

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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ISSAC '93 Manuel Bronstein, 1993-01-01

Computer Algebra Handbook Johannes Grabmeier, Erich Kaltofen, Volker Weispfenning, 2012-12-06 Two ideas lie gleaming on the jeweler's velvet. The first is the calculus, the second the algorithm. The calculus and the rich body of mathematical analysis to which it gave rise made modern science possible but it has been the algorithm that has made possible the modern world. David Berlinski, *The Advent of the Algorithm*. First there was the concept of integers then there were symbols for integers I II III 1111 fttt what might be called a sticks and stones representation I II III IV V Roman numerals 1 2 3 4 5 Arabic numerals etc. Then there were other concepts with symbols for them and algorithms sometimes for manipulating the new symbols. Then came collections of mathematical knowledge tables of mathematical computations theorems of general results. Soon after algorithms came devices that provided assistance for carrying out computations. Then mathematical knowledge was organized and structured into several related concepts and symbols logic algebra analysis topology algebraic geometry number theory combinatorics etc. This organization and abstraction lead to new algorithms and new fields like universal algebra. But always our symbol systems reflected and influenced our thinking our concepts and our algorithms.

Modern Computer Algebra Joachim von zur Gathen, Jürgen Gerhard, 2003-07-03 Computer algebra systems are gaining importance in all areas of science and engineering. This textbook gives a thorough introduction to the algorithmic basis of the mathematical engine in computer algebra systems. It is designed to accompany one or two semester courses for advanced undergraduate or graduate students in computer science or mathematics. Its comprehensiveness and authority also make it an essential reference for professionals in the area. Special features include detailed study of algorithms including time analysis implementation reports on several topics complete proofs of the mathematical underpinnings a wide variety of applications among others in chemistry coding theory cryptography computational logic and the design of calendars and musical scales. Some of this material has never appeared before in book form. For the new edition errors have been corrected the text has been smoothed and updated and new sections on greatest common divisors and symbolic integration have been added.

Computer algebra Michael Kaplan, 2005-07-28 Computer algebra bezeichnet den Grenzbereich zwischen Algebra und Informatik der sich mit Entwurf Analyse Implementierung und Anwendung algebraischer Algorithmen befasst. Der Autor stellt einige Computer algebra Systeme vor und zeigt an Beispielen deren Leistungsfähigkeit. Grundlegende Techniken werden untersucht für komplexe Fragestellungen werden mehrere Algorithmen angeboten. Die ersten Kapitel beinhalten die nötigen mathematischen Grundlagen diebrigen können weitestgehend unabhängig voneinander gelesen werden. Alle vorgestellten Algorithmen werden begründet und teilweise in einer Pseudoprogrammiersprache dargestellt. Gleichermassen geeignet für Studierende der Mathematik und der Informatik.

Proceedings of the International Conference on Application Specific Array

Processors Peter R. Cappello, 1994 Papers presented at ASAP 94 held in August 1994 The conference serves as a forum for researchers from universities as well as industry who are interested in the fundamental aspects of application specific computing systems Sessions are devoted to signal image processing CAD case studies meth

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

Teubner-Taschenbuch der Mathematik Günter Grosche, Viktor Ziegler, Eberhard Zeidler, Dorothea Ziegler, 2013-03-08 Das Teubner Taschenbuch der Mathematik erfüllt aktuell umfassend und kompakt alle Erwartungen die an ein mathematisches Nachschlagewerk gestellt werden Es vermittelt ein lebendiges und modernes Bild der heutigen Mathematik Als Handbuch begleitet es die Studierenden vom ersten Semester an und der Praktiker nutzt es als unentbehrliches Nachschlagewerk Der Teil II dieses erfolgreichen Werkes behandelt die vielfältigen Anwendungen der Mathematik in Informatik Operations Research und mathematischer Physik Das thematische Spektrum reicht von Tensoranalysis Mathematik und Funktionalanalysis über Dynamische Systeme und Variationsrechnung bis zu Mannigfaltigkeiten Riemannscher Geometrie Liegruppen und Topologie

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Design and Implementation of Symbolic Computation Systems Alfonso

Miola,1993-09-02 This volume constitutes the proceedings of the International Symposium on Design and Implementation of Symbolic Computation Systems DISCO 93 held in Gmunden Austria in September 1993 The growing importance of systems for symbolic computation has greatly influenced the decision of organizing this third conference in the series DISCO 93 focuses mainly on the most innovative methodological and technological aspects of the design and implementation of hardware and software systems for symbolic and algebraic computation automated reasoning geometric modeling and computation and automatic programming The general objective of DISCO 93 is to present an up to date view of the field and to serve as a forum insymbolic computation for the scientific exchange among academic industrial and user communities Besides invited talks by Buchberger Monagan Omodeo and Hong the volume contains 28 contributions carefully selected by a highly competent international program committee from a total of 56 submissions *Computer Algebra in Industry 2* Arjeh M. Cohen,Leendert van Gastel,Sjoerd M. Verduyn Lunel,1995-06-20 This is the second of two books on Computer Algebra in Industry whose contents are based on the assertion that the proper use of computer algebra especially the general purpose software packages presently available will enhance the capabilities of technical and mathematical researchers in industry Reflecting the rapid growth in the area the contributions are written with the non expert in mind with the intention of demonstrating the effective use and cost effectiveness of computer algebra **Proceedings of the 2002 International Symposium on Symbolic and Algebraic Computation** Marc Giusti,International Symposium on Symbolic and Algebraic Computation,2002 Algorithmic Algebra and Number Theory B.Heinrich Matzat,Gert-Martin Greuel,1999 This book contains 22 lectures presented at the final conference of the German research program Algorithmic Number Theory and Algebra 1991 1997 sponsored by the Deutsche Forschungsgemeinschaft The purpose of this research program and the meeting was to bring together developers of computer algebra software and researchers using computational methods to gain insight into experimental problems and theoretical questions in algebra and number theory The book gives an overview on algorithmic methods and results obtained during this period mainly in algebraic number theory commutative algebra and algebraic geometry and group and representation theory Some of the articles illustrate the current state of the computer algebra systems developed with support from the research program for example KANT and LiDIA for algebraic number theory SINGULAR REDLOG and INVARI for commutative algebra and invariant theory respectively and GAP SYSYPHOS and CHEVIE for group and representation theory *Contributions to General Algebra 14* Ivan Chajda,2004 The International Conference on Application Specific Array Processors Peter R. Cappello,Catherine Mongenet,Guy-René Perrin,1995 Papers invited talks and poster sessions from the July 1995 conference address problems and solutions in the field of parallel array algorithms and architectures for special purpose systems Topics include scheduling and mapping techniques design methodologies array architectures computer arith Journal of Dynamic Systems, Measurement, and Control ,2005 *Proceedings of the Seventh Annual International Conference on Technology in Collegiate Mathematics* Gail

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