

LEFT-ROTATE(T, x)

```

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( $T, z$ )

```

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  $z = \text{right}[p[p[z]]]$ 
10 then  $z \leftarrow p[p[z]]$                  ▷ 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)

```

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  $\text{color}[x] \leftarrow \text{BLACK}$ 

```