MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 27 / 1983

AG Algebra: Combinatorics and algebraic groups

19. bis 25. 6. 1983

Die international zusammengesetzte Tagung fand unter der Leitung von H. Kraft (Basel), I.G. Macdonald (London) und C. Procesi (Rom) statt. Die Vorträge konzentrierten sich um die drei folgenden Schwerpunkte:

- Schur Funktoren (Auflösung der Determinantenvarietäten, Schur - Komplexe, Schubert Funktoren)
- Lie - Gruppen und Kombinatorik (Macdonald - Identitäten und Verallgemeinerungen, Kombinatorik und Darstellungstheorie)
- Theorie der Standard - Monome (Geometrie von G / P , Schubert - Varietäten, Hodge - Algebren, Anwendung auf Normalität und Cohen - Macaulay - Eigenschaft)

Gemäss der Tradition der AG - Algebra wurden diese drei Gebiete jeweils durch einen grösseren Übersichtsvortrag eingeführt und anschliessend durch mehrere Spezialvorträge vertieft. Weitere Vorträge beschäftigten sich mit Fragen aus der abzählenden Geometrie, Invarianten von unipotenten Gruppen, polaren Darstellungen und nilpotenten Dreiecksmatrizen. Einzelheiten können den nachstehenden Vortragsauszügen entnommen werden.

D. Buchsbaum:

Introduction to Schur modules

To reproduce Lascoux' resolution of determinantal ideals in characteristic 0, a definiton of Schur and coSchur modules over arbitrary commutative rings R was given and discussed. For a matrix $A = (a_{ij})$ of zeroes and ones, and any free R-module F a Schur map $d_A : \Lambda_A F \to S_{\tilde{A}}^{*} F$ was defined, where $\Lambda_A F = \Lambda^{a_1} F \otimes \cdots \otimes \Lambda^{a_s} F$, $S_{\tilde{A}}^{*} F = S_{b_1} F \otimes \cdots \otimes S_{b_r} F$, $a_i = \sum_j a_{ij}$, $b_j = \sum_i a_{ij}$. The image of d_A is denoted by $L_A F$ and called the Schur module of shape A. When A is the matrix corresponding to a partition λ or skew partition λ/μ, the modules $L_\lambda F$ and $L_{\lambda/\mu} F$ are universally free. (A similar construction involving the divided power algebra defines coSchur modules K_A, K_λ, $K_{\lambda/\mu}$.) These modules may be used to reproduce the terms of Lascoux' resolution, but over $\mathbb{Z}$ it has non-zero torsion homology. This leads to the study of $\mathbb{Z}$-forms of rational representations of GL(F). Examples connecting these $\mathbb{Z}$-forms with Ext and Giambelli identities lead to construction of "resolutions" of $L_{\lambda/\mu}$ by means of sums of tensor products of exterior powers. These resolutions should be constructible by means of iterated mapping cones (a complete description was given for two-rowed shapes), but since the terms of the resolution are not projective, one needs a proof of existence of maps on which these mapping cones are to be built. This problem is solved by looking at resolutions of coSchur modules in terms of tensor products of divided powers. These latter modules are projective over the Schur algebra, so iterated mapping cones may be constructed. Invoking the involution between divided and exterior powers, the corresponding mapping cone constructions for Schur modules could also be effected.

T. Jozefiak:

Syzygies of determinantal ideals

Let X be an affine space of all m×n matrices over a field K of characteristic 0 and let Y_r be a set of all matrices of rank $\leq r$ in X. Y_r is called a determinantal variety and its coordinate ring $\mathcal{O}_{Y_r}$ is isomorphic to $K[T_{ij}]/I_{r+1}(T)$ where $T = (T_{ij})$ is a generic m×n matrix of indeterminates and the ideal $I_{r+1}(T)$ is generated by (r+1)-order minors of T. The problem discussed in the talk consists in fixing an explicit minimal free resolution of $\mathcal{O}_{Y_r}$ over $\mathcal{O}_X$. Attempts of many

mathematicians to solve the problem were presented in the chronological order. Emphasis was put on a geometrical construction of A. Lascoux allowing to construct components of a minimal free resolution and a recent work of P. Pragacz & J. Weyman that also contains an explicit construction of differentials.
Lascoux' method is based on a geometric construction of a desingularisation Z of Y_r in a suitable Grassmannian G. Z is a complete intersection in G, i.e. $\mathcal{O}_Z$ has a simple resolution over $\mathcal{O}_G$ which is given by a Koozul complex $K^\bullet$. By using a spectral sequence of hypercohomology associated to $K^\bullet$ and Bott's theorem one finds components of a minimal resolution of $\mathcal{O}_{Y_r}$ over $\mathcal{O}_X$ as sum of certain Schur functors. Pragacz & Weyman's construction describes the resolution as a total complex associated with certain double complex. At first one constructs rows of a double complex using trace and evaluation maps between Schurcomplexes.Differentials in rows are of degree 1. Then one complets the picture by defining maps of degree $r+1$ between consecutive rows. Exactness of the complex is proved by applying the acyclicity lemma.

R. Stanley:

Combinatoricsand representations of $GL(n,\mathbb{C})$

The characters of the polynomial representations of $GL(n,\mathbb{C})$ or $SL(n,\mathbb{C})$ are symmetric functions in the eigenvalues of $A \in GL(n,\mathbb{C})$ known as Schur functions. They have a combinatorial definition involving Young tableaux which leads to many connections between combinatorics and representation theory. One instance of this connection is to the enumeration of plane partitions, a generalization due to P. MacMahon of the classical theory of partitions. The Weyl character formula leads immediately to most of the basic results in this area. Moreover, an elegant generating function for a certain class of plane partitions can be obtained by decomposing the restriction of certain representations of $\underline{so}(2n+1,\mathbb{C})$ to the Levisubalgebra $\underline{gl}(n,\mathbb{C})$. Another connection between combinatorics and representation theory arises from the problem of decomposing the virtual character $\det \prod_i (1-z_i \operatorname{ad} x)/(1-w_i \operatorname{ad} x)$ of $SL(n,\mathbb{C})$ as $n \to \infty$. An explicit decomposition into irreducibles is found which can be applied to the computation of the generalized exponent of $SL(n,\mathbb{C})$, the q-Dyson conjecture, and related problems.

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I.G. Macdonald:

Constant term identities related to root systems

A survey of various conjectures relating to constant terms in Laurent polynomials constructed from root systems, of which the following (generalizing "Dyson's conjecture" (1962)) is the simplest to state : let R be a reduced root system, W its Weyl group, d_i ($1 \leq i \leq l$) the degree of the fundamental polynomial invariants of W ; also for each $\alpha \in R$ let e^α be the corresponding formal exponential. Then we conjecture that the constant term in the Laurent polynomial $\prod_{\alpha \in R} (1-e^\alpha)^k$ (where k is a positive integer) should be $\prod_{i=1}^{l} \binom{k\,d_i}{k}$. This is true for all values of k when R is of classical type (A_n, B_n, C_n, D_n) ; also for all R when k = 1,2 . For R exceptional and $k \geq 3$ it remains an open question. More details may be found in "Some conjectures for root systems", SIAM J.Math.Anal. 13 (1982) 988 - 1007 .

A. Lascoux:

Schubert Functors (joint work with M.P. Schützenberger)

The ring of symmetric polynomials $\mathbb{Z}[a,b,\ldots]^{W_n}$, W_n being the symmetric group on n elements , can be considered as the ring of representations of the symmetric group, or the linear group, or absolute cohomology ring of the Grassmann variety. Its natural basis, the Schur functions, can be generalized in different manners : they can be considered as sums of Young tableaux (=> in the "plactic ring") or looked at as functors on modules (Schur functors). Another generalization comes from the action of W_n on $\mathbb{Z}[a,b,\ldots]$ .Essentially, for the group W_2 , there are three actions :

$$f(a,b) \longmapsto f(b,a) ,$$

$$f(a,b) \longmapsto [f(a,b) - f(b,a)] / (a-b) ,$$

$$f(a,b) \longmapsto [a\,f(a,b) - b\,f(b,a)] / (a-b) .$$

One can interpolate between these tree actions and extend them to W_n . Now, the action on the special polynomial $a^{n-1}\,b^{n-2}\,c^{n-3}\ldots$ gives a family of polynomials ("Schubert polynomials") which contains the Schur functions. The Schubert polynomials can be lifted to the plactic ring, giving sums of tableaux with flags of alphabets, or can be considered as functors of flags of modules, in connection with the study of Schubert varieties in the flag manifold.
Another extension applies to the ring of reduced decompositions in the symmetric group and this ring can also be considered as a quotient of the nilplactic ring (a non commutative ring very similar to the ring of tableaux).

C. DeConcini:

Enumerative Geometry and Embeddings

Let G be a semisimple adjoint group, $\sigma : G \to G$ an order 2 automorphism, $H = G^\sigma$ the group of elements fixed by σ. We set $\underline{g} = \text{Lie } G$, $\underline{h} = \text{Lie } H$, $l = \text{rk } G/H$, $m = \dim \underline{h}$. We can consider $\underline{h}$ as a point in the Grassmann variety $G_m(\underline{g})$ of m-dimensional subspace of $\underline{g}$. The action of G on $G_m(\underline{g})$ induced by the adjoint action allows us to define a G-variety $X = \overline{G\underline{h}} \subseteq G_m(\underline{g})$. It is easily seen that $H = \text{Stab } \underline{h}$, so X is an embedding of G/H. X has many pleasent properties :

a) X is smooth projective

b) $X - G\underline{h} = \bigcup_{i=1}^{l} S_i$, where S_i is a smooth divisor which is a orbit closure for each $i = 1,\dots,l$.

c) The S_i's meet transversally.

d) Each orbit closure in X is of the form $S_I = \bigcap_{i\in I} S_i$ for some $I \subseteq \{1,\dots,l\}$; so in particular it is smooth by properity c); furthermore $\bigcap_{i=1}^{l} S_i$ is the unique closed orbit in X.

Two special cases of this construction have been classically studied in the field of enumerative geometry.

In the first case $G = \mathbb{P}GL(n+2) \times \mathbb{P}GL(n+2)$ and $\sigma(g,g') = (g',g)$ for any $(g,g') \in G$. In this case X is the variety of complete collineations of $\mathbb{P}^n$.

In the second case $G = \mathbb{P}GL(n+1)$ and σ is the involution on G induced by the involution σ' on $GL(n+1)$ defined by $\sigma'(g) = {}^t g^{-1}$. In this case the variety X is the variety of complete quadrics.

J. Dadok:

Polar Representations (joint work with V. Kac)

Let $G|V$ be a rational representation of a linear reductive algebraic group G over $\mathbb{C}$ on a vectorspace V. If $v \in V$ lies on a closed G orbit let

$$c_v = \{ x \in V \mid \mathfrak{g}\cdot x \subseteq \mathfrak{g}\, v \}$$

where $\mathfrak{g} = \text{L.A.}(G)$. The representation is called polar if for some c_v, henceforth called Cartan subspace, $\dim c_v = \dim V/G$, where V/G is the affine variety corresponding to the ring of invariants $\mathbb{C}[V]^G$. If $G|V$ is polar then all Cartan subspaces are G conjugate; all closed G orbits meet a given Cartan subspace c, and all orbits through c are closed. Intersection for a closed G orbit with c is a W orbit, where the Weyl group W is a finite group. Via restriction one obtains

$\mathbb{C}[V]^G \cong \mathbb{C}[c]^W$. In case G is connected W is generated by unitary reflections, and hence $\mathbb{C}[V]^G$ is a polynomial algebra. Polar representations include adjoint actions, representations associated to symmetric spaces, θ-groups and irreducible visible representations.

C. Procesi:

Introduction to standard monomials

The classical representation theory of the linear group, as developped by I. Schur, has a tight connection with invariant theory. This connection brings forth the role of determinantal varieties. In order to interpret the picture of A. Young, giving bases of representations of the symmetric group by standard diagrams, in the previous setting it is best to use Hodge's approach to the postulation formula for the Grassmann variety. In this picture the standard tableaux appear related to the natural geometric ordering of Schubert cells.
In fact the Schubert varieties correspond bijectively to the Plücker coordinates and the monomials $a_1 \cdot a_2 \cdot \ldots \cdot a_s$ in the Plücker coordinates, such that $a_i \leq a_{i+1}$ (in the corresponding ordering of Schubert cells) are a basis for the projective ring of Grassmannian.
The determinantal varieties appear then as affine parts of Schubert varieties and the previous theory of standard monomials becomes the theory of Double Standard Tableaux (as in Doubilet - Rota - Stein). Thus one can go back to the representation theory and start a connection which has very large possibilities of generalizations.

V. Lakshmibai:

Geometry of G/P

In this talk we gave a survey of "standard monomial theory", mentioned various applications. Standard monomial theory for a semisimple algebraic group G consists in the construction of an explicit basis for $H^\circ(G/B, L)$ (where B is a Borel subgroup and L is a positive line bundle on G/B) as a generalization of the classical Hodge - Young theory. The construction is done using the Schubert calculus.

Step 1 : Construction of an explicit basis for $H^\circ(G/P, L)$ and more generally for $H^\circ(X, L)$, where P is a maximal parabolic subgroup and L an ample generator of $\mathrm{Pic}(G/P)$ and X a Schubert variety in G/P .

Step 2 : Notion of monomials in the basis elements being standard.

Step 3 : Proof of the fact that standard monomials on X of degree m give a basis of $H^{o}(X, L^{m})$.

Step 4 : Using the theory for G/P , one obtains the theory for G/Q where Q is any parabolic subgroup.

The above problem has been solved for parabolic subgroups $Q = \cap P_i$ where P_i is such that the associated fundamental weight ω_i satisfies $|\langle \omega_i , \check{\alpha} \rangle| \leq 2$ for all roots α ;and also for the parabolic subgroubs P_2 (and P_1) of a group of type G_2 . Among the various applications of standard monomial theory one striking application is the determination of singular locus of a Schubert variety.

D. Eisenbud:

Hodge Algebras and Cohen - Macaulayness

(Ref: Hodge algebras, by C.DeConcini, D.Eisenbud and C.Procesi, asterisque, 1982)

A Hodge algebra A over a ring R (commutative, noetherian,...) on a poset H governed by an ideal of monomials $\Sigma \subset \mathbb{N}^H$ is a (commutative) algebra A generated by H , such that

1) the monomials in H that are not in Σ (the standard monomials) form a basis for A ,
2) if N is an element of the minimal generating set for Σ , and $N = \Sigma\, r_i M_i$ is its unique expression as an R - linear combination of standard monomials M_i ,

then for each i and each $x \in H$ dividing N formally, there is an $x_i \in H$ dividing M formally such that $x_i \leq x$.

The simplest Hodge algebra on H generated by Σ is then the discrete algebra A_o
$A_o = R[H] / (\Sigma)$, where $R[H]$ is the polynomial ring and (Σ) is the ideal in $R[H]$ generated by monomials in Σ . The significance of the condition 2) above is that it makes A a deformation of A_o in a nice way; probably there are even weaker conditions that do this.

Note that if $I \subset H$ is an order ideal ($x \in I$, $y \leq x \Rightarrow y \in I$) then A/I is again a Hodge algebra; this is the significance of allowing arbitrary partial orders on H . The notion of Hodge algebra abstracts the notion of "standard monomials" found in G/P (Lakshmibai,Musili,Seshadri) and elsewhere. Because of the deformation idea above properties of interesting Hodge algebras (reducedness, Cohen-Macaulayness,etc) can often be deduced from properties of the discrete algebras, which are subject to a very penetrating combinatorial study (Reisner,Hochster,Stanley,Björner, Baclawski,Garsia ...)

A. Björner:

Cohen - Macaulayness and shellability of Bruhat order and buildings

Algebraic groups are related to the combinatorics of posets and simplicial complexes in at least two important ways: via the "Bruhat" ordering and via Tits buildings. On the other hand posets and complexes are related to commutative rings via the construction of Hochster and Stanley, alias the "discrete rings" in the theory of Hodge algebras. In this talk we attempted to describe a few basic facts about these connections and about the use of shellability for establishing Cohen - Macaulayness out of combinatorial structure.

V. Kac:

Infinite - dimensional groups and their flag varieties

A Lie algebra (possibly infinite - dimensional) is called integrable if it is generated by locally - finite elements (then it is spanned by them). Given an integrable Lie algebra $\underline{g}$, we associate to it a group G as follows. Denote by S the set of all locally - finite elements of $\underline{g}$. We call a $\underline{g}$ - module V integrable if every $x \in S$ acts locally - finite on V . Then G is a group, generated by symbols $\exp x$, with relations between $\exp x = 1 + x + \frac{1}{2}x^2 + \cdots$ in all representations of $\underline{g}$. Given a generalized Cartan matrix A , we denote by G (A) the group associated to the Kac - Moody Lie algebra $\underline{g}$ (A). Then G (A) has a structure of a Tits system and one can study the associated flag varieties, Schubert varieties, highest weight representations, etc. One of the consequences is the description of the compact form K (A) in terms of generators and relations and the study of homology of K (A). At the end the group GL_∞ (or rather its central extention) was discussed, along with application to soliton solutions of KP - equation .

References: V. Kac: Algebraic definiton of compact Lie groups; Trudy MIEM, 1969.

V. Kac, D. Peterson: Regular functions on certain infinite - dimensional groups; in "Arithmetric and Geometry", Birkhäuser,1983.

D. Peterson, V. Kac: Infinite flag varieties and conjugacy theorems; Proc.Nat.Acad.Sci. March 1983.

Date, Jimbo, Kashiwara, Miura: Transformation groups of soliton equation; Kyoto, 1981 - 82.

G.D. James:

Representations of general linear groups

We discuss the unipotent representations of finite general linear groups $G_n = GL_n(q)$ over a field K whose characteristic does not divide q.
Let M^λ be the permutation module of KG_n on the parabolic subgroup corresponding to the partition λ on n. The module S^λ is defined to be the subset of M^λ which equals the intersection of the kernels of all KG_n - homomorphisms which map M^λ into some M^μ for which $\mu > \lambda$. If K has characteristic zero, then S^λ is irreducible, and more generally S^λ has an unique irreducible image D^λ. As λ runs over partitions of n, D^λ runs over a complete set of inequivalent irreducible unipotent KG_n - modules. The matrix which records the composition multiplicities of the D^μ's in the S^λ's is part of the decomposition matrix of KG_n, and is lower unitriangular.
The remarkable feature is that the representation theory of the symmetric group (and perhaps even the theory of Weyl modules) appears to be the case "$q = 1$" of this theory.

G. Towber:

Shape algebras and applications

A review of shape functor constructions for several typical cases (GL_n, $SO(2l+1)$, G_2) was given. The strategy leading to these constructions was then described and its connection with Kostants theorem on the kernel of a Cartan product. An alternative multiplication on the shape algebra for $GL(E)$ was described and an application to the plethysm problem was given.

K. Pommerening:

Invariant algebras stable under straightening

There are only a few results in the invariant theory of non - reductive groups:

a) Nagata's counterexample

b) the converse of the invariant theorem for reductive groups (Popov)

c) Zariski's theorem: When a group G acts rationally on a finitely generated algebra A and trdeg $A^G \leq 2$, then A^G is finitely generated.

d) Grosshans'criterion: Let $H \subseteq SL_n$ act on the polynomial algebra $k[X] =$ $= k[X_{ij} \mid 1 \leq i,j \leq n]$ by left translation and let $k[X]^H$ be finitely generated. Then for any finitely generated algebra A on which a reductive group G, $H \subseteq G \subseteq GL_n$, acts rationally, A^H is finitely generated.

So a good substitute for Hilbert's 14 th problem is: find the "Grosshans subgroups" of a reductive group G.

For a regular (= normalized by a maximal torus) unipotent subgroup U of GL_n a necessary and sufficient condition is given for the stronger property that $k[X]^U$ is spanned by the invariant standard bitableaux. This proves the Grosshans property for a large class of regular nilpotent subgroup of GL_n.

W. Hesselink:

Nilpotent triangular matrices

A nilpotent endomorphism x of a vectorspace V with $\dim V = n$ is characterized by a partition $\lambda(x:V) = (\lambda_1, \dots, \lambda_r)$ of n. Let $Y(x)$ be the set of the x-invariant flags $F_* = (F_0, F_1, \dots, F_n)$ in V. A natural discrete invariant of a flag $F_* \in Y(x)$ is the system of partitions $\tau(x,F_*) = (\tau[p,q])_{p \leq q}$ with $\tau[p,q] = \lambda(x:F_q/F_p)$. We give a representation of τ by strictly upper triangular matrix A of zeroes and ones. Such a matrix is called a typrix.

Let F_* be the standard flag in K^n. If x is a strictly upper triangular matrix of order n, then $F_* \in Y(x)$, so that we have a system $\tau(x,F_*)$ and a typrix $A(x)$, say. The following rules hold:

1) $x = 0 \iff A = 0$

2) x is regular (i.e. $x^{n-1} \neq 0$) $\iff A = E$ where $E_{ij} = 1 \ \forall i < j$

3) if $1 < p < n$ then $A(x) = \begin{pmatrix} A(x:F_p) & * \\ 0 & A(x:V/F_p) \end{pmatrix}$

Overview of results:

There is a combinatorial bijection between the standard tableaux and the generic typrix, say $S \mapsto A$, such that $Y(x,A)$ is dense in the irreducible component $Y(x)_S$ of $Y(x)$. A typrix A is called very acceptable if it satisfies certain highly involved combinatorial inequalities.

Theorem: All occurring typrices are very acceptable.

Theorem (H. Bürgstein): If $n \leq 6$ and $\#(K) > 2$, all very acceptable typrices occur.

Table of number of typrices:

n	2	3	4	5	6	7
# very acceptable	2	5	16	61	174	1419
# irr.comp. of Y(x)	2	4	10	26	76	232
# B-orbits in $\underline{U}$	2	5	16	61	273 + ∞	∞ + ...

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