

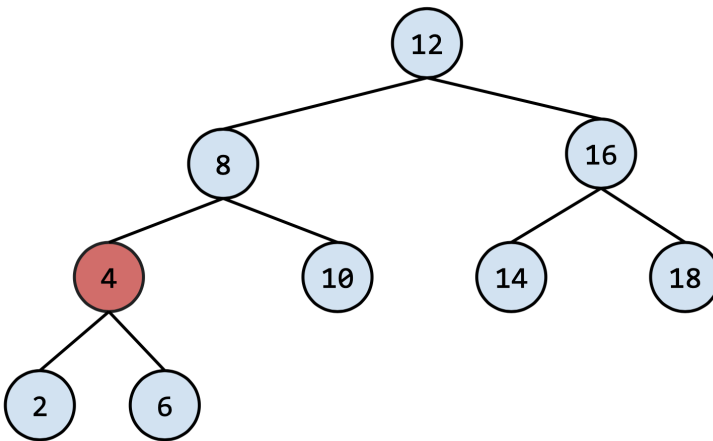
# LLRB<sub>s</sub>

a) (2 Points). Perform the following insertions on the Left Leaning Red Black Tree (LLRB) given below. For each insertion, give the fix up operations needed. Recall a fix up operation is one of the following:

- rotateLeft
- rotateRight
- colorFlip
- change the root node to black.

Note that insertions are **dependent**. If only two operations are necessary, pick “None” for the third operation. If only one operation is necessary, pick “None” for the second and third operation. If no operations are necessary, pick “None” for all three operations.

If you put “None” for the “Operation applied”, leave the “Node to apply on” **blank**. (Summer 2021 MT2)



i) (0.5 Points). Insert 17

	Operation applied	Node to apply on
1st operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	
2nd operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	
3rd operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	

ii) (0.5 Points). Insert 15. Note that insertions are dependent, so insert 15 into the state of the LLRB after the insertion of 17.

	Operation applied	Node to apply on
1st operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	
2nd operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	
3rd operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	

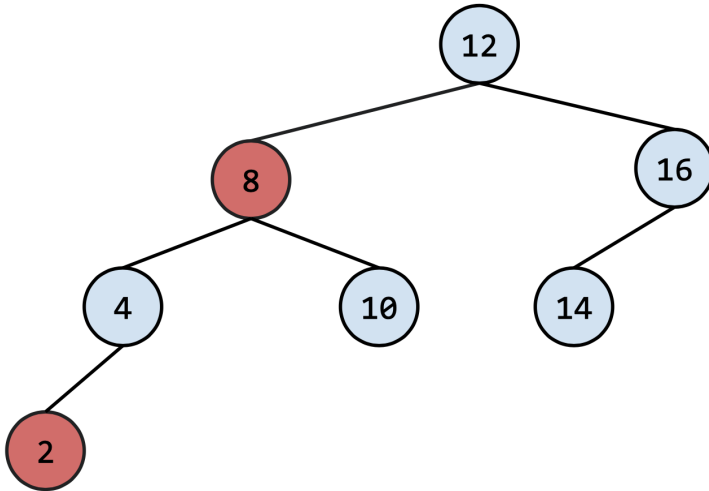
iii) (0.75 Points). Insert 13. Note that insertions are dependent, so insert 13 into the state of the LLRB after the insertion of 15.

	Operation applied	Node to apply on
1st operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	
2nd operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	
3rd operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	

iv) (0.75 Points). Insert 19. Note that insertions are dependent, so insert 19 into the state of the LLRB after the insertion of 13.

	Operation applied	Node to apply on
1st operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	
2nd operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	
3rd operation	<input type="radio"/> rotateLeft() <input type="radio"/> rotateRight() <input type="radio"/> colorFlip() <input type="radio"/> change root to black <input type="radio"/> None	

b) (1.5 Points). The tree below is **not** a valid LLRB (hint: to see why this is the case, draw the corresponding 2-3 tree) but it's close! In this part, we will try to *transform* it into a valid LLRB in two different ways. Note that each way acts **independently** of the previous. If a way isn't possible, put **impossible**. Recall that LLRBs **cannot** have duplicates.



i) (0.75 Points). Way 1: Remove a **single leaf** node from the tree. Which leaf node?

- 2  
  4  
  8  
  10  
  12  
  14  
  16  
  impossible

ii) (0.75 Points). Way 2: Flip the color of a **single node**. Which node?

- 2  
  4  
  8  
  10  
  12  
  14  
  16  
  impossible