Chapter 19

Binary Search Trees

Data Structures & Problem Solving
Using JAVA
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Figure 19.39
A color flip at 50 induces a violation; because the violation is outside, a single rotation fixes it.
Figure 19.40
Result of single rotation that fixes the violation at node 50
Figure 19.41
Insertion of 45 as a red node
Figure 19.50

\( X \) has two black children, and both of its sibling’s children are black; do a color flip.
Figure 19.51

$X$ has two black children, and the outer child of its sibling is red; do a single rotation.
Figure 19.52

X has two black children, and the inner child of its sibling is red; do a double rotation.
Figure 19.53

$X$ is black, and at least one child is red; if we fall through to the next level and land on a red child, fine; if not, we rotate a sibling and parent.
Figure 19.54
AA-tree resulting from the insertion of 10, 85, 15, 70, 20, 60, 30, 50, 65, 80, 90, 40, 5, 55, and 35
Figure 19.55
The skew procedure is a simple rotation between $X$ and $P$. 

![Diagram of skew procedure]

- The skew procedure involves rotating node $P$ and node $X$ around their common parent, effectively changing the connections between nodes $A$, $B$, and $C$. 

$P$ originally connected to $X$, which then connects to $A$, $B$, and $C$. After the skew procedure, $X$ connects directly to $A$, $B$, and $C$, and $P$ loses its direct connection to $X$. 

This transformation helps maintain the balance of the data structure, ensuring efficient operations.
Figure 19.56
The split procedure is a simple rotation between $X$ and $R$; note that $R$’s level increases.
Figure 19.57
After insertion of 45 in the sample tree; consecutive horizontal links are introduced, starting at 35.
Figure 19.58
After split at 35; a left horizontal link at 50 is introduced.
Figure 19.59
After skew at 50; consecutive horizontal nodes are introduced starting at 40.
Figure 19.60
After split at 40; 50 is now on the same level as 70, inducing an illegal left horizontal link.
Figure 19.61
After skew at 70; consecutive horizontal links are introduced, starting at 30.
Figure 19.62
After split at 30; the insertion is complete.
Figure 19.63
When 1 is deleted, all nodes become level 1, thereby introducing horizontal left links.
Figure 19.82
A 5-ary tree of 31 nodes has only three levels
Figure 19.83
A B-tree of order 5
Figure 19.84
The B-tree after insertion of 57 in the tree shown in Figure 19.83.
Figure 19.85
Insertion of 55 in the B-tree shown in Figure 19.84 causes a split into two leaves.
Figure 19.86
Insertion of 40 in the B-tree shown in Figure 19.85 causes a split into two leaves and then a split of the parent node.