

# Lie Algebras of Approximate Symmetries

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## Abstract

Properties of approximate symmetries of equations with a small parameter are discussed. It turns out that approximate symmetries form an approximate Lie algebra. A concept of approximate invariants is introduced and the algorithm of their calculating is proposed.

A concept of approximate symmetry of an equation with a small parameter and algorithm of calculating such symmetries were proposed in [1] (see also [3\*–7\*]). Examples of the approximate symmetries show that such symmetries usually do not form a Lie algebra, but form a so-called *approximate Lie algebra* in sense of definition given in [2].

In this paper, we continue investigation of properties of approximate transformation groups and corresponding Lie algebras. In §1, the concept of the approximate Lie algebra introduced in [2] is discussed. Some properties of approximate symmetries are investigated in §2. The §3 is devoted to approximate invariants and algorithms of their calculating for one- and multiparameter groups.

The following notation is used:  $x = (x^1, \dots, x^N)$  is an independent variable;  $\varepsilon$  is a small parameter; all functions under consideration are assumed to be locally analytic in their arguments. We write  $F(x, \varepsilon) = o(\varepsilon^p)$  if  $\lim_{\varepsilon \rightarrow 0} \frac{F(x, \varepsilon)}{\varepsilon^p} = 0$  or, equivalently, if  $F(x, \varepsilon) = \varepsilon^{p+1}\varphi(x, \varepsilon)$ , where  $\varphi(x, \varepsilon)$  is an analytic function defined in a neighborhood of  $\varepsilon = 0$  and  $p$  is an arbitrary positive integer. If  $f(x, \varepsilon) - g(x, \varepsilon) = o(\varepsilon^p)$ , we write briefly  $f \approx g$ .

## 1 Approximate Lie algebras

**Definition 1.** A class of first-order differential operators

$$X = \xi^i(x, \varepsilon) \frac{\partial}{\partial x^i}$$

such that

$$\xi^i(x, \varepsilon) \approx \xi_0^i(x) + \varepsilon \xi_1^i(x) + \dots + \varepsilon^p \xi_p^i(x), \quad i = 1, \dots, N,$$

with some fixed functions  $\xi_0^i(x)$ ,  $\xi_1^i(x), \dots, \xi_p^i(x)$ ,  $i = 1, \dots, N$ , is called an *approximate operator*.

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# Symmetries Lie Algebras And Representations

**Alexey P Isaev, Valery A Rubakov**



## **Symmetries Lie Algebras And Representations:**

**Symmetries, Lie Algebras and Representations** Jürgen Fuchs, Christoph Schweigert, 2003-10-07 This book gives an introduction to Lie algebras and their representations Lie algebras have many applications in mathematics and physics and any physicist or applied mathematician must nowadays be well acquainted with them Groups and Symmetries Yvette Kosmann-Schwarzbach, 2022-07-16 Combines material from many areas of mathematics including algebra geometry and analysis so students see connections between these areas Applies material to physics so students appreciate the applications of abstract mathematics Assumes only linear algebra and calculus making an advanced subject accessible to undergraduates Includes 142 exercises many with hints or complete solutions so text may be used in the classroom or for self study

**Theory Of Groups And Symmetries: Representations Of Groups And Lie Algebras, Applications** Alexey P Isaev, Valery A Rubakov, 2020-07-16 This book is a sequel to the book by the same authors entitled Theory of Groups and Symmetries Finite Groups Lie Groups and Lie Algebras The presentation begins with the Dirac notation which is illustrated by boson and fermion oscillator algebras and also Grassmann algebra Then detailed account of finite dimensional representations of groups  $SL(2, \mathbb{C})$  and  $SU(2)$  and their Lie algebras is presented The general theory of finite dimensional irreducible representations of simple Lie algebras based on the construction of highest weight representations is given The classification of all finite dimensional irreducible representations of the Lie algebras of the classical series  $\mathfrak{sl}(n, \mathbb{C})$ ,  $\mathfrak{so}(n, \mathbb{C})$  and  $\mathfrak{sp}(2r, \mathbb{C})$  is exposed Finite dimensional irreducible representations of linear groups  $SL(N, \mathbb{C})$  and their compact forms  $SU(N)$  are constructed on the basis of the Schur-Weyl duality A special role here is played by the theory of representations of the symmetric group algebra  $\mathbb{C} S_r$  Schur-Frobenius theory Okounkov-Vershik approach based on combinatorics of Young diagrams and Young tableaux Similar construction is given for pseudo-orthogonal groups  $O(p, q)$  and  $SO(p, q)$  including Lorentz groups  $O(1, N-1)$  and  $SO(1, N-1)$  and their Lie algebras as well as symplectic groups  $Sp(p, q)$  The representation theory of Brauer algebra, centralizer algebra of  $SO(p, q)$  and  $Sp(p, q)$  groups in tensor representations is discussed Finally the covering groups  $Spin(p, q)$  for pseudo-orthogonal groups  $SO(p, q)$  are studied For this purpose Clifford algebras in spaces  $\mathbb{R}^{p, q}$  are introduced and representations of these algebras are discussed Symmetry, Representations, and Invariants Roe Goodman, Nolan R. Wallach, 2009-07-30 Symmetry is a key ingredient in many mathematical, physical and biological theories Using representation theory and invariant theory to analyze the symmetries that arise from group actions and with strong emphasis on the geometry and basic theory of Lie groups and Lie algebras Symmetry, Representations and Invariants is a significant reworking of an earlier highly acclaimed work by the authors The result is a comprehensive introduction to Lie theory, representation theory, invariant theory and algebraic groups in a new presentation that is more accessible to students and includes a broader range of applications The philosophy of the earlier book is retained, i.e. presenting the principal theorems of representation theory for the classical matrix groups as motivation for the general theory of reductive groups The wealth

of examples and discussion prepares the reader for the complete arguments now given in the general case

**Key Features of Symmetry Representations and Invariants**

- 1 Early chapters suitable for honors undergraduate or beginning graduate courses requiring only linear algebra basic abstract algebra and advanced calculus
- 2 Applications to geometry curvature tensors topology Jones polynomial via symmetry and combinatorics symmetric group and Young tableaux
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- 5 Serves as an excellent main text for a one year course in Lie group theory
- 6 Benefits physicists as well as mathematicians as a reference work

**Continuous Symmetries, Lie Algebras, Differential Equations And Computer Algebra (2nd Edition)** Willi-hans Steeb, 2007-07-26 This textbook comprehensively introduces students and researchers to the application of continuous symmetries and their Lie algebras to ordinary and partial differential equations Covering all the modern techniques in detail it relates applications to cutting edge research fields such as Yang Mills theory and string theory Aimed at readers in applied mathematics and physics rather than pure mathematics the material is ideally suited to students and researchers whose main interest lies in finding solutions to differential equations and invariants of maps A large number of worked examples and challenging exercises help readers to work independently of teachers and by including SymbolicC implementations of the techniques in each chapter the book takes full advantage of the advancements in algebraic computation Twelve new sections have been added in this edition including Haar measure Sato's theory and sigma functions universal algebra anti self dual Yang Mills equation and discrete Painlevé equations

**Theory Of Groups And Symmetries: Finite Groups, Lie Groups, And Lie Algebras** Alexey P Isaev, Valery A Rubakov, 2018-03-22 The book presents the main approaches in study of algebraic structures of symmetries in models of theoretical and mathematical physics namely groups and Lie algebras and their deformations It covers the commonly encountered quantum groups including Yangians The second main goal of the book is to present a differential geometry of coset spaces that is actively used in investigations of models of quantum field theory gravity and statistical physics The third goal is to explain the main ideas about the theory of conformal symmetries which is the basis of the AdS/CFT correspondence The theory of groups and symmetries is an important part of theoretical physics In elementary particle physics cosmology and related fields the key role is played by Lie groups and algebras corresponding to continuous symmetries For example relativistic physics is based on the Lorentz and Poincaré groups and the modern theory of elementary particles the Standard Model is based on gauge local symmetry with the gauge group  $SU(3) \times SU(2) \times U(1)$  This book presents constructions and results of a general nature along with numerous concrete examples that have direct applications in modern theoretical and mathematical physics

**Group And Representation Theory** Ioannis John Demetrius Vergados, 2016-12-29 This volume goes beyond the understanding of symmetries and exploits them in the study of the behavior of both classical and quantum physical systems Thus it is important to study the symmetries described by continuous Lie groups of transformations We then discuss how we get operators that form a Lie algebra Of

particular interest to physics is the representation of the elements of the algebra and the group in terms of matrices and in particular the irreducible representations. These representations can be identified with physical observables. This leads to the study of the classical Lie algebras associated with unitary, unimodular, orthogonal and symplectic transformations. We also discuss some special algebras in some detail. The discussion proceeds along the lines of the Cartan-Weyl theory via the root vectors and root diagrams and in particular the Dynkin representation of the roots. Thus the representations are expressed in terms of weights which are generated by the application of the elements of the algebra on uniquely specified highest weight states. Alternatively these representations can be described in terms of tensors labeled by the Young tableaux associated with the discrete symmetry  $S_n$ . The connection between the Young tableaux and the Dynkin weights is also discussed. It is also shown that in many physical systems the quantum numbers needed to specify the physical states involve not only the highest symmetry but also a number of sub-symmetries contained in them. This leads to the study of the role of subalgebras and in particular the possible maximal subalgebras. In many applications the physical system can be considered as composed of subsystems obeying a given symmetry. In such cases the reduction of the Kronecker product of irreducible representations of classical and special algebras becomes relevant and is discussed in some detail. The method of obtaining the relevant Clebsch-Gordan C.G. coefficients for such algebras is discussed and some relevant algorithms are provided. In some simple cases suitable numerical tables of C.G. are also included. The above exposition contains many examples both as illustrations of the main ideas as well as well motivated applications. To this end two appendices of 51 pages, 11 tables in Appendix A summarizing the material discussed in the main text and 39 tables in Appendix B containing results of more sophisticated examples are supplied. Reference to the tables is given in the main text and a guide to the appropriate section of the main text is given in the tables.

**Shattered Symmetry** Pieter Thyssen, Arnout Ceulemans, 2017-01-02 Symmetry and its breaking is at the heart of our understanding of matter. The book tells the tale of two constituents of matter, quarks and atoms, from a common symmetry perspective. *Continuous Symmetries, Lie Algebras and Differential Equations* Norbert Euler, W.-H. Steeb, 1992. *Classical Field Theories* Bertrand Berche, Ernesto Medina, 2025-03-18 This exceptional textbook provides extensive discussions and worked exercises to accompany a field theory course at the advanced undergraduate or beginning graduate level. There are many questions that arise both philosophical and practical during a standard course in classical field theory that are addressed here in discussions between an advanced graduate student and her inquisitive undergrad friend. The discussion involves explicitly working out exercises and making pertinent remarks on the results and potential of the developed formalism. The book is ideal for readers who have taken or are taking the classical field theory course so that they already have a mathematical background in vector and tensor calculus and are willing to learn the basics of differential forms and exterior calculus to gain further insight into field theory formulation. The text can also be used to answer what you've always wanted to know but never dared to ask about field theory.

**Quantum Field Theory III:**

**Gauge Theory** Eberhard Zeidler, 2011-08-17 In this third volume of his modern introduction to quantum field theory Eberhard Zeidler examines the mathematical and physical aspects of gauge theory as a principle tool for describing the four fundamental forces which act in the universe gravitative electromagnetic weak interaction and strong interaction Volume III concentrates on the classical aspects of gauge theory describing the four fundamental forces by the curvature of appropriate fiber bundles This must be supplemented by the crucial but elusive quantization procedure The book is arranged in four sections devoted to realizing the universal principle force equals curvature Part I The Euclidean Manifold as a Paradigm Part II Ariadne's Thread in Gauge Theory Part III Einstein's Theory of Special Relativity Part IV Ariadne's Thread in Cohomology For students of mathematics the book is designed to demonstrate that detailed knowledge of the physical background helps to reveal interesting interrelationships among diverse mathematical topics Physics students will be exposed to a fairly advanced mathematics beyond the level covered in the typical physics curriculum Quantum Field Theory builds a bridge between mathematicians and physicists based on challenging questions about the fundamental forces in the universe macrocosmos and in the world of elementary particles microcosmos *Symmetries and Algebraic Structures in Physics* V. V. Dodonov, Vladimir Ivanovich Man'ko, 1991

**Symmetries, Particles and Fields** Ben Allanach, 2021-08-05 A coursebook for a Master's level course at the University of Cambridge to prepare students for a Ph.D. in theoretical particle physics Lie groups and Lie algebras are important in the construction of quantum field theories that describe interactions between known particles One particle states are described in terms of irreducible representations of the Poincaré group a Lie group Quantum fields may be acted on by operators of the Poincaré group Gauge theories which describe many of the interactions in the Standard Model of particle physics also rely on Lie groups We assume knowledge of quantum mechanics linear algebras and vector spaces at the undergraduate level We do not require knowledge of quantum field theory although the book was designed with the assumption that some basic quantum field theory is studied simultaneously in particular the construction of Lagrangian densities in terms of fields then a few applications will make more sense After some basic properties and preliminaries we introduce matrix Lie groups which rely on continuous parameters Differentially these act as a Lie algebra The exponential map connects the Lie algebra to the Lie group We then introduce representations in terms of square matrices describing how to construct various new representations in terms of combinations of others The group of rotations in three dimensional space  $SO(3)$  is examined along with  $SU(2)$  and the connection to angular momentum states in quantum theory Representations of each are covered The relativistic symmetries the Lorentz group and the Poincaré group in four dimensions are studied from the point of view of their group elements and Lie algebras Analysis of compact simple Lie algebras and their finite representations comes from mapping them to a geometrical picture involving roots and weights via the Cartan matrix An overview of the results of the Cartan classification of simple Lie algebras is included An application in terms of representations of a global  $SU(3)_F$  flavour symmetry explains some features of the spectrum of hadronic particles

Further properties of the spectrum lead one to introduce an additional local  $SU(3)$  colour symmetry leading to a particular gauge theory called quantum chromodynamics We cover abelian and non abelian gauge theories before returning to irreducible induced representations of the Poincare group which are used to describe one particle states *Hadron Constituents and Symmetries* J. Lánik, M. Noga, 1978 **Proceedings of the Conference on General Relativity, Cosmology and Relativistic Astrophysics (Journées Relativistes)**, 2002 Spacetime Symmetries Y. S. Kim, W. W. Zachary, 1989 **Supersymmetry and Quantum Field Theory** Dmitrii Sorokin, 2001 Hokkaido Mathematical Journal, 1996 *Acta Scientiarum Mathematicarum* József Attila Tudományegyetem, 1998 **Lie Theory and Its Applications in Physics** Vladimir Dobrev, 2023-01-29 This volume presents modern trends in the area of symmetries and their applications based on contributions to the Workshop Lie Theory and Its Applications in Physics held in Sofia Bulgaria on line in June 2021 Traditionally Lie theory is a tool to build mathematical models for physical systems Recently the trend is towards geometrization of the mathematical description of physical systems and objects A geometric approach to a system yields in general some notion of symmetry which is very helpful in understanding its structure Geometrization and symmetries are meant in their widest sense i.e representation theory algebraic geometry number theory infinite dimensional Lie algebras and groups superalgebras and supergroups groups and quantum groups noncommutative geometry symmetries of linear and nonlinear partial differential operators special functions and others Furthermore the necessary tools from functional analysis are included This is a big interdisciplinary and interrelated field The topics covered in this Volume are the most modern trends in the field of the Workshop Representation Theory Symmetries in String Theories Symmetries in Gravity Theories Supergravity Conformal Field Theory Integrable Systems Quantum Computing and Deep Learning Entanglement Applications to Quantum Theory Exceptional quantum algebra for the standard model of particle physics Gauge Theories and Applications Structures on Lie Groups and Lie Algebras This book is suitable for a broad audience of mathematicians mathematical physicists and theoretical physicists including researchers and graduate students interested in Lie Theory

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