Category $\mathcal{O}$, Problem Set 4

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Thursday 16^{th} April, 2020

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1 Humphreys 3.1

Let $\mathfrak{g} = \mathfrak{sl}(2, \mathbb{C})$ and identify $\lambda \in \mathfrak{h}^\vee$ with a scalar. Let N be a 2-dimensional $U(\mathfrak{b})$-module defined by letting x act as 0 and h act as $\begin{pmatrix} \lambda & 1 \\ 0 & \lambda \end{pmatrix}$.

Show that the induced $U(\mathfrak{g})$-module structure $M \coloneqq U(\mathfrak{g}) \otimes_{U(\mathfrak{b})} N$ fits into an exact sequence which fails to split:

$$0 \longrightarrow M(\lambda) \longrightarrow M \longrightarrow M(\lambda) \longrightarrow 0$$

1.1 Solution

Reference 1 Reference 2

Hence $M \notin \mathcal{O}$.

2 Humphreys 3.2

Show that for $M \in \mathcal{O}$ and $\dim L < \infty$,

$$(M \otimes L)^\vee \cong M^\vee \otimes L^\vee$$

Reference for Dual of Sum

2.1 Solution

By theorem 3.2d, we have

$$M, N \in \mathcal{O} \implies (M \oplus N)^\vee \cong M^\vee \oplus N^\vee$$

and by definition, $M^\vee := \bigoplus_{\lambda \in \mathfrak{h}^\vee} M_\lambda^\vee$ is the direct sum of the duals of various weight spaces.

3 Humphreys 3.4

Show that $\Phi_{[\lambda]} \bigcap \Phi^+$ is a positive system in the root system $\Phi_{[\lambda]}$, but the corresponding simple system $\Delta_{[\lambda]}$ may be unrelated to Δ.

For a concrete example, take Φ of type B_2 with a short simple root α and a long simple root β. If $\lambda := \alpha/2$, check that $\Phi_{[\lambda]}$ contains just the four short roots in Φ.

3.1 Solution

We would like to show the following two propositions:

1. $\Phi_{[\lambda]}^+ := \Phi_{[\lambda]} \bigcap \Phi^+$ is a positive system in $\Phi_{[\lambda]}$,
2. The simple system $\Delta_{[\lambda]}$ corresponding to $\Phi_{[\lambda]}^+$ is *not* generally given by $\Delta_{[\lambda]} = \Phi_{[\lambda]} \bigcap \Delta$, where Δ is the simple system corresponding to Φ.

We proceed by first showing (2) using the hinted counterexample when Φ is of type B_2 with $\Delta = \{\alpha, \beta\}$ with α a short root and β a long root.

Concretely, we can realize Φ as a subset of $\mathbb{R}^2$ in the following way:

$$\Phi = \{[1,0], [0,1], [-1,0], [0,-1]\} \bigcup \{[1,1], [-1,1], [1,-1], [-1,-1]\},$$

where we note that the first set consists of short roots and the second of long roots.

We can choose the simple system $\Delta = \{\alpha := [1,0], \beta := [-1,1]\}$, and then let

$$\Phi_{[\lambda]} := \left\{ \gamma \in \Phi \;\middle|\; \langle \lambda,\ \gamma^\vee \rangle \in \mathbb{Z} \right\} \qquad \gamma^\vee := \frac{2}{\|\gamma\|^2}\,\gamma.$$

Now choosing $\lambda := \frac{\alpha}{2} = \left[\frac{1}{2}, 0\right]$, a short calculation shows that for an arbitrary $\gamma \in \Phi$,

$$\langle \lambda,\ \gamma^\vee \rangle := \left\langle \left[\frac{1}{2}, 0\right],\ \frac{2}{\|\gamma\|^2}\gamma \right\rangle.$$

4 Humphreys 3.7

4.1 a

If a module M has a standard filtration and there exists an epimorphism $\phi : M \longrightarrow M(\lambda)$, prove that $\ker \phi$ admits a standard filtration.

4.2 b

Show by example that when $\mathfrak{g} = \mathfrak{sl}(2, \mathbb{C})$ that the existence of a monomorphism $\phi : M(\lambda) \longrightarrow M$ where M has a standard filtration fails to imply that $\operatorname{coker} \phi$ has a standard filtration.