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2025 USA-NA-AIO Round 2, Problem 2, Part 2

USAAIO May 2025

Part 2 (5 points, non-coding task)

For $\mathbf{M} \in \{\mathbf{Q}, \mathbf{K}, \mathbf{V}\}$, We concatenate $\mathbf{M}$-projection matrices $\{\mathbf{W}_h^{\mathbf{M}} : h \in \{0, 1, \cdots, H-1\}\}$ along axis 0 as

$$\mathbf{W}^{\mathbf{M}} = \begin{bmatrix} \mathbf{W}_0^{\mathbf{M}} \\ \mathbf{W}_1^{\mathbf{M}} \\ \vdots \\ \mathbf{W}_{H-1}^{\mathbf{M}} \end{bmatrix}.$$

At each position l_1 in an attending sequence, we concatenate queries $\{\mathbf{q}_{l_1,h} : h \in \{0, 1, \cdots, H-1\}\}$ along axis 0 to get

$$\mathbf{q}_{l_1} = \begin{bmatrix} \mathbf{q}_{l_1,0} \\ \mathbf{q}_{l_1,1} \\ \vdots \\ \mathbf{q}_{l_1,H-1} \end{bmatrix}.$$

At each position l_2 in a being attended sequence, we concatenate keys/values $\mathbf{m} \in \{\mathbf{k}, \mathbf{v}\}$ $\{\mathbf{m}_{l_2,h} : h \in \{0, 1, \cdots, H-1\}\}$ along axis 0 to get

$$\mathbf{m}_{l_2} = \begin{bmatrix} \mathbf{m}_{l_2,0} \\ \mathbf{m}_{l_2,1} \\ \vdots \\ \mathbf{m}_{l_2,H-1} \end{bmatrix}.$$

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Do the following tasks (Reasoning is not required).

1. What is the shape of $\mathbf{W}^{\mathrm{M}}$ for $\mathbf{M} \in \{\mathbf{Q}, \mathbf{K}, \mathbf{V}\}$?
2. What is the shape of $\mathbf{q}_{l_1}$?
3. What is the relationship between $\mathbf{q}_{l_1}$ and $\mathbf{W}^{\mathrm{Q}}$?
4. For $\mathbf{m} \in \{\mathbf{k}, \mathbf{v}\}$, what is the shape of $\mathbf{m}_{l_2}$?
5. What is the relationship between $\mathbf{m}_{l_2}$ and $\mathbf{W}^{\mathrm{M}}$?

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Misplaced '#'

1. The shape of $\mathbf{W}^{\mathrm{Q}}$ is $(H \cdot D_{qk}, D_1)$.

   The shape of $\mathbf{W}^{\mathrm{K}}$ is $(H \cdot D_{qk}, D_2)$.

   The shape of $\mathbf{W}_h^{\mathrm{V}}$ is $(H \cdot D_v, D_2)$.

2. The shape of $\mathbf{q}_{l_1}$ is $(H \cdot D_{qk},)$.

3. $$\mathbf{q}_{l_1} = \mathbf{W}^{\mathrm{Q}} \mathbf{x}_{l_1}.$$

4. The shape of $\mathbf{k}_{l_2}$ is $(H \cdot D_{qk},)$.

   The shape of $\mathbf{v}_{l_2}$ is $(H \cdot D_v,)$.

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5.

$$\mathbf{k}_{l_2} = \mathbf{W}^{\mathbf{K}}\mathbf{y}_{l_2}.$$

$$\mathbf{v}_{l_2} = \mathbf{W}^{\mathbf{V}}\mathbf{y}_{l_2}.$$

""" END OF THIS PART """

Doughwhee **Dec 2025**

1. In part 1, we found the shapes in each head to be $D_{qk} \times D_1, D_{qk} \times D_2$ and $D_v \times D_2$. Since they are concatenated now, we simply multiply the number of rows by H. This yields $\boxed{HD_{qk} \times D_1, HD_{qk} \times D_2}$ and $\boxed{HD_v \times D_2}$.
2. q_{l_1} is a concatenation of all the query vectors, which are $D_{qk} \times 1$. So we get $\boxed{HD_{qk} \times 1}$.
3. q_{l_1} is obtained from multiplying W^Q with the input x_{l_1}.
4. Similar to question 2, we have $\boxed{HD_{qk} \times 1, HD_v \times 1}$
5. They are obtained from multiplying W^K and W^V with y_{l_2}, respectively.

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