Kazhdan-Lusztig polynomials for signatures

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Outline

Character formulas

Hermitian forms

Character formulas for invariant forms

Computing easy Hermitian KL polynomials

Unitarity algorithm

Categories of representations

Recall from lecture of Jeff Adams Verma modules. . .

$B \subset G$ Borel subgp of cplx red alg gp,

W Weyl grp $\leftrightarrow$ hwt mods, triv infl char

$M(w)$ Verma, hwt $-w\rho - \rho$, $L(w)$ irr quot

and, in a parallel way, Harish-Chandra modules. . .

$K \subset G$ complexified maximal compact

X parameter set for irr $(\mathfrak{g}, K)$-mods

$I(x)$ std $(\mathfrak{g}, K)$-mod, param $x \in X$ $J(x)$ irr quot

Character formulas

Can decompose Verma module into irreducibles

$$M(w) = \sum_{v \le w} m_{v,w} L(v) \qquad (m_{v,w} \in \mathbb{N})$$

or write a formal character for an irreducible

$$L(w) = \sum_{v \le w} M_{v,w} M(v) \qquad (M_{v,w} \in \mathbb{Z})$$

Can decompose standard HC module into irreducibles

$$I(x) = \sum_{y \le x} m_{y,x} J(y) \qquad (m_{y,x} \in \mathbb{N})$$

or write a formal character for an irreducible

$$J(x) = \sum_{y \le x} M_{y,x} I(y) \qquad (M_{y,x} \in \mathbb{Z})$$

Matrices m and M upper triang, ones on diag, mutual inverses. Entries are KL polynomials eval at 1.

Forms and dual spaces

V cplx vec space (or alg rep of K, or $(\mathfrak{g}, K)$-mod).

Hermitian dual of V

$$V^h = \{\xi : V \to \mathbb{C} \text{ additive} \mid \xi(zv) = \overline{z}\xi(v)\}$$

(If V is K-rep, also require ξ is K-finite.)

Sesquilinear pairings between V and W

$$\mathrm{Sesq}(V, W) = \{\langle , \rangle : V \times W \to \mathbb{C}, \text{lin in } V, \text{conj-lin in } W\}$$

$$\mathrm{Sesq}(V, W) \simeq \mathrm{Hom}(V, W^h), \quad \langle v, w\rangle_T = (Tv)(w).$$

Cplx conj of forms is (conj linear) isom

$$\mathrm{Sesq}(V, W) \simeq \mathrm{Sesq}(W, V).$$

Corr (conj linear) isom is Hermitian transpose

$$\mathrm{Hom}(V, W^h) \simeq \mathrm{Hom}(W, V^h), \quad (T^h w)(v) = (Tv)(w).$$

Sesq form $\langle , \rangle_T$ Hermitian if

$$\langle v, v'\rangle_T = \overline{\langle v', v\rangle_T} \Leftrightarrow T^h = T.$$

Defining a rep on V^h

Suppose V is a $(\mathfrak{g}, K)$-module. Write π for repn map.

Want to construct

$$\text{cplx linear } (\pi, V) \rightsquigarrow \text{cplx linear } (\pi^h, V^h)$$

using Hermitian transpose map of operators. REQUIRES twisting by conj linear aut of $\mathfrak{g}$.

Assume

$$\sigma \colon G \to G \quad \text{antiholom aut}, \quad \sigma(K) = K.$$

Define $(\mathfrak{g}, K)$-module $\pi^{h,\sigma}$ on V^h,

$$\pi^{h,\sigma}(X) \cdot \xi = [\pi(-\sigma(X))]^h \cdot \xi \qquad (X \in \mathfrak{g}, \xi \in V^h).$$

$$\pi^{h,\sigma}(k) \cdot \xi = [\pi(\sigma(k)^{-1})]^h \cdot \xi \qquad (k \in K, \xi \in V^h).$$

Traditionally use

$$\sigma_0 = \text{ real form with complexified maximal compact } K.$$

We need also

$$\sigma_c = \text{ compact real form of } G \text{ preserving } K.$$

Invariant Hermitian forms

$V = (\mathfrak{g}, K)$-module, σ antihol aut of G preserving K.

A σ-invariant sesq form on V is sesq pairing $\langle , \rangle$ on V with

$$\langle X \cdot v, w\rangle = \langle v, -\sigma(X) \cdot w\rangle, \qquad \langle k \cdot v, w\rangle = \langle v, -\sigma(k^{-1}) \cdot w\rangle$$

$(X \in \mathfrak{g},\ k \in K,\ v, w \in V)$.

Proposition

A σ-invt sesq form on V is the same thing as an intertwining operator T from V to $V^{h,\sigma}$:

$$\langle v, w\rangle_T = (Tv)(w).$$

Form is Hermitian iff $T^h = T$.

Assume V is irreducible. Then invt sesq form exists iff $V \simeq V^{h,\sigma}$. A σ-invt Herm form is unique up to real scalar; non-deg whenever nonzero.

Invariant forms on standard reps

Recall multiplicity formula

$$I(x) = \sum_{y \leq x} m_{y,x} J(y) \qquad (m_{y,x} \in \mathbb{N})$$

for standard $(\mathfrak{g}), K)$-mod $I(x)$.

Want parallel formulas for σ-invt Hermitian forms.
Need forms on standard modules.

Form on irr $J(x) \overrightarrow{\text{deformation}}$ Jantzen filt $I_n(x)$ on std,
nondeg forms $\langle , \rangle_n$ on I_n/I_{n+1}.
Details (proved by Beilinson-Bernstein):

$$I(x) = I_0 \supset I_1 \supset I_2 \supset \cdots, \qquad I_0/I_1 = J(x)$$
$$I_n/I_{n+1} \text{ completely reducible}$$

$$[J(y) \colon I_n/I_{n+1}] = \text{coeff of } q^{(\ell(x)-\ell(y)-n)/2} \text{ in KL poly } Q_{y,x}$$

Hence $\langle , \rangle_{I(x)} = \sum_n \langle , \rangle_n$, nondeg form on gr $I(x)$.
Restricts to original form on irr $J(x)$.

virtual Hermitian forms

$$\mathbb{Z} = \text{Groth group of vec spaces.}$$

These are mults of irr reps in virtual reps.

$$\mathbb{Z}[X] = \text{Groth grp of fin lgth reps.}$$

For invariant forms...

$$\mathbb{W} = \mathbb{Z} \oplus \mathbb{Z} = \text{Groth grp of fin diml forms.}$$

Ring structure

$$(p, q)(p', q') = (pp' + qq', pq' + q'p).$$

Mult of irr-with-forms in virtual-with-forms is in $\mathbb{W}$:

$$\mathbb{W}[X] \approx \text{Groth grp of fin lgth reps with invt forms.}$$

Two problems: invt form $\langle , \rangle_J$ may not exist for irr J; and $\langle , \rangle_J$ may not be preferable to $-\langle , \rangle_J$.

Hermitian KL polynomials: multiplicities

Fix σ-invt Hermitian form $\langle,\rangle_{J(x)}$ on each irr admitting one; recall Jantzen form $\langle,\rangle_n$ on $I(x)_n/I(x)_{n+1}$.

MODULO problem of irrs with no invt form, write

$$(I_n/I_{n-1}, \langle,\rangle_n) = \sum_{y \le x} w_{y,x}(n)(J(y), \langle,\rangle_{J(y)}),$$

coeffs $w(n) = (p(n), q(n)) \in \mathbb{W}$; summand means

$$p(n)(J(y), \langle,\rangle_{J(y)}) \oplus q(n)(J(y), -\langle,\rangle_{J(y)})$$

Define Hermitian KL polynomials

$$Q^{\sigma}_{y,x} = \sum_n w_{y,x}(n) q^{(l(x)-l(y)-n)/2} \in \mathbb{W}[q]$$

Eval in $\mathbb{W}$ at $q = 1 \leftrightarrow$ form $\langle,\rangle_{I(x)}$ on std.

Reduction to $\mathbb{Z}[q]$ by $\mathbb{W} \to \mathbb{Z} \leftrightarrow$ KL poly $Q_{x,y}$.

Hermitian KL polynomials: characters

Matrix $Q^\sigma_{y,x}$ is upper tri, 1s on diag: INVERTIBLE.

$$P^\sigma_{x,y} \overset{\text{def}}{=} (-1)^{l(x)-l(y)}((x,y) \text{ entry of inverse}) \in \mathbb{W}[q].$$

Definition of $Q_{x,y}$ says

$$(\text{gr } I(x), \langle, \rangle_{I(x)}) = \sum_{y \leq x} Q_{x,y}(1)(J(y), \langle, \rangle_{J(y)});$$

inverting this gives

$$(J(x), \langle, \rangle_{J(x)}) = \sum_{y \leq x} (-1)^{l(x)-l(y)} P^\sigma_{x,y}(1)(\text{gr } I(y), \langle, \rangle_{I(y)})$$

Next question: how do you compute $P^\sigma_{x,y}$?

Herm KL polys for σ_c

σ_c = cplx conj for cpt form of G, $\sigma_c(K) = K$.

Plan: study σ_c-invt forms, relate to σ_0-invt forms.

Proposition

Suppose $J(x)$ irr $(\mathfrak{g}, K)$-module, real infl char. Then $J(x)$ has σ_c-invt Herm form $\langle , \rangle^c_{J(x)}$, characterized by

$\langle , \rangle^c_{J(x)}$ is pos def on the lowest K-types of $J(x)$.

Proposition $\Longrightarrow$ Herm KL polys $Q^{\sigma_c}_{x,y}$, $P^{\sigma_c}_{x,y}$ well-def.

These have coeffs in $\mathbb{W} = \mathbb{Z} \oplus s\mathbb{Z}$;

here $s = (0, 1) \leftrightsquigarrow$ one-diml neg def form.

Conjecture: $Q^{\sigma_c}_{x,y}(q) = Q_{x,y}(qs)$, $\quad P^{\sigma_c}_{x,y}(q) = P_{x,y}(qs)$.

Equiv: if $J(y)$ appears at level n of Jantzen filt of $I(x)$, then Jantzen form is $(-1)^{(l(x)-l(y)-n)/2}$ times $\langle , \rangle_{J(y)}$.

Deforming to $\nu = 0$

Now have a computable (conjectural) formula

$$(J(x), \langle , \rangle^c_{J(x)}) = \sum_{y \le x} (-1)^{l(x)-l(y)} P_{x,y}(s) (\text{gr } I(y), \langle , \rangle^c_{I(y)})$$

for σ^c-invt forms in terms of forms on stds, same inf char.

Std rep $I = I(\nu)$ deps on cont param ν. Put $I(t) = I(t\nu),\ t \ge 0$.

If std rep $I = I(\nu)$ admits σ-invt Herm form $\langle , \rangle_I$ (on assoc graded for Jantzen filt), so does $I(t)$ (all $t \ge 0$).

(Signature for $I(t)$) $=$ (signature on $I(t + \epsilon)$), all $\epsilon \ge 0$ suff small.

Sig on $I(t)$ differs from $I(t - \epsilon)$ on odd levels of Jantzen filt:

$$\langle , \rangle_{\text{gr } I(t-\epsilon)} = \langle , \rangle_{\text{gr } I(t)} + (s-1) \sum_m \langle , \rangle_{I(t)_{2m+1}/I(t)_{2m}}.$$

Each summand after first on right is known comb of stds, all with cont param strictly smaller than $t\nu$. ITERATE...

$$\langle , \rangle^c_J = \sum_{I'(0) \text{ std at } \nu' = 0} v_{J,I'} \langle , \rangle^c_{I'(0)} \qquad (v_{J,I'} \in \mathbb{W}).$$

From σ_c to σ_0

Cplx conjs σ_c (compact form) and σ_0 (our real form) differ by Cartan involution θ: $\sigma_0 = \theta \circ \sigma_c$.

Irr $(\mathfrak{g}, K)$-mod $J \rightsquigarrow J^\theta$ (same space, rep twisted by θ).

Proposition

J admits σ-invt Herm form if and only if $J^\theta \simeq J$. If $T_0 \colon J \xrightarrow{\sim} J^\theta$, and $T_0^2 = \mathrm{Id}$, then

$$\langle v, w \rangle_J^0 = \langle v, T_0 w \rangle_J^c.$$

$T \colon J \xrightarrow{\sim} J^\theta \Rightarrow T^2 = z \in \mathbb{C} \Rightarrow T_0 = z^{-1/2} T \rightsquigarrow \sigma$-invt Herm form.

To convert formulas for σ_c invt forms $\rightsquigarrow$ formulas for σ_0-invt forms need intertwining ops $T_J \colon J \xrightarrow{\sim} J^\theta$, consistent with decomp of std reps.

Equal rank case

rk K = rk $G \Rightarrow$ Cartan inv inner: $\exists \tau \in K$, $\mathrm{Ad}(\tau) = \theta$.

$\theta^2 = 1 \Rightarrow \tau^2 = \zeta \in Z(G) \cap K$.

Study reps π with $\pi(\zeta) = z$. Fix sq root $z^{1/2}$.

If ζ acts by z on V, and $\langle , \rangle_V^c$ is σ_c-invt form, then
$\langle v, w \rangle_V^0 \overset{\text{def}}{=} \langle v, z^{-1/2}\tau \cdot w \rangle_V^c$ is σ_0-invt form.

$$\langle , \rangle_J^c = \sum_{I'(0) \text{ std at } \nu' = 0} v_{J,I'} \langle , \rangle_{I'(0)}^c \qquad (v_{J,I'} \in \mathbb{W}).$$

translates to

$$\langle , \rangle_J^0 = \sum_{I'(0) \text{ std at } \nu' = 0} v_{J,I'} \langle , \rangle_{I'(0)}^0 \qquad (v_{J,I'} \in \mathbb{W}).$$

I' has LKT $\mu' \Rightarrow \langle , \rangle_{I'(0)}^0$ definite, sign $z^{-1/2}\mu(I')(t)$.

$\langle , \rangle_J^0$ pos def $\Leftrightarrow$ each summand on right pos def.

Computability of $v_{J,I'}$ needs conj about $P_{x,y}^{\sigma_c}$.

General case

Fix "dist inv" δ_0 of G in inner class of θ

Define extended group $G^\Gamma = G \rtimes \{1, \delta_0\}$.

Can arrange $\theta = \mathrm{Ad}(\tau\delta_0)$, some $\tau \in K$.

Define $K^\Gamma = \mathrm{Cent}_{G^\Gamma}(\tau\delta_0) = K \rtimes \{1, \delta_0\}$.

Study $(\mathfrak{g}, K^\Gamma)$-mods $\leftrightsquigarrow$ $(\mathfrak{g}, K)$-mods V with $D_0 \colon V \xrightarrow{\sim} V^{\delta_0}$, $D_0^2 = \mathrm{Id}$.

Beilinson-Bernstein localization: $(\mathfrak{g}, K^\Gamma)$-mods $\leftrightsquigarrow$ action of δ_0 on K-eqvt perverse sheaves on G/B.

Should be computable by mild extension of Kazhdan-Lusztig ideas. Not done yet!

Now translate σ_c-invt forms to σ_0 invt forms

$$\langle v, w\rangle_V^0 \stackrel{\text{def}}{=} \langle v, z^{-1/2}\tau\delta_0 \cdot w\rangle_V^c$$

on $(\mathfrak{g}, K^\Gamma)$-mods as in equal rank case.