MATHEMATISCHES FORSCHUNGSINSTITUT
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Darstellungstheorie endlichdimensionaler Algebren

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The meeting was organized by I. Reiten (Trondheim) and C. M. Ringel (Bielefeld).

Several talks of the meeting focussed on the calculation of quivers and relations in representation theory and various other fields of mathematics. Experts from algebraic topology, algebraic and symplectic geometry, group representation theory, algebraic group theory and representation theory of Lie algebras and quantum groups reported on situations where quivers and their relations appear, and where their computation leads to new insights.

Further topics of the meeting were the application of combinatorial, geometric and homological methods in representation theory of algebras, for example yielding a better understanding of several classes of tame algebras, homological properties of representations, tilting modules and degenerations of modules.

The stimulating talks presented many results and open questions, suggesting directions for future research. They initiated interesting discussions and conversations, leading to solutions of some problems posed in the lectures.

The talks reflected the rich development and the liveliness of the field, and its interplay with other branches of mathematics.

The inspiring atmosphere of both the location and the meeting, the growth as well as the deepening of contacts were very stimulating for all participants, and will certainly contribute to further progress.

Abstracts of talks at the meeting

H. H. ANDERSEN

Tilting modules for algebraic groups and quantum groups

Let G be a reductive algebraic group over a field k of characteristic p. Fix a maximal torus T, set $X = X(T)$, the character group of T and choose a dominant chamber X^+. For each dominant weight $\lambda \in X^+$ we have the Weyl module $\Delta(\lambda)$, the dual Weyl module $\nabla(\lambda)$ and the simple module $L(\lambda)$, all having highest weight λ. In addition there exists a unique indecomposable tilting module $T(\lambda)$ with heighest weight λ. Here tilting means having both a Δ-filtration and a ∇-filtration. If $\{\lambda_1, \lambda_2, \ldots, \lambda_r\} = \{\nu \mid [T(\lambda) : \Delta(\nu)] \neq 0\}$ is ordered such that $\lambda_i > \lambda_j$ only if $i < j$ then $T(\lambda)$ has a unique Δ-filtration of the form

$$0 \subset \Delta(\lambda) = E_0 \subset E_1 \subset \ldots \subset E_r = T(\lambda)$$

with $E_i/E_{i-1} \simeq \Delta(\lambda_i)^{d_i}$. We recall the Ringel/Donkin construction which gives $d_i = \dim \mathrm{Ext}^1_G(\Delta(\lambda_i), E_{i-1})$.
The very same procedure works for the quantum groups U_q corresponding to G when $q \in \mathbb{C}$ is a p'th root of 1. Denoting the tilting module by $T_q(\lambda)$ in this case we have

Conjecture: *Suppose* $\langle \lambda + \rho, \alpha^\vee \rangle < p^2$ *for all roots* α *and* $p > h$. *Then* $\mathrm{ch}\, T(\lambda) = \mathrm{ch}\, T_q(\lambda)$.

We show that this conjecture is equivalent to a statement about the $\mathrm{Ext}^1_{U_A}(\Delta_A(\lambda_i), E_{i-1})$, $i = 1, \ldots, r$ where $A = \mathbb{Z}[v]_{(p, v-1)}$.

H. J. BAUES

Classification of homotopy types

Let V_1, V_2, V_3, V_4, V_5 and H be finitely generated free abelian groups. Moreover let M be an automorphism of $V = V_1 \oplus V_2 \oplus V_3 \oplus V_4 \oplus V_5$ given by a matrix M_{ij} of the form

$$\begin{array}{cccccc} & V_1 & V_2 & V_3 & V_4 & V_5 \\ V_1 & \cdot & * & * & \cdot & \cdot \\ V_2 & \cdot & \cdot & \cdot & 0 & \cdot \\ V_3 & \cdot & * & \cdot & 0 & 0 \\ V_4 & 0 & 0 & 0 & \cdot & \cdot \\ V_5 & 0 & 0 & 0 & 0 & \cdot \end{array}$$

Here 0 is the zero matrix and $*$ denotes matrices divisible by 2 and $\cdot$ denotes matrices. Then M acts on the abelian group

$$\overline{V} = V_1 \otimes \mathbb{Z}/8 \oplus (V_2 \oplus V_3) \otimes \mathbb{Z}/4 \oplus (V_4 \oplus V_5) \otimes \mathbb{Z}/2.$$

For example $M_{12} \in \mathrm{Hom}(V_2, V_1)$ is divisible by 2 and acts by

$$(\frac{1}{2}M_{12}) \otimes 2 \,:\, V_2 \otimes \mathbb{Z}/4 \to V_1 \otimes \mathbb{Z}/8.$$

The same holds for M_{13}. All the other entries M_{ij} act by using the canonical inclusions $\mathbb{Z}/2 \subset \mathbb{Z}/4 \subset \mathbb{Z}/8$. For example M_{15} acts by

$$M_{15} \otimes 4 \,:\, V_5 \otimes \mathbb{Z}/2 \to V_1 \otimes \mathbb{Z}/8$$

and M_{32} acts by $M_{32} \otimes \mathbb{Z}/4$. We define an equivalence relation for homomorphisms $u, u' : H \to \overline{V}$ by setting $u \sim u'$ if there exists an automorphism N of H and M as above with $MuN^{-1} = u'$. Each u is equivalent to a sum $u_1 \oplus \ldots \oplus u_r$ where the u_i are indecomposable. Moreover this decomposition of u is unique up to permutation.

"Classify and describe explicitely all indecomposable equivalence classes!"

This classification implies the classification of all 2-primary $(r-1)$-connected $(r+4)$-dimensional homotopy types with finitely generated torsion free homology, $r \geq 4$.

H. J. Baues

Homology types in the stable range with at most two homotopy groups which are not trivial

An abelian group E is elementary if E is a finite direct sum of cyclic groups of prime order. An elementary functor from abelian groups to abelian groups is a functor of the form $F(A) = A \otimes E \oplus A * E'$ where E and E' are elementary. Cartan showed that all stable Eilenberg-Mac Lane functors $H_n K(A, m)$, $n < 2m$, are elementary. This leads to the following problem in representation theory. Consider the category for which the objects are given by chain complexes

$$H_1 \to E(A) \xrightarrow{\partial} T \xrightarrow{\delta} F(A) \to 0$$

where H_1, A, T are finitely generated abelian groups and H_1 is free. Moreover the chain complex is exact in $E(A)$ and $F(A)$ and E and F are elementary functors which are fixed. Morphisms in the category $\mathcal{C}(E, F)$ are triple of homomorphisms $h : H_1 \to H_1'$, $\alpha : A \to A'$, $t : T \to T'$ compatible with the operators in the chain complex. Two morphisms (h,α,t) and (h',α',t') are equivalent if $h = h'$, $\alpha = \alpha'$ and $t_* = t'_*$: cokernel$(\partial) \to$ cokernel(∂'). Then $C(E,F)/\sim$ is an additive category. The classification of indecomposables in $C(E,F)/\sim$ yields the classification of all indecomposable spaces with at most 2 nontrivial homotopy groups π_m and π_n, $m < n < 2m$.

T. Brüstle

Orbits of parabolic subgroups and good modules over certain quasi-hereditary algebras

Let P be a parabolic subgroup of a reductive algebraic group G. It acts by conjugation on its unipotent radical P_u as well as on the members $P_u^{(l)}$ of the lower descending central series of P_u and on their Lie algebras $\mathfrak{p}_u^{(l)}$.
Recently, L. Hille and G. Röhrle determined those parabolic subgroups of classical groups such that the number of orbits on P_u is finite. In joint work with L. Hille, we extend this result in case $G = GL(V)$ to all $\mathfrak{p}_u^{(l)}$, $l \in \mathbb{N}$. Recall that a parabolic subgroup of $GL(V)$ is of the form $P = \text{Stab}\ \mathcal{F}$, where $\mathcal{F}$ is a proper flag of length t:

$$\mathcal{F}: \quad V_1 \subset V_2 \subset \ldots \subset V_t.$$

Theorem: *Let k be an infinite field, and $P \subset GL(V)$ a parabolic subgroup of the form $P = \text{Stab}\ \mathcal{F}$, $\mathcal{F}$ a proper flag of length t. Then the number of orbits of P on $\mathfrak{p}_u^{(l)}$ is finite precisely when $t \leq 5$ in case $l = 0$ and $t \leq 2l + 6$ for $l \geq 1$.*

The proof follows an idea of P. Gabriel. For fixed rank l, the orbits of all P on all $\mathfrak{p}_u^{(l)}$ are identified with the isomorphism classes of good modules over a quasihereditary algebra $\mathcal{A}(t,l)$.
example:

$$\mathcal{A}(t,0): \quad 1 \underset{\beta}{\overset{\alpha}{\rightleftarrows}} 2 \quad \cdots \quad t-1 \underset{\beta}{\overset{\alpha}{\rightleftarrows}} t \ / \alpha\beta = \beta\alpha \text{in } 1,\ldots,t-1$$

S. Donkin

On the existence of Aulander-Reiten sequences of group representations

We consider the problem of the existence of almost split sequences in the category of finite dimensional modules for a group Γ, over a field k. Defining $O(\Gamma)$ to be the largest normal subgroup of Γ such that all finite dimensional $k\Gamma$-modules are semisimple, on restriction to $O(\Gamma)$, we show in particular that if there is any almost split sequence of finite dimensional $k\Gamma$-modules then $\Gamma/O(\Gamma)$ has a torsion free subgroup of finite index. The method is to consider instead the corresponding problem for an affine group scheme G over k. From the solution to this problem we can read of a solution to the corresponding problem also for: discrete modules for profinite groups; finite dimensional modules for enveloping algebras; and restriced finite dimensional modules for restricted enveloping algebras.

P. DRÄXLER

Circular biextensions of tame concealed algebras

Fix an algebraically closed field k. For $n \in \mathbb{N}$ define

$$C_n := k\left[\begin{tikzcd} & 2 \arrow[dr, "\alpha_2"] & \\ 1 \arrow[ur, "\alpha_1"] & & 3 \arrow[d] \\ & n \arrow[ul, "\alpha_n"] & \cdots \arrow[l] \end{tikzcd}\right]/(\alpha_{i+1}\alpha_i).$$

Let B be tame concealed, $\bigcup_{\lambda\in\mathbb{P}_1(k)} \mathcal{T}(\lambda)$ the indecomposable regular B-(left)-modules, $\mathcal{T}(\lambda)$ a stable tube of rank $n(\lambda) \in \mathbb{N}$ for each $\lambda \in \mathbb{P}_1(k)$.
For $\lambda \in \mathbb{P}_1(k)$ let $\{\underbrace{\tau^{n(\lambda)}X}_{=X}, \tau^{n(\lambda)-1}X, \ldots, \tau^1 X\}$ be the τ-orbit of objects of length $= 2$ in $\mathcal{T}(\lambda)$.
Define $R(\lambda)$ as the contravariant representation of $C_{n(\lambda)}$ given by

$$\begin{tikzcd} & \tau^2 X \arrow[dl, "f_1"'] & \\ \tau X \arrow[dr, "f_{n(\lambda)}"'] & & \tau^3 X \arrow[ul, "f_2"'] \\ & \tau^{n(\lambda)}X \arrow[r] & \cdots \arrow[u] \end{tikzcd},$$

where the f_i are non-zero maps. Thus $R(\lambda)$ is a B-$C_{n(\lambda)}$-bimodule.
For a finite subset $T = \{\lambda_1, \ldots, \lambda_t\}$ of $\mathbb{P}_1(k)$ put $C(T) := C_{n(\lambda_1)} \times \ldots \times C_{n(\lambda_t)}$ and $R(T) := \bigoplus_{i=1}^t R(\lambda_i)$. Hence $R(T)$ is a B-$C(T)$-bimodule.

Theorem: *Let S, T be two finite subsets of $\mathbb{P}_1(k)$. The algebra*

$$\underbrace{\langle S\rangle B\langle T\rangle}_{\text{circular biextension}} := \begin{pmatrix} C(T) & 0 & 0 \\ R(T) & B & 0 \\ DR(S)\otimes_B R(T) & DR(S) & C(S) \end{pmatrix}$$

is tame provided

1. *B of type $\tilde{\mathbb{D}}_n$, $T = \{\lambda_1\}$, $S = \{\mu_1\}$, $n(\lambda_1) = n(\mu_1) = n-2$ or*
2. *B of type $\tilde{\mathbb{A}}_{p,q}$, $T = \{\lambda_1, \lambda_2\}$, $S = \{\mu_1, \mu_2\}$, $n(\lambda_1) = n(\mu_1) = p$, $n(\lambda_2) = n(\mu_2) = q$.*

Conversely, if $\langle S\rangle B\langle T\rangle$ is tame and $S \cup T \neq 0$, then $\langle S\rangle B\langle T\rangle$ is a subbiextension of one of the cases 1., 2..

Y. A. Drozd

Solution of a problem raised by H. J. Baues

The complete list of indecomposable objects in the category $F\mathcal{A}^4$ has been calculated and the laws of decomposition of objects of this category into direct sums of indecomposables has been established.

Y. A. Drozd

Some finite-dimensional algebras related to the classification of vector bundles over projective curves

A 'projective configuration' is by definition a projective curve such that all its components are projective lines and all intersections are transversal. To each projective configuration C one can associate a finite dimensional algebra $A(C)$ such that the classification problems for $A(C)$-modules and for vector bundles over C are "almost equivalent". For instance, if C is just $\mathbb{P}^1$ with one simple self-intersection, then $A(C)$ is $\bullet \overset{a}{\underset{b}{\rightrightarrows}} \bullet \overset{x}{\underset{y}{\rightrightarrows}} \bullet$ with $x\alpha = y\beta = 0$. The question arises to give a priori reasons for this correspondance.

Solution of the problem arising from the classification of topological spaces with 2 non-trivial homotopy groups

The problem is to classify chain complexes of the form $H \to \underline{E(A)} \to T \to \underline{F(A)} \to 0$ exact in underlined terms, where A, T, H are finitely generated abelian groups, H is free and $E(A) := A \otimes E_1 \oplus A * E_2$, $F(A) := A \otimes F_1 \oplus A * F_2$ for some elementary abelian groups.

Results:

1. *this problem is:*

   (a) *of finite type if for all p, among the orders of E_1, E_2, F_1, F_2 there is only one divisible by p (but not by p^2),*

   (b) *tame if either orders of E_1, F_2 are divisible by p (not by p^2) and the orders of E_2, F_1 are p-free or vice versa,*

   (c) *wild otherwise.*

2. *In the tame case a complete list of indecomposable objects is given.*

K. Erdmann

Quivers and relations for some group algebras and related algebras

Let A be the group algebra of some finite group, or a Hecke algebra of some finite Coxeter group. In spite of many tools and results available, to find the quiver and relations for the basic algebra of A is a hard problem. The aim of the lecture was to describe some methods, results and difficulties.
In particular we discussed the case of symmetric groups (and Hecke algebras of symmetric groups).

E. L. Green

Projective resolutions and Ext

This represents joint work with Ø. Solberg and D. Zacharia. A new approach to finding minimal projective resolutions for both finite dimensional modules over finite dimensional quotients of path algebras and for graded modules over (length) graded quotients of path algebras.
We begin with generators and relations of the Λ-module M and construct a

filtration $\ldots P_n \subset P_{n-1} \subset \ldots \subset P_0$ where P_0 is the $k\Gamma$-projective cover of the module in question, where $\Lambda = k\Gamma/I$. All information, including homomorphisms is included in this filtration. We give algorithms to construct the P_n's. We also show that given the filtrations for both $\Lambda/\mathbf{r}$ and M, (where $\Lambda = k\Gamma/I$, I admissible) the algebraic structure of $\mathrm{Ext}^*(\Lambda/\mathbf{r}, \Lambda/\mathbf{r})$ can be found and the structure of $\mathrm{Ext}^*(M, \Lambda/\mathbf{r})$ as an $\mathrm{Ext}^*(\Lambda/\mathbf{r}, \Lambda/\mathbf{r})$-module is also encoded in the filtrations.

We also provide new examples where the projective dimension of a simple module and $\mathrm{gl\,dim}\,\Lambda$ are characteristic dependent.

D. HAPPEL

On hereditary categories with tilting object

Let $\mathcal{H}$ be a hereditary, abelian, locally finite k-category (k algebraically closed field). $T \in \mathcal{H}$ is called a tilting object if $\mathrm{Fac}\ T = \mathcal{E}(T) := \{X \in \mathcal{H} \mid \mathrm{Ext}^1(T, X) = 0\}$. If T is a tilting object, then End T is called a quasitilted algebra.

Examples of hereditary categories containing a tilting object are mod H (category of finitely generated modules over a finite dimensional hereditary k-algebra) and coh $\mathbb{X}$ (category of coherent sheaves over a weighted projective line). It is conjectured that these are the only two classes of such categories (up to derived equivalence). Besides a summary of known results in this direction the following two results were presented:

Theorem: *If $\mathcal{H}$ is a hereditary category with tilting object containing an indecomposable directing object, then $\mathcal{H}$ is derived equivalent to* mod H *for a finite-dimensional hereditary algebra H.*

Theorem: *If $\mathcal{H}$ is a hereditary category with tilting object containing a simple object, then $\mathcal{H}$ is derived equivalent to one of the classes mentioned above.*

A. S. KLESHCHEV

On dimensions of simple S_n-modules

The irreducible modules of the symmetric group S_n in characteristic p are constructed as the simple tops of the Specht modules. This implicit realization does not give answers to many important questions on the simple modules. In this expository talk we presented some of the results which may be considered as steps towards describing the dimensions of the simple modules. The main tool is the branching rules, i.e. the results on the restrictions to the natural subgroup S_{n-1}. We also described an application to the ideal structure of the modular group algebra of the finitary symmetric group.

S. KÖNIG

Brauer algebras

Brauer introduced these algebras as a tool for decomposing $V^{\otimes m}$ over $O(n)$ or $Sp(2n)$ (over any field k). More generally, a Brauer algebra $B(n,\delta)$ ($n \in \mathbb{N}$, $\delta \in k$) can be defined by generators and relations or via a k-basis of diagrams. One gets back Brauer's algebras by putting $\delta = n$ or $\delta = -2n$.
One is interested in the vertices and in the connected components of the quiver of $B(n,\delta)$.
The first question has been answered by Graham and Lehrer (96) by showing that $B(n,\delta)$ is cellular.
In joint work with C. C. Xi another (less computational) proof of this result is given by showing that $B(n,\delta)$ is an iterated inflation of group algebras of symmetric groups: as vector spaces, $B(n,\delta) = k\Sigma_n \oplus (V_2 \otimes V_2 \otimes k\Sigma_{n-2}) \oplus (V_4 \otimes V_4 \otimes k\Sigma_{n-4}) \oplus \ldots$ (and these 'pieces' yield a cell chain).
This implies an answer to the second question as well in the case of δ regular. (δ regular means non-vanishing of certain determinants, this is the generic case; by a result of Wenzl only 'small' integers are not regular.)

Theorem (König-Xi): *k any field, δ regular. Then $B(n,\delta)$ is Morita equivalent to $k\Sigma_n \oplus k\Sigma_{n-2} \oplus \ldots$.*
Hence the blocks of $B(n,\delta)$ are known in that case.

Another consequence of our description of $B(n,\delta)$ as iterated inflation is an 'explicit' description of its simple modules, thus reproving and extending a result by Kerov.

H. KRAUSE

On extensions of simple functors (on work of Piriou and Schwartz)

I gave a report on some recent work of Piriou and Schwartz. They study the abelian category $\mathcal{F}$ of all functors $\mathrm{mod}\, k \to \mathrm{Mod}\, k$ from finite dimensional to all vectorspaces over a field k with p elements (p a prime). This category is of interest for topologists since the mod p cohomology of a space can be interpreted as an object in $\mathcal{F}$. In fact, the category of unstable modules over the mod p Steenrod algebra is equivalent (modulo nilpotent objects) to the category of locally finite objects in $\mathcal{F}$. Piriou and Schwartz consider a filtration $\mathcal{F}_0 \subset \mathcal{F}_1 \subset \mathcal{F}_2 \subset \ldots$ of localizing subcategories of $\mathcal{F}$ and prove that $\mathcal{F}_n/\mathcal{F}_{n-1}$ is equivalent to Mod $k\Sigma_n$ where $k\Sigma_n$ denotes the group algebra of the symmetric group Σ_n. This filtration is used to give a complete classification of the simple objects in $\mathcal{F}$, and it is shown that $\mathrm{Ext}^1_{\mathcal{F}}(S,S) = 0$ for every simple object S in $\mathcal{F}$.

L. Le Bruyn

Brauer-Severi varieties and quivers

In this talk I tried (but failed) to show how one can describe an order, A, with the property that $\mathrm{mod}_n^{tr} A$ is smooth, locally by a quiver. The idea is that a maximal ideal $\mathfrak{m}$ of the center of A corresponds to an isoclass of a semi-simple n-dimensional module $SS_m = S_1^{\oplus e_1} \oplus \ldots \oplus S_k^{\oplus e_k}$ with S_i simple of dimension d_i, whence $n = \sum e_i d_i$. The stabilizer subgroup of SS_m in $\mathrm{mod}_n^{tr} A$ is then $GL(\alpha) = GL_{e_1} \times \ldots \times GL_{e_k} \hookrightarrow GL_n$. Computing the normal space to the orbit one obtains a quiver-situation (Q_m, α) where Q_m is a quiver on m vertices describing the "trace preserving" selfextensions of SS_m. It then follows from combining Luna's theory of étale slices with Procesi's reconstruction result (recovering A from $\mathrm{mod}_n^{tr} A$) that $\widehat{A}_m$ is isomorphic to the completion (at the zero representation) of the ring of GL_n-equivariant maps $GL_n \times^{GL(\alpha)} \mathrm{Rep}(Q_m, \alpha) \to M_n(\mathbb{C})$. Moreover, for fixed dimension of the center of A one can compile a list of possible occuring quiver-settings.
As a consequence one can describe the fibers of Van den Bergh's Brauer-Severi variety associated to A and show that it is a smooth projective space bundle over the variety of the center. In particular, one can extend the Artin-Mumford geometric description of maximal orders in quaternion algebras over a smooth surface having nonsingular curves of ramification to arbitrary degree.

O. Mathieu

On the cohomology of symplectic manifolds

Let X be a compact riemannian manifold. A differential form α is called harmonic iff $d\alpha = d^*\alpha = 0$. Here d is the de Rham differential and $d^* = *d*$ where $*$ is the Hodge operator (usually, one requires $\Delta\alpha = 0$: it's equivalent). Hodge's Theorem asserts that any cohomology class contains exactly one harmonic form. Make new hypotheses: let X be a compact symplectic manifold. We can define a Hodge operator $*$ and again set $d^\bullet = *d*$. Similarly, a harmonic form is a form killed by d and $d^\bullet$. By analogy with the riemannian case, J. L. Brylinksi proposed the following conjecture: any cohomology class can be represented by at least one harmonic form. The answer of this conjecture is "no". Indeed we proved

Theorem: *Brylinkski's conjecture holds iff X satisfies the strong Lefchetz theorem, i.e. $[\omega^i] : H^{n-i}(X) \to H^{n+i}(X)$ is an isomorphism for all i, where $n = \frac{1}{2}\dim X$, and where $[\omega^i]$ is the cup product by the i-th power of the symplectic form.*

The relation with the present conference is as follows: the theorem is based on Gabriel's theorem on representations of quivers of type A (see my publication in Comm. Helv.). As pointed out by some auditors, it corresponds with the quiver

$$\bullet \rightleftarrows \bullet \rightleftarrows \bullet \underset{T^-}{\overset{T^+}{\rightleftarrows}} \bullet \rightleftarrows \bullet \ldots$$

with relations $(T^\pm)^2 = 0$, $[T^+, T^-] = 0$.

O. Mathieu

Representations of $\mathfrak{sl}(n,1)$ (after J. Germoni)

Let $\mathcal{M}$ be the category of finite dimensional representations of the Lie superalgebra $\mathfrak{sl}(n,m)$. Define the degree of the simple module $L(\lambda)$ with highest weight λ as $\frac{1}{2}\#\{\alpha \in \Delta \mid \langle \lambda + \rho, \alpha \rangle = 0\}$. Denote by $\mathcal{B}(\lambda)$ the block of $\mathcal{M}$ containing $L(\lambda)$; the degree is indeed an invariant of the block. Say that $\mathcal{B}(\lambda)$ is typical (simply atypical) iff its degree is zero (iff it is one). It follows easily from the work of V. G. Kac that a typical block is equivalent to nilpotent representations of the quiver $\bullet \circlearrowright$. Let $\mathcal{A}$ be the graded algebra $\langle T^\pm \mid (T^\pm)^2 = 0 \rangle$ with $\deg T^\pm = \pm 1$. By nilpotent $\mathcal{A}$-module, we mean that $[T^+, T^-]$ acts nilpotently.

Theorem (J. Germoni): *If $\mathcal{B}(\lambda)$ is simply atypical, it is equivalent to the category of nilpotent graded $\mathcal{A}$-modules.*

Thus it follows from the work of C. M. Ringel on $\mathcal{A}$ that the indecomposable modules of $\mathcal{B}(\lambda)$ can be classified if $\mathcal{B}(\lambda)$ is simply atypical. It should be noted that any block of $\mathfrak{sl}(n,1)$ is typical or simply atypical, thus Germoni classified all $\mathfrak{sl}(n,1)$-modules. Moreover Germoni proved that $\mathcal{M}$ contains some wild blocks if $n, m \geq 2$. Quite recently, V. Serganova announced the following nice complement:

Theorem (announced by V. Seganova): *Two blocks of same degree (regardless of n, m) are equivalent. In particular they are wild if their degree is* ≥ 2.

For simply atypical blocks, the quiver is:

$$\cdots \bullet \rightleftarrows \bullet \underset{T^-}{\overset{T^+}{\rightleftarrows}} \bullet \rightleftarrows \bullet \rightleftarrows \bullet \cdots$$

with relations $(T^{\pm})^2 = 0$, $[T^+, T^-]$ nilpotent.

H. Meltzer

Tame tilting complexes for hyperelliptic algebras

Let Λ be a canonical algebra in the sense of Ringel of type $(2, 2, \ldots, 2)$, t-entries. For $t \geq 5$ we call Λ hyperelliptic. We study tilting complexes in the derived category $D^b(\text{mod}\Lambda) = D^b(\text{coh}\mathbb{X})$, where $\text{mod}\Lambda$ is the category of finite-dimensional right Λ-modules and $\text{coh}\mathbb{X}$ denotes the category of coherent sheaves on the associated weighted projective line $\mathbb{X}$ in the sense of Geigle and Lenzing.

For such a tilting complex T it is shown that its endomorphism ring Σ admits the structure of a layered algebra. Furthermore we prove that two types of diophantine equations in terms of the ranks and degrees of the indecomposable direct summands of T, or in terms of the entries of the Cartan matrix of Σ, are satisfied.

We determine the possible Cartan matrices for tame layered algebras and give a complete classification of all tame algebras which are derived equivalent to a hyperelliptic algebra. These algebras are described by quivers and relations where the parameters of $\mathbb{X}$ play an important role. We illustrate how these relations can be determined applying the interplay between vector bundles and sheaves of finite length. As a consequence we see that such algebras are quasitilted and exist only in case $t \leq 8$.

Applying results about perpendicular categories we also characterize all tame algebras which are derived equivalent to t-subspace problem algebras.

S. A. Ovsienko

Interplay between relations and additions

Let $\Gamma = (\Gamma_0, \Gamma_1)$ be a finite connected tree, k be a field, $A = k\Gamma/I$ be a category. A set $\Phi = \{\phi\}$ consists of labels of a minimal set of relations $\phi : \alpha \to \beta$, $\alpha, \beta \in \Gamma_0$, $\alpha = \alpha(\phi)$, $\beta = \beta(\phi)$ and $\delta : \Phi \to k\Gamma$, $\phi \mapsto l \in k\Gamma(\alpha,\beta)$ maps a label to the corresponding relation. Also $\mathcal{A} = (A, V, \mu, \varepsilon)$ is a box over A, where $\mu : V \to V \otimes_A V$ is a coassocative comultiplication, $\varepsilon : V \to A$ is a counit and V does not contain a free direct summand (it is an analogue of minimality of a set of relations). By $\Pi = \{\psi\}$, $\psi \in V(\alpha,\beta)$, $\alpha = \alpha(\psi)$, $\beta = \beta(\psi)$ we denote the set of free generators of V, by (ind $\mathcal{A}$) rep $\mathcal{A}$ we denote the category of (indecomposable) representations of $\mathcal{A}$, by dim : rep $\mathcal{A} \to \mathbb{Z}^{\Gamma_0}$ denote the dimension map and by $B = (B_0, B_1)$ the bigraph (oriented) $B_0 = \Gamma_0$, $B_1 = \Gamma_1 \amalg (\Phi \amalg \Pi)$ with obvious orientation, given by $\alpha, \beta : B_1 \to \Gamma_0$. For $\vec{d} \in \mathbb{Z}^{\Gamma_0}$ by ind $\mathcal{A}(\vec{d})$ we denote the set $\dim^{-1}(\vec{d})$, by $\sim$ the isomorphism relation. Then we obtain:

Theorem:

1. *The representation type of $\mathcal{A}$, the set* dim(ind $\mathcal{A}$) $\subset \mathbb{Z}^{\Gamma_0}$ *and the maximal number of parameters in* ind $\mathcal{A}(\vec{d})/\sim$ *for any* $\vec{d} \in (\mathbb{Z}^+)^{\Gamma_0}$ *do not depend on an orientation α, β, but only on the unoriented bigraph $\overline{B}$ underlying B.*

2. *If*

$$q(x) = \sum_{\phi \in \Phi} x_{\alpha(\phi)} x_{\beta(\phi)} + \sum_{\gamma \in \Gamma_0} x_\gamma^2 - \sum_{a \in \Gamma_1} x_{\alpha(a)} x_{\beta(a)} + \sum_{\psi \in \Pi} x_{\alpha(\psi)} x_{\beta(\psi)},$$

then $\mathcal{A}$ is of finite type if and only if $q(x)$ is weakly positive. In this case

- dim : ind $\mathcal{A}/\sim \to \Sigma_q^+$ *is a bijection, where* $\Sigma_q^+ = \{x \in (\mathbb{Z}^+)^{\Gamma_0} \mid q(x) = 1\}$.
- *If $X \in$ ind $\mathcal{A}$, then* $\mathrm{Hom}_{\mathcal{A}}(X,X) = k$, $\mathrm{Ext}^i_{\mathcal{A}}(X,X) = 0$ *for* $i \in \mathbb{Z} \setminus \{0\}$.

The proof is based on the theory of D$\mathbb{Z}$GC representations: we correspond to $\mathcal{A}$ a D$\mathbb{Z}$GC T, such that rep T is a "derived category" of rep $\mathcal{A}$. Then for a (+)-admitted vertex $i \in \Gamma_0$ we construct a "reflection" $\mathbb{W}_i : T \to T_i$, inducing W_i : rep $T_i \to$ rep T and inducing in dimensions the usual reflection with respect to q and i $w_i : \mathbb{Z}^{\Gamma_0} \to \mathbb{Z}^{\Gamma_0}$ such that $\dim(W_i(X)) = w_i(\dim(X))$ holds, $X \in$ ind $\mathcal{A}$.

J. A. de la Peña

Non-negative integral quadratic forms

A quadratic form $q : \mathbb{Z}^n \to \mathbb{Z}$ of the shape $q(v) = \sum_{i=1}^n q_i v(i)^2 + \sum_{i<j} q_{ij} v(i) v(j)$ is said to be unit (resp. semiunit) if $q_i = 1$ (resp. $q_i \leq 1$).

In representation theory of algebras there are important examples of unit forms associated to algebras. Let $A = kQ/I$ be a finite dimensional k-algebra where Q is a quiver without oriented cycles and $K_0(A) = \mathbb{Z}^n$ the Grothendieck group. The Euler form $\chi_A : \mathbb{Z}^n \to \mathbb{Z}$ is the quadratic form associated to the bilinear form $\langle [X], [Y] \rangle = \sum_{i=0}^{\infty} (-1)^i \dim_k \mathrm{Ext}_A^i(X, Y)$. Then χ_A is a unit form. Important instances are the following: if A is tame concealed, then χ_A is non-negative and corank $\chi_A = 1$; if A is a tubular algebra, then χ_A is non-negative and corank $\chi_A = 2$. Moreover in these cases corank χ_A = corank$^+ \chi_A$, where corank$^+ \chi_A$ is the maximal number of linearly independent positive vectors in rad χ_A.

We study non-negative semi-unit forms $q : \mathbb{Z}^n \to \mathbb{Z}$ with the property that corank q = corank$^+ q = 2$. Using the method of deflations we classify these forms and show the structure of rad$^+ q = \{v \in \text{rad } q : v \geq 0\}$ as an integral lattice. We show that for a general non-negative semi-unit form q which is connected (that is, the bigraph of q is connected), there is a unique Dynkin diagram Δ and an invertible $\mathbb{Z}$-transformation $T : \mathbb{Z}^n \to \mathbb{Z}^n$ such that $qT = q_0^s \oplus q_\Delta$, where q_0 is the zero form in one variable, s = corank q and $\overline{q} = q_\Delta$ is the positive form associated to Δ. As a consequence we show the following results.

Theorem (joint with Barot): *Let A be a strongly simply connected algebra. Then A is derived equivalent to a tubular algebra with more than 6 vertices iff χ_A is non-negative with* corank $\chi_A = 2$ *and $\overline{\chi_A}$ is of type $\mathbb{E}_p$, $p = 6, 7, 8$.*

Theorem: *Let A be a strongly simply connected algebra. Assume χ_A is non-negative and $\overline{\chi_A}$ is of type $\mathbb{E}_p$ $(p = 6, 7, 8)$, then A is a tame algebra of polynomial growth (and moreover* corank $\chi_A \leq 2$*).*

T. PIRASHVILI

Leibniz algebras and Leibniz representations

A Leibniz algebra is a vector space $\mathfrak{g}$ equipped with a linear map

$$[,] : \mathfrak{g} \otimes \mathfrak{g} \to \mathfrak{g}$$

satisfying the equation

$$[x, [y, z]] = [[x, y], z] - [[x, z], y].$$

Clearly any Lie algebra is a Leibniz algebra. A Leibniz representation of a Leibniz algebra $\mathfrak{g}$ is a vector space M equipped with two actions

$$[,] : \mathfrak{g} \otimes M \to M, \quad [,] : M \otimes \mathfrak{g} \to M$$

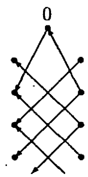
for which the following holds

$$
\begin{aligned}
[m,[x,y]] &= [[m,x],y] - [[m,y],x] \\
[x,[m,y]] &= [[x,m],y] - [[x,y],m] \\
[x,[y,m]] &= [[x,y],m] - [[x,m],y].
\end{aligned}
$$

Starting with a Lie algebra $\mathfrak{g}$ and a Lie algebra representation M, one can consider two Leibniz representations M^s and M^a, for which

$$[x,m] = -[m,x] \quad \text{and} \quad [x,m] = 0,$$

respectively.
Now assume $\mathfrak{g}$ is a classical semi-simple Lie algebra over a field of characteristic zero. And let $\mathbb{L}(\mathfrak{g})$ denote the category of finite dimensional Leibniz representations of $\mathfrak{g}$. We prove that $\operatorname{gl\,dim} \mathbb{L}(\mathfrak{g}) = 2$. Moreover one can describe the Gabriel quiver for $\mathbb{L}(\mathfrak{g})$, which shows that it is tame only for $\mathfrak{g} = \mathfrak{sl}(2)$ (here $\mathfrak{g}$ is now a simple Lie algebra). The corresponding quiver looks as follows



with one relation at 0:
the product of the corresponding edges is zero.

M. Reineke

Multiplicative properties of dual canonical bases of quantum groups

Let $\mathcal{U}$ be the quantized enveloping algebra (over $\mathbb{Q}(v)$) of type A, $\mathcal{U}^+$ its positive part, $\mathcal{B} \subset \mathcal{U}^+$ Lusztig's canonical basis, $\mathcal{B}^*$ the dual of $\mathcal{B}$ with respect to the standard inner product of $\mathcal{U}^+$.
Berenstein and Zelevinsky studied multiplicative properties of $\mathcal{B}^*$ centering around the following notions:
b_1^*, b_2^* in $\mathcal{B}^*$ quasicommute if $b_2^* b_1^* = v^D b_1^* b_2^*$, and they are multiplicative if $b_1^* b_2^* = v^D b^*$ for some $b^* \in \mathcal{B}^*$, $D \in \mathbb{Z}$.
They conjectured: if two elements of $\mathcal{B}^*$ quasicommute, they are multiplicative; there exists a (conjecturally finite) subset $\mathcal{P} \subset \mathcal{B}^*$ such that all $b^* \in \mathcal{B}^*$ equal v^D times a quasicommuting product of elements of $\mathcal{P}$.
(This is true for type A_2, A_3, where $\mathcal{P}$ consists of so-called quantum minors.)
The topic of the talk was to present the following results:

- if two elements of $\mathcal{B}^*$ quasicommute, where one of them is a 'small' quantum minor, then they are multiplicative.

- One 'chamber' of $\mathcal{B}^*$ (given by linear inequalities if $\mathcal{B}^*$ is parametrized appropriately) consists of products of quantum minors.

Moreover, $\mathcal{P} \neq \{\text{quantum minors}\}$ even for type A_4.
Our main tool is Ringel's Hall algebra approach; in particular we use

- the connection between $\mathcal{B}$ and degenerations of representations of quivers observed by Lusztig,

- the description of the coloured graph structure of $\mathcal{B}$ in terms of representations of quivers (M.R.).

Moreover, Hall algebras seem to give a (partial) explanation why $\mathcal{B}^*$ may be better suited for studying multiplicative properties than $\mathcal{B}$.

J. H. SCHRÖER

Hammocks for string algebras

Let k be an algebraically closed field, A a finite-dimensional k-algebra and rad_A the radical of A-mod (= category of finite-dimensional A-modules). Let I be an ideal in A-mod and n a finite ordinal. Define $I^n = I \cdot \ldots \cdot I$. For a limit number β let $I^\beta = \bigcap_{\alpha<\beta} I^\alpha$. If α is any infinite ordinal (thus $\alpha = \beta + n$ where β is a limit number and n a finite ordinal) then define $I^\alpha = (I^\beta)^{n+1}$. Set $\mathrm{nil}(A) = \infty$ if $\bigcap_\alpha \mathrm{rad}\,{}^\alpha_A \neq 0$. Otherwise, let $\mathrm{nil}(A) = \min\{\alpha \mid \mathrm{rad}\,{}^\alpha_A = 0\}$. Denote the first limit number by ω, the second by $\omega \cdot 2$, etc.. The smallest limit number which is not of the form ωn is denoted by ω^2.

Theorem: *Let A be a string algebra (definition see [BR]). Then the following are equivalent:*

1. $\mathrm{nil}(A) < \infty$,

2. $\mathrm{nil}(A) < \omega^2$,

3. *A is domestic.*

Theorem: *Let $(1,1) \neq (n,d) \in \mathbb{N} \times \mathbb{N}$. Then one can construct an algebra $A_{\omega n+d}$ such that $\mathrm{nil}(A_{\omega n+d}) = \omega n + d$.*

Remarks:

1. Examples of this type were known before only for $\mathrm{nil}(A) \leq \omega + 8$.

2. nil(A) is not a limit number.

3. Our proofs use a generalization of the concept of hammocks as introduced by S. Brenner in 1984.

[BR] M. C. R. Butler, C. M. Ringel: *Auslander-Reiten sequences with few middle terms and applications to string algebras.* Comm. Alg. 15(1987), 145-179.

L. UNGER

The genus of the graph of tilting modules (after a work of Michael Ungruhe)

Let Λ be a finite dimensional algebra over a field k, and let modΛ be the category of finite dimensional left Λ-modules. A Λ-module T is called a tilting module, if its projective dimension is finite, if $\mathrm{Ext}^i_\Lambda(T,T) = 0$ for all $i > 0$ and if there is an exact sequence $0 \to {}_\Lambda\Lambda \to T^1 \to \ldots \to T^r \to 0$, where the modules T^i are direct sums of direct summands of T.
Let $\mathcal{E}$ denote the set of tilting modules over Λ, up to isomorphism. We associate with $\mathcal{E}$ a graph G as follows: the vertices of G are the elements of $\mathcal{E}$, and there is an edge T—T' if T and T' differ by one indecomposable direct summand, and if $\mathrm{Ext}^1_\Lambda(T,T') \neq 0$ or $\mathrm{Ext}^1_\Lambda(T',T) \neq 0$.
Examples show that G, the graph of tilting modules, may be very complicated. A measure for the complexity of a graph is its genus.

Definition: *A graph G has genus $\gamma(G) = n$, if n is the minimal genus of a surface where we can embed G without crossings.*

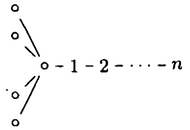
Determining the genus of a graph is in general a very difficult problem. The following result shows, that the feeling, that the graph of tilting modules may be complicated, is correct.

Theorem (Ungruhe): *For all $n \in \mathbb{N}$ there is an algebra Λ_n such that the genus of the corresponding graph of tilting modules is n.*

The proof is constructive. If Λ_n denotes the path algebra of the quiver

$$\begin{tikzcd}
& \circ \arrow[dl, "\alpha"'] & & 2 \arrow[dl, "\nu_1"] & 3 \arrow[l, "\nu_2"'] & 4 \arrow[l, "\nu_3"'] & \ldots \arrow[l] & n-1 \arrow[l] & n \arrow[l, "\nu_{n-1}"'] \\
\circ & & 1 \arrow[ul, "\beta"'] \arrow[dl, "\delta"] & & & & & & \\
& \circ \arrow[ul, "\gamma"] & & \circ \arrow[ul, "\varepsilon"'] & & & & &
\end{tikzcd}$$

bound by the relations $\alpha\beta = \gamma\delta$, $0 = \beta\varepsilon = \delta\varepsilon = \beta\nu_1 = \delta\nu_1$ and $\nu_{i-1}\nu_i = 0$ for $2 \leq i \leq n-1$, then the corresponding graph of tilting modules has genus n.
Λ_n is representation finite, directed and has orbit graph



JIE XIAO

Root vectors arising from Auslander-Reiten quivers

According to the canonical isomorphism between the Ringel-Hall algebra $\mathcal{H}(\Lambda)$ and the positive part U^+ of the Drinfeld-Jimbo quantum group $U_q(g)$, where the finite dimensional hereditary algebra Λ and the semisimple Lie algebra $\mathfrak{g}$ enjoy a common Dynkin diagram. We get an algorithm to decompose the root vectors into the combinations of monomials of the canonical generators E_i in the quantum group only depending on the structure of the Auslander-Reiten quiver of Λ. We state our main results as follows:

Proposition: *Let V_λ be an indecomposable projective Λ-module, V_α be the simple top of V_λ. Let* rad $V_\lambda = m_1 V_{\beta_1} \oplus \ldots \oplus m_n V_{\beta_n}$*, where V_{β_l}, $1 \le l \le n$, are orthogonal indecomposable projective Λ-modules. Then $m_l = \frac{-2(\alpha,\beta_l)}{(\beta_l,\beta_l)}$ for $1 \le l \le n$, and we have in the Hall algebra $\mathcal{H}(\Lambda)$:*

$$u_\lambda = \sum_{i_1,\ldots,i_n=0}^{m_1,\ldots,m_n} (-1)^{i_1+\ldots+i_n} (v^{\varepsilon(\beta_1)})^{m_1-i_1} \ldots (v^{\varepsilon(\beta_n)})^{m_n-i_n} \times$$

$$\times u_{\beta_1}^{(i_1)} \ldots u_{\beta_n}^{(i_n)} u_\alpha u_{\beta_n}^{(m_n-i_n)} \ldots u_{\beta_1}^{(m_1-i_1)}.$$

Proposition: *Let $0 \to V_\alpha \to m_1 V_{\beta_1} \oplus \ldots \oplus m_n V_{\beta_n} \to V_{\tau^{-1}\alpha} \to 0$ be an Auslander-Reiten sequence and $(V_{\beta_1}, \ldots, V_{\beta_n})$ be orthogonal exceptional modules. Then in the Hall algebra $\mathcal{H}(\Lambda)$, we have*

$u_{\tau^{-1}\alpha} =$

$$v^{\varepsilon(\alpha)} \sum_{r_1,\ldots,r_n=0}^{m_1,\ldots,m_n} (-1)^{r_1+\ldots+r_n} (v^{-\varepsilon(\beta_1)})^{(m_1-r_1)(m_1-1)} \ldots (v^{-\varepsilon(\beta_n)})^{(m_n-r_n)(m_n-1)} \times$$

$$\times u_{\beta_1}^{(r_1)} \ldots u_{\beta_n}^{(r_n)} \delta_\alpha (u_{\beta_1}^{(m_1-r_1)} \ldots u_{\beta_n}^{(m_n-r_n)}),$$

where δ_α is the derivation corresponding to V_α.

G. ZWARA

Degenerations of modules over finite dimensional algebras

Let $\mathrm{mod}_A(d)$ be an affine variety of d-dimensional A-modules. The general linear group $GL_d(k)$ acts on $\mathrm{mod}_A(d)$ by conjugation and orbits correspond to isomorphism classes of d-dimensional A-modules. Let $M, N \in \mathrm{mod}_A(d)$. One says that M degenerates to N ($M \leq_{deg} N$) iff $N \in \overline{GL_d(k) \cdot M}$. This defines a partial order on the set $\mathrm{mod}_A(d)/\simeq$.
There are known other partial orders $\leq_{ext}$ and $\leq$ defined in terms of extensions and homomorphisms as follows:

$$M \leq_{ext} N :\iff \begin{array}{l} \text{there exist exact sequences} \\ 0 \to U_1 \to M \to V_1 \to 0 \\ 0 \to U_2 \to U_1 \oplus V_1 \to V_2 \to 0 \\ \dots \\ 0 \to U_s \to U_{s-1} \oplus V_{s-1} \to V_s \to 0 \end{array}$$

with $N = U_s \oplus V_s$.

$$M \leq N :\iff \dim_k \mathrm{Hom}_A(M, X) \leq \dim_k \mathrm{Hom}_A(N, X) \quad \text{for all } A\text{-modules } X.$$

Then the following implications hold

$$M \leq_{ext} N \Rightarrow M \leq_{deg} N \Rightarrow M \leq N.$$

But even for very simple representation-finite algebras there is a proper degeneration $M <_{deg} N$ with indecomposable module N (so $M \not\leq_{ext} N$).
First aim of the talk is to introduce a new partial order

$$M \leq_R N :\iff \begin{array}{l} \text{there is an exact sequence} \\ 0 \to N \to M \oplus Z \to Z \to 0 \quad \text{for some } A\text{-module } Z; \end{array}$$

and to show that it is a "better" order than the order $\leq_{ext}$.
Second aim of the talk was to present some results showing when the order $\leq_{deg}$ and other orders coincide.

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