Lecture 24: Balanced Binary Search Trees

CS 62
Spring 2018
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Rotating Binary Trees

Key idea: Rotate node higher in tree while keeping it in order.

![Diagram of tree rotations](image-url)
Rotating Trees

- Rotate A to root (Right rotation)
  - All nodes in subtrees $\alpha$ go up one level, all in $\gamma$ go down one level, all in $\beta$ stay same.

- Rotate B to root (Left Rotation)
  - All nodes in subtrees $\gamma$ go up one level, all in $\alpha$ go down one level, all in $\beta$ stay same.

- See code in BinaryTree.java
Shifting elements toward root

- Move $x$ up two levels w/ two rotations
- If $x$ is left child of a left child...

After the splay has been completed, the node $x$ is located at the root of the tree. If node $x$ were to be immediately accessed again (a strong possibility), the tree is clearly optimized to handle this situation. It is not the case that the tree becomes more balanced (see Figure 14.5a). Clearly, if the tree is splayed at an extremal value, the tree is likely to be extremely unbalanced. An interesting feature, however, is that the depth of the nodes on the original path from $x$ to the root of the tree is, on average, halved. Since the average depth of these
Shifting elements toward root

• If $x$ is a right child of a left child...

Symmetric if interchangeable left and right
Splay Trees

- Self-adjusting Binary Search Trees
- Fast access to elements accessed recently (locality)

- Every time contains, add or remove an element \( x \), move it to the root by a series of rotations (splay \( x \))

- Splay trees are balanced
  - But are not strictly balanced, unlike AVL trees
  - On average height is \( O(\log n) \)
  - Worst case height is \( O(n) \)
  - Average and worst case amortized cost is \( O(\log n) \) for all operations

- Popular: caches, garbage collectors, routing
Splay operations

• Zig
  • Zag
• Zig-zig
  • Zag-zag
• Zig-zag
  • Zag-zig
Zig or Zag: node is child of root

Zig (Right Rotation on (x,y))

Zag (Left Rotation on (x,y))
Zig-zig (Left Left case)

Node $x$ has both parent $P$ and grandparent $G$. Both $x$ and $P$ are the left children of their parents.
Zag-zag (Right Right case)

Node \( x \) has both parent \( P \) and grandparent \( G \). Both \( x \) and \( P \) are the right children of their parents.
Zig-zag (Left Right case)

Node $x$ has both parent $P$ and grandparent $G$. $x$ is right child and $P$ is left child of their parents.
Zag-zig (Right Left case)

Node $x$ has both parent $P$ and grandparent $G$. $x$ is left child and $P$ is right child of their parents.
Operation sketches

• **contains**: Use `locate` method of BSTs. Splay the located node

• **add**: Use `add` method of BSTs and then splay node

• **remove**: Use `contains` to splay the node to be removed to the root. Delete it. You now have two independent trees. Find the maximum node in left subtree and splay it. Make root of right subtree its right child.

• [https://www.cs usfca edu/~galles/visualization/SplayTree.html](https://www.cs.usfca.edu/~galles/visualization/SplayTree.html)
Practice time

- **add**: 8 1 80 50 2 60 90 51
Practice time

- contains: 2
Practice time

- remove: 51