Tagungsbericht 20/1995

Computational Aspects of Commutative Algebra and Algebraic Geometry

21. 5. – 27. 5. 1995

The conference was organized by D. Eisenbud (Brandeis), G. Scheja (Tübingen) and F.-O. Schreyer (Bayreuth) and attended by about 45 participants from USA and Europe. There werde 18 hours of lectures and three evenings of active informal discussions among smaller groups. The talks included discussions of computer algebra packages, presentations of new algorithms, and new theoretical results in which the computer played only a background role. The general atmosphere of the meeting seemed particularly lively, perhaps because of the varied background of the participants.

Vortragsauszüge

HENDRIK W. LENSTRA, JR.

Approximating Rings of Integers in Number Fields

Joint work with J. A. Buchmann (Saarbrücken).

This talk is concerned with the algorithmic problem of finding the ring of integers of a given algebraic number field. In practice, this problem is often considered to be well-solved, but theoretical results indicate that it is intractable for number fields that are defined by equations with large coefficients. Such fields occur in the number field sieve algorithm for factoring integers. Applying a variant of a standard algorithm for finding rings of integers, one finds a subring of the number field that one may view as the "best guess" one has for the ring of integers. This best guess is probably "often" correct. One may wonder what can be *proved* about this subring, and which good properties it shares with the ring of integers. The main result is that it has a particularly transparent local structure, which mimics the structure of tamely ramified extensions of local fields. In particular, it is a complete intersection ring, and each of its maximal ideals can be generated by two elements. It is not clear how the final ring can be 'intrinsically' characterized in terms of the initial data specifying the number field.

JAN-ERIK ROOS

Homological Classification of Families of Quadratic Forms

Let $R = k[X_1, \dots, X_n]/(f_1, \dots, f_t)$ be a quotient of a polynomial ring in n variables over a field k by an ideal generated by t quadratic forms f_i. Two invariants can be associated to such a ring R:

(1) The Hilbert series of R.

(2) The bigraded Hilbert series of the Yoneda Ext-algebra $\mathrm{Ext}^*_R(k, k)$ (which is the enveloping algebra of a certain bigraded Lie-Algebra).

The behavior of these invariants for $n \leq 3$ is well-known (cf. the literature cited in my paper in *J. Pure Appl. Algebra*, 91, 1994, 255–315). For fixed $n \geq 6$ I have proved (*Comptes Rendus*, vol. 316, 1993, 1123–1128) that there can be infinite families of rings R, having the same Hilbert series of type (1) but having different Hilbert series of type (2).

For $n = 4$ and $n = 5$ I have found by computer studies that there seem to be finitely many cases (80 and ≥ 2600 cases respectively) and that these cases occur nicely in families. The attempt to prove that this is a complete structure theorem gives rise to rather difficult problems, at least for $n = 5$. As a by-product I have found four counter-examples to a problem about the characterization of Koszul algebras (*Comptes Rendus*, vol. 320, 1995).

TEO MORA

Gröbner Duality

Gröbner proved that there is a duality 'between' primary ideals at the origin and suitable vector spaces of differential conditions. The theory he introduced was mainly aimed at understanding multiplicity and Macaulay's inverse systems. Up to fixing minor complexity problems it is easy to verify that Gröbner's proposal is a reasonable alternative to the classical ways of describing multiplicities within polynomial system solving theory. Apparently Gröbner's theory has also other applications from commutative algebra to numerical analysis.

HUBERT FLENNER

Some Examples of Cuspidal Rational Curves

Joint work with M. Zaidenberg (Grenoble)

A cuspidal curve is an algebraic curve which is locally analytically irreducible. It is easy to construct rational cuspidal curves in the projective plane $\mathbb{P}^2$ with one or two singular points. In contrast there are only a few rational cuspidal curves known which have at least three cusps. The most classical one is the rational cuspidal quartic having three simple cusps. Other examples are known from the classification of quintics in $\mathbb{P}^2$ due to Namba where one can find three further examples, one with four and two with three singularities. A basic invariant of a cusp is its multiplicity sequence which is the sequence of multiplicities of the proper transforms of the curve in a minimal embedded resolution. The main result exhibits new examples of rational cuspidal curves C of degree d with three cusps where the highest multiplicity of a cusp is $d-2$. A complete classification of such curves is given. The multiplicity sequences of the singular points are $(d-2)$, (2_a), (2_b) with $a+b=d-2$, and for each such pair a, b there exists such a curve which is unique up to projective equivalence. This seems to give the first known infinite series of rational cuspidal curves with at least three singular points.

GERD-MARTIN GREUEL

Classifikation of Simple Space Curve Singularities

I report on recent work of my student Anne Frühbis who classified all reduced curve singularities in $(\mathbb{C}^3,0)$ which have the property that they deform only into finitely many other singularities (up to analytic isomorphism).

The case of hypersurface singularities is covered by Arnold's list of A-D-E singularities (they really embed into $(\mathbb{C}^2,0) \subset (\mathbb{C}^3,0)$); the simple complete intersections are classified by M. Giusti. The simple space surve singularities which are not complete intersections consist of two infinite series and eleven "exceptional" singularities. The ideal of these singularities in $\mathbb{C}\{x, y, z\}$ is always generated by the 2×2 minors of a 3×2 matrix, the multiplicity of the singularities is either 3 or 4. Geometrically they can be nicely described by looking at their generic projection to $(\mathbb{C}^2, 0)$ or as a specialization of some of the simple complete intersections.

BERND STURMFELS

Polyhedral Methods for Solving Polynomial Equations

A basic problem in computational algebra is to find all zeros of a sparse system of polynomial equations. The situation is fairly well understood for complex zeros: their expected number is the mixed volume of the given Newton polytopes. This result due to Bernstein can be proved by an elementary algorithm using toric deformations. Things are more difficult (and interesting) over the real numbers: Khovanskii has shown that the number of real roots is bounded by a function which is independent of the degree of the given equations. More precise upper bounds are stated in conjectures of Kouchnirenko and Itenberg-Roy. We discuss these results and conjectures, and we illustrate them with many colorful pictures of planar polygons.

DANIEL R. GRAYSON AND MICHAEL E. STILLMANN

Macaulay

We gave a demonstration of Macaulay 2, a successor to the computer program Macaulay, written by David Bayer and Michael Stillman. Macaulay 2 is designed to compute Gröbner bases and syzygies over quotient rings of polynomial rings over finite fields, the integers, and the rationals, and includes a general purpose object-oriented programming language for the user.

In its current state the only ground fields available are finite prime fields, the Gröbner basis routines function but have not been optimized for speed yet, and the documentation (readable through netscape or Mosaic) is incomplete. On the positive side, it is easy to implement new features daily. Recent ones include lifting of module maps to their resolutions, and computation of the syzygy variety.

We will complete the documentation and then, in a couple of weeks provide the program to those volunteering as α-testers. Anyone desiring to make suggestions about the algorithms or the look-and-feel of the program is welcome to participate. It is still possible to make major changes.

PAUL PEDERSEN

Newton Polytopes and Trace Forms

Joint work with Bernd Sturmfels

We consider toric deformations of systems of Laurent polynomials:
$f_i(x,t) = \sum_{q\in\mathcal{A}_i} c_{iq}\, x^q\, t^{\omega_i(q)}$, $1 \le i \le n$. If f_i has Newton polytope P_i, then the weights $\omega_i(q)$ determine lifted polytopes $\widehat{P}_i := \{(q,\omega_i(q)) : q \in P_i\}$ in $\mathbb{R}^{n+1}$. Let $\widehat{P} = \widehat{P}_1 + \ldots + \widehat{P}_n$ denote the Minkowski sum upstairs. The projection $\pi(\widehat{P}_-)$ to the first n coordinates of the *lower convex hull* $\widehat{P}_-$ of $\widehat{P}$ determines a subdivision Δ of $\sum P_i = P = \pi(\widehat{P}_-)$. Each cell C of Δ has the form $F_1 + \ldots + F_n = \pi(\widehat{F})$ where $F_i = \pi(\widehat{F}_i)$ is a subpolytope of P_i. The *mixed cells* of Δ are defined by the condition $\dim(F_1) = \ldots = \dim(F_n) = 1$. The sum of the volumes of the mixed cells of any mixed subdivision equals the *mixed volume* $\mathcal{MV}(P_1,\ldots,P_n)$. This is an integer which does not depend on the choice of subdivision, and by Bernstein's Theorem, it equals the number of toric roots $\{x \in (\mathbb{C}^*)^n : f_i(x) = 0, \forall i\}$. Any mixed cell C is a parallelotope, and when considered "half-open" C', then $\mathrm{Vol}(C) = \#|C' \cap \mathbb{Z}^n|$.

Theorem 1. *Let $f_1,\ldots,f_n$ be generic Laurent polynomials with Newton polytopes $P_1,\ldots,P_n$, respectively. The monomials corresponding to the lattice points lying in the half-open mixed cells C' of any mixed subdivision Δ of $P = P_1 + \ldots + P_n$ form a vector space basis for the quotient ring $A = K[x_1,x_1^{-1},\ldots,x_n,x_n^{-1}]\,/\,(f_1,\ldots,f_n)$.*

Theorem 2. *With respect to the basis in Theorem 1, the trace form of the deformed system is a matrix polynomial $B(t) = B_0\, t^d\, (1 + o(1))$, where*

$$d = \sum_C \gamma_C \cdot a_C, \qquad det(B_0) = \prod_C \mathrm{Vol}(C)^{\mathrm{Vol}(C)} \cdot b_C^{2U_C^{-1}a_C}.$$

$(\gamma_C, 1)$ is the vector supporting the mixed facet above C, $a_C = \sum\{q \in C'\}$, and $x^{U_C} = b_C$ is the binomial "degeneration" of the equation system to the facet over C. (Sum and product over all mixed cells of Δ.)

Theorem 3. *The number of real roots of the deformed system for all sufficiently small t, is bounded by $\sum_{C\ mixed} 2^{p(C)}$, where $p(C) =$ the number of even invariant factors of the finite Abelian group $\mathbb{Z}^n/U_C$.*

G.-M. GREUEL, G. PFISTER, H. SCHÖNEMANN

Demonstration of the Computer Algebra System SINGULAR

SINGULAR is a system for algebraic geometry and singularity theory. It is being developed at the University of Kaiserslautern and its implementation is directed by G.-M. Greuel,

G. Pfister and H. Schönemann with contributions by H. Grassmann, B. Martin, W. Neumann, W. Pohl and T. Siebert. Recently, W. Decker, M. Messollen und R. Stobbe contributed to primary decomposition in SINGULAR. The basic algorithms are a general standard basis algorithm (implemented for any semigroup ordering, not necessarily well–orderings), syzygy algorithms and combinatorial algorithms (for computation of Hilbert series, etc.). This generality allows the computation in polynomial rings, localizations hereof, factorings of these and tensor products of all these. The possible ground fields are $\mathbb{Z}/p\mathbb{Z}$ (p a prime ≤ 32003), arbitrary finite fields, the rational numbers and finite transcendental extension of these. Multivariate algebraic extensions will be ready very soon and float coefficients are under experimentation.

SINGULAR has a flexible programming language with `for`, `if` ... `else`, `while` constructs and contains also a continuously growing library with useful procedures for algebraic geometry and singularity theory.

SINGULAR has developed through the necessity of carrying out complicated computations in connection with mathematical problems and is, therefore, designed for speed. It has the most flexible broad standard basis algorithms with respect to monomial orderings of all known computer algebra systems. Moreover, many comparisons show that it is also the fastest system for computations of standard bases and syzygies (at least over $\mathbb{Z}/p\mathbb{Z}$).

The programme is available under ftp helios.mathematik.uni-kl.de or www.mathematik.uni-kl.de, requests and comments may be sent to singular@mathematik.uni-kl.de.

KAREN E. SMITH

Simplicity of Rings of Differential Operators

Joint work with Michel Van den Berg

Let R be a commutative Noetherian k algebra where k is an arbitrary field. Let $D_k(R)$ denote the ring of k linear differential operators on R. A basic question is: when is $D_k(R)$ a simple ring?

We proved the following theorem: Let R be a graded subring of a polynomial ring S over a perfect field k of characteristic $p > 0$. If the inclusion map of R into S splits in the category of graded R modules, then $D_k(R)$ is a simple ring.

A key idea in the proof is the introduction of the notion of "Finite F-representation type". A (reduced) ring of characteristic $p > 0$ has finite F-representation type if there are only finitely many isomorphism classes of indecomposable R modules that appear as summands in a direct sum decomposition of $R^{1/q}$ as q ranges over all integer powers of p.

LORENZO ROBBIANO

CoCoA 3

The system CoCoA does **Co**mputations in **Co**mmutative **A**lgebra.

1987 Two small projects (Giovini and Niesi)

1988 Merging the two projects into a bigger one: CoCoA

1989 First distributed version (0.99) at the COCOA II Meeting in Genova.

1990 Second version (1.0)

1991 Third version (1.5)

After the death of Giovini (**January 1993**)
another project started, the " CoCoA 3"

Project Manager: Robbiano
Authors: Capani, Niesi
Co-workers: Bigatti, Caboara, De Dominicis,
α-Testers: Elias, Eliahou, Kreuzer, Loustaunau, Recio, Sturmfels.

1995 First distributed β-version at the COCOA IV Meeting

Genova, May 29^{th} – June 2^{nd}, 1995

ALESSANDRO LOGAR

Computation of the Lines of a Cubic Surface

Joint work with Michela Brundu

Let S be a smooth cubic surface in $\mathbb{P}^3$. A classic theorem claims that S contains 27 distinct lines. In the paper we discuss some computational approaches to the determination of the lines. In particular, we show how to parametrize all the smooth cubic surfaces up to a linear change of coordinates and we explicitely give the equations of the 27 lines in terms of the parameters.

We then get a procedure to construct all the cubic surfaces having only rational lines. Finally we discuss some methods to get a rational representation of S.

EBERHARD BECKER

The Real Radical of an Ideal and its Computation

We report on

1) the theoretical relevance of the real radical of an ideal,

2) the algorithm of Becker-Neuhaus,

3) the complexity analysis of this algorithm.

The algorithm depends on various other algorithms of computational commutative algebra (e.g. computing the ordinary radical) as well as on genuine problems of real algebraic geometry, e.g. deciding whether a polynomial is positive semi-definite. The last task can be carried out by a variant of Renegar's ideas and a real root counting method.

MONIQUE LEJEUNE-LALABERT

Arc Structure of Singularities

In an unpublished preprint written in the sixties, J. Nash initiated the study of the set of arcs on the germ (V, O) of an algebraic, or analytic, variety V at a singular point O. In his terminology, an arc is a parametrized formal curve lying on (V, O). In connection with the desingularization problem, he first recognized some finiteness properties that this set enjoys, despite its natural structure of a non noetherin affine scheme. We made a survey of old and new results by Nash, Bouvier, González-Sprinberg, Hickel, Reguera in this area.

ARJEH M. COHEN

Structure Determination of Lie Algebras

The idea behind some of the algorithms implemented in GAP by W. de Graaf have been discussed. Particular attention has been given to algorithms for finding a non-nilpotent element, a Cartan subalgebra, the nilradical, and the solvabel radical for a finite-dimensional Lie algebra given by structure constants.

KEITH PARDUE

Crossing the Hilbert Scheme

I state the following two theorems and give a sketch of the main technique used in their proof. I describe the earlier contributions of Hartshorne, Baptista de Campos, Reeves, Macaulay, Bigatti and Hulett.

Let S be a polynomial ring over an infinite field.

Theorem A If F is a graded free S-module of finite rank and F/M and F/N are two graded quotient modules with the same Hilbert function, then there is a series of deformations, all defined over $\mathbb{A}_k^1$, taking one to the other.

Theorem B If F is a graded free module, M is a graded submodule, and L is the lexicographic submodule of F with the same Hilbert function as M, then the graded Betti numbers of F/M are bounded by those of F/L.

ALDO CONCA

Sagbi Bases and Applications to Blow-ups

Joint work with J. Herzog and T. Valla

Sagbi bases theory was introduced by Robbiano and Sweedler, and independently by Kapur and Madlener. Given a sub-k-algebra A of a polynomial ring R, one associates to A its initial algebra in(A) which is the k-algebra generated by the initial monomials of the elements of A.

The algebra in(A) need not to be finitely generated, but in the cases in which it is finitely generated it can be described as the special fibre of a 1-parameter flat family whose generic fibre is A. As a consequence of this fact one has that A is Cohen-Macaulay or normal whenever in(A) is so.

We apply this idea to the study of the Rees algebra $R(I)$ associated with the ideal I of definition of a rational normal curve. It turns out that $R(I)$ is normal Cohen-Macaulay and Koszul.

IRENA PEEVA AND JÜRGEN HERZOG

Resolution of Monomial Ideals

Stable ideals are an important class of monomial ideals; the interest in studying these ideals comes from Gröbner basis theory. We consider resolutions related to stable ideals; we build a special algebraic structure on some finite resolutions, and using it we obtain numerical information about infinite resolutions.

We introduce squarefree stable ideals and squarefree lexsegment ideals, and construct their minimal free resolution. This information is used to prove some inequalities about Betti numbers and conjecture others. This part is joint work with Aramova and Hibi.

BARRY TRAGER

Square-Free Algorithms in Positive Characteristic

Joint work with P. Gianni

We study the problem of the square free decomposition for polynomials with coefficients over fields, of positive characteristic or fields which are explicitly finitely generated over perfect fields; the classical algorithm from characteristic zero can be generalized using multiple derivations. For more general fields one must make an additional hypothesis for the problem to be decidable. Seidenberg's condition P gives a necessary and sufficient condition on the field k for computing a complete square free decomposition of polynomials with coefficients in any finite algebraic extension of k.

DALE CUTKOWSKI

Local Factorization of Birational Maps

We give a positive answer to a question of Abhyankar, generalizing the local factorization theorem of Zariski and Abhyankar on birational maps of regular local rings of dimension 2. We prove

Theorem Let K be a field of algebraic functions over an algebraically closed field k of characteristic zero. Let $R \subset S \subset K$ be regular local rings of dimension 3 with quotient field K such that the residue fields of R and S are k. Let V be a valuation ring of K dominating S. Then there exists a factorization by a triangle

$$\begin{array}{ccc} & V & \\ & \cup & \\ & T & \\ \alpha \nearrow & & \nwarrow \beta \\ R & \longrightarrow & S \end{array}$$

where α, β are products of monoidal transforms.

SORIN POPESCU

Geometry and Equations of a Smooth Surface

We discuss various construction techniques for smooth surfaces in $\mathbb{P}^n$ and as example we prove the existence of a component of the Hilbert scheme of surfaces in $\mathbb{P}^n$ parametrizing smooth non-minimal K3 surfaces, blown up in 15 points and embedded via a linear system

$$H = H_{min} - 4E_0 - \sum_{i=1}^{4} 2E_i - \sum_{j=5}^{14} E_j$$

where H_{min} is a very ample linear system on the minimal model S_{min}, giving an embedding $S_{min} \hookrightarrow^{H_{min}} \mathbb{P}^{29}$. The invariants of such surfaces are $d = 14$, $\pi = 19$, $\kappa^2 = -15$, $\chi = 2$. We give an explicit method to construct the equations of such surfaces and we describe part of their rich geometry.

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