Keyword operation($\mathcal{H} : S \mapsto (A, T)$)
Single keyword operation

91. $\mathcal{H}[\![from\langle tname\rangle]\!] \triangleq (A, A(\langle tname\rangle))$
92. $\mathcal{H}[\![from\langle tname_1\rangle, \langle tname_2\rangle]\!] \triangleq (A, \mathcal{C}[\![A(\langle tname_1\rangle), A(\langle tname_2\rangle)],\ cross\ join\ ]\!])$
93. $\mathcal{H}[\![select\ *]\!] \triangleq (\{T\}, \pi_{T.\overline{\beta}}(T))$
94. $\mathcal{H}[\![select\ \langle cname\rangle\ [,\ \langle cname\rangle...]]\!] \triangleq (\{T\}, \pi_{\langle cname\rangle\ [,\ \langle cname\rangle...]}(T))$
95. $\mathcal{H}[\![on\ \langle bvexp\rangle]\!] \triangleq (\{T\}, \sigma_{\mathcal{B}(\langle bvexp\rangle)}(T))$
96. $\mathcal{H}[\![where\ \langle bvexp\rangle]\!] \triangleq (\{T\}, \sigma_{\mathcal{B}(\langle bvexp\rangle)}(T))$
97. $\mathcal{H}[\![group\ by\ \langle cname\rangle]\!] \triangleq (\{T\}, (\widehat{\alpha_1}, ..., \widehat{\alpha_k}) : \forall \widehat{\alpha_p} \in\ (\widehat{\alpha_1}, ..., \widehat{\alpha_k}), \forall\ v_{ij} \in\ \pi_{\langle cname\rangle}(\widehat{\alpha_p}), (v_{ij} = v_{i1}))$
98. $\mathcal{H}[\![having\ \langle bvexp\rangle]\!] \triangleq (\{T\}, \sigma_{\mathcal{B}(\langle bvexp\rangle)}(T))$
99. $\mathcal{H}[\![order\ by\ \langle cname\rangle\ asc]\!] \triangleq (\{T\}, T_1)\ where\ (\forall \alpha \in T_1,\ \xi_\alpha(T_1) = \xi_\alpha(T)) \wedge (\forall \alpha \in T,$
$\xi_\alpha(T) = \xi_\alpha(T_1)) \wedge (\forall v_i, v_j \in \sigma_{T_1.\langle cname\rangle}(T_1), i > j$ iff $v_i >= v_j)$
100. $\mathcal{H}[\![order\ by\ \langle cname\rangle\ desc]\!] \triangleq (\{T\}, T_1)\ where\ (\forall \alpha \in T_1,\ \xi_\alpha(T_1) = \xi_\alpha(T)) \wedge (\forall \alpha$
$\in T, \xi_\alpha(T) = \xi_\alpha(T_1)) \wedge (\forall v_i, v_j \in \sigma_{T_1.\langle cname\rangle}(T_1), i < j$ iff $v_i <= v_j)$
101. $\mathcal{H}[\![\langle subquery\rangle]\!] \triangleq \mathcal{H}[\![\langle query\ expression\rangle]\!]$

Composite keyword operation

102. $\diamond$: (1) $\dfrac{\mathcal{H}[\![expression_1]\!] \triangleq (A, T),\ \mathcal{H}[\![expression_2]\!] \triangleq (\{T\}, T')}{\mathcal{H}[\![expression_1]\!] \diamond \mathcal{H}[\![expression_2]\!] \triangleq (A, T')}$

(2) $\dfrac{\mathcal{H}[\![expression]\!] \triangleq (A, T),\ \mathcal{C}[\![\{\{T\}, OP\}]\!] \triangleq T'}{\mathcal{H}[\![expression]\!] \diamond \mathcal{C}[\![\{\{T\}, OP\}]\!] \triangleq (A, T')}$

(3) $\dfrac{\mathcal{C}[\![\{L, OP\}]\!] \triangleq T,\ \mathcal{H}[\![expression]\!] \triangleq (\{T\}, T')}{\mathcal{C}[\![\{L, OP\}]\!] \diamond \mathcal{H}[\![expression]\!] \triangleq (L, T')}$

(4) $\dfrac{\mathcal{H}[\![expression_1]\!] \triangleq (A, T_1),\ \mathcal{H}[\![expression_2]\!] \triangleq (A, T_2),\ \mathcal{C}[\![\{\{T_1, T_2\}, OP\}]\!] \triangleq T_3}{(\mathcal{H}[\![expression_1]\!], \mathcal{H}[\![expression_2]\!]) \diamond \mathcal{C}[\![\{\{T_1, T_2\}, OP\}]\!] \triangleq (A, T_3)}$

103. $\mathcal{H}[\![\langle queryexp\rangle]\!] =$
$\mathcal{H}[\![select$ **[**$\langle sop\rangle|\langle af\rangle$**]** $\langle cname_1\rangle$**[**$, \langle cname_2\rangle$...**]** $from\langle tname_1\rangle$**[**$, \langle tname_2\rangle$...**]**$|from\ \langle tname_1\rangle\ natural/cross\ join\ \langle tname_2\rangle$
$|from\ \langle tname_1\rangle\ left/right/full/inner\ join\ \langle tname_2\rangle\ on\langle bvexp\rangle$ **[**$where\langle bvexp\rangle$**]** **[**$group\ by\ \langle cname\rangle$**]** **[**$having\ \langle bvexp\rangle$**]**
[$order\ by\ \langle cname\rangle\ [asc|desc]$**]**$]\!]$
$\triangleq$
$\mathcal{H}[\![from\langle tname_1\rangle]\!]$
$|(\mathcal{H}[\![from\ \langle tname_1\rangle]\!], \mathcal{H}[\![from\ \langle tname_2\rangle]\!]) \diamond \mathcal{C}[\![L, natural/cross\ join\ ]\!]$
$|(\mathcal{H}[\![from\ \langle tname_1\rangle]\!], \mathcal{H}[\![from\ \langle tname_2\rangle]\!]) \diamond \mathcal{C}[\![L, left/right/inner/full\ join\ ]\!] \diamond \mathcal{H}[\![on\ \langle bvexp\rangle]\!]$
[$\diamond$ $\mathcal{H}[\![where\ \langle bvexp\rangle]\!]$**]**
[$\diamond \mathcal{H}[\![group\ by\ \langle cname\rangle]\!]$**]**
[$\diamond \mathcal{H}[\![having\ \langle bvexp\rangle]\!]$**]**
$\diamond\ \mathcal{H}[\![select\ \langle cname_1\rangle$**[**$, \langle cname_2\rangle$...**]**$]\!]$**[** $\diamond \mathcal{C}[\![\{T_1, \langle sop/af\rangle\}]\!]$**]**
[$\diamond$ $\mathcal{H}[\![order\ by\ \langle cname\rangle$ **[**$asc|desc$**]**$]\!]$**]**

104. $\mathcal{H}[\![\langle queryexp_1\rangle\ \langle cop\rangle\ \langle queryexp_2\rangle]\!] \triangleq (\mathcal{H}[\![\langle queryexp_1\rangle]\!], \mathcal{H}[\![\langle queryexp_2\rangle]\!]) \diamond \mathcal{C}[\![\{[T_1, T_2], \langle cop\rangle\}]\!]$

Fig. 7: The full list of semantic definitions for SQL keywords `from`, `select`, `on`, `group by`, `having`, `order by`, subquery operations, and composite semantics on SQL queries