

LEFT-ROTATE(T, x)

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1  $y \leftarrow \text{right}[x]$            ▷ Set  $y$ .
2  $\text{right}[x] \leftarrow \text{left}[y]$    ▷ Turn  $y$ 's left subtree into  $x$ 's right subtree.
3  $p[\text{left}[y]] \leftarrow x$ 
4  $p[y] \leftarrow p[x]$            ▷ Link  $x$ 's parent to  $y$ .
5 if  $p[x] = \text{nil}[T]$ 
6   then  $\text{root}[T] \leftarrow y$ 
7   else if  $x = \text{left}[p[x]]$ 
8     then  $\text{left}[p[x]] \leftarrow y$ 
9     else  $\text{right}[p[x]] \leftarrow y$ 
10  $\text{left}[y] \leftarrow x$           ▷ Put  $x$  on  $y$ 's left.
11  $p[x] \leftarrow y$ 
```

RB-INSERT(T, z)

```
1  $y \leftarrow \text{nil}[T]$ 
2  $x \leftarrow \text{root}[T]$ 
3 while  $x \neq \text{nil}[T]$ 
4   do  $y \leftarrow x$ 
5     if  $\text{key}[z] < \text{key}[x]$ 
6       then  $x \leftarrow \text{left}[x]$ 
7       else  $x \leftarrow \text{right}[x]$ 
8  $p[z] \leftarrow y$ 
9 if  $y = \text{nil}[T]$ 
10 then  $\text{root}[T] \leftarrow z$ 
11 else if  $\text{key}[z] < \text{key}[y]$ 
12   then  $\text{left}[y] \leftarrow z$ 
13   else  $\text{right}[y] \leftarrow z$ 
14  $\text{left}[z] \leftarrow \text{nil}[T]$ 
15  $\text{right}[z] \leftarrow \text{nil}[T]$ 
16  $\text{color}[z] \leftarrow \text{RED}$ 
17 RB-INSERT-FIXUP( $T, z$ )
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RB-INSERT-FIXUP(T, z)

```
1 while  $\text{color}[p[z]] = \text{RED}$ 
2   do if  $p[z] = \text{left}[p[p[z]]]$ 
3     then  $y \leftarrow \text{right}[p[p[z]]]$ 
4     if  $\text{color}[y] = \text{RED}$ 
5       then  $\text{color}[p[z]] \leftarrow \text{BLACK}$            ▷ Case 1
6          $\text{color}[y] \leftarrow \text{BLACK}$                  ▷ Case 1
7          $\text{color}[p[p[z]]] \leftarrow \text{RED}$              ▷ Case 1
8          $z \leftarrow p[p[z]]$                        ▷ Case 1
9     else if  $z = \text{right}[p[z]]$ 
10      then  $z \leftarrow p[z]$                          ▷ Case 2
11          LEFT-ROTATE( $T, z$ )                          ▷ Case 2
12       $\text{color}[p[z]] \leftarrow \text{BLACK}$                  ▷ Case 3
13       $\text{color}[p[p[z]]] \leftarrow \text{RED}$                  ▷ Case 3
14      RIGHT-ROTATE( $T, p[p[z]]$ )                      ▷ Case 3
15   else (same as then clause
        with "right" and "left" exchanged)
16  $\text{color}[\text{root}[T]] \leftarrow \text{BLACK}$ 
```

RB-DELETE(T, z)

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1 if  $\text{left}[z] = \text{nil}[T]$  or  $\text{right}[z] = \text{nil}[T]$ 
2   then  $y \leftarrow z$ 
3   else  $y \leftarrow \text{TREE-SUCCESSOR}(z)$ 
4 if  $\text{left}[y] \neq \text{nil}[T]$ 
5   then  $x \leftarrow \text{left}[y]$ 
6   else  $x \leftarrow \text{right}[y]$ 
7  $p[x] \leftarrow p[y]$ 
8 if  $p[y] = \text{nil}[T]$ 
9   then  $\text{root}[T] \leftarrow x$ 
10  else if  $y = \text{left}[p[y]]$ 
11    then  $\text{left}[p[y]] \leftarrow x$ 
12    else  $\text{right}[p[y]] \leftarrow x$ 
13 if  $y \neq z$ 
14   then  $\text{key}[z] \leftarrow \text{key}[y]$ 
15   copy  $y$ 's satellite data into  $z$ 
16 if  $\text{color}[y] = \text{BLACK}$ 
17   then RB-DELETE-FIXUP( $T, x$ )
18 return  $y$ 
```

RB-DELETE-FIXUP(T, x)

```
1 while  $x \neq \text{root}[T]$  and  $\text{color}[x] = \text{BLACK}$ 
2   do if  $x = \text{left}[p[x]]$ 
3     then  $w \leftarrow \text{right}[p[x]]$ 
4     if  $\text{color}[w] = \text{RED}$ 
5       then  $\text{color}[w] \leftarrow \text{BLACK}$                  ▷ Case 1
6          $\text{color}[p[x]] \leftarrow \text{RED}$                  ▷ Case 1
7         LEFT-ROTATE( $T, p[x]$ )                       ▷ Case 1
8          $w \leftarrow \text{right}[p[x]]$                    ▷ Case 1
9     if  $\text{color}[\text{left}[w]] = \text{BLACK}$  and  $\text{color}[\text{right}[w]] = \text{BLACK}$ 
10      then  $\text{color}[w] \leftarrow \text{RED}$                  ▷ Case 2
11           $x \leftarrow p[x]$                            ▷ Case 2
12      else if  $\text{color}[\text{right}[w]] = \text{BLACK}$ 
13        then  $\text{color}[\text{left}[w]] \leftarrow \text{BLACK}$          ▷ Case 3
14           $\text{color}[w] \leftarrow \text{RED}$                  ▷ Case 3
15          RIGHT-ROTATE( $T, w$ )                       ▷ Case 3
16           $w \leftarrow \text{right}[p[x]]$                    ▷ Case 3
17           $\text{color}[w] \leftarrow \text{color}[p[x]]$            ▷ Case 4
18           $\text{color}[p[x]] \leftarrow \text{BLACK}$              ▷ Case 4
19           $\text{color}[\text{right}[w]] \leftarrow \text{BLACK}$          ▷ Case 4
20          LEFT-ROTATE( $T, p[x]$ )                       ▷ Case 4
21           $x \leftarrow \text{root}[T]$                        ▷ Case 4
22      else (same as then clause with "right" and "left" exchanged)
23  $\text{color}[x] \leftarrow \text{BLACK}$ 
```