Programski jezik PREV'25

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Kazalo

1 Leksikalna pravila

Programi so napisani v naboru ASCII in so sestavljeni iz naslednjih leksikalnih elementov:

1. *Konstante*:

   (a) *Celoštevilske konstante*:
   Neprazen končen niz desetiških števk (‘0’ ... ‘9’), pred katerim lahko stoji predznak (‘+’ ali ‘-’).

   (b) *Znakovne konstante*:
   Znak obdan z enojnimi narekovaji (‘’’).
   Znak je lahko predstavljen kot izpisljiv znak z ASCII kodo od 32 do 126 z izjemo znakov ‘’’ in ‘\’, ki sta zapisana kot ‘\’’ in ‘\\’, zaporedoma, ali z ASCII kodo v obliki ‘\0xXX’, pri čemer je X šestnajstiška števka (‘0’ ... ‘9’ ali ‘A’ ... ‘F’).

   (c) *Nizi*:
   Neprazen končen niz znakov obdan z dvojnimi narekovaji (‘"’).
   Znak je lahko predstavljen kot izpisljiv znak z ASCII kodo od 32 do 126 z izjemo znakov ‘"’ in ‘\’, ki sta zapisana kot ‘\"’ in ‘\\’, zaporedoma, ali z ASCII kodo v obliki ‘\0xXX’, pri čemer je X šestnajstiška števka (‘0’ ... ‘9’ ali ‘A’ ... ‘F’).

2. *Simboli*:
   `& | == != < > <= >= * / % + - ! . ^ = : , { } ( ) [ ]`

3. *Ključne besede*:
   `bool char do else end false fun if in int let null return sizeof then true typ var void while`

4. *Imena*:
   Neprazen niz malih črk (‘a’ ... ‘z’), velikih črk (‘A’ ... ‘Z’), desetiških števk (‘0’ ... ‘9’) in podčrtajev (‘_’), ki se ne začne z desetiško številko in ni ključna beseda.

5. *Komentarji*:

   Niz znakov, ki se začne z ograjico (‘`#`’) in ne vsebuje znakov CR in LF.

6. *Belo besedilo*:

   Presledki (‘ ’) ter znaki HT, CR in LF. Znak HT je širok 8 presledkov.

Leksikalne elemente se razpoznava od leve proti desni po pravilu najdaljšega ujemanja.
Znak LF označuje konec vrstice.

2 Sintaksa

Sintaksna zgradba je opisana z množicami PROG, DEFN, STMT, TYPE in EXPR, ki vsebujejo vse sintaksno pravilne programe, definicije, stavke, tipe in izraze, zaporedoma, množica ID pa vsebuje vsa imena. Pri tem *int*, *char* in *string* predstavljajo celoštevilske konstante, znakovne konstante in nize, zaporedoma.

2.1 Pravila

Programi:

$$\frac{D_1\ D_2\ \ldots\ D_d \in \mathsf{DEFN}^+}{D_1\ D_2\ \ldots\ D_d \in \mathsf{PROG}}\ \text{SYN:1}$$

Definicije:

$$\frac{id \in \mathsf{ID} \quad T \in \mathsf{TYPE}}{\texttt{typ}\ id\ \texttt{=}\ T \in \mathsf{DEFN}}\ \text{SYN:2} \qquad \frac{id \in \mathsf{ID} \quad T \in \mathsf{TYPE}}{\texttt{var}\ id\ \texttt{:}\ T \in \mathsf{DEFN}}\ \text{SYN:3}$$

$$\frac{\langle id_1, T_1\rangle\ \langle id_2, T_2\rangle\ \ldots\ \langle id_p, T_p\rangle \in (\mathsf{ID} \times \mathsf{TYPE})^* \quad T \in \mathsf{TYPE}}{\texttt{fun}\ id\ \texttt{(}\ id_1\ \texttt{:}\ T_1\ \texttt{,}\ id_2\ \texttt{:}\ T_2\ \texttt{,}\ \ldots\ \texttt{,}\ id_p\ \texttt{:}\ T_p\ \texttt{)}\ \texttt{:}\ T \in \mathsf{DEFN}}\ \text{SYN:4}$$

$$\frac{\langle id_1, T_1\rangle\ \langle id_2, T_2\rangle\ \ldots\ \langle id_p, T_p\rangle \in (\mathsf{ID} \times \mathsf{TYPE})^* \quad S_1\ S_2\ \ldots\ S_s \in \mathsf{STMT}^+ \quad T \in \mathsf{TYPE}}{\texttt{fun}\ id\ \texttt{(}\ id_1\ \texttt{:}\ T_1\ \texttt{,}\ id_2\ \texttt{:}\ T_2\ \texttt{,}\ \ldots\ \texttt{,}\ id_p\ \texttt{:}\ T_p\ \texttt{)}\ \texttt{:}\ T\ \texttt{=}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s \in \mathsf{DEFN}}\ \text{SYN:5}$$

Stavki:

$$\frac{E \in \mathsf{EXPR}}{E \in \mathsf{STMT}}\ \text{SYN:6} \qquad \frac{E_1, E_2 \in \mathsf{EXPR}}{E_1\ \texttt{=}\ E_2 \in \mathsf{STMT}}\ \text{SYN:7} \qquad \frac{E \in \mathsf{EXPR}}{\texttt{return}\ E \in \mathsf{STMT}}\ \text{SYN:8}$$

$$\frac{E \in \mathsf{EXPR} \quad S_1\ S_2\ \ldots\ S_s \in \mathsf{STMT}^*}{\texttt{while}\ E\ \texttt{do}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end} \in \mathsf{STMT}}\ \text{SYN:9}$$

$$\frac{E \in \mathsf{EXPR} \quad S_1\ S_2\ \ldots\ S_s \in \mathsf{STMT}^*}{\texttt{if}\ E\ \texttt{then}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end} \in \mathsf{STMT}}\ \text{SYN:10}$$

$$\frac{E \in \mathsf{EXPR} \quad S_1\ S_2\ \ldots\ S_s \in \mathsf{STMT}^* \quad S'_1\ S'_2\ \ldots\ S'_{s'} \in \mathsf{STMT}^*}{\texttt{if}\ E\ \texttt{then}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{else}\ S'_1\ \texttt{,}\ S'_2\ \texttt{,}\ \ldots\ \texttt{,}\ S'_{s'}\ \texttt{end} \in \mathsf{STMT}}\ \text{SYN:11}$$

$$\frac{D_1\ D_2\ \ldots\ D_d \in \mathsf{DEFN}^+ \quad S_1\ S_2\ \ldots\ S_s \in \mathsf{STMT}^+}{\texttt{let}\ D_1\ D_2\ \ldots\ D_d\ \texttt{in}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end} \in \mathsf{STMT}}\ \text{SYN:12}$$

Tipi:

$$\frac{}{\texttt{int} \in \mathsf{TYPE}}\ \text{SYN:13} \qquad \frac{}{\texttt{char} \in \mathsf{TYPE}}\ \text{SYN:14}$$

$$\frac{}{\texttt{bool} \in \mathsf{TYPE}}\ \text{SYN:15} \qquad \frac{}{\texttt{void} \in \mathsf{TYPE}}\ \text{SYN:16}$$

$$\frac{id \in \mathsf{ID}}{id \in \mathsf{TYPE}}\ \text{SYN:17} \qquad \frac{T \in \mathsf{TYPE}}{\texttt{[}\ int\ \texttt{]}\ T \in \mathsf{TYPE}}\ \text{SYN:18} \qquad \frac{T \in \mathsf{TYPE}}{\texttt{\^{}}\ T \in \mathsf{TYPE}}\ \text{SYN:19}$$

$$\frac{\langle id_1, T_1\rangle\ \langle id_2, T_2\rangle\ \ldots\ \langle id_c, T_c\rangle \in (\mathsf{ID} \times \mathsf{TYPE})^+}{\texttt{<}\ id_1 : T_1\ \texttt{,}\ id_2 : T_2\ \texttt{,}\ \ldots\ \texttt{,}\ id_c : T_c\ \texttt{>} \in \mathsf{TYPE}}\ \text{SYN:20}$$

$$\frac{\langle id_1, T_1\rangle\ \langle id_2, T_2\rangle\ \ldots\ \langle id_c, T_c\rangle \in (\mathsf{ID} \times \mathsf{TYPE})^+}{\texttt{\{}\ id_1 : T_1\ \texttt{,}\ id_2 : T_2\ \texttt{,}\ \ldots\ \texttt{,}\ id_c : T_c\ \texttt{\}} \in \mathsf{TYPE}}\ \text{SYN:21}$$

$$\frac{T_1\ T_2\ \ldots\ T_p \in \mathsf{TYPE}^* \quad T \in \mathsf{TYPE}}{\texttt{(}\ T_1\ \texttt{,}\ T_2\ \texttt{,}\ \ldots\ \texttt{,}\ T_p\ \texttt{)} : T \in \mathsf{TYPE}}\ \text{SYN:22}$$

Izrazi:

$$\frac{}{int \in \mathsf{EXPR}}\ \text{SYN:23} \qquad \frac{}{char \in \mathsf{EXPR}}\ \text{SYN:24} \qquad \frac{}{string \in \mathsf{EXPR}}\ \text{SYN:25}$$

$$\frac{}{\texttt{true} \in \mathsf{EXPR}}\ \text{SYN:26} \qquad \frac{}{\texttt{false} \in \mathsf{EXPR}}\ \text{SYN:27} \qquad \frac{}{\texttt{null} \in \mathsf{EXPR}}\ \text{SYN:28}$$

$$\frac{E \in \mathsf{EXPR} \quad \text{op} \in \{\texttt{+}, \texttt{-}, \texttt{!}\}}{\text{op}\ E \in \mathsf{EXPR}}\ \text{SYN:29}$$

$$\frac{E_1, E_2 \in \mathsf{EXPR} \quad \text{op} \in \{\texttt{\&}, \texttt{|}, \texttt{==}, \texttt{!=}, \texttt{<}, \texttt{>}, \texttt{<=}, \texttt{>=}, \texttt{*}, \texttt{/}, \texttt{\%}, \texttt{+}, \texttt{-}\}}{E_1\ \text{op}\ E_2 \in \mathsf{EXPR}}\ \text{SYN:30}$$

$$\frac{E_1, E_2 \in \mathsf{EXPR}}{E_1\ \texttt{[}\ E_2\ \texttt{]} \in \mathsf{EXPR}}\ \text{SYN:31} \qquad \frac{E \in \mathsf{EXPR}}{E\ \texttt{.}\ id \in \mathsf{EXPR}}\ \text{SYN:32}$$

$$\frac{E \in \mathsf{EXPR}}{E\ \texttt{\^{}} \in \mathsf{EXPR}}\ \text{SYN:33} \qquad \frac{E \in \mathsf{EXPR}}{\texttt{\^{}}\ E \in \mathsf{EXPR}}\ \text{SYN:34}$$

$$\frac{E_1\ E_2\ \ldots\ E_a \in \mathsf{EXPR}^* \quad E \in \mathsf{EXPR}}{E\ \texttt{(}\ E_1\ \texttt{,}\ E_2\ \texttt{,}\ \ldots\ \texttt{,}\ E_a\ \texttt{)} \in \mathsf{EXPR}}\ \text{SYN:35}$$

$$\frac{T \in \mathsf{TYPE}}{\texttt{sizeof}\ T \in \mathsf{EXPR}}\ \text{SYN:36} \qquad \frac{E \in \mathsf{EXPR} \quad T \in \mathsf{TYPE}}{\texttt{\{}\ E\ \texttt{:}\ T\ \texttt{\}} \in \mathsf{EXPR}}\ \text{SYN:37}$$

$$\frac{E \in \mathsf{EXPR}}{\texttt{(}\ E\ \texttt{)} \in \mathsf{EXPR}}\ \text{SYN:38} \qquad \frac{id \in \mathsf{ID}}{id \in \mathsf{EXPR}}\ \text{SYN:39}$$

Prioriteto operatorjev v izrazih določa naslednja tabela:

postfiksni operatorji	`(···) [·] ^ .`	NAJVIŠJA PRIORITETA
prefiksni operatorji	`+ - ! ^`	
multiplikativni operatorji	`* / %`	
aditivni operatorji	`+ -`	
primerjalni operatorji	`== != < > <= >=`	
logični operatorji	`&`	
logični operatorji	`|`	NAJNIŽJA PRIORITETA

Primerjalni operatorji so neasociativni, ostali dvomestni operatorji so levoasociativni.

3 Semantika

3.1 Imena

Funkcija

$$[\![\cdot]\!]_{\mathsf{BINDS}} \colon \mathsf{ID} \longrightarrow \mathsf{DEFN}$$

preslika ime v definicijo v skadu s pravili, ki veljajo za imenske prostore in dosege.

Imenski prostori.

1. Globalni imenski prostor vsebuje vsa imena tipov, spremenljivk, funkcij in parametrov.
2. Vsak zapis definira svoj lastni imenski prostor, ki vsebuje komponente tega zapisa.

Dosegi.

1. Program ustvari nov doseg.
2. Stavek `let-in-end`ustvari nov doseg.
3. Definicija funkcije ustvari nov doseg, v katerem so parameteri in morebitno telo funkcije. Ime funkcije, tipi parametrov in tip rezultata niso del novo ustvarjenega dosega.

Vsako ime, ki je definirano v določenem dosegu,

1. je v tem dosegu lahko definirano le enkrat in
2. je (razen kjer je zasenčeno z definicijo v vgnezdenem dosegu) vidno v celotnem dosegu.

3.2 Sistem tipov

Množica

$$
\begin{aligned}
\mathcal{T} = {} & \{\mathbf{int}, \mathbf{char}, \mathbf{bool}, \mathbf{void}\} && \text{(atomarni tipi)} \\
& \cup \{\mathbf{ptr}(\tau) \mid \tau \in \mathcal{T}\} && \text{(kazalci)} \\
& \cup \{\mathbf{arr}(n \times \tau) \mid n > 0 \wedge \tau \in \mathcal{T}\} && \text{(tabele)} \\
& \cup \{\mathbf{struct}_{ids}(\overline{\tau}) \mid n > 0 \wedge ids \in \mathsf{ID}^n \wedge \overline{\tau} \in \mathcal{T}^n\} && \text{(strukture)} \\
& \cup \{\mathbf{union}_{ids}(\overline{\tau}) \mid n > 0 \wedge ids \in \mathsf{ID}^n \wedge \overline{\tau} \in \mathcal{T}^n\} && \text{(unije)} \\
& \cup \{\mathbf{fun}(\overline{\tau} \to \tau) \mid n \geq 0 \wedge \overline{\tau} \in \mathcal{T}^n \wedge \tau \in \mathcal{T}\} && \text{(funkcije)} \\
& \cup \{\mathbf{name}(id, \tau) \mid id \in \mathsf{ID} \wedge \tau \in \mathcal{T}\} && \text{(poimenovani tip)}
\end{aligned}
$$

vsebuje vse tipe. Pri tem velja naslednje:

1. Tip **int** predstavlja cela števila množice $\{-2^{63} \ldots 2^{63} - 1\}$, ki so predstavljena kot 64-bitna predznačena cela števila v dvojiškem komplementu.
2. Tip **char** predstavljat znake ASCII besede, ki so predstavljeni z ASCII kodami kot 8-bitna nepredznačena cela števila v obsegu $0 \ldots 127$ (8. bit je neuporabljen).
3. Tip **bool** predstavlja vrednosti true in false, ki sta kot 1 in 0, zaporedoma, predstavljeni kot 8-bitni nepredznačeni celi števili (uporabljen je le 1. bit).
4. Kazalec hrani naslov, katerega širina je določena z arhitekturo.
5. Tabela je predstavljena kot zaporedje elementov brez polnila.
6. Struktura je predstavljena kot množica komponent zloženih ena za drugo z morebitnim polnilom.
7. Unija je predstavljena kot množica na istem mestu prekrivajočih se komponent.
8. Funkcija je predstavljena kot kazalec na začetni naslov kode funkcije.

Strukturno ekvivalenco tipov opisuje relacija $(\equiv) \subset \mathcal{T} \times \mathcal{T}$:

$$\frac{\tau_1 = \tau_2}{\tau_1 \equiv \tau_2}\ \text{EQU:1} \qquad \frac{\tau_1 \equiv \tau_2}{\mathbf{name}(id, \tau_1) \equiv \tau_2}\ \text{EQU:2}$$

$$\frac{n_1 = n_2 \quad \tau_1 \equiv \tau_2}{\mathbf{arr}(n_1 \times \tau_1) \equiv \mathbf{arr}(n_2 \times \tau_2)}\ \text{EQU:3} \qquad \frac{\tau_1 \equiv \tau_2}{\mathbf{ptr}(\tau_1) \equiv \mathbf{ptr}(\tau_2)}\ \text{EQU:4}$$

$$\frac{\tau_i \equiv \tau_i'}{\mathbf{struct}_{id_1 id_2 \ldots id_n}(\tau_1\ \tau_2\ \ldots\ \tau_n) \equiv \mathbf{struct}_{id_1 id_2 \ldots id_n}(\tau_1'\ \tau_2'\ \ldots\ \tau_n')}\ \text{EQU:5}$$

$$\frac{\tau_i \equiv \tau_i'}{\mathbf{union}_{id_1 id_2 \ldots id_n}(\tau_1\ \tau_2\ \ldots\ \tau_n) \equiv \mathbf{union}_{id_1 id_2 \ldots id_n}(\tau_1'\ \tau_2'\ \ldots\ \tau_n')}\ \text{EQU:6}$$

$$\frac{\tau_i \equiv \tau_i' \quad \tau \equiv \tau'}{\mathbf{fun}(\tau_1\ \tau_2\ \ldots\ \tau_n \to \tau) \equiv \mathbf{fun}(\tau_1'\ \tau_2'\ \ldots\ \tau_n' \to \tau')}\ \text{EQU:7}$$

Prilagajanje tipov opisuje relacija $(\rightsquigarrow) \subset \mathcal{T} \times \mathcal{T}$:

$$\frac{\tau \equiv \mathbf{int}}{\mathbf{int} \rightsquigarrow \tau}\ \text{COE:1} \qquad \frac{\tau \equiv \mathbf{char}}{\mathbf{char} \rightsquigarrow \tau}\ \text{COE:2} \qquad \frac{\tau \equiv \mathbf{bool}}{\mathbf{bool} \rightsquigarrow \tau}\ \text{COE:3} \qquad \frac{\tau \equiv \mathbf{void}}{\mathbf{void} \rightsquigarrow \tau}\ \text{COE:4}$$

$$\frac{\tau_1 \rightsquigarrow \tau_2}{\mathbf{ptr}(\tau_1) \rightsquigarrow \mathbf{ptr}(\tau_2)}\ \text{COE:5} \qquad \frac{\tau \equiv \mathbf{ptr}(\tau')}{\mathbf{ptr}(\mathbf{void}) \rightsquigarrow \tau}\ \text{COE:6}$$

$$\frac{n_1 = n_2 \quad \tau_1 \rightsquigarrow \tau_2}{\mathbf{arr}(n_1 \times \tau_1) \rightsquigarrow \mathbf{arr}(n_2 \times \tau_2)}\ \text{COE:7}$$

$$\frac{\tau_i \rightsquigarrow \tau_i'}{\mathbf{struct}_{id_1 id_2 \ldots id_n}(\tau_1 \tau_2 \ldots \tau_n) \rightsquigarrow \mathbf{struct}_{id_1 id_2 \ldots id_n}(\tau_1' \tau_2' \ldots \tau_n')}\ \text{COE:8}$$

$$\frac{\tau_i \rightsquigarrow \tau_i'}{\mathbf{union}_{id_1 id_2 \ldots id_n}(\tau_1 \tau_2 \ldots \tau_n) \rightsquigarrow \mathbf{union}_{id_1 id_2 \ldots id_n}(\tau_1' \tau_2' \ldots \tau_n')}\ \text{COE:9}$$

$$\frac{\tau_i \rightsquigarrow \tau_i' \quad \tau \rightsquigarrow \tau'}{\mathbf{fun}(\tau_1\ \tau_2\ \ldots\ \tau_n \to \tau) \rightsquigarrow \mathbf{fun}(\tau_1'\ \tau_2'\ \ldots\ \tau_n' \to \tau')}\ \text{COE:10}$$

$$\frac{id = id' \quad \tau \equiv \tau'}{\mathbf{name}(id, \tau) \rightsquigarrow \mathbf{name}(id', \tau')}\ \text{COE:11}$$

Pravila Funkciji

$$[\![\cdot]\!]_{\mathsf{ISTYPE}} \colon \mathsf{TYPE} \longrightarrow \mathcal{T}$$

in

$$[\![\cdot]\!]_{\mathsf{OFTYPE}} \colon \mathsf{PROG} \cup \mathsf{DEFN} \cup \mathsf{STMT} \cup \mathsf{EXPR} \longrightarrow \mathcal{T}$$

preslikata konstrukte jezika v tipe: prva opisuje konstrukcijo tipa, druga pa pripis tipa posameznemu konstruktu jezika. Funkciji

$$[\![\cdot]\!]_{\mathsf{ISCONST}} \colon \mathsf{EXPR} \longrightarrow \{\mathsf{true}, \mathsf{false}\}$$

in

$$[\![\cdot]\!]_{\mathsf{ISADDR}} \colon \mathsf{EXPR} \longrightarrow \{\mathsf{true}, \mathsf{false}\}$$

določata, kateri izrazi so konstantni in kateri izrazi opisujejo poleg vrednosti tudi naslov, na katerem je vrednost. Funkcija

$$[\![\cdot]\!]_{\mathsf{VALUE}} \colon \mathsf{EXPR} \longrightarrow \{-2^{63} \ldots 2^{63} - 1\}$$

preslika izraze v vrednosti (kjer je to mogoče in potrebno).

Programi:

$$\frac{\begin{array}{c}[\![\ D_i\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void} \\ \exists m \colon D_m = \texttt{fun}\ \text{main}\ \texttt{( ) : int =}\ S_1\ S_2\ \ldots\ S_s\end{array}}{[\![\ D_1\ D_2\ \ldots\ D_n\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}\ \text{TYP:1}$$

Definicije:

$$\frac{[\![\ id\ ]\!]_{\mathsf{BINDS}} = \texttt{typ}\ id\ \texttt{=}\ T \quad [\![\ T\ ]\!]_{\mathsf{ISTYPE}} = \tau}{\begin{array}{c}[\![\ \texttt{typ}\ id\ \texttt{=}\ T\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void} \\ [\![\ id\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{name}(id, \tau)\end{array}}\ \text{TYP:2}$$

$$\frac{[\![\ id\ ]\!]_{\mathsf{BINDS}} = \texttt{var}\ id : T \quad [\![\ T\ ]\!]_{\mathsf{ISTYPE}} = \tau \quad \tau \not\equiv \mathbf{void}}{\begin{array}{c}[\![\ \texttt{var}\ id : T\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void} \\ [\![\ id\ ]\!]_{\mathsf{OFTYPE}} = \tau \quad [\![\ id\ ]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![\ id\ ]\!]_{\mathsf{ISADDR}} = \mathsf{true}\end{array}}\ \text{TYP:3}$$

$$\frac{\begin{array}{c}[\![\ id\ ]\!]_{\mathsf{BINDS}} = \texttt{fun}\ id\ \texttt{(}\ id_1 : T_1\texttt{,}\ id_2 : T_2\texttt{,}\ \ldots\ \texttt{,}\ id_p : T_p\texttt{)} : T\ \big[\ \texttt{=}\ S_1\ S_2\ \ldots\ S_s\ \big]^{?} \\ [\![\ T_i\ ]\!]_{\mathsf{ISTYPE}} = \tau_i \quad \tau_i \equiv \tau_i' \quad [\![\ T\ ]\!]_{\mathsf{ISTYPE}} = \tau \quad \tau \equiv \tau' \quad [\![\ S_i\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void} \\ \tau_i' \in \{\mathbf{int}, \mathbf{char}, \mathbf{bool}\} \cup \{\mathbf{ptr}(\tau), \mathbf{fun}(\bar{\tau} \to \tau) | \bar{\tau} \in \mathcal{T}^* \wedge \tau \in \mathcal{T}\} \\ \tau' \in \{\mathbf{int}, \mathbf{char}, \mathbf{bool}, \mathbf{void}\} \cup \{\mathbf{ptr}(\tau), \mathbf{fun}(\bar{\tau} \to \tau) | \bar{\tau} \in \mathcal{T}^* \wedge \tau \in \mathcal{T}\}\end{array}}{\begin{array}{c}[\![\ \texttt{fun}\ id\ \texttt{(}\ id_1 : T_1\texttt{,}\ id_2 : T_2\texttt{,}\ \ldots\ \texttt{,}\ id_p : T_p\texttt{)} : T\ \big[\ \texttt{=}\ S_1\ S_2\ \ldots\ S_s\ \big]^{?}\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void} \\ [\![\ id\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{fun}(\tau_1\ \tau_2\ \ldots\ \tau_n \to \tau) \quad [\![\ id\ ]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![\ id\ ]\!]_{\mathsf{ISADDR}} = \mathsf{false} \\ [\![\ id_i\ ]\!]_{\mathsf{BINDS}} = id_i : T_i \quad [\![\ id_i\ ]\!]_{\mathsf{OFTYPE}} = \tau_i \\ [\![\ id_i\ ]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![\ id_i\ ]\!]_{\mathsf{ISADDR}} = \mathsf{true}\end{array}}\ \text{TYP:4}$$

Stavki:

$$\frac{\begin{array}{c}[\![\ E_1\ ]\!]_{\mathsf{OFTYPE}} = \tau_1 \quad [\![\ E_2\ ]\!]_{\mathsf{OFTYPE}} = \tau_2 \quad \tau_1 \equiv \tau_1' \quad \tau_2 \equiv \tau_2' \quad \tau_2 \rightsquigarrow \tau_1 \\ \tau_1', \tau_2' \in \{\mathbf{int}, \mathbf{char}, \mathbf{bool}\} \cup \{\mathbf{ptr}(\tau), \mathbf{fun}(\bar{\tau} \to \tau) | \bar{\tau} \in \mathcal{T}^* \wedge \tau \in \mathcal{T}\} \\ [\![\ E_1\ ]\!]_{\mathsf{ISADDR}} = \mathsf{true}\end{array}}{[\![\ E_1\ \texttt{=}\ E_2\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}\ \text{TYP:5}$$

$$\frac{\begin{array}{c}\texttt{return}\ E \in \texttt{fun}\ id\ \texttt{(}\ id_1 : T_1\ \texttt{,}\ id_2 : T_2\ \texttt{,}\ \ldots\ \texttt{,}\ id_p : T_p\ \texttt{)} : T\ \texttt{=}\ S_1\ S_2\ \ldots\ S_s \\ [\![\ id\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{fun}(\bar{\tau} \to \tau_1) \quad [\![\ E\ ]\!]_{\mathsf{OFTYPE}} = \tau_2 \quad \tau_2 \rightsquigarrow \tau_1 \quad \tau_1 \equiv \tau_1' \quad \tau_2 \equiv \tau_2' \\ \tau_1', \tau_2' \in \{\mathbf{int}, \mathbf{char}, \mathbf{bool}\} \cup \{\mathbf{ptr}(\tau), \mathbf{fun}(\bar{\tau} \to \tau) | \bar{\tau} \in \mathcal{T}^* \wedge \tau \in \mathcal{T}\}\end{array}}{[\![\ \texttt{return}\ E\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}\ \text{TYP:6}$$

$$\frac{[\![\ E\ ]\!]_{\mathsf{OFTYPE}} \equiv \mathbf{bool} \quad [\![\ S_i\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}{[\![\ \texttt{while}\ E\ \texttt{do}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end}\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}\ \text{TYP:7}$$

$$\frac{[\![\ E\ ]\!]_{\mathsf{OFTYPE}} \equiv \mathbf{bool} \quad [\![\ S_i\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}{[\![\ \texttt{if}\ E\ \texttt{then}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end}\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}\ \text{TYP:8}$$

$$\frac{[\![\ E\ ]\!]_{\mathsf{OFTYPE}} \equiv \mathbf{bool} \quad [\![\ S_i\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void} \quad [\![\ S_i'\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}{[\![\ \texttt{if}\ E\ \texttt{then}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{else}\ S_1'\ \texttt{,}\ S_2'\ \texttt{,}\ \ldots\ \texttt{,}\ S_{s'}'\ \texttt{end}\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}\ \text{TYP:9}$$

$$\frac{[\![\ D_i\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void} \quad [\![\ S_i\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}{[\![\ \texttt{let}\ D_1\ D_2\ \ldots\ D_d\ \texttt{in}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end}\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{void}}\ \text{TYP:10}$$

Tipi:

$$\frac{}{[\![\ \texttt{int}\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{int}}\ \text{TYP:11} \qquad \frac{}{[\![\ \texttt{char}\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{char}}\ \text{TYP:12}$$

$$\frac{}{[\![\ \texttt{bool}\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{bool}}\ \text{TYP:13} \qquad \frac{}{[\![\ \texttt{void}\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{void}}\ \text{TYP:14}$$

$$\frac{[\![\ T\ ]\!]_{\mathsf{ISTYPE}} = \tau \quad \tau \in \mathcal{T} \setminus \{\mathbf{void}\}}{[\![\ \texttt{\^{}}\ T\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{ptr}(\tau)}\ \text{TYP:15}$$

$$\frac{[\![\ int\ ]\!]_{\mathsf{VALUE}} = n \quad 0 < n < 2^{63} \quad [\![\ T\ ]\!]_{\mathsf{ISTYPE}} = \tau \quad \tau \not\equiv \mathbf{void}}{[\![\ \texttt{[}\ int\ \texttt{]}\ T\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{arr}(n \times \tau)}\ \text{TYP:16}$$

$$\frac{\begin{array}{c}[\![\ T_i\ ]\!]_{\mathsf{ISTYPE}} = \tau_i \quad \tau_i \not\equiv \mathbf{void} \\ \hline [\![\ \texttt{<}\ id_1 : T_1\ \texttt{,}\ id_2 : T_2\ \texttt{,}\ \ldots\ \texttt{,}\ id_c : T_c\ \texttt{>}\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{struct}_{id_1\ id_2\ \ldots\ id_c}(\tau_1\ \tau_2\ \ldots\ \tau_c) \\ [\![\ id_i\ ]\!]_{\mathsf{BINDS}} = id_i : T_i \quad [\![\ id_i\ ]\!]_{\mathsf{OFTYPE}} = \tau_i \\ [\![\ id_i\ ]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![\ id_i\ ]\!]_{\mathsf{ISADDR}} = \mathsf{true}\end{array}}\ \text{TYP:17}$$

$$\frac{\begin{array}{c}[\![\ T_i\ ]\!]_{\mathsf{ISTYPE}} = \tau_i \quad \tau_i \not\equiv \mathbf{void} \\ \hline [\![\ \texttt{<}\ id_1 : T_1\ \texttt{,}\ id_2 : T_2\ \texttt{,}\ \ldots\ \texttt{,}\ id_c : T_c\ \texttt{>}\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{union}_{id_1\ id_2\ \ldots\ id_c}(\tau_1\ \tau_2\ \ldots\ \tau_c) \\ [\![\ id_i\ ]\!]_{\mathsf{BINDS}} = id_i : T_i \quad [\![\ id_i\ ]\!]_{\mathsf{OFTYPE}} = \tau_i \\ [\![\ id_i\ ]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![\ id_i\ ]\!]_{\mathsf{ISADDR}} = \mathsf{true}\end{array}}\ \text{TYP:18}$$

$$\frac{\begin{array}{c}[\![\ T_i\ ]\!]_{\mathsf{ISTYPE}} = \tau_i \quad [\![\ T\ ]\!]_{\mathsf{ISTYPE}} = \tau \quad \tau_i \equiv \tau_i' \quad \tau \equiv \tau' \\ \tau_i' \in \{\mathbf{int}, \mathbf{char}, \mathbf{bool}\} \cup \{\mathbf{ptr}(\tau), \mathbf{fun}(\bar{\tau} \to \tau) | \bar{\tau} \in \mathcal{T}^* \wedge \tau \in \mathcal{T}\} \\ \tau' \in \{\mathbf{int}, \mathbf{char}, \mathbf{bool}, \mathbf{void}\} \cup \{\mathbf{ptr}(\tau), \mathbf{fun}(\bar{\tau} \to \tau) | \bar{\tau} \in \mathcal{T}^* \wedge \tau \in \mathcal{T}\} \\ \hline [\![\ \texttt{(}\ T_1\ \texttt{,}\ T_2\ \texttt{,}\ \ldots\ \texttt{,}\ T_p\ \texttt{)}\ \texttt{:}\ T\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{fun}(\tau_1 \tau_2 \ldots \tau_p \to \tau)\end{array}}\ \text{TYP:19}$$

Izrazi:

$$\frac{\begin{array}{c}[\![\ int\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{int} \\ [\![\ int\ ]\!]_{\mathsf{ISCONST}} = \mathsf{true} \\ [\![\ int\ ]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}}\ \text{TYP:20} \qquad \frac{\begin{array}{c}[\![\ char\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{char} \\ [\![\ char\ ]\!]_{\mathsf{ISCONST}} = \mathsf{true} \\ [\![\ char\ ]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}}\ \text{TYP:21}$$

$$\frac{\begin{array}{c}[\![\ \texttt{true}\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{bool} \\ [\![\ \texttt{true}\ ]\!]_{\mathsf{ISCONST}} = \mathsf{true} \\ [\![\ \texttt{true}\ ]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}}\ \text{TYP:22} \qquad \frac{\begin{array}{c}[\![\ \texttt{false}\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{bool} \\ [\![\ \texttt{false}\ ]\!]_{\mathsf{ISCONST}} = \mathsf{true} \\ [\![\ \texttt{false}\ ]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}}\ \text{TYP:23}$$

$$\frac{\begin{array}{c}[\![\ string\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{ptr}(\mathbf{char}) \\ [\![\ string\ ]\!]_{\mathsf{ISCONST}} = \mathsf{true} \\ [\![\ string\ ]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}}\ \text{TYP:24} \qquad \frac{\begin{array}{c}[\![\ \texttt{null}\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{ptr}(\mathbf{void}) \\ [\![\ \texttt{null}\ ]\!]_{\mathsf{ISCONST}} = \mathsf{true} \\ [\![\ \texttt{null}\ ]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}}\ \text{TYP:25}$$

$$\frac{[\![E]\!]_{\mathsf{OFTYPE}} = \tau \quad \tau \equiv \mathbf{int} \quad \mathrm{op} \in \{\texttt{+}, \texttt{-}\}}{[\![\mathrm{op}\ E]\!]_{\mathsf{OFTYPE}} = \tau \quad [\![\mathrm{op}\ E]\!]_{\mathsf{ISCONST}} = [\![E]\!]_{\mathsf{ISCONST}} \quad [\![\mathrm{op}\ E]\!]_{\mathsf{ISADDR}} = \mathsf{false}} \text{ TYP:26}$$

$$\frac{[\![E]\!]_{\mathsf{OFTYPE}} = \tau \quad \tau \equiv \mathbf{bool} \quad \mathrm{op} \in \{\texttt{!}\}}{[\![\mathrm{op}\ E]\!]_{\mathsf{OFTYPE}} = \tau \quad [\![\mathrm{op}\ E]\!]_{\mathsf{ISCONST}} = [\![E]\!]_{\mathsf{ISCONST}} \quad [\![\mathrm{op}\ E]\!]_{\mathsf{ISADDR}} = \mathsf{false}} \text{ TYP:27}$$

$$\frac{\begin{array}{c}[\![E_1]\!]_{\mathsf{OFTYPE}} = \tau_1 \quad [\![E_2]\!]_{\mathsf{OFTYPE}} = \tau_2 \quad \mathrm{op} \in \{\texttt{\&}, \texttt{|}\} \\ \tau_1 \equiv \mathbf{bool} \quad \tau_2 \equiv \mathbf{bool} \quad \tau_2 \rightsquigarrow \tau_1\end{array}}{\begin{array}{c}[\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{OFTYPE}} = \tau_1 \\ [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISCONST}} = [\![E_1]\!]_{\mathsf{ISCONST}} \wedge [\![E_2]\!]_{\mathsf{ISCONST}} \quad [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}} \text{ TYP:28}$$

$$\frac{\begin{array}{c}[\![E_1]\!]_{\mathsf{OFTYPE}} = \tau_1 \quad [\![E_2]\!]_{\mathsf{OFTYPE}} = \tau_2 \quad \mathrm{op} \in \{\texttt{\&}, \texttt{|}\} \\ \tau_1 \equiv \mathbf{bool} \quad \tau_2 \equiv \mathbf{bool} \quad \tau_1 \rightsquigarrow \tau_2\end{array}}{\begin{array}{c}[\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{OFTYPE}} = \tau_2 \\ [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISCONST}} = [\![E_1]\!]_{\mathsf{ISCONST}} \wedge [\![E_2]\!]_{\mathsf{ISCONST}} \quad [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}} \text{ TYP:29}$$

$$\frac{\begin{array}{c}[\![E_1]\!]_{\mathsf{OFTYPE}} = \tau_1 \quad [\![E_2]\!]_{\mathsf{OFTYPE}} = \tau_2 \quad \mathrm{op} \in \{\texttt{*}, \texttt{/}, \texttt{\%}, \texttt{+}, \texttt{-}\} \\ \tau_1 \equiv \mathbf{int} \quad \tau_2 \equiv \mathbf{int} \quad \tau_2 \rightsquigarrow \tau_1\end{array}}{\begin{array}{c}[\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{OFTYPE}} = \tau_1 \\ [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISCONST}} = [\![E_1]\!]_{\mathsf{ISCONST}} \wedge [\![E_2]\!]_{\mathsf{ISCONST}} \quad [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}} \text{ TYP:30}$$

$$\frac{\begin{array}{c}[\![E_1]\!]_{\mathsf{OFTYPE}} = \tau_1 \quad [\![E_2]\!]_{\mathsf{OFTYPE}} = \tau_2 \quad \mathrm{op} \in \{\texttt{*}, \texttt{/}, \texttt{\%}, \texttt{+}, \texttt{-}\} \\ \tau_1 \equiv \mathbf{int} \quad \tau_2 \equiv \mathbf{int} \quad \tau_1 \rightsquigarrow \tau_2\end{array}}{\begin{array}{c}[\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{OFTYPE}} = \tau_2 \\ [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISCONST}} = [\![E_1]\!]_{\mathsf{ISCONST}} \wedge [\![E_2]\!]_{\mathsf{ISCONST}} \quad [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}} \text{ TYP:31}$$

$$\frac{\begin{array}{c}[\![E_1]\!]_{\mathsf{OFTYPE}} = \tau_1 \quad [\![E_2]\!]_{\mathsf{OFTYPE}} = \tau_2 \quad \mathrm{op} \in \{\texttt{==}, \texttt{!=}, \texttt{<}, \texttt{>}, \texttt{<=}, \texttt{>=}\} \\ \tau_1 \equiv \tau_1' \quad \tau_2 \equiv \tau_2' \quad \tau_1 \rightsquigarrow \tau_2 \vee \tau_2 \rightsquigarrow \tau_1 \\ \tau_1', \tau_2' \in \{\mathbf{int}, \mathbf{char}, \mathbf{bool}\} \cup \{\mathbf{ptr}(\tau), \mathbf{fun}(\bar{\tau} \to \tau) | \bar{\tau} \in \mathcal{T}^* \wedge \tau \in \mathcal{T}\}\end{array}}{\begin{array}{c}[\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{OFTYPE}} = \mathbf{bool} \\ [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISCONST}} = [\![E_1]\!]_{\mathsf{ISCONST}} \wedge [\![E_2]\!]_{\mathsf{ISCONST}} \quad [\![E_1\ \mathrm{op}\ E_2]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}} \text{ TYP:32}$$

$$\frac{[\![E_1]\!]_{\mathsf{OFTYPE}} \equiv \mathbf{arr}(n \times \tau_1) \quad [\![E_2]\!]_{\mathsf{OFTYPE}} = \tau_2 \quad \tau_2 \equiv \mathbf{int} \quad [\![E_1]\!]_{\mathsf{ISADDR}} = \mathsf{true}}{[\![E_1\ \texttt{[}\ E_2\ \texttt{]}]\!]_{\mathsf{OFTYPE}} = \tau_1 \quad [\![E_1\ \texttt{[}\ E_2\ \texttt{]}]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![E_1\ \texttt{[}\ E_2\ \texttt{]}]\!]_{\mathsf{ISADDR}} = \mathsf{true}} \text{ TYP:33}$$

$$\frac{[\![E]\!]_{\mathsf{OFTYPE}} \equiv \mathbf{ptr}(\tau) \quad [\![E]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad \tau \not\equiv \mathbf{void}}{[\![E\ \texttt{\^{}}]\!]_{\mathsf{OFTYPE}} = \tau \quad [\![E\ \texttt{\^{}}]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![E\ \texttt{\^{}}]\!]_{\mathsf{ISADDR}} = \mathsf{true}} \text{ TYP:34}$$

$$\frac{[\![E]\!]_{\mathsf{OFTYPE}} = \tau \quad [\![E]\!]_{\mathsf{ISADDR}} = \mathsf{true} \quad \tau \not\equiv \mathbf{void}}{[\![\texttt{\^{}}\ E]\!]_{\mathsf{OFTYPE}} = \mathbf{ptr}(\tau) \quad [\![\texttt{\^{}}\ E]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![\texttt{\^{}}\ E]\!]_{\mathsf{ISADDR}} = \mathsf{false}} \text{ TYP:35}$$

$$\frac{[\![E]\!]_{\mathsf{OFTYPE}} \equiv \mathbf{struct}_{id_1 id_2 \ldots id_c}(\tau_1 \tau_2 \ldots \tau_c) \quad [\![E]\!]_{\mathsf{ISADDR}} = \mathsf{true} \quad id = id_i}{[\![E\ \texttt{.}\ id]\!]_{\mathsf{OFTYPE}} = \tau_i \quad [\![E\ \texttt{.}\ id]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![E\ \texttt{.}\ id]\!]_{\mathsf{ISADDR}} = \mathsf{true}} \text{ TYP:36}$$

$$\frac{[\![\ E\ ]\!]_{\mathsf{OFTYPE}} \equiv \mathbf{union}_{id_1 id_2 \ldots id_c}(\tau_1 \tau_2 \ldots \tau_c) \quad [\![\ E\ ]\!]_{\mathsf{ISADDR}} = \mathsf{true} \quad id = id_i}{[\![\ E\ .\ id\ ]\!]_{\mathsf{OFTYPE}} = \tau_i \quad [\![\ E\ .\ id\ ]\!]_{\mathsf{ISCONST}} = \mathsf{false} \quad [\![\ E\ .\ id\ ]\!]_{\mathsf{ISADDR}} = \mathsf{true}}\ \text{TYP:37}$$

$$\frac{[\![\ E\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{fun}(\tau_1 \tau_2 \ldots \tau_a \to \tau) \quad [\![\ E_i\ ]\!]_{\mathsf{OFTYPE}} = \tau_i' \quad \tau_i' \rightsquigarrow \tau_i}{\begin{array}{c}[\![\ E\ (\ E_1\ ,\ E_2\ ,\ \ldots\ ,\ E_a\ )\ ]\!]_{\mathsf{OFTYPE}} = \tau \\ [\![\ E\ (\ E_1\ ,\ E_2\ ,\ \ldots\ ,\ E_a\ )\ ]\!]_{\mathsf{ISCONST}} = \mathsf{false} \\ [\![\ E\ (\ E_1\ ,\ E_2\ ,\ \ldots\ ,\ E_a\ )\ ]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}}\ \text{TYP:38}$$

$$\frac{[\![\ T\ ]\!]_{\mathsf{ISTYPE}} \not\equiv \mathbf{void}}{\begin{array}{c}[\![\ \texttt{sizeof}\ T\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{int} \\ [\![\ \texttt{sizeof}\ T\ ]\!]_{\mathsf{ISCONST}} = \mathsf{true} \\ [\![\ \texttt{sizeof}\ T\ ]\!]_{\mathsf{ISADDR}} = \mathsf{false}\end{array}}\ \text{TYP:39} \qquad \frac{[\![\ E\ ]\!]_{\mathsf{OFTYPE}} \not\equiv \mathbf{void} \quad [\![\ T\ ]\!]_{\mathsf{ISTYPE}} \not\equiv \mathbf{void}}{\begin{array}{c}[\![\ \{\ E : T\ \}\ ]\!]_{\mathsf{OFTYPE}} = [\![\ T\ ]\!]_{\mathsf{ISTYPE}} \\ [\![\ \{\ E : T\ \}\ ]\!]_{\mathsf{ISCONST}} = [\![\ E\ ]\!]_{\mathsf{ISCONST}} \\ [\![\ \{\ E : T\ \}\ ]\!]_{\mathsf{ISADDR}} = [\![\ E\ ]\!]_{\mathsf{ISADDR}}\end{array}}\ \text{TYP:40}$$

$$\frac{}{\begin{array}{c}[\![\ (\ E\ )\ ]\!]_{\mathsf{OFTYPE}} = [\![\ E\ ]\!]_{\mathsf{OFTYPE}} \\ [\![\ (\ E\ )\ ]\!]_{\mathsf{ISCONST}} = [\![\ E\ ]\!]_{\mathsf{ISCONST}} \quad [\![\ (\ E\ )\ ]\!]_{\mathsf{ISCONST}} = [\![\ E\ ]\!]_{\mathsf{ISADDR}}\end{array}}\ \text{TYP:41}$$

3.3 Operacijska semantika

Operacijsko semantiko opišemo s funkcijami

$$\begin{aligned}[\![\ \cdot\ ]\!]_{\mathrm{ADDR}} &: \mathsf{EXPR} \times \mathcal{M} \to \mathcal{I} \times \mathcal{M} \\ [\![\ \cdot\ ]\!]_{\mathrm{EXPR}} &: \mathsf{EXPR} \times \mathcal{M} \to \mathcal{I} \times \mathcal{M} \\ [\![\ \cdot\ ]\!]_{\mathrm{STMT}} &: \mathsf{STMT} \times \mathcal{M} \to \mathcal{M}\end{aligned}$$

Pri tem $\mathcal{I}$ predstavlja 64-bitna predznačena števila v dvojiškem komplementu, $\mathcal{M}$ pa stanja pomnilnika.

Funkcija addr vrne bodisi absolutni naslov statične spremenljivke ali niza bodisi odmik lokalne spremenljivke, parametra ali komponente zapisa. Funckija sizeof vrne velikost podatkovnega tipa. Funkcija val vrne celoštevilsko vrednost konstante.

Naslovi.

$$\frac{}{[\![\ \mathit{string}\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle \mathrm{addr}(\mathit{string}), \mathrm{M} \rangle}\ \text{SEM:1}$$

$$\frac{\mathrm{addr}(\mathit{identifier}) = a}{[\![\ \mathit{identifier}\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle a, \mathrm{M} \rangle}\ \text{SEM:2}$$

$$\frac{[\![\ E_1\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle n_1, \mathrm{M}' \rangle \quad [\![\ E_2\ ]\!]^{\mathrm{M}'}_{\mathrm{EXPR}} = \langle n_2, \mathrm{M}'' \rangle \quad [\![\ E_1\ ]\!]_{\mathsf{OFTYPE}} = \mathbf{arr}(n \times \tau)}{[\![\ E_1 \texttt{[} E_2 \texttt{]}\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle n_1 + n_2 * \mathrm{sizeof}(\tau), \mathrm{M}'' \rangle}\ \text{SEM:3}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle n_1, \mathrm{M}' \rangle}{[\![\ E\,.\,\mathit{identifier}\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle n_1 + \mathrm{addr}(\mathit{identifier}), \mathrm{M}' \rangle}\ \text{SEM:4}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}' \rangle}{[\![\ E\texttt{\^{}}\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle n, \mathrm{M}' \rangle}\ \text{SEM:5}$$

Izrazi.

$$\frac{}{[\![\ \texttt{null}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle 0, \mathrm{M}\rangle}\ \textsc{sem:6}$$

$$\frac{}{[\![\ \texttt{true}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle 1, \mathrm{M}\rangle}\ \textsc{sem:7} \qquad \frac{}{[\![\ \texttt{false}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle 0, \mathrm{M}\rangle}\ \textsc{sem:8}$$

$$\frac{}{[\![\ \mathit{char}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathrm{val}(\mathit{char}), \mathrm{M}\rangle}\ \textsc{sem:9} \qquad \frac{}{[\![\ \mathit{int}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathrm{val}(\mathit{int}), \mathrm{M}\rangle}\ \textsc{sem:10}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}'\rangle \quad \mathrm{op} \in \{\texttt{!}, \texttt{+}, \texttt{-}\}}{[\![\ \mathrm{op}\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathrm{op}\ n, \mathrm{M}'\rangle}\ \textsc{sem:11}$$

$$\frac{\begin{array}{c}[\![\ E_1\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n_1, \mathrm{M}'\rangle \quad [\![\ E_2\ ]\!]^{\mathrm{M}'}_{\mathrm{EXPR}} = \langle n_2, \mathrm{M}''\rangle \\ \mathrm{op} \in \{\texttt{|}, \texttt{\&}, \texttt{==}, \texttt{!=}, \texttt{<}, \texttt{>}, \texttt{<=}, \texttt{>=}, \texttt{+}, \texttt{-}, \texttt{*}, \texttt{/}, \texttt{\%}\}\end{array}}{[\![\ E_1\ \mathrm{op}\ E_2\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n_1\ \mathrm{op}\ n_2, \mathrm{M}''\rangle}\ \textsc{sem:12}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle n, \mathrm{M}'\rangle}{[\![\ \texttt{\^{}}E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}'\rangle}\ \textsc{sem:13} \qquad \frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}'\rangle}{[\![\ E\texttt{\^{}}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathrm{M}'[n], \mathrm{M}'\rangle}\ \textsc{sem:14}$$

$$\frac{\mathrm{addr}(\mathit{identifier}) = a}{[\![\ \mathit{identifier}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle M[a], \mathrm{M}\rangle}\ \textsc{sem:15} \qquad \frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}'\rangle}{[\![\ \texttt{(}E\texttt{)}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}'\rangle}\ \textsc{sem:16}$$

$$\frac{[\![\ E_1\texttt{[}E_2\texttt{]}\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle a, M'\rangle}{[\![\ E_1\texttt{[}E_2\texttt{]}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle M'[a], \mathrm{M}'\rangle}\ \textsc{sem:17} \qquad \frac{[\![\ E\texttt{.}\mathit{identifier}\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle a, M'\rangle}{[\![\ E\texttt{.}\mathit{identifier}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle M'[a], \mathrm{M}'\rangle}\ \textsc{sem:18}$$

$$\frac{[\![\ E_1\ ]\!]^{\mathrm{M}_0}_{\mathrm{EXPR}} = \langle n_1, \mathrm{M}_1\rangle\ \ldots\ [\![\ E_m\ ]\!]^{\mathrm{M}_{m-1}}_{\mathrm{EXPR}} = \langle n_m, \mathrm{M}_m\rangle}{[\![\ \mathit{identifier}\texttt{(}E_1\texttt{,}\ \ldots\ \texttt{,}E_m\texttt{)}\ ]\!]^{\mathrm{M}_0}_{\mathrm{EXPR}} = \langle \mathit{identifier}(n_1, \ldots, n_m), \mathrm{M}_m\rangle}\ \textsc{sem:19}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}'\rangle \quad [\![\ T\ ]\!]_{\mathsf{ISTYPE}} \notin \{\mathbf{bool}, \mathbf{char}\}}{[\![\ \texttt{\{}E\texttt{:}\ T\texttt{\}}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}'\rangle}\ \textsc{sem:20}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}'\rangle \quad [\![\ T\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{bool}}{[\![\ \texttt{\{}E\texttt{:}\ T\texttt{\}}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n \bmod 2, \mathrm{M}'\rangle}\ \textsc{sem:21}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}'\rangle \quad [\![\ T\ ]\!]_{\mathsf{ISTYPE}} = \mathbf{char}}{[\![\ \texttt{\{}E\texttt{:}\ T\texttt{\}}\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n \bmod 256, \mathrm{M}'\rangle}\ \textsc{sem:22}$$

Stavki.

$$\frac{[\![\ E\ ]\!]^{M}_{\mathrm{EXPR}} = \langle n, \mathrm{M}' \rangle}{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{STMT}} = \mathrm{M}'} \text{ SEM:23}$$

$$\frac{[\![\ E_1\ ]\!]^{\mathrm{M}}_{\mathrm{ADDR}} = \langle n_1, \mathrm{M}' \rangle \quad [\![\ E_2\ ]\!]^{\mathrm{M}'}_{\mathrm{EXPR}} = \langle n_2, \mathrm{M}'' \rangle \quad \forall a\colon \mathrm{M}'''[a] = \begin{cases} n_2 & a = n_1 \\ M''[a] & \text{otherwise} \end{cases}}{[\![\ E_1 \texttt{ = } E_2\ ]\!]^{\mathrm{M}}_{\mathrm{STMT}} = \mathrm{M}'''} \text{ SEM:24}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathbf{true}, \mathrm{M}_0 \rangle \quad [\![\ S_1\ ]\!]^{\mathrm{M}_0}_{\mathrm{STMT}} = \mathrm{M}_1 \ \ldots\ [\![\ S_s\ ]\!]^{\mathrm{M}_{s-1}}_{\mathrm{STMT}} = \mathrm{M}_s}{[\![\ \texttt{if}\ E\ \texttt{then}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end}\ ]\!]_{\mathrm{STMT}} = \mathrm{M}_s} \text{ SEM:25}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathbf{false}, \mathrm{M}_0 \rangle}{[\![\ \texttt{if}\ E\ \texttt{then}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end}\ ]\!]_{\mathrm{STMT}} = \mathrm{M}_0} \text{ SEM:26}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathbf{true}, \mathrm{M}_0 \rangle \quad [\![\ S_1\ ]\!]^{\mathrm{M}_0}_{\mathrm{STMT}} = \mathrm{M}_1 \ \ldots\ [\![\ S_s\ ]\!]^{\mathrm{M}_{s-1}}_{\mathrm{STMT}} = \mathrm{M}_s}{[\![\ \texttt{if}\ \textit{expr}\ \texttt{then}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{else}\ S'_1\ \texttt{,}\ S'_2\ \texttt{,}\ \ldots\ \texttt{,}\ S'_s\ \texttt{end}\ ]\!]_{\mathrm{STMT}} = \mathrm{M}_s} \text{ SEM:27}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathbf{true}, \mathrm{M}_0 \rangle \quad [\![\ S'_1\ ]\!]^{\mathrm{M}_0}_{\mathrm{STMT}} = \mathrm{M}_1 \ \ldots\ [\![\ S'_s\ ]\!]^{\mathrm{M}_{s-1}}_{\mathrm{STMT}} = \mathrm{M}_s}{[\![\ \texttt{if}\ E\ \texttt{then}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{else}\ S'_1\ \texttt{,}\ S'_2\ \texttt{,}\ \ldots\ \texttt{,}\ S'_s\ \texttt{end}\ ]\!]_{\mathrm{STMT}} = \mathrm{M}_s} \text{ SEM:28}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathbf{true}, \mathrm{M}_0 \rangle \quad [\![\ S_1\ ]\!]^{\mathrm{M}_0}_{\mathrm{STMT}} = \mathrm{M}_1 \ \ldots\ [\![\ S_s\ ]\!]^{\mathrm{M}_{s-1}}_{\mathrm{STMT}} = \mathrm{M}_s}{[\![\ \texttt{while}\ E\ \texttt{do}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end}\ ]\!]^{\mathrm{M}}_{\mathrm{STMT}} = [\![\ \texttt{while}\ E\ \texttt{do}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ ]\!]^{\mathrm{M}_s}_{\mathrm{STMT}}} \text{ SEM:29}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle \mathbf{false}, \mathrm{M}_0 \rangle}{[\![\ \texttt{while}\ E\ \texttt{do}\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ \texttt{end}\ ]\!]^{\mathrm{M}}_{\mathrm{STMT}} = \mathrm{M}_0} \text{ SEM:30}$$

$$\frac{[\![\ S_1\ ]\!]^{\mathrm{M}_0}_{\mathrm{STMT}} = \mathrm{M}_1 \ \ldots\ [\![\ S_s\ ]\!]^{\mathrm{M}_{s-1}}_{\mathrm{STMT}} = \mathrm{M}_s}{[\![\ S_1\ \texttt{,}\ S_2\ \texttt{,}\ \ldots\ \texttt{,}\ S_s\ ]\!]^{\mathrm{M}_0}_{\mathrm{STMT}} = \mathrm{M}_s} \text{ SEM:31}$$

$$\frac{[\![\ E\ ]\!]^{\mathrm{M}}_{\mathrm{EXPR}} = \langle n, \mathrm{M}' \rangle}{[\![\ \texttt{return}\ E\ ]\!]^{\mathrm{M}}_{\mathrm{STMT}} = \mathrm{M}' \ \wedge \text{ funkcija takoj vrne } n} \text{ SEM:32}$$