

Category \mathcal{O} , Problem Set 4

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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 $M := U(\mathfrak{g}) \otimes_{U(\mathfrak{b})} N$ 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 $\Phi_{[\lambda]} \cap \Phi^+$ 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. $\Phi_{[\lambda]}^+ := \Phi_{[\lambda]} \cap \Phi^+$ is a positive system in $\Phi_{[\lambda]}$,
2. In general, the associated simple system $\Delta_{[\lambda]} \neq \Phi_{[\lambda]}^+ \cap \Delta$.

3.1.1 Proof of Proposition 1

We'll use the definition that for an abstract root system Φ , a positive system Φ^+ is defined by picking a hyperplane H not containing any roots and taking all roots on one side of this hyperplane.

However, if every element of Φ^+ is on one side of H , then any subset satisfies this property as well, thus $\Phi_{[\lambda]} \cap \Phi^+$ consists only of positive roots.

3.1.2 Proof of Proposition 2

Concretely, we can realize Φ and Δ as subsets of \mathbb{R}^2 in the following way:

$$\begin{aligned} \Phi &= P_1 \amalg P_2 := \{[1, 0], [0, 1], [-1, 0], [0, -1]\} \amalg \{[1, 1], [-1, 1], [1, -1], [-1, -1]\} \\ \Delta &:= \{\alpha, \beta\} := \{[1, 0], [-1, 1]\}, \end{aligned}$$

where we note that P_1 consists of short roots (of norm 1) and P_2 of long roots (of norm $\sqrt{2}$) and we've chosen a simple system consisting of one short root and one long root.

Now by definition,

$$\begin{aligned}\Phi_{[\lambda]} &:= \left\{ \gamma \in \Phi \mid \langle \lambda, \gamma^\vee \rangle \in \mathbb{Z} \right\}, & \gamma^\vee &:= \frac{2}{\|\gamma\|^2} \gamma, \\ \Delta_{[\lambda]} &:= \left\{ \gamma \in \Delta \mid \langle \lambda, \gamma^\vee \rangle \in \mathbb{Z} \right\}.\end{aligned}$$

Now choosing $\lambda := \frac{\alpha}{2} = \left[\frac{1}{2}, 0 \right]$, we now consider the inner products $\langle \lambda, \gamma^\vee \rangle$ for $\gamma \in \Phi$:

Thus

$$\begin{aligned}\gamma_1 \in P_1 &\implies \left\langle \left[\frac{1}{2}, 0 \right], 2\gamma_1 \right\rangle = 2 \left(\frac{1}{2} \right) \langle [1, 0], \gamma_1 \rangle = (\gamma_1)_1 \in \{0, \pm 1\} \in \mathbb{Z} \\ \gamma_2 \in P_2 &\implies \langle \lambda, \gamma_2^\vee \rangle = \left\langle \left[\frac{1}{2}, 0 \right], \frac{2}{(\sqrt{2})^2} [\pm 1, \pm 1] \right\rangle = \pm \frac{1}{2} \notin \mathbb{Z}\end{aligned}$$

where $(\gamma_1)_1$ denotes the first component of γ_1 .

We thus find that

$$\begin{aligned}\Phi_{[\lambda]} &= P_1 && \text{the short roots} \\ \Delta_{[\lambda]} &= \{\alpha\} && \text{the single short simple root.}\end{aligned}$$

Choosing the following green hyperplane not containing any root, we can choose a positive system

$$\Phi^+ = \{[1, 0], [0, 1], [1, 1], [-1, -1]\} = \{\alpha, \beta, \alpha + \beta, 2\alpha + \beta\}$$

where we can note that $\Phi^+ \cap \Delta = \Delta$, since we've placed both simple roots on the positive side of this hyperplane by construction.

But by taking roots on the positive side of this plane, we have

$$\Phi_{[\lambda]} = \{\alpha, -\alpha, \alpha + \beta, -\alpha - \beta\} \implies \Phi_{[\lambda]}^+ = \{\alpha, \alpha + \beta\}$$

where we can now note that a simple system in *this* root system must still have rank 2, so we can take $\Delta_{[\lambda]} = \{\alpha, \alpha + \beta\}$. But now we can note

$$\Delta_{[\lambda]} = \{\alpha, \alpha + \beta\} \neq \{\alpha\} = \{\alpha, \alpha + \beta\} \cap \{\alpha, \beta\} = \Phi_{[\lambda]}^+ \cap \Delta,$$

which is what we wanted to show.

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 $\text{coker } \phi$ has a standard filtration.