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Smooth Duals of Inner Forms of $GL_n$ and $SL_n$

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Abstract. Let $F$ be a non-archimedean local field. We prove that every Bernstein component in the smooth dual of each inner form of the general linear group $GL_n(F)$ is canonically in bijection with the extended quotient for the action, given by Bernstein, of a finite group on a complex torus. For inner forms of $SL_n(F)$ we prove that each Bernstein component is canonically in bijection with the associated twisted extended quotient. In both cases, the bijections satisfy naturality properties with respect to the tempered dual, parabolic induction, central character, and the local Langlands correspondence.

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Introduction

Let $X$ be a complex affine variety. Denote the coordinate algebra of $X$ by $\mathcal{O}(X)$. The Hilbert Nullstellensatz asserts that $X \mapsto \mathcal{O}(X)$ is an equivalence of categories

$$
\left( \begin{array}{c}
\text{unital commutative finitely} \\
\text{generated nilpotent-free} \\
\mathbb{C}\text{-algebras}
\end{array} \right) \sim
\left( \begin{array}{c}
\text{affine complex} \\
\text{algebraic varieties}
\end{array} \right)^{\text{op}}
$$

$$\mathcal{O}(X) \mapsto X$$

where $\text{op}$ denotes the opposite category.

A finite type algebra is a $\mathbb{C}$-algebra $A$ with a given structure as an $\mathcal{O}(X)$-module such that $A$ is finitely generated as an $\mathcal{O}(X)$-module. A compatibility is required between the algebra structure of $A$ and the given action of $\mathcal{O}(X)$ on $A$. However, $A$ is not required to be unital. Due to the above equivalence of categories, any finite type algebra can be viewed as a slightly non-commutative affine algebraic variety. This will be the point of view of the paper.

Following this point of view, each Bernstein component in the smooth dual of any reductive $p$-adic group $G$ is a non-commutative affine algebraic variety. In a series of papers we have examined the question “What is the geometric structure of any given Bernstein component?” Our proposed answer to this (which has been verified for all the classical split reductive $p$-adic groups) is based on the notion of extended quotient. In the present paper we show that for inner forms of $\text{SL}_n$ it is necessary to use a twisted extended quotient (see the Appendix). The twisting is given by a family of 2-cocycles.

Let $F$ be a non-archimedean local field. Let $D$ be a central simple $F$-algebra with $\dim_F(D) = d^2$. Then $\text{GL}_m(D)$ is an inner form of $\text{GL}_{md}(F)$ and the derived group $\text{GL}_m(D)_{\text{der}}$ is an inner form of $\text{SL}_{md}(F)$. The main result of this paper is

**Theorem 1.** Let $G$ be an inner form of $\text{GL}_n(F)$ or $\text{SL}_n(F)$. Let $\text{Irr}^s(G)$ be any Bernstein component in the smooth dual of $G$. Let $T_s//W_s$ and $(T_s//W_s)_{\natural}$ be the appropriate extended quotient and twisted extended quotient. Then:

1. If $G$ is an inner form of $\text{GL}_n(F)$ there exists a bijection

   $$\text{Irr}^s(G) \leftrightarrow T_s//W_s.$$

2. If $G$ is an inner form of $\text{SL}_n(F)$ there exists a family of 2-cocycles $\natural$ and a bijection

   $$\text{Irr}^s(G) \leftrightarrow (T_s//W_s)_{\natural}.$$

3. In either case, the bijection satisfies naturality properties with respect to the tempered dual, parabolic induction, and central character.
We remark that
• $T_s/W_s$ is the non-commutative affine variety whose coordinate algebra is the crossed product algebra $O(T_s) \rtimes W_s$ where $T_s, W_s$ are respectively the complex torus and finite group acting on the torus which Bernstein assigns to $\Irr^s(G)$. The crossed product algebra $O(T_s) \rtimes W_s$ is a finite $O(T_s/W_s)$-algebra.

• $(T_s//W_s)_{\natural}$ is the non-commutative affine variety whose coordinate algebra is the twisted crossed product algebra $O(T_s) \rtimes_{\natural} W_s$. The twisted crossed product algebra $O(T_s) \rtimes_{\natural} W_s$ is a finite $O(T_s/W_s)$-algebra. Example 7.7 shows that for inner forms of $\text{SL}_5$ there are Bernstein components where the twisting is non-trivial.

We observe that it is somewhat remarkable that many of the subtleties of the representation theory of $\text{GL}_m(D)$, $\text{SL}_m(D)$ are captured by the algebras

$$O(T_s) \rtimes W_s \quad O(T_s) \rtimes_{\natural} W_s$$

and their geometric realizations $T_s//W_s, (T_s//W_s)_{\natural}$.

The proof of Theorem 1 uses a weakening of Morita equivalence called stratified equivalence, see [ABPS7]. The proof is achieved by combining the theory of types with an analysis of the structure of Hecke algebras.

Outline of the proof.
The proof of Theorem 1 for $\text{GL}_m(D)$ consists of two steps.

• Step 1: For each point $s$ in the Bernstein spectrum $\mathfrak{B}(\text{GL}_m(D))$, the ideal $\mathcal{H}(G)^s$ in the Hecke algebra $\mathcal{H}(\text{GL}_m(D))$ is Morita equivalent to an affine Hecke algebra, see [ABPS4].

• Step 2: Using the Lusztig asymptotic algebra, a stratified equivalence is constructed between this affine Hecke algebra and the associated crossed product algebra. The irreducible representations of the crossed product algebra (in a canonical way) are the required extended quotient.

The proof of Theorem 1 for $\text{SL}_m(D)$ is achieved by introducing an intermediate group $\text{SL}_m(D) \cdot Z(\text{GL}_m(D))$:

$$\text{SL}_m(D) \subset \text{SL}_m(D) \cdot Z(\text{GL}_m(D)) \subset \text{GL}_m(D),$$

where $Z(\text{GL}_m(D))$ is the center of $\text{GL}_m(D)$. It consists in two analogous steps.

• Step 1: For each point $s$ in the Bernstein spectrum $\mathfrak{B}(\text{SL}_m(D))$, the ideal $\mathcal{H}(\text{SL}_m(D))^s$ in the Hecke algebra $\mathcal{H}(\text{SL}_m(D))$ is Morita equivalent to a twisted affine Hecke algebra.

• Step 2: Using the Lusztig asymptotic algebra, a stratified equivalence is constructed between this twisted affine Hecke algebra and the associated twisted crossed product algebra. The irreducible representations of the twisted crossed product algebra (in a canonical way) are the required twisted extended quotient.
In Section 7, we prove that the bijections of Theorem 1 are compatible with the local Langlands correspondence, in the sense below. Let $G$ be an inner form of $\text{GL}_n(F)$ or $\text{SL}_n(F)$, and let $\hat{G}$ denote $\text{GL}_n(\mathbb{C})$ or $\text{PGL}_n(\mathbb{C})$, respectively. The set of $\hat{G}$-conjugacy classes of Langlands parameters (resp. enhanced Langlands parameters) for $G$ is denoted by $\Phi(G)$ (resp. $\Phi_e(G)$). We may identify $\Phi_e(G)$ with $\Phi(G)$ when $G$ is an inner form of $\text{GL}_n(F)$.

Let $L$ be a set of representatives for the conjugacy classes of Levi subgroups of $G$. For $L$ in $\mathcal{L}$, we denote by $\text{Irr}_{\text{cusp}}(L)$ the set of isomorphism classes of supercuspidal irreducible representations of $L$ and we let $\Phi(L)_{\text{cusp}}$ be its image in $\Phi_e(L)$. The group $W(G, L) = N_G(L)/L$, quotient by $L$ of the normalizer of $L$ in $G$, acts naturally on both sets. Thus we may consider the extended quotients $\text{Irr}_{\text{cusp}}(L)/W(G, L)$ and $\Phi(L)_{\text{cusp}}/W(G, L)$, as well as their twisted versions. It follows directly from the definitions that

$$\left(\text{Irr}_{\text{cusp}}(L)/W(G, L)\right)_\sharp = \bigsqcup_s (T_s//W_s)_\sharp,$$

where the disjoint union runs over all $s \in \mathfrak{S}(G)$ coming from supercuspidal $L$-representations.

**Theorem 2.** The following statements hold:

- If $G = \text{GL}_m(D)$ there exists a canonical, bijective, commutative diagram

$$\begin{array}{ccc}
\text{Irr}(G) & \xrightarrow{\sim} & \Phi(G) \\
\downarrow & & \downarrow \\
\bigsqcup_{L \in \mathcal{L}} \text{Irr}_{\text{cusp}}(L)/W(G, L) & \xrightarrow{\sim} & \bigsqcup_{L \in \mathcal{L}} \Phi(L)_{\text{cusp}}/W(G, L).
\end{array}$$

- If $G = \text{SL}_m(D)$ there exists a family of 2-cocycles $\sharp$ and a (canonical up to permutations within $L$-packets) bijective commutative diagram

$$\begin{array}{ccc}
\text{Irr}(G) & \xrightarrow{\sim} & \Phi_e(G) \\
\downarrow & & \downarrow \\
\bigsqcup_{L \in \mathcal{L}} (\text{Irr}_{\text{cusp}}(L)/W(G, L))_\sharp & \xrightarrow{\sim} & \bigsqcup_{L \in \mathcal{L}} (\Phi(L)_{\text{cusp}}/W(G, L))_\sharp.
\end{array}$$

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1 Preliminaries

We start with some generalities, to fix the notations. Let $G$ be a connected reductive group over a local non-archimedean field $F$ of residual characteristic $p$. All our representations are assumed to be smooth and over the complex numbers. We write $\text{Rep}(G)$ for the category of such $G$-representations and $\text{Irr}(G)$ for the collection of isomorphism classes of irreducible representations therein. Let $P$ be a parabolic subgroup of $G$ with Levi factor $L$. The Weyl group of $L$ is $\text{W}(G,L) = N_G(L)/L$. It acts on equivalence classes of $L$-representations $\pi$ by

$$(w \cdot \pi)(g) = \pi(\bar{w}g\bar{w}^{-1}),$$

where $\bar{w} \in N_G(L)$ is a chosen representative for $w \in \text{W}(G,L)$. We write $\text{W}_\pi = \{w \in \text{W}(G,L) | w \cdot \pi \cong \pi\}$.

Let $\omega$ be an irreducible supercuspidal $L$-representation. The inertial equivalence class $s_L = [L,\omega]_L$ gives rise to a category of smooth $G$-representations $\text{Rep}_s(G)$ and a subset $\text{Irr}^s(G) \subset \text{Irr}(G)$. Write $X_{nr}(L)$ for the group of unramified characters $L \to \mathbb{C}^\times$. Then $\text{Irr}^s(G)$ consists of all irreducible constituents of the parabolically induced representations $I^G_P(\omega \otimes \chi)$ with $\chi \in X_{nr}(L)$. We note that $I^G_P$ always means normalized, smooth parabolic induction from $L$ via $P$ to $G$.

The set $\text{Irr}^{s_L}(L)$ with $s_L = [L,\omega]_L$ can be described explicitly, namely by

$$X_{nr}(L,\omega) = \{\chi \in X_{nr}(L) : \omega \otimes \chi \cong \omega\},$$

$$\text{Irr}^{s_L}(L) = \{\omega \otimes \chi : \chi \in X_{nr}(L)/X_{nr}(L,\omega)\}.$$

Several objects are attached to the Bernstein component $\text{Irr}^s(G)$ of $\text{Irr}(G)$ [BeDe]. Firstly, there is the torus

$$T_s := X_{nr}(L)/X_{nr}(L,\omega),$$

which is homeomorphic to $\text{Irr}^{s_L}(L)$. Secondly, we have the groups

$$N_G(s_L) = \{g \in N_G(L) | g \cdot \omega \in \text{Irr}^{s_L}(L)\} = \{g \in N_G(L) | g \cdot [L,\omega]_L = [L,\omega]_L\},$$

$$W_s := \{w \in W(G,L) | w \cdot \omega \in \text{Irr}^{s_L}(L)\} = N_G(s_L)/L.$$

Of course $T_s$ and $W_s$ are only determined up to isomorphism by $s$, actually they depend on $s_L$. To cope with this, we tacitly assume that $s_L$ is known when considering $s$.

The choice of $\omega \in \text{Irr}^{s_L}(L)$ fixes a bijection $T_s \to \text{Irr}^{s_L}(L)$, and via this bijection the action of $W_s$ on $\text{Irr}^{s_L}(L)$ is transferred to $T_s$. The finite group $W_s$ can be thought of as the “Weyl group” of $s$, although in general it is not generated by reflections.
Let $C_c^\infty(G)$ be the vector space of compactly supported locally constant functions $G \to \mathbb{C}$. The choice of a Haar measure on $G$ determines a convolution product $*$ on $C_c^\infty(G)$. The algebra $(C_c^\infty(G), *)$ is known as the Hecke algebra $\mathcal{H}(G)$. There is an equivalence between $\text{Rep}(G)$ and the category $\text{Mod}(\mathcal{H}(G))$ of $\mathcal{H}(G)$-modules $V$ such that $\mathcal{H}(G) \cdot V = V$. We denote the collection of inequivalent classes for $G$ by $\mathfrak{B}(G)$, the Bernstein spectrum of $G$. The Bernstein decomposition

$$\text{Rep}(G) = \prod_{s \in \mathfrak{B}(G)} \text{Rep}^s(G)$$

induces a factorization in two-sided ideals

$$\mathcal{H}(G) = \bigoplus_{s \in \mathfrak{B}(G)} \mathcal{H}(G)^s.$$

From now on we discuss things that are specific for $G = \text{GL}_m(D)$, where $D$ is a central simple $F$-algebra. We write $\dim_F(D) = d^2$. Every Levi subgroup $L$ of $G$ is conjugate to $\prod_i \text{GL}_{m_i}(D)$ for some $m_i \in \mathbb{N}$ with $\sum_i m_i = m$. Hence every irreducible $L$-representation $\omega$ can be written as $\otimes_j \omega_j$ with $\omega_j \in \text{Irr}(\text{GL}_{m_j}(D))$. Then $\omega$ is supercuspidal if and only if every $\omega_j$ is so. As above, we assume that this is the case. Replacing $(L, \omega)$ by an inertially equivalent pair allows us to make the following simplifying assumptions:

Condition 1.1.

1. if $\tilde{m}_i = \tilde{m}_j$ and $[\text{GL}_{\tilde{m}_i}(D), \tilde{\omega}_i]|_{\text{GL}_{m_i}(D)} = [\text{GL}_{\tilde{m}_j}(D), \tilde{\omega}_j]|_{\text{GL}_{m_j}(D)}$, then $\tilde{\omega}_i = \tilde{\omega}_j$;

2. $\omega = \bigotimes_i \omega_i^{e_i}$, such that $\omega_i$ and $\omega_j$ are not inertially equivalent if $i \neq j$;

3. $L = \prod_i L_i^{e_i} = \prod_i \text{GL}_{m_i}(D)^{e_i}$, embedded diagonally in $\text{GL}_m(D)$ such that factors $L_i$ with the same $(m_i, e_i)$ are in subsequent positions;

4. as representatives for the elements of $W(G, L)$ we take permutation matrices;

5. $P$ is the parabolic subgroup of $G$ generated by $L$ and the upper triangular matrices;

6. if $m_i = m_j, e_i = e_j$ and $\omega_i$ is isomorphic to $\omega_j \otimes \gamma$ for some character $\gamma$ of $\text{GL}_{m_i}(D)$, then $\omega_i = \omega_j \otimes \gamma \chi$ for some $\chi \in X(m_i(\text{GL}_{m_i}(D)))$.

Most of the time we will not need the conditions for stating the results, but they are useful in many proofs. Under Conditions 1.1 we consider

$$M_i = \text{GL}_{m_i, e_i}(D) \text{ naturally embedded in } Z_G\left(\prod_{j \neq i} L_j^{e_j}\right). \quad (3)$$

Then $\prod_i M_i$ is a Levi subgroup of $G$ containing $L$. For $s = [L, \omega]_G$ we have

$$W_s = N_{\prod_i M_i}(L)/L = \prod_i N_{M_i}(L_i^{e_i})/L_i^{e_i} \cong \prod_i S_e_i, \quad (4)$$

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a direct product of symmetric groups. Writing \( s_i = [L_i, \omega_i]_{L_i} \), the torus associated to \( s \) becomes

\[
T_s = \prod_{i} (T_{s_i})^{c_{\omega_i}} = \prod_{i} T_{\omega_i}^{c_{\omega_i}} = \prod_{i} T_{\omega_i},
\]

(5)

\[
T_{s_i} = X_{nr}(L_i)/X_{nr}(L_i, \omega_i).
\]

(6)

By our choice of representatives for \( W(G, L) \), \( \omega_i^{\geq c_{\omega_i}} \) is stable under \( N_{M_i}(L_i^n)/L_i^n \cong S_i. \) Let \( R_i \subset X_s(\prod_i Z(L_i)^{\omega_i}) \) denote the coroot system of \((M_i, Z(L_i)^{\omega_i})\) and recall the meaning of the notation \( W(R_i). \) Then we can identify \( S_i \) with \( W(R_i). \) The action of \( W_s \) on \( T_s \) is just permuting coordinates in the standard way and

\[
W_s = W_{\omega}.
\]

(7)

The reduced norm map \( D \to F \) gives rise to a group homomorphism \( \text{Nrd} : G \to F^\times. \) We denote its kernel by \( G^\sharp \), so \( G^\sharp \) is also the derived group of \( G \). For subgroups \( H \subset G \) we write

\[
H^\sharp = H \cap G^\sharp.
\]

In [ABPS4] we determined the structure of the Hecke algebras associated to types for \( G^\sharp \), starting with those for \( G \). As an intermediate step, we did this for the group \( G^\sharp Z(G) \), where \( Z(G) \cong F^\times \) denotes the centre of \( G \). The advantage is that the comparison between \( G^\sharp \) and \( G^\sharp Z(G) \) is easy, while \( G^\sharp Z(G) \subset G \) can be treated as an extension of finite index. In fact it is a subgroup of finite index if \( p \) does not divide \( nm \). In case \( p \) does divide \( nm \), the quotient \( G/G^\sharp Z(G) \) is compact and similar techniques can be applied.

For an inertial equivalence class \( s = [L, \omega]_G \) we define \( \text{Irr}^s(G^\sharp) \) as the set of irreducible \( G^\sharp \)-representations that are subquotients of \( \text{Res}_{G^\sharp}^G(\pi) \) for some \( \pi \in \text{Irr}^s(G) \), and \( \text{Rep}^s(G^\sharp) \) as the collection of \( G^\sharp \)-representations all of whose irreducible subquotients lie in \( \text{Irr}^s(G^\sharp) \). We want to investigate the category \( \text{Rep}^s(G^\sharp) \). It is a product of finitely many Bernstein blocks for \( G^\sharp \), see [ABPS4, Lemma 2.2]:

\[
\text{Rep}^s(G^\sharp) = \prod_{t \prec s} \text{Rep}^t(G^\sharp).
\]

(8)

We note that the Bernstein components \( \text{Irr}^s(G^\sharp) \) which are subordinate to one \( s \) (i.e., such that \( t^\sharp < s \)) form precisely one class of L-indistinguishable components: every L-packet for \( G^\sharp \) which intersects one of them intersects them all.

Analogously we define \( \text{Rep}^s(G^\sharp Z(G)) \), and we obtain

\[
\text{Rep}^s(G^\sharp Z(G)) = \prod_{t \prec s} \text{Rep}^t(G^\sharp Z(G)),
\]

where the \( t \) are inertial equivalence classes for \( G^\sharp Z(G) \). The restriction of \( t \) to \( G^\sharp \) is a single inertial equivalence class \( t^\sharp \), and by [ABPS4, (43)]:

\[
T_{t^\sharp} = T_t/X_{nr}(\text{Nrd}(Z(G))).
\]

(9)
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For \( \pi \in \text{Irr}(G) \) we put
\[
X^G(\pi) := \{ \gamma \in \text{Irr}(G/G^\sharp) : \gamma \otimes \pi \cong \pi \}.
\]
The same notation will be used for representations of parabolic subgroups of \( G \) which admit a central character. For every \( \gamma \in X^G(\pi) \) there exists a nonzero intertwining operator
\[
I(\gamma, \pi) \in \text{Hom}_G(\pi \otimes \gamma, \pi) = \text{Hom}_G(\pi, \pi \otimes \gamma^{-1}),
\]
which is unique up to a scalar. As \( G^\sharp \subset \ker(\gamma) \), \( I(\gamma, \pi) \) can also be considered as an element of \( \text{End}_{G^\sharp}(\pi) \). As such, these operators determine a 2-cocycle \( \kappa_{\pi} \) by
\[
I(\gamma, \pi) \circ I(\gamma', \pi) = \kappa_{\pi}(\gamma, \gamma')I(\gamma \gamma', \pi).
\]
By [HiSa, Lemma 2.4] they span the \( G^\sharp \)-intertwining algebra of \( \pi \):
\[
\text{End}_{G^\sharp}(\text{Res}_{G^\sharp}G(\pi)) \cong \mathbb{C}[X^G(\pi), \kappa_{\pi}],
\]
where the right hand side denotes the twisted group algebra of \( X^G(\pi) \). Furthermore by [HiSa, Corollary 2.10]
\[
\text{Res}_{G^\sharp}G(\pi) \cong \bigoplus_{\rho \in \text{Irr}(\mathbb{C}[X^G(\pi), \kappa_{\pi}], \kappa_{\pi})} \text{Hom}_{\mathbb{C}[X^G(\pi), \kappa_{\pi}]}(\rho, \pi) \otimes \rho.
\]

The role of the group \( W_s \) for \( \text{Rep}^s(G^\sharp) \) is played by
\[
W^s \cong \{ w \in W(G, L) \mid \exists \gamma \in \text{Irr}(L/L^\sharp Z(G)) \text{ such that } w(\gamma \otimes \omega) \in [L, \omega]_L \}.
\]
By [ABPS4, Lemma 2.3]
\[
W^s = W_s \rtimes \mathfrak{R}_s^2, \quad \text{where } \mathfrak{R}_s^2 = W_s \cap N_G(P \cap \prod_i M_i)/L.
\]
while [ABPS4, Lemma 2.4.d] says that
\[
X^G(s)/X^L(s) \cong \mathfrak{R}_s^2.
\]
For another way to view \( X^G(s) \), we start with
\[
\text{Stab}(s) := \{ (w, \gamma) \in N_G(L)/L \times \text{Irr}(L/L^\sharp Z(G)) \mid w(\gamma \otimes \omega) \in [L, \omega]_L \}.
\]
The normal subgroup $W_s$ has a complement:

$$\text{Stab}(s) = \text{Stab}(s, P \cap \prod_i M_i) \ltimes W_s := \text{Stab}(s)^+ \ltimes W_s$$

$$\text{Stab}(s)^+ := \{ (w, \gamma) \in N_G(P \cap \prod_i M_i)/L \times \text{Irr}(L/L^G Z(G)) \mid w(\gamma \otimes \omega) \in [L, \omega]_L \}$$

By [ABPS4, Lemma 2.4.a] projection of $\text{Stab}(s)$ on the second coordinate gives an isomorphism

$$X^G(s) \cong \text{Stab}(s)/W_s \cong \text{Stab}(s)^+$$

(16)

In particular

$$\text{Stab}(s)^+/X^L(s) \cong \mathfrak{nr}_L^s.$$

(17)

As in [ABPS4, (159)–(161)] we choose $\chi_\gamma \in X_{nr}(L)^{W_s}$ for $(w, \gamma) \in \text{Stab}(s)^+$, such that

$$w(\omega) \otimes \gamma \cong \omega \otimes \chi_\gamma.$$

(18)

Notice that $\chi_\gamma$ is unique up to $X_{nr}(L, \omega)$. Furthermore we choose an invertible $J(\gamma, \omega \otimes \chi_\gamma^{-1}) \in \text{Hom}_L(\omega \otimes \chi_\gamma^{-1}, w^{-1}(\omega) \otimes \gamma^{-1})$.

(19)

This generalizes (10) in the sense that

$$J(\gamma, \omega \otimes \chi_\gamma^{-1}) = I(\gamma, \omega) \quad \text{if} \quad \gamma \in X^L(\omega) \text{ and } \chi_\gamma = 1.$$

Let $V_\omega$ denote the vector space underlying $\omega$. We may assume that

$$\chi_\gamma = \gamma \quad \text{and} \quad J(\gamma, \omega \otimes \chi_\gamma^{-1}) = \text{id}_{V_\omega} \quad \text{if} \quad \gamma \in X_{nr}(L/L^G Z(G)).$$

(20)

2 Bernstein tori

We will determine the Bernstein tori for $G^s Z(G)$ and $G^t$, in terms of those for $G$.

The group $X^L(s)$ acts on $T_s = \text{Irr}^{s+}(L)$ by $\pi \mapsto \pi \otimes \gamma$. By [ABPS4, Proposition 2.1] $\text{Res}^L_{L^G}(\omega)$ and $\text{Res}^L_{L^G}(\omega \otimes \chi)$ with $\chi \in X_{nr}(L)$ have a common irreducible subquotient if and only if there is a $\gamma \in X^L(s)$ such that $\omega \otimes \chi \cong \omega \otimes \chi_\gamma$. As in (19) we choose a nonzero

$$J(\gamma, \omega) \in \text{Hom}_L(\omega \otimes \chi_\gamma \gamma^{-1}) = \text{Hom}_L(\omega \otimes \gamma, \omega \otimes \chi_\gamma).$$

Then $J(\gamma, \omega) \in \text{Hom}_{L^G}(\omega, \omega \otimes \chi_\gamma)$ and for every irreducible subquotient $\sigma^\sharp$ of $\text{Res}^L_{L^G}(\omega)$

$$\gamma \ast (\sigma^\sharp \otimes \chi) : m \mapsto J(\gamma, \omega) \circ (\sigma^\sharp \otimes \chi)(m) \circ J(\gamma, \omega)^{-1}$$

(21)

is an irreducible subquotient representation of

$$\text{Res}^L_{L^G}(\omega \otimes \chi \chi_\gamma) = \text{Res}^L_{L^G}(\omega \otimes \chi \chi_\gamma \gamma^{-1}).$$

This prompts us to consider

$$X^L(s, \sigma^\sharp) := \{ \gamma \in X^L(s) \mid \gamma \ast \sigma^\sharp \cong \sigma^\sharp \otimes \chi_\gamma \}.$$
By [ABPS4, Lemma 4.14]

\[ \sigma^+ \otimes \chi \cong \sigma^+ \] for all \( \chi \in X_{nr}(L, \omega) \).  \hfill (23)

Hence the group (22) is well-defined, that is, independent of the choice of the \( \chi_\gamma \). For \( \gamma \in X^L(\omega) \) (21) reduces to \( \sigma^+ \otimes \chi \), so \( \gamma \in X^L(\omega, \sigma^+) \). By (20) the same goes for \( \gamma \in X_{nr}(L/L^tZ(G)) \), so there is always an inclusion

\[ X^L(\omega)X_{nr}(L/L^tZ(G)) \subset X^L(\omega, \sigma^+). \hfill (24) \]

We gathered enough tools to describe the Bernstein tori for \( G^\# \) and \( G^sZ(G) \). Recall that \( s_L = [L, \omega]_L, T_s \cong X_{nr}(L)/X_{nr}(L, \omega) \). Let \( T_s^G \) be the restriction of \( T_s \) to \( L^t \), that is,

\[ T_s^G := T_s/X_{nr}(G) = T_s/X_{nr}(L/L^t) \cong X_{nr}(L^t)/X_{nr}(L, \omega), \hfill (25) \]

where \( X_{nr}(L/L^t) \) denotes the group of unramified characters of \( L \) which are trivial on \( L^t \).

**Proposition 2.1.** Let \( \sigma^+ \) be an irreducible subquotient of \( \text{Res}^{L^t}_L(\omega) \) and write \( t = [L^tZ(G), \sigma^+]_{G^1Z(G)} \) and \( \psi = [L^s, \sigma^+]_{G^1} \).

(a) \( X^L(\omega, \sigma^+) \) depends only on \( s_L \), not on the particular \( \sigma^+ \).

(b) \( X_{nr}(L, \omega)\{\chi_\gamma \mid \gamma \in X^L(\omega, \sigma^+)\} \) is a subgroup of \( X_{nr}(L) \) which contains \( X_{nr}(L/L^tZ(G)) \).

(c) \( T_1 \cong T_s^G\{\chi_\gamma \mid \gamma \in X^L(\omega, \sigma^+)\} \cong X_{nr}(L^tZ(G))/X_{nr}(L, \omega)\{\chi_\gamma \mid \gamma \in X^L(\omega, \sigma^+)\} \).

(d) \( T_0 \cong T_s^G\{\chi_\gamma \mid \gamma \in X^L(\omega, \sigma^+)\} \cong X_{nr}(L^t)/X_{nr}(L, \omega)\{\chi_\gamma \mid \gamma \in X^L(\omega, \sigma^+)\} \).

**Proof.** (a) By [ABPS4, Proposition 2.1] every two irreducible subquotients of \( \text{Res}^{L^t}_L(\omega) \) are direct summands and are conjugate by an element of \( L \). Given \( \gamma \in X^L(\omega) \), pick \( m_\gamma \in L \) such that

\[ \gamma \ast \sigma^+ \cong (\omega(m_\gamma)^{-1} \circ \sigma^+ \circ \omega(m_\gamma)) \otimes \chi_\gamma = (m_\gamma \cdot \sigma^+) \otimes \chi_\gamma. \]

For any other irreducible summand \( \tau = m_\tau \cdot \sigma^+ \) of \( \text{Res}^{L^t}_L(\omega) \) we compute

\[
\gamma \ast \tau = \gamma \ast (m_\tau \cdot \sigma^+) = J(\gamma, \omega) \circ \omega(m_\tau)^{-1} \circ \sigma^+ \circ \omega(m_\tau) \circ J(\gamma, \omega)^{-1} \\
= (\chi_\gamma \gamma^{-1} \otimes \omega)(m_\tau^{-1}) \circ J(\gamma, \omega) \circ \sigma^+ \circ J(\gamma, \omega)^{-1} \circ (\chi_\gamma \gamma^{-1} \otimes \omega)(m_\tau) \\
\cong \omega(m_\tau^{-1}) \circ (m_\tau \cdot \sigma^+) \otimes \chi_\gamma \circ \omega(m_\tau) \\
\cong (m_\tau \cdot m_\gamma \cdot \sigma^+) \otimes \chi_\gamma.
\]

As \( L/L^t \) is abelian, we find that \( m_\tau \cdot m_\gamma \cdot \sigma^+ \cong m_\gamma \cdot m_\tau \cdot \sigma^+ \) and that

\[ \gamma \ast \tau \cong (m_\gamma \cdot m_\tau \cdot \sigma^+) \otimes \chi_\gamma = m_\gamma \cdot \tau \otimes \chi_\gamma. \]
Writing \( L_\tau = \{ m \in L \mid m \cdot \tau \cong \tau \} \), we deduce the following equivalences:

\[
\gamma \ast \sigma^2 \cong \sigma^2 \otimes \chi_\gamma \iff m_\gamma \in L_{\sigma^2} \iff m_\gamma \in m_\tau L_{\sigma^1} m_\tau^{-1} = L_\tau \iff \gamma \ast \tau \cong \tau \otimes \chi_\gamma.
\]

This means that \( X^L(s, \sigma^2) = X^L(s, \tau) \).

(b) By (20) and (24)

\[
X_{\text{nr}}(L/L^LZ(G)) \subset \{ \chi_\gamma \mid \gamma \in X^L(s, \sigma^2) \}.
\]

In view of the uniqueness property of \( \chi_\gamma \) the map

\[
X^L(s) \rightarrow X_{\text{nr}}(L)/X_{\text{nr}}(L, \omega) : \gamma \mapsto \chi_\gamma
\]

is a group homomorphism with kernel \( X_{\text{nr}}(L, \omega) \). Hence the \( \chi_\gamma \) form a subgroup of \( X_{\text{nr}}(L)/X_{\text{nr}}(L, \omega) \), isomorphic to \( X^L(s)/X^L(\omega) \).

(c) Consider the family of \( L^LZ(G) \)-representations \( \{ \sigma^2 \otimes \chi \mid \chi \in X_{\text{nr}}(L) \} \).

We have to determine the \( \chi \) for which \( \sigma^2 \otimes \chi \cong \sigma^2 \in \text{Irr}(L^LZ(G)) \). From [ABPS4, Lemma 4.14] we see that this includes all the elements of \( X_{\text{nr}}(L, \omega)X_{\text{nr}}(L/L^LZ(G)) \). By [ABPS4, Proposition 2.1.b] and part (a), all the remaining \( \chi \) come from \( \{ \chi_\gamma \mid \gamma \in X^L(s, \sigma^2) \} \). This gives the first isomorphism, and the second follows with part (b).

(d) This is a consequence of part (c) and (9).

Proposition 2.1 entails that for every inertial equivalence class

\[
t = [L^LZ(G), \sigma^2]|_{\sigma^2 Z(G)} \prec s = [L, \omega]_G
\]

the action (21) of \( X^L(s, \sigma^2) \) leads to

\[
T_1 \cong T_s/X^L(s, \sigma^2).
\]

However, some of the tori

\[
T_i = T_{il} = \text{Irr}([L^LZ(G), \sigma^2]|_{L^LZ(G)}(L^LZ(G)))
\]

associated to inequivalent \( \sigma^2 \subset \text{Res}_{L^LZ}^L(\omega) \) can coincide as subsets of \( \text{Irr}(L^LZ(G)) \). This is caused by elements of \( X^L(s) \setminus X^L(s, \sigma^2) \) via the action (21). With (23), (22) and (13) we can write

\[
\text{Irr}^s(L^LZ(G)) = \bigcup_{T_i \prec s} T_{il} = (T_s \times \text{Irr}(\mathbb{C}[X^L(\omega), \kappa_\omega]))/X^L(s),
\]

where \( (\omega \otimes \chi, \rho) \in T_s \times \text{Irr}(\mathbb{C}[X^L(\omega), \kappa_\omega]) \) corresponds to

\[
\text{Hom}_{\mathbb{C}[X^L(\omega), \kappa_\omega]}(\rho, \omega \otimes \chi) \in \text{Irr}(L^LZ(G)).
\]
With (9) we can deduce a similar expression for $L^2$:

$$
\text{Irr}^Z(L^2) = \bigcup_{t_k < s} T^4_{t_k} (T^4_s \times \text{Irr}(\mathbb{C}[X^L(\omega), \kappa_\omega])) / X^L(s)
\quad = (T^4_s \times \text{Irr}(\mathbb{C}[X^L(\omega), \kappa_\omega])) / X^L(s) X_{nr}(L^2 Z(G)/L^2).
$$

In the notation of (26) and (27) the action of $\gamma \in X^L(s)$ becomes

$$
\gamma \cdot (\omega \otimes \chi, \rho) = (\omega \otimes \chi \gamma, \phi_{\omega, \gamma} \rho),
$$

where $\phi_{\omega, \gamma}$ is yet to be determined. Any $\gamma \in X^L(\omega)$ can be adjusted by an element of $X_{nr}(L, \omega)$ to achieve $\chi \gamma = 1$. Then (23) shows that $\phi_{\omega, \gamma} \rho \cong \rho$ for all $\gamma \in X^L(\omega)$.

**Lemma 2.2.** For $\gamma \in X^L(s)$, $\phi_{\omega, \gamma} \rho$ is $\rho$ tensored with a character of $X^L(\omega)$, which we also call $\phi_{\omega, \gamma}$. Then

$$
X^L(s) \rightarrow \text{Irr}(X^L(\omega)): \gamma \mapsto \phi_{\omega, \gamma}
$$

is a group homomorphism.

**Proof.** Let $N_{\gamma'}$ be a standard basis element of $\mathbb{C}[X^L(\omega), \kappa_\omega]$. In view of (21) $\phi_{\omega, \gamma} \rho$ is given by

$$
N_{\gamma'} \mapsto J(\gamma, \omega) I(\gamma', \omega) J(\gamma, \omega)^{-1} \in \text{Hom}_L(\omega \otimes \chi \gamma, \omega \otimes \chi \gamma).
$$

Since these are irreducible $L$-representations, there is a unique $\lambda \in \mathbb{C}^\times$ such that

$$
J(\gamma, \omega) I(\gamma', \omega) J(\gamma, \omega)^{-1} = \lambda^{-1} I(\gamma', \omega \otimes \chi \gamma),
$$

$$(\phi_{\omega, \gamma} \rho)(N_{\gamma'}) = \rho(\lambda I(\gamma', \omega)) = \lambda \rho(N_{\gamma'}).$$

Moreover the relation

$$
I(\gamma'_1, \omega \otimes \chi \gamma) I(\gamma'_2, \omega \otimes \chi \gamma) = \kappa_{\omega \otimes \chi \gamma}(\gamma'_1, \gamma'_2) I(\gamma'_1 \gamma'_2, \omega \otimes \chi \gamma)
$$

also holds with $J(\gamma, \omega) I(\gamma', \omega) J(\gamma, \omega)^{-1}$ instead of $I(\gamma', \omega)$—a basic property of conjugation. It follows that $\gamma' \mapsto \lambda$ defines a character of $X^L(\omega)$ which implements the action $\rho \mapsto \phi_{\omega, \gamma} \rho$. As $\phi_{\omega, \gamma}$ comes from conjugation by $J(\gamma, \omega \otimes \chi)$ and by (30), $\gamma \mapsto \phi_{\omega, \gamma}$ is a group homomorphism.

A straightforward check, using the above proof, shows that

$$
\text{Hom}_{\mathbb{C}[X^L(\omega), \kappa_\omega]}(\rho, \omega \otimes \chi) \rightarrow \text{Hom}_{\mathbb{C}[X^L(\omega), \kappa_\omega]}(\phi_{\omega, \gamma} \rho, \omega \otimes \chi \gamma)
\quad \mapsto J(\gamma, \omega \otimes \chi) \circ f
$$

is an isomorphism of $L^2 Z(G)$-representations.
3 Hecke algebras

We will show that the algebras $\mathcal{H}(G^2Z(G))^\circ$ and $\mathcal{H}(G^2)^\circ$ are stratified equivalent [ABPS7] with much simpler algebras. In this section we recall the final results of [ABPS4], which show that up to Morita equivalence these algebras are closely related to affine Hecke algebras. In section 4 we analyse the latter algebras in the framework of [ABPS7].

Our basic affine Hecke algebra is called $\mathcal{H}(T_s, W_s, q_s)$. By definition [ABPS4, (119)] it has a $C$-basis $\{\theta_x[w] : x \in X^*(T_s), w \in W_s\}$ such that

- the span of the $\theta_x$ is identified with the algebra $O(T_s)$ of regular functions on $T_s$;
- the span of the $[w]$ is the finite dimensional Iwahori–Hecke algebra $\mathcal{H}(W_s, q_s)$;
- the multiplication between these two subalgebras is given by
  \[ f[s] - [s](s \cdot f) = (q_s(s) - 1)(f - (s \cdot f))(1 - \theta_\alpha)^{-1} \quad f \in O(T_s), \]
  for a simple reflection $s = s_\alpha$;
- the algebra is well-defined for any array of parameters $q_s = (q_s,i)$ in $\mathbb{C}^\times$.

The parameters $q_s,i$ that we will use are given explicitly in [Séc, Théorème 4.6].

Thus $\mathcal{H}(T_s, W_s, q_s)$ is a tensor product of affine Hecke algebras of type $GL_e$, but written in such a way that the torus $T_s$ appears canonically in it (i.e. independent of the choice of a base point of $T_s$). Sécherre and Stevens [Séc, SécSt2] showed that

$$\mathcal{H}(G)^\circ$$

is Morita equivalent with $\mathcal{H}(T_s, W_s, q_s)$. (33)

From [SéSt1] we know that there exists a simple type $(K, \lambda)$ for $[L, \omega]_M$, and in [SéSt2] it was shown to admit a $G$-cover $(K_G, \lambda_G)$. We denote the associated central idempotent of $\mathcal{H}(K)$ by $e_\lambda$, and similarly for other irreducible representations. Then $V_\lambda = e_\lambda V_\omega$.

For the restriction process we need an idempotent that is invariant under $X^G(s)$. To that end we replace $\lambda_G$ by the sum of the representations $\gamma \otimes \lambda_G$ with $\gamma \in X^G(s)$, which we call $\mu_G$. In [ABPS4, (91)] we constructed an idempotent $e_{\mu_G} \in \mathcal{H}(G)$ which is supported on the compact open subgroup $K_G \subset G$.

It follows from the work of Sécherre and Stevens [SécSt2] that $e_{\mu_G} \mathcal{H}(G)e_{\mu_G}$ is Morita equivalent with $\mathcal{H}(G)^\circ$.

In [ABPS4, (128)] we defined a finite dimensional subspace

$$V_\mu := \sum_{\gamma \in X^G(s)} e_{\gamma \otimes \lambda} V_\omega$$
of \( V_\omega \) which is stable under the operators \( I(\gamma, \omega) \) with \( \gamma \in X^L(s) \). By [Séc] and [ABPS4, Theorem 4.5.d]

\[ e_{\mu_G} \mathcal{H}(G)e_{\mu_G} \cong \mathcal{H}(T_2, W_2, q_2) \otimes \text{End}_\mathbb{C}(V_\mu \otimes \mathbb{C}N^g_+) \quad (34) \]

The groups \( X^G(s) \) and \( X_{\omega e}(G) \) act on \( e_{\mu_G} \mathcal{H}(G)e_{\mu_G} \) by pointwise multiplication of functions \( G \to \mathbb{C} \) with characters of \( G \). However, for technical reasons we use the action

\[ \alpha_\gamma(f)(g) = \gamma^{-1}(g)f(g) \quad f \in \mathcal{H}(G), \gamma \in \text{Irr}(G/G^2), g \in G. \quad (35) \]

The action on the right hand side of (34) preserves the tensor factors, and on \( \text{End}_\mathbb{C}(\mathbb{C}N_+) \) it is the natural action of \( X^G(s)/X^L(s) \cong \mathbb{R}^g_+ \).

Although \( e_{\mu_G} \) looks like the idempotent of a type, it is not clear whether it is one, because the associated \( K \)-representation is reducible and no more suitable compact subgroup of \( G \) is in sight. Let \( e_{\mu_G} \) (respectively \( e_{\mu_G} \)) be the restriction of \( e_{\mu_G} : G \to \mathbb{C} \) to \( G^2 \) (resp. \( G^2Z(G) \)). We normalize the Haar measure on \( G^2 \) (resp. \( G^2Z(G) \)) such that it becomes an idempotent in \( \mathcal{H}(G^2) \) (resp. \( \mathcal{H}(G^2Z(G)) \)).

In [ABPS4, Lemma 3.3] we constructed a certain finite set \([L/H_\lambda]\), consisting of representatives for a normal subgroup \( H_\lambda \subset L \). Consider the elements

\[ e^\lambda_{H_\lambda} := \sum_{a \in [L/H_\lambda]} ae_{\mu_G}a^{-1} \in \mathcal{H}(G), \]
\[ e^{G^2Z(G)}_{H_\lambda} := \sum_{a \in [L/H_\lambda]} ae_{\mu_G}a^{-1} \in \mathcal{H}(G^2Z(G)), \quad (36) \]
\[ e^G_{H_\lambda} := \sum_{a \in [L/H_\lambda]} ae_{\mu_G}a^{-1} \in \mathcal{H}(G^2). \]

It follows from [ABPS4, Lemma 3.12] that they are again idempotent. Notice that \( e^\lambda_{H_\lambda} \) detects the same category of \( G \)-representations as \( e_{\mu_G} \), namely \( \text{Rep}^s(G) \). In the proof of [ABPS4, Proposition 3.15] we established that (34) extends to an isomorphism

\[ e^G_{H_\lambda} \mathcal{H}(G)e_{H_\lambda} \cong \mathcal{H}(T_2, W_2, q_2) \otimes \text{End}_\mathbb{C}(V_\mu \otimes \mathbb{C}N^g_+) \otimes M_{[L/H_\lambda]}(\mathbb{C}). \quad (37) \]

**Theorem 3.1.** [ABPS4, Theorem 4.13] Let \( G = \text{GL}_m(D) \) be an inner form of \( \text{GL}_n(F) \). Then for any \( s \in \mathfrak{B}(G) \):

(a) \( \mathcal{H}(G^2Z(G))^s \) is Morita equivalent with its subalgebra

\[ e^{G^2Z(G)}_{H_\lambda} \mathcal{H}(G^2Z(G))e^{G^2Z(G)}_{H_\lambda} = \bigoplus_{a \in [L/H_\lambda]} ae_{\mu_G}a^{-1} \mathcal{H}(G^2Z(G))ae_{\mu_G}a^{-1} \]

(b) Each of the algebras \( ae_{\mu_G}a^{-1} \mathcal{H}(G^2Z(G))ae_{\mu_G}a^{-1} \) is isomorphic to

\[ (\mathcal{H}(T_2, W_2, q_2) \otimes \text{End}_\mathbb{C}(V_\mu))^{x^L(s)} \cong \mathbb{H}^f_2. \quad (38) \]
(c) Under these isomorphisms the action of $X_{nr}(G)$ on $\mathcal{H}(G^sZ(G))^s$ becomes the action of $X_{nr}(L/L^s) \cong X_{nr}(G)$ on (38) via translations on $T_s$.

Recall from (25) that $T^s_s$ is the restriction of $T_s$ to $L^s$. With this torus we build an affine Hecke algebra $\mathcal{H}(T^s_s, W_s, q_s)$ for $G^s$.

**Theorem 3.2.** [ABPS4, Theorem 4.15]

(a) $\mathcal{H}(G^s)^s$ is Morita equivalent with

$$e^s_{\chi G} \mathcal{H}(G^s) e^s_{\chi G} = \bigoplus_{a \in [L/H_\lambda]} ae_{\mu G^s} a^{-1} \mathcal{H}(G^s) ae_{\mu G^s} a^{-1}$$

(b) Each of the algebras $ae_{\mu G^s} a^{-1} \mathcal{H}(G^s) ae_{\mu G^s} a^{-1}$ is isomorphic to

$$(\mathcal{H}(T^s_s, W_s, q_s) \otimes \text{End}_\mathbb{C}(V_\mu)) X^*(s) \times \mathfrak{g}_s^\lambda.$$  

Let us describe the above actions of the group $X^G(s)$ explicitly. The action on

$$ae_{\mu G^Z(G)} a^{-1} \mathcal{H}(G^s Z(G)) ae_{\mu G^Z(G)} a^{-1} \cong \mathcal{H}(T_s, W_s, q_s) \otimes \text{End}_\mathbb{C}(V_\mu). \quad (39)$$

does not depend on $a \in [L/H_\lambda]$ because

$$\alpha_\gamma(a fa^{-1}) = a(\alpha_\gamma(f))a^{-1} \quad f \in \mathcal{H}(G).$$

The isomorphism (17) yields an action $\alpha$ of $\text{Stab}(s)^+$ on (39).

**Theorem 3.3.** [ABPS4, Lemmas 3.5 and 4.11]

(a) The action of $\text{Stab}(s)^+$ on $\mathcal{H}(T_s, W_s, q_s) \otimes \text{End}_\mathbb{C}(V_\mu)$ in Theorem 3.1 preserves both tensor factors. On $\mathcal{H}(T_s, W_s, q_s)$ it is given by

$$\alpha_{(w, \gamma)}(\theta_v[v]) = \chi^{-1}_\gamma(x) \theta_{w(x)}[w v w^{-1}] \quad x \in X^*(T_s), v \in W_s,$$

and on $\text{End}_\mathbb{C}(V_\mu)$ by

$$\alpha_{(w, \gamma)}(h) = J(\gamma, \omega \otimes \chi^{-1}_\gamma) \circ h \circ J(\gamma, \omega \otimes \chi^{-1}_\gamma)^{-1}.$$  

(b) The subgroup of elements that act trivially is

$$X^L(\omega, V_\mu) = \{ \gamma \in X^L(\omega) \mid I(\gamma, \omega)|_{V_\mu} \in \mathbb{C} \}.$$  

Its cardinality equals $[L : H_\lambda]$.

(c) Part (a) and Theorem 3.1.c also describe the action of $\text{Stab}(s)^+ X_{nr}(G)$ on $\mathcal{H}(T^s_s, W_s, q_s) \otimes \text{End}_\mathbb{C}(V_\mu)$ in Theorem 3.2. The subgroup of elements that act trivially on this algebra is

$$X^L(\omega, V_\mu) X_{nr}(G) = X^L(\omega, V_\mu) X_{nr}(L/L^s).$$
4 Spectrum preserving morphisms and stratified equivalences

We will show that the Hecke algebras obtained in Theorems 3.1 and 3.2 fit in the framework of spectrum preserving morphisms and stratified equivalence of finite type algebras, see [ABPS7]. First we exhibit an algebra that interpolates between

\[(\mathcal{H}(T_s, W_s, q_s) \otimes \text{End}_\mathbb{C}(V_\mu))^{X_s(\mathfrak{s})} \times \mathfrak{g}\]

and \((\mathcal{O}(T_s) \times W_s \otimes \text{End}_\mathbb{C}(V_\mu))^{X_s(\mathfrak{s})} \times \mathfrak{g}\). Recall that Conditions 1.1 are in force and write

\[T_s = \prod_i T_i, \quad R_s = \bigcup_i R_i, \quad W_s = \prod_i W(R_i) = \prod_i S_c .\]

Let \(q_s\) be the restriction of \(q_s : X^*(T_s) \times W_s \to \mathbb{R}_{\geq 0}\) to \(X^*(T_i) \times W(R_i)\). Recall Lusztig’s asymptotic Hecke algebra \(J(X^*(T_i) \times W(R_i))\) from [Lus2, Lus3]. We remark that, although in [Lus2] it is supposed that the underlying root datum is semisimple, this assumption is shown to be unnecessary in [Lus3]. This algebra is unital and of finite type over \(\mathcal{O}(T_i)^{W(R_i)}\). It has a distinguished \(\mathbb{C}\)-basis \(\{t_x, w \in X^*(T_i), v \in W(R_i)\}\) and the \(t_x\) with \(x \in X^*(T_i)^{W(R_i)}\) are central. We define

\[J(X^*(T_s) \times W_s) = \bigotimes_i J(X^*(T_i) \times W(R_i)).\]

This is a unital finite type algebra over \(\mathcal{O}(T_s)^{W_s}\), in fact for several different \(\mathcal{O}(T_s)^{W_s}\)-module structures.

Lusztig [Lus3, §1.4] defined injective algebra homomorphisms

\[\mathcal{H}(T_i, W(R_i), q_i) \xrightarrow{\phi_{i,q_i}} J(X^*(T_i) \times W(R_i)) \xleftarrow{\phi_{i,1}} \mathcal{O}(T_i) \times W(R_i) \quad (40)\]

with many nice properties. Among these, we record that

\(\phi_{i,q_i}\) and \(\phi_{i,1}\) are the identity on \(\mathbb{C}[X^*(T_i)^{W(R_i)}] \cong \mathcal{O}(X_{ri}(Z(M_i)))\). \quad (41)

There exist \(\mathcal{O}(T_i)^{W(R_i)}\)-module structures on \(J(X^*(T_i) \times W(R_i))\) for which the maps \((40)\) are \(\mathcal{O}(T_i)^{W(R_i)}\)-linear, namely by letting \(\mathcal{O}(T_i)^{W(R_i)}\) act via the map \(\phi_{i,q_i}\) or via \(\phi_{i,1}\). Taking tensor products over \(i\) in \((40)\) and with the identity on \(\text{End}_{\mathbb{C}}(V_\mu)\) gives injective algebra homomorphisms

\[\phi_{q_s} : \mathcal{H}(T_s, W_s, q_s) \otimes \text{End}_{\mathbb{C}}(V_\mu) \to J(X(T_s) \times W_s) \otimes \text{End}_{\mathbb{C}}(V_\mu),\]

\[\phi_1 : \mathcal{O}(T_s) \times W_s \otimes \text{End}_{\mathbb{C}}(V_\mu) \to J(X(T_s) \times W_s) \otimes \text{End}_{\mathbb{C}}(V_\mu).\] \quad (42)

The maps \(\phi_{q_s}\) and \(\phi_1\) are \(\mathcal{O}(T_s)^{W_s}\)-linear with respect to the appropriate module structure on \(J(X(T_s) \times W_s)\).

**Lemma 4.1.** Via \((42)\) the action of \(\text{Stab}(\mathfrak{s})^+\) on \(\mathcal{H}(T_s, W_s, q_s) \otimes \text{End}_{\mathbb{C}}(V_\mu)\) from Theorem 3.3 extends canonically to an action on \(J(X^*(T_s) \times W_s) \otimes \text{End}_{\mathbb{C}}(V_\mu)\), which stabilizes the subalgebra \(\mathcal{O}(T_s) \times W_s \otimes \text{End}_{\mathbb{C}}(V_\mu)\).
Proof. In $X^*(T_s) \rtimes W(G, L)$ every $w \in R^L_s$ normalizes the subgroup $X^*(T_s) \rtimes W_s$. The group automorphism

$$xv \mapsto wxvw^{-1} \quad \text{of} \quad X^*(T_s) \rtimes W_s$$

(43)

only permutes the subgroups $X^*(T_s) \rtimes W(R_i)$. In particular it stabilizes the set of simple reflections. With the canonical representatives for $R^L_s$ in $G$ from (14), conjugation by $w$ stabilizes the type for $s_L$ (it is a product of simple types in the sense of [Séc, §4]). Hence (43) preserves $q_s$. Thus (43) can be factorized as

$$\prod_j \omega_j \in \text{Aut}( \prod_{i : R_i = R_j, q_i = q_j} X^*(T_i) \rtimes W(R_i))$$

(44)

The function $q_s$ takes the same value on all simple (affine) roots associated to the group for one $j$ in (44), so the algebra

$$\bigotimes_{i : R_i = R_j, q_i = q_j} J(X^*(T_i) \rtimes W(R_i))$$

(45)

is of the kind considered in [Lus3, §1]. Then $\omega_j$ is an automorphism which fits in a group called $\Omega$ in [Lus3, §1.1], so it gives rise to an automorphism of the algebra (45). In this way the group $R^L_s \cong \text{Stab}(s)^+ / X^L(s)$ acts naturally on $J(X^*(T_s) \rtimes W_s)$.

Since $T^W_s$ is central in $T_s \rtimes W_s$, every $\chi \in T^W_s$ gives rise to an algebra automorphism of $J(X^*(T_s) \rtimes W_s)$:

$$t_{xv} \mapsto \chi(x)t_{xv} \quad x \in X^*(T_s), v \in W_s.$$ 

(46)

Thus we can make $\text{Stab}(s)^+$ act on $J(X^*(T_s) \rtimes W_s)$ by

$$(w, \gamma) \cdot t_{xv} = \chi^{-1}(x)(w_{xvw^{-1}}) \quad x \in X^*(T_s), v \in W_s.$$ 

The action of $\text{Stab}(s)^+$ on $\text{End}_C(V_\mu)$ may be copied to this setting, so we can define the following action on $J(X^*(T_s) \rtimes W_s) \otimes \text{End}_C(V_\mu)$:

$$\alpha_{(w, \gamma)}(t_{xv} \otimes h) = \chi^{-1}(x)(w_{xvw^{-1}}) \otimes J(\gamma, \omega \otimes \chi^{-1}) \circ h \circ J(\gamma, \omega \otimes \chi^{-1})^{-1}.$$ 

(47)

Of course the above also works with the label function 1 instead of $q_s$. That yields a similar action of $\text{Stab}(s)^+$ on $O(T_s) \rtimes W_s \otimes \text{End}_C(V_\mu)$, namely

$$\alpha_{(w, \gamma)}(xv \otimes h) = \chi^{-1}(x) \text{w}_{xvw^{-1}} \otimes J(\gamma, \omega \otimes \chi^{-1}) \circ h \circ J(\gamma, \omega \otimes \chi^{-1})^{-1},$$

where $xv \in X^*(T_s) \rtimes W_s$. It follows from [Lus3, §1.4] that $\phi_{q_s}$ and $\phi_1$ are now $\text{Stab}(s)^+$-equivariant.

**Lemma 4.2.** The $O(T_s)^{W_s}$-algebra homomorphisms $\phi_{q_s}$ and $\phi_1$ from (42) are spectrum preserving with respect to filtrations, in the sense of [ABPS7].

---

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Proof. It suffices to consider the map $\phi_{q_1}$, for the same reasoning will apply to $\phi_1$. Our argument is a generalization of [BaNi, Theorem 10], which proves the analogous statements for $J(X^*(T_i) \rtimes W(R_i))$. Recall the function

$$a : X^*(T_s) \rtimes W_s \to \mathbb{Z}_{\geq 0}$$

from [Lus3, §1.3]. For fixed $n \in \mathbb{Z}_{\geq 0}$, the subspace of $J(X^*(T_i) \rtimes W(R_i))$ spanned by the $t_{xv}$ with $a(xv) = n$ is a two-sided ideal, let us call it $J^{i,n}$. Then

$$J(X^*(T_i) \rtimes W(R_i)) = \bigoplus_{n \geq 0} J^{i,n}$$

and the sum is finite by [Lus1, §7]. Moreover

$$H^{i,n} := \phi^{-1}_{1,q} \left( \bigoplus_{k \geq n} J^{i,k} \right)$$

is a two-sided ideal of $H(T_s, W(R_i), q)$. According to [Lus2, Corollary 3.6] the morphism of $O(T_{s})^{W(R_i)}$-algebras

$$\bigotimes_i \left( H^{i,n}/H^{i,n+1} \right) \to J^{i,n}$$

induced by $\phi_{1,q}$ is spectrum preserving, and that every irreducible $J^{i,n}$-module $M^i_j$ has a distinguished quotient $M^i_H$, which is an irreducible $H^{i,n}/H^{i,n+1}$-module.

Let $\mathbf{n}$ be a vector with coordinates $n_i \in \mathbb{Z}_{\geq 0}$ and put $|\mathbf{n}| = \sum_i n_i$. We write $\mathbf{n} \leq \mathbf{n}'$ if $n_i \leq n'_i$ for all $i$. We define the two-sided ideals

$$J^\mathbf{n} := \bigotimes_i J^{i,n_i} \otimes \text{End}_\mathbb{C}(V_{\mu}) \subset J(X^*(T_s) \rtimes W_s) \otimes \text{End}_\mathbb{C}(V_{\mu}),$$

$$\mathcal{H}^\mathbf{n} := \bigotimes_i \mathcal{H}^{i,n_i} \otimes \text{End}_\mathbb{C}(V_{\mu}) \subset \mathcal{H}(T_s, W_s, q) \otimes \text{End}_\mathbb{C}(V_{\mu}),$$

$$\mathcal{H}^{\mathbf{n}+} := \bigoplus_{n' \geq n, |n'| = |n|+1} \mathcal{H}^{n'}.$$ 

It follows from the above that the morphism of $O(T_{s})^{W}$-algebras

$$\bigotimes_i (H^{i,n}/H^{i,n+1}) \otimes \text{End}_\mathbb{C}(V_{\mu}) \cong \mathcal{H}^{\mathbf{n}}/\mathcal{H}^{\mathbf{n}+} \to J^\mathbf{n}$$

induced by $\phi_{q_1}$ is spectrum preserving, and that every irreducible $J^\mathbf{n}$-module $M^\mathbf{n}_j$ has a distinguished quotient $M^\mathbf{n}_H$ which is an irreducible $\mathcal{H}^{\mathbf{n}}/\mathcal{H}^{\mathbf{n}+}$-module.

Next we define, for $n \in \mathbb{Z}_{\geq 0}$:

$$J^n := \bigoplus_{|\mathbf{n}|=n} J^\mathbf{n}, \quad \mathcal{H}^n := \bigoplus_{|\mathbf{n}|=n} \mathcal{H}^\mathbf{n}. \quad (50)$$

The aforementioned properties of the map (49) are also valid for

$$\mathcal{H}^{n}/\mathcal{H}^{n+1} \to J^{n}, \quad (51)$$

which shows that $\phi_{q_1}$ is spectrum preserving with respect to the filtrations $(\mathcal{H}^{n})_{n \geq 0}$ and $(\bigoplus_{m \geq n} J^m)_{n \geq 0}$.
By Lemma 4.1 and (17)
\[
\begin{align*}
(H(T_s, W_s, q_s) \otimes \text{End}_\mathbb{C}(V_\mu))^L(s) & \otimes \mathfrak{H}_s^2, \\
(J(X^*(T_s) \times W_s) \otimes \text{End}_\mathbb{C}(V_\mu))^L(s) & \otimes \mathfrak{H}_s^2, \\
(O(T_s) \times W_s \otimes \text{End}_\mathbb{C}(V_\mu))^L(s) & \otimes \mathfrak{H}_s^2
\end{align*}
\]
(52)
are unital finite type $O(T_s)^{\text{Stab}(s)}$-algebras, while $\phi_{q_s}$ and $\phi_1$ provide morphisms between them.

**Theorem 4.3.** (a) The above morphisms between the $O(T_s)^{\text{Stab}(s)}$-algebras (52) are spectrum preserving with respect to filtrations.

(b) The same holds for the three algebras of (52) with $T_s^d$ instead of $T_s$.

**Proof.** (a) We use the notations from the proof of Lemma 4.2. Since Lusztig’s $a$-function is constant on two-sided cells [Lus3, §1.3] and conjugation by elements of $\mathfrak{H}_s^2$ preserves the set of simple (affine) reflections in $X^*(T_s) \times W_s$:
\[
a(wxvw^{-1}) = a(xv) \text{ for all } x \in X^*(T_s), v \in W_s, w \in \mathfrak{H}_s^2.
\]
Hence $J^n$ and $H^n$ are stable under the respective actions $\alpha$ and (51) is $\text{Stab}(s)^+$-equivariant. Let $M_J$ be an irreducible $J^n$-module and regard it as a $(J^n)^L(s)$-module via the map $J^n \to J^n$ from (50). By Clifford theory (see [RaRa, Appendix]) its decomposition is governed by a twisted group algebra of the stabilizer of $M_J$ in $X^L(s)$. Since (51) is $X^L(s)$-equivariant and $M_H$ is a quotient of $M_J$, the decomposition of $M_H$ as module over $(H^n/H^{n+1})X^L(s)$ is governed by the same twisted group algebra in the same way. Therefore (51) restricts to a spectrum preserving morphism of $O(T_s)^{W_s \times X^L(s)}$-algebras
\[
(H^n/H^{n+1})X^L(s) \to (J^n)^L(s).
\]
Now a similar argument with Clifford theory for crossed product algebras shows that
\[
(H^n/H^{n+1})X^L(s) \otimes \mathfrak{H}_s^2 \to (J^n)^L(s) \otimes \mathfrak{H}_s^2
\]
is a spectrum preserving morphism of $O(T_s)^{\text{Stab}(s)}$-algebras. By definition [BaNi, §5], this means that the map
\[
\phi_{q_s} : (H(T_s, W_s, q_s) \otimes \text{End}_\mathbb{C}(V_\mu))^L(s) \otimes \mathfrak{H}_s^2 \to (J(X^*(T_s) \times W_s) \otimes \text{End}_\mathbb{C}(V_\mu))^L(s) \otimes \mathfrak{H}_s^2
\]
(53)
induced by $\phi_{q_s}$ is spectrum preserving with respect to filtrations.

The same reasoning is valid with $O(T_s) \times W_s$ instead of $H(T_s, W_s, q_s)$ – it is simply the case $q_s = 1$ of the above.
Theorem 4.4. \[ H \text{ are stratified equivalent (see [ABPS7]) to much simpler algebras. Recall the }
\]
With Theorem 4.3 we can show that the Hecke algebras for \( G \) identified with \( \mathcal{T} \). Here that \( T \) comes only from its action on the torus \( X \). Hence these three algebras do not change if we replace \( T \) by \( (54) \). Equivalently, we may replace \( T \) by \( T \times X \). It follows that
\[
(\mathcal{H}(T, W, q_\lambda) \otimes \text{End}_C(V_\mu))^{X(G)} \times \mathcal{N}_T^e \cong \\
(\mathcal{O}(X_n^e(Z(G))) \otimes \mathcal{H}(T, W, q_\lambda) \otimes \text{End}_C(V_\mu))^{X(G)} \times \mathcal{N}_T^e.
\]
The other two algebras in \( (52) \) can be rewritten similarly. By \( (41) \) the morphisms \( \phi_{q_\lambda} \) and \( \phi_\lambda \) fix the respective subalgebras \( \mathcal{O}(X_n^e(Z(G))) \) pointwise. It follows that \( (53) \) decomposes as
\[
\phi_{q_\lambda} \otimes \text{id} : (\mathcal{H}(T, W, q_\lambda) \otimes \text{End}_C(V_\mu))^{X(G)} \times \mathcal{N}_T^e \otimes \mathcal{O}(X_n^e(Z(G))) \\
(\mathcal{O}(T, W, q_\lambda) \otimes \text{End}_C(V_\mu))^{X(G)} \times \mathcal{N}_T^e \otimes \mathcal{O}(X_n^e(Z(G))).
\]
and similarly for \( \phi_\lambda \). From part (a) we know that \( \phi_{q_\lambda} = \phi_{q_\lambda} \otimes \text{id} \) and \( \phi_\lambda = \phi_\lambda \otimes \text{id} \) are spectrum preserving with respect to filtrations. So \( \phi_{q_\lambda} \) and
\[
\phi_\lambda : (\mathcal{O}(T, W, q_\lambda) \otimes \text{End}_C(V_\mu))^{X(G)} \times \mathcal{N}_T^e \\
(\mathcal{O}(T, W, q_\lambda) \otimes \text{End}_C(V_\mu))^{X(G)} \times \mathcal{N}_T^e.
\]
have that property as well.

With Theorem 4.3 we can show that the Hecke algebras for \( G \) and for \( G^e(Z(G)) \) are stratified equivalent (see [ABPS7]) to much simpler algebras. Recall the subgroup \( H \subset L \) from [ABPS4, Lemma 3.3].

**Theorem 4.4.** (a) The algebra \( \mathcal{H}(G^e(Z(G))^e \) is stratified equivalent with
\[
\bigoplus_{1}^{[L:H]} (\mathcal{O}(T, W, q_\lambda))^{X(G)} \times W^e.
\]
Here the action of \( w \in W^e \) is \( \alpha(w, \gamma) \) (as in Theorem 3.3) for any \( \gamma \in \text{Irr}(L/L^2Z(G)) \) such that \( (w, \gamma) \in \text{Stab}(s) \).
(b) The algebra \( \mathcal{H}(G^\sharp)^{\#} \) is stratified equivalent with

\[
\bigoplus_{1}^{[L,H_{\lambda}]} (\mathcal{O}(T_{s}^\sharp) \otimes \text{End}_{\mathbb{C}}(V_{\mu}))^{X^{L}(s)} \times W_{s}^1,
\]

with respect to the same action of \( W_{s}^1 \).

Remark. In principle one could factorize the above algebras according to single Bernstein components for \( G^\sharp Z(G) \) and \( G^\sharp \). However, this would result in less clear formulas.

Proof. (a) Recall from Theorem 3.1 that \( \mathcal{H}(G^\sharp Z(G))^{\#} \) is Morita equivalent with

\[
\bigoplus_{1}^{[L,H_{\lambda}]} \mathcal{H}(T_{s}, W_{s}, q_{\lambda}) \otimes \text{End}_{\mathbb{C}}(V_{\mu})^{X^{L}(s)} \times \mathfrak{g}_{s}^1.
\]  

Consider the sequence of algebras

\[
(\mathcal{H}(T_{s}, W_{s}, q_{\lambda}) \otimes \text{End}_{\mathbb{C}}(V_{\mu}))^{X^{L}(s)} \times \mathfrak{g}_{s}^1 \\
\rightarrow (J(X^{*}(T_{s}) \rtimes W_{s}) \otimes \text{End}_{\mathbb{C}}(V_{\mu}))^{X^{L}(s)} \times \mathfrak{g}_{s}^1 \quad (56) \\
= (J(X^{*}(T_{s}) \rtimes W_{s}) \otimes \text{End}_{\mathbb{C}}(V_{\mu}))^{X^{L}(s)} \times \mathfrak{g}_{s}^1 \\
\leftarrow (\mathcal{O}(T_{s}) \rtimes W_{s} \otimes \text{End}_{\mathbb{C}}(V_{\mu}))^{X^{L}(s)} \times \mathfrak{g}_{s}^1.
\]

In Theorem 4.3.a we proved that the map between the first two lines is spectrum preserving with respect to filtrations. The equality sign does nothing on the level of \( \mathbb{C} \)-algebras, but we use it to change the \( \mathcal{O}(T_{s})^{\text{Stab}(s)} \)-module structure, such that the map from

\[
(\mathcal{O}(T_{s}) \rtimes W_{s} \otimes \text{End}_{\mathbb{C}}(V_{\mu}))^{X^{L}(s)} \times \mathfrak{g}_{s}^1
\]

becomes \( \mathcal{O}(T_{s})^{\text{Stab}(s)} \)-linear. By Theorem 4.3.a that map is also spectrum preserving with respect to filtrations.

Every single step in the above sequence is an instance of stratified equivalence from [ABPS7] (the second step by definition), so \( \mathcal{H}(G^\sharp Z(G))^{\#} \) is stratified equivalent with a direct sum of \( [L : H_{\lambda}] \) copies of \( (57) \). Since \( \chi_{\gamma} \in T_{s} \) in \( (47) \) is \( W_{s} \)-invariant, the actions of \( X^{L}(s) \) and \( W_{s} \) on \( \mathcal{O}(T_{s}) \otimes \text{End}_{\mathbb{C}}(V_{\mu}) \) commute. This observation and \( (14) \) allow us to identify \( (57) \) with

\[
((\mathcal{O}(T_{s}) \otimes \text{End}_{\mathbb{C}}(V_{\mu}))^{X^{L}(s)} \times W_{s}) \times \mathfrak{g}_{s}^1 = (\mathcal{O}(T_{s}) \otimes \text{End}_{\mathbb{C}}(V_{\mu}))^{X^{L}(s)} \times W_{s}^2. 
\]

The description of the action of \( W_{s}^2 \) can be derived from Theorem 3.3.

(b) This follows from Theorem 3.2 and the same proof as for part (a).
5 Extended quotients for inner forms of GL_n

It turns out that via (33) any Bernstein component for $G$ can be described in a canonical way with an extended quotient. Before we prove that, we recall the parametrization of irreducible representations of $\mathcal{H}(T_s, W_s, q_s)$.

Let $\tilde{G}_s$ be the complex reductive group with root datum $(X^*(T_s), \mathcal{R}_s, X_*(T_s), \mathcal{R}_s^\vee)$, it is isomorphic to $\prod GL_{m_i}(\mathbb{C})$, embedded in $\tilde{G} = GL_{md}(\mathbb{C})$ as

$$\tilde{G}_s = Z_{\tilde{G}}(\tilde{L}) = Z_{GL_{md}(\mathbb{C})}(\prod GL_{m_i}(\mathbb{C})^{e_i}).$$

Recall that a Kazhdan–Lusztig triple for $\tilde{G}_s$ consists of:

• a unipotent element $u = \prod_i u_i \in \tilde{G}_s$;

• a semisimple element $t_q \in \tilde{G}_s$ with $t_q u t_q^{-1} = u^{q_0} := \prod_i u_i^{q_0}$;

• a representation $\rho_q \in \text{Irr}(\pi_0(Z_{\tilde{G}_s}(t_q, u)))$ which appears in the homology of variety of Borel subgroups of $\tilde{G}_s$ containing $\{t_q, u\}$.

Typically such a triple is considered up to $\tilde{G}_s$-conjugation, we denote its equivalence class by $[t_q, u, \rho_q]_{\tilde{G}_s}$. These equivalence classes parametrize $\text{Irr}(\mathcal{H}(T_s, W_s, q_s))$ in a natural way, see [KaLu]. We denote that by

$$[t_q, u, \rho_q]_{\tilde{G}_s} \mapsto \pi(t_q, u, \rho_q). \quad (59)$$

Recall from [ABPS6, §7] that an affine Springer parameter for $\tilde{G}_s$ consists of:

• a unipotent element $u = \prod_i u_i \in \tilde{G}_s$;

• a semisimple element $t \in Z_{\tilde{G}_s}(u)$;

• a representation $\rho \in \text{Irr}(\pi_0(Z_{\tilde{G}_s}(t, u)))$ which appears in the homology of variety of Borel subgroups of $\tilde{G}_s$ containing $\{t, u\}$.

Again such a triple is considered up to $\tilde{G}_s$-conjugacy, and then denoted $[t, u, \rho]_{\tilde{G}_s}$. Kato [Kat] established a natural bijection between such equivalence classes and $\text{Irr}(\mathcal{O}(T_s) \rtimes W_s)$, say

$$[t, u, \rho]_{\tilde{G}_s} \mapsto \tau(t, u, \rho). \quad (60)$$

For a more explicit description, we note that $Z_{\tilde{G}_s}(t)$ is a connected reductive group with Weyl group $W_{s,t}$, and that $(u, \rho)$ represents a Springer parameter for $W_{s,t}$. Via the classical Springer correspondence

$$(u, \rho) \text{ determines an irreducible } W_{s,t}\text{-representation } \pi(u, \rho). \quad (61)$$

Then [Kat] and (60) work out to

$$\tau(t, u, \rho) = \text{ind}_{\mathcal{O}(T_s) \rtimes W_s}(C_t \otimes \pi(u, \rho)). \quad (62)$$

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From [KaLu, §2.4] we get a canonical bijection between Kazhdan–Lusztig triples and affine Springer parameters:

\[ [t, u, \rho \gamma] \leftrightarrow [t, u, \rho] \mathcal{G}_s. \]  

(63)

Basically it adjusts \( t \) in a minimal way so that it commutes with \( u \), and then there is only one consistent way to modify \( \rho \gamma \) to \( \rho \).

Via Lemma 4.2 the algebra homomorphisms (42) give rise to a bijection

\[ \text{Irr}(\mathcal{H}(T_s, W_s, q_s)) \leftrightarrow \text{Irr}(\mathcal{O}(T_s) \times W_s). \]  

(64)

We showed in [ABPS6, (90)] that (64) is none other than the composition of (63) with (60) and the inverse of (59):

\[ \pi(t, u, \rho) \leftrightarrow \tau(t, u, \rho). \]  

(65)

**Theorem 5.1.** The Morita equivalence \( \mathcal{H}(G)^s \sim_M \mathcal{H}(T_s, W_s, q_s) \) and (64) give rise to a bijection

\[ \text{Irr}^s(G) \leftrightarrow T_s//W_s \]  

(66)

with the following properties:

1. Let \( T_{s, \text{un}} \) be the maximal compact subtorus of \( T_s \) and let \( \text{Irr}_{\text{temp}}(G) \subset \text{Irr}(G) \) be the subset of tempered representations. Then (66) restricts to a bijection \( \text{Irr}_{\text{temp}}^s(G) \leftrightarrow T_{s, \text{un}}//W_s \).

2. (66) can be obtained from its restriction to tempered representations by analytic continuation, as in [ABPS1]. For instance, suppose that \( \sigma \in \text{Irr}_{\text{temp}}^s(L') \) for some standard parabolic \( P' = L'U' \supset P = LU \), and that \( I_{P'}^{L'}(\sigma \otimes \chi) \) is mapped to \( \tau(t \chi, u, \rho) \) for almost all unitary \( \chi \in X_{nr}(L') \). Then, whenever \( \chi_{nr}(L') \) and \( I_{P'}^{L'}(\sigma \otimes \chi) \) is irreducible, it is mapped to \( \tau(t \chi, u, \rho) \).

3. If \( \pi \in \text{Irr}_{\text{temp}}^s(G) \) is mapped to \([t, \rho'] \in T_{s, \text{un}}//W_s\) and has cuspidal support \( W_s \sigma \in T_s//W_s \), then \( W_s \) is the unitary part of \( W_s \sigma \), with respect to the polar decomposition

\[ T_s = T_{s, \text{un}} \times \text{Hom}_\mathbb{Z}(X^*(T_s), \mathbb{R}_{>0}). \]

4. In the notation of (3), suppose that the parameter of \( \rho' \in \text{Irr}(W_{s, A}) \) in the classical Springer correspondence (61) involves a unipotent class \( [u] \) which is distinguished in a Levi subgroup \( \tilde{M} \subset Z_{\mathcal{G}_s}(t) \). Then \( \pi = I_{\tilde{P}_{\tilde{M}}}(\delta) \), where \( \tilde{M} \supset L \) is the unique standard Levi subgroup of \( G \) corresponding to \( \tilde{M} \) and \( \delta \in \text{Irr}_{\text{temp}}^s(M) \) is square-integrable modulo centre.

Moreover (66) is the unique bijection with the properties (1)–(4).
Proof. The Morita equivalence \((33)\) gives a bijection
\[
\text{Irr}^\circ(G) \leftrightarrow \text{Irr}(H(T_s, W_s, q_s)).
\] (67)

Via Lemmas 4.2 and A.1 the right hand side is in bijection with
\[
\text{Irr}(O(T_s) \times W_s) \cong T_s/W_s.
\] (68)

In this way we define the map \((66)\). (1) It is easy to check from [SéC, Théorème 4.6] and [SéSt2, Theorem C] that the Morita equivalence \(H(G)^e \sim_{\text{ad}} H(T_s, W_s, q_s)\) preserves the canonical involution and trace (maybe up to a positive scalar). Accepting that, [DeOp, Theorem 10.1] says that the ensuing bijection between \(\text{Irr}^\circ(G)\) and \(\text{Irr}(H(T_s, W_s, q_s))\) respects the subsets of tempered representations. By [ABPS6, Proposition 9.3] the latter subset corresponds to the set of Kazhdan–Lusztig triples such that the \(t\) in \((63)\) lies in \(T_s\).un.

(2) Consider the bijection \((64)\) and its formulation \((65)\). Here the representations are tempered if and only if \(t \in T_s\) is unitary. Thus \((65)\) for tempered representations determines the bijection \((64)\), by analytic continuation (in the parameters \(t\) and \(t_q\)) of the formula. The relation between \(\text{Irr}^\circ(G)\) and \(\text{Irr}_{\text{temp}}^\circ(G)\) is similar, see [ABPS1, Proposition 2.1]. Hence \((67)\) is also can be deduced from its restriction to tempered representations, with the method from [ABPS1, §4].

(3) In [SéC, Théorème 4.6] a \(\mathfrak{g}_L\)-type \((K_L, \lambda_L)\) is constructed, with
\[
e_{\lambda_L} H(L)e_{\lambda_L} \cong O(T_s) \otimes \text{End}_C(V_\lambda).
\]
It [SéSt2] it is shown that it admits a cover \((K_G, \lambda_G)\) with
\[
e_{\lambda_G} H(G)e_{\lambda_G} \cong H(T_s, W_s, q_s) \otimes \text{End}_C(V_\lambda),
\]
see also [ABPS4, §4.1]. It follows from [ABPS4, Proposition 3.15] that \((67)\) arises from this cover of a \(\mathfrak{g}_L\)-type. With [BuKu, §7] this implies that \((66)\) translates the cuspidal support of a \((\pi, V_\pi) \in \text{Irr}^\circ(G)\) to the unique \(W_s t_q \in T_s/W_s\) such that \(e_{\lambda_G} V_\pi\) is a subquotient of \(\text{ind}^{H(T_s, W_s, q_s)}_{O(T_s)}(C_{t_q}) \otimes V_\lambda\). It follows from [ABPS6, (33) and Lemma 7.1] that the bijection \((65)\) sends any tempered irreducible subquotient of \(\text{ind}^{H(T_s, W_s, q_s)}_{O(T_s)}(C_{t_q})\) to an irreducible \(O(T_s) \times W_s\)-representation with \(O(T_s)\)-weights \(W_s(t_q |t_q|^{-1})\). The associated element of \(T_s/W_s\) is then \([t = t_q |t_q|^{-1}, \rho]\) with \(\rho \in \text{Irr}(W_s\lambda)\).

(4) Since \(W_{s,\lambda}\) is a direct product of symmetric groups, the representations \(\rho'\) of the component groups in the Springer parameters are all trivial. By \((61)\), \((62)\) and \((65)\) the \(H(T_s, W_s, q_s)\)-representation associated to \([t, \rho]\) is \(\pi(t_q, u, \text{triv})\). Then \((t_q, u, \text{triv})\) is also a Kazhdan–Lusztig triple for \(H(T_s, W_s, q_s)\) and by [KaLu, §7.8]
\[
\pi(t_q, u, \text{triv}) = \text{ind}^{H(T_s, W_s, q_s)}_{M}(t_q, u, \text{triv}).
\]
By [ABPS6, Proposition 9.3] (see also [KaLu, Theorem 8.3]) \( \pi_M(t_q, u, \text{triv}) \) is essentially square-integrable and tempered, that is, square-integrable modulo centre.

Since \((K_G, \lambda_G)\) is a a cover of \([L, \omega]_{M}\text{-type } (K_M, \lambda_M)\) which covers \((K_L, \lambda_L)\) and is covered by \((K_G, \lambda_G)\). By [ABPS6, Proposition 16.6] \( \pi_M(t_q, u, \text{triv}) \) corresponds to a \(M\)-representation \(\delta\) which is square-integrable modulo centre. By [BuKu, Corollary 8.4] the bijection (67) respects parabolic induction, so \(\pi(t_q, u, \text{triv})\) corresponds to \(I^G_{PM}(\delta)\).

Now we check that (66) is canonical in the specified sense. By (1) and (2) it suffices to do so for tempered representations. For \(\pi \in \text{Irr}_{\text{temp}}^s(G)\), property (3) determines the \(W_\pi\)-orbit \(W_\pi t\). Fix a \(t\) in this orbit. By a result of Harish-Chandra [Wal, Proposition III.4.1] there are a Levi subgroup \(M \subset G\) containing \(L\) and a square-integrable (modulo centre) representation \(\delta \in \text{Irr}(M)\) such that \(\pi\) is a subquotient of \(I^G_{PM}(\delta)\). Moreover \((M, \delta)\) is unique up to conjugation.

For \(t \in T_{s, \text{un}}\), \(W_{\pi t}\) is a product of symmetric groups \(S_e\) and \(Z_{G_e}(t)\) is a product of groups of the form \(\text{GL}_e(\mathbb{C})\). Hence the Springer correspondence for \(W_{\pi t}\) is a bijection between \(\text{Irr}(W_{\pi t})\) and unipotent classes in \(Z_{G_e}(t)\). Every Levi subgroup of \(\text{GL}_e(\mathbb{C})\) has a unique distinguished unipotent class, and these exhaust the unipotent classes in \(\text{GL}_e(\mathbb{C})\). Hence \(\text{Irr}(W_{\pi t})\) is also in canonical bijection with the set of conjugacy classes of Levi subgroups \(M \subset Z_{G_e}(t)\).

Viewed in this light, properties (3) and (4) entail that for every pair \((M, t)\) as above there is precisely one square-integrable modulo centre \(\delta \in \text{Irr}(M)\) such that \(W_{\pi t}\) is the unitary part of the cuspidal support of \(I^G_{PM}(\delta)\). Thus (3) and (4) determine the (tempered) \(G\)-representation associated to \([l, \rho] \in T_{s, \text{un}}/W_\pi\).

\section{Twisted extended quotients for inner forms of \(SL_n\)}

Twisted extended quotients appear naturally in the description of the Bernstein components for \(L^2(Z(G))\) and \(L^2\).

\textbf{Lemma 6.1.} Let \(\mathfrak{s}_L = [L, \omega]_L\) and define a two-cocycle \(\kappa_\omega\) by (11).

(a) Equation (13) for \(L\) determines bijections

\[
(T_{s}/X^L(\mathfrak{s}))_{\kappa_\omega} \to \text{Irr}^{\text{at}} (L^2(Z(G))),
\]

\[
(T_{s}/X^L(\mathfrak{s})X_{\text{un}}(L/L^2))_{\kappa_\omega} = (T_{s}/X^L(\mathfrak{s})X_{\text{un}}(L^2Z(G)/L^2)) \to \text{Irr}^{\text{at}}(L^2).
\]

(b) The induced maps

\[
\text{Irr}^{\text{at}}(L^2Z(G)) \to T_{s}/X^L(\mathfrak{s}) \quad \text{and} \quad \text{Irr}^{\text{at}}(L^2) \to T_{s}/X^L(\mathfrak{s})X_{\text{un}}(L/L^2)
\]

are independent of the choice of \(\kappa_\omega\).

(c) Let \(T_{s, \text{un}}\) be the real subtorus of unitary representations in \(T_s\). The subspace of tempered representations \(\text{Irr}^{\text{at}}_{\text{temp}}(L^2Z(G))\) corresponds to \((T_{s, \text{un}}/X^L(\mathfrak{s}))_{\kappa_\omega}\). Similarly \(\text{Irr}^{\text{at}}_{\text{temp}}(L^2)\) is obtained by restricting the second line of part (a) to \(T_{s, \text{un}}\).
The subgroup \( X^L(\omega, V_\mu) \) acts trivially on \( \mathcal{O}(T_\omega) \otimes \text{End}_C(V_\mu) \), and for that reason it can be pulled out of the extended quotient from Lemma 6.1.

**Lemma 6.2.** There are bijections

\[
(T_\omega // X^L(\omega, V_\mu))_{\kappa_\omega} \leftrightarrow (T_\omega // X^L(\omega, V_\mu))_{\kappa_\omega} \times \text{Irr}(X^L(\omega, V_\mu)),
\]

\[
(T_\omega // X^L(\omega, V_\mu))_{\kappa_\omega} \leftrightarrow (T_\omega // X)_{\kappa_\omega} \times \text{Irr}(X^L(\omega, V_\mu)),
\]

where \( X = X^L(\omega, V_\mu) \) acts trivially on \( \mathcal{O}(T_\omega) \otimes \text{End}_C(V_\mu) \), and for that reason it can be pulled out of the extended quotient from Lemma 6.1.

**Proof.** In Lemma 6.1.a we saw that \((T_\omega // X^L(\omega, V_\mu))_{\kappa_\omega}\) is in bijection with \(\text{Irr}(\mathcal{H}(L^2Z(G))^{\mu})\). By [ABPS4, (169)] \(\mathcal{H}(L^2Z(G))^{\mu}\) is Morita equivalent with \((\mathcal{H}(L)^{\mu})^{X^L(\omega)}\) and with the subalgebra

\[
\text{End}_C(e^\omega_L V_\omega) \cong \bigoplus_{\chi \in [L/H\lambda]} (\mathcal{O}(T_\omega) \otimes \text{End}_C(V_\mu))^{X^L(\omega, V_\mu)}. \tag{69}
\]

Here the \(X^L(\omega, V_\mu)\)-action on the middle term comes from an isomorphism

\[
\text{End}_C(e^\omega_L V_\omega) \cong \text{End}_C(V_\mu) \otimes \mathbb{C}[L/H\lambda] \otimes \mathbb{C}[L/H\lambda]^*.
\]

We recall that by [ABPS4, Lemma 3.5] there is a group isomorphism

\[
L/H\lambda \cong \text{Irr}(X^L(\omega, V_\mu)). \tag{70}
\]

By the above Morita equivalences, Lemma 6.1.a and Clifford theory, the set

\[
\{ \rho \in \text{Irr}(\mathbb{C}[X^L(\omega, V_\mu)]) : \rho|_{X^L(\omega, V_\mu)} = \text{triv} \} \tag{71}
\]

parametrizes the irreducible representations of \(69\) associated to a fixed \(\chi \in T_\omega\) and the trivial character of \(X^L(\omega, V_\mu)\).
For any $\chi \in T_s$, the $X^L(s)/X^L(\omega, V_\mu)$-stabilizer of the irreducible representation $C \otimes V_\mu$ of $O(T_s) \otimes \text{End}(V_\mu)$ is $X^L(\omega)/X^L(\omega, V_\mu)$. It follows that the irreducible representations of (69) with fixed $a \in [L/H_3]$ and fixed $O(T_s)$-character $\chi$ are in bijection with $\text{Irr}(\text{End}_C(V_\mu)^{X^L(\omega)/X^L(\omega, V_\mu)})$. Comparing with (71), we see that every irreducible representation of $C[X^L(\omega)/X^L(\omega, V_\mu), \kappa_\omega]$ appears in $V_\mu$. This is equivalent to each irreducible representation of $\text{End}_C(V_\mu) \times X^L(\omega)/X^L(\omega, V_\mu)$ having nonzero vectors fixed by $X^L(\omega)/X^L(\omega, V_\mu)$. Thus Lemma A.2 can be applied to $X^L(\omega)/X^L(\omega, V_\mu)$ acting on $O(T_s) \otimes \text{End}_C(V_\mu)$, and it shows that the irreducible representations on the right hand side of (69) are in bijection with

$$(T_s/X^L(s)/X^L(\omega, V_\mu))_{\kappa_\omega} \times \text{Irr}(X^L(\omega, V_\mu)).$$

The second bijection follows by dividing out the free action of $X_{nr}(L^2Z(G)/L^2)$, as in the proof of Lemma 6.1.a.

As a result of the work in Section 4, twisted extended quotients can also be used to describe the spaces of irreducible representations of $G^Z(\mu)$.

Let us extend $\kappa_\omega$ to a two-cocycle of $\text{Stab}(s)$, trivial on the normal subgroup $W_s \times X^L(\omega, V_\mu)$, by

$$J(\gamma, \omega)J(\gamma', \omega) = \kappa_\omega(\gamma, \gamma')J(\gamma \gamma', \omega) \quad \gamma, \gamma' \in X^G(s).$$

Theorem 6.3. (a) Lemmas A.1 and A.2 gives rise to bijections

$$(T_s/\text{Stab}(s)/X^L(\omega, V_\mu))_{\kappa_\omega} \rightarrow \text{Irr}((O(T_s) \otimes \text{End}_C(V_\mu))^{X^L(s)} \times W_3^2),$$

$$(T_s/\text{Stab}(s)X_{nr}(L/L^2)/X^L(\omega, V_\mu))_{\kappa_\omega} \rightarrow \text{Irr}((O(T_s) \otimes \text{End}_C(V_\mu))^{X^L(s)} \times W_3^2).$$

(b) The stratified equivalences from 4.4 provide bijections

$$(T_s/\text{Stab}(s))_{\kappa_\omega} \rightarrow (T_s/\text{Stab}(s)/X^L(\omega, V_\mu))_{\kappa_\omega} \times \text{Irr}(X^L(\omega, V_\mu)) \rightarrow \text{Irr}^s(G^Z(\mu)),$$

$$(T_s/\text{Stab}(s)X_{nr}(L/L^2))_{\kappa_\omega} \rightarrow (T_s/\text{Stab}(s)X_{nr}(L/L^2))_{\kappa_\omega} \times \text{Irr}(X^L(\omega, V_\mu)) \rightarrow \text{Irr}^{S}(G^2),$$

where $S = \text{Stab}(s)X_{nr}(L/L^2)/X^L(\omega, V_\mu)$.

(c) In part (b) $\text{Irr}^{\text{temp}}_s(G^Z(\mu))$ (respectively $\text{Irr}^{\text{temp}}_s(G^2)$) corresponds to the same extended quotient, only with $T_{s,\text{un}}$ instead of $T_s$.

Proof. In each of the three parts the second claim follows from the first upon dividing out the action of $X_{nr}(L^2Z(G)/L^2)$, like in Lemma 6.1.a

(a) In the proof of Lemma 6.2 we exhibited a bijection

$$(T_s/\text{Stab}(s)/X^L(\omega, V_\mu))_{\kappa_\omega} \leftrightarrow \text{Irr}((O(T_s) \otimes \text{End}_C(V_\mu))^{X^L(s)}).$$

With Lemma A.2 we deduce a Morita equivalence

$$(O(T_s) \otimes \text{End}_C(V_\mu))^{X^L(s)} \sim_M (O(T_s) \otimes \text{End}_C(V_\mu)) \times (X^L(s)/X^L(\omega, V_\mu)).$$
In the notation of (98) this means that \( p := p_{X_L(s)/X_L(\omega, V_\mu)} \) is a full idempotent in the right hand side of (73), that is, the two-sided ideal it generates is the entire algebra. Then \( p \) is also full in

\[
(O(T_s) \otimes \text{End}_C(V_\mu)) \rtimes (\text{Stab}(s)/X_L(\omega, V_\mu)),
\]

which implies that (74) is Morita equivalent with

\[
p((O(T_s) \otimes \text{End}_C(V_\mu)) \rtimes (\text{Stab}(s)/X_L(\omega, V_\mu)))p \cong
(O(T_s) \otimes \text{End}_C(V_\mu))^{X_L(s)/X_L(\omega, V_\mu)} \rtimes (\text{Stab}(s)/X_L(s)).
\]

As a direct consequence of (14), (16) and (17),

\[
\text{Stab}(s)/X_L(s) \cong W_s^\sharp.
\]

In this way we reach the algebra featuring in part (a). By the above Morita equivalence, its irreducible representations are in bijection with those of (74). Apply Lemma A.1.a to the latter algebra.

(b) All the morphisms in (56) are spectrum preserving with respect to filtrations. In combination with the other remarks in the proof of Theorem 4.4.a this gives a bijection

\[
\text{Irr}^x(G^2Z(G)) \rightarrow \text{Irr}((O(T_s) \otimes \text{End}_C(V_\mu))^{X_L(s)} \rtimes W^\sharp_s) \times [L/H_\lambda].
\]

By part (a) and (70) the right hand side of (75) is in bijection with

\[
(T_s//X_L(\omega, V_\mu))_{\kappa_{\omega}} \times \text{Irr}(X_L(\omega, V_\mu)).
\]

The group \( X_L(s) \) acts on \( C[L] \) by pointwise multiplication of functions on \( L \). That gives rise to actions on \( C[L/H_\lambda] \) and on

\[
\text{End}_C(C[L/H_\lambda]) \cong C[L/H_\lambda] \otimes C[L/H_\lambda]^*.
\]

Regarding \( C[L/H_\lambda] \) as the algebra \( \bigoplus_{a \in [H/H_\lambda]} C \), (70) leads to an isomorphism

\[
(O(T_s) \otimes \text{End}_C(V_\mu))^{X_L(s)} \rtimes W^\sharp_s \otimes C[L/H_\lambda] \cong
(O(T_s) \otimes \text{End}_C(V_\mu \otimes C[L/H_\lambda]))^{X_L(s)} \rtimes W^\sharp_s.
\]

We note that (76) is also the space of irreducible representations of (77). In the proof of Lemma 6.2 we encountered a bijection

\[
(T_s//X_L(s))_{\kappa_{\omega}} \leftrightarrow \text{Irr}((O(T_s) \otimes \text{End}_C(V_\mu \otimes C[L/H_\lambda]))^{X_L(s)}).
\]

It implies a Morita equivalence

\[
(O(T_s)\otimes\text{End}_C(V_\mu\otimes C[L/H_\lambda]))^{X_L(s)} \sim_M (O(T_s)\otimes\text{End}_C(V_\mu\otimes C[L/H_\lambda])) \rtimes X_L(s).
\]
Just as in the proof of part (a), this extends to

\[
(\mathcal{O}(T_s) \otimes \text{End}_C(V_\mu \otimes \mathbb{C}[L/H_\lambda]))^{X^L(s)} \times W_2^s \sim_M (\mathcal{O}(T_s) \otimes \text{End}_C(V_\mu \otimes \mathbb{C}[L/H_\lambda])) \times \text{Stab}(s). \tag{78}
\]

Finally we apply Lemma A.1.a to the right hand side and we combine it with (78), (77) and (75).

(c) The first bijection in part (b) obviously preserves the subspaces associated to $T_{a,\text{un}}$. We need to show that the second bijection sends them to $\text{Irr}_{\text{temp}}(G^Z(G))$. This is a property of the geometric equivalences in Theorem 4.4, as we will now check.

We may and will assume that $\omega$ is unitary, or equivalently that it is tempered. The Morita equivalence between $\mathcal{H}(G^Z(G))^s$ and (55) is induced by an idempotent $e^1_{\lambda G^Z(G)} \in \mathcal{H}(G^Z(G))$, see Theorem 3.1. Its construction (which starts around (34)) shows that eventually it comes from a central idempotent in the algebra of a profinite group, so it is a self-adjoint element. Hence, by [BHK, Theorem A] this Morita equivalence preserves temperedness. The notion of temperedness in [BHK] agrees with temperedness for representations of affine Hecke algebras (see [Opd]) because both are based on the Hilbert algebra structure and the canonical tracial states on these algebras.

The sequence of algebras (56) is derived from its counterpart for $\mathcal{H}(T_s, W_\omega, q_\mu) \otimes \text{End}_C(V_\mu)$. By Theorem 5.1 that one matches tempered representations with $T_{a,\text{un}}/W_\omega$. By Clifford theory any irreducible representation $\pi$ of

\[
(\mathcal{H}(T_s, W_\omega, q_\mu) \otimes \text{End}_C(V_\mu))^{X^L(s)} \times \mathfrak{g}_2^s \tag{79}
\]

is contained in a sum of irreducible representations $\tilde{\pi}$ of $\mathcal{H}(T_s, W_\omega, q_\mu) \otimes \text{End}_C(V_\mu)$, which are all in the same $\text{Stab}(s)$-orbit. Temperedness of $\pi$ depends only on the action of the subalgebra $\mathcal{O}(T_s) \cong \mathbb{C}[X^*(T_s)]$, and in fact can already be detected on $\mathbb{C}[X]$ for any finite index sublattice $X \subset X^*(T_s)$. The analogous statement for (79) holds as well, with $X = X^*(T_s/X^L(s))$, and it is stable under the action of $\text{Stab}(s)$. Consequently $\pi$ is tempered if and only if $\tilde{\pi}$ is tempered.

These observations imply that the sequence of algebra homomorphisms (56) preserves temperedness of irreducible representations, and that it maps such representations of (79) to irreducible representations of (58) with $\mathcal{O}(T_s/X^L(s))$-weights in $T_{a,\text{un}}/X^L(s)$.

Now we invoke this property for every $a \in L/H_\lambda \cong \text{Irr}(X^L(\omega, V_\mu))$ and we deduce that the second map in part (b) has the required property with respect to temperedness.

We will work out what Theorem 6.3 says for a single Bernstein component of $G^Z$. To this end, we first analyse what parabolic induction from $L^Z$ to $G^Z$ looks like in the setting of Theorem 3.2.
The analogue of part (b) for \( L \) corresponds to induction from which shows that

\[
\text{Hom}
\]

Proof. Part (a) is a consequence of [ABPS4, (169)] and [ABPS4, Lemma 4.8], hence we may identify Hom

To see that it is true, we reduce with [ABPS4, Theorem 4.5] to the algebras desired claim for

Then we are in the situation where (a canonical anti-involution

We note that here, for a given algebra homomorphism \( \phi : A \to B \), we must use induction in the version \( \text{Ind}_B^A(M) = \text{Hom}_A(B, M) \). However, in all the cases we encounter \( B \) is free of finite rank as a module over \( A \) and it is endowed with a canonical anti-involution

Hence we may identify \( \text{Hom}_A(B, M) \equiv B^* \otimes_A M \equiv B \otimes_A M \). This shows the desired claim for \( I^G_B \).
this implies the analogue of (82) on the whole of Rep$^G_\kappa(L)$. In particular
\[ \text{Res}_{G_1}^G \circ I_P^G = I_P^{G_1} \circ \text{Res}_{L_2}^L \quad \text{as functors} \quad \text{Rep}^G_\kappa(L) \to \text{Rep}^G(G^\sharp). \] (80)

The functor $\text{Res}_{L_2}^L$ corresponds to $\text{Res}_{e_L^L H(L)} e_{L_2}^L$, and $\text{Res}_{G_1}^G$ to restriction from $e_{\lambda_G}^L \mathcal{H}(G)e_{\lambda_G}^L$ to $e_{\lambda_{G_1}}^L \mathcal{H}(G^\sharp)e_{\lambda_{G_1}}^L$, which is the algebra appearing in the statement of part (b).

The set $\mathcal{H}(W_s, q_b) \otimes \mathbb{C}[\mathfrak{R}_s^\natural]$ forms a basis for $e_{\lambda_G}^L \mathcal{H}(G)e_{\lambda_G}^L$ as a module over $e_{\lambda_L}^L \mathcal{H}(L)e_{\lambda_L}^L$ and for $e_{\lambda_{G_1}}^L \mathcal{H}(G^\sharp)e_{\lambda_{G_1}}^L$ as a module over $e_{\lambda_{L_1}}^L \mathcal{H}(L^\sharp)e_{\lambda_{L_1}}^L$. It follows that
\[ \text{Res}_{e_L^L H(L)} e_{L_2}^L \circ \text{ind}_{e_{L_2}^L H(L)} e_{L_1}^L = \text{ind}_{e_L^L H(L)} e_{L_1}^L \circ \text{Res}_{e_{L_1}^L H(L)} e_{L_2}^L. \] (81)

Comparing (80) and (81), we find that
\[ I_P^{G_1} \circ \text{Res}_{L_2}^L \quad \text{corresponds to} \quad \text{ind}_{e_{L_2}^L H(L)} e_{L_1}^L \circ \text{Res}_{e_{L_1}^L H(L)} e_{L_2}^L \] (82)
under the Morita equivalences from Theorems 3.2 and 6.4.a. Here both inductions can be constructed entirely in $\mathcal{H}(G^\sharp)$. The two sides of (82) are then related by applications of the idempotents $e_{L_2}^L$ and $e_{\lambda_G}^L$, which are supported on $G^\sharp$. Hence the correspondence (82) preserves $L^\sharp$-subrepresentations. Since every irreducible $L^\sharp$-representation appears as a summand of an $L$-representation, this implies the analogue of (82) on the whole of $\text{Rep}^G_\kappa(L^\sharp)$. \hfill $\Box$

Let $\mathfrak{t}^\sharp = [L^\sharp, \sigma^\sharp]_{G_1}$ be an inertial equivalence class for $L^\sharp$, with $\mathfrak{t}^\sharp \prec \mathfrak{s} = [L, \omega]_{G_1}$. We abbreviate $\mathfrak{f}_{\omega, X^L(\mathfrak{s})} = \{ \mathfrak{f}_{\omega, \gamma} : \gamma \in X^L(\mathfrak{s}) \}$, where $\mathfrak{f}_{\omega, \gamma}$ is as in Lemma 2.2. By (27) there is a unique $X^L(\mathfrak{s})$-orbit
\[ \mathfrak{f}_{\omega, X^L(\mathfrak{s})}\rho \subset \text{Irr}(\mathbb{C}[X^L(\omega), \kappa_\omega]) \] (83)
such that $T_{\mathfrak{t}^\sharp} = (T^\sharp_{\mathfrak{t}^\sharp} \times \mathfrak{f}_{\omega, X^L(\mathfrak{s})}\rho) / X^L(\mathfrak{s})$. Then $\mathfrak{f}_{\omega, X^L(\mathfrak{s})}\rho$ determines a unique summand $\mathbb{C}_\rho$ of $\mathbb{C}[L/H_L] \cong \bigoplus_{L/H_L} \mathbb{C}$, namely the irreducible representation of $X^L(\omega, V_\rho)$ obtained by restricting $\rho$. Let $V_{\mathfrak{t}^\sharp}$ be the intersection of $V_\mu$ with the subspace of $V_{\omega}$ on which $\sigma^\sharp$ is defined, and let $\mathfrak{R}_{\mathfrak{t}^\sharp}$ be its stabilizer in $\mathfrak{R}_{\mathfrak{s}}^\sharp$. Then $\mathfrak{R}_{\mathfrak{t}^\sharp}$ is also the stabilizer of $\mathfrak{t}^\sharp$ in $\mathfrak{R}_{\mathfrak{s}}^\sharp$ and
\[ W_{\mathfrak{t}^\sharp} = W_\omega \rtimes \mathfrak{R}_{\mathfrak{t}^\sharp}, \] (84)
by [ABPS4, Lemma 2.3]. Via the formula (72) the operators $J(\gamma, \omega)|_{V_{\mathfrak{s}_1}}$ determine a 2-cocycle $\kappa_\omega$ of the group
\[ W' = \{ (w, \gamma) \in \mathfrak{f}(\mathfrak{s}) : w \in W_{\mathfrak{t}^\sharp} \}. \] (85)
Since (72) is 1 on $W_s$, so is $\kappa_{\omega^s}$. By (15) $W'/X^L(s) \cong W_{\Omega}$. As $V_{\sigma t}$ is associated to the single $X^L(s)$-orbit (83), $\kappa_{\omega^s}(w,\gamma),(w',\gamma'))$ depends only on $(w,w')$. Thus it determines a 2-cocycle $\kappa_{\sigma t}$ of $W_{\Omega}$, which factors through $\mathcal{R}_{\Omega} \cong W_{\varepsilon}/W_s$.

**Lemma 6.5.** (a) The bijections in Theorem 6.3 restrict to

$$\text{Irr}^{\text{bf}}(G^2) \longleftrightarrow (T_{\Omega}/W_{\Omega})_{\kappa_{\sigma t}},$$

$$\text{Irr}^{\text{temp}}_{\Omega}(G^2) \longleftrightarrow (T_{\Omega,\text{un}}/W_{\Omega})_{\kappa_{\sigma t}},$$

where $T_{\Omega,\text{un}}$ denotes the space of unitary representations in $T_{\varepsilon}$. 

(b) Suppose $\pi \in \text{Irr}^{\text{bf}}_{\Omega}(G^2)$ corresponds to $[t,\rho]$ and has cuspidal support $W_{\Omega}(\chi \otimes \sigma^2) \subset T_{\Omega}/W_{\Omega}$. Then $W_{\varepsilon}t$ is the unitary part of $\chi \otimes \sigma^2$, with respect to the polar decomposition

$$T_{\varepsilon} = T_{\Omega,\text{un}} \times \text{Hom}_\mathbb{Z}(X^*(T_{\varepsilon}), \mathbb{R}_{>0}).$$

**Proof.** (a) Recall that $\text{Irr}^{\text{bf}}(G^2)$ consists of those irreducible representations that are contained in $I_{p_\varepsilon}^G(\chi \otimes \sigma^2)$ for some $\chi \otimes \sigma^2 \in T_{\Omega}$. In Theorem 6.4.b we translated $I_{p_\varepsilon}^G$ to induction between two algebras. The first one, Morita equivalent with $\mathcal{H}(L^1)^{\Omega_{\varepsilon}}$, was

$$\mathbb{C}[L/H_\lambda] \otimes \left( \mathcal{O}(T_{\varepsilon}^2) \otimes \text{End}_\mathbb{C}(V_{\mu}) \right)^{X^\varepsilon(s)}.$$

The second algebra, Morita equivalent with $\mathcal{H}(G^2)^{\Omega_{\varepsilon}}$, was

$$\mathbb{C}[L/H_{\lambda}] \otimes \left( \mathcal{H}(T_{\varepsilon}^2, W_{\varepsilon}, q_{\varepsilon}) \otimes \text{End}_\mathbb{C}(V_{\mu}) \right)^{X^\varepsilon(s)} \rtimes \mathcal{R}_{\varepsilon}^2.$$

As above, the $L^1$-representation $\sigma^2$ determines a summand $\mathbb{C}u$ of $\mathbb{C}[L/H_{\lambda}]$ and a $X^L(s)$-stable subspace $V_{\sigma t} \subset V_{\mu}$. Consequently $\mathcal{H}(L^1)^{[L^1,\sigma^2]}$ is Morita equivalent with the two algebras

$$\left( \mathcal{O}(T_{\varepsilon}^2) \otimes \text{End}_\mathbb{C}(V_{\sigma t}) \right)^{X^\varepsilon(s)} \text{ and } \left( \mathcal{O}(T_{\varepsilon}^2) \otimes \text{End}_\mathbb{C}(\mathcal{R}_{\varepsilon}^2, V_{\sigma t}) \right)^{X^\varepsilon(s)}.$$  

(86)

In these terms Theorem 6.4 shows that $\mathcal{H}(G^2)^{\Omega_{\varepsilon}}$ is is Morita equivalent with

$$\left( \mathcal{H}(T_{\varepsilon}^2, W_{\varepsilon}, q_{\varepsilon}) \otimes \text{End}_\mathbb{C}(\mathcal{R}_{\varepsilon}^2, V_{\sigma t}) \right)^{X^\varepsilon(s)} \rtimes \mathcal{R}_{\varepsilon}^2.$$  

(87)

Here the subspaces $wV_{\sigma t}$ with $w \in \mathcal{R}_{\varepsilon}^2$ are permuted transitively by $\mathcal{R}_{\varepsilon}^2$, so upon taking $\mathcal{R}_{\varepsilon}^2$-invariants only the $\mathcal{R}_{\varepsilon}$ on $V_{\sigma t}$ survives. Recall that, for any finite group $\Gamma$ and any $\Gamma$-algebra $A$:

$$A \rtimes \Gamma \cong \left( A \otimes \text{End}_\mathbb{C}(\mathbb{C}\Gamma) \right)^\Gamma.$$  

(88)
Applying (88) to (87) first with \( \Gamma = R_s \) and subsequently with \( \Gamma = R_t \) (in the opposite direction, taking the above transitivity into account), we find that (87) is Morita equivalent with

\[
(\mathcal{H}(T_s^2, W_s, q_s) \otimes \text{End}_C(V_{s!}))^{X^s(s)} \rtimes R_t.
\] (89)

The constructions in Section 4 restrict to stratified equivalences between (87) and

\[
(O(T_s^2) \otimes \text{End}_C(CR_s \cdot V_{s!}))^{X^s(s)} \rtimes W_t.
\] (90)

By (86)

\[
\text{Irr}((O(T_s^2) \otimes \text{End}_C(V_{s!}))^{X^s(s)}) \cong T_{st}.
\] (91)

As explained above with (85), the 2-cocycle \( \kappa_\omega \) of \( \text{Stab}(s) \) reduces to the 2-cocycle \( \kappa_{st} \) for the action of \( W_{st} \) in (90). Now we apply Lemma A.1.a to (90) and we find the first bijection. To obtain the second bijection, we use Theorem 6.3.c.

(b) For the stratified equivalence between

\[
\mathcal{H}(T_s^2, W_s, q_s) \otimes \text{End}_C(V_{s!}) \text{ and } O(T_s^2) \otimes \text{End}_C(V_{s!}) \rtimes W_s
\]

the analogous claim about the cuspidal support is property (3) of Theorem 5.1. Clifford theory relates the irreducible representations of these algebras to those of (87) and (90), in a way already discussed after (79). This implies that the desired property of the cuspidal support persists to the stratified equivalence between (87) and (90), which underlies part (a).

\[ \square \]

7 Relation with the local Langlands correspondence

We show how the local Langlands correspondence (LLC) for \( G \) and \( G^\sharp \) can be reconstructed in terms of twisted extended quotients.

Let \( W_F \) be the Weil group of the local non-archimedean field \( F \). Recall that the Langlands dual group of \( G = \text{GL}_m(D) \) is \( \check{G} = \text{GL}_{md}(C) \). A Langlands parameter for \( G \) is continuous group homomorphism \( \phi : W_F \times SL_2(C) \rightarrow \check{G} \) such that:

- \( \phi |_{\text{SL}_2(C)} \) is a homomorphism of algebraic groups.

- \( \phi(W_F) \) consists of semisimple elements.

- \( \phi \) is relevant for \( G \): if \( \check{L} \) is a Levi subgroup of \( \check{G} \) which contains \( \text{im}(\phi) \) and is minimal for that property, then (the conjugacy class of) \( \check{L} \) corresponds to (the conjugacy class of) a Levi subgroup of \( G \).
We denote the collection of Langlands parameters for $G$, modulo conjugation by $\tilde{G}$, by $\Phi(G)$.

Every smooth character of $G$ is of the form $\nu \circ \text{Nrd}$, with $\nu$ a smooth character of $F^\times$. Via Artin reciprocity it determines a Langlands parameter (trivial on $\text{SL}_2(C)$)

$$\hat{\nu} : W_F \to C^\times \cong Z(\text{GL}_{md}(C)). \quad (92)$$

For any $\phi \in \Phi(G)$, $\phi \hat{\nu}$ is a well-defined element of $\Phi(G)$ because the image of $\hat{\nu}$ is central in $\tilde{G}$.

**Theorem 7.1.** The local Langlands correspondence for $G$ is a canonical bijection

$$\text{rec}_{D,m} : \text{Irr}(G) \to \Phi(G)$$

with the following properties:

(a) $\pi \in \text{Irr}(G)$ is tempered if and only if $\text{rec}_{D,m}(\pi)$ is bounded, that is, if $\text{rec}_{D,m}(\pi)(W_F)$ is a bounded subset of $\tilde{G}$.

(b) The $L$-packet $\Pi_\phi(G)$ is the single representation $\text{rec}^{-1}_{D,m}(\phi)$.

(c) $\text{rec}_{D,m}$ is equivariant for the two actions of $\text{Irr}(G/G^\#)$: on $\text{Irr}(G)$ by twisting with smooth characters and on $\Phi(G)$ by multiplication with central Langlands parameters as in (92).

**Proof.** For the bijection and part (a) see [HiSa, §11] and [ABPS3, §2]. Ultimately it relies on the Jacquet–Langlands correspondence from [DKV, Bad]. Ultimately it relies on the Jacquet–Langlands correspondence from [DKV, Bad].

(b) This is a direct consequence of the bijectivity.

(c) Since $\text{rec}_{D,m}$ is determined completely by its behaviour on essentially square integrable representations of Levi subgroups of $G$ [ABPS3, (13)], it suffices to prove (c) for such representations. Via the Jacquet–Langlands correspondence the issue can be transferred to $\text{Irr}(\text{GL}_n(F))$ with $n \leq md$. For general linear groups (c) is a well-known property of the LLC, and in fact constitutes a starting point of the construction, confer [Hen, 1.2].

For $s = [L, \omega]_G$ we define $\Phi(G)^s$ as the image of $\text{Irr}(G)^s$ under the bijection $\text{rec}_{D,m}$. Similarly we define $\Phi(L)^s_{\{c\}} \subset \Phi(L)$.

**Lemma 7.2.** The LLC for $G$ fits in a commutative diagram of canonical bijections

$$\begin{array}{ccc}
\text{Irr}^s(G) & \xrightarrow{\text{rec}_{D,m}} & \Phi(G)^s \\
\downarrow & & \downarrow \\
T_s/\text{W}_s & \xrightarrow{\Phi(L)^s_{\{c\}}/\text{W}_s} & \Phi(L)^s_{\{c\}}/\text{W}_s
\end{array}$$

Here the bottom map comes from the LLC for $\text{Irr}^s_{\{c\}}(L)$ and the left hand side comes from Theorem 5.1.
Suppose that $[\phi_L] \in \Phi(L)^{\ddot{\mathfrak{z}}}$ and that $\rho \in \text{Irr}(W_{\mathfrak{s}, \phi_L})$ has as Langlands parameter a unipotent class $[u] \in Z_{G_{t}}(\phi_L)$. Then there is a representative $u$ such that the right hand side sends $[\phi_L, \rho]$ to a Langlands parameter $\phi$ with $\phi|_{W_{\rho}} = \phi_L|_{W_{\rho}}$ and $\phi(1, (1 \ 1)) = \phi_L(1, (1 \ 1))u$.

(b) Two elements $[t, \rho]$ and $[t', \rho']$ of $T_{s}/W_{s}$ map to the same $G$-representation if and only if there exists a $w \in W_{s}$ such that $wt = t'$ and the $W_{s,t}$-representations $\rho, w\rho'$ have Springer parameters involving the same unipotent class.

Proof. The top horizontal and left vertical maps have already been established as bijective and canonical. The LLC for $L$ is the Cartesian product of the LLCs for the factors of $L$. Hence it is $W(G, L)$-equivariant, and its restriction to $T_{s} \leftrightarrow \Phi(L)^{\ddot{\mathfrak{z}}}$ is $W_{s}$-equivariant. The canonicity and bijectivity of the LLC for $L$ are inherited by the bottom horizontal map in the diagram. This leaves a unique, canonical way to complete the commutative diagram.

(a) To work out the map on the right hand side, it suffices to consider

$$L = \prod_{i} L_{i}^{e_{i}} \quad \text{and} \quad \omega = \prod_{i} \omega_{i}^{c_{i}},$$

such that $(L_{i}, \omega_{i})$ is not isomorphic to $(L_{j}, \omega_{j})$ for $i \neq j$. Let $\phi_{i} : W_{F} \times \text{SL}_{2}(C) \rightarrow \text{GL}_{m_{i}}(C)$ be a Langlands parameter for $\omega_{i}$. Then

$$\phi_{L} = \prod_{i} \phi_{i}^{c_{i}} : W_{F} \times \text{SL}_{2}(C) \rightarrow \prod_{i} \text{GL}_{m_{i}}(C)^{c_{i}}$$

is a Langlands parameter for $\omega$. We have $W_{s, \phi_{L}} = \prod_{i} S_{c_{i}}$, where $S_{c_{i}}$ is embedded in $N_{\text{GL}_{m_{i}}(C)}(\text{GL}_{m_{i}}(C)^{c_{i}})$ as permutation matrices. The unipotent class

$$[u] = [\prod_{i} u_{i}] \in \prod_{i} \text{GL}_{m_{i}}(C) \subset Z_{G_{t}}(\phi_{L})$$

is determined by the standard Levi subgroup in which it is distinguished, say

$$M = \prod_{i,j} \text{GL}_{b_{ij}}(C)^{c_{ij}} \quad \text{with} \quad \sum_{j} c_{ij} b_{ij} = c_{i}.$$

Assume for the moment that $\omega$ is tempered. By Theorem 5.1 $[\omega, \rho] \in T_{s,un}/W_{s}$ corresponds to $I_{P_{M}^{G}}(\delta)$, where

$$\delta = \prod_{i,j} \delta_{ij}^{c_{ij}} \in \text{Irr}_{temp}^{[L, \omega]}(M)$$

is the unique square-integrable modulo centre representation such that $W_{s,M,\omega}$ is the unitary part of the cuspidal support of $\delta$. By construction [ABPS4, §2] the Langlands parameter $\phi$ of $I_{P_{M}^{G}}(\delta)$ is the same as that of $\delta$, namely $\phi = \prod_{i,j} \phi_{ij}^{c_{ij}}$ with $\phi_{ij}|_{W_{\rho}} = \phi_{ij}^{b_{ij}}|_{W_{\rho}}$ and

$$\phi_{ij}(1, (1 \ 1)) = \phi_{i}(1, (1 \ 1))^{b_{ij} u_{ij}}$$

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where $u_{ij}$ is a distinguished unipotent element in $Z_{\Gamma_{ij,m,d}(C)}(\Gamma_{m.d}(C)^{bij})$. Thus $\phi(1,(\begin{smallmatrix}1 & 1 \\ 0 & 1 \end{smallmatrix}))$ is distinguished in $\tilde{M}$ and $\phi$ has the asserted shape.

The general case, where $\omega$ is not necessarily tempered, follows from the tempered case. The reason is that all the maps in the commutative diagram (a priori except the right hand side) can be obtained from their tempered parts by some kind of analytic continuation, as in [ABPS1] and Theorem 5.1.

(b) By Theorem 7.1.b the elements of $T_s/W_s$ are in bijection with the L-packets in $\text{Irr}^\ell(G)$. Two elements $[t, \rho]$ and $[t', \rho']$ are equal if and only if there is a $w \in W_s$ such that $w t' = t$ and $w \cdot \rho' = \rho$. We note also that for every $t \in T_s$ the group $W_{s,t} = W(R_{s,t})$ is product of symmetric groups. Hence all irreducible representations of $W_{s,t}$ are parametrized by different unipotent classes in a connected complex reductive group with maximal torus $T_s$ and root system $R_{s,t}$. So the condition becomes that $\rho$ and $w \cdot \rho'$ have the same unipotent class as Springer parameter. 

Let $\text{Irr}_{\text{cusp}}(L)$ be the space of supercuspidal $L$-representations and let $\Phi(L)_{\text{cusp}}$ be its image in $\Phi(L)$. The Weyl group

$$W(G,L) = N_G(L)/L \cong N_{\tilde{G}}(\tilde{L})/\tilde{L}$$

acts naturally on both sets.

**Theorem 7.3.** Let $\mathcal{L}$ be a set of representatives for the conjugacy classes of Levi subgroups of $G$. The maps from Lemma 7.2 combine to a commutative diagram of canonical bijections

$$
\begin{array}{ccc}
\text{Irr}(G) & \overset{\text{rec}_{D,m}}{\rightarrow} & \Phi(G) \\
\downarrow & & \downarrow \\
\bigsqcup_{L \in \mathcal{L}} \text{Irr}_{\text{cusp}}(L)/W(G,L) & \overset{\rightarrow}{\longrightarrow} & \bigsqcup_{L \in \mathcal{L}} \Phi(L)_{\text{cusp}}/W(G,L)
\end{array}
$$

Here the tempered representations correspond to the bounded Langlands parameters.

**Proof.** The action of $W(G,L)$ on $L$ is simply by permuting some direct factors of $L$, and the same for $\tilde{L}$. Hence the canonical bijection $\text{Irr}(L) \leftrightarrow \Phi(L)$ is $W(G,L)$-equivariant. The group $W_s$ is defined as the stabilizer in $W(G,L)$ of $T_s = \text{Irr}^\ell_s(L)$, and by the above equivariance it is also the stabilizer of $\Phi^\ell_s(L)$. Consequently

$$
\text{Irr}_{\text{cusp}}(L)/W(G,L) \cong \bigsqcup_{s = [L,\omega]/G} T_s/W_s,
\Phi(L)_{\text{cusp}}/W(G,L) \cong \bigsqcup_{s = [L,\omega]/G} \Phi^\ell_s(L)/W_s.
$$

Now we simply take the union of the commutative diagrams of Lemma 7.2. The characterization of temperedness and boundedness comes from Theorems 7.1.a and 6.3.c. 

\[\square\]
To formulate the LLC for $G^♯$, we need enhanced Langlands parameters. In fact these are already present in the LLC for $G$, but there the enhancement can be neglected without any problems.

Recall that a Langlands parameter for $G^♯ = \text{GL}_m(D)$ is a homomorphism $\phi : W_F \times \text{SL}_2(\mathbb{C}) \to \text{PGL}_{md}(\mathbb{C})$ subject to the same requirements as a Langlands parameter for $G$. The set of such parameters modulo conjugation by $\breve{\pi}^G = \text{PGL}_{md}(\mathbb{C})$ is denoted $\Phi(G^♯)$. We note that the simply connected cover $\text{SL}_{md}(\mathbb{C})$ of $\text{PGL}_{md}(\mathbb{C})$ also acts by conjugation on Langlands parameters for $G^♯$. An enhancement of $\phi$ is an irreducible representation $\rho$ of $\pi_0(\text{Z}_{\text{SL}_{md}(\mathbb{C})}(\phi))$. In order that $(\phi, \rho)$ is relevant for $G^♯$, an extra condition is needed. For this we have to regard $D$ as part of the data of $G^♯$, in other words, we must consider not just the inner form $G^♯$ of $\text{SL}_m(F)$, but even the inner twist determined by $(G^♯, D)$. The Hasse invariant of $D$ gives a character $\chi_D$ of $\text{Z}(\text{SL}_{md}(\mathbb{C})) \cong \mathbb{Z}/md\mathbb{Z}$ with kernel $m\mathbb{Z}/md\mathbb{Z}$. Notice that, by Schur’s lemma, every enhancement $\rho$ of $\phi$ determines a character of $\text{Z}(\text{SL}_{md}(\mathbb{C}))$. We define an enhanced Langlands parameter for $G^♯ = \text{GL}_m(D)$ as a pair $(\phi, \rho)$ such that $\rho|_{\text{Z}(\text{SL}_{md}(\mathbb{C}))} = \chi_D$. The collection of these, modulo conjugation by $\text{SL}_{md}(\mathbb{C})$, is denoted $\Phi_e(G^♯)$.

The LLC for $G^♯$ [ABPS3] is a bijection

$$\Phi_e(G^♯) \leftrightarrow \text{Irr}(G^♯) : (\phi, \rho) \mapsto \pi(\phi, \rho).$$

such that

(i) if $\phi$ lifts to a Langlands parameter $\tilde{\phi}$ for $G$, then $\pi(\phi, \rho)$ is a direct summand of $\text{Res}_{G^♯}(\text{rec}_{D,m}(\tilde{\phi}))$,

(ii) $\pi(\phi, \rho)$ is tempered if and only if $\phi$ is bounded,

(iii) the L-packet

$$\Pi_\phi(G^♯) = \{ \pi(\phi, \rho) : \rho \in \text{Irr}(\pi_0(\text{Z}_{\text{SL}_{md}(\mathbb{C})}(\phi))), \rho|_{\text{Z}(\text{SL}_{md}(\mathbb{C}))} = \chi_D \}$$

is canonically determined.

As $\text{Irr}^a(G^♯)$ is defined in terms of restriction from $\text{Irr}^a(G)$, it is a union of L-packets for $G^♯$. With (i) it canonically determines a set $\Phi_e(G^♯)^a$ of enhanced Langlands parameters for $G^♯$.

In the same way as for $G$, the LLC for a Levi subgroup $L^♯ = L \cap G^♯$ follows from that for $L = \prod_i \text{GL}_{m_i}(D)$. It involves enhancements from the action of

$$(L^♯)_{sc} = \text{SL}_{md}(\mathbb{C}) \cap \prod_i \text{GL}_{m_i}(\mathbb{C}).$$

Given $\mathfrak{s}_L = \{L, \omega\}_L$, $\text{Irr}^{L_{sc}}(L^♯)$ is a union of L-packets for $L^♯$. Hence the corresponding set $\Phi_e(L^♯)^{a+}$ of enhanced Langlands parameters is well-defined.
Lemma 7.4. The LLC for $G^\sharp$ and the maps from Lemma 6.1 and Theorem 6.3.b fit in the following commutative bijective diagram:

All these maps are canonical up to permutations within $L$-packets. In the last row the collection of $L$-packets is in bijection with $(T_s//W_s)/\Stab(s)X_{nr}(L/L^2)$ and with $\Phi(L)/(\Phi(L)/\Stab(s)X_{nr}(L/L^2))$. 

Proof. The bijection between the first and the fourth set on the left hand side is given by Theorem 6.3.b. Then Corollary A.4 and (78) give bijections to the third and fifth sets on the left, as the 2-cocycle $\kappa_\omega$ is by construction (72) trivial on $W_s$. The bijection between the second and third sets on the left comes from Lemma 6.1.a. By Lemma 6.1.b it is canonical up to permutations within $L$-packets.

The LLC for $L$ is equivariant for permutations of the direct factors of $L$ and for twisting with characters of $L$. This gives the three lower horizontal bijections. Applying Corollary A.4 to the three lower terms on the right hand side gives bijections between them, and shows that the two lower squares in the diagram are canonical and commutative.

Similarly the LLC for $L^\sharp$ is equivariant for the action of $W_s^\sharp$, which leads to the second horizontal bijection. We define the upper two maps on the right hand side as the unique bijections that make the diagram commute. Since all the other maps in the upper two squares are canonical up to permutations within $L$-packets, so are the last two.

An $L$-packet for $G^\sharp$ consists of the irreducible $G^\sharp$-constituents of an irreducible $G$-representation. In view of Lemma 7.2, the collection of $L$-packets in $\Irr^s(G^\sharp)$ is canonically in bijection with $T_s//W_s$. From (56) we can see how

is constructed on the level of representations. We take an element $\pi \in \Irr^s(G)$ and transform it to an irreducible representation of $O(T_s)\rtimes W_s$ by a geometric
equivalence. Then we form the twisted extended quotient by \( \text{Stab}(s)^+ \), using Lemmas A.1 and A.2, which corresponds to identifying \( \pi \) with \( \pi' \) if they have the same restriction to \( G^\sharp Z(G) \), and decomposing \( \pi \) in irreducible \( G^\sharp Z(G) \)-subrepresentations. Finally we divide out the action of \( X_{nr}(L^\sharp Z(G)/L^\sharp) \), thus identifying the \( G^\sharp Z(G) \)-representations with the same restriction to \( G^\sharp \). The implies the description of the \( L \)-packets in the lower left term of the commutative diagram, and hence also in the lower right term.

The bijection between the upper and the lower term on the right hand side of Lemma 7.4 can also be obtained as follows. First apply the recipe from Lemma 7.2 to \( \Phi(L)^{\sigma}\Sigma //W \), then take the twisted extended quotient with respect to \( \text{Stab}(s)^+ \), and finally divide out the free action of \( X_{nr}(L^\sharp Z(G)/L^\sharp) \) to reach \( \Phi_e(G^\sharp)^{\sigma'} \).

Let \( R_{t,t}^\sharp \) be the root system associated to \( (G^\sharp, t) \) be Harish-Chandra, by means of zeros of the \( \mu \)-function [Wal, §V.2]. Recall that the classical Springer correspondence was extended to Weyl groups of disconnected complex reductive groups in [ABPS5, Theorem 4.4].

Lemma 7.5. Let \( t = [L^\sharp, \sigma^\sharp]_G \) be an inertial equivalence class subordinate to \( s = [L_\omega]_G \). Lemma 6.5.a and the LLC for \( G^\sharp \) and for \( L^\sharp \) provide a commutative, bijective diagram

\[
\begin{array}{ccc}
\text{Irr}^t(G^\sharp) & \longrightarrow & \Phi_e(G^\sharp)^{t^\sharp} \\
\downarrow & & \downarrow \\
(\nu\Sigma //W)^{\kappa_{\sigma^\sharp}} & \longrightarrow & (\Phi_e(L^\sharp)^{[L^\sharp, \sigma^\sharp]} //\Sigma)^{\kappa_{\sigma^\sharp}}
\end{array}
\]

Two elements \([t, \rho], [t', \rho'] \in (\nu\Sigma //W)^{\kappa_{\sigma^\sharp}}\) are mapped to \( G^\sharp \)-representations in the same \( L \)-packet if and only if

- \( wt = t \) for some \( w \in W_t \);
- the \( W_{t,t}^\sharp \)-representations \( \rho \) and \( w \cdot \rho' \) have parameters (in the Springer correspondence for possibly disconnected complex reductive groups) with the same unipotent class, in the complex reductive group with maximal torus \( T_t \), root system \( R_{t,t}^\sharp \) and Weyl group \( W_{t,t}^\sharp \).

Proof. The commutative diagram is obtained from Lemma 7.4, taking (27) into account. To see whether \([t, \rho] \) and \([t', \rho'] \) belong to the same \( L \)-packet, Lemma 7.4 says that it suffices to look at their images in \( (\nu\Sigma //W)\Sigma_{\text{nr}}(L^\sharp/L^\sharp) \). Let \( \tilde{t} \in T_\sigma \) be a lift of \( t \). Then \( W_{t,t}^\sharp \) is the isotropy group of \( X^L(\sigma)X_{nr}(L/L^\sharp)(\tilde{\sigma}^\sharp) \in T_{\tilde{t}} \) in \( W_{t,t}^\sharp \). Here \( \tilde{\sigma}^\sharp \) is a projective representation of \( (X^L(\sigma)X_{nr}(L/L^\sharp))_{\tilde{t}} = X^L(\omega) \).

With Lemma A.1 we get

\[
\sigma^\sharp \times \rho \in \text{Irr}(C[(\text{Stab}(s))X_{nr}(L/L^\sharp)_{\tilde{t}}, \kappa_{\omega}]).
\]
The intersection of \((\text{Stab}(s) X_{_{\mathfrak{s}}} (L/L^2))_\tilde{t}\) with \(W_{_{\mathfrak{s}}} \tilde{t} = W(R_{_{\mathfrak{s}}} \tilde{t})\). Since \(W_{_{\mathfrak{s}}} \tilde{t}\) commutes with \(X^L(s) X_{_{\mathfrak{s}}} (L/L^2)\), the restriction of \(\sigma^2 \rtimes \rho\) to \(W_{_{\mathfrak{s}}} \tilde{t}\) is \(\dim(\sigma^2)\) times \(\rho|_{W_{_{\mathfrak{s}}} \tilde{t}}\). We want to show that

\[ R_{_{\mathfrak{s}}} \tilde{t} = R_{_{\mathfrak{s}}} \tilde{t}, \tag{94} \]

although in general \(W_{_{\mathfrak{s}}} \tilde{t}\) is strictly larger than \(W_{_{\mathfrak{s}}} \tilde{t}\). Both root systems can be defined in terms of zeros of Harish-Chandra \(\mu\)-functions associated to roots \(\alpha \in R_{_{\mathfrak{s}}}\). The function \(\mu_\alpha\) (for \(G\)) is defined via intertwining operators between \(G\)-representations, see [Wal, §IV.3 and §V.2]. These remain well-defined as intertwining operators between \(G^\mathbb{C}\)-representations, which implies that \(\mu_\alpha\) factors through \(T_\alpha \to T_\tilde{\alpha}\) and in this way gives the function \(\mu_\alpha\) for \(G^\mathbb{C}\). By [Sil2, Theorem 1.6] all zeros of \(\mu_\alpha\) are fixed points of the reflection \(s_\alpha \in W_{_{\mathfrak{s}}}\). Hence \(\mu_\alpha(t) \neq 0\) if \(s_\alpha(t) \neq t\), proving (94).

It follows that \([t, \rho]\) maps to \([\tilde{t}, \rho|_{W(R_{_{\mathfrak{s}}} \tilde{t})}]\) in \((T_\alpha//W_{_{\mathfrak{s}}})/\text{Stab}(s) X_{_{\mathfrak{s}}} (L/L^2)\), and similarly for \([t', \rho']\). The \(\text{Stab}(s)^+ X_{_{\mathfrak{s}}} (L/L^2)\)-orbits of \([\tilde{t}, \rho|_{W(R_{_{\mathfrak{s}}} \tilde{t})}]\) and \([\tilde{t}', \rho|_{W(R_{_{\mathfrak{s}}} \tilde{t}')}]\) are equal if and only if

there is a \(w \in W_{_{\mathfrak{s}}}\) such that \(wt' = t\) and \((w \rho')|_{W(R_{_{\mathfrak{s}}} \tilde{t})} = \rho|_{W(R_{_{\mathfrak{s}}} \tilde{t})}\).

By Lemma 7.2.b the last condition is equivalent to \(w \rho' = \rho\) having the same unipotent class as Springer parameter. Because \(w\) is only determined up to \(W_{_{\mathfrak{s}}} \tilde{t}\), these unipotent classes must be considered in the complex reductive group with maximal torus \(T_\alpha\), root system \(R_{_{\mathfrak{s}}} \tilde{t}\) and Weyl group \(W_{_{\mathfrak{s}}} \tilde{t}\).

As before, let \(\mathcal{L}\) be a set of representatives for the conjugacy classes of Levi subgroups of \(G\). Then \(\{L^2 : L \in \mathcal{L}\}\) is a set of representatives for the conjugacy classes of Levi subgroups of \(G^\mathbb{C}\).

**Theorem 7.6.** The maps from Lemma 7.4 combine to a commutative diagram of bijections

\[
\begin{array}{ccc}
\text{Irr}(G^\mathbb{C}) & \longrightarrow & \Phi_c(G^\mathbb{C}) \\
\downarrow & & \downarrow \\
\bigsqcup_{L \in \mathcal{L}} (\text{Irr}_{\text{cusp}}(L^1)/W(G^2, L^1))_2 & \longrightarrow & \bigsqcup_{L \in \mathcal{L}} (\Phi(L^1)_{\text{cusp}}/W(G^2, L^2))_2 \\
\downarrow & & \downarrow \\
\bigsqcup_{L \in \mathcal{L}} (\text{Irr}_{\text{cusp}}(L)/\text{Irr}(L/L^1)W(G, L))_2 & \longrightarrow & \bigsqcup_{L \in \mathcal{L}} (\Phi(L)_{\text{cusp}}/\text{Irr}(L/L^2)W(G, L))_2
\end{array}
\]

*Here the family of 2-cocycles \(\zeta\) restricts to \(\kappa_\omega\) on \(\text{Irr}^{[L, \omega]_\zeta}(L)\). The tempered representations correspond to the bounded enhanced Langlands parameters and the entire diagram is canonical up to permutations within \(L\)-packets.*
Proof. The upper square follows quickly from Lemma 7.4, in the same way as
Theorem 7.3 followed from Lemma 7.2.
Recall from Lemma 6.1 that
\[ \text{Irr}^{rs}(L^2) \] is in bijection with \( (T_\sigma//X^L(s)X_{nr}(L/L^2))_{s,\omega} \).
Here \( X^L(s) \) is the stabilizer of \( s = [L,\omega]_L \) in \( \text{Irr}(L/L\sharp Z(G)) \). A character of \( L/L^2 \), which is ramified on \( Z(G) \) cannot stabilize \( s_L \), so \( X^L(s)X_{nr}(L/L^2) \) is the stabilizer of \( s_L \) in \( \text{Irr}(L/L^2) \). By Theorem 7.1 the LLC for \( L \) is bijective and \( \text{Irr}(L/L^2) \)-equivariant, so \( X^L(s)X_{nr}(L/L^2) \) is also the stabilizer of \( \Phi(L)^{s_L} \) in \( \text{Irr}(L/L^2) \). This implies
\[
((\text{Irr}_{cusp}(L)//\text{Irr}(L/L^2))_{s,\omega} \cong \bigsqcup_{s_L = [L,\omega]_L} (\text{Irr}^{rs}(L)//X^L(s)X_{nr}(L/L^2))_{s,\omega}
\]
and similarly for Langlands parameters. These bijections are equivariant for
permutations of the direct factors of \( L \), so applying \((-//W(G,L))_{s,\omega}\) to all of
them produces a commutative square as in the theorem, but with lower row
\[
\bigsqcup_{L \in L} ((\text{Irr}_{cusp}(L)//\text{Irr}(L/L^2))_{s,\omega}//W(G,L))_{s,\omega} \leftrightarrow \bigsqcup_{L \in L} (\Phi(L)^{s_L}//\text{Irr}(L/L^2))_{s,\omega}//W(G,L))_{s,\omega}.
\]
We apply Corollary A.4 to get the row in the theorem. The canonicity of the
thus obtained commutative diagram is a consequence of the analogous property
in Lemma 7.4. The temperedness/boundedness correspondence follows from
the properties of the local Langlands correspondences for \( G,G,^\sharp \, L \) and \( L^2 \). □

Example 7.7. Let \( G = \text{SL}_5(D) \). Let \( V_4 \) denote the non-cyclic group of order
4. Let \( W_F \) denote the Weil group of \( F \). There exists a classical Langlands
parameter \( \phi \) which factors through \( V_4 \):
\[
\phi: W_F \to V_4 \to \text{PGL}_2(C)
\]
Let \( \tau \) be the cuspidal representation of \( D^\times \) which has, as its Langlands parameter,
a lift of \( \phi \) to \( \text{GL}_2(C) \). Consider the group of characters \( \chi \) for which \( \chi \tau \cong \tau \).
This group is isomorphic to \( V_4 \) and comprises the four characters \{1,\( \gamma,\eta,\gamma\eta \}\),
where \( \gamma,\eta \) are quadratic characters. Let
\[
L = (D^\times)^5 \cap \text{SL}_5(D)
\]
\[
\sigma = \tau \otimes 1 \otimes \gamma \otimes \eta \otimes \gamma \eta \in \text{Irr}(L)
\]
\[ s = [L,\sigma]_G \]
Twisting by \( \eta \) corresponds to the permutation \((13)(24)\), twisting by \( \gamma \eta \) corre-
sponds to the permutation \((14)(23)\). The Bernstein finite group \( W^s \) is isomor-
phic to \( V_4 \). The corresponding Bernstein variety is the quotient \( T^s/V_4 \), where
\( T^s \) has the structure of a complex torus of dimension 4.
The summand $H^s(G)$ of the Hecke algebra $H(G)$ is Morita equivalent to the twisted crossed product
\[ \mathcal{O}(T^s) \rtimes_\natural V_4, \]
where $\natural$ is the 2-cocycle associated to the above projective representation of $V_4$. Following [ABPS3], $\text{Irr}(\mathcal{O}(T^s) \rtimes_\natural V_4)$ is the twisted extended quotient $(T^s//V_4)_\natural$. Now consider the standard projection $\pi^s : (T^s//V_4)_\natural \to T^s/V_4$.

Let $(V_4)_t$ denote the isotropy group of $t \in T^s$. Let
\begin{align*}
X &= \{ t \in T^s : |(V_4)_t| = 2 \}, \\
Y &= \{ t \in T^s : (V_4)_t = V_4 \}.
\end{align*}

We note that
- on the complement of $(X \cup Y)/V_4$ the fibre of $\pi^s$ has cardinality 1: the corresponding (parabolically) induced representation is irreducible
- on $X/V_4$ the fibre of $\pi^s$ has cardinality 2: the corresponding induced representation has two inequivalent irreducible constituents
- on $Y/V_4$ the fibre of $\pi^s$ has cardinality 1, because $V_4$ admits a unique irreducible projective representation with cocycle $\natural$: the corresponding induced representation has two equivalent constituents.

The geometric structure of $\text{Irr}^s(\text{SL}_5(D))$ is the variety $T^s/V_4$ with doubling on $X/V_4$.

### A. Twisted extended quotients

Let $\Gamma$ be a group acting on a topological space $X$. In [ABPS6, §2] we studied various extended quotients of $X$ by $\Gamma$. In this paper we need the most general version, the twisted extended quotients.

Let $\natural$ be a given function which assigns to each $x \in X$ a 2-cocycle
\[ \natural_x : \Gamma_x \times \Gamma_x \to \mathbb{C}^\times, \text{ where } \Gamma_x = \{ \gamma \in \Gamma : \gamma x = x \}. \]

It is assumed that $\natural_{\gamma x}$ and $\gamma_* \natural_x$ define the same class in $H^2(\Gamma_x, \mathbb{C}^\times)$, where $\gamma_* : \Gamma_x \to \Gamma_{\gamma x}$ sends $\alpha$ to $\gamma \alpha \gamma^{-1}$. Define
\[ \tilde{X}_{\natural} := \{ (x, \rho) : x \in X, \rho \in \text{Irr} \mathbb{C}[\Gamma_x, \natural_x] \}. \]

We require, for every $$(\gamma, x) \in \Gamma \times X$$, a definite algebra isomorphism
\[ \phi_{\gamma,x} : \mathbb{C}[\Gamma_x, \natural_x] \to \mathbb{C}[\Gamma_{\gamma x}, \natural_{\gamma x}] \]
such that:
• $\phi_{\gamma,x}$ is inner if $\gamma x = x$;
• $\phi_{\gamma',\gamma x} \circ \phi_{\gamma,x} = \phi_{\gamma',\gamma x}$ for all $\gamma', \gamma \in \Gamma, x \in X$.

We call these maps connecting homomorphisms, because they are reminiscent of a connection on a vector bundle. Then we can define a $\Gamma$-action on $\tilde{X}$ by

$$\gamma \cdot (x, \rho) = (\gamma x, \rho \circ \phi_{\gamma,x}^{-1}).$$

We form the \textit{twisted extended quotient}

$$(X//\Gamma)_2 := \tilde{X}/\Gamma.$$ 

We note that this reduces to the extended quotient of the second kind $X//\Gamma$ from [ABPS6, §2] if $\tilde{x}$ is trivial for all $x \in X$ and $\phi_{\gamma,x}$ is conjugation by $\gamma$.

The map

$$\tilde{X} \to X, \quad (x, \rho) \mapsto x$$

induces a map

$$\pi_1 : (X//\Gamma)_2 \to X/\Gamma$$

which we will call the \textit{standard projection}.

Such twisted extended quotients typically arise in the following situation. Let $A$ be a $\mathbb{C}$-algebra such that all irreducible $A$-modules have countable dimension over $\mathbb{C}$. Let $\Gamma$ be a group acting on $A$ by automorphisms and form the crossed product $A \rtimes \Gamma$.

Let $X = \text{Irr}(A)$. Now $\Gamma$ acts on $\text{Irr}(A)$ and we get $\natural$ as follows. Given $x \in \text{Irr}(A)$ choose an irreducible representation $(\pi_x, V_x)$ whose isomorphism class is $x$. For each $\gamma \in \Gamma$ consider $\pi_x$ twisted by $\gamma$:

$$\gamma \cdot \pi_x : a \mapsto \pi_x(\gamma^{-1} a \gamma).$$

Then $\gamma \cdot x$ is defined as the isomorphism class of $\gamma \cdot \pi_x$. Since $\gamma \cdot \pi_x$ is equivalent to $\pi_{\gamma x}$, there exists a nonzero intertwining operator

$$T_{\gamma,x} \in \text{Hom}_A(\gamma \cdot \pi_x, \pi_{\gamma x}).$$

By Schur’s lemma (which is applicable because dim $V_x$ is countable) $T_{\gamma,x}$ is unique up to scalars, but in general there is no preferred choice. For $\gamma, \gamma' \in \Gamma_x$ there exists a unique $c \in \mathbb{C}^\times$ such that

$$T_{\gamma,x} \circ T_{\gamma',x} = cT_{\gamma \gamma',x}.$$

We define the 2-cocycle by

$$\natural_{x}(\gamma, \gamma') = c.$$

Let $N_{\gamma,x}$ with $\gamma \in \Gamma_x$ be the standard basis of $\mathbb{C}[\Gamma_x, \natural_x]$. The algebra homomorphism $\phi_{\gamma,x}$ is essentially conjugation by $T_{\gamma,x}$, but we must be careful if some of the $T_{\gamma}$ coincide. The precise definition is

$$\phi_{\gamma,x}(N_{\gamma',x}) = \lambda N_{\gamma \gamma' \gamma^{-1},x} \quad \text{if} \quad T_{\gamma,x}T_{\gamma',x}T_{\gamma,x}^{-1} = \lambda T_{\gamma \gamma' \gamma^{-1},x}, \lambda \in \mathbb{C}^\times.$$  

(97)
Notice that (97) does not depend on the choice of $T_{\gamma,x}$.
Suppose that $\Gamma_x$ is finite and $(\tau, V_\tau) \in \text{Irr}(C[\Gamma_x, \sharp_x])$. Then $V_\tau \otimes V^*_\tau$ is an irreducible $A \rtimes \Gamma_x$-module, in a way which depends on the choice of intertwining operators $T_{\gamma,x}$.

**Lemma A.1.** [ABPS6, Lemma 2.3]
Let $A$ and $\Gamma$ be as above and assume that the action of $\Gamma$ on $\text{Irr}(A)$ has finite isotropy groups.

(a) There is a bijection

\[
\frac{\text{Irr}(A)}{\Gamma_\natural} \leftrightarrow \text{Irr}(A \rtimes \Gamma) \quad \frac{(\pi_x, \tau)}{\pi_x \rtimes \tau := \text{Ind}_{A \rtimes \Gamma_x}^{A \rtimes \Gamma}(V_\tau \otimes V^*_\tau)}.
\]

(b) If all irreducible $A$-modules are one-dimensional, then part (a) becomes a natural bijection

\[
\text{Irr}(A) \leftrightarrow \text{Irr}(A \rtimes \Gamma).
\]

Via the following result twisted extended quotients also arise from algebras of invariants.

**Lemma A.2.** Let $\Gamma$ be a finite group acting on a $C$-algebra $A$. There is a bijection

\[
\{ V \in \text{Irr}(A \rtimes \Gamma) : V^\Gamma \neq 0 \} \leftrightarrow \text{Irr}(A^\Gamma) \quad \frac{V}{V^\Gamma}.
\]

If all elements of $\text{Irr}(A)$ have countable dimension, it becomes

\[
\{ (\pi_x, \tau) \in \frac{\text{Irr}(A)}{\Gamma_\natural} : \text{Hom}_{\Gamma_x}(V_\tau, V_x) \neq 0 \} \leftrightarrow \text{Irr}(A^\Gamma) \quad \frac{\text{Hom}_{\Gamma_x}(V_\tau, V_x)}{\text{Hom}_{\Gamma_x}(V_\tau, V_x)}.
\]

**Proof.** Consider the idempotent

\[
P_\Gamma = |\Gamma|^{-1} \sum_{\gamma \in \Gamma} \gamma \in C[\Gamma]. \tag{98}
\]

It is well-known and easily shown that

\[A^\Gamma \cong p_\Gamma(A \rtimes \Gamma)p_\Gamma\]

and that the right hand side is Morita equivalent with the two-sided ideal

\[I = (A \rtimes \Gamma)p_\Gamma(A \rtimes \Gamma) \subset A \rtimes \Gamma.
\]

The Morita equivalence sends a module $V$ over the latter algebra to

\[p_\Gamma(A \rtimes \Gamma) \otimes (A \rtimes \Gamma)p_\Gamma(A \rtimes \Gamma) V = V^\Gamma.
\]

As $I$ is a two-sided ideal,

\[\text{Irr}(I) = \{ V \in \text{Irr}(A \rtimes \Gamma) : I \cdot V \neq 0 \} = \{ V \in \text{Irr}(A \rtimes \Gamma) : p_\Gamma V = V^\Gamma \neq 0 \}
\]
This gives the first bijection. From Lemma A.1.a we know that every such V is of the form \( \pi \times \tau \). With Frobenius reciprocity we calculate

\[
(\pi \times \tau)^\Gamma = \left( \text{Ind}_{A \rtimes \Gamma_x}^A \left( (V_\pi \otimes V_\tau)^\ast \right) \right)^\Gamma \cong (V_\pi \otimes V_\tau)^{\Gamma_x} = \text{Hom}_{\Gamma_x}(V_\tau, V_\pi).
\]

Now Lemma A.1.a and the first bijection give the second.

Let \( A \) be a commutative \( \mathbb{C} \)-algebra all whose irreducible representations are of countable dimension over \( \mathbb{C} \). Then \( \text{Irr}(A) \) consists of characters of \( A \) and is a \( T_1 \)-space. Typical examples are \( A = C_0(X) \) (with \( X \) locally compact Hausdorff), \( A = C^\infty(X) \) (with \( X \) a smooth manifold) and \( A = \mathcal{O}(X) \) (with \( X \) an algebraic variety).

As a kind of converse to Lemmas A.1 and A.2, we show that every twisted extended quotient of \( \text{Irr}(A) \) appears as the space of irreducible representations of some algebras. With small modifications, the argument also works for smooth manifolds and algebraic varieties.

Let \( \Gamma \) be a group acting on \( A \) by algebra automorphisms, such that \( \Gamma_x \) is finite for every \( x \in \text{Irr}(A) \). Recall that every 2-cocycle \( \natural \) of \( \Gamma \) arises from a projective \( \Gamma \)-representation \((\mu, V_\mu)\) by

\[
\mu(\gamma)\mu(\gamma') = \natural(\gamma, \gamma')\mu(\gamma, \gamma').
\]

Let \( \Gamma \) act on \( A \otimes \text{End}_\mathbb{C}(V_\mu) \) by

\[
\gamma \cdot (a \otimes h) = \gamma(a) \otimes \mu(\gamma)h\mu(\gamma)^{-1}.
\]

**Lemma A.3.** There are bijections

\[
\begin{align*}
\text{Irr}(A \otimes \text{End}_\mathbb{C}(V_\mu)) \times \Gamma & \leftrightarrow (\text{Irr}(A)//\Gamma)_{\natural}, \\
\text{Irr}(A \otimes \text{End}_\mathbb{C}(V_\mu) \Gamma) & \leftrightarrow \{[x, \rho] \in (X//\Gamma)_\natural : \rho \text{ appears in } V_\mu\}.
\end{align*}
\]

**Proof.** We can identify \( \text{Irr}(A \otimes \text{End}_\mathbb{C}(V_\mu)) \) with \( \{\mathbb{C}_x \otimes V_\mu : x \in \text{Irr}(A)\} \). It follows directly from (96) that we can take \( T_{\gamma, x} = \mu(\gamma) \) for all \( \gamma \in \Gamma \) and \( x \in \text{Irr}(A) \). Thus the first bijection is an instance of Lemma A.1.a.

Let \( x \in \text{Irr}(A) \) and \( (\tau, V_\tau) \in \text{Irr}(\mathbb{C}[\Gamma_x, \natural]) \). Then

\[
\text{Hom}_{\Gamma_x}(\tau, \mathbb{C}_x \otimes V_\mu) = \text{Hom}_{\Gamma_x}(\tau, V_\mu),
\]

and this is nonzero if and only if \( \tau \) appears in \( V_\mu \). Now an application of Lemma A.2 proves the second bijection.

**Corollary A.4.** In the above setting, suppose that \( \Gamma = \Gamma_1 \rtimes \Gamma_2 \) is a semidirect product. Then there is a canonical bijection

\[
(\text{Irr}(A)//\Gamma)_\natural \leftrightarrow ((\text{Irr}(A)//\Gamma_1)_\natural//\Gamma_2)_\natural.
\]

**Proof.** The bijection is obtained from Lemma A.3 and

\[
(A \otimes \text{End}_\mathbb{C}(V_\mu)) \rtimes \Gamma = ((A \otimes \text{End}_\mathbb{C}(V_\mu)) \rtimes \Gamma_1) \rtimes \Gamma_2.
\]

It is canonical because the same 2-cocycle is used on both sides.
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