

# Eine Woche, ein Beispiel

## 10.2 equivariant K-theory of Steinberg variety : notation

This document is written to reorganize the notations in Tomasz Przezdziecki's master thesis:  
[http://www.math.uni-bonn.de/ag/stroppel/Master%27s%20Thesis\\_Tomasz%20Przezdziecki.pdf](http://www.math.uni-bonn.de/ag/stroppel/Master%27s%20Thesis_Tomasz%20Przezdziecki.pdf)

We changed some notation for the convenience of writing.

Task.

1. dimension vector
2. Weyl gp
3. alg group & Lie algebra
4. typical variety
5. (equivariant) stratifications
6. change of basis
  - § 6.1 two basis
  - § 6.2 tangent space
  - § 6.3 Euler class
  - § 6.4 transition matrix, localization formula
  - § 6.5 generators
7. convolution product
  - § 7.1 clean intersection formula
  - § 7.2. convolution for canonical basis
  - § 7.3. expression of  $D_\lambda$ .

We may use two examples for the convenience of presentation.  
Readers can easily distinguish them by the dim vectors.

## 1. dimension vector

$$|\underline{d}| = 5$$

$$\underline{d} = (3, 2)$$

$$\underline{d} = \begin{pmatrix} 3, 2 \\ 2, 2 \\ 2, 1 \\ 1, 1 \\ 0, 0 \\ 0, 0 \end{pmatrix} = \begin{array}{c} \diagup \diagdown \diagup \diagdown \diagup \diagdown \\ \text{Young Tableaux} \end{array} = \begin{array}{c} \uparrow \uparrow \uparrow \uparrow \uparrow \\ \downarrow \downarrow \downarrow \downarrow \downarrow \end{array} = \begin{array}{c} \times \times \times \\ \times \times \end{array} \in W_d \backslash W_{\text{id}} \text{ or } \text{Min}(W_{\text{id}}, W_d)$$

$v_{\text{id}} = \pi_{\underline{d}}^{-1}(F_{\text{id}})$

## 2. Weyl group

| Set  | element            | special element  | others                       |
|--|--------------------|--|------------------------------|
| $W_{\text{id}} = S_5$  | $w, x$             | $w_{\text{max}} = \begin{array}{ c c c }\hline & \times & \times \\ \hline & \times & \times \\ \hline & \times & \times \\ \hline\end{array}$ | $T = \{s_1, s_2, s_3, s_4\}$ |
| $W_d = S_3 \times S_2$   | $w$                | $w_{\text{max}} = \begin{array}{ c c }\hline & X \\ \hline X & \end{array}$  | $T_d = \{s_1, s_2, s_4\}$    |
| $W_d \backslash W_{\text{id}} = S_3 \times S_2 \backslash S_5$ | $w, \underline{d}$ | $\begin{array}{ c c c }\hline & \times & \times \\ \hline & \times & \times \\ \hline & \times & \times \\ \hline\end{array}$                  | (Comp <sub>d</sub> )         |

$$\text{Min}(W_{\text{id}}, W_d) = \left\{ \begin{array}{c} \diagup \diagdown \diagup \diagdown \diagup \diagdown \\ \text{Young Tableaux} \end{array}, \dots \right\} u \quad \begin{array}{c} \diagup \diagdown \diagup \diagdown \diagup \diagdown \\ \text{Young Tableaux} \end{array} \quad (\text{Shuffled})$$

$$0 \longrightarrow W_d \longrightarrow W_{\text{id}} \longrightarrow W_{\text{id}} \backslash W_d \longrightarrow 0 \quad w = wu \mapsto \underline{d}$$

$\xrightarrow{\text{Min}(W_{\text{id}}, W_d)} \xrightarrow{\cong} u \quad \downarrow \quad \underline{d}$

$w = \begin{array}{|c|c|c|}\hline & \times & \times \\ \hline & \times & \times \\ \hline & \times & \times \\ \hline\end{array}$   
 $u = \begin{array}{|c|c|}\hline & X \\ \hline X & \end{array}$   
 $w = \begin{array}{|c|c|}\hline & X \\ \hline X & \end{array}$

Another example:  $\underline{d} = (1, 2)$   $\xrightarrow{\langle v_1 \rangle \rightarrow \langle v_2, v_1 \rangle}$

|     | $w = wu$  | $w$   | $\underline{d}, u$  | order of basis      | $(w)$ | $l(w)$ | $B_w$   | $B_{wu}$                                       | $wB_{wu}^{-1}$                                 |
|-----|-----------|---|---|---------------------|-------|--------|---|--|--|
| Id  | $(1^2 3)$ | $\begin{array}{ c c }\hline \diagup & \diagdown \\ \hline \end{array}$                              | $\begin{array}{ c c }\hline 1 & 1 \\ \hline 1 & 1 \\ \hline\end{array}$ | $\{v_1, v_2, v_3\}$ | 0     | 0      | $\begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix}$ | $\begin{bmatrix} * & * \\ * & * \end{bmatrix}$ | $\begin{bmatrix} * & * \\ * & * \end{bmatrix}$ |
| t   | $(23)$    | $\begin{array}{ c c }\hline \diagup & \diagdown \\ \hline \diagdown & \diagup \\ \hline\end{array}$ | $\begin{array}{ c c }\hline 1 & 1 \\ \hline 1 & 1 \\ \hline\end{array}$ | $\{v_1, v_3, v_2\}$ | 1     | 1      | $\begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix}$ | $\begin{bmatrix} * \\ * \end{bmatrix}$         | $\begin{bmatrix} * \\ * \end{bmatrix}$         |
| s   | $(12)$    | $\begin{array}{ c c }\hline \diagup & \diagdown \\ \hline \diagdown & \diagup \\ \hline\end{array}$ | $\begin{array}{ c c }\hline 1 & 1 \\ \hline 1 & 1 \\ \hline\end{array}$ | $\{v_2, v_1, v_3\}$ | 1     | 0      | $\begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix}$ | $\begin{bmatrix} * & * \\ * & * \end{bmatrix}$ | $\begin{bmatrix} * & * \\ * & * \end{bmatrix}$ |
| ts  | $(132)$   | $\begin{array}{ c c }\hline \diagup & \diagdown \\ \hline \diagdown & \diagup \\ \hline\end{array}$ | $\begin{array}{ c c }\hline 1 & 1 \\ \hline 1 & 1 \\ \hline\end{array}$ | $\{v_3, v_1, v_2\}$ | 2     | 1      | $\begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix}$ | $\begin{bmatrix} * \\ * \end{bmatrix}$         | $\begin{bmatrix} * & * \\ * & * \end{bmatrix}$ |
| st  | $(123)$   | $\begin{array}{ c c }\hline \diagup & \diagdown \\ \hline \diagdown & \diagup \\ \hline\end{array}$ | $\begin{array}{ c c }\hline 1 & 1 \\ \hline 1 & 1 \\ \hline\end{array}$ | $\{v_2, v_3, v_1\}$ | 2     | 0      | $\begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix}$ | $\begin{bmatrix} * & * \\ * & * \end{bmatrix}$ | $\begin{bmatrix} * & * \\ * & * \end{bmatrix}$ |
| sts | $(13)$    | $\begin{array}{ c c }\hline \diagup & \diagdown \\ \hline \diagdown & \diagup \\ \hline\end{array}$ | $\begin{array}{ c c }\hline 1 & 1 \\ \hline 1 & 1 \\ \hline\end{array}$ | $\{v_3, v_2, v_1\}$ | 3     | 1      | $\begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix}$ | $\begin{bmatrix} * & * \\ * & * \end{bmatrix}$ | $\begin{bmatrix} * & * \\ * & * \end{bmatrix}$ |

### 3. alg group & Lie algebra

$$G_{\text{Idl}}, B_{\text{Idl}}, T_{\text{Idl}}, N_{\text{Idl}} \quad W_{\text{Idl}} = N_{G_{\text{Idl}}}(\Pi_{\text{Idl}}) / \Pi_{\text{Idl}} \quad GL_5(\mathbb{C}) = \begin{pmatrix} * & * \\ * & * \end{pmatrix}$$

$$G_d, B_d, T_d, N_d \quad W_d = N_{G_d}(T_d) / T_d \quad GL_3(\mathbb{C}) \times GL_2(\mathbb{C}) = \begin{pmatrix} * & * \\ * & * \end{pmatrix}$$

$$B_\infty = B_{\text{Idl}} \omega^{-1} = \text{Stab}_{G_{\text{Idl}}}(F_\infty)$$

$$B_\infty = \omega B_d \omega^{-1} = \text{Stab}_{G_d}(F_\infty) \quad N_\infty = R_u(B_\infty)$$

For  $s \in \Pi$  s.t.  $\omega s \omega^{-1} \in W_d$  (i.e.  $W_d \omega = W_d \omega s$ ), define

$$P_{\infty, \omega s} = \omega (B_d s s^{-1} B_d \cup B_d) \omega^{-1} \quad N_{\infty, \omega s} = R_u(B_{\infty, \omega s})$$

$$= B_\infty \omega s \omega^{-1} B_\infty \cup B_\infty \quad = N_\infty \cap N_{\infty, \omega s}$$

$$M_{\infty, \omega s} = N_\infty / N_{\infty, \omega s}$$

$$= B_\infty / B_\infty \cap B_{\infty, \omega s}$$

Ex. Show that

$$u s_i u^{-1} \in W_d \Rightarrow u s_i u^{-1} = s_{\sigma(i)} \in \Pi_d$$

We can generalize the unipotent part.

$$N_{\infty, \omega''} := N_\infty \cap N_\infty$$

$$M_{\infty, \omega''} := N_\infty / N_{\infty, \omega''}$$

$$= B_\infty / B_\infty \cap B_{\infty, \omega''}$$

Their Lie algebras are collected here.

$$\mathfrak{g}_{\text{Idl}}, \mathfrak{b}_{\text{Idl}}, \mathfrak{t}_{\text{Idl}}, \mathfrak{n}_{\text{Idl}}$$

$$g_d \quad b_d \quad t_d \quad n_d$$

$$\mathfrak{b}_\infty \quad \bar{\mathfrak{b}}_\infty$$

$$b_\infty \quad n_\infty$$

$$P_{\infty, \omega s} \quad N_{\infty, \omega''}$$

$$m_{\infty, \omega''}$$

$$\bar{b}_\infty = b_{\omega \max \infty}$$

$$\bar{b}_\infty = b_{w \max \infty}$$

$$\bar{P}_{\infty, \omega s} = P_{w \max \infty, w \max \infty s}$$

$$m_{\infty, \omega''}$$

$$\text{Rep}_d(Q) := \bigoplus_{e \in Q_1} \text{Hom}(V_{s(e)}, V_{t(e)}) = \begin{pmatrix} * & * & * \\ * & * & * \end{pmatrix} \subseteq \mathfrak{g}_{\text{Idl}}^{\oplus k}$$

$$V_\infty = \{f \in \text{Rep}_d(Q) \mid f: F_{\infty, i} \subseteq F_{\infty, i}\} = \mu_d \pi_d^{-1}(F_\infty)$$

$$= \begin{pmatrix} v_3 & v_1 & v_2 \\ v_4 & * & * \\ * & * & * \end{pmatrix} = \begin{pmatrix} v_1 & v_2 & v_3 \\ v_4 & * & * \\ * & * & * \end{pmatrix}$$

$$V_{\omega(i)}$$

$$V_{\infty, \omega''} = V_\infty \cap V_{\infty''}$$

$$J_{\infty, \omega''} = V_\infty / V_{\infty, \omega''}$$

Later we may twist the group actions.

$$\text{E.g. } \underline{r}_{\infty, \omega'} := r_{\infty, \omega \omega'} \quad r_{\infty, \omega''} = \underline{r}_{\infty, \omega^{-1} \omega''}$$

#### 4. typical variety

Id corres to

$$\begin{aligned}
 F_{\text{Id}\text{Id}} &\cong G_{\text{Id}\text{Id}} / B_{\text{Id}\text{Id}} & F_{\text{Id}} \\
 F_{\underline{d}} &\cong G_{\underline{d}} / B_{\underline{d}} & F_u \\
 F_{\infty} &\cong G_{\underline{d}} / B_{\infty} & F_{\omega} \\
 F_{\underline{d}} &= \coprod_{\underline{d}'} F_{\underline{d}'} & - \\
 F_{g\infty} &\cong G_{\underline{d}} / gB_{\infty}g^{-1} & F_{g\infty} \\
 F_{\infty, \cdot} &= \text{Flag}_{\underline{d}}(F_{\text{Id}}) = F_{\{v_{\infty(1)}, v_{\infty(2)}, \dots, v_{\infty(\text{Id})}\}} & \\
 &= F_{\{u_5, u_3, u_1, u_6, u_2\}}
 \end{aligned}$$

✓ The action on Flag is not the same as in

[http://www.math.uni-bonn.de/ag/stroppel/Master%27s%20Thesis\\_Tomasz%20Przezdziecki.pdf](http://www.math.uni-bonn.de/ag/stroppel/Master%27s%20Thesis_Tomasz%20Przezdziecki.pdf)

$$F_{\text{Id}\text{Id}} \neq \coprod_{\underline{d}} F_{\underline{d}}$$

$F_{\infty} \cong F_{\underline{d}}$  with different base pt. Base pt makes difference!

$$\begin{aligned}
 F_{\text{Id}\text{Id}} \times F_{\text{Id}\text{Id}} && F_{\text{Id}, \text{Id}} \\
 F_{\underline{d}} \times F_{\underline{d}'} && F_{u, u'} \\
 F_{\infty} \times F_{\infty'} && F_{\infty, \infty'} \\
 F_{\underline{d}} \times F_{\underline{d}'} &= \coprod_{\underline{d}, \underline{d}'} (F_{\underline{d}} \times F_{\underline{d}'}) & -
 \end{aligned}$$

$$F_{\infty, \infty'} := (F_{\infty}, F_{\infty'})$$

$$\begin{array}{ccc}
 \widetilde{\text{Rep}}_{\underline{d}}(\mathbb{Q}) & \subset & \text{Rep}_{\underline{d}}(\mathbb{Q}) \times F_{\underline{d}} \\
 \downarrow M_{\underline{d}} & & \downarrow \pi_{\underline{d}} \\
 \text{Rep}_{\underline{d}}(\mathbb{Q}) & & F_{\underline{d}}
 \end{array}$$

$$\begin{array}{ccc}
 \widetilde{\text{Rep}}_{\underline{d}}(\mathbb{Q}) & \subset & \text{Rep}_{\underline{d}}(\mathbb{Q}) \times F_{\underline{d}} \\
 \downarrow M_{\underline{d}} & & \downarrow \pi_{\underline{d}} \\
 \text{Rep}_{\underline{d}}(\mathbb{Q}) & & F_{\underline{d}}
 \end{array}$$

$\mu_{\underline{d}}^{-1}(M) \cong \text{Flag}_{\underline{d}}(M) \subseteq F_{\underline{d}}$  is the Springer fiber.

$$\begin{array}{ccc}
 Z_{\underline{d}, \underline{d}'} & \subset & \text{Rep}_{\underline{d}}(\mathbb{Q}) \times F_{\underline{d}} \times F_{\underline{d}'} \\
 \downarrow M_{\underline{d}, \underline{d}'} & & \downarrow \pi_{\underline{d}, \underline{d}'} \\
 \text{Rep}_{\underline{d}}(\mathbb{Q}) & & F_{\underline{d}} \times F_{\underline{d}'}
 \end{array}$$

$$\begin{array}{ccc}
 Z_{\underline{d}} & \subset & \text{Rep}_{\underline{d}}(\mathbb{Q}) \times F_{\underline{d}} \times F_{\underline{d}} \\
 \downarrow M_{\underline{d}, \underline{d}} & & \downarrow \pi_{\underline{d}, \underline{d}} \\
 \text{Rep}_{\underline{d}}(\mathbb{Q}) & & F_{\underline{d}} \times F_{\underline{d}}
 \end{array}$$

$$\begin{array}{c}
 \widetilde{\text{Rep}}_{\underline{d}}(\mathbb{Q}) \subseteq \text{Rep}_{\underline{d}}(\mathbb{Q}) \times F_{\underline{d}} \\
 \widetilde{\text{Rep}}_{\underline{d}}(\mathbb{Q}) := \bigsqcup_{\underline{d}} \widetilde{\text{Rep}}_{\underline{d}}(\mathbb{Q})
 \end{array}$$

$$\widetilde{\text{Rep}}_{\infty}(\mathbb{Q}) \cong G_{\underline{d}} \times^{B_{\infty}} r_{\infty}$$

$$\begin{aligned}
 Z_{\underline{d}, \underline{d}'} &= \widetilde{\text{Rep}}_{\underline{d}}(\mathbb{Q}) \times_{\text{Rep}_{\underline{d}}(\mathbb{Q})} \widetilde{\text{Rep}}_{\underline{d}'}(\mathbb{Q}) \\
 Z_{\underline{d}} &= \bigsqcup_{\underline{d}', \underline{d}''} Z_{\underline{d}, \underline{d}'} \\
 &= \widetilde{\text{Rep}}_{\underline{d}}(\mathbb{Q}) \times_{\text{Rep}_{\underline{d}}(\mathbb{Q})} \widetilde{\text{Rep}}_{\underline{d}}(\mathbb{Q})
 \end{aligned}$$

$$Z_{\infty, \infty'} = Z_{u, u'}$$

## 5. (equivariant) stratifications.

In the following tables,  $uw' = \tilde{w}'\tilde{u}$ .

$F_\infty \in \widetilde{\text{Rep}}_d(Q)$  means  $(p_0, F_\infty); (F_\infty, F_{\infty'}) \in Z_d$  means  $(p_0, F_\infty, F_{\infty'})$ .

▽  $G \times G$  acts on  $\mathcal{F} \times \mathcal{F}$  in a twisted way

$$\text{e.g. } (g_1, g_2) F_{\infty, \infty'} = F_{g_1 \infty, g_1 \tilde{w} g_2 \infty'^{-1}}$$

$$(g_1, g_2) E_{\infty, \infty'} = E_{g_1 \infty, g_2 \infty'}$$

| variety<br>base point                           | stratification<br>stabilizer                             | type | B-orbit   | $B \times B$ -orbit<br>stabilizer are twisted | $B \times G$ -orbit                    | $G \times B$ -orbit   | Remark<br>$G \times \{*\}$ -orbit |
|---|--|------|---|---|--|---|-----------------------------------|
| $\mathcal{B}$                                   | $\mathcal{B} \times \mathcal{B}$                         |      | $\Omega_g$  | $\Omega_{g, g'}$                              | $\text{pr}_i^{-1}(\Omega_g)$           | $\Omega_{g'}$   |                                   |
| $F_g$<br>( $F_g, F_{gg'}$ )                     | $B \cap gBg^{-1}$  |      | $B \cap gBg^{-1} \times B \cap (gg')B(gg')^{-1}$                    |   |  |   | $gBg^{-1} \cap gg'B(gg')^{-1}$    |
| $\mathcal{F}_{\text{id}}$                       | $\mathcal{F}_{\text{id}} \times \mathcal{F}_{\text{id}}$ |      | $\mathcal{V}_\infty$  | $\mathcal{V}_{\infty, \infty'}$               | $\text{pr}_i^{-1}(\mathcal{V}_\infty)$ | $\mathcal{V}_\infty$  |                                   |
| $F_\infty$<br>( $F_\infty, F_{\infty\infty'}$ ) | $B_{\text{id}} \cap B_\infty$                            |      | $B_{\text{id}} \cap B_\infty \times B_{\text{id}} \cap B_{\infty'}$ |   |  |   | $B_\infty \cap B_{\infty\infty'}$ |
| $\mathcal{F}_u$                                 | $\mathcal{F}_u \times \mathcal{F}_u$                     |      | $\Omega_w^u$  | $\Omega_{w, w'}^{u, u'}$                      | $\text{pr}_{i,u}^{-1}(\Omega_w^u)$     | $\Omega_{w'}^{u, u'}$                                       |                                   |
| $F_{wu}$<br>( $F_{wu}, F_{wuwu'}$ )             | $B_d \cap B_w$   |      | $B_d \cap B_w \times B_d \cap B_{ww'}$                              |   |  |   | $B_w \cap B_{ww'}$                |
| $\mathcal{F}_d$                                 | $\mathcal{F}_d \times \mathcal{F}_d$                     |      | $\Omega_w^u$  | $\Omega_{w, \tilde{w}}^{u, \tilde{u} u'}$     | $\text{pr}_{i,u}^{-1}(\Omega_w^u)$     | $\Omega_{\infty'}^u = \Omega_{\tilde{w}}^{u, \tilde{u} u'}$ | compatibility                     |
| $F_\infty$<br>"                                 | $B_d \cap B_w$   |      | $B_d \cap B_w \times B_d \cap B_{w\tilde{w}}$                       |   |  |   | $B_w \cap B_{w\tilde{w}}$         |
| $F_{wu}$<br>( $F_{wu}, F_{wuwu'}$ )             |  |      |   |   |  |   |                                   |

The following may not be single orbit, but derived from the above definition.

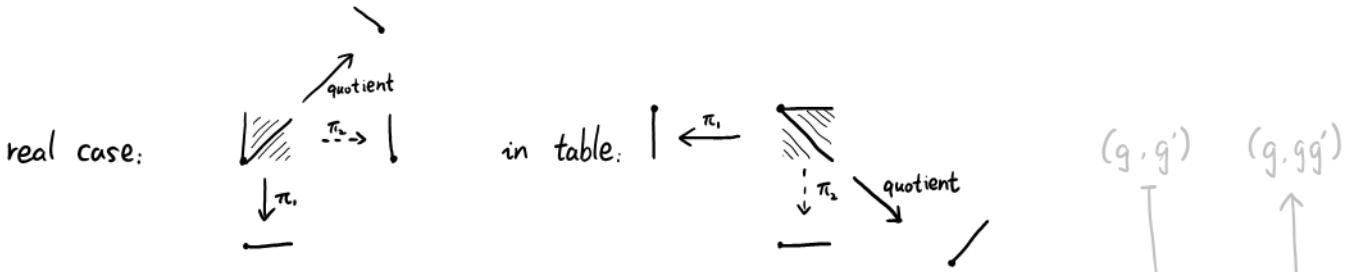
|   |                                      |                                  |   |  |  |  |  |
|---|--------------------------------------|----------------------------------|---|--|--|--|--|
| $\mathcal{F}_d$                                 | $\mathcal{F}_d \times \mathcal{F}_d$ | $\mathcal{O}_\infty$             | $\mathcal{O}_{\infty, \infty'}$                       | $\text{pr}_i^{-1}(\mathcal{O}_\infty)$                     | $\mathcal{O}_\infty$   |  | preimage of<br>$\mathcal{F}_d \times \mathcal{F}_d \hookrightarrow \mathcal{F}_{\text{id}} \times \mathcal{F}_{\text{id}}$ |
| $F_\infty$<br>( $F_\infty, F_{\infty\infty'}$ ) |                                      | $\Omega_w^u$                     | $\Omega_{w, \tilde{w}}^{u, \tilde{u} u'}$             | $\bigsqcup_u \text{pr}_{i,u}^{-1}(\Omega_w^u)$             | $\bigsqcup_u \Omega_{\tilde{w}}^{u, \tilde{u} u'}$             |  | preimage of<br>$\mathcal{Z}_{d, d'} \rightarrow \mathcal{F}_d \times \mathcal{F}_d$  |
| $\widetilde{\text{Rep}}_d(Q)$                   | $Z_d$                                | $\widetilde{\Omega}_w^u$         | $\widetilde{\Omega}_{w, w'}^{u, u'}$                  | $\text{pr}_{i,u}^{-1}(\widetilde{\Omega}_w^u)$             | $\widetilde{\Omega}_w^{u, u'}$                                 |  | preimage of<br>$\mathcal{Z}_d \rightarrow \mathcal{F}_d \times \mathcal{F}_d$  |
| $F_\infty$<br>( $F_\infty, F_{\infty\infty'}$ ) |                                      |                                  |   |  |  |  |  |
| $\widetilde{\text{Rep}}_d(Q)$                   | $Z_d$                                | $\widetilde{\mathcal{O}}_\infty$ | $\widetilde{\mathcal{O}}_{\infty, \infty'}$           | $\text{pr}_i^{-1}(\widetilde{\mathcal{O}}_\infty)$         | $\widetilde{\mathcal{O}}_\infty$                               |  | preimage of<br>$\mathcal{Z}_d \rightarrow \mathcal{F}_d \times \mathcal{F}_d$  |
| $F_\infty$<br>( $F_\infty, F_{\infty\infty'}$ ) |                                      | $\widetilde{\Omega}_w^u$         | $\widetilde{\Omega}_{w, \tilde{w}}^{u, \tilde{u} u'}$ | $\bigsqcup_u \text{pr}_{i,u}^{-1}(\widetilde{\Omega}_w^u)$ | $\bigsqcup_u \widetilde{\Omega}_{\tilde{w}}^{u, \tilde{u} u'}$ |  |  |

$$\mathcal{Z}_{\infty'} := \overline{\widetilde{\mathcal{O}}_\infty} \subseteq \overline{\widetilde{\mathcal{O}}_{\infty'}}$$

$$\mathcal{Z}_{w'}^{u, u'} := \overline{\widetilde{\Omega}_{w'}^{u, u'}} \subseteq \overline{\widetilde{\Omega}_w^{u, u'}}$$

$$\mathcal{Z}_d^\infty = \mathcal{Z}_\infty \cap \mathcal{Z}_{d, d'}$$

Zar-loc sub v.b.?



We want gp action to be compatible with  $\pi_i$  and the quotient map.  
Therefore, we would do a twist.



Rmk. The stabilizer is not trivial to determine because of this twist!

$$\begin{aligned}
 E_{g_1, g_2} = E_{g_3, g_4} &\Leftrightarrow g_1 B = g_3 B, g_2 B = g_4 B \\
 &\Leftrightarrow g_1 B = g_3 B, g_1 g_2 B = g_3 g_4 B \\
 E_{g_1\omega, g_2\omega'} = E_{\omega, \omega'} &\Leftrightarrow g_1 \omega B = \omega B, g_1 \omega g_2 \omega' B = g_2 \omega' B \\
 &\Leftrightarrow g_1 = \omega b, \omega^{-1} \in B_\omega \quad b, g_2 \in B_{\omega'} \\
 &\Leftrightarrow g_1 \in B_\omega, \quad g_2 \in \omega^{-1} g_1 \omega \cdot B_{\omega'}
 \end{aligned}$$

The following tables may help you to understand the notations.

| $\dim$ | $B_{\text{Id}} \cdot F_{\text{var}}$  | 0                         | 1                                   | 1                           | 2                           | 2                            | 3                            |
|--------|---|---------------------------|-------------------------------------|-----------------------------|-----------------------------|------------------------------|------------------------------|
|        | $B_{\text{Id}} \times B_{\text{Id}} \cdot (F_{\text{var}}, F_{\text{var}})$ | $\mathcal{V}_{\text{Id}}$ | $\mathcal{V}_t$                     | $\mathcal{V}_s$             | $\mathcal{V}_{ts}$          | $\mathcal{V}_{st}$           | $\mathcal{V}_{sts}$          |
|        | $B_{\text{Id}} \cdot F_w$   | $\mathcal{V}_{\text{Id}}$ | $\mathcal{V}_{\text{Id},\text{Id}}$ | $\mathcal{V}_{\text{Id},t}$ | $\mathcal{V}_{\text{Id},s}$ | $\mathcal{V}_{\text{Id},ts}$ | $\mathcal{V}_{\text{Id},st}$ |
| 0      |   |                           |                                     |                             |                             |                              |                              |
| 1      |   |                           |                                     |                             |                             |                              |                              |
| 2      |   |                           |                                     |                             |                             |                              |                              |
| 3      |   |                           |                                     |                             |                             |                              |                              |

| $\dim$ | $B_d \cdot F_{\text{var}}$                              | 0                         | 1                              | 2                      | 3                      | 4                       | 5                       |
|--------|---|---------------------------|--------------------------------|------------------------|------------------------|-------------------------|-------------------------|
|        | $B_d \times B_d \cdot (F_{\text{var}}, F_{\text{var}})$ | $\mathcal{O}_{\text{Id}}$ | $\mathcal{O}_t$                | $\mathcal{O}_s$        | $\mathcal{O}_{ts}$     | $\mathcal{O}_{st}$      | $\mathcal{O}_{sts}$     |
|        | $B_d \cdot F_w$   | $\mathcal{O}_{\text{Id}}$ | $\Omega_{\text{Id},\text{Id}}$ | $\Omega_{\text{Id},t}$ | $\Omega_{\text{Id},s}$ | $\Omega_{\text{Id},ts}$ | $\Omega_{\text{Id},st}$ |
| 0      |   |                           |                                |                        |                        |                         |                         |
| 1      |   |                           |                                |                        |                        |                         |                         |
| 2      |   |                           |                                |                        |                        |                         |                         |
| 3      |   |                           |                                |                        |                        |                         |                         |
| 4      |   |                           |                                |                        |                        |                         |                         |
| 5      |   |                           |                                |                        |                        |                         |                         |

The following tables may help you to understand the notations.

$$\omega = ts, \omega' = s$$

| $\dim$ | $B_{Id} \cdot F_{ts}$                         | 0                   | 1                       | 1                      | 2                      | 2                     | 3                     | $\text{pr}_i^{-1}(\mathcal{V}_{ts})$ |
|--------|---|---------------------|-------------------------|------------------------|------------------------|-----------------------|-----------------------|--------------------------------------|
|        | $B_{Id} \times B_{Id} \cdot (F_{ts}, F_{ts})$ | $\mathcal{V}_{Id}$  | $\mathcal{V}_t$         | $\mathcal{V}_s$        | $\mathcal{V}_{ts}$     | $\mathcal{V}_{st}$    | $\mathcal{V}_{sts}$   |                                      |
|        | $B_{Id} \cdot F_{ts}$                         | $\mathcal{V}_{Id}$  | $\mathcal{V}_{Id,Id}$   | $\mathcal{V}_{Id,t}$   | $\mathcal{V}_{Id,s}$   | $\mathcal{V}_{Id,ts}$ | $\mathcal{V}_{Id,st}$ | $\mathcal{V}_{Id,sts}$               |
| 0      |   | $\mathcal{V}_{Id}$  | $\mathcal{V}_{Id,Id}$   | $\mathcal{V}_{Id,t}$   | $\mathcal{V}_{Id,s}$   | $\mathcal{V}_{Id,ts}$ | $\mathcal{V}_{Id,st}$ | $\mathcal{V}_{Id,sts}$               |
| 1      |   | $\mathcal{V}_t$     | $\mathcal{V}_{t,t}$     | $\mathcal{V}_{t,Id}$   | $\mathcal{V}_{t,ts}$   | $\mathcal{V}_{t,s}$   | $\mathcal{V}_{t,sts}$ | $\mathcal{V}_{t,st}$                 |
| 1      |   | $\mathcal{V}_s$     | $\mathcal{V}_{s,s}$     | $\mathcal{V}_{s,st}$   | $\mathcal{V}_{s,Id}$   | $\mathcal{V}_{s,sts}$ | $\mathcal{V}_{s,t}$   | $\mathcal{V}_{s,ts}$                 |
| 2      |   | $\mathcal{V}_{ts}$  | $\mathcal{V}_{ts,st}$   | $\mathcal{V}_{ts,s}$   | $\mathcal{V}_{ts,sts}$ | $\mathcal{V}_{ts,Id}$ | $\mathcal{V}_{ts,ts}$ | $\mathcal{V}_{ts,t}$                 |
| 2      |   | $\mathcal{V}_{st}$  | $\mathcal{V}_{st,ts}$   | $\mathcal{V}_{st,sts}$ | $\mathcal{V}_{st,t}$   | $\mathcal{V}_{st,st}$ | $\mathcal{V}_{st,Id}$ | $\mathcal{V}_{st,s}$                 |
| 3      |   | $\mathcal{V}_{sts}$ | $\mathcal{V}_{sts,sts}$ | $\mathcal{V}_{sts,ts}$ | $\mathcal{V}_{sts,st}$ | $\mathcal{V}_{sts,t}$ | $\mathcal{V}_{sts,s}$ | $\mathcal{V}_{sts,Id}$               |

| $\text{shape}$     | $B_d \cdot F_{ts}$                      | $\mathcal{F}_{Id}$       | $\mathcal{F}_s$         | $\mathcal{F}_{st}$      | $\text{pr}_i^{-1}(\mathcal{O}_{ts})$ | $\text{pr}_{i,Id}^{-1}(\Omega_t^s)$ | $\Omega_{t,Id}^{s,Id} = \mathcal{O}_{ts,s}$ |
|--------------------|---|--------------------------|-------------------------|-------------------------|--------------------------------------|-------------------------------------|---|
|                    | $B_d \times B_d \cdot (F_{ts}, F_{ts})$ | $\mathcal{O}_{Id}$       | $\mathcal{O}_t$         | $\mathcal{O}_s$         | $\mathcal{O}_{ts}$                   | $\mathcal{O}_{st}$                  | $\mathcal{O}_{sts}$                         |
|                    | $B_d \cdot F_{ts}$                      |                          |                         |                         |                                      |                                     |   |
| $\mathcal{F}_{Id}$ | $\mathcal{O}_{Id}$                      | $\Omega_{Id,Id}^{Id,Id}$ | $\Omega_{Id,t}^{Id,Id}$ | $\Omega_{Id,s}^{Id,s}$  | $\Omega_{Id,t}^{Id,s}$               | $\Omega_{Id,ts}^{Id,st}$            | $\Omega_{Id,t}^{Id,st}$                     |
|                    | $\mathcal{O}_t$                         | $\Omega_{t,t}^{Id,Id}$   | $\Omega_{t,Id}^{Id,Id}$ | $\Omega_{t,t}^{Id,s}$   | $\Omega_{t,Id}^{Id,s}$               | $\Omega_{t,ts}^{Id,st}$             | $\Omega_{t,Id}^{Id,st}$                     |
| $\mathcal{F}_s$    | $\mathcal{O}_s$                         | $\Omega_{Id,Id}^{s,Id}$  | $\Omega_{Id,t}^{s,Id}$  | $\Omega_{Id,Id}^{s,s}$  | $\Omega_{Id,t}^{s,s}$                | $\Omega_{Id,ts}^{s,st}$             | $\Omega_{Id,t}^{s,st}$                      |
|                    | $\mathcal{O}_{ts}$                      | $\Omega_{t,t}^{s,Id}$    | $\Omega_{t,Id}^{s,Id}$  | $\Omega_{t,t}^{s,s}$    | $\Omega_{t,Id}^{s,s}$                | $\Omega_{t,ts}^{s,st}$              | $\Omega_{t,Id}^{s,st}$                      |
| $\mathcal{F}_{st}$ | $\mathcal{O}_{ts}$                      | $\Omega_{Id,Id}^{st,Id}$ | $\Omega_{Id,t}^{st,Id}$ | $\Omega_{Id,Id}^{st,s}$ | $\Omega_{Id,t}^{st,s}$               | $\Omega_{Id,ts}^{st,st}$            | $\Omega_{Id,t}^{st,st}$                     |
|                    | $\mathcal{O}_{sts}$                     | $\Omega_{t,t}^{st,Id}$   | $\Omega_{t,Id}^{st,Id}$ | $\Omega_{t,t}^{st,s}$   | $\Omega_{t,Id}^{st,s}$               | $\Omega_{t,ts}^{st,st}$             | $\Omega_{t,Id}^{st,st}$                     |

## 6. change of basis

### §6.1 two basis

Def Let  $Y \subset X$  be  $G$ -equiv closed subvariety,  $X$  proj.

$$[Y]^G := (\iota_Y)_*(\pi_Y)^* 1_{R(G)} \in K_0^G(X)$$

with same notation,

$$[Y]^G := (\iota_Y)_*(\pi_Y)^* 1_{S(G)} \in H_q^*(X; \mathbb{Q})$$

$$\begin{array}{ccc} Y & \xhookrightarrow{\iota_Y} & X \\ & \downarrow \pi_Y & \\ & pt & \end{array}$$

By cellular fibration lemma,

$$\begin{array}{ccccccc} K_0^{Td}(F_d) & \cong & K_0^{Cd}(F_d \times F_d) & \cong & K_0^{Cd}(Z_d) \\ \oplus_{\omega \in W_{td}} R(T_d)[\bar{\mathcal{O}}_\omega]^{Td} & \cong & \oplus_{\omega \in W_{td}} R(T_d)[\bar{\mathcal{O}}_\omega]^{Cd} & \cong & \oplus_{\omega \in W_{td}} R(T_d)[Z_\omega]^{Cd} \\ & & & & & & \downarrow \\ & & & & & \parallel S & K_0^{Td}(Z_d) \\ & & & & & & \\ & & & & & & \oplus_{\omega, \omega' \in W_{td}} R(T_d)[\bar{\mathcal{O}}_{\omega, \omega'}]^{Td} \end{array}$$

as  $R(T_d)$ -modules.

⚠ There is no evidence if  $[Z_\omega]^{Cd}$  will be mapped to  $\oplus_{\omega \in W_{td}} [\bar{\mathcal{O}}_{\omega, \omega'}]^{Td}$ . Luckily, the horizontal line sends generators to generators.

Hint: Consider the following commutative diagram:

$$\begin{array}{ccccc} F_d & \xrightarrow{(F_d, Id)} & F_d \times F_d & \xrightarrow{(p_0, Id)} & Z_d \\ \bar{\mathcal{O}}_\omega & \nearrow & \nearrow & \nearrow & \\ pt & = & pt & = & pt \end{array}$$

To do linear alg, we take

$$\begin{aligned} \mathcal{R}(G) &:= \text{Frac } (R(G)) \\ \mathcal{S}(G) &:= \text{Frac } (S(G)) \end{aligned}$$

$$\begin{aligned} \mathcal{K}_o^G(X) &= K_o^G(X) \otimes_{R(T_d)} \mathcal{R}(T_d) \\ \mathcal{H}_G^*(X; \mathbb{Q}) &= H_G^*(X; \mathbb{Q}) \otimes_{S(T_d)} S(T_d) \end{aligned}$$

For  $R(T_d)$ -mod  $K_o^G(X)$ ,  $S(T_d)$ -mod  $H_G^*(X; \mathbb{Q})$

$$\begin{aligned} \text{Define } \psi_\infty &= [\{F_\infty\}]^{T_d} = (i_\infty)_* 1_{R(T_d)} \in K_o^{T_d}(\mathcal{F}_d) \\ \psi_{\infty, \infty'} &= [\{(\rho_0, F_\infty, F_{\infty'})\}]^{T_d} = (i_{\infty, \infty'})_* 1_{R(T_d)} \in K_o^{T_d}(\mathbb{Z}_d) \\ \psi_{\infty, \infty'} &= [\{(\rho_0, F_\infty, F_{\infty'})\}]^{T_d} \end{aligned}$$

We get two  $\mathcal{R}(T_d)$ -basis. ( $\psi_\infty$  is  $\mathcal{R}(T_d)$ -basis, by Localization theorem.)

$$\begin{array}{ccc} K_o^{T_d}(\mathcal{F}_d) & \longrightarrow & K_o^{T_d}(\mathbb{Z}_d) \\ [\overline{O_\infty}]^{T_d} & & [\overline{O_{\infty, \infty'}}]^{T_d} \\ \psi_\infty & & \psi_{\infty, \infty'} \end{array} \quad \begin{array}{l} \text{standard basis for stratification} \\ \text{canonical basis for convolution} \end{array}$$

Localization thm [Thm 10.1]

Let  $i: X^{T_d} \hookrightarrow X$ ,  $X$  is smooth.

$$\begin{array}{ccccc} \mathcal{K}_o^{T_d}(X^{T_d}) & \xrightarrow{i^*} & \mathcal{K}_o^{T_d}(X) & \xrightarrow{i^*} & \mathcal{K}_o^{T_d}(X^{T_d}) \\ \mathcal{H}_{T_d}^*(X^{T_d}; \mathbb{Q}) & \xrightarrow{i^*} & \mathcal{H}_{T_d}^*(X; \mathbb{Q}) & \xrightarrow{i^*} & \mathcal{H}_{T_d}^*(X^{T_d}; \mathbb{Q}) \end{array}$$

are isos as  $\mathcal{R}(T_d)$  or  $\mathcal{S}(T_d)$ -module.

Q: The Steinberg variety  $Z_d$  is usually not smooth.

How to show that  $\{\psi_{\infty, \infty'}\}$  forms a basis?

Guess: apply localization thm to  $T_d \times T_d$  first.

## § 6.2. tangent space

Def (tangent space of fixed pts. in  $R(T_d)$ )

$$\widetilde{T}_\infty := T_{F_\infty} \overline{F_d} \cong T_{Id}(G_d/B_\infty) \cong \mathfrak{g}_d/b_\infty = n_\infty^-$$

$$\widetilde{T}_\infty := T_{(p_0, F_\infty)} \widetilde{Rep_d(\mathbb{Q})} \cong T_{r_\infty} \oplus T_{F_\infty} \overline{F_d} = r_\infty \oplus n_\infty^-$$

$$\widetilde{T}_{\infty, \infty'}^x := T_{(p_0, F_\infty, F_{\infty'})} \overline{\mathcal{O}}_x$$

$$\widetilde{T}_{\infty, \infty'}^x := T_{(p_0, F_\infty, F_{\infty'})} \mathcal{Z}_x \cong T_{r_{\infty, \infty'}} \oplus T_{(F_\infty, F_{\infty'})} \overline{\mathcal{O}}_x = r_{\infty, \infty'} \oplus \underline{L}_{\infty, \infty'}^x$$

Hint:

$$\begin{array}{ccc} \overline{\mathcal{O}}_x & \xrightarrow{(p_0, Id)} & \mathcal{Z}_x \\ & \searrow & \downarrow \\ & & \overline{\mathcal{O}}_x \end{array}$$

$$T_{x_0} (\cancel{\nearrow}) = T_{x_0} (\nearrow) \oplus T_{x_0} (\nwarrow)$$

$$\widetilde{T}_{\infty, \infty'}^x := T_{(F_\infty, F_{\infty \infty'})} \overline{\mathcal{O}}_x$$

Rmk. It is still not easy to express  $\widetilde{T}_{\infty, \infty'}^x$  as Lie alg.  
However, we still know some special cases:

$$\begin{aligned} \mathcal{I}_{\infty, x}^x &:= T_{(F_\infty, F_{\infty x})} \overline{\mathcal{O}}_x \\ &= T_{(F_\infty, F_{\infty x})} \mathcal{O}_x^u \\ &= T_{(F_\infty, F_{\infty x})} \mathcal{O}_x^u \\ &= T_{Id} G_d/B_\infty \cap B_{\infty x} \\ &= \mathfrak{g}_d - b_\infty \cap b_{\infty x} \\ &= \mathfrak{g}_d - b_\infty + b_\infty / (b_\infty \cap b_{\infty x}) \\ &= n_\infty^- + \underline{m}_{\infty, x} \end{aligned}$$

( $\underline{m}_{\infty, Id} = 0$ . For  $s \in \Pi$ ,  $\infty s \in \mathcal{W}_d$ , we have  $\underline{m}_{\infty, s} = 0$ )

Now suppose  $\infty s \in \mathcal{W}_d$ .

$$\begin{aligned} T_{\infty, \infty s}^s &= n_\infty^- \oplus \underline{m}_{\infty, \infty s} \\ T_{\infty, \infty}^s &:= T_{(F_\infty, F_\infty)} \overline{\mathcal{O}}_s \\ &= T_{(Id, Id)} G_d/B_\infty \times P_{\infty, \infty s}/B_\infty \\ &= n_\infty^- \oplus \underline{m}_{\infty s, \infty} \end{aligned}$$

$$T_{\infty, \infty s}^s = r_{\infty, \infty s} \oplus n_\infty^- \oplus \underline{m}_{\infty, \infty s}$$

$$T_{\infty, \infty}^s = r_{\infty, \infty} \oplus n_\infty^- \oplus \underline{m}_{\infty s, \infty}$$

§6.3. Euler class.

## §6.4. transition matrix, localization formula

Thm. (Localization formula) [Thm 10.2]

Suppose  $Y \subset X$  is  $T$ -equivariant,  $\alpha \in \mathcal{K}_o^T(X)$ ,  $X$  smooth.

$X^T = \{x_1, \dots, x_m\}$ ,  $i_k : \{x_k\} \hookrightarrow X$ , then

$$\alpha = \sum_{k=1}^m \varepsilon_k (i_k)_* (i_k)^*(\alpha) \quad \varepsilon_k = (\text{eu}(T_{x_k} X))^{-1} \in \mathcal{R}(T)$$

$$\begin{aligned} \text{e.p. } [Y]^T &= \sum_{k=1}^m \varepsilon_k (i_k)_* ((i_k)^*[Y]^T \cdot 1_{R(T)}) \\ &= \sum_{k=1}^m \varepsilon_k ((i_k)^*[Y]^T) (i_k)_* 1_{R(T)} \\ &= \sum_{k=1}^m \varepsilon_k ((i_k)^*[Y]^T) [x_k]^T \\ [X]^T &= \sum_{k=1}^m \varepsilon_k [x_k]^T \end{aligned}$$

Suppose  $Y^T = \{x_1, \dots, x_n\}$ ,  $i_k : \{x_k\} \hookrightarrow Y$ , then

$$[Y]^T = \sum_{k=1}^n \beta_k [x_k]^T \quad \beta_k = \varepsilon_k \cdot (i_k)^*[Y]^T$$

When  $Y$  is sm at  $x_k$ ,

$$\begin{cases} \beta_k &= (\text{eu}(T_{x_k} Y))^{-1} \\ (i_k)^*[Y]^T &= \text{eu}(T_{x_k} X) \cdot (\text{eu}(T_{x_k} Y))^{-1} \end{cases}$$

I believe that this theorem corresponds to the coherent trace formula in this article:  
<https://www.sciencedirect.com/science/article/pii/0022404994900884>

Ex 1.  $X = \widetilde{\text{Rep}}_d(Q)$ ,  $Y = \overline{\mathcal{O}}_x$ ,  $T = T_d$

$$\begin{aligned} i_\infty : \{(p_0, F_\infty)\} &\hookrightarrow \widetilde{\text{Rep}}_d(Q) \\ \widetilde{\text{Rep}}_d(Q)^{T_d} &= \{(p_0, F_\infty) \mid \infty \in W_{ldl}\} \\ [\widetilde{\text{Rep}}_d(Q)]^{T_d} &= \sum_{\infty \in W_{ldl}} \widetilde{\Delta}_\infty^{-1} (i_\infty)_* (i_\infty)^* 1_{K_o^{T_d}(\widetilde{\text{Rep}}_d(Q))} \\ &= \sum_{\infty \in W_{ldl}} \widetilde{\Delta}_\infty^{-1} (i_\infty)_* 1_{R(T_d)} \\ &= \sum_{\infty \in W_{ldl}} \widetilde{\Delta}_\infty^{-1} \psi_\infty \end{aligned}$$

$$\begin{aligned} \overline{\mathcal{O}}_x^{T_d} &= \{(p_0, F_\infty) \mid \infty \leq x\} \\ [\overline{\mathcal{O}}_x]^{T_d} &= \sum_{\infty \leq x} \widetilde{\Delta}_\infty^{-1} \underbrace{(i_\infty)^* [\overline{\mathcal{O}}_x]^{T_d}}_{f_{\infty, x}} \psi_\infty \end{aligned}$$

when  $\overline{\mathcal{O}}_x$  is sm at  $(p_0, F_\infty)$ ,  $f_{\infty, x} = \widetilde{\Delta}_\infty (T_{(p_0, F_\infty)} \overline{\mathcal{O}}_x)^{-1}$

Ex 2.  $X = \text{Rep}_d(Q) \times \mathcal{F}_d \times \mathcal{F}_d$ ,  $Y = \mathcal{Z}_x$ ,  $T = T_d$

$$\begin{aligned} (\mathcal{Z}_s)^{T_d} &= \overline{\mathcal{O}}_s^{T_d} \sqcup (\mathcal{Z}_s - \overline{\mathcal{O}}_s)^{T_d} \\ &= \{(p_0, F_\infty, F_{\infty s}) \mid \infty \in W_{ldl}\} \sqcup \{(p_0, F_\infty, F_{\infty s}) \mid \infty \in W_{ldl}, \infty s \in W_d\} \\ \Rightarrow [\mathcal{Z}_s]^{T_d} &= \sum_{\infty \in W_{ldl}} (\widetilde{\Delta}_{\infty, \infty s})^{-1} \psi_{\infty, \infty s} + \sum_{\substack{\infty \in W_{ldl} \\ \infty s \in W_d}} (\widetilde{\Delta}_{\infty, \infty s})^{-1} \psi_{\infty, \infty s} \quad \text{in } \mathcal{K}_o^{T_d}(X) \\ &\Rightarrow \text{in } \mathcal{K}_o^{T_d}(\mathcal{Z}_d) \end{aligned}$$

In general,  $[\mathcal{Z}_x]^{T_d} = \sum_{\infty, \infty'} \beta_{\infty, \infty'}^\times \psi_{\infty, \infty \infty'}$

When  $\mathcal{Z}_x$  is sm at  $(p_0, F_\infty, F_{\infty \infty'})$ ,  $\beta_{\infty, \infty'}^\times = (\widetilde{\Delta}_{\infty, \infty'})^{-1}$ .

§ 6.5. generators. Define  $e_i$  and  $D_i$ .

In this subsection,  $W_{Id} = W_d$ ,  $\widetilde{\text{Rep}_d(Q)} = F_d$ ,  $Z_d = F_d \times F_d$ . (Otherwise  $K_0^{G_d}(F_d) \cong \bigoplus_{\alpha} K_0^{T_\alpha}(\text{pt})$ )

$$K_0^{G_d}(\widetilde{\text{Rep}_d(Q)}) \cong K_0^{G_d}(F_d) \cong K_0^{T_d}(\text{pt})$$

$$\begin{array}{ccccc} \pi_T^G & \downarrow & R(T_d) [\widetilde{\text{Rep}_d(Q)}]^{G_d} & \cong & R(T_d) [F_d]^{G_d} \cong R(T_d) = \mathbb{Z}[x_1^{\pm 1}, \dots, x_{|Id|}^{\pm 1}] \\ \downarrow & & f[\widetilde{\text{Rep}_d(Q)}]^{G_d} & & \\ K_0^{T_d}(\widetilde{\text{Rep}_d(Q)}) & \cong & \sum_{\infty \in W_{Id}} f \widetilde{\Delta}_{\infty}^{-1} \psi_{\infty} & & \\ \downarrow & & & & \\ \bigoplus_{\infty \in W_{Id}} R(T_d) \psi_{\infty} & & & & \\ & & \sum_{\infty \in W_{Id}} f \widetilde{\Delta}_{\infty}^{-1} \psi_{\infty} & & \end{array}$$

Q: Does  $f[\widetilde{\text{Rep}_d(Q)}]^{T_d} = \sum_{\infty \in W_{Id}} f \widetilde{\Delta}_{\infty}^{-1} \psi_{\infty}$ ?

This is needed  
but I can't get it.

Let  $e_i := x_i [\widetilde{\text{Rep}_d(Q)}]^{G_d} \in K_0^{G_d}(\widetilde{\text{Rep}_d(Q)})$ , then

$$\pi_T^G(e_i) = \sum_{\infty \in W_{Id}} x_{i\infty} \widetilde{\Delta}_{\infty}^{-1} \psi_{\infty}$$

$$\in K_0^{T_d}(\widetilde{\text{Rep}_d(Q)})$$

$$K_0^{G_d}(\widetilde{\text{Rep}_d(Q)}) \cong \mathbb{Z}[e_1, \dots, e_{|Id|}]$$

$K_0^{G_d}(Z_d)$  is a  $\mathbb{Z}[e_1, \dots, e_{|Id|}]$ -module.

$$\left[ \begin{array}{l} \text{Reason: } K_0^{G_d}(\widetilde{\text{Rep}_d(Q)}) \cong K_0^{G_d}(Z_d) \hookrightarrow K_0^{G_d}(Z_d) \\ K_0^{G_d}(Z_d) \times K_0^{G_d}(Z_d) \xrightarrow{\text{convolution}} K_0^{G_d}(Z_d) \\ \downarrow \\ K_0^{G_d}(Z_d) \times K_0^{G_d}(Z_d) \xrightarrow{\text{convolution}} K_0^{G_d}(Z_d) \end{array} \right]$$

We will mention about the convolution in the next section.

Denote

$$\begin{aligned} D_i &= [Z_{s_i}]^{G_d} \in K_0^{G_d}(Z_d) \\ \pi_T^G(D_i) &= \sum_{\infty \in W_{Id}} (\widetilde{\Delta}_{\infty, \infty s_i}^{-1}) \psi_{\infty, \infty s_i} + \sum_{\substack{\infty \in W_{Id} \text{ s.t.} \\ \infty s_i^{-1} \in W_d}} (\widetilde{\Delta}_{\infty, \infty}^{-1}) \psi_{\infty, \infty} \end{aligned}$$

we will show that, in the case  $Z_d \cong F_d \times F_d$ ,

$$K_0^{G_d}(Z_d) = \langle e_1, e_2, \dots, e_{|Id|}, D_1, \dots, D_{|Id|-1} \rangle_{\mathbb{Z}\text{-alg}} \subseteq \text{End}_{\mathbb{C}\text{-v.s.}}(\mathbb{Z}[e_1, \dots, e_{|Id|}])$$

Before that, the more interesting question is to compute

$$D_i \in \text{End}_{\mathbb{C}\text{-v.s.}}(\mathbb{Z}[e_1, \dots, e_{|Id|}]).$$

## 7. convolution product

### §7.1. clean intersection formula

Thm. Suppose  $X$  sm  $G$ -equiv proj variety,  
 $Y_1, Y_2 \subset X$  are  $G$ -equiv subvariety,  
 $Y = Y_1 \cap Y_2$        $\pi_Y: Y \rightarrow \text{pt}$   
 $T = TX|_Y / (TY_1|_Y + TY_2|_Y)$

Assume that

$$TY_1|_Y \wedge TY_2|_Y = TY,$$

then

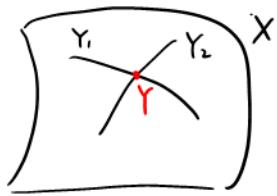
$$[Y_1]^G \otimes [Y_2]^G = \text{eu}(\pi_{Y,*}(T)) \cdot [Y]^G$$

Need a reference.

I believe that the first page of this document write the same thing:

[https://www.uni-due.de/~adc301m/staff.uni-duisburg-essen.de/Publications\\_files/excessgw.pdf](https://www.uni-due.de/~adc301m/staff.uni-duisburg-essen.de/Publications_files/excessgw.pdf)

However, there is no proof.



$$\pi_{Y,*}: K^G_0(Y) \rightarrow K^G_0(\text{pt}) = R(G)$$

## §7.2. convolution for canonical basis.

Thm  $\psi_{\infty'', \infty''} * \psi_{\infty', \infty} = \delta_{\infty'', \infty'} \widetilde{\Delta}_{\infty'} \psi_{\infty'', \infty}$   
 $\psi_{\infty'', \infty'} \diamond \psi_{\infty} = \delta_{\infty', \infty} \widetilde{\Delta}_{\infty} \psi_{\infty''}$

Proof. It reduce to the case

$$\begin{aligned} \psi_{\infty'', \infty'} * \psi_{\infty', \infty} &= \widetilde{\Delta}_{\infty'} \psi_{\infty'', \infty} \\ \psi_{\infty', \infty} \diamond \psi_{\infty} &= \widetilde{\Delta}_{\infty} \psi_{\infty'} \end{aligned}$$

$*: K_0^{Cd}(Z_d) \times K_0^{Cd}(Z_d) \rightarrow K_0^{Cd}(Z_d)$

$\{(\rho_0, F_{\infty''}), (\rho_0, F_{\infty'})\}$

$Y_{12} = \{(\rho_0, F_{\infty''}, F_{\infty'})\} \quad Y_{23} = \{(\rho_0, F_{\infty'}, F_{\infty})\}$

$\begin{array}{ccc} Y_{12} \times \widetilde{\text{Rep}}_d(Q) & \subset & M_{123} \\ \{y\} \subset \widetilde{\text{Rep}}_d \times Y_{23} & \subset & M_{123} \end{array}$

where

$y = ((\rho_0, F_{\infty''}), (\rho_0, F_{\infty'}), (\rho_0, F_{\infty})) \in M_{123}$

$y_{13} = ((\rho_0, F_{\infty''}), (\rho_0, F_{\infty})) \in M_{13}$

$T = \frac{\widetilde{T}_{\infty''} \oplus \widetilde{T}_{\infty'} \oplus \widetilde{T}_{\infty}}{\widetilde{T}_{\infty''} \oplus \widetilde{T}_{\infty}} = \widetilde{T}_{\infty'}$

$$\begin{aligned} \psi_{\infty'', \infty'} * \psi_{\infty', \infty} &= [Y_{12}]^{Td} * [Y_{23}]^{Td} \\ &= \pi_{13,*}([Y_{12} \times \widetilde{\text{Rep}}_d(Q)]^{Td} \otimes [\widetilde{\text{Rep}}_d(Q) \times Y_{23}]^{Td}) \\ &= \pi_{13,*}(\widetilde{\Delta}_{\infty'} \cdot [y]^{Td}) \\ &= \widetilde{\Delta}_{\infty'} \cdot [y_{13}]^{Td} \\ &= \widetilde{\Delta}_{\infty'} \psi_{\infty'', \infty} \end{aligned}$$

$\diamond: K_0^{Cd}(Z_d) \times K_0^{Cd}(\widetilde{\text{Rep}}_d(Q)) \rightarrow K_0^{Cd}(\widetilde{\text{Rep}}_d(Q))$

$\begin{array}{ccc} Y_{12} = \{(\rho_0, F_{\infty'}, F_{\infty})\} & & Y_{23} = \{(\rho_0, F_{\infty})\} \\ \{y\} \subset Y_{12} \times pt & & \{y\} \subset M_{123} \\ \subset \widetilde{\text{Rep}}_d \times Y_{23} & & \subset M_{123} \end{array}$

where

$y = ((\rho_0, F_{\infty'}), (\rho_0, F_{\infty})) \in M_{123}$

$y_{13} = (\rho_0, F_{\infty}) \in M_{13}$

$T = \frac{\widetilde{T}_{\infty'} \oplus \widetilde{T}_{\infty} \oplus 0}{\widetilde{T}_{\infty'} \oplus 0} = \widetilde{T}_{\infty}$

$$\begin{aligned} \psi_{\infty', \infty} * \psi_{\infty} &= [Y_{12}]^{Td} * [Y_{23}]^{Td} \\ &= \pi_{13,*}([Y_{12} \times pt]^{Td} \otimes [\widetilde{\text{Rep}}_d(Q) \times Y_{23}]^{Td}) \\ &= \pi_{13,*}(\widetilde{\Delta}_{\infty} \cdot [y]^{Td}) \\ &= \widetilde{\Delta}_{\infty} \cdot [y_{13}]^{Td} \\ &= \widetilde{\Delta}_{\infty} \psi_{\infty} \end{aligned}$$

### § 7.3. expression of $D_k$ .

In this subsection,  $W_{Id} = W_d$ ,  $\widetilde{Rep}_d(Q) = F_d$ .  $Z_d = F_d \times F_d$ . (Otherwise  $K_0(F_d) \cong \bigoplus_{\underline{d}} K_0^{T_d}(pt)$ )

In the example,  $|d| = 3$ ,  $i = 1$

The convolution is compatible with forget map  $\pi_T^G$ .

$$\begin{array}{ccc} K_0^{G_d}(Z_d) \times K_0^{G_d}(\widetilde{Rep}_d(Q)) & \longrightarrow & K_0^{G_d}(\widetilde{Rep}_d(Q)) \\ \downarrow \pi_B^G & \downarrow \pi_B^G & \downarrow \pi_B^G \\ K_0^{T_d}(Z_d) \times K_0^{T_d}(\widetilde{Rep}_d(Q)) & \longrightarrow & K_0^{T_d}(\widetilde{Rep}_d(Q)) \end{array}$$

So we do our computation in  $K_0^{T_d}$ . (View  $K_0^{G_d}$  as subalg of  $K_0^{T_d}$ )

Recall that

$$D_i = \sum_{\omega \in W_{Id}} (\widetilde{\Delta}_{\infty, \omega s}^s)^{-1} \psi_{\infty, \omega s} + \sum_{\substack{\omega \in W_{Id} \\ \omega s \omega^{-1} \in W_d}} (\widetilde{\Delta}_{\infty, \omega}^s)^{-1} \psi_{\infty, \omega}$$

$\omega s \omega^{-1} \in W_d \leftarrow \text{automatically satisfied}$

$$f = \sum_{\omega \in W_{Id}} (\omega f) \widetilde{\Delta}_{\infty}^{-1} \psi_{\infty} \quad \text{e.p. } e_i = \sum_{\omega \in W_{Id}} x_{\omega(i)} \widetilde{\Delta}_{\infty}^{-1} \psi_{\infty}$$

Therefore,

$$\begin{aligned} D_i \diamond f &= \sum_{\omega \in W_{Id}} (\widetilde{\Delta}_{\infty, \omega s}^s)^{-1} \psi_{\infty, \omega s} \sum_{\omega \in W_{Id}} (\omega s f) \widetilde{\Delta}_{\infty s}^{-1} \psi_{\infty s} + \sum_{\omega \in W_{Id}} (\widetilde{\Delta}_{\infty, \omega}^s)^{-1} \psi_{\infty, \omega} \sum_{\omega \in W_{Id}} (\omega f) \widetilde{\Delta}_{\infty}^{-1} \psi_{\infty} \\ &= \sum_{\omega \in W_{Id}} (\widetilde{\Delta}_{\infty, \omega s}^s)^{-1} (\omega s f) \widetilde{\Delta}_{\infty s}^{-1} \widetilde{\Delta}_{\infty s} \psi_{\infty} + \sum_{\omega \in W_{Id}} (\widetilde{\Delta}_{\infty, \omega}^s)^{-1} (\omega f) \widetilde{\Delta}_{\infty}^{-1} \widetilde{\Delta}_{\infty} \psi_{\infty} \\ &= \sum_{\omega \in W_{Id}} \left[ (\widetilde{\Delta}_{\infty, \omega s}^s)^{-1} \omega s f + (\widetilde{\Delta}_{\infty, \omega}^s)^{-1} (\omega f) \right] \psi_{\infty} \\ &= \sum_{\omega \in W_{Id}} \omega \left[ \left( \frac{sf}{\widetilde{\Delta}_{Id,s}^s} + \frac{f}{\widetilde{\Delta}_{Id,Id}^s} \right) \cdot \widetilde{\Delta}_{Id} \right] \widetilde{\Delta}_{\infty}^{-1} \psi_{\infty} \\ \therefore D_i f &= \left( \frac{sf}{\widetilde{\Delta}_{Id,s}^s} + \frac{f}{\widetilde{\Delta}_{Id,Id}^s} \right) \cdot \widetilde{\Delta}_{Id} \end{aligned}$$

$$\begin{aligned} \text{In our case, } \widetilde{T}_{Id} &= T_{Id} = n_{Id}^- & = \begin{pmatrix} 0 & 0 & 0 \\ * & 0 & 0 \\ * & * & 0 \end{pmatrix} & = A \\ \widetilde{T}_{Id,s}^s &= T_{Id,s}^s = n_{Id}^- \oplus m_{Id,s} = \begin{pmatrix} 0 & 0 & 0 \\ * & 0 & 0 \\ * & * & 0 \end{pmatrix} \oplus \begin{pmatrix} 0 & * & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & = A + \frac{1}{3} \\ \widetilde{T}_{Id,Id}^s &= T_{Id,Id}^s = n_{Id}^- \oplus m_{s,Id} = \begin{pmatrix} 0 & 0 & 0 \\ * & 0 & 0 \\ * & * & 0 \end{pmatrix} \oplus \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} & = A + B \end{aligned}$$

$$\begin{aligned} \text{where } A &= \sum_{j>k} \frac{e_j}{e_k} = \frac{e_2}{e_1} + \frac{e_3}{e_1} + \frac{e_3}{e_2} \\ B &= \frac{e_{ii}}{e_i} = \frac{e_2}{e_2} \end{aligned}$$

$$\begin{array}{ccc} K_0^{T_d}(Z_d) & \xrightarrow{\hspace{2cm}} & K_0^{T_d}(Z_d) \\ eu(A) & (1 - \frac{e_2}{e_1})(1 - \frac{e_3}{e_1})(1 - \frac{e_3}{e_2}) & \cdot (1 - \lambda_2)(1 - \lambda_3)(1 - \lambda_1)(1 - \lambda_2) \\ eu(B) & 1 - \frac{e_2}{e_2} & \lambda_2 - \lambda_1 \\ eu(\frac{1}{B}) & 1 - \frac{e_1}{e_1} & \lambda_1 - \lambda_2 \end{array}$$

$$\begin{aligned} D_i f &= \left( \frac{sf}{eu(A + \frac{1}{B})} + \frac{f}{eu(A+B)} \right) eu(A) & f \in K_0^{G_d}(\widehat{\text{Rep}}(\omega)) \\ &= \frac{sf}{eu(\frac{1}{B})} + \frac{f}{eu(B)} \\ &= \frac{sf}{1 - \frac{e_i}{e_{i+1}}} + \frac{f}{1 - \frac{e_{i+1}}{e_i}} \end{aligned}$$

$$\begin{aligned} D_i fg &= \frac{sf \cdot g}{eu(\frac{1}{B})} + \frac{sf \cdot g}{eu(B)} + \frac{f \cdot g}{eu(B)} - \frac{sf \cdot g}{eu(B)} \\ &= sf \cdot D_i g + \frac{f - sf}{eu(B)} g \end{aligned}$$

Here,  $f \in K_0^{G_d}(\mathcal{Z}_{Id})$ ,  $g \in K_0^{G_d}(\widehat{\text{Rep}}(\omega))$

$$\Rightarrow D_i f = sf D_i + \frac{f - sf}{1 - \frac{e_{i+1}}{e_i}}$$

In the case of equivariant cohomology, the computation is similar:

$$\begin{aligned} \partial_i f &= \left( \frac{sf}{eu(\widehat{\Lambda}_{Id,s}^s)} + \frac{f}{eu(\widehat{\Lambda}_{Id,Id}^s)} \right) \cdot eu(\widehat{\Lambda}_{Id}^s) & f \in K_0^{G_d}(\widehat{\text{Rep}}(\omega)) \\ &= \frac{sf}{eu(\frac{1}{B})} + \frac{f}{eu(B)} \\ &= \frac{sf}{\lambda_i - \lambda_{i+1}} + \frac{f}{\lambda_{i+1} - \lambda_i} \\ \partial_i f &= sf \partial_i + \frac{f - sf}{\lambda_{i+1} - \lambda_i} & f \in K_0^{G_d}(\mathcal{Z}_{Id}) \end{aligned}$$