Γ_N remains unchanged.

② Since Γ_T and so Γ are changed, we should change the definition of $\rightarrow$. We will also have to ~~include~~ add a ~~new~~ rule for fail. Here is the new set of rules.

Three rules. The first (new) is due to fail, and the other two are due to the change of Γ_T

$$\frac{}{\langle fail, \sigma\rangle \rightarrow \langle abort, \sigma\rangle}$$ terminal configuration.

$$\frac{}{\langle skip, \sigma\rangle \rightarrow \sigma} \qquad \frac{}{\langle v := e, \sigma\rangle \rightarrow [\sigma \mid v : [\![e]\!]\sigma]}$$

$$\frac{}{\langle \text{if } b \text{ then } c_1 \text{ else } c_2, \sigma\rangle \rightarrow \langle c_1, \sigma\rangle} ([\![b]\!]\sigma = tt)$$

$$\frac{}{\langle \text{if } b \text{ then } c_1 \text{ else } c_2, \sigma\rangle \rightarrow \langle c_2, \sigma\rangle} ([\![b]\!]\sigma = ff)$$

$$\frac{\langle c_1, \sigma\rangle \rightarrow \langle c_1', \sigma'\rangle}{\langle c_1 ; c_2, \sigma\rangle \rightarrow \langle c_1' ; c_2, \sigma'\rangle} \qquad \frac{\langle c_1, \sigma\rangle \rightarrow \sigma'}{\langle c_1 ; c_2, \sigma\rangle \rightarrow \langle c_2, \sigma'\rangle}$$

$$\frac{\langle c_1, \sigma\rangle \rightarrow \langle abort, \sigma'\rangle}{\langle c_1 ; c_2, \sigma\rangle \rightarrow \langle abort, \sigma'\rangle}$$

$$\frac{}{\langle \text{while } b \text{ do } c, \sigma\rangle \rightarrow \sigma} ([\![b]\!]\sigma = ff)$$

$$\frac{}{\langle \text{while } b \text{ do } c, \sigma\rangle \rightarrow \langle c ; \text{while } b \text{ do } c, \sigma\rangle} ([\![b]\!]\sigma = tt)$$

$$\frac{\langle c, [\sigma \mid v : [\![e]\!]\sigma]\rangle \rightarrow \langle abort, \sigma'\rangle}{\langle \text{newvar } v := e \text{ in } c, \sigma\rangle \rightarrow \langle abort, [\sigma' \mid v : \sigma(v)]\rangle}$$

$$\frac{\langle c, [\sigma \mid v : [\![e]\!]\sigma]\rangle \rightarrow \sigma'}{\langle \text{newvar } v := e \text{ in } c, \sigma\rangle \rightarrow [\sigma' \mid v : \sigma(v)]} \qquad \frac{\langle c, [\sigma \mid v : [\![e]\!]\sigma]\rangle \rightarrow \langle c', \sigma'\rangle}{\langle \text{newvar } v := e \text{ in } c, \sigma\rangle \rightarrow \langle \text{newvar } v := \sigma'(v) \text{ in } c', [\sigma' \mid v : \sigma(v)]\rangle}$$

6. Handling input and output.

$\langle comm\rangle ::= \ldots \mid ?\langle var\rangle \mid !\langle interp\rangle$

① This time we have to change the form or type of $\rightarrow$. It is no longer a binary relation, but a ternary relation:

$$\rightarrow \subseteq \Gamma_N \times \Lambda \times \Gamma$$

$$\lambda \in \Lambda \stackrel{def}{=} \{\varepsilon\} \cup \{?n \mid n \in \mathbb{Z}\} \cup \{!n \mid n \in \mathbb{Z}\}$$

- ε: transition or execution without input or output
- $?n$: transition with an input
- $!n$: transition with an output.

We write $\langle c, \sigma\rangle \xrightarrow{\lambda} \gamma$ to mean $\langle\langle c, \sigma\rangle, \lambda, \gamma\rangle \in \rightarrow$.

We also often omit λ if $\lambda = \varepsilon$.

② Why do we make this change? It ~~has~~ is because adding $?v$ and $!e$ to the language ~~changes~~ makes it necessary to describe some aspects of intermediate steps of computations explicitly. (except the ones for $c_1 ; c_2$ and newvar)

③ We ~~have~~ include all the rules that we defined in 5. of course, the occurences of $\rightarrow$ in those old rules should be understood as $\xrightarrow{\varepsilon}$ with ε omitted for simplicity. In addition to these rules, we have the following rules:

$$\frac{}{\langle ?v, \sigma\rangle \xrightarrow{?n} [\sigma \mid v : n]} \qquad \frac{}{\langle !e, \sigma\rangle \xrightarrow{!\,[\![e]\!]\sigma} \sigma}$$