MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

T a g u n g s b e r i c h t 16/1988

Algebraische Gruppen

10.4.-16.4.1988

Die Tagung fand unter der Leitung von Herrn T.A. Springer (Utrecht) und Herrn J. Tits (Paris) statt. Im Mittelpunkt des Interesses standen Fragen zu folgenden Themenkreisen:

- Sphärische, insbesondere symmetrische Räume
- Kac-Moody-Gruppen
- Unendlich dimensionale Lie-Algebren
- Diskrete Untergruppen von Lie-Gruppen
- Gebäude und Gruppen
- Darstellungen und Gruppenoperationen
- Standard-Monomial-Theorie
- Quantengruppen

Vortragsauszüge

M. BRION

Embeddings of homogeneous spaces, with applications to enumerative geometry

For G a reductive complex algebraic group, the homogeneous space G/H is special if a Borel subgroup B of G has an open orbit in G/H. For such a space, De Concini and Procesi have defined a "ring of Schubert conditions" $C^*(G/H)$. It is isomorphic to the direct limit of the cohomology algebras $H^*(X, \mathbb{C}), X$ equivariant smooth compactification of G/H. I describe the Picard group of X, and the intersection numbers of divisors on X. Assume (for simplicity) that there is only one closed orbit Y of G in X.
th 1 Pic (X) is freely generated by the classes of B-stable irreducible divisors $D_1, ..., D_p$ of X which do not contain Y. Moreover $\sum_{i=1}^{p} n_i D_i$ is generated by its global sections (resp. ample) iff every n_i is ≥ 0 (resp. > 0).
In order to compute intersection numbers, I determine the push-forward of the Liouville measure for the moment map. As a corollary I get:
th 2 (X as above) For every divisor D on X, there exists a convex polyhedron $\mathcal{C}(X, D) = \mathcal{C}$ in the dominant weights of G, so that $H^0(X, D)$ is $G-$isomorphic to the sum of the simple $G-$modules with highest weights $\lambda \in \mathcal{C}$. Moreover, the degree of D is $(\dim X)! \int_{\mathcal{C}} \prod_{\alpha \in \mathbf{R}^+} \frac{(\alpha,\gamma)}{(\alpha,\rho)} d\gamma$.

C. PROCESI

Cohomology of Complete Symmetric Varieties

Joint work with Bifet, de Concini: G semi simple adjoint over $\mathbb{C}, \sigma : G \to G$ autom. of order 2. We study the cohomology of the regular G- equivariant compactifications of G/G^σ. This is obtained from equivariant cohomology which in turn admits a rather explicit description. The relevant geometry is connected to the moment map and the study of a fundamental domain for a maximal compact subgroup K of G.

O. MATHIEU

Construction of Kac Moody groups and applications

Let g be a Kac-Moody Lie algebra. For each dominant integral weight, let $L(\lambda)$ the maximal integrable quotient of the Verma module $M(\lambda)$ of highest weight λ. For each $w \in W$, let $S_{w\lambda}$ the corresponding Schubert variety in $\mathbb{P}L(\lambda)$.
Theorem 1 Suppose the ground ring k is normal. Then the scheme $S_{w\lambda}$ is normal, and projectively normal in $\mathbb{P}L(\lambda)$. In particular (for any ground ring k) $S_{w\lambda}$ does not depend upon λ, but only on the set of simple coroots killed by λ.
Theorem 2 Let λ, μ, ν be 3 dominant weights, $v, w \in W$ with $\lambda + w\mu = v\nu$. Then $L(\nu)$ is a natural subquotient of $L(\lambda) \otimes L(\mu)$ (Parthasaraty-Varadarajan-Ranga Rao conjecture).
The both theorems result from a common statement about line bundles over flag spaces. The proof of the statement uses the following techniques:

- Construction of a Kac Moody group ind-scheme
- Frobenius splitting of Demazure varieties over fields of non zero characteristic
- Topology of the fiber of the desingularisations of some generalized Schubert varieties.

M. RONAN

Double Buildings and their Groups

The content of this talk partly concerns joint work with J. Tits. A double building is a pair of buildings (Δ, Δ^-) related by a "codistance function" $c : \Delta \times \Delta^- \to W$, where W is the Coxeter group. It was explained that, with a midel restriction on the type of diagram, the automorphism group of(Δ, Δ^-) contains a BN-pair with a splitting in particular both (Δ and Δ^-) can be constructed from a blueprint as in "Building Buildings" (Ronan-Tits, Math. Annalen 278). It was also explained that Δ is uniquely determined by its foundation $E_2(c)$ (rank 2 residues containing c), and that Δ^- can be obtained, purely combinatorially, from an "appartment system with a splitting."

MARGULIS

Flows on homogeneous spaces and indefinite quadratic forms

Theorem 1. Let B be a real nondegenerate indefinite quadratic form in n variables. Suppose that $n \geq 3$ and that B is not proportional to a form with rational coefficients. Then for any $\varepsilon > 0$, there exist integers $x_1, ..., x_n$ not all equal to 0, such that $|B(x_1, ..., x_n)| < \varepsilon$.
Theorem 1 was conjectured in 1929 by Oppenheim for the case $n \geq 5$ and in 1946 by Davenport for the general case. Theorem 1 can be easily deduced from the following
Theorem 2. Let $G = SL(3, \mathbb{R}), \Gamma = SL(3, \mathbb{Z})$ and let H denote the group of elements of G preserving the form $2x_1x_3 - x_2^2$. If $z \in \Omega = G/\Gamma$ and the orbit H_z is relatively compact in Ω then the quotient space $H/H \cap G_z$ is compact where $G_z = \{g \in G | gz = z\}$ denotes the stabilizer of z.
The proof of theorem 2 is mainly based on the study of closed subsets in G/Γ invariant under unipotent subgroups.

A. LUBOTZKY

Discrete subgroups of semi-simple groups over local fields applied to combinatorics and Computer Science

In this survey talk some applications of discrete subgroups of $G = PGL_2(\mathbb{Q}_p)$ to computer science will be described, more specifically:
1) Let K be a maximal compact subgroup of $G, X = G/K$ the associated tree and Γ a congruence subgroup of an arithmetic cocompact lattice (built using, say, the standard quoternion algebra). It follows from the theory of automorphic forms that the finite graph $Y = \Gamma\backslash G/K$ has "small" eigenvalues. This implies that Y is an excellent "expander". - a property which is extremely important in the construction of communication networks such as super-concentrators, etc. Moreover the graphs Y turn out to have some more external properties which solves some other problems in combinatorics.
2) Using Γ as before one can present an algorithm to distribute points on the sphere S^2. This method is of importance in numerical analysis.
These works were done in collaboration with R. Phillips and P. Sarnak. Most of the applications have been found indepently by Margulis.

V. LAKSHMIBAI

Towards a standard monomial theory for infinite dimensional flagmanifolds

The aim of standard monomial theory is to generalize the classical Hodge-Young theory giving explicit bases for the homogeneous coordinate ring of a Grassmannian (and its Schubert varieties) to Schubert varieties in the flag manifold G/B, where G is any semi-simple algebraic group and B a Borel subgroup. The theory has been developed for classical and some exceptional groups and some important geometric and representation-theoretic results have been obtained as consequences of this theory. A natural question that arises is "Does this theory extend to Schubert varieties in the infinite dimensional flag manifolds?" We answered the question in the affirmative by developing it for Schubert varieties in $\widehat{SL_2}/\mathcal{B}$.

W.J. HABOUSH

Equivariant K-theory and the homotopy invariance theorem

Let $A = \mathbb{C}[x_1, ..., x_n]$ be a polynomial ring in n-variables $\mathbf{A}_n = SpecA$. It is conjectured that every algebraic action of the reductive group G on $\mathbf{A}_n$ is conjugate to a linear representation. To seek a counterexample, one might seek a G bundle E over the linear representation V^* so that the action of the group G on the total space E is not linearizable. I showed that this would be the case if the class of E in the Grothendieck ring of $\mathbf{A}_n$ is not in the image of the representation ring of G over $\mathbb{C}$. Unfortunately this can never be the case. I gave a proof of the equivariant homotopy invariance theorem. Namely if X is smooth and $E \to X$ is an equivariant vector bundle then the equivariant K-groups of E are isomorphic to the equivariant K-groups of X. The unstable version of this result, the equivariant Serre conjecture remains in question.

W. KRÁSKIEWICZ

Schubert functors, reduced decompositions in Weyl groups

For each permutation π we construct a representation of the group of upper triangular matrices which character is the Schubert polynomial s_π. The combinatorics used in the construction gives a new parametrization of reduced decompositions of permutations. This parametrization allows us to introduce a natural action of the symmetric group on the space spanned with reduced decompositions of fixed permutation.

T. JÓZEFIAK

Characters of projective representations of symmetric groups

The outline of Schur's theory (Crelle Journal, 1911) of projective representations of the symmetric group S_n has been given from the point of view of semisimple superalgebras. If $\tilde{S}_n$ is the representation group of S_n then the ring of negative supermodules over $\tilde{S}_n$, for all n, has been described in terms of the ring Γ spanned by symmetric Q-functions of Schur. The Q-functions correspond to characters of simple negative $\tilde{S}_n$-supermodules. The passage from simple negative $\tilde{S}_n$-supermodules to simple negative $\tilde{S}_n$-modules explains certain mysterious constructions in Schur's original exposition.

I.G. MACDONALD

Orthogonal polynomials associated with root systems

We define for each reduced root system R a family of orthogonal polynomials P_λ indexed by the dominant weights, and depending on two parameters q and t. When $q = t, P_\lambda$ reduces to the Weyl character corresponding to λ. When $q = 0$ and t^{-1} is a prime power, the P_λ give the values of zonial spherical functions on a semisimple group G over a non-archimedean local field F, relative to a maximal compact subgroup K; the relative root system of G/K is the dual R^v of R, and t^{-1} is the cardinality of the residue field of F. When q and t both tend to 1 in such a way that $(1-t)/(1-q) \to a$ a fixed limit k, the P_λ are (for certain values of k) again values of zonal spherical functions, but now on a real semisimple Lie group G relative to a maximal compact subgroup K; the relative root system of G/K is R, and the multiplicity of each root is $2k$.

K. BONGARTZ

Rationality of sheets of matrices

Let $GL_n(k)$ (k = arbitrary alg. closed field) act by conjugation on the set $gl_n(k)$ of all $n \times n$-matrices. Then the sheets (= irreducible components of the sets of points which generate orbits of fixed dimension) are in one-one correspondence to the partitions of n by classical results of Dixmier, Peterson et al.
We give a simple description of an open set $U(p)$ of each sheet $S(p)$, which meets any orbit in $S(p)$. This description implies immediately, that $S(p)$ is a rational smooth variety. Moreover, we construct affine transversal cross-sections for the action of GL_n, which are easier to understand than Petersons cross-sections and work in all characteristics.
All our arguments are at the level of linear algebra and independent of the general theory of linear algebraic groups.

C. YU

Representations of Skew linear groups

1. Let D be a non-commutative division ring with centre F and H be a skew linear group, i.e. subgroup of $GL_n(D), n \in \mathbb{N}$. If H contains a subgroup S isomorphic to $SL_2(S)$, then the following three statements are equivalent:

1. There exists a homomorphism $\pi : H \rightarrow GL_m(k)$ for some $m \in \mathbb{N}$ such that $ker\ \pi \not\supseteq S$.
2. There exists a non-trivial homomorphism of rings $\varphi : D \rightarrow Mat_l(k)$ for some $l \in \mathbb{N}$ with Zariski dense image.
3. D is a finite dimensional central algebra and there is an injection from F into k.

2. There exists a non-trivial representation of $SL_n(D)$ or $SU_n(D)$ with index larger than 1 if and only if D is of finite dimension over its centre.
3. Let D be an infinite dimensional central division algebra, then the irreducible representations of normal subgroups of $GL_n(D), n \in \mathbb{N}$, must be one-dimensional.

J.C. JANTZEN

Crystalline Cohomology of the Drinfel'd Curve

This talk was a report on joint work with B. Haastert. Let p be a prime number, set $q = p^n$ for some $n > 0$ and let $C \subset \mathbb{P}^2$ be the Drinfel'd curve $x^q y - y^q x - z^{q+1}$. Then $SL(2,q)$ and the cyclic group of order $q+1$ act on C naturally, and those actions commute. One gets thus commuting operations on the crystalline cohomology groups $H^*_{cris}(C/\mathbb{F}_{q^2})$. The group $H^1_{cris}(C/\mathbb{F}_{q^2})$ decomposes into a direct sum $\bigoplus_{r=1}^{q} M_r$ of eigenspaces for the cyclic group, and the M_r are $SL(2,q)$-modules: These are the discrete series representations of $SL(2,q)$. For the reduction $\overline{M}_r mod\ p$ of M_r one gets from the Hodge filtration of the cohomology an exact sequence of $SL(2,q)$-modules over k (= algebraic closure of $\mathbb{F}_p$)
$0 \to S^{r-2}(k^{2*}) \to \overline{M}_r \to S^{q-(r+1)}(k^{2*})^* \to 0$. Using the action on the cohomology of the Frobenius endomorphism (with respect to $\mathbb{F}_q$) one can construct a filtration on $\overline{M}_r$ inducing (up to shifts) the "usual" filtrations on the Weyl modules $S^{a-(r+1)}(k^2)^*$ and the dual Weyl modules $S^{r-2}(k^2)$.

A. DASZKIEWICZ

Invariant ideals of the symmetric algebra $S(V + \wedge^2 V)$

We study the invariant ideals of the symmetric algebra $R = S(V + \wedge^2 V)$ applying the methods developed by De Concini, Eisenbud, and Procesi. We describe the structure of all invariant ideals of R, we also give lists of all invariant prime, radical and primary ideals of R. To describe the product of any irreducible summand of R and the generating one, we use the method based on the detailed study of the inclusion maps in Pieri formulas. We use the description of these maps given by P. Olver.

W. VAN DER KALLEN

Excellent filtrations of tensor products

Let G be a semi-simple simply connected algebraic group with Borel subgroup B. Let L be a line bundle on G/B with non-trivial global sections and let $X(w)$ be a Schubert variety. The B module of global sections of the restriction of L to $X(w)$ is called a dual Joseph module. For each weight λ there is a unique dual Joseph module with highest weigth λ. Call it $P(\lambda)$. We consider the following question of P. Polo, generalizing conjectures of Donkin, Wang Jian-Pan and Joseph: Can the tensor product of dual Joseph modules be filtered by dual Joseph modules?
Positive results have been obtained by Donkin and by Polo. Some cohomological algebra related with the existence of filtrations by dual Joseph modules (= excellent filtrations) can be based on the existence of a filtration of the B bimodule $k[B]$ by modules of the form $P(\lambda) \Box Q(-\lambda)$. Here the $Q(-\lambda)$ are certain modules of highest weight $-\lambda$.

P. LITTELMANN

A generalization of the Littlewood-Richardson rule

If G is a simple, simply connected algebraic group of type $A_n, B_n, C_n or D_n$, and λ and μ are dominant weights, then using standard monomial theory we give a filtration of the G-module $H^0(G/B, \mathcal{L}_\lambda) \otimes H^0(G/B, \mathcal{L}_\mu)$ such that the quotient modules are again of the form $H^0(G/B, \mathcal{L}_\nu)$. (We assume the groundfield k to be algebraically closed, arbitrary characteristic.) Further, using the notion of λ-dominant standard monomials, we give an algorithm to compute for which dominant weights ν the G-module $H^0(G/B, \mathcal{L}_\nu)$ will appear as a quotient in the filtration and its multiplicity. For $G = Sl_n$, this is nothing else than the Littlewood-Richardson rule. For char $k = 0$, using different methods, we can also give a generalization of the Littlewood-Richardson rule for groups of type G_2 and E_6. We obtain also a method to compute the decomposition of an irreducible G-module into irreducible L-modules, where L is a Levi subgroup of G(G of type $A_n, B_n, C_n, D_n, G_2, E_6, char k = 0$).

T. A. SPRINGER

An introduction to quantum groups

A quantum group is an object discribed by a – non-commutative and non-cocommutative – Hopf algebra, which is a definition of the algebra of regular functions of an algebraic group. In this talk, by a layman in the subject, the example of SL_2 was discussed, as well as some background material.

C. DE CONCINI

Infinite dimensional Lie algebras and curves

(Joint work with E. Arbarello, V. Kăc and C. Procesi)
One notices a remarkable coincidence of numbers. Consider the Lie algebra $\underline{d}$ of regular vector fields on $\mathbb{C}^*$ and the Lie algebra D of regular differential operators of degree ≤ 1 on $\mathbb{C}^*$. Consider the automorphism $t : \mathcal{D} \to \mathcal{D}$ defined by $t\left(f\frac{\partial}{\partial z} + g\right) = f\frac{\partial}{\partial z} + g + f'$. Then

$H^2(\underline{d}, \mathbb{C}) = \mathbb{C}, H^2(\mathcal{D}, \mathbb{C}) = \mathbb{C}^3$ and $H^2(\mathcal{D}, \mathbb{C})$ is a cyclic module under the action generated by t with cyclic generator the class of the cocycle $\Theta(g\partial + h, f\partial + k) = -Res_{z=0}\frac{1}{6}fg''' + \frac{1}{2}Res_{z=0}(gk'' - fh'') + k'$. On the other hand for $g \geq 3$ consider the following varieties of moduli $\tilde{\mathcal{M}}_g = \{(C, p, v)|C$ is a Riemann surface of genus $g, p \in C, v \in T_pC \backslash \{0\}\}$. $J_g = \{(C, p, v, L)|(C, p, v) \in \tilde{\mathcal{M}}_g, L \in Pic^{g-1}(C)\}$. Consider the automorphism $t : J_g \longrightarrow J_g$ given by $t(C, p, v, L) = (C, p, v, L \otimes K_C((2-2g)p))$. Then $H^2(\tilde{\mathcal{M}}_g, \mathbb{C}) = \mathbb{C}$ (Harer), $H^2(J_g, \mathbb{C}) = \mathbb{C}^3$ and $H^2(J_g, \mathbb{C})$ is a cyclic module under the group generated by t^* with cyclic generator the class of the universal Θ-divisor. Furthermore there exists a formal isomorphism

$$(*) \qquad H^2(\mathcal{D}, \mathbb{C}) \rightarrow H^2(J_g, \mathbb{C})$$

compatible with the t^*-actions and taking θ to $[\Theta]$. We explain this by constructing infinite analogues of $\tilde{\mathcal{M}}_g$ (resp J_g) and showing that $\underline{d}$ (resp. $\mathcal{D}$) can be considered as global vector fields on these varieties. Using this one can geometrically construct the isomorphism (*) and an isomorphism between $H^2(\underline{d}, \mathbb{C})$ and $H^2(\tilde{\mathcal{M}}_g, \mathbb{C})$.

J.-Y. HÉE

A relative theory of algebraic groups adapted to Suzuki and Ree groups, and Kac-Moody analogues.

Let p be a prime, k a field of characteristic p, n an integer ≥ 1 and σ an endomorphism of k such that $\sigma^n = Fr_k(: x \longmapsto x^p)$. An affine (k, σ)-variety is a pair (V, τ) where V is an affine k-variety and $\tau : A \rightarrow A(A = k[G])$ is a σ-semi-linear ring homomorphism such that $\tau^n = Fr_A$. One defines, in the obvious way, (k, σ)-morphisms and subvarieties defined over (k, σ). Then a (k, σ)-group ist a group (G, τ) in the category of affine (k, σ)-varieties. Examples of such (k, σ)-groups are obtained when studying Suzuki and Ree groups. But there also exist examples for which G is a non-split reductive k-group. I reported on some results that I proved towards the classification of reductive (k, σ)-groups (existence of a maximal torus) of G defined over $(k, \sigma), \ldots$).

A "good" relative theory in the infinite dimensional case should apply to analogues of (k, σ)-groups. For Kac-Moody groups (as defined by J. Tits in: J. of Algebra (1987)), I stated a theorem of existence of "isogenies" generalizing Chevalley's theorem on semi-simple algebraic groups.

P. SLODOWY

Instability for Kac-Moody-Groups

The goal of this talk is to report about recent progress on extending the Kempf-Rousseau theory of optimal one-parameter groups for unstable vectors to Kac-Moody groups. Here, all vectors of highest weight integrable representations are unstable. To pick out optimal one-parameter groups one has to study the geometry of the Tits-cone and of Looijenga's partial compactification $\hat{J}$ of the dual Tits-cone J. We introduce a "sphere" in $\hat{J}$ and show that the minimum of any finite set of weights obtains a maximum in a unique point of that sphere. Together with a finiteness result and the Bruhat decomposition, this provides optimal one-parameter-subsemigroups. One also obtains that the stabilizer of any vector $\neq 0$ is contained in a proper parabolic subgroup, a fact which is useful in the study of adjoint quotients of Kac-Moody groups.

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Gefördert durch
DFG Deutsche Forschungsgemeinschaft