$$
\begin{array}{rcll}
E & ::= & c & \text{(定数)} \\
 & | & v & \text{(変数)} \\
 & | & v_1 + v_2 \mid v_1 - v_2 \mid v_1 * v_2 \mid v_1 / v_2 \mid v_1 \% v_2 & \text{(四則演算)} \\
 & | & v_1 +. v_2 \mid v_1 -. v_2 \mid v_1 *. v_2 \mid v_1 /. v_2 & \text{(実数演算)} \\
 & | & \texttt{if}\ v_1 = v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4 & \text{(条件分岐１)} \\
 & | & \texttt{if}\ v_1 < v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4 & \text{(条件分岐２)} \\
 & | & \texttt{let}\ v = E_1\ \texttt{in}\ E_2 & \text{(局所変数定義)} \\
 & | & \texttt{let rec}\ f\ v_1 \ldots v_n = E_1\ \texttt{in}\ E_2 & \text{(局所関数定義)} \\
 & | & v_0\ v_1 \ldots v_n & \text{(関数適用)}
\end{array}
$$

図 1: k-正規形の構文

$$
\begin{array}{rcll}
P & ::= & \{D_1, \ldots, D_m\}\ E & \text{(プログラム)} \\
D & ::= & f\ v_1 \ldots v_n = E & \text{(定義)} \\
E & ::= & c & \text{(定数)} \\
 & | & v & \text{(変数)} \\
 & | & v_1 + v_2 \mid v_1 - v_2 \mid v_1 * v_2 \mid v_1 / v_2 \mid v_1 \% v_2 & \text{(四則演算)} \\
 & | & v_1 +. v_2 \mid v_1 -. v_2 \mid v_1 *. v_2 \mid v_1 /. v_2 & \text{(実数演算)} \\
 & | & \texttt{if}\ v_1 = v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4 & \text{(条件分岐１)} \\
 & | & \texttt{if}\ v_1 < v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4 & \text{(条件分岐２)} \\
 & | & \texttt{let}\ v = E_1\ \texttt{in}\ E_2 & \text{(局所変数定義)} \\
 & | & f\ v_1 \ldots v_n & \text{(関数適用)}
\end{array}
$$

図 2: １階の言語の構文

$$
\begin{array}{rcll}
\mathcal{F}_P\ :\ \texttt{Knormal.t} & \to & \texttt{First.prog\_t} & \\
\mathcal{F}_P[\![\ \texttt{let rec}\ f_1\ v_{11} \ldots v_{1n_1} = E_1\ \texttt{in} & = & \{(f_1\ v_{11} \ldots v_{1n_1} = \mathcal{F}_E[\![E_1]\!]), & ※ \\
\ldots & & \quad \ldots, & \\
\texttt{let rec}\ f_m\ v_{m1} \ldots v_{mn_m} = E_m\ \texttt{in}\ E]\!] & & \quad (f_m\ v_{m1} \ldots v_{mn_m} = \mathcal{F}_E[\![E_m]\!])\}\ \mathcal{F}_E[\![E]\!] & \\
 & & & \\
\mathcal{F}_E\ :\ \texttt{Knormal.t} & \to & \texttt{First.t} & \\
\mathcal{F}_E[\![c]\!] & = & c & \\
\mathcal{F}_E[\![v]\!] & = & v & \\
\mathcal{F}_E[\![v_1 + v_2]\!] & = & v_1 + v_2 & \\
\mathcal{F}_E[\![\texttt{if}\ v_1 = v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4]\!] & = & \texttt{if}\ v_1 = v_2\ \texttt{then}\ \mathcal{F}_E[\![E_3]\!]\ \texttt{else}\ \mathcal{F}_E[\![E_4]\!] & \\
\mathcal{F}_E[\![\texttt{if}\ v_1 < v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4]\!] & = & \texttt{if}\ v_1 < v_2\ \texttt{then}\ \mathcal{F}_E[\![E_3]\!]\ \texttt{else}\ \mathcal{F}_E[\![E_4]\!] & \\
\mathcal{F}_E[\![\texttt{let}\ v = E_1\ \texttt{in}\ E_2]\!] & = & \texttt{let}\ v = \mathcal{F}_E[\![E_1]\!]\ \texttt{in}\ \mathcal{F}_E[\![E_2]\!] & \\
\mathcal{F}_E[\![\texttt{let rec}\ f\ v_1 \ldots v_n = E_1\ \texttt{in}\ E_2]\!] & = & \text{未サポート} & ※ \\
\mathcal{F}_E[\![f\ v_1 \ldots v_n]\!] & = & f\ v_1 \ldots v_n &
\end{array}
$$

図 3: １階の言語への変換 $\mathcal{F}$

$$
\begin{array}{rcll}
\mathcal{P}_P\ :\ \texttt{First.prog\_t} & \to & \texttt{First.prog\_t} & \\
\mathcal{P}_P[\![\{D_1,\ldots,D_m\}\ E]\!] & = & \{\mathcal{P}_D[\![D_1]\!],\ldots,\mathcal{P}_D[\![D_m]\!]\}\ \mathcal{P}_E[\![E]\!] & \\
 & & & \\
\mathcal{P}_D\ :\ \texttt{First.def\_t} & \to & \texttt{First.def\_t} & \\
\mathcal{P}_D[\![f\ v_1\ldots v_n = E]\!] & = & f\ \texttt{R}_1\ldots\texttt{R}_n = & ※ \\
 & & \quad \texttt{let}\ v_1 = \texttt{R}_1\ \texttt{in}\ \ldots\ \texttt{let}\ v_n = \texttt{R}_n\ \texttt{in}\ \mathcal{P}_E[\![E]\!] & \\
 & & & \\
\mathcal{P}_E\ :\ \texttt{First.t} & \to & \texttt{First.t} & \\
\mathcal{P}_E[\![c]\!] & = & c & \\
\mathcal{P}_E[\![v]\!] & = & v & \\
\mathcal{P}_E[\![v_1 + v_2]\!] & = & v_1 + v_2 & \\
\mathcal{P}_E[\![\texttt{if}\ v_1 = v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4]\!] & = & \texttt{if}\ v_1 = v_2\ \texttt{then}\ \mathcal{P}_E[\![E_3]\!]\ \texttt{else}\ \mathcal{P}_E[\![E_4]\!] & \\
\mathcal{P}_E[\![\texttt{if}\ v_1 < v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4]\!] & = & \texttt{if}\ v_1 < v_2\ \texttt{then}\ \mathcal{P}_E[\![E_3]\!]\ \texttt{else}\ \mathcal{P}_E[\![E_4]\!] & \\
\mathcal{P}_E[\![\texttt{let}\ v = E_1\ \texttt{in}\ E_2]\!] & = & \texttt{let}\ v = \mathcal{P}_E[\![E_1]\!]\ \texttt{in}\ \mathcal{P}_E[\![E_2]\!] & \\
\mathcal{P}_E[\![f\ v_1\ldots v_n]\!] & = & \texttt{let}\ \texttt{R}_1 = v_1\ \texttt{in}\ \ldots\ \texttt{let}\ \texttt{R}_n = v_n\ \texttt{in} & ※ \\
 & & f\ \texttt{R}_1\ldots\texttt{R}_n &
\end{array}
$$

図 4: 1 階の言語に対するレジスタ割り当ての前処理 $\mathcal{P}$。

$$
\begin{array}{rcll}
\mathcal{A}_P\ :\ \texttt{First.prog\_t} \times (\text{変数} \to \text{変数}) & \to & \texttt{First.prog\_t} & \\
\mathcal{A}_P[\![\{D_1,\ldots,D_m\}\ E]\!]\,\rho & = & \{\mathcal{A}_D[\![D_1]\!]\,\rho,\ldots,\mathcal{A}_D[\![D_m]\!]\,\rho\}\ \mathcal{A}_E[\![E]\!]\,\rho & \\
 & & & \\
\mathcal{A}_D\ :\ \texttt{First.def\_t} \times (\text{変数} \to \text{変数}) & \to & \texttt{First.def\_t} & \\
\mathcal{A}_D[\![f\ \texttt{R}_1\ldots\texttt{R}_n = E]\!]\,\rho & = & f\ \texttt{R}_1\ldots\texttt{R}_n = \mathcal{A}_E[\![E]\!]\,\rho & \\
 & & & \\
\mathcal{A}_E\ :\ \texttt{First.t} \times (\text{変数} \to \text{変数}) & \to & \texttt{First.t} & \\
\mathcal{A}_E[\![c]\!]\,\rho & = & c & \\
\mathcal{A}_E[\![v]\!]\,\rho & = & \rho(v) & \\
\mathcal{A}_E[\![v_1 + v_2]\!]\,\rho & = & \rho(v_1) + \rho(v_2) & \\
\mathcal{A}_E[\![\texttt{if}\ v_1 = v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4]\!]\,\rho & = & \texttt{if}\ \rho(v_1) = \rho(v_2)\ \texttt{then}\ \mathcal{A}_E[\![E_3]\!]\,\rho\ \texttt{else}\ \mathcal{A}_E[\![E_4]\!]\,\rho & \\
\mathcal{A}_E[\![\texttt{if}\ v_1 < v_2\ \texttt{then}\ E_3\ \texttt{else}\ E_4]\!]\,\rho & = & \texttt{if}\ \rho(v_1) < \rho(v_2)\ \texttt{then}\ \mathcal{A}_E[\![E_3]\!]\,\rho\ \texttt{else}\ \mathcal{A}_E[\![E_4]\!]\,\rho & \\
\mathcal{A}_E[\![\texttt{let}\ \texttt{R}_i = E_1\ \texttt{in}\ E_2]\!]\,\rho & = & \texttt{let}\ \texttt{R}_i = \mathcal{A}_E[\![E_1]\!]\,\rho\ \texttt{in}\ \mathcal{A}_E[\![E_2]\!]\,\rho & \\
\mathcal{A}_E[\![\texttt{let}\ v = E_1\ \texttt{in}\ E_2]\!]\,\rho & = & \text{新しいレジスタ}\ \texttt{R}_i\ \text{をとってきて} & ※ \\
 & & \texttt{let}\ \texttt{R}_i = \mathcal{A}_E[\![E_1]\!]\,\rho\ \texttt{in}\ \mathcal{A}_E[\![E_2]\!]\,\rho[v \mapsto \texttt{R}_i] & \\
\mathcal{A}_E[\![f\ \texttt{R}_1\ldots\texttt{R}_n]\!]\,\rho & = & f\ \texttt{R}_1\ldots\texttt{R}_n &
\end{array}
$$

図 5: （非常に単純な）レジスタ割り当て $\mathcal{A}$。ρ は、変数を受け取ったら、その変数に割り当てられているレジスタを返す関数。ただし $\rho(\texttt{R}_i) = \texttt{R}_i$ とする。