AVL Tree II

- Time complexity
- Reconstruct AVL tree from BST in O(n)
  - rebalanceTree()
  - Use inorder() either keys or nodes
- growN(), trimN()
  - use rebalanceTree() instead of rebalance()

Prof. Youngsup Kim, idebtor@gmail.com, Data Structures, CSEE Dept., Handong Global University

Time Complexity in big O notation:

Algorithm	BST		AVL	
	Worst	Average	Worst	Average
Search	O(n)	O(log n)	O(log n)	O(log n)
Insertion	O(n)	O(log n)	O(log n)	O(log n)
Deletion	O(n)	O(log n)	O(log n)	O(log n)
grow N, trim N	O(n^2)	O(n log n)	O(n log n)	O(n log n)
rebalance()			O(log n)	O(log n)
rebalance N			O(n log n)	O(n log n)

Time Complexity in big O notation:

```
// inserts a key into the AVL tree and rebalance it.
tree growAVL(tree node, int key) {
  if (node == nullptr) return new TreeNode(key);

  // your code here

  return rebalance(node);      // O(log n)
}
```

```
tree rebalanceTree(tree node) { // may need a better solution here
  if (node == nullptr) return nullptr;

  while (!isAVL(node))                // O(n) ~ O(n^2)
    node = _rebalanceTree(node);      // n log(n)

  return node;
}
```

Time Complexity in big O notation:

```
// inserts N numbers of keys in the tree(AVL or BST)
// If it is empty, the key values to add ranges from 0 to N-1.
// If it is not empty, it ranges from (max+1) to (max+1 + N).
tree growN(tree root, int N, bool AVLtree) {    // recode tree.cpp
  int start = empty(root) ? 0 : value(maximum(root)) + 1;

  int* arr = new (nothrow) int[N];
  assert(arr != nullptr);
  randomN(arr, N, start);

  for (int i = 0; i < N; i++) root = grow(root, arr[i]);

  if (AVLtree) root = rebalanceTree(root);

  delete[] arr;
  return root;
}
```

Use BST grow() **instead of growAVL()**
since AVL is a BST and
we can avoid calling rebalance() N times.

Time Complexity in big O notation:

```
// removes randomly N numbers of nodes in the tree(AVL or BST).
// It gets N node keys from the tree, trim one by one randomly.
tree trimN(tree root, int N, bool AVLtree) {  // recode tree.cpp
  vector<int> vec;
  inorder(root, vec);
  shuffle(vec.data(), vec.size());
  int tsize = size(root);
  assert(vec.size() == tsize);    // make sure we've got them all

  int count = N > tsize ? tsize : N;
  for (int i = 0; i < N; i++) root = trim(root, arr[i]);

  if (AVLtree) root = rebalanceTree(root);

  delete[] arr;
  return root;
}
```

Use BST trim() instead of trimAVL()
since AVL is a BST and
we can avoid calling rebalance() N times.

Building AVL tree from BST in O(n)

```
// rebuilds an AVL tree with a list of keys sorted.
// v - an array of keys sorted, n - the array size
tree buildAVL(int* v, int n) {
  if (n <= 0) return nullptr;
  int mid = n / 2;
  // create a root node

  // recursive buildAVL() calls for left & right

  // your code here
  return root;
}
```

mid = 6

n = 13	0	1	2	3	4	5	6	7	8	9	11	12
v	2	3	5	6	8	9	11	15	20	22	23	25

left subtree | root | right subtree

Building AVL tree from BST in O(n)

mid = 6

n = 13	0	1	2	3	4	5	6	7	8	9	11	12
v	2	3	5	6	8	9	11	15	20	22	23	25

left subtree | root | right subtree

Building AVL tree from BST in O(n)

mid = 6

n = 13	0	1	2	3	4	5	6	7	8	9	11	12
v	2	3	5	6	8	9	11	15	20	22	23	25

left subtree | root | right subtree

mid = 3

n = 6	0	1	2	3	4	5
v	2	3	5	6	8	9

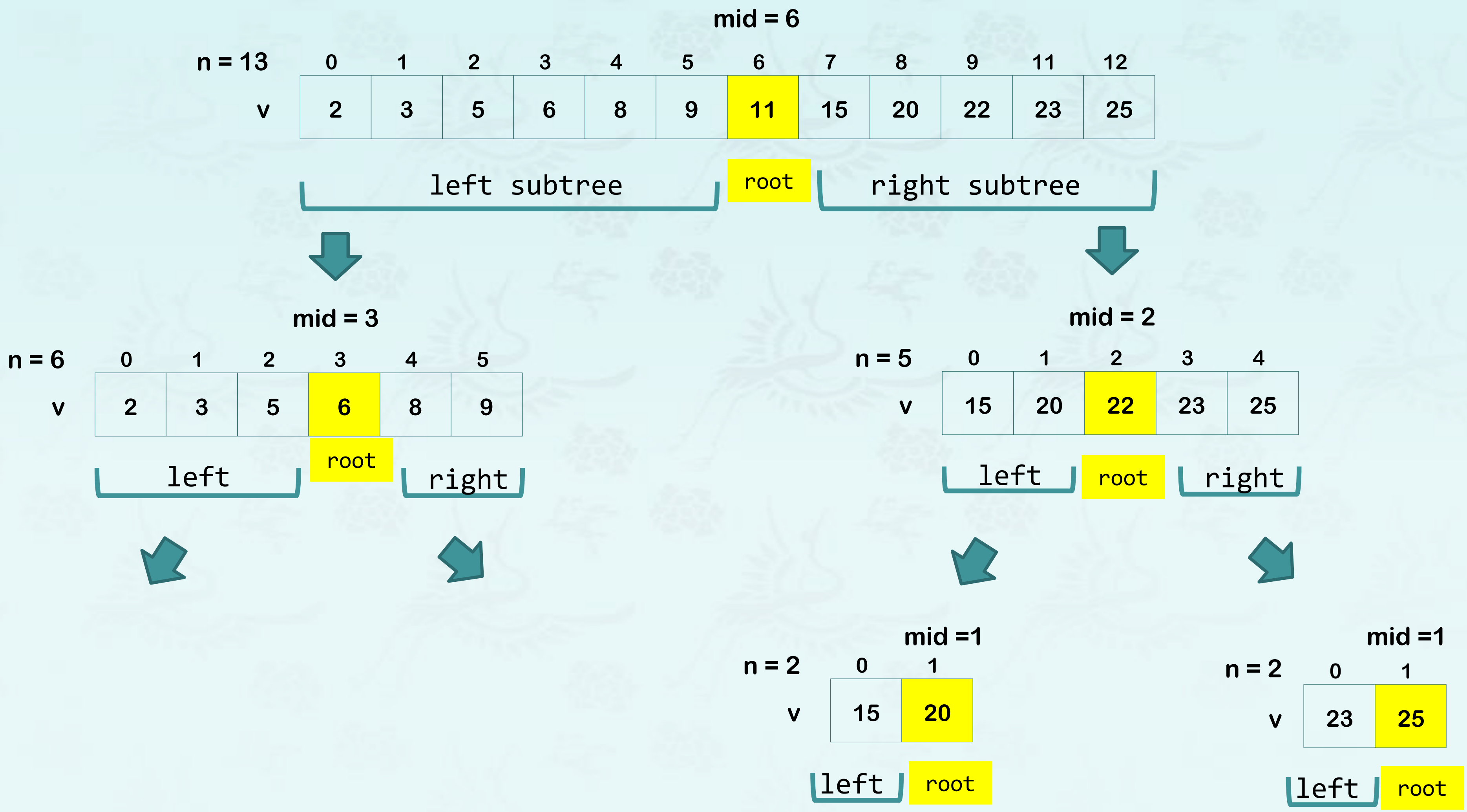
left | root | right

mid = 2

n = 5	0	1	2	3	4
v	15	20	22	23	25

left | root | right

Building AVL tree from BST in O(n)



Building AVL tree from BST in O(n)

mid = 6

n = 13	0	1	2	3	4	5	6	7	8	9	11	12
v	2	3	5	6	8	9	**11**	15	20	22	23	25

left subtree | root | right subtree

mid = 3

n = 6	0	1	2	3	4	5
v	2	3	5	**6**	8	9

left | root | right

mid = 2

n = 5	0	1	2	3	4
v	15	20	**22**	23	25

left | root | right

mid =1

n = 2	0	1
v	15	**20**

left | root

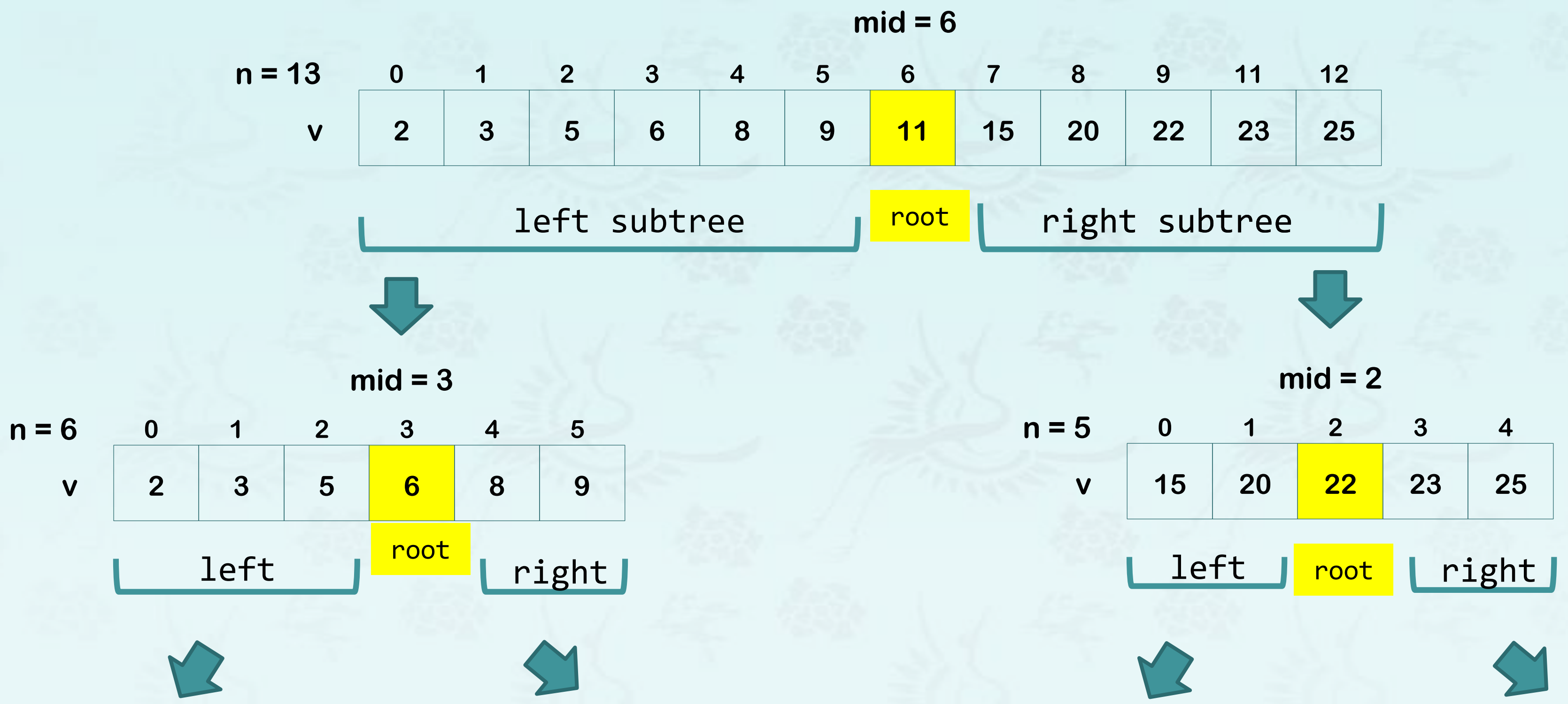
mid =1

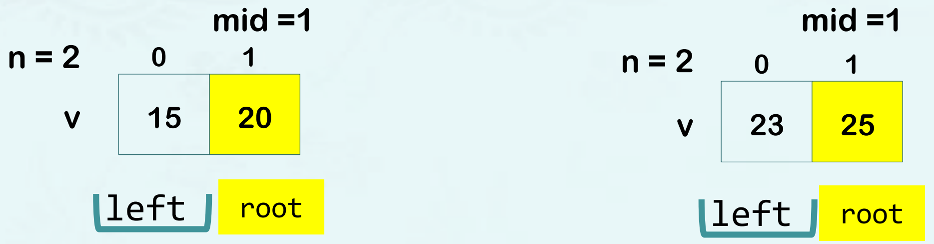
n = 2	0	1
v	23	**25**

left | root

What is the time complexity of this algorithm?

Building AVL tree from BST in O(n)





What is the time complexity of this algorithm?
O(n)
How is it possible?

RebalanceTree() reconstructs AVL from BST in O(n)

```
// reconstructs a new AVL tree from BST in O(n).
tree rebalanceTree(tree root) {
  if (root == nullptr) return nullptr;

  // you may use inorder() to get an array of keys or nodes
  // if you use an array of nodes, you just reconstructs AVL tree using nodes.
  // if you use an array of keys, the root should be cleared (or deallocated)

  // your code here                   // O(n)

  return buildAVL(v.data(), v.size()); // O(n)
}
```

mid = 6

n = 13	0	1	2	3	4	5	6	7	8	9	11	12
v	2	3	5	6	8	9	11	15	20	22	23	25

left subtree   root   right subtree

RebalanceTree() reconstructs AVL from BST in O(n)

```
tree rebalanceTree(tree node) {     // may need a better solution here
  if (node == nullptr) return nullptr;

  while (!isAVL(node))               // O(n) ~ O(n log n)
    node = _rebalanceTree(node);    // log(n)

  return node;
} // this algorithm needs to be improved.
```

invokes rebalance() recursively for left and right subtrees