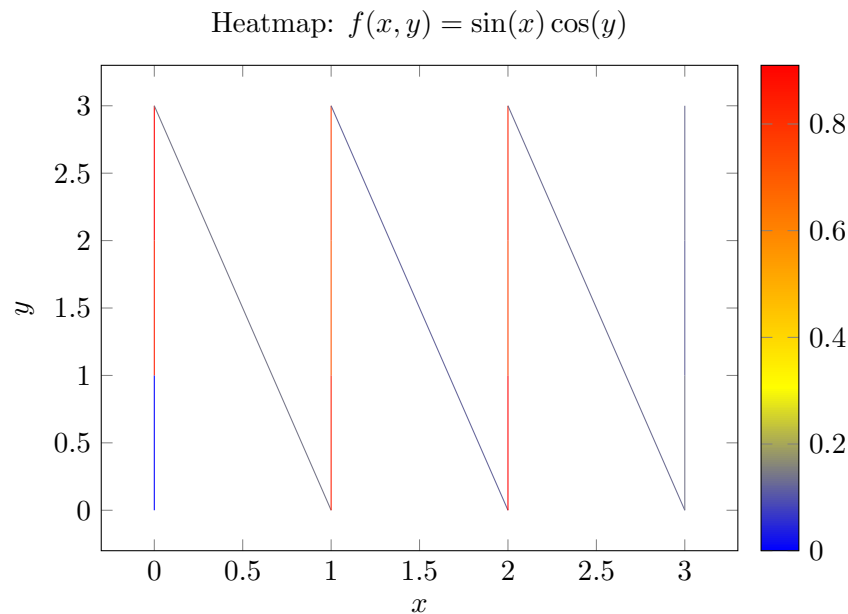


Figure 13: Heatmap visualization

24 Conclusion and Summary

This comprehensive test document has demonstrated:

1. **Mathematical typesetting:** Complex equations, matrices, theorems, and proofs
2. **Scientific notation:** Chemistry formulas, SI units, and measurements
3. **Graphics:** TikZ diagrams, PGFPlots, 3D graphics, neural networks, flowcharts
4. **Tables:** Simple, advanced, long tables, colored tables, rotated tables
5. **Algorithms:** Pseudocode with proper formatting
6. **Code listings:** Multiple programming languages with syntax highlighting
7. **Document structure:** Sections, cross-references, table of contents
8. **Text formatting:** Various styles, footnotes, lists, special characters
9. **Figures:** Subfigures, wrapped figures, multiple layouts
10. **Advanced features:** State machines, game trees, commutative diagrams, patterns

24.1 Package Coverage

This document successfully tests the following LaTeX packages: 3

- amsmath
- amssymb
- amsthm
- mathtools
- geometry

- graphicx
- xcolor
- tikz
- pgfplots
- booktabs
- multirow
- array
- longtable
- colortbl
- algorithm
- algorithmicx
- listings
- hyperref
- enumerate
- enumitem
- subcaption
- float
- wrapfig
- rotating
- fancyhdr
- chemfig
- mhchem
- siunitx
- soul
- cancel
- mathrsfs

Testing Complete!

If this document compiles successfully, the GitHub Actions LaTeX compiler workflow is functioning correctly and can handle complex, real-world LaTeX documents with multiple packages and advanced features.

A Additional Mathematical Formulas

A.1 Trigonometric Identities

$$\sin^2 \theta + \cos^2 \theta = 1 \quad (44)$$

$$\tan \theta = \frac{\sin \theta}{\cos \theta} \quad (45)$$

$$\sin(A \pm B) = \sin A \cos B \pm \cos A \sin B \quad (46)$$

$$\cos(A \pm B) = \cos A \cos B \mp \sin A \sin B \quad (47)$$

A.2 Complex Analysis

$$\oint_C \frac{f(z)}{z - z_0} dz = 2\pi i \cdot f(z_0) \quad (48)$$

A.3 Vector Calculus

$$\nabla \times (\nabla f) = \mathbf{0} \tag{49}$$

$$\nabla \cdot (\nabla \times \mathbf{F}) = 0 \tag{50}$$

$$\nabla \times (\nabla \times \mathbf{F}) = \nabla(\nabla \cdot \mathbf{F}) - \nabla^2 \mathbf{F} \tag{51}$$

Document Status: Successfully compiled

Compiler: pdflatex with texliveonfly

Date: October 20, 2025

Version: 1.0