

③ a)  $\text{rtree } f_{\text{un}} \equiv \lambda l. \text{ listcase } l \text{ of } ($

$\text{nil},$   
 $\lambda h. \lambda t. \text{ listcase } t \text{ of } ($

$h :: \text{nil},$

$\lambda h'. \lambda t'. h :: f_{\text{un}} ((h + h') :: t')$

)

b)  $\text{rtree } l \equiv \lambda n. \lambda \text{stop}. n :: l (n + \text{stop})$

$f_{\text{un}} \equiv \dots$

in  $f_{\text{un}} (l 1 4)$



Questão 4

①  $\langle \text{exp} \rangle ::= \text{empty} \mid \text{node } \langle \text{exp} \rangle, \langle \text{exp} \rangle \mid \text{node case } \langle \text{exp} \rangle \text{ of } \langle \langle \text{exp} \rangle, \langle \text{exp} \rangle \rangle \mid \dots$

$\langle \text{type} \rangle ::= \text{RTree } \langle \text{type} \rangle \mid \dots$

$$\frac{}{\Gamma \vdash \text{empty} : \text{RTree } \theta} \quad \frac{\Gamma \vdash e_1 : \theta \quad \Gamma \vdash e_2 : [\text{RTree } \theta]}{\Gamma \vdash \text{node } e_1, e_2 : \text{RTree } \theta}$$

$$\frac{\Gamma \vdash e : \text{RTree } \theta \quad \Gamma \vdash e_1 : \theta' \quad \Gamma \vdash e_2 : \theta \rightarrow [\text{RTree } \theta] \rightarrow \theta'}{\Gamma \vdash \text{node case } e \text{ of } (e_1, e_2) : \theta'}$$

②  $\langle \text{cfm} \rangle ::= \text{empty} \mid \text{node } \langle \text{cfm} \rangle, \langle \text{cfm} \rangle \mid \dots$

$$\left( \frac{}{\text{empty} \Rightarrow \text{empty}} \quad \frac{e \Rightarrow z \quad e' \Rightarrow z'}{\text{node } e, e' \Rightarrow \text{node } z, z'} \quad \frac{e \Rightarrow \text{empty} \quad e_1 \Rightarrow z}{\text{node case } e \text{ of } (e_1, e_2) \Rightarrow z} \right)$$

$$\frac{e \Rightarrow \text{node } z, z' \quad e_2 \Rightarrow z''}{\text{node case } e \text{ of } (e_1, e_2) \Rightarrow z''}$$

③ letrec sumRT  $\equiv$   $\lambda \text{let. node case let of}$

$(0, \lambda x. \lambda \text{let. } x + \text{sum} \mid \text{map sumRT let})$

$\text{map} \equiv \lambda f. \lambda l. \text{listcase } l \text{ of } (\text{nil}, \lambda h. \lambda t. f h :: \text{map } f t)$

$\text{sum} \equiv \lambda l. \text{listcase } l \text{ of } (0, \lambda h. \lambda t. h + \text{sum } t)$

in ...



$$④ \quad \text{RTree } \theta \doteq 1 + \theta \times \text{dist}(\text{RTree } \theta)$$

$$\text{empty} \doteq @1()$$

$$\text{node} \doteq x \cdot x \cdot y \cdot @2(x, y)$$

$$\text{succ } x \text{ of } (\text{leaf}) \doteq \text{succ } x \text{ of } (x() \cdot o_1 \cdot x(x, y) \cdot r_2 \cdot y)$$