Tagungsbericht 16/1995

Algebraische Gruppen

23.04 bis 29.04.1995

Nach einem Zeitraum von vier Jahren fand in diesem Jahr erneut eine Tagung über "Algebraische Gruppen" unter der Leitung von P. Slodowy (Hamburg), T.A. Springer (Utrecht) und J. Tits (Paris) mit breiter internationaler Beteiligung statt. Im Mittelpunkt der 22 ausgewählten Vorträge standen neuere Ergebnisse und Entwicklungen aus den folgenden Bereichen:

- Strukturtheorie
- Darstellungstheorie (klassisch, modular, p-adisch, Hecke-Algebren, Quantengruppen, Tensoroperationen)
- Algebraische Transformationsgruppen (Invarianten, homogene Räume, Vervollständigungen)
- Arithmetische und Zopfgruppen
- Kac-Moody-Algebren

Für eine detailliertere Beschreibung ziehe man die folgenden Vortragsauszüge zu Rate.

Typeset by $\mathcal{A}\mathcal{M}\mathcal{S}$-TEX

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Vortragsauszüge:

H.H. ANDERSEN

Tilting modules and fusion rules

Let V be a finite dimensional vector space over an algebraically closed field k of char(k) $= p > 0$. Then the problem of decomposing $V^{\otimes m}, m \geq 1$ into indecomposable summands for $SL(V)$ is wide open. So is the more general problem of decomposing tensor products of Weyl modules for a semisimple algebraic group G over k.

To attack some aspects of this problem we study tilting modules for G, i.e. modules M for which both M and M^* have Weyl filtrations. In the case when we replace G by the corresponding quantum group U_q at a complex root of unity q we point out that all injective U_q-modules are tilting. Hence by the Kazhdan-Lusztig conjecture (which is a theorem when the order ℓ of q is at least equal to the Coxeter number) we know the characters of the tilting modules with highest weights away from the ℓ-strips adjacent to the walls of the dominant chamber.

In joint work with J. Paradowski we prove the following fusion rule: Let λ, μ and ν be weights of the fundamental dominant alcove. Then the number of times the Weyl module $V(\nu)$ appears as a direct summand in $V(\lambda) \otimes V(\mu)$ is

$$\sum_{w \in W_p} (-1)^{\ell(w)} \dim V(\lambda)_{w \cdot \nu - \mu}.$$

Here W_p (which should be W_ℓ in the quantum case) denotes the affine Weyl group attached to G (resp. U_q).

A. BOREL

Rational curves on homogeneous spaces

This is a report on joint work with F. Bien and J. Kollár.

An irreducible variety X over an algebraically closed field is "quasi-complete" (q.c.) if the k-algebra $k[X]$ of regular functions reduces to the constants.

In the sequel $X = G/H$, where G is a connected affine algebraic group and H is a closed connected algebraic sugroup. Then X is q.c. if and only if H is epimorphic (in the sense of [BB]), i.e. if every morphism $G \to G'$ is determined by its restriction to H. A "rational curve" is here a smooth complete curve of genus 0, i.e. a copy of $\mathbb{P}^1$. The following conditions imply obviously q.c.

(1) X is "rationally connected" (r.c.): given $x, y \in X$, there exists a morphism $f : \mathbb{P}^1 \to X$ such that $\operatorname{Im} f \ni x, y$.

(2) X is "generically rationally connected" (g.r.c.): the above condition is fullfilled for (x, y) in an open dense subset of $X \times X$.

(3) X is "rationally chain connected" (r.c.c.): a chain $C = \cup_{i=1}^{n} C_i$ of rational curves is a curve consisting of rational curves such that $C_i \cap C_{i+1}$ is one point $(i = 1, 2, \ldots, n-1)$ and there are no other intersections. X is r.c.c. if given $x, y \in X$, there exists a morphism $f : C \to X$ such that $x \in f(C_1)$ and $y \in f(C_n)$.

Obviously (1) $\Rightarrow$ (2) $\Rightarrow$ (3). It can be proved that (2) $\Leftrightarrow$ (3) and that (2) $\Leftrightarrow$ (1) in characteristic 0 and that there exists a unique sequence of subgroups

$$H = H_0 \subset H_1 \subset \ldots \subset H_n = K \subset G \qquad (*)$$

such that H_i/H_{i-1} is r.c.c. ($i = 1, 2, \ldots, n$) and every morphism $f : \mathbb{P}^1 \to G/K$ is constant.

Moreover, if $H' \supset H$ and H'/H is g.r.c. and $\mathcal{F}$ is a coherent G-sheaf on X, then its direct image on G/H' is also coherent. In particular, if X is r.c.c. or more generally if $K = G$ in (*), then H has property F in the sense of [BB], i.e. induction from H to G preserves finite dimensionality.

The proofs make essential use of foundational results on schemes of morphisms of schemes, proved in EGA and in [K].

In many cases, which cover most of those considered in [BB], it is possible to prove r.c.c. using orbits of suitable SL_2's. I gave a series of examples where this allows to prove g.r.c. or property F. In particular, if H is epimorphic and contains a maximal torus of G (assumed reductive), then H has property F.

The talk ended with a discussion of projective embeddings, open problems and conjectures. Details will be published in [BBK].

[BB] Bien, Borel: *C. R. Acad. Sci.* Paris, **315** (1992), 649 – 653.
[BBK] Bien, Borel, Kollár: Rationally connected homogeneous spaces, to appear.
[K] Kollár, Rational curves on varieties, *Ergebnisse der Mathematik und ihrer Grenzgebiete*, to appear.

M. Brion

Plethysm and symmetric functions

Let G be a connected semisimple algebraic group over $\mathbb{C}$. For a dominant weight ω of G, denote by V_ω a simple G-module with highest weight ω. In the case where $G = SL(V)$, we index dominant weights by partitions in at most $\dim(V)$ parts. The simple $SL(V)$-module associated with the partition λ will be denoted by $S^\lambda V$ (ex: $S^{(n)}V = S^n V = n$-th-symmetric power of V; $S^{(1,\ldots,1)}V = S^{(1^n)}V = \Lambda^n V = n$-th alternating power).

The problem of *plethysm* asks for the description of the G-module $S^\lambda V_\omega$. Even in the simple case: $S^m(S^n V)$, there is no complete answer. It is conjectured (Foulkes, 1950) that $S^m(S^n V) \hookrightarrow S^n(S^m V)$ as a $SL(V)$-module, if $n \geq m$.

We present the following (partial) results:

(1) There is a canonical equivariant map $S^n(S^m V) \to S^m(S^n V)$ and this map is surjective for $n \geq m^2 \dim(S^m V)$.
(2) The multiplicity of $V_{m\omega-\chi}$ in $S^\lambda V_\omega$ is at most the multiplicity of the S_m-module $[\lambda]$ in $S^\circ(\mathbb{C}^{m-1} \otimes \mathfrak{n})_\chi$, with equality for χ small with respect to ω. Here $[\lambda]$ denotes the simple S_m-module associated with λ, a partition of m; $\mathfrak{n}$ is the Lie algebra of a maximal unipotent subgroup of G; $\mathbb{C}^{m-1}$ is the "natural" S_m-module; $S^\circ(\mathbb{C}^{m-1} \otimes \mathfrak{n})_\chi$ is the χ-weight space in the symmetric algebra of $\mathbb{C}^{m-1} \otimes \mathfrak{n}$.

(3) The multiplicity of $V_{mn\omega-\chi}$ in $S^m V_{n\omega}$ is at most $\dim S^\circ(S^2\mathfrak{n} \oplus S^3\mathfrak{n} \oplus \dots)_\chi$ with equality if χ is small with respect to m and n (a generalization of Hermite reciprocity).

(4) For $G = SL(2)$: there exist $SL(2)$-modules $M_{\lambda,p}$ ($0 \le p \le m =$ size of λ) such that $S^\lambda(S^n\mathbb{C}^2) \simeq \bigoplus_{p=0}^{n} M_{\lambda,p} \otimes S^m(S^{n-p}\mathbb{C}^2)$ for all n. Moreover, $M_{\lambda,p} \simeq M_{\lambda',m-1-p}$, where λ' is the conjugate partition of λ.

R.W. Carter

Canonical bases, reduced words, and Lusztig's piecewise linear function

A report was given on work done in collaboration with J.W. Cockerton.

Let $U = U^- \otimes U^0 \otimes U^+$ be the quantum group associated with a simple Lie algebra of simply-laced type. We consider the canonical basis B of U^- introduced by Kashiwara and Lusztig. The elements of B fall into "types" with one type for each region of linearity of a certain piecewise-linear function $R : \mathbb{R}^N \longrightarrow \mathbb{R}^N$ defined by Lusztig, where N is the length of the longest element w_0 in the Weyl group.

The regions of linearity of the function R may be determined from a graph Γ, called the braid graph, defined in terms of reduced expressions for w_0. Each subset S of Γ determines a region C_S in $\mathbb{R}^N$ on which the function R is linear. It is possible for C_S to be empty – we say S is consistent if C_S is non-empty. It is also possible for the linear functions on $C_S, C_{S'}$ to be the same – we write $S \sim S'$ when this happens. Then the regions of linearity of R correspond to equivalence classes of consistent subset of the braid graph.

In the case of non-simply-laced type the regions of linearity of R are in one-to-one correspondence with the σ-stable regions of linearity for a suitable simply-laced type with graph automorphism σ. The cases in which the number of regions is known are as follows.

Type:	A_1	A_2	A_3	A_4	A_5	D_4	B_2	B_3	C_3	G_2
Number of regions:	1	2	10	144	6608	1204	4	140	140	16

J. Denef

Character sums associated to prehomogeneous vector spaces

This is a report on joint work with A. Gyoja.

Let G be a connected complex reductive group, and $\rho : G \to GL(V)$ a finite dimensional rational representation. A triple (G, ρ, V) is called a *prehomogeneous vector space* if V has an open G-orbit, say $\mathcal{O}_0$. Let $0 \ne f \in \mathbb{C}[V]$ be a relative invariant with the character $\phi \in \mathrm{Hom}(G, \mathbb{C}^\times)$; $f(gv) = \phi(g)f(v)$ for all $g \in G$ and $v \in V$. Let $\rho^\vee : G \to GL(V^\vee)$ be the dual of ρ. Then it is known that $(G, \rho^\vee, V^\vee)$ also has an open G-orbit, say $\mathcal{O}_0^\vee$, and that there exists a relative invariant $0 \ne f^\vee \in \mathbb{C}[V^\vee]$ whose character is ϕ^{-1}.

Roughly, the fundamental theorem of the theory of prehomogeneous vector spaces due to M. Sato says that

$$\text{Fourier transform of } f^s = f^{\vee -s} \times \text{ (some factors), for } s \in \mathbb{C}. \qquad (1)$$

The purpose of our work is to study a finite field analogue of (1) and to give a completely explicit description of the Fourier transform assuming that the characteristic of the base field $\mathbb{F}_q$ is large enough. Now f^s, resp. $f^{\vee - s}$, is replaced by $\chi(f)$, resp. $\chi^{-1}(f^\vee)$, and the factors involve Gauss sums, the Bernstein polynomial of f and the parity of the split rank of the isotropy group at $v^\vee \in V^\vee(\mathbb{F}_q)$. (We also express this parity in terms of the quadratic residue of the discriminant of the Hessian of $\log f^\vee(v^\vee)$.)

F. Knop

Differentiable properties of the moment map

Let K be a connected, compact Lie group and M a Hamiltonian K-manifold with moment map $\mu : M \to \mathfrak{k}^*$. $C^\infty(M)$ carries the structure of a Poisson algebra. We are concerned with the commutant of the K-invariants:

$$\mathcal{A}^c := \{h \in C^\infty(M) |\ \{f,h\} = 0 \text{ for all } f \in \mathcal{A} := C^\infty(M)^K\}.$$

$\mathcal{A}$ and $\mathcal{A}^c$ form a dual pair with common center $\mathcal{C} = \mathcal{A} \cap \mathcal{A}^c$. It is known that all pull-back functions $\mu^* C^\infty(\mathfrak{k}^*)$ lie in $\mathcal{A}^c$ but $\mathcal{A}^c$ may be (slightly) larger. Let $\mathfrak{h} \subseteq \mathfrak{k}$ be a Cartan subalgebra, W the Weyl group and $\mathfrak{h}^*_+ \subseteq \mathfrak{h}^*$ a Weyl chamber. Then we have a continous map:

$$\varphi_+ : M \xrightarrow{\mu} \mathfrak{k}^* \longrightarrow \mathfrak{k}^*/K \cong \mathfrak{h}^*/W \overset{\text{bijective}}{\longleftrightarrow} \mathfrak{h}^*_+.$$

Theorem. *There is a finite reflection subgroup W_M of W such that $\mathcal{C} = \varphi_+^* C^\infty(\mathfrak{h}^*)^{W_M}$.*

The proof uses two ingredients: A comparison theorem by Tougeron, Bierstone-Milman which reduces the problem to formal power series (Taylor series). The second ingredient is the symplectic slice theorem by Weinstein, Marle which allows to replace M by a certain real algebraic variety. The complexification $M \times_{\mathbb{R}} \mathbb{C}$ turns out to be the cotangent bundle T^*_X for a complex algebraic variety on which the complexified group $G = K^{\mathbb{C}}$ acts. In this setting an analogous result was already obtained by me in earlier work.

There are two applications:

– A criterion on M to carry a K-equivariant compatible Kähler structure.

– The determination of an important subgroup of the automorphism group of (M, μ).

V. Lakshmibai

Bases of Demazure modules and applications to singularities of Schubert varieties

Let G be a semisimple, simply connected algebraic group over an algebraically closed field k. Let T be a maximal torus, and B a Borel subgroup $B \supset T$. Let W be the Weyl group. For $w \in W$, let $X(w)$ $(= \overline{BwB}(\bmod B))$ be the Schubert variety in G/B associated to e_{Id}. Let λ be a dominant weight, and L_λ the associated line bundle on G/B. Consider the projective embedding

$$X(w) \subset G/B \hookrightarrow \operatorname{Proj}(S^\circ H^0(G/B, L_\lambda))$$

(if λ is not regular, then we replace B by a suitable parabolic P_λ). Let $V(\lambda)$ be the Weyl module ($= H^0(G/B, L_\lambda)^\vee$). Let e be a highest weight vector in $V(\lambda)$. For $w \in W$ let $e_w = we$, the extremal weight vector in $V(\lambda)$ of weight $w(\lambda)$. Let V_w be the B-submodule of $V(\lambda)$ generated by e_w. Then $\mathbb{P}(V_w)$ is the smallest linear subspace of $\mathbb{P}(V)$ containing $X(w)$. We call $V(w)$ the Demazure module associated to w. We construct a basis $\mathcal{B}(\lambda)$ indexed by L-S paths of shape λ such that

(1) $\mathcal{B}(\lambda)$ consists of $\{De\}$, where D is either 1 or $F_{i_1}^{(n_i)} \cdots F_{i_r}^{(n_r)}$, F_i being the root vectors in the Chevalley basis;

(2) $\mathcal{B}(\lambda)$ is Bruhat order compatible.

Applications to singularities: For a weight μ, let $m(\mu)$ (resp. $m_w(\mu)$) denote the multiplicity of μ in $V(\lambda)$ (resp. V_w). Let $\mathrm{T}(w, Id)$ denote the tangent space to $X(w)$ at e_{Id}.

Theorem 1. *$\mathrm{T}(w, Id)$ is spanned by $\{F_\beta \mid \beta \in R^+, m(\rho - \beta) = m_w(\rho - \beta)\}$.*

Define $\deg p_w$ as the smallest r such that $F_{i_1}^{(n_i)} \cdots F_{i_r}^{(n_r)} p_w = c p_{Id}$, $c \in k^*$.

Theorem 2. *$m_{Id}w \cdot \deg p_w = \sum m(w_i, w) m_{Id} w_i$, where the summation runs over all the Schubert divisors $X(w_i)$ of $X(w)$, and $m(w_i, w)$ is given by $m(w_i, w) = (\lambda, \beta_i^\vee)$, β_i being $w_i = w s_{\beta_i}$ ($\beta_i \in R^+$).*

G. Lehrer

Cellular Algebras

Consider the following two problems: first, if G is a connected reductive group and L is a Levi subgroup, both defined over $\mathbb{F}_q$, describe an "additive decomposition" of $R_L^G \rho$, for ρ an appropriate (cuspidal) representation of of L^F and R_L^G the "Lusztig induction" functor; second, let H be a subgroup of $GL(V)$, V a vector space; decompose (additively) $V^{\otimes n}$ as H-module. Both problems involve the consideration of non-semisimple endomorphism algebras - the first Hecke algebras and the second (for H classical) the Brauer algebra. The purpose of cellular algebras is to encapsulate such problems into standard problems of linear algebra. The definition is: An R-algebra A is cellular if it has a "cell datum" $(\Lambda, M, C, *)$, where Λ is a poset, $M(\lambda)$ is a set for every $\lambda \in \Lambda$, $C : \coprod_{\lambda \in \Lambda} M(\lambda)^2 \to A$ is a map with image an R-basis and $*$ is an anti-involution satisfying (if $C(S,T) := C_{S,T}^\lambda$ for $S, T \in M(\lambda)$) ${C_{S,T}^\lambda}^* = C_{T,S}^\lambda$. The key axiom is: for every $a \in A$, $aC_{S,T}^\lambda = \sum_{S' \in M(\lambda)} r_a(S', S) C_{S',T}^\lambda$ modulo smaller elements $(C_{S',T'}^\mu, \mu < \lambda)$. These axioms suffice to prove (if Λ is finite and R is a field) a complete classification of the simple modules and give a complete description of the block theory. There are "cell modules" $W(\lambda)$ which have "invariant forms" φ_λ. If $L_\lambda = W(\lambda)/\operatorname{Rad}\varphi_\lambda$, then

Theorem 1. *The $L_\lambda \neq 0$ form a complete set of absolutely irreducible A-modules.*

Theorem 2. *If $d_{\lambda,\mu} = [W(\lambda) : L_\lambda]$, then $\mathbf{D} = (d_{\lambda,\mu})$ is upper triangular and if $\mathbf{C}$ is the Cartan Matrix, then $\mathbf{C} = \mathbf{D}^t\mathbf{D}$.*

Theorem 3. *A is semisimple if and only if (roughly) φ_λ is non-degenerate for each $\lambda \in \Lambda$.*

In this context we have

Theorem 4. *Let* $\mathrm{Br}(n, \delta, R)$ *be the Brauer algebra with parameter δ over R. The irreducible modules are parametrized by* $\{(t, \lambda) \mid n - t \in 2\mathbb{Z}, \lambda \vdash t, \lambda$ *is p-regular,* $p = \mathrm{char}(R)\} \cup \{point\}$ *(if $\delta \neq 0$). Their dimensions are determined in terms of those of the Hecke algebras of type A.*

Theorem 5. *There is a cellular structure on the cyclotomic Hecke algebras of Ariki-Koike.*

q-Schur algebras, Temperley Lieb and Jones algebras and Lusztig's $\dot{U}$-quantum group may be discussed in this context.

This is joint work with John Graham.

P. Littelmann

The path model of representations

Let $\mathfrak{g}$ be a semisimple Lie algebra over $\mathbb{C}$, and let X be the weight lattice of $\mathfrak{g}$. Denote by Π the set of all piecewise linear paths $\eta : [0,1] \longrightarrow X_\mathbb{R}$ such that $\eta(0) = 0$ and $\eta(1) \in X$. For every simple root α we define operators $e_\alpha, f_\alpha \in \mathrm{End}_\mathbb{Z}\mathbb{Z}\Pi$, where $\mathbb{Z}\Pi$ is the free $\mathbb{Z}$-module generated by Π. Let Π^+ be the subset of paths such that the image is completely contained in the dominant Weyl chamber.

Let $A \subset \mathrm{End}_\mathbb{Z}\mathbb{Z}\Pi$ be the algebra generated by these "root operators". The modules $A\pi$, $\pi \in \Pi^+$, provide a very powerful combinatorial tool:

(1) Set $B_\pi := A\pi \cap \Pi$, the set of paths in $A\pi$. Then $B\pi$ is a $\mathbb{Z}$-basis for $A\pi$, and $B_\pi \cap \Pi^+ = \{\pi\}$.

(2) If $\pi, \eta \in \Pi^+$ are such that $\pi(1) = \eta(1)$, then the map $A\pi \to A\eta, a\pi \mapsto a\eta$, is an isomorphism.

(3) Let $\mathrm{Char}\, A\pi = \sum_{\eta \in B_\pi} e^{\eta(1)}$ for $\pi \in \Pi^+$. Then $\mathrm{Char}\, A\pi = \mathrm{Char}\, V_\lambda$, where $\lambda = \pi(1)$.

(4) For $\pi, \eta \in \Pi^+$ set $A\pi * A\eta = <\pi' * \eta' | \pi' \in B_\pi, \eta' \in B_\eta>$, the span of the concatenations of the paths in B_π and B_η. Then this is an A-module, in fact $A\pi * A\eta = \oplus_{\eta'} A\ (\pi * \eta')$, where the sum runs over all $\eta' \in B_\eta$, such that $\pi * \eta' \in \Pi^+$. Hence for $\lambda = \pi(1), \mu = \eta(1)$ one gets:
$$V_\lambda \otimes V_\mu \simeq \oplus_{\eta'} V_{\lambda + \eta'(1)},$$
where the sum runs over all $\eta' \in B_\eta$ such that $\pi * \eta' \in \Pi^+$.

(5) For any reduced decomposition of w_0, there is a canonical way to associate to B_π a basis $\{v_\eta | \eta \in B_\pi\}$ of $V_\lambda, \lambda = \pi(1)$.

A. Lubotzky

Eigenvalues of the Laplacian, First Betti number and the congruence subgroup problem

We present a new method to show non-vanishing of the first Betti number for arithmetic hyperbolic manifolds. So we prove:

Theorem 1. *Let Γ be an arithmetic lattice in $SO(n,1)$ (if $n = 7$ assume Γ does not come from forms of type ${}^3D_4$ or ${}^6D_4$, and if $n = 3$ and Γ comes from units of a quaternion algebra over a number field L, assume L has a subfield of index 2). Then Γ has a finite index congruence subgroup Γ_0 which can be mapped onto $\mathbb{Z}$.*

Corollary 2. *Γ has negative answer to the congruence subgroup problem (as conjectured by Serre).*

Corollary3. *If $n = 3, M^3 = \Gamma \setminus SO(3,1)/SO(3)$ has a finite sheeted cover which is Haken (as conjectured by Thurston).*

Theorem 1 is not new. It follows from the accumulation of works of Millson, Labesse-Schwermer, Li, Raghunathan-Venkataramana, and Li-Millson. Our new method gives a unified approach whose main novelty is "property τ" which is a bound on the eigenvalues of the laplacian á la Selberg's Theorem $\lambda_1(\Gamma(m)\backslash\mathbb{H}^2) \geq \frac{3}{16}$ for congruence subgroups of the modular group.

D. LUNA

Combinatorial invariants for spherical homogeneous spaces

Let G be a connected reductive group over $\mathbb{C}$ and let B denote a Borel subgroup of G. An algebraic G-variety X is called *spherical* if X is normal and if B has a dense orbit in X. An algebraic subgroup H of G is called spherical if G/H is a spherical variety.

The set $\Delta_{G/H}$ of "colors" of G/H is by definition the set of codimension 1 orbits of B in G/H. We will say that a spherical subgroup H of G is *good* if $H = \{s \in N_G(H), s \text{ acts trivially on } \Delta_{G/H}\}$. We will say that a spherical variety is *wonderful* if X is complete, if G has only one closed orbit in X, if every irreducible B-stable divisor in X which contains a G-orbit is G-stable, if X is smooth and if the centre of G acts trivially on X.

The following result has been proved by Brion-Pauer (Comment. '87) and Knop (to appear in J. AMS): for every good subgroup H of G there exists an (open G-)embedding $G/H \hookrightarrow X$, with X wonderful, and this X is unique (up to isomorphism).

Using the geometry of this *wonderful embedding* of G/H, we defined some combinatorial invariants for every good spherical subgroup H of G. We gave some properties of these invariants, mentioned some results concerning the classification of good spherical subgroups, and discussed the example $G = SL_4(\mathbb{C})$.

G. LUSZTIG

Classification of unipotent representations of simple p-adic groups

Let $\mathcal{G}$ be a split adjoint simple algebraic group over K, a non-archimedean local field with residue field $k, |k| = q$. Let G be a simply connected almost simple algebraic group over $\mathbb{C}$ of type dual to that $\mathcal{G}$. The unipotent representations of $\mathcal{G}$ are those irreducible admissible representations V such that there exists a parahoric subgroup P of $\mathcal{G}$, with reductive quotient $\overline{P}$ (over k) and a unipotent cuspidal representation ρ of $\overline{P}$ such that the restriction $V|_P$ contains a nonzero subspace on which P acts according with the representation $\overline{\rho}$.

Theorem. *There is a natural one-to-one correspondence between the set of isomorphism classes of unipotent representations of $\mathcal{G}$ and the set of all triples (s, y, v) up to G-conjugacy, where $s \in G$ is semisimple, $y \in \operatorname{Lie} G$ is nilpotent, $Ad(s)y = qg$, and v is an irreducible representation of $Z_G(s, y)/Z_G^\circ(s, y)$ on which the centre of G acts trivially.*

This is an extension of the Deligne-Langlands conjecture (connected with representations of $\mathcal{G}$ with nonzero vectors fixed by an Iwahori subgroup, which was proved by Kazhdan and me). The general case above provides further confirmation for Langlands philosophy.

The proof consists in a geometric realization of various affine Hecke algebras with unequal parameters in the framework of character sheaves and equivariant homology.

V.B. MEHTA

Invariants of 3×3 matrices, Frobenius-splitting and moduli of vector bundles in char $p > 0$

Let $G = SL(3)$ with B, T and U as usual, with Lie algebras $\mathfrak{g}, \mathfrak{b}, \mathfrak{t}$ and $\mathfrak{u}$. Let Z_0 denote the vector space $(\mathfrak{g} \otimes \mathfrak{g} \oplus \ldots \oplus \mathfrak{g})$ k-times, with the diagonal adjoint action of G and let R_0 be the ring of polynomial functions on Z_0. In joint work with T. Ramadas, we prove the following:

Theorem 1. *The ring of invariants $(R^0)^G$ is F-split and C.M.*

Theorem 2. *The projective G.I.T. quotient $P(Z^0)//G$ is also F-split and C.M.*

This has the following application. Let C be a non-singular projective curve and $SU(3)$ the moduli space of semisimple vector bundles on C with trivial det. Then $SU(3)$ is C.M.

The results are proved using a combination of F-splitting and G.I.T., and have potential applications Verlinde's formulae in characteristic $p > 0$.

YU.A. NERETIN

Extensions of representations of classical groups to representations of categories

0. Linear relations. Let $P \subset V \oplus W$ be a linear relation. Let $\operatorname{Ker} P := P \cap V$ and $\operatorname{Indef} P := P \cap W$. Let $\operatorname{Dom} P$ and $\operatorname{Im} P$ be the projections of P to V and W respectively. The product of linear relations is the usual product of binary correspondences.

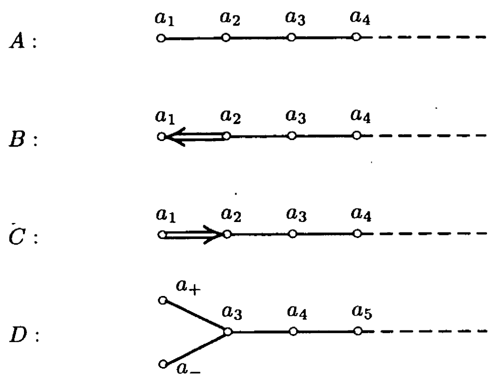
1. Categories. The objects of the category CA are complex finite-dimensional linear spaces. The space $\operatorname{Mor}_{CA}(V, W)$ consists of all linear relations $P \subset V \oplus W$ and the formal element null $= \text{null}_{V,W}$. The product of null and any morphism equals null. Let $P \subset V \oplus W$ and $Q \subset W \oplus Y$ be linear relations. If

$$\operatorname{Ker} Q \cap \operatorname{Indef} P = 0, \quad \operatorname{Dom} Q + \operatorname{Im} P = W,$$

then the product of Q and P is the usual product of linear relations. In all other cases $QP =$ null. The objects of the category B (resp. C, D) are odd dimensional complex linear spaces provided with a symmetric nondegenerate bilinear form (resp. complex linear spaces equipped with a skew-symmetric nondegenerate linear form; even dimensional linear spaces equipped with a symmetric bilinear form). The morphisms in all cases are maximal isotropic subspaces in $V \oplus W$ and null. The definition of the product is the same as in the category CA.

2. Representations.

Theorem. *a) Holomorphic projective representations of the categories A, B, C, D are completely reducible.*
b) These representations are enumerated by the diagrams



(∗)

where $a_j \in \mathbb{Z}_+$ and $a_j = 0$ for large j. Let a_α be the last nonzero label. If $n \geq \alpha - 1$, then the representation of the group $K_n = A_n, B_n, C_n, D_n$ corresponding to the representation (∗) of A, B, C, D is an irreducible representation with labels $(\dots, a_{n-1}, a_n)$. If $n < \alpha - 1$, then the representation of K_n is zero-dimensional.

V.P. Platonov

Representations of $\mathrm{Aut}(F_2)$ and braid groups

Let F_2 be the free group of rank 2, $\mathrm{Aut}(F_2)$ be the automorphism group of F_2, and B_4 the braid group on four strings. We consider the general problem of description of all n-dimensional rerpresentations of $\mathrm{Aut}(F_2)$ and B_4 over an arbitrary field K. We give a description of all n-dimensional representations of $\mathrm{Aut}(F_2)$ for $n \leq 4$ which restrict to a given representation of F_2 (There exists a natural connection between $\mathrm{Aut}(F_2)$ and B_4: if Z_4 is the center of B_4, then $B_4/Z_4 \hookrightarrow \mathrm{Aut}(F_2)$). In particular, we prove the following

Theorem. *Let $\rho : \mathrm{Aut}(F_2) \to GL_n(K)$ be an n-dimensional representation. If $n \leq 4$, then $\rho(F_2)$ is solvable.*

Corollary. *The group $\mathrm{Aut}(F_2)$ has no faithful 4-dimensional representations.*

We construct new classes of 3 and 4-dimensional representations of B_3 and B_4. It looks plausible that these representations will have new applications.

G. PRASAD

Representation theory of reductive p-adic groups: theory of minimal K-types

This is a report on some joint work with Allen Moy. Let k be a non-archimedean local field and G a connected reductive group defined over k. Let $\mathcal{G} = G(k)$ and $\mathcal{B} = \mathcal{B}(G)$ be the Bruhat-Tits building (enlarged building) of $\mathcal{G}$. Let S be a maximal k-split torus of G and $A = A(S)$ the apartment corresponding to S.

Our (long term) goal is to classify irreducible admissible representations of $\mathcal{G}$ in terms of their restrictions to suitable compact-open subgroups. For this purpose for each $x \in \mathcal{B}(\mathcal{G})$, we introduce a natural filtration $\mathcal{G}_{x,r}, r \geq 0$, of the parahoric subgroup $\mathcal{G}_x$ using the Bruhat-Tits theory. For $r \geq 0$, we let $\mathcal{G}_{x,r+} = \bigcup_{s>r} \mathcal{G}_{x,s}$. Then $\mathcal{G}_{x,r}/\mathcal{G}_{x,s}$, and so in particular, $\mathcal{G}_{x,r}/\mathcal{G}_{x,r+}$, is abelian for $0 < r$ and $r \geq \frac{1}{2}s$. We also introduce filtration lattices $\mathfrak{g}_{x,r}$ in the Lie algebra $\mathfrak{g}$ and $\mathfrak{g}^*_{x,r}$ in the dual $\mathfrak{g}^*$. Let $\{r_i\}$ be the sequence such that $\mathcal{G}_{x,s} = \mathcal{G}_{x,r_{i+1}}$ for $r_i < s \leq r_{i+1}$. Then the character group of $\mathcal{G}_{x,r_i}/\mathcal{G}_{x,r_{i+1}}$ for $i > 0$ is isomorphic to $\mathfrak{g}^*_{x,-r_i}/\mathfrak{g}^*_{x,-r_{i-1}}$ and a character of the former is said to be nondegenerate if the corresponding coset $X + \mathfrak{g}_{x,-r_{i-1}}$ does not contain any nilpotent elements.

Definition (1) A depth zero minimal K-type is a cuspidal representation of $M = \mathcal{G}_x/\mathcal{G}_{x,0+}$ inflated to $\mathcal{G}_x$.

(2) An unrefined minimal K-type of depth $r(> 0)$ is a nondegenerate character (1-dimensional representation) of $\mathcal{G}_{x,r}/\mathcal{G}_{x,r+}$ inflated to $\mathcal{G}_{x,r}$.

We prove that any admissible representation (π, V) of $\mathcal{G}$ contains an unrefined minimal K-type. Moreover, if r is the smallest non-negative real number such that for some $x \in \mathcal{B}$, V contains a nonzero vector fixed under $\mathcal{G}_{x,r+}$, then any (unrefined) minimal K-type contained in V has depth r; r is a rational number and it is called the depth of π.

Depth of a representation is preserved under parabolic induction and Jacquet restriction.

We have also found a complete description of irreducible absolutely cuspidal representations of depth zero generalizing Borel's results on representations which contain a nonzero vector fixed under an Iwahori subgroup.

A. RAPINCHUK

Determination of the metaplectic kernel for algebraic groups over global fields

Let G be a simple, simply connected algebraic group over a global field K and S a finite (possibly empty) set of places of K. The metaplectic kernel $M(S,G)$ is defined to be the kernel of the restriction map $H^2_{meas}(G(A(S))) \to H^2_{abs}(G(K))$, where $G(A(S))$ is the group of S-adeles of G with its natural topology. In this definition, H^2_{meas} (resp. H^2_{abs}) denotes the second measurable (resp. abstract) cohomology with coefficients in the one-dimensional torus $I = \mathbb{R}/\mathbb{Z}$ under trivial action. Observe that in the main case where S contains the set V^K_∞ of archimedean places of K ($V^K_\infty = \emptyset$ if char$K > 0$), $H^2_{meas}(G(A(S))) = H^2_{cont}(G(A(S)))$, the second continuous cohomology. In any case, the elements of $M(S,G)$ are in one-to-one correspondence with the equivalence classes of central topological extensions

$$1 \to I \longrightarrow E \longrightarrow G(A(S)) \to 1$$

which split over $G(K)$, hence the obvious connection with the computation of the congruence kernel for the S-arithmetic group $G(O(S))$ in case $S \supset V_\infty^K$. On the other hand, the case $S = \emptyset$ is of importance for the theory of automorphic forms of fractional weight. Primarily, these two applications stimulated the research towards the precise determination of $M(S,G)$. The computation of $M(S,G)$ for the split groups was obtained by Moore and Matsumoto (1969). Their methods and results were extended to the quasi-split case by Deodhar (1978). Using the machinery of algebraic K-theory, Bak-Rehmann (1979-81) considered the case of isotropic classical groups of rank > 1. The final result for K-isotropic groups is due to Prasad-Raghunathan (1983). The computation of $M(S,G)$ for some K-anisotropic groups was carried out by Rapinchuk (1984-85). Recently, in joint work with G. Prasad we obtained the following practically complete description of $M(S,G)$ for arbitrary groups.

Theorem. *Assume that if G is of type ${}^2A_n$ $(n > 1)$, then S contains V_∞^K. If there exists a place v_0 in S which is either non-archimedean and G is K_{v_0}-isotropic, or it is real and the group $G(K_{v_0})$ is not topologically simply connected, then the metaplectic kernel $M(S,G)$ is trivial. Otherwise, $M(S,G)$ is isomorphic to a subgroup of $\hat{\mu}(K)$, the dual group of the group $\mu(K)$ of all roots of unity in K, and $M(\emptyset,G)$ is isomorphic to a subgroup of $\hat{\mu}(K)$ of index at most two.*

One of the notable consequences of this result (which is, in fact, an important step of the proof) is the triviality of the weak metaplectic kernel $M_V(G) = \mathrm{Ker}(H^2(G(V)) \to H^2(G(K))$ (where $G(V) = \prod_{v \in V} G(K_v)$), for any finite set V of places of K, under the assumption that if G is of type ${}^2A_n$, then V consists entirely of non-archimedean places. We used this result to give a uniform proof of the congruence subgroup property for the groups of points of G over semi-local subrings of K. To be more precise, let V be a finite set of places of K and O_V the subring of K consisting of elements which are integral with respect to all places in V.

Theorem. *Suppose that $G(K)$ has the standard description of normal subgroups (i.e. $G(K)$ satisfies the Platonov-Margulis conjecture) and that V contains all non-archimedean anisotropic places for G. Then the congruence subgroup problem for $G(O_V)$ has a positive solution.*

J. Rohlfs

Cohomology of arithmetic groups and the Steinberg representation

Let $G/\mathbb{Q}$ be a reductive connected group defined over $\mathbb{Q}$ with corresponding symmetric space X_∞. Put $X = X_\infty \times G(\mathbb{A}_f)$, where $\mathbb{A}_f$ are the finite adeles over $\mathbb{Q}$. Let K_f be an open and compact subgroup of $G(\mathbb{A}_f)$ and put $S(K_f) = G(\mathbb{Q})\backslash X/K_f$ resp. $S = G(\mathbb{Q}) \setminus X$. Let $\tilde{V}^{K_f}$ resp. $\tilde{V}$ be the sheaves on $S(K_f)$ resp. S given by a representation $\rho : G(\mathbb{Q}) \to GL(V)$, $\dim_{\mathbb{Q}} V < \infty$. It is shown that

$$\varinjlim_{K_f} H^*(S(K_f), \tilde{V}^{K_f}) = H^*(S, \tilde{V})$$

as right $G(\mathbb{A}_f)$-modules. The same result holds for all smooth $G(\mathbb{A}_f)$-sheaves on the Borel-Serre compactification $\bar{S}$ of S. Moreover, it is shown that $H^*(S,\tilde{V}) \xrightarrow{\sim} H^*(G(\mathbb{Q}), V_X)$, where V_X is the $G(\mathbb{Q})$-module of locally constant V-valued functions on X. The cohomology with compact support $H_c^j(S,\tilde{V})$ is identified with $H^{j-\ell}(G(\mathbb{Q}), \mathrm{Hom}_{\mathbb{Z}}(\mathrm{St}_G, V_X))$, where ℓ is the semisimple rank of G. Here St_G is the Steinberg representation of $G(\mathbb{Q})$. The cohomology $H^*(\partial\bar{S},\tilde{V})$ of the boundary $\partial\bar{S}$ of $\bar{S}$ can be expressed as $G(\mathbb{Q})$-hypercohomology of a complex constructed out of the complex of parabolic subgroups of G. A similar construction gives rise to a decreasing filtration $F^iH^*(S,\tilde{V})$, where $F^\ell H^*(S,\tilde{V})$ is the image of $H_c^*(S,\tilde{V})$ in $H^*(S,\tilde{V})$. The quotient $F^1H^*(S,\tilde{V})/F^\ell H^*(S,\tilde{V})$ can be identified with the space of ghost classes. A new non-trivial ghost class is constructed in $H^2(SL_4(\mathbb{Q}), \mathcal{C}^\infty(SL_4(\mathbb{A}_f)))$. Finally, an algebraic construction of an "Eisenstein section" $\mathrm{Eis}^* : H^*(\partial\bar{S},\tilde{V}) \to H^*(\bar{S}, p_*^G\, Hom(\mathrm{St}_G, \mathrm{St}_G^\vee \otimes V_X))$ is given. Here $p : \bar{X} \to \bar{S}$ is the projection, $\mathrm{St}_G^\vee$ is the $\mathbb{Z}$-dual of St_G and p_*^G is the $G(\mathbb{Q})$-invariant direct image functor.

G. ROUSSEAU

Real forms of Kac-Moody algebras

A form over a field $K \subset \mathbb{C}$ of an indecomposable, infinite dimensional Kac-Moody algebra $\mathfrak{g}$, is a Lie algebra $\mathfrak{g}_K$ with an isomorphism $\mathfrak{g}_K \otimes \mathbb{C} \simeq \mathfrak{g}$. So there is an action of the Galois group $\Gamma = \mathrm{Gal}(\mathbb{C}/K)$ on $\mathfrak{g}$ and we define $G_K = G^\Gamma$, where G is the adjoint group of $\mathfrak{g}$.

As there are 2 conjugacy classes under G of Borel subalgebras of $\mathfrak{g}$, there are 2 cases:

(1) Γ mixes the 2 conjugacy classes: $\mathfrak{g}_K$ is called almost compact.
(2) Γ stabilizes each conjugacy class: $\mathfrak{g}_K$ is called almost split.

In this last case many results à la Borel-Tits are known (see Back-Valente, Bardy-Panse, Messaoud, Rousseau; Journal of Algebra 1995).

For other results suppose now $K = \mathbb{R}$ and $\mathfrak{g}$ symmetrizable: $\mathfrak{g}_\mathbb{R}$ is given by a conjugation σ'. There exists a compact conjugation ω' commuting with σ' : $\sigma = \omega'\sigma' = \sigma'\omega'$ is a (linear) involution.

If $\mathfrak{g}_\mathbb{R}$ is almost split, the correspondences $\mathfrak{g}_\mathbb{R} \longleftrightarrow \sigma' \longleftrightarrow \sigma$ are one-to-one and we get good classifications of them (see above article). If $\mathfrak{g}_\mathbb{R}$ is almost compact, then σ is of first kind (it stabilizes the 2 conjugacy classes of Borel subalgebras), and there is a map which is onto (but perhaps not one-to-one) $\sigma \longmapsto \mathfrak{g}_\mathbb{R}$.

Suppose now $K = \mathbb{R}$, $\mathfrak{g}$ affine, $\mathfrak{g}_\mathbb{R}$ almost compact. We know then a complete list of first kind involutions, and the problem is to tell whether the corresponding almost compact forms may be isomorphic.

The answer is known in the untwisted cases, and is negative in this case. So the above map is one-to-one in these cases.

The proof uses invariants of these forms, one of them is the rank of maximal split toral subalgebras of these forms (this is an invariant, even if these algebras are not conjugate under $G_\mathbb{R}$).

W. SOERGEL

Representations of restricted enveloping algebras:
Independence of the characteristic

In this talk I reported on joint work with H.H. Andersen and J.C. Jantzen.

For a fixed root system R and a field k of finite characteristic we can form the corresponding semisimple simply connected algebraic group G/k, its Lie algebra $\mathfrak{g}_k$ and the restricted enveloping algebra $\mathcal{U}_k$.

Theorem. *There is a $\mathbb{Z}$-algebra $\mathcal{B}_\mathbb{Z}$, free of finite rank over $\mathbb{Z}[i^{-1}|1 \leq i < h]$ ($h =$ Coxeter number) such that for all k with* $\operatorname{char} k > h$

$$\mathcal{B}_\mathbb{Z} \otimes_\mathbb{Z} k \text{ is Morita-equivalent to the principal block of } \mathcal{U}_k.$$

There is an analogous interpretation of $\mathcal{B}_\mathbb{Z} \otimes_\mathbb{Z} \mathbb{Q}(\sqrt[\ell]{1})$ in terms of quantum groups at $\sqrt[\ell]{1}$.

A refinement of this theorem tells us that the decomposition matrices for restricted representations of $\mathfrak{g}_k$ are (for $\operatorname{char} k \gg 0$) independent of k and coincide with their (known) quantum analoga, thereby proving Luzstig's modular conjecture for $\operatorname{char} k \gg 0$.

D.M. TESTERMAN

A_1-type subgroups in exceptional algebraic groups

The work discussed below was done in collaboration with Ross Lawther of Warwick University.

We take as our starting point the following characteristic p analogue of the Jacobsen-Morozov theorem.

Theorem. *(Testerman) Let G be a semisimple algebraic group defined over an algebraically closed field k of characteristic $p > 0$. Assume p to be a good prime for G. Let $u \in G$ with $u^p = 1$. Then there exists a closed connected subgroup $X < G$ with $X \simeq SL_2(k)$ or $PSL_2(k)$ and $u \in X$.*

Thus, the map $\{G$-classes of A_1-subgroups of $G\} \longrightarrow \{G$-classes of elements of order $p\}$ is onto. We consider here the question: Is it a bijection? If not, what can be said about the G-classes of A_1-subgroups lying above a fixed unipotent element of G?

Theorem. *Let G have type G_2, F_4, E_6, E_7, E_8 and assume $p > 3, 3, 5, 7, 7$, respectively. Then there exists a complete classification of the G-conjugacy classes of closed connected subgroups $X < G, X \simeq SL_2(k)$ or $PSL_2(k)$. For each class of subgroups the G-class of its unipotent elements is identified and $C_G(X)^\circ$ is determined.*

Corollary. $\operatorname{Lie}(C_G(X)^\circ) = C_{\operatorname{Lie}(G)}(X)$.

To X can be associated a labelled Dynkin diagram; this encodes the set of weights of a maximal torus of X acting on $\operatorname{Lie}(G)$. Liebeck and Seitz have shown that the G-class of X is uniquely determined by its labelled Dykin diagram. In general, there will be infinitely many non-conjugate A_1-subgroups above a given unipotent element; however, most of these arise from "twisted diagonal" embeddings of A_1 in a direct product or from twisted tensor product embeddings of A_1 in a classical subgroup of G. If we consider only "untwisted" embeddings, we get

Corollary. *The map*

$$\{G\text{-classes of untwisted } A_1\text{-subgroups of } G\} \longrightarrow \{G\text{-classes of elements of order } p\}$$

is a bijection for the groups G_2, E_7, E_8, and for $G = F_4, E_6$, there exists a unique class of elements of order p for which there are precisely 2 non-conjugate untwisted A_1-subgroups mapping to this class, and this only for $p = 7$.

Corollary. *Let $u \in G, u^p = 1$. Let X be an untwisted A_1-subgroup with $u \in X$. Then $C_G(X)^\circ$ is a maximal reductive subgroup of $C_G(u)^\circ$.*

E.B. Vinberg

Reductive algebraic semigroups

The theory of algebraic semigroups was developed by Putcha and Renner in the 80's. Some basic theorems of this theory are presented in the first half of the lecture. In particular, let S be an algebraic semigroup with unit and G its group of invertible elements. Suppose that G is reductive. Then any $(G \times G)$-orbit in S contains exactly one conjugacy class of idempotents. Any idempotent is conjugate to an idempotent of $\overline{T}$, where T is a maximal torus of G. Two idempotents of $\overline{T}$ are conjugate if they are equivalent with respect to the Weyl group.

In the second half of the lecture, a classification of all reductive algebraic semigroups is given in terms of some geometrical data in the space of characters of T. For any semisimple algebraic group G_0, a remarkable semigroup S is distinguished among all the semigroups having G_0 as the commutator subgroup of the group of invertible elements. The "wonderful" completion of G_0, constructed by DeConcini and Procesi, can be described in terms of this semigroup.

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