

Introductory Complex Analysis Cheat Sheet

Field of Complex Numbers

We construct the field of complex numbers in the following quotient ring, $\mathbb{C} = \mathbb{R}[i]/(i^2 + 1)$.

Algebra of Complex Numbers

- Addition: $(a + bi) + (c + di) = (a + c) + (b + d)i$
- Multiplication: $(a + bi)(c + di) = (ac - bd) + (ad + bc)i$
- Division: $\frac{a + bi}{c + di} = \frac{(a + bi)(c - di)}{(c + di)(c - di)} = \frac{(ac + bd) + (bc - ad)i}{c^2 + d^2}$
- Square root: $\sqrt{a + bi} = z = \left(\sqrt{\frac{|a + bi| + a}{2}} + i \sqrt{\frac{|a + bi| - a}{2}} \right)$
- $\overline{a + bi} = a - bi$, $|a + bi|^2 = a^2 + b^2$

Conjugation, Absolute Value

- Complex conjugation: $\overline{z + w} = \overline{z} + \overline{w}$
 $\overline{z \cdot w} = \overline{z} \cdot \overline{w}$
 $\overline{\overline{z}} = z$
 Geometrically, conjugation is reflection over the real axis.
- Absolute value: $|z| = \sqrt{z \overline{z}}$
 $|z| = |z| \cdot |w|$
 $|z + w|^2 = |z|^2 + |w|^2 + 2\operatorname{Re}(z \overline{w})$
 $|z - w|^2 = |z|^2 + |w|^2 - 2\operatorname{Re}(z \overline{w})$
 $|z + w|^2 + |z - w|^2 = 2(|z|^2 + |w|^2)$
 The absolute value function turns the metric on $\mathbb{C}$ to complete under this metric.

Basic Topological Definitions in $\mathbb{C}$

Some basic results:

- For $a_0 \in \mathbb{C}$, $r > 0$ we denote the ball (i.e. disk) of radius r around a_0 by $B(a_0, r) = \{z \in \mathbb{C} : |z - a_0| < r\}$.
- A point $z \in \mathbb{C}$ is a **limit point** of $E \subseteq \mathbb{C}$ if $w \in B(z, r) \cap E$ contains a point other than z .
- A subset $E \subseteq \mathbb{C}$ is said to be **open** if $\forall z \in E, \exists r > 0$ s.t. $B(z, r) \subseteq E$.
- A subset $E \subseteq \mathbb{C}$ is said to be **closed**, if E^c is open in $\mathbb{C}$, or equivalently z is which contains all its limit points.

Some properties of open sets:

- $\mathbb{C}$ and $\emptyset$ are open subsets of $\mathbb{C}$.
- All finite intersections of open sets are open sets.
- The collection of all open sets on $\mathbb{C}$ form a topology on $\mathbb{C}$.

Interior, closure, density

- Interior:** Let $E \subseteq \mathbb{C}$. The interior of E is defined as, E° is set of all interior points of E , or equivalently, $\bigcup \{B(z, r) : B(z, r) \subseteq E\}$.
- Closure:** Let $E \subseteq \mathbb{C}$. The closure of E is defined as $\overline{E} = E \cup E'$ where E' is the set of all limit points of E .
- Density:** Let $E \subseteq \mathbb{C}$, the closure of E is $\mathbb{C}$. Then E is called dense in $\mathbb{C}$.

Path: A path is a metric space from a point $a \in \mathbb{C}$ to $b \in \mathbb{C}$ is a continuous mapping $\gamma : [0, 1] \rightarrow \mathbb{C}$ s.t. $\gamma(0) = a$ and $\gamma(1) = b$.

Separated and Connected

For a metric space (X, d) ,

- Separated:** X is separated if it disjoint non-empty open subsets A, B of X s.t. $X = A \cup B$.
- Connected:**
 - X is connected if it has no separation.
 - X is connected $\iff X$ does not contain a proper subset of X which is both open and closed in X .
 - Continuous functions preserve connectedness.
 - An open subset $U \subseteq \mathbb{C}$ is connected $\iff$ for $z, w \in U$, there exists a path from z to w .

Basic Topological definitions in $\mathbb{C}$ space

Open subset: Let (X, d) be a metric space and E be a collection of open sets in X . We say that E is an open cover of a subset $K \subseteq X$, if $K \subseteq \bigcup \{U : U \in E\}$. **Compactness:** For subset $K \subseteq X$ is compact if for every open cover E of K , there exists $E_0 = \{U_1, \dots, U_n\} \subseteq E$ s.t. $K \subseteq \bigcup_{i=1}^n U_i$. i.e. K is compact if it has a finite open cover.

- In a metric space, a compact set is closed.
- A closed subset of a compact set is closed.

Limit point compact: We say a metric space X is limit point compact if every infinite subset of X has a limit point.

- If X is a compact metric space, then it is also limit point compact.
- Sequentially compact:** We say a metric space X is sequentially compact if every sequence has a convergent subsequence.

- If X is limit point compact then X is sequentially compact.
- Let X be sequentially compact, then X is a compact metric space.

Lebesgue number lemma: Let X be sequentially compact, and let $\mathcal{W}$ be an open cover of X . Then $\exists \delta > 0$ s.t. for , $\forall x \in \mathcal{W}$ s.t. $B(x, \delta) \subseteq x$.

Isometries on the Complex Plane

A function $f : \mathbb{C} \rightarrow \mathbb{C}$ is called an **isometry** if $|f(z) - f(w)| = |z - w|, \forall z, w \in \mathbb{C}$.

- Let f be an isometry s.t. $f(0) = 0$, then the linear product $\langle f(z), f(w) \rangle = \langle z, w \rangle, \forall z, w \in \mathbb{C}$.
- If f is an isometry s.t. $f(0) = 0$ then f is a linear map.
- The standard isometry for $z = a + bi \in \mathbb{C}$, $\operatorname{Arg}(z + bi) = \tan^{-1} \frac{b}{a}$.

Functions on the Complex Plane

Uniform convergence: Let $M \subseteq \mathbb{C}$ and $f_1, \dots, f_n : D \subseteq \mathbb{C} \rightarrow \mathbb{C}$ be a set of functions on D . We say, $\{f_n\}_{n \in \mathbb{N}}$ converges uniformly to f if given $\epsilon > 0$, for $n \in \mathbb{N}$ s.t. $|f_n(z) - f(z)| < \epsilon, \forall z \in D$ and $n \geq N$.

Complex exponential: For $z \in \mathbb{C}$, $\exp(z) = \sum_{n=0}^{\infty} \frac{z^n}{n!}$.

Trigonometric functions: For $z \in \mathbb{C}$, $\cos(z) = \frac{\exp(iz) + \exp(-iz)}{2}$ and $\sin(z) = \frac{\exp(iz) - \exp(-iz)}{2i}$.

Hyperbolic trigonometric functions: For $z \in \mathbb{C}$, $\cosh(z) = \frac{\exp(z) + \exp(-z)}{2}$ and $\sinh(z) = \frac{\exp(z) - \exp(-z)}{2}$.

Complex Differentiability

Complex differentiable: Let $U \subseteq \mathbb{C}$ and $f : U \rightarrow \mathbb{C}$, we say that f is complex differentiable at a point $z_0 \in U$ if z_0 is an interior point and the following limit exists $\lim_{z \rightarrow z_0} \frac{f(z) - f(z_0)}{z - z_0}$. The limit is denoted as $f'(z_0)$ or $\frac{df}{dz}$.

Bi-holomorphic functions: If $f : U \rightarrow \mathbb{C}$ is complex differentiable at every point $z \in U$, then f is said to be a bi-holomorphic on U . **Entire functions:** Functions which are complex differentiable on $\mathbb{C}$ are called entire functions.

- Complex differentiability implies continuity.
- Complex derivatives of a function are linear transformations.
- Product rule:** If $f, g : U \rightarrow \mathbb{C}$ are complex differentiable at $z_0 \in U$. Then fg is complex differentiable at z_0 with derivative $f'(z_0)g(z_0) + f(z_0)g'(z_0)$.
- Quotient rule:** If $f, g : U \rightarrow \mathbb{C}$ are complex differentiable at $z_0 \in U$, and g doesn't vanish at z_0 . Then $\left(\frac{f}{g}\right)'(z_0) = \frac{f'(z_0)g(z_0) - f(z_0)g'(z_0)}{g(z_0)^2}$.
- Chain rule:** If $f : U \rightarrow \mathbb{C}$ and $g : D \rightarrow U$ are complex differentiable at $z_0 \in D$, and $f'(g(z_0)) \neq 0$. Then $g'(z_0)f'(g(z_0)) = f'(f(g(z_0)))$.

Power Series

Formal Power Series: A formal power series around $z_0 \in \mathbb{C}$ is a formal expression $\sum_{n=0}^{\infty} a_n(z - z_0)^n$, where $a_n \in \mathbb{C}$ and z is indeterminate.

Radius of convergence: For a formal power series $\sum_{n=0}^{\infty} a_n(z - z_0)^n$ the radius of convergence $R \in [0, \infty]$ given by $R = \lim_{n \rightarrow \infty} |a_n|^{-1/n}$. Using the ratio test is identical (i.e. $R = \lim_{n \rightarrow \infty} \left| \frac{a_n}{a_{n+1}} \right|$).

- The series converges absolutely when $z \in B(z_0, R)$, and for $z \in R$, the series converges uniformly, else if $z = z_0 + R$ the series diverges.
- Let $z \in \mathbb{C}$ s.t. $|z - z_0| = R$, then $\exists$ infinitely many $n \in \mathbb{N}$ s.t. $|a_n|^{1/n} \rightarrow |z - z_0|$.

Abel's Theorem: Let $f(z) = \sum_{n=0}^{\infty} a_n(z - z_0)^n = a_0 + \dots$ be a power series with a positive radius of convergence R , suppose $z_1 = z_0 + R e^{i\theta}$ for a point $\theta \in \mathbb{R}$, $f(z_1)$ converges. Then $\lim_{z \rightarrow z_1} f(z) = (z_1 - z_0)^{-1} = f(z_1)$.

Differentiation of Power Series

Let $f(z) = \sum_{n=0}^{\infty} a_n(z - z_0)^n = a_0 + \dots$ be a power series around z_0 with a radius of convergence R . Then f is **holomorphic** in $B(z_0, R)$.

- $f'(z) = \sum_{n=1}^{\infty} n a_n(z - z_0)^{n-1}$ with same radius of convergence R .
- $a_n = \frac{f^{(n)}(z_0)}{n!}$

Cauchy product of two power series: For power series $f(z) = \sum_{n=0}^{\infty} a_n(z - z_0)^n$ and $g(z) = \sum_{n=0}^{\infty} b_n(z - z_0)^n$ with degree of convergence at least R . Then the Cauchy product $f(z)g(z) = \sum_{n=0}^{\infty} c_n(z - z_0)^n$ where $c_n = \sum_{k=0}^n a_k b_{n-k}$ also has degree of convergence at least R .

Cauchy-Riemann Differential Equations

For a complex function $f(z) = u(x, y) + i v(x, y)$,

$$f'(z) = \frac{\partial f}{\partial z} = \frac{\partial u}{\partial x} + i \frac{\partial v}{\partial x} = \frac{\partial u}{\partial z} + i \frac{\partial v}{\partial z}$$

Therefore, we get the two **Cauchy-Riemann Differential equations**,

$$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y}, \quad \frac{\partial u}{\partial y} = -\frac{\partial v}{\partial x}$$

A function is holomorphic if it satisfies the Cauchy-Riemann equations.

Wirtinger Derivatives:

$$\frac{\partial}{\partial z} = \frac{1}{2} \left(\frac{\partial}{\partial x} + i \frac{\partial}{\partial y} \right), \quad \frac{\partial}{\partial \bar{z}} = \frac{1}{2} \left(\frac{\partial}{\partial x} - i \frac{\partial}{\partial y} \right)$$

If f is holomorphic at z_0 then $\frac{\partial f}{\partial \bar{z}} = 0$ and $f'(z_0) = \frac{\partial f}{\partial z}(z_0) = \frac{df}{dz}(z_0)$.

Harmonic Functions

Laplace's Delta: $\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$.

Harmonic functions: Let $u : U \rightarrow \mathbb{R}$ be a twice differentiable function. We say that u is a harmonic function if $\Delta u = 0$.

For any holomorphic function f , $u(x, y), v(x, y)$ are examples of harmonic functions, but there are harmonic functions which are not holomorphic.

Boundary of a set: For a metric space $(X, d) \in \mathbb{R}$,

the boundary of $U = \partial U = \overline{U} \cap U^c$.

Maximum principle for harmonic functions: Let $u : U \rightarrow \mathbb{R}$ be a twice differentiable harmonic function. Let $K \subseteq U$ be a compact sub set of U . Then, $\max_{\overline{U}} u(x, y) = \max_{\partial U} u(x, y)$ and $\min_{\overline{U}} u(x, y) = \min_{\partial U} u(x, y)$.

Maximum principle for holomorphic functions: Let $U \subseteq \mathbb{C}$ be open and connected and let $f : U \rightarrow \mathbb{C}$ be a holomorphic function. Then, for compact $K \subseteq U$, we have, $\max_{\overline{U}} |f(z)| = \max_{\partial U} |f(z)|$.

Harmonic conjugates: Let $u : U \rightarrow \mathbb{R}$ be a twice differentiable harmonic function. We say that $v : U \rightarrow \mathbb{R}$ is a harmonic conjugate of u if $f = u + iv$ is holomorphic.

- For a harmonic function from $\mathbb{C}$ to $\mathbb{R}$, there exists a uniquely determined harmonic conjugate from $\mathbb{C}$ to $\mathbb{R}$ (up to constant).

Complex Analysis With Mathematica

William T. Shaw



Complex Analysis With Mathematicar:

Complex Analysis with MATHEMATICA® William T. Shaw, 2006-04-20 This book presents a way of learning complex analysis using Mathematica Includes CD with electronic version of the book **Complex Analysis** Dennis G. Zill, Patrick D. Shanahan, 2013-09-20 Designed for the undergraduate student with a calculus background but no prior experience with complex analysis this text discusses the theory of the most relevant mathematical topics in a student friendly manner With a clear and straightforward writing style concepts are introduced through numerous examples illustrations and applications Each section of the text contains an extensive exercise set containing a range of computational conceptual and geometric problems In the text and exercises students are guided and supported through numerous proofs providing them with a higher level of mathematical insight and maturity Each chapter contains a separate section devoted exclusively to the applications of complex analysis to science and engineering providing students with the opportunity to develop a practical and clear understanding of complex analysis The Mathematica syntax from the second edition has been updated to coincide with version 8 of the software **A First Course in Complex Analysis with Applications** Dennis Zill, Patrick Shanahan, 2009

The new Second Edition of A First Course in Complex Analysis with Applications is a truly accessible introduction to the fundamental principles and applications of complex analysis Designed for the undergraduate student with a calculus background but no prior experience with complex variables this text discusses theory of the most relevant mathematical topics in a student friendly manor With Zill s clear and straightforward writing style concepts are introduced through numerous examples and clear illustrations Students are guided and supported through numerous proofs providing them with a higher level of mathematical insight and maturity Each chapter contains a separate section on the applications of complex variables providing students with the opportunity to develop a practical and clear understanding of complex analysis

Friendly Approach To Complex Analysis, A (Second Edition) Amol Sasane, Sara Maad Sasane, 2023-06-28 The book constitutes a basic concise yet rigorous first course in complex analysis for undergraduate students who have studied multivariable calculus and linear algebra The textbook should be particularly useful for students of joint programmes with mathematics as well as engineering students seeking rigour The aim of the book is to cover the bare bones of the subject with minimal prerequisites The core content of the book is the three main pillars of complex analysis the Cauchy Riemann equations the Cauchy Integral Theorem and Taylor and Laurent series Each section contains several problems which are not drill exercises but are meant to reinforce the fundamental concepts Detailed solutions to all the 243 exercises appear at the end of the book making the book ideal for self study There are many figures illustrating the text The second edition corrects errors from the first edition and includes 89 new exercises some of which cover auxiliary topics that were omitted in the first edition Two new appendices have been added one containing a detailed rigorous proof of the Cauchy Integral Theorem and another providing background in real analysis needed to make the book self contained *Visual Complex Analysis* Tristan

Needham,2023-02-07 Complex Analysis is the powerful fusion of the complex numbers involving the imaginary square root of 1 with ordinary calculus resulting in a tool that has been of central importance to science for more than 200 years This book brings this majestic and powerful subject to life by consistently using geometry not calculation as the means of explanation The 501 diagrams of the original edition embodied geometrical arguments that for the first time replaced the long and often opaque computations of the standard approach in force for the previous 200 years providing direct intuitive visual access to the underlying mathematical reality This new 25th Anniversary Edition introduces brand new captions that fully explain the geometrical reasoning making it possible to read the work in an entirely new way as a highbrow comic book **Complex**

Analysis John M. Howie,2012-12-06 Complex analysis is one of the most attractive of all the core topics in an undergraduate mathematics course Its importance to applications means that it can be studied both from a very pure perspective and a very applied perspective This book takes account of these varying needs and backgrounds and provides a self study text for students in mathematics science and engineering Beginning with a summary of what the student needs to know at the outset it covers all the topics likely to feature in a first course in the subject including complex numbers differentiation integration Cauchy's theorem and its consequences Laurent series and the residue theorem applications of contour integration conformal mappings and harmonic functions A brief final chapter explains the Riemann hypothesis the most celebrated of all the unsolved problems in mathematics and ends with a short descriptive account of iteration Julia sets and the Mandelbrot set Clear and careful explanations are backed up with worked examples and more than 100 exercises for which full solutions are provided Complex Analysis Mr. Rohit Manglik,2024-07-26 EduGorilla Publication is a trusted name in the education sector committed to empowering learners with high quality study materials and resources Specializing in competitive exams and academic support EduGorilla provides comprehensive and well structured content tailored to meet the needs of students across various streams and levels Complex Analyses in Engineering, Science and Technology S. G. Ahmed,2015-04-27

Complex Analysis for Science and Technology is a textbook for undergraduate and postgraduate students undertaking science technology engineering and mathematics STEM courses The book begins with an introduction to basic complex numbers followed by chapters covering complex functions integrals transformations and conformal mapping Topics such as complex series and residue theory are also covered Key features of this textbook include simple easy to understand explanations of relevant concepts a wide range of simple and complex examples several figures where appropriate

Complex Analysis, Harmonic Analysis and Applications Robert Deville,J Esterle,V Petkov,A Sebbar,A Yger,1996-04-30 Multivariable complex analysis and harmonic analysis provide efficient techniques to study many applied mathematical problems The main objective of a conference held in Bordeaux in June 1995 in honour of Professor Roger Gay was to connect these mathematical fields with some of their applications This was also the guideline for the fourteen contributions collected in this volume Besides presenting new results each speaker made a substantial effort in order to

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Recent Developments in Complex Analysis and Computer Algebra R.P. Gilbert, Joji Kajiwara, Yongzhi S. Xu, 2013-12-01 This volume consists of papers presented in the special sessions on Complex and Numerical Analysis Value Distribution Theory and Complex Domains and Use of Symbolic Computation in Mathematics Education of the ISAAC 97 Congress held at the University of Delaware during June 2 7 1997 The ISAAC Congress coincided with a U S Japan Seminar also held at the University of Delaware The latter was supported by the National Science Foundation through Grant INT 9603029 and the Japan Society for the Promotion of Science through Grant MTCS 134 It was natural that the participants of both meetings should interact and consequently several persons attending the Congress also presented papers in the Seminar The success of the ISAAC Congress and the U S Japan Seminar has led to the ISAAC 99 Congress being held in Fukuoka Japan during August 1999 Many of the same participants will return to this Seminar Indeed it appears that the spirit of the U S Japan Seminar will be continued every second year as part of the ISAAC Congresses We decided to include with the papers presented in the ISAAC Congress and the U S Japan Seminar several very good papers by colleagues from the former Soviet Union These participants in the ISAAC Congress attended at their own expense

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