

A Dynamic Algorithm for Gröbner basis computation

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Introduction

Gröbner bases are fundamental tools for effective computations in polynomial ideal theory; they allow to solve the ideal membership problem, to perform operations on ideals and compute their numerical invariants; they also allow to present a system of polynomial equations in a shape suitable for solution (both symbolically and numerically).

The complexity of a Gröbner basis and the time required to compute it strongly depend on the choice of the term-ordering. On the other hand most applications don't depend on a specific ordering.

The structure of term-orderings was analyzed in [RoZ] and [MR], where it is proved that, for a given ideal I , the set of term-orderings is partitioned in finitely many classes so that orders in the same class yield the same reduced Gröbner basis of I . As a consequence, [MR] suggested the possibility of finding constructively the "shortest" reduced Gröbner basis for a given ideal, by the appropriate choice of the order.

Such an order cannot be chosen a priori, since the behaviour of Buchberger algorithm is quite unpredictable; it can however be adapted dynamically during execution, exploiting the data made available by the computation itself.

This can be done by a dynamic version of Buchberger algorithm: by some heuristic criteria on the input polynomials, an initial ordering is chosen; the computation then is the same as the usual Buchberger algorithm, except that, any time a polynomial is adjoined to the basis, the ordering may be changed, again by heuristic criteria. To have as little overhead as necessary, the new order is chosen so that the computations already performed with the old order, are correct for the new order too.

The purpose of this paper is to investigate the behaviour of a dynamic version of Buchberger algorithm and its effects on the complexity of Gröbner basis computation.

Different orders can be just characterized by different choices of leading terms of basis elements. Therefore problems on orders can be translated into combinatorial problems on terms. So the question of changing order, keeping it compatible with previous computations, means fixing a term in the new polynomial as the leading one, while keeping unchanged the leading term of previous elements. The existence of an ordering for which a given term for each basis element is the leading one is so reduced to the existence of an integral solution to a system of inequalities, which is solved by the Simplex algorithm. Other methods using convex geometry techniques are discussed in [Sw] and [GS]. The information available during execution allows to simplify only the "combinatorial" complexity of the algorithm. (essentially the number of polynomials in the basis and the number of S-polynomials); a heuristic of combinatorial nature is therefore used in the dynamic algorithm, based on the Hilbert Function of the ideal.

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generated by the leading terms of the current basis elements. In Section 1, we recall preliminaries on Gröbner bases, Gröbner Fans and Hilbert functions; in Section 2 we give an outline of the dynamic algorithm; Section 3 reports statistics on some experiments; a few conclusions are given in Section 4.

Experiments performed (and reported in this paper) show an actual improvement of the combinatorial complexity. However this doesn't reflect on timings, since the "arithmetical" complexity both of the basis (number of monomials appearing in it) and of the algorithm (number of monomial operations) is not reduced. In the important case of binomial ideals (where the arithmetical complexity of the basis is constant), the dynamic algorithm gives superior timings than the classical one.

1 Prerequisites

In this section we give the basic definitions and properties of Gröbner bases, Gröbner Fan and Hilbert Function, without any proof, for which we refer to [BCR, Fu, MR, Ro].

Some notation

Let $R = K[x_1, \dots, x_n]$ be the polynomial ring in n indeterminates over the field K and T the semigroup of terms of R . If σ is a total semigroup order on T , it is called *term-ordering* if $t >_\sigma 1$ for each term t . The set of the term-orderings on T is denoted $\text{TO}(T)$. The lexicographic term-ordering identified by $x_1 > x_2 > \dots > x_n$ is denoted $\text{lex}(x_1, \dots, x_n)$. From here on, when the word order will be used, it will be implicit that the order is a term-ordering.

If f is a polynomial in R , then:

- $\text{LT}_\sigma(f)$ is the largest term in f w.r.t. σ and it is called the leading term of f w.r.t. σ . Similarly, $\text{LM}_\sigma(f)$ is the monomial with the largest term.
- If $t \in T$ then $c(f, t)$ is the coefficient of the term t in f .
- $\text{lc}_\sigma(f) := c(f, \text{LT}_\sigma(f))$ is the leading coefficient of f w.r.t. σ .
- $\text{Supp}(f) := \{t : c(f, t) \neq 0\}$, the support of f is the set of the terms which have non zero coefficient in f .

Let $F := \{f_1, \dots, f_r\} \subset R$, then the list $(\text{LT}_\sigma(f_1), \dots, \text{LT}_\sigma(f_r))$ is denoted $\text{LT}_\sigma(F)$. $\text{LM}_\sigma(F)$, $\text{lc}_\sigma(F)$ are defined in the same way.

The ideal of R generated by $F := \{f_1, \dots, f_r\} \subset R$ is denoted by $\langle F \rangle$, and the monomial ideal generated by $\text{LT}_\sigma(f_1), \dots, \text{LT}_\sigma(f_r)$ is denoted by $\text{LT}_\sigma(I)$.

The function $\log : T^n \rightarrow \mathbb{N}^n$ which is defined by $\log(x_1^{a_1}, \dots, x_n^{a_n}) := (a_1, \dots, a_n)$ is a monoid isomorphism between T^n and \mathbb{N}^n .

Gröbner bases

Definition. Let σ be an order. Then a set $F := \{f_1, \dots, f_r\} \subset R$ is termed a *Gröbner basis* of $\langle F \rangle$ w.r.t. σ if $\text{LT}_\sigma(F)$ generates $\text{LT}_\sigma(I)$.

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Manuel Bronstein,1993-01-01 *Differential Equations with Symbolic Computation* Dongming Wang,Zhiming
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Modular Algorithms in Symbolic Summation and Symbolic Integration Jürgen Gerhard, 2004-12 This book brings together two streams of computer algebra symbolic summation and integration on the one hand and fast algorithmics on the other hand In symbolic integration and summation not too many algorithms with analyzed run times are known and until now the mathematically oriented world of integration and summation and the computer science world of algorithm analysis have not had much to say to each other The progress presented in this work towards overcoming this situation is threefold a clear framework for algorithm analysis with the appropriate parameters is provided modular algorithmic techniques are introduced in this area and almost optimal algorithms are presented for the basic problems

Selected Works of Ellis Kolchin with Commentary Ellis Robert Kolchin, Alexandru Buium, Phyllis Joan Cassidy, 1999 The work of Joseph Fels Ritt and Ellis Kolchin in differential algebra paved the way for exciting new applications in constructive symbolic computation differential Galois theory the model theory of fields and Diophantine geometry This volume assembles Kolchin's mathematical papers contributing solidly to the archive on construction of modern differential algebra This collection of Kolchin's clear and comprehensive papers in themselves constituting a history of the subject is an invaluable aid to the student of differential algebra In 1910 Ritt created a theory of algebraic differential equations modeled not on the existing transcendental methods of Lie but rather on the new algebra being developed by E Noether and B van der Waerden Building on Ritt's foundation and deeply influenced by Weil and Chevalley Kolchin opened up Ritt theory to modern algebraic geometry In so doing he led differential geometry in a new direction By creating differential algebraic geometry and the theory of differential algebraic groups Kolchin provided the foundation for a new geometry that has led to both a striking and an original approach to arithmetic algebraic geometry Intriguing possibilities were introduced for a new language for nonlinear differential equations theory The volume includes commentary by A Borel M Singer and B Poizat Also Buium and Cassidy trace the development of Kolchin's ideas from his important early work on the differential Galois theory to his later groundbreaking results on the theory of differential algebraic geometry and differential algebraic groups Commentaries are self contained with numerous examples of various aspects of differential algebra and its applications Central topics of Kolchin's work are discussed presenting the history of differential algebra and exploring how his work grew from and transformed the work of Ritt New directions of differential algebra are illustrated outlining important current advances Prerequisite to understanding the text is a background at the beginning graduate level in algebra specifically commutative algebra the theory of field extensions and Galois theory

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Computer - Human Interaction in Symbolic Computation Norbert Kajler, 2012-12-06 The well attended March 1994 HIse workshop in Amsterdam was a very lively conference which stimulated much discussion and human human interaction As the editor of this volume points out the Amsterdam meeting was just part of a year long project that brought many people together from many parts of the world The value of the effort was not only in generating new ideas but in making people aware of work that

has gone on on many fronts in using computers to make mathematics more understandable The author was very glad he attended the workshop In thinking back over the conference and in reading the papers in this collection the author feels there are perhaps four major conclusions to be drawn from the current state of work 1 graphics is very important but such features should be made as easy to use as possible 2 symbolic mathematical computation is very powerful but the user must be able to see intermediate steps 3 system design has made much progress but for semester long coursework and book length productions we need more tools to help composition and navigation 4 monolithic systems are perhaps not the best direction for the future as different users have different needs and may have to link together many kinds of tools The editor of this volume and the authors of the papers presented here have also reached and documented similar conclusions

Symbolic Rewriting Techniques Manuel Bronstein, Johannes Grabmeier, Volker Weispfenning, 2013-03-11 Symbolic rewriting techniques are methods for deriving consequences from systems of equations and are of great use when investigating the structure of the solutions Such techniques appear in many important areas of research within computer algebra the Knuth Bendix completion for groups monoids and general term rewriting systems the Buchberger algorithm for Gröbner bases the Ritt Wu characteristic set method for ordinary differential equations and the Riquier Janet method for partial differential equations This volume contains invited and contributed papers to the Symbolic Rewriting Techniques workshop which was held at the Centro Stefano Franscini in Ascona Switzerland from April 30 to May 4 1995 That workshop brought together 40 researchers from various areas of rewriting techniques the main goal being the investigation of common threads and methods Following the workshops each contribution was formally refereed and 14 papers were selected for publication *Polynomial Algorithms in Computer Algebra* Franz Winkler, 2012-12-06 For several years now I have been teaching courses in computer algebra at the Universitat Linz the University of Delaware and the Universidad de Alcalá de Henares In the summers of 1990 and 1992 I have organized and taught summer schools in computer algebra at the Universitat Linz Gradually a set of course notes has emerged from these activities People have asked me for copies of the course notes and different versions of them have been circulating for a few years Finally I decided that I should really take the time to write the material up in a coherent way and make a book out of it Here now is the result of this work Over the years many students have been helpful in improving the quality of the notes and also several colleagues at Linz and elsewhere have contributed to it I want to thank them all for their effort in particular I want to thank B Buchberger who taught me the theory of Gröbner bases nearly two decades ago B F Caviness and B D Saunders who first stimulated my interest in various problems in computer algebra G E Collins who showed me how to compute in algebraic domains and J R Sendra with whom I started to apply computer algebra methods to problems in algebraic geometry Several colleagues have suggested improvements in earlier versions of this book However I want to make it clear that I am responsible for all remaining mistakes **The Essence of Computation** Torben Mogensen, David Schmidt, I. Hal Sudborough, 2003-07-01 By

presenting state of the art aspects of the theory of computation this book commemorates the 60th birthday of Neil D Jones whose scientific career parallels the evolution of computation theory itself The 20 reviewed research papers presented together with a brief survey of the work of Neil D Jones were written by scientists who have worked with him in the roles of student colleague and in one case mentor In accordance with the Festschrift s subtitle the papers are organized in parts on computational complexity program analysis and program transformation

Encyclopedia of Cryptography, Security and Privacy Sushil Jajodia,Pierangela Samarati,Moti Yung,2025-01-10 A rich stream of papers and many good books have been written on cryptography security and privacy but most of them assume a scholarly reader who has the time to start at the beginning and work his way through the entire text The goal of Encyclopedia of Cryptography Security and Privacy Third Edition is to make important notions of cryptography security and privacy accessible to readers who have an interest in a particular concept related to these areas but who lack the time to study one of the many books in these areas The third edition is intended as a replacement of Encyclopedia of Cryptography and Security Second Edition that was edited by Henk van Tilborg and Sushil Jajodia and published by Springer in 2011 The goal of the third edition is to enhance on the earlier edition in several important and interesting ways First entries in the second edition have been updated when needed to keep pace with the advancement of state of the art Second as noticeable already from the title of the encyclopedia coverage has been expanded with special emphasis to the area of privacy Third considering the fast pace at which information and communication technology is evolving and has evolved drastically since the last edition entries have been expanded to provide comprehensive view and include coverage of several newer topics

Using Algebraic Geometry David A. Cox,John Little,DONAL OSHEA,2013-04-17 In recent years the discovery of new algorithms for dealing with polynomial equations coupled with their implementation on fast inexpensive computers has sparked a minor revolution in the study and practice of algebraic geometry These algorithmic methods have also given rise to some exciting new applications of algebraic geometry This book illustrates the many uses of algebraic geometry highlighting some of the more recent applications of Grobner bases and resultants In order to do this the authors provide an introduction to some algebraic objects and techniques which are more advanced than one typically encounters in a first course but nonetheless of great utility The book is written for nonspecialists and for readers with a diverse range of backgrounds It assumes knowledge of the material covered in a standard undergraduate course in abstract algebra and it would help to have some previous exposure to Grobner bases The book does not assume the reader is familiar with more advanced concepts such as modules

Geospatial Algebraic Computations Joseph Awange,Béla Paláncz,2016-01-29 Improved geospatial instrumentation and technology such as in laser scanning has now resulted in millions of data being collected e g point clouds It is in realization that such huge amount of data requires efficient and robust mathematical solutions that this third edition of the book extends the second edition by introducing three new chapters Robust parameter estimation Multiobjective optimization and Symbolic regression

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Advances in Computer Algebra Carsten Schneider, Eugene Zima, 2018-02-26 This book discusses the latest advances in algorithms for symbolic summation factorization symbolic numeric linear algebra and linear functional equations It presents a collection of papers on original research topics from the Waterloo Workshop on Computer Algebra WWCA 2016 a satellite workshop of the International Symposium on Symbolic and Algebraic Computation ISSAC 2016 which was held at Wilfrid Laurier University Waterloo Ontario Canada on July 23 24 2016 This workshop and the resulting book celebrate the 70th birthday of Sergei Abramov Dorodnicyn Computing Centre of the Russian Academy of Sciences Moscow whose highly regarded and inspirational contributions to symbolic methods have become a crucial benchmark of computer algebra and have been broadly adopted by many Computer Algebra systems

Computer Algebra in Scientific Computing Viktor G. Ganzha, Ernst W. Mayr, Evgenii V. Vorozhtsov, 2012-12-06 Proceedings of the Third Workshop on Computer Algebra in Scientific Computing Samarkand Octobe5r 5 9 2000

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