Exercise 1. describe the frame process for in-place increment.

Exercise 2. specify the tree copy function.

Exercise 3. describe the frame process for tree copy.

Exercise 4. give small footprint specifications for array operations. How to derive the large footprint specifications from them?

$\{\quad\}$ `(Array.get i p)` $\{\quad\}$
$\{\quad\}$ `(Array.set i p v)` $\{\quad\}$
$\{\quad\}$ `(Array.length p)` $\{\quad\}$

Exercise 5. give a small-footprint specification for quicksort.

Exercise 6. For each heap implication below, say whether it is true or false.

1. $(r \mapsto 3) \star (s \mapsto 4) \rhd (s \mapsto 4) \star (r \mapsto 3)$
2. $(r \mapsto 3) \rhd (s \mapsto 4) \star (r \mapsto 3)$
3. $(s \mapsto 4) \star (r \mapsto 3) \rhd (r \mapsto 4)$
4. $(s \mapsto 4) \star (r \mapsto 3) \rhd (r \mapsto 3)$
5. $[\mathsf{False}] \star (r \mapsto 3) \rhd (s \mapsto 4) \star (r \mapsto 4)$
6. $(r \mapsto 4) \star (s \mapsto 3) \rhd [\mathsf{False}]$
7. $(r \mapsto 4) \star (r \mapsto 3) \rhd [\mathsf{False}]$
8. $(r \mapsto 3) \star (r \mapsto 3) \rhd [\mathsf{False}]$

Exercise 7. For each heap implication below, say whether it is true or false.

1. $(r \mapsto 3) \vdash \exists n.\, (r \mapsto n)$
2. $\exists n.\, (r \mapsto n) \vdash (r \mapsto 3)$
3. $\exists n.\, (r \mapsto n) \star [n > 0] \vdash \exists n.\, [n > 1] \star (r \mapsto (n-1))$
4. $(r \mapsto 3) \star (s \mapsto 3) \vdash \exists n.\, (r \mapsto n) \star (s \mapsto n)$
5. $\exists n.\, (r \mapsto n) \star [n > 0] \star [n < 0] \vdash (r \mapsto n) \star (r \mapsto n)$

Exercise 8. show that GC-PRE is derivable from GC-POST and FRAME.

$$\frac{\{H\}\ t\ \{Q\}}{\{H \star \mathsf{GC}\}\ t\ \{Q\}}$$

Exercise 9. give a specification of `copy` in terms of MtreeComplete; which rules are used to derive this specification?

Exercise 10. complete the rule for sequences.

$$\frac{\{\qquad\}\ t_1\ \{\qquad\} \qquad \{\qquad\}\ t_2\ \{\qquad\}}{\{H\}\ (t_1\,;\, t_2)\ \{Q\}}$$

Exercise 11. complete the reasoning rule for let-bindings.

$$\frac{\{\qquad\}\ t_1\ \{\qquad\} \qquad \forall x.\ \{\qquad\}\ t_2\ \{\qquad\}}{\{H\}\ (\mathsf{let}\, x = t_1\, \mathsf{in}\, t_2)\ \{Q\}}$$

Exercise 12. instantiate the rule for let-bindings on the following code.

$$\{r \mapsto 3\}\ (\texttt{let a = !r in a+1})\ \{Q\}$$

$$\begin{aligned} H &\equiv \\ Q &\equiv \\ Q' &\equiv \end{aligned}$$

Exercise 13. Reasoning rule for values:

$$\frac{\vdash}{\{H\}\ v\ \{Q\}}$$