Keyword operation($\mathcal{C}:\{L,OP\}\mapsto T$)
Join operation

76. $\mathcal{C}[\![\{[T_1,T_2],\ natural\ join\}]\!] \triangleq \{\alpha_1\circ\alpha_2|\alpha_1\in T_1,\alpha_2\in T_2,\overline{\beta}_I=T_1.\overline{\beta}\cap T_2.\overline{\beta}\}$

$$\alpha_1\circ\alpha_2\triangleq\begin{cases}\alpha_1\ \bowtie\alpha_2; & (\overline{\beta}_I\neq\emptyset)\wedge(\pi_{\overline{\beta}_I}(\{\alpha_1\})=\pi_{\overline{\beta}_I}(\{\alpha_2\}))\\ skip; & otherwise\end{cases}$$

77. $\mathcal{C}[\![\{[T_1,T_2],\ left\ join\}]\!] \triangleq \{\alpha_1\bullet\alpha_2|\alpha_1\in T_1,\alpha_2\in T_2,\overline{\beta}_I=T_1.\overline{\beta}\cap T_2.\overline{\beta}\}$

$$\alpha_1\bullet\alpha_2\triangleq\begin{cases}\alpha_1\ \bowtie\alpha_2; & (\overline{\beta}_I\neq\emptyset)\wedge(\pi_{\overline{\beta}_I}(\{\alpha_1\})=\pi_{\overline{\beta}_I}(\{\alpha_2\}))\\ \alpha_1\bowtie[null,...,null]_{|\{\alpha_2\}.\overline{\beta}|-|\overline{\beta}_I|}; & (\overline{\beta}_I\neq\emptyset)\wedge(\pi_{\overline{\beta}_I}(\{\alpha_1\})\neq\pi_{\overline{\beta}_I}(\{\alpha_2\}))\\ skip; & otherwise\end{cases}$$

78. $\mathcal{C}[\![\{[T_1,T_2],\ right\ join\}]\!] \triangleq \{\alpha_1\bullet\alpha_2|\alpha_1\in T_1,\alpha_2\in T_2,\overline{\beta}_I=T_1.\overline{\beta}\cap T_2.\overline{\beta}\}$

$$\alpha_1\bullet\alpha_2\triangleq\begin{cases}\alpha_1\ \bowtie\alpha_2; & (\overline{\beta}_I\neq\emptyset)\wedge(\pi_{\overline{\beta}_I}(\{\alpha_1\})=\pi_{\overline{\beta}_I}(\{\alpha_2\}))\\ [null,...,null]_{|\{\alpha_1\}.\overline{\beta}|-|\overline{\beta}_I|}\bowtie\alpha_2; & (\overline{\beta}_I\neq\emptyset)\wedge(\pi_{\overline{\beta}_I}(\{\alpha_1\})\neq\pi_{\overline{\beta}_I}(\{\alpha_2\}))\\ skip; & otherwise\end{cases}$$

79. $\mathcal{C}[\![\{[T_1,T_2],\ cross\ join\}]\!] \triangleq \{\alpha_1\times\alpha_2|\alpha_1\in T_1,\alpha_2\in T_2\}$
80. $\mathcal{C}[\![\{[T_1,T_2],\ inner\ join\}]\!] \triangleq \mathcal{C}[\![\{[T_1,T_2],\ cross\ join\}]\!]$

Collection operation

81. $\mathcal{C}[\![\{[T_1,T_2],\ union\}]\!] \triangleq \{\alpha_{u(T_1,T_2)}|\xi_{\alpha_{u(T_1,T_2)}}(T)=1\}$

$\mathcal{C}[\![\{[T_1,T_2],\ union\ all\}]\!] \triangleq \{\alpha_{u(T_1,T_2)}\}$

$$\alpha_{u(T_1,T_2)}\triangleq\begin{cases}\alpha; & (\alpha\in T_1)\vee(\alpha\in T_2)\\ skip; & otherwise\end{cases}$$

82. $\mathcal{C}[\![\{[T_1,T_2],\ intersect\}]\!] = \{\alpha_{i(T_1,T_2)}|\xi_{\alpha_{i(T_1,T_2)}}(T)=1\}$

$\mathcal{C}[\![\{[T_1,T_2],\ intersect\ all\}]\!] = \{\alpha_{i(T_1,T_2)}|\xi_{\alpha_{i(T_1,T_2)}}(T)=min(\xi_{\alpha_{i(T_1,T_2)}}(T_1),\xi_{\alpha_{i(T_1,T_2)}}(T_2))\}$

$$\alpha_{i(T_1,T_2))}=\begin{cases}\alpha; & (\alpha\in T_1)\wedge(\alpha\in T_2)\\ skip; & otherwise\end{cases}$$

83. $\mathcal{C}[\![\{[T_1,T_2],\ except\}]\!] = \{\alpha_{e(T_1,T_2}|\xi_{\alpha_{e(T_1,T_2}}(T)=1\}$

$$\alpha_{e(T_1,T_2))}=\begin{cases}\alpha; & (\alpha\in T_1)\wedge(\alpha\notin T_2)\\ skip; & otherwise\end{cases}$$

$\mathcal{C}[\![\{[T_1,T_2],\ except\ all\}]\!] = \{\alpha_{ea(T_1,T_2)}|\xi_{\alpha_{ea(T_1,T_2)}}(T)=max(0,\xi_{\alpha_{ea(T_1,T_2)}}(T_1)-\xi_{\alpha_{ea(T_1,T_2)}}(T_2))\}$

$$\alpha_{ea(T_1,T_2)}=\begin{cases}\alpha; & \xi_\alpha(T_1)>\xi_\alpha(T_2)\\ skip; & otherwise\end{cases}$$

Filter operation

84. $\mathcal{C}[\![\{[T],\ distinct\}]\!] \triangleq \{\alpha|(\forall\alpha\in T,\ \xi_\alpha(T_1)=1)\wedge(\forall\alpha\in T_1,\ \alpha\in T)\}$
85. $\mathcal{C}[\![\{[T],\ all\}]\!] \triangleq T$

Aggregation operation

86. $\mathcal{C}[\![\{[T],\ max\}]\!] \triangleq \{v|(v\in\pi_{T.\overline{\beta}}(T))\wedge(\forall v_1\in\pi_{T.\overline{\beta}}(T),\sigma_{(v_1>v)}(\pi_{T.\overline{\beta}}(T))=\oslash)\}$
87. $\mathcal{C}[\![\{[T],\ min\}]\!] \triangleq \{v|(v\in\pi_{T.\overline{\beta}}(T))\wedge(\forall v_1\in\pi_{T.\overline{\beta}}(T),\sigma_{(v_1<v)}(\pi_{T.\overline{\beta}}(T))=\oslash)\}$
88. $\mathcal{C}[\![\{[T],\ sum\}]\!] \triangleq \{v|v=\sum_{v_1\in\pi_{T.\overline{\beta}}(T)}v_1\}$
89. $\mathcal{C}[\![\{[T],\ count\}]\!] \triangleq \{v|v=\sum_{\alpha\in\pi_{T.\overline{\beta}}(T)}(\xi_\alpha(T))\}$
90. $\mathcal{C}[\![\{[T],\ avg\}]\!] \triangleq \{v|v=\sum_{v_1\in\pi_{T.\overline{\beta}}(T)}v_1/\sum_{\alpha\in\pi_{T.\overline{\beta}}(T)}(\xi_\alpha(T))\}$

Fig. 6: The full list of semantic definitions for join operation, collection operation, filtering operation, and aggregation operation