Exercise 1. Give the instantiation of the frame rule in the proof of `mlength`

$$\frac{\{H_1\}\ t\ \{\lambda x.\, H_1'\}}{\{H_1 * H_2\}\ t\ \{\lambda x.\, H_1' * H_2\}}\ \textsc{Frame}$$

$H_1 =$
$H_1' =$
$H_2 =$

Exercise 2. Proof sketch for in-place increment, case $p \neq \mathsf{null}$.

$\{p \rightsquigarrow \mathsf{MList}\,(x :: L')\}$

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$\{\lambda\_.\ p \rightsquigarrow \mathsf{MList}\,(\mathsf{map}\,(+1)\,(x :: L'))\}$

Exercise 3. Specify the tree copy function.

Exercise 4. Proof sketch for tree copy.

$\{p \rightsquigarrow \mathsf{Mtree}\, T\}$

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$\{\lambda\ .\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\}$

Exercise 5. 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 6. give a small-footprint specification for quicksort.

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

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

Exercise 8. For each heap implication below, say whether it is true or false.

1. $(r \mapsto 3) \rhd \exists n.\, (r \mapsto n)$
2. $\exists n.\, (r \mapsto n) \rhd (r \mapsto 3)$
3. $\exists n.\, (r \mapsto n) * n > 0 \rhd \exists n.\, n > 1 * (r \mapsto (n-1))$
4. $(r \mapsto 3) * (s \mapsto 3) \rhd \exists n.\, (r \mapsto n) * (s \mapsto n)$
5. $\exists n.\, (r \mapsto n) * n > 0 * n < 0 \rhd (r \mapsto n) * (r \mapsto n)$

Exercise 9. show that GC-PRE is derivable from GC-POST and FRAME.

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

Exercise 10. give a specification of `copy` in terms of MtreeComplete; which rules are used to derive this specification?

Exercise 11. complete the rule for sequences.

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

Exercise 12. 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 13. 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 14. Reasoning rule for values:

$$\frac{\rhd}{\{H\} \; v \; \{Q\}}$$