

# Grammar

## Base Type

$\tau ::= \sigma \mid r$

$\sigma ::= \text{float} \mid \sigma \times \sigma \mid \eta \cdot \sigma$

## Natural Numbers

$\eta ::= 0 \mid 1 \mid \dots$

## Range

$r ::= \eta..\eta \mid \text{empty}$

## Term

$t ::= \text{fl} \mid \eta \mid p \mid \text{for } i : r \text{ in } t \mid \text{let } x := t \text{ in } t \mid (t, t) \mid \text{if } t \subseteq t \text{ then } t \text{ else } t \mid t + t \mid t * t \mid t - t \mid t / t$

- $i$  and  $x$  are identifiers.

## Literal

$\text{fl} ::= 0.0 \mid -4.21 \mid 523.215 \mid \dots$

## Place Expression

$p ::= x \mid p[t] \mid p.\text{fst} \mid p.\text{snd}$

## Environment

### Type Environment

$\Gamma ::= \bullet \mid \Gamma, (x : \tau)$

## Typing Rules

$$\frac{\Gamma \vdash t_l : \text{float} \quad \Gamma \vdash t_r : \text{float} \quad \text{op} \in \{+, -, *, /\}}{\Gamma \vdash t_l \text{ op } t_r : \text{float}} \text{T-ARITH}$$

$$\frac{x : \sigma \in \Gamma}{\Gamma \vdash x : \sigma} \text{T-VAR}$$

$$\frac{\Gamma \vdash t : \sigma \quad \Gamma, (x : \sigma) \vdash t_{\text{body}} : \sigma_{\text{body}}}{\Gamma \vdash \text{let } x := t \text{ in } t_{\text{body}} : \sigma_{\text{body}}} \text{T-LET}$$

$$\begin{array}{c}
\frac{r' = \text{mkRng}(\eta_l.. \eta_r) \quad \Gamma, (i : r') \vdash t_{\text{body}} : \sigma}{\Gamma \vdash \text{for } i : \eta_l.. \eta_r \text{ in } t_{\text{body}} : \text{length}(r') \cdot \sigma} \text{T-FOR} \\
\\
\frac{\Gamma \vdash t : \eta_t \cdot \sigma \quad \Gamma \vdash t_{\text{index}} : \eta_l.. \eta_r \quad \eta_r < \eta_t}{\Gamma \vdash t[t_{\text{index}}] : \sigma} \text{T-INDEX-RANGE} \\
\\
\frac{\Gamma \vdash t_{\text{index}} : \text{empty} \quad \Gamma \vdash t : \eta_t \cdot \sigma}{\Gamma \vdash t[t_{\text{index}}] : \sigma} \text{T-INDEX-RANGE-EMPTY} \\
\\
\frac{}{\Gamma \vdash \eta : \eta.. \eta} \text{T-NAT} \\
\\
\frac{\Gamma \vdash t : \sigma_1 \times \sigma_2}{\Gamma \vdash t.\text{fst} : \sigma_1} \text{T-FST} \\
\\
\frac{\Gamma \vdash t : \sigma_1 \times \sigma_2}{\Gamma \vdash t.\text{snd} : \sigma_2} \text{T-SND} \\
\\
\frac{\Gamma \vdash t_l : r_l \quad \Gamma \vdash t_r : r_r \quad \Gamma, (t_l : r_l \cap r_r) \vdash t_{\text{if}} : \sigma_{\text{if}} \quad (r_0, r_1) = r_l / r_r \quad \Gamma, (t_l : r_0) \vdash t_{\text{else}} : \sigma_{\text{else0}} \quad \Gamma, (t_l : r_1) \vdash t_{\text{else}} : \sigma_{\text{else1}} \quad \sigma = \sigma_{\text{if}} = \sigma_{\text{else0}} = \sigma_{\text{else1}}}{\Gamma \vdash \text{if } t_l \subseteq t_r \text{ then } t_{\text{if}} \text{ else } t_{\text{else}} : \sigma} \text{T-IF}
\end{array}$$

## Auxillary definitions

$\text{mkRng}(\eta_l.. \eta_r) = \text{if } 0 \leq \eta_l \leq \eta_r \text{ then } \eta_l.. \eta_r \text{ else empty}$

$\text{length}(r) = \text{match } r \text{ with}$

$\text{empty} \Rightarrow 0$   
     $\eta_l.. \eta_r \Rightarrow \eta_r - \eta_l + 1$

$r_l \cap r_r = \text{match } (r_l, r_r) \text{ with}$

$(\text{empty}, \_) \Rightarrow \text{empty}$   
     $(\_, \text{empty}) \Rightarrow \text{empty}$   
     $(\eta_{l0}.. \eta_{l1}, \eta_{r0}.. \eta_{r1}) \Rightarrow \text{mkRng}(\max(\eta_{l0}, \eta_{r0}), \min(\eta_{l1}, \eta_{r1}))$

$r_l / r_r = \text{match } r_l \cap r_r \text{ with}$

$\text{empty} \Rightarrow (r_l, \text{empty})$   
     $\eta_0.. \eta_1 \Rightarrow \text{match } r_l \text{ with}$   
         $\eta_{l0}.. \eta_{l1} \Rightarrow (\text{mkRng}(\eta_{l0}, \eta_0 - 1), \text{mkRng}(\eta_1 + 1, \eta_{l1}))$   
         $\_ \Rightarrow \text{unreachable}$

# Examples

## For expression

```
for i: (0..5) in
  for j: (0..6) in
    for k: (0..7) in
      4.2
```

This results in a value of type  $5 \cdot 6 \cdot 7 \cdot \text{float}$

```
for i : 0..5 in
  for j: 0..10 in
    1.2
```

This results in a value of type  $5 \cdot 10 \cdot \text{float}$

## Indexing by a value of type range

```
for i: 0..5 in
  a[0][i]
```

This is equivalent to: `a[0][0:5]`

## Slicing

```
for i: 0..10 in
  for j: 0..5 in
    a[i][j]
```

This is of type  $10 \cdot 5 \cdot \sigma$  and equivalent to `a[0..10][0..5]` where  $\sigma$  is the type of `a[0][0]`

## let in

```
let arr =
  for i: 0..5 in
    for j : 0..5 in
      3.14159
in
for i: 0..2 in
  for j: 0..1 in
    arr[i][j]
```

This is of type  $2 \cdot 1 \cdot \text{float}$

## let in, for, and tuple

### tuple

```
let arr_1 =  
  for i: 0..5 in  
    for j: 0..5 in  
      3.14159 in  
let arr_2 =  
  for i: 2..4 in  
    for j: 1..3 in  
      arr_1[i][j] in  
(arr_1, arr_2)
```

This is of type  $(5 \cdot 5 \cdot \text{float}) \times (2 \cdot 2 \cdot \text{float})$

### Nested tuple/array

```
let tup = (3.14159, for i : 0..5 in 6.25) in  
  for i : 0..10 in  
    tup
```

This is of type  $10 \cdot (\text{float} \times (5 \cdot \text{float}))$