Lattices and the Geometry of Numbers

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1. ABSTRACT

In this paper we discuss about properties of lattices and its application in theoretical and algorithmic number theory. This result of Minkowski regarding the lattices initiated the subject of Geometry of Numbers, which uses geometry to study the properties of algebraic numbers. It has application on various other fields of mathematics especially the study of Diophantine equations, analysis of functional analysis etc. This paper gives an elementary introduction to the field of geometry of numbers. In this paper we shall first give a broad overview of the concept of lattice and then discuss about the geometrical properties it has and its applications.

2. LATTICE

Before introducing Minkowski's theorem we shall first discuss what is a lattice.

Definition 1: A lattice τ is a subgroup of R^n such that it can be represented as

$$\tau = a_1 Z + a_2 Z + .. + a_m Z$$

Here $\{a_i\}$ are linearly independent vectors of the space R^m and $m \leq n$. Here Z is the set of whole numbers.

We call these vectors $\{a_i\}$ the *basis* of the lattice. By the definition we can see that a lattice is a subgroup and a free abelian group of rank m, of the vector space R^m. The rank and dimension of the lattice is m and n respectively, the lattice will be complete if $m = n$. This definition is not only limited to the vector space R^m. It can be extended to any arbitrary field F, in which the basis vectors $\{a_i\}$ will belong to the field F. In this article we shall discuss about both complete or full-rank lattices and incomplete lattices. We will now define another terms known as the fundamental mesh.

Definition 2: The set of elements which can be denoted as

$$\varphi(a) = \{a_1 v_1 + a_2 v_2 + .. + a_m v_m | v_i \in R, 0 \leq v_i \leq 1\}$$

is called a fundamental mesh of the lattice.

A very important thing to notice is that not every given set of vectors $\{a_i\}$ forms the basis of a given lattice τ. In the next lemma we shall state the condition for a given set of vectors $\{a_i\}$ to form the basis of a given lattice τ.

Lemma 1: A given set of vectors $\{a_i\}$ form the basis of a given lattice τ if it satisfies the following condition:

$$\varphi(a) \cap \tau = \{0\}$$

Proof: *The* lattice τ is the set of all their integer combinations of the basis vectors $\{a_i\}$. We also know that $\varphi(a)$ is the set of linear combinations of basis vectors $\{a_i\}$ with the coefficients $v_i \in R, 0 \leq v_i \leq 1$. Therefore the only element in common is the zero vector 0.

Let us now state a lemma regarding the properties of the lattice τ. This proof can be found in many articles and books. We state here the elegant proof as stated and given by Comeaux[1] and Neukirch[2]

Geometry Of Numbers

Álvaro Lozano-Robledo

Geometry Of Numbers:

   Geometry of Numbers C. G. Lekkerkerker,2014-05-12 Bibliotheca Mathematica A Series of Monographs on Pure and Applied Mathematics Volume VIII Geometry of Numbers focuses on bodies and lattices in the n dimensional euclidean space The text first discusses convex bodies and lattice points and the covering constant and inhomogeneous determinant of a set Topics include the inhomogeneous determinant of a set covering constant of a set theorem of Minkowski Hlawka packing of convex bodies successive minima and determinant of a set successive minima of a convex body extremal bodies and polar reciprocal convex bodies The publication ponders on star bodies as well as points of critical lattices on the boundary reducible and irreducible star bodies and reduction of automorphic star bodies The manuscript reviews homogeneous and inhomogeneous s forms and some methods Discussions focus on asymmetric inequalities inhomogeneous forms in more variables indefinite binary quadratic forms diophantine approximation sums of powers of linear forms spheres and quadratic forms and a method of Blichfeldt and Mordell The text is a dependable reference for researchers and mathematicians interested in bodies and lattices in the n dimensional euclidean space   **The Geometry of Numbers** C. D. Olds,Anneli Lax,Giuliana Davidoff,Giuliana P. Davidoff,2000 A self contained introduction to the geometry of numbers   **Lectures on the Geometry of Numbers** Carl Ludwig Siegel,2013-03-09 Carl Ludwig Siegel gave a course of lectures on the Geometry of Numbers at New York University during the academic year 1945 46 when there were hardly any books on the subject other than Minkowski s original one This volume stems from Siegel s requirements of accuracy in detail both in the text and in the illustrations but involving no changes in the structure and style of the lectures as originally delivered This book is an enticing introduction to Minkowski s great work It also reveals the workings of a remarkable mind such as Siegel s with its precision and power and aesthetic charm It is of interest to the aspiring as well as the established mathematician with its unique blend of arithmetic algebra geometry and analysis and its easy readability   **Development of the Minkowski geometry of numbers : in two volumes. 2 (1964)** Harris Hancock,1964   **Development of the Minkowski Geometry of Numbers** Harris Hancock,1964 The Geometry of Numbers as presented here is a sequel to my work on the Foundations of the Theory of Algebraic Numbers An attempt is made to broaden the bases or substructures of these subjects rather than to amplify their superstructures By making a dilation a term often used in the present work of the original realm and extended realm upon these new bases is derived within which the theorems of the original realm are more readily proved theorems hitherto unsolved are solved while new and more comprehensive theorems may be introduced Hermann Minkowski was one of the great mathematicians of all time His grasp of geometrical concepts seem almost superhuman Minkowski came to his theorems through spacial intuitions Due to the limitations of a manifold in three dimensions he presented his theory in a purely analytic manner Thus while he was able to treat manifolds of any order the work is far more difficult of comprehension that if he had first derived his results in a two or three dimensional geometry with illustrative figures and then presented the

general theory analytically with the use of such expressions that are indicative of geometric concepts From this standpoint I have given the entire theory which I call the Development of the Minkowski Geometry of Numbers By using the qualifying word Minkowski I am able to limit the content of this work which otherwise would be beyond bounds from the introduction

   An Introduction to the Geometry of Numbers J.W.S. Cassels,2012-12-06 From the reviews The work is carefully written It is well motivated and interesting to read even if it is not always easy historical material is included the author has written excellent account of an interesting subject Mathematical Gazette A well written very thorough account Among the topi are lattices reduction Minkowskis Theorem distance functions packings and automorphs some applications to number theory excellent bibliographical references The American Mathematical Monthly   **Geometry of Numbers** Peter M. Gruber,Cornelis Gerrit Lekkerkerker,1987-01-01 Hardbound This volume contains a fairly complete picture of the geometry of numbers including relations to other branches of mathematics such as analytic number theory diophantine approximation coding and numerical analysis It deals with convex or non convex bodies and lattices in euclidean space etc This second edition was prepared jointly by P M Gruber and the author of the first edition The authors have retained the existing text with minor corrections while adding to each chapter supplementary sections on the more recent developments While this method may have drawbacks it has the definite advantage of showing clearly where recent progress has taken place and in what areas interesting results may be expected in the future   Number, Shape, & Symmetry Diane L. Herrmann,Paul J. Sally Jr.,2012-10-18 Through a careful treatment of number theory and geometry Number Shape Symmetry An Introduction to Number Theory Geometry and Group Theory helps readers understand serious mathematical ideas and proofs Classroom tested the book draws on the authors successful work with undergraduate students at the University of Chicago seventh

   The Geometry of Numbers C D Olds,Giuliana Davidoff,Anneli Lax,   An Introduction to the Geometry of Numbers ,1971   **Number Theory and Geometry: An Introduction to Arithmetic Geometry** Álvaro Lozano-Robledo,2019-03-21 Geometry and the theory of numbers are as old as some of the oldest historical records of humanity Ever since antiquity mathematicians have discovered many beautiful interactions between the two subjects and recorded them in such classical texts as Euclid s Elements and Diophantus s Arithmetica Nowadays the field of mathematics that studies the interactions between number theory and algebraic geometry is known as arithmetic geometry This book is an introduction to number theory and arithmetic geometry and the goal of the text is to use geometry as the motivation to prove the main theorems in the book For example the fundamental theorem of arithmetic is a consequence of the tools we develop in order to find all the integral points on a line in the plane Similarly Gauss s law of quadratic reciprocity and the theory of continued fractions naturally arise when we attempt to determine the integral points on a curve in the plane given by a quadratic polynomial equation After an introduction to the theory of diophantine equations the rest of the book is structured in three acts that correspond to the study of the integral and rational solutions of linear quadratic and cubic curves respectively This book

describes many applications including modern applications in cryptography it also presents some recent results in arithmetic geometry With many exercises this book can be used as a text for a first course in number theory or for a subsequent course on arithmetic or diophantine geometry at the junior senior level   **Lectures on geometry of numbers** Carl Siegel,1946
    Development of the Minkowski Geometry of Numbers Harris Hancock,1964   **Development of the Minkowski Geometry of Numbers** Harris Hancock,1964   **Lecture Notes on Geometry of Numbers** R. J. Hans-Gill,Madhu Raka,Ranjeet Sehmi,2025-07-16 This book serves as an illuminating introduction to the intricacies of the geometry of numbers It commences by exploring basic concepts of convex sets and lattices in Euclidean space and goes on to delve into Minkowski s fundamental theorem for convex bodies and its applications It discusses critical determinants and successive minima before explaining the core results of packings and coverings The text goes on to delve into the significance of renowned conjectures such as Minkowski s conjecture regarding the product of linear forms Watson s conjecture and the conjecture of Bambah Dumir and Hans Gill concerning non homogeneous minima of indefinite quadratic forms Dedicated to Prof R P Bambah on his 98th birthday a living legend of number theory in India this comprehensive book addresses both homogeneous and non homogeneous problems while sprinkling in historical insights and highlighting unresolved questions in the field It is ideally suited for beginnersembarking on self study as well as for use as a text for a one or two semester introductory course   **Complex Numbers and Geometry** Liang-shin Hahn,1994 This book demonstrates how complex numbers and geometry can be blended together to give easy proofs of many theorems in plane geometry   **Arithmetic Geometry and Number Theory** Lin Weng,Iku Nakamura,2006 Mathematics is very much a part of our culture and this invaluable collection serves the purpose of developing the branches involved popularizing the existing theories and guiding our future explorations More precisely the goal is to bring the reader to the frontier of current developments in arithmetic geometry and number theory through the works of Deninger Werner in vector bundles on curves over p adic fields of Jiang on local gamma factors in automorphic representations of Weng on Deligne pairings and Takhtajan Zograf metrics of Yoshida on CM periods of Yu on transcendence of special values of zetas over finite fields In addition the lecture notes presented by Weng at the University of Toronto from October to November 2005 explain basic ideas and the reasons not just the language and conclusions behind Langlands fundamental yet notably difficult works on the Eisenstein series and spectral decompositions And finally a brand new concept by Weng called the Geometric Arithmetic program that uses algebraic and or analytic methods based on geometric considerations to develop the promising and yet to be cultivated land of global arithmetic that includes non abelian Class Field Theory Riemann Hypothesis and non abelian Zeta and L Functions etc
    Numbers and Geometry John Stillwell,1997-10-30 A beautiful and relatively elementary account of a part of mathematics where three main fields algebra analysis and geometry meet The book provides a broad view of these subjects at the level of calculus without being a calculus book Its roots are in arithmetic and geometry the two opposite poles of

mathematics and the source of historic conceptual conflict The resolution of this conflict and its role in the development of mathematics is one of the main stories in the book Stillwell has chosen an array of exciting and worthwhile topics and elegantly combines mathematical history with mathematics He covers the main ideas of Euclid but with 2000 years of extra insights attached Presupposing only high school algebra it can be read by any well prepared student entering university Moreover this book will be popular with graduate students and researchers in mathematics due to its attractive and unusual treatment of fundamental topics A set of well written exercises at the end of each section allows new ideas to be instantly tested and reinforced **Geometric and Analytic Number Theory** Edmund Hlawka,Johannes Schoißengeier,Rudolf Taschner,2012-12-06 In the English edition the chapter on the Geometry of Numbers has been enlarged to include the important findings of H Lenstraj furthermore tried and tested examples and exercises have been included The translator Prof Charles Thomas has solved the difficult problem of the German text into English in an admirable way He deserves transferring our Unreserved praise and special thailks Finally we would like to express our gratitude to Springer Verlag for their commitment to the publication of this English edition and for the special care taken in its production Vienna March 1991 E Hlawka J SchoiBengeier R Taschner Preface to the German Edition We have set ourselves two aims with the present book on number theory On the one hand for a reader who has studied elementary number theory and who has knowledge of analytic geometry differential and integral calculus together with the elements of complex variable theory we wish to introduce basic results from the areas of the geometry of numbers diophantine ap proximation prime number theory and the asymptotic calculation of number theoretic functions However on the other hand for the student who has al ready studied analytic number theory we also present results and principles of proof which until now have barely if at all appeared in text books **The American Mathematical Monthly** ,1914 Includes section Recent publications

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