

Algebraic-geometric codes from vector bundles and their decoding

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Abstract—Algebraic-geometric codes can be constructed by evaluating a certain set of functions on a set of distinct rational points of an algebraic curve. The set of functions that are evaluated is the linear space of a given divisor or, equivalently, the set of sections of a given line bundle. Using arbitrary rank vector bundles on algebraic curves, we propose a natural generalization of the above construction. Our codes can also be seen as interleaved versions of classical algebraic-geometric codes. We show that the algorithm of Brown, Minder and Shokrollahi can be extended to this new class of codes and it corrects any number of errors up to $t^* = g/2$, where t^* is the designed correction capacity of the code and g is the curve genus.

I. INTRODUCTION

The construction of error correcting codes using methods from algebraic-geometry was first proposed by Goppa [4], [5] in the early '80s. He constructed codes by evaluating a certain set of differential forms on a set of distinct rational points of an algebraic curve. From a dual point of view, Goppa's codes can be constructed by evaluating a certain set of functions on a set of distinct rational points of an algebraic curve [1]. The set of functions that are evaluated is the linear space of a given divisor, whose support is disjoint from the set of evaluation points. These codes generalize the Bose-Chaudhuri-Hocquenghem (BCH), Reed-Solomon (RS) and Goppa codes (latest codes being introduced by Goppa in the early '70s). Unlike the RS codes, algebraic-geometric (AG) codes are not generally MDS codes, but their Singleton defect is upper bounded by the genus of the curve. However, despite their Singleton defect, AG codes are better than RS codes, since they allow the construction of longer codes over the same alphabet. Another advantage of AG codes is that for fixed code parameters, their encoding and decoding algorithms run faster as they can be performed in a smaller field. Since the end of the 80s, intensive research has been done on decoding algorithms and most of the methods used to decode BCH, RS or Goppa codes were extended to the class of AG codes [7].

In order to explain our approach to construct codes from vector bundles on projective curves, let us recall the classical construction of AG codes. Let C be an absolutely irreducible, smooth, projective curve of genus g , defined over a finite base field $\mathbb{F}_q$. Let $P = \{P_1, P_2, \dots, P_n\}$ be a set of distinct rational points of C and $D \in \text{Div}(C)$ be a divisor whose support is disjoint from the set P . The linear code $C(P, D)$ is defined as the image of the evaluation map:

$$\begin{aligned} ev : \mathcal{L}(D) &\longrightarrow \mathbb{F}_q^n \\ f &\longmapsto (f(P_1), f(P_2), \dots, f(P_n)) \end{aligned} \quad (1)$$

where $\mathcal{L}(D)$ is the linear space of D . The parameters of the code, or bound on them, can be determined using well-known statements in algebraic-geometry, notably the Hasse-Weil theorem and the Riemann-Roch theorem, and it can be seen that the Singleton defect of the code is upper bounded by the curve genus g .

Interleaved AG codes were defined in [3] as follows. Suppose that $Q = q^r$ and identify $\mathbb{F}_Q$ and $\mathbb{F}_q^r$ as $\mathbb{F}_q$ -vector spaces by fixing a basis of $\mathbb{F}_Q$ over $\mathbb{F}_q$. For any point $P \in C$ and any $f = (f_1, f_2, \dots, f_r) \in \mathcal{L}(D)^{\oplus r}$, the evaluation vector $f(P) = (f_1(P), f_2(P), \dots, f_r(P)) \in \mathbb{F}_q^r$ can be identified with an element of $\mathbb{F}_Q$. The code $C(P, D, r)$ is defined as the image of the evaluation map:

$$\begin{aligned} ev : \mathcal{L}(D)^{\oplus r} &\longrightarrow \mathbb{F}_Q^n \\ f &\longmapsto (f(P_1), f(P_2), \dots, f(P_n)) \end{aligned} \quad (2)$$

This code does not generally lie in $\mathbb{F}_Q$, however it is a $\mathbb{F}_q$ -vector subspace of $\mathbb{F}_Q^n$.

To explain our approach, we first remark that there is a one-to-one correspondence between the divisor class group $\text{Cl}(C)$ (the group of equivalence classes of $\text{Div}(C)$) and isomorphism classes of line bundles on C . For any divisor D , we denote by $\mathcal{O}(D)$ the line bundle associated with D . The linear space $\mathcal{L}(D)$ is isomorphic to the space of global sections of $\mathcal{O}(D)$, which is generally denoted by $H^0(C, \mathcal{O}(D))$.

We construct AG codes by evaluating global sections of arbitrary rank vector bundles E on the points $P_1, P_2, \dots, P_n$. Thus, the classical construction of AG codes (1) corresponds to the case $E = \mathcal{O}(D)$ and the construction of interleaved AG codes (2) corresponds to $E = \mathcal{O}(D)^{\oplus r}$. In general, if E is a rank- r vector bundle, we obtain a code $C(P, E)$ over $\mathbb{F}_Q$, not necessarily linear, where $Q = q^r$. Further, we investigate the parameters of these codes, or bound on them, such as the code length, dimension, and minimum distance. While the code dimension can still be lower bounded by the Riemann-Roch theorem, it is much harder to compute its exact value or to give a lower bound on the minimum distance. The main reason is that unlike line vector bundles, arbitrary rank vector bundles of negative degree may have non zero sections. To overcome such situations, we need the vector bundle to satisfy some stability condition. When this condition is satisfied, we can compute the code dimension and we can show that the Singleton defect is upper bounded by the curve genus g .

Now we come to the decoding problem. Bleichenbacher, Klavias and Yung [2] proposed a new decoding algorithm for interleaved Reed-Solomon codes over the Q -ary symmetric channel, which was later extended by Brown, Minder and

Algebraic Geometric Codes

**Michael Tsfasman, Serge Vlăduț, Dmitry
Nogin**



Algebraic Geometric Codes:

Algebraic-Geometric Codes M. Tsfasman, S.G. Vladut, 2013-12-01 Et moi si j'avait su comment en revenir One service mathematics has rendered the je n'y serais point alle human race It has put common sense back Jules Verne where it belongs on the topmost shelf next to the dusty canister labelled discarded non sense The series is divergent therefore we may be able to do something with it Eric T Bell O Heavieside Mathematics is a tool for thought A highly necessary tool in a world where both feedback and non linearities abound Similarly all kinds of parts of mathematics serve as tools for other parts and for other sciences Applying a simple rewriting rule to the quote on the right above one finds such statements as One service topology has rendered mathematical physics One service logic has rendered computer science One service category theory has rendered mathematics All arguably true And all statements obtainable this way form part of the raison d'être of this series

Advances in Algebraic Geometry Codes Edgar Martinez-Moro, 2008 Advances in Algebraic Geometry Codes presents the most successful applications of algebraic geometry to the field of error correcting codes which are used in the industry when one sends information through a noisy channel The noise in a channel is the corruption of a part of the information due to either interferences in the telecommunications or degradation of the information storing support for instance compact disc An error correcting code thus adds extra information to the message to be transmitted with the aim of recovering the sent information With contributions from renowned researchers this pioneering book will be of value to mathematicians computer scientists and engineers in information theory

Algebraic Geometry Codes: Advanced Chapters Michael Tsfasman, Serge Vlăduț, Dmitry Nogin, 2019-07-02 Algebraic Geometry Codes Advanced Chapters is devoted to the theory of algebraic geometry codes a subject related to local libraryBook Catalogseveral domains of mathematics On one hand it involves such classical areas as algebraic geometry and number theory on the other it is connected to information transmission theory combinatorics finite geometries dense packings and so on The book gives a unique perspective on the subject Whereas most books on coding theory start with elementary concepts and then develop them in the framework of coding theory itself within this book systematically presents meaningful and important connections of coding theory with algebraic geometry and number theory Among many topics treated in the book the following should be mentioned curves with many points over finite fields class field theory asymptotic theory of global fields decoding sphere packing codes from multi dimensional varieties and applications of algebraic geometry codes The book is the natural continuation of Algebraic Geometric Codes Basic Notions by the same authors The concise exposition of the first volume is included as an appendix

Coding Theory and Algebraic Geometry Henning Stichtenoth, Michael A. Tsfasman, 2006-11-15 About ten years ago V D Goppa found a surprising connection between the theory of algebraic curves over a finite field and error correcting codes The aim of the meeting Algebraic Geometry and Coding Theory was to give a survey on the present state of research in this field and related topics The proceedings contain research papers on several aspects of the theory among them Codes

constructed from special curves and from higher dimensional varieties
Decoding of algebraic geometric codes
Trace codes
Exponential sums
Fast multiplication in finite fields
Asymptotic number of points on algebraic curves
Sphere packings

Introduction to Coding Theory and Algebraic Geometry J. van Lint, G. van der Geer, 2012-12-06 These notes are based on lectures given in the seminar on Coding Theory and Algebraic Geometry held at Schloss Mickeln Diisseldorf November 16-21 1987 In 1982 Tsfasman Vladut and Zink using algebraic geometry and ideas of Goppa constructed a sequence of codes that exceed the Gilbert Varshamov bound The result was considered sensational Furthermore it was surprising to see these unrelated areas of mathematics collaborating The aim of this course is to give an introduction to coding theory and to sketch the ideas of algebraic geometry that led to the new result Finally a number of applications of these methods of algebraic geometry to coding theory are given Since this is a new area there are presently no references where one can find a more extensive treatment of all the material However both for algebraic geometry and for coding theory excellent textbooks are available The combination of the two subjects can only be found in a number of survey papers A book by C Moreno with a complete treatment of this area is in preparation We hope that these notes will stimulate further research and collaboration of algebraic geometers and coding theorists G van der Geer J H van Lint Introduction to Coding Theory and Algebraic Geometry Part I Coding Theory Jacobus H van Lint 11-1 Finite fields In this chapter we collect without proof the facts from the theory of finite fields that we shall need in this course

Algebraic Geometry for Coding Theory and Cryptography Everett W. Howe, Kristin E. Lauter, Judy L. Walker, 2017-11-15 Covering topics in algebraic geometry coding theory and cryptography this volume presents interdisciplinary group research completed for the February 2016 conference at the Institute for Pure and Applied Mathematics IPAM in cooperation with the Association for Women in Mathematics AWM The conference gathered research communities across disciplines to share ideas and problems in their fields and formed small research groups made up of graduate students postdoctoral researchers junior faculty and group leaders who designed and led the projects Peer reviewed and revised each of this volume's five papers achieves the conference's goal of using algebraic geometry to address a problem in either coding theory or cryptography Proposed variants of the McEliece cryptosystem based on different constructions of codes constructions of locally recoverable codes from algebraic curves and surfaces and algebraic approaches to the multicast network coding problem are only some of the topics covered in this volume Researchers and graduate level students interested in the interactions between algebraic geometry and both coding theory and cryptography will find this volume valuable

Algebraic Geometry in Coding Theory and Cryptography Harald Niederreiter, Chaoping Xing, 2009-09-21 This textbook equips graduate students and advanced undergraduates with the necessary theoretical tools for applying algebraic geometry to information theory and it covers primary applications in coding theory and cryptography Harald Niederreiter and Chaoping Xing provide the first detailed discussion of the interplay between nonsingular projective curves and algebraic function fields over finite fields This

interplay is fundamental to research in the field today yet until now no other textbook has featured complete proofs of it Niederreiter and Xing cover classical applications like algebraic geometry codes and elliptic curve cryptosystems as well as material not treated by other books including function field codes digital nets code based public key cryptosystems and frameproof codes Combining a systematic development of theory with a broad selection of real world applications this is the most comprehensive yet accessible introduction to the field available Introduces graduate students and advanced undergraduates to the foundations of algebraic geometry for applications to information theory Provides the first detailed discussion of the interplay between projective curves and algebraic function fields over finite fields Includes applications to coding theory and cryptography Covers the latest advances in algebraic geometry codes Features applications to cryptography not treated in other books

Introduction To Algebraic Coding Theory

Tzuong-tsieng Moh,2022-02-18 We live in the age of technology where messages are transmitted in sequences of 0 s and 1 s through space It is possible to make an error with noisy channels so self correcting codes become vital to eradicate all errors as the number of errors is small These self correcting codes are widely used in the industry for a variety of applications including e mail telephone remote sensing e g photographs of Mars amongst others We will present some essentials of the theory in this book Using linear algebra we have the salient Hamming codes The next level of coding theory is through the usage of ring theory especially polynomials rational functions and power series to produce BCH codes Reed Solomon codes and the classical Goppa codes Then we progress to the geometric Goppa code using Algebraic Geometry

Algebraic Geometry Codes

Michael A. Tsfasman,2014-05-21 This book is devoted to the theory of algebraic geometric codes a subject formed on the border of several domains of mathematics On one side there are such classical areas as algebraic geometry and number theory on the other information transmission theory combinatorics finite geometries and dense packings

Algebraic Function Fields and Codes Henning Stichtenoth,2009-08-29 This book links two subjects algebraic geometry and coding theory It uses a novel approach based on the theory of algebraic function fields Coverage includes the Riemann-Roch theorem zeta functions and Hasse-Weil's theorem as well as Goppa's algebraic geometric codes and other traditional codes It will be useful to researchers in algebraic geometry and coding theory and computer scientists and engineers in information transmission

Codes on Algebraic Curves Serguei A. Stepanov,2012-12-06 This is a self contained introduction to algebraic curves over finite fields and geometric Goppa codes There are four main divisions in the book The first is a brief exposition of basic concepts and facts of the theory of error correcting codes Part I The second is a complete presentation of the theory of algebraic curves especially the curves defined over finite fields Part II The third is a detailed description of the theory of classical modular curves and their reduction modulo a prime number Part III The fourth and basic is the construction of geometric Goppa codes and the production of asymptotically good linear codes coming from algebraic curves over finite fields Part IV The theory of geometric Goppa codes is a fascinating topic where two extremes meet the highly abstract and

deep theory of algebraic specifically modular curves over finite fields and the very concrete problems in the engineering of information transmission At the present time there are two essentially different ways to produce asymptotically good codes coming from algebraic curves over a finite field with an extremely large number of rational points The first way developed by M A Tsfasman S G Vladut and Th Zink 210 is rather difficult and assumes a serious acquaintance with the theory of modular curves and their reduction modulo a prime number The second way proposed recently by A

Algebraic Geometric Codes: Basic Notions Michael Tsfasman, Serge Vlăduț, Dmitry Nogin, 2022-04-15 The book is devoted to the theory of algebraic geometric codes a subject formed on the border of several domains of mathematics On one side there are such classical areas as algebraic geometry and number theory on the other information transmission theory combinatorics finite geometries dense packings etc The authors give a unique perspective on the subject Whereas most books on coding theory build up coding theory from within starting from elementary concepts and almost always finishing without reaching a certain depth this book constantly looks for interpretations that connect coding theory to algebraic geometry and number theory There are no prerequisites other than a standard algebra graduate course The first two chapters of the book can serve as an introduction to coding theory and algebraic geometry respectively Special attention is given to the geometry of curves over finite fields in the third chapter Finally in the last chapter the authors explain relations between all of these the theory of algebraic geometric codes

Algebraic Codes on Lines, Planes, and Curves Richard E. Blahut, 2008-04-03 The past few years have witnessed significant developments in algebraic coding theory This book provides an advanced treatment of the subject from an engineering perspective covering the basic principles and their application in communications and signal processing Emphasis is on codes defined on the line on the plane and on curves with the core ideas presented using commutative algebra and computational algebraic geometry made accessible using the Fourier transform Starting with codes defined on a line a background framework is established upon which the later chapters concerning codes on planes and on curves are developed The decoding algorithms are developed using the standard engineering approach applied to those of Reed Solomon codes enabling them to be evaluated against practical applications Integrating recent developments in the field into the classical treatment of algebraic coding this is an invaluable resource for graduate students and researchers in telecommunications and applied mathematics

Forward Error Correction Based On Algebraic-Geometric Theory Jafar A. Alzubi, Omar A. Alzubi, Thomas M. Chen, 2014-06-12 This book covers the design construction and implementation of algebraic geometric codes from Hermitian curves Matlab simulations of algebraic geometric codes and Reed Solomon codes compare their bit error rate using different modulation schemes over additive white Gaussian noise channel model Simulation results of Algebraic geometric codes bit error rate performance using quadrature amplitude modulation 16QAM and 64QAM are presented for the first time and shown to outperform Reed Solomon codes at various code rates and channel models The book proposes algebraic geometric block turbo codes It also presents simulation results that show an improved

bit error rate performance at the cost of high system complexity due to using algebraic geometric codes and Chase Pyndiah's algorithm simultaneously. The book proposes algebraic geometric irregular block turbo codes AG IBTC to reduce system complexity. Simulation results for AG IBTCs are presented for the first time. **Algebraic Geometric Codes** Daisy Anne Amelia Wise, 2000

Codes and Curves Judy L. Walker, 2000 When information is transmitted errors are likely to occur. Coding theory examines efficient ways of packaging data so that these errors can be detected or even corrected. The traditional tools of coding theory have come from combinatorics and group theory. Lately however coding theorists have added techniques from algebraic geometry to their toolboxes. In particular by re interpreting the Reed Solomon codes one can see how to define new codes based on divisors on algebraic curves. For instance using modular curves over finite fields Tsfasman Vladut and Zink showed that one can define a sequence of codes with asymptotically better parameters than any previously known codes. This monograph is based on a series of lectures the author gave as part of the IAS PCMI program on arithmetic algebraic geometry. Here the reader is introduced to the exciting field of algebraic geometric coding theory. Presenting the material in the same conversational tone of the lectures the author covers linear codes including cyclic codes and both bounds and asymptotic bounds on the parameters of codes. Algebraic geometry is introduced with particular attention given to projective curves rational functions and divisors. The construction of algebraic geometric codes is given and the Tsfasman Vladut Zink result mentioned above is discussed. **Linear and Algebraic-geometric Codes** Melanie Reed Smith, 1992

This paper gives a brief introduction to linear and algebraic geometric codes. Some basic results are covered from finite field theory before going into coding theory. Linear codes are discussed and four well known codes are presented. Next is background material from algebraic geometry. Finally algebraic geometric codes are introduced and their improvement over other codes discussed. Document *Algebraic Geometry Modeling In Information Theory* Edgar Martinez-moro, 2012-12-18

Algebraic geometry methods have constituted a basic background and tool for people working on classic block coding theory and cryptography. Nowadays new paradigms on coding theory and cryptography have arisen such as Network coding S Boxes APN Functions Steganography and decoding by linear programming. Again understanding the underlying procedure and symmetry of these topics needs a whole bunch of non trivial knowledge of algebra and geometry that will be used to both evaluate those methods and search for new codes and cryptographic applications. This book shows those methods in a self contained form. **Applied Algebra, Algebraic Algorithms and Error-Correcting Codes** Maria Bras-Amorós, Tom Høholdt, 2009-05-25

This book constitutes the refereed proceedings of the 18th International Symposium on Applied Algebra Algebraic Algorithms and Error Correcting Codes AAECC 18 held in Tarragona Spain in June 2009. The 22 revised full papers presented together with 7 extended abstracts were carefully reviewed and selected from 50 submissions. Among the subjects addressed are block codes including list decoding algorithms algebra and codes rings fields algebraic geometry codes algebra rings and fields polynomials permutations lattices cryptography cryptanalysis and complexity.

computational algebra algebraic algorithms and transforms sequences and boolean functions

Geometry and Codes

Goppa, 2013-06-29 Approach your problems from the right end It isn't that they can't see the solution It is and begin with the answers Then one day that they can't see the problem perhaps you will find the final question G K Chesterton The Scandal of Father The Hermit Clad in Crane Feathers in R Brown The point of a Pin van Gulik's The Chinese Maze Murders Growing specialization and diversification have brought a host of monographs and textbooks on increasingly specialized topics However the tree of knowledge of mathematics and related fields does not grow only by putting forth new branches It also happens quite often in fact that branches which were thought to be completely disparate are suddenly seen to be related Further the kind and level of sophistication of mathematics applied in various sciences has changed drastically in recent years measure theory is used non trivially in regional and theoretical economics algebraic geometry interacts with physics the Minkowsky lemma coding theory and the structure of water meet one another in packing and covering theory quantum fields crystal defects and mathematical programming profit from homotopy theory Lie algebras are relevant to filtering and prediction and electrical engineering can use Stein spaces And in addition to this there are such new emerging subdisciplines as experimental mathematics CFD completely integrable systems chaos synergetics and large scale order which are almost impossible to fit into the existing classification schemes They draw upon widely different sections of mathematics

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