Red-Black Tree

Data structure research

Cheng Fei 12/27/2022

Definition

A special case of BST

- A red-black tree is a special case of a binary search tree with an extra bit of “color” (red/black).

- Time complexity:
  The color bit is used to ensure the time complexity of the insertion/deletion is around O(logN), where N denotes the number of nodes in the tree, although a red-black tree is not perfectly balanced.

- Space complexity:
  Since a red-black tree only needs one extra bit to store the color data, the space complexity of a red-black tree is relatively close to a normal BST.

Performance

N is the total number of nodes in the tree.

- Search: O(logN)
- Insertion: O(logN)
- Deletion: O(logN)

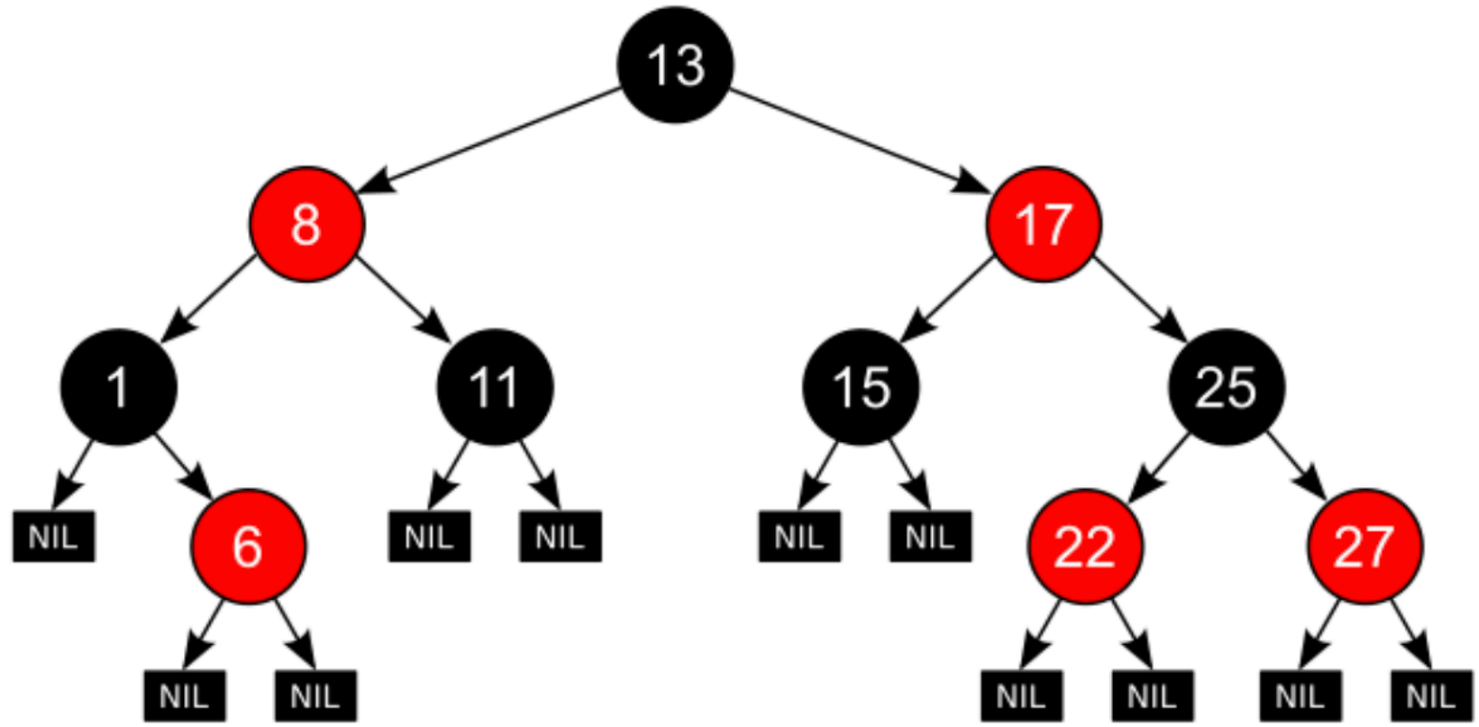

Figure. An example of the red-black tree

Figure Source: https://en.wikipedia.org/wiki/Red%E2%80%93black_tree

Comparison

Compared with AVL tree

- The AVL tree is more balanced than the red-black tree, but the AVL tree might cause more rotations than desired in insertion/deletion.

- If we need more search than insertion/deletion: we prefer the AVL tree.

- If we need more insertion/deletion than search: we prefer the red-black tree.

Applications

- Most of the self-balancing BST library functions like map, multiset, and multimap in C++ and TreeMap/TreeSet in Java use the red-black tree as the data structure.
- OS uses the red-black tree to implement the task scheduler.
- The machine learning algorithm, like the K-means clustering, uses the red-black tree to reduce the time complexity.
- MySQL database uses the red-black tree to store indexes on tables to reduce the time complexity of search and insertion.

References

- GeekforGeeks red-black tree introduction: https://www.geeksforgeeks.org/introduction-to-red-black-tree

- Wikipedia red-black tree introduction: https://en.wikipedia.org/wiki/Red%E2%80%93black_tree

- MIT OCW red-black tree lecture: https://ocw.mit.edu/courses/6-046j-introduction-to-algorithms-sma-5503-fall-2005/resources/lecture-10-red-black-trees-rotations-insertions-deletions/