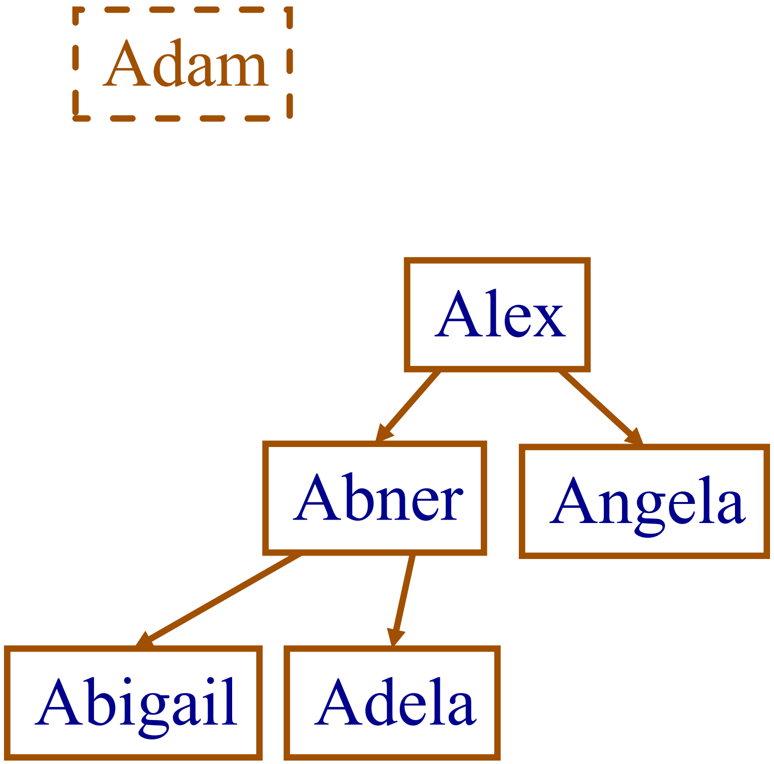
# CS 261 – Data Structures

AVL Trees

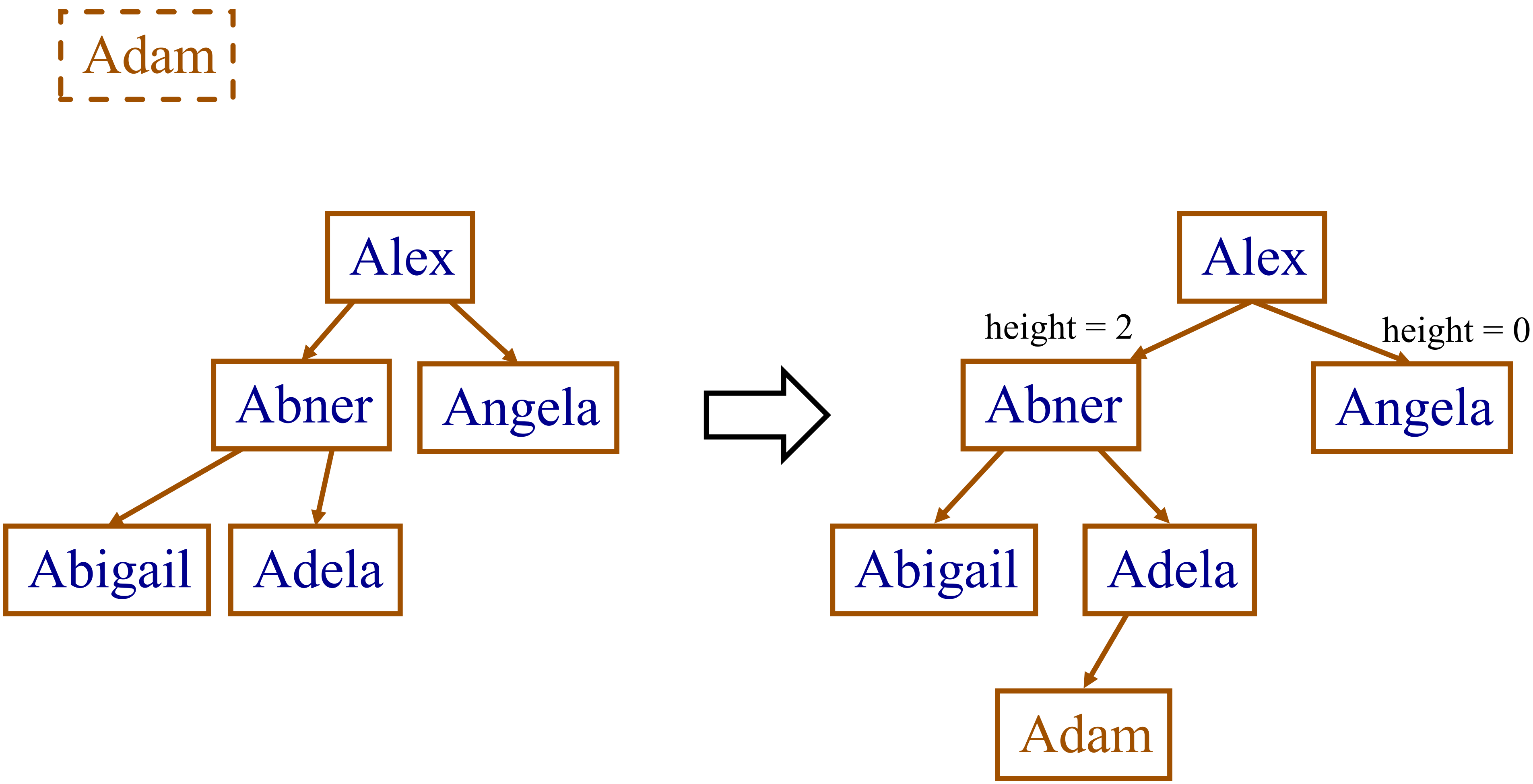
# AVL Implementation

```
struct AVLNode {
  TYPE            val;
  struct AVLNode *left;
  struct AVLNode *rght;
  int             hght;  /* Height of node*/
};
```

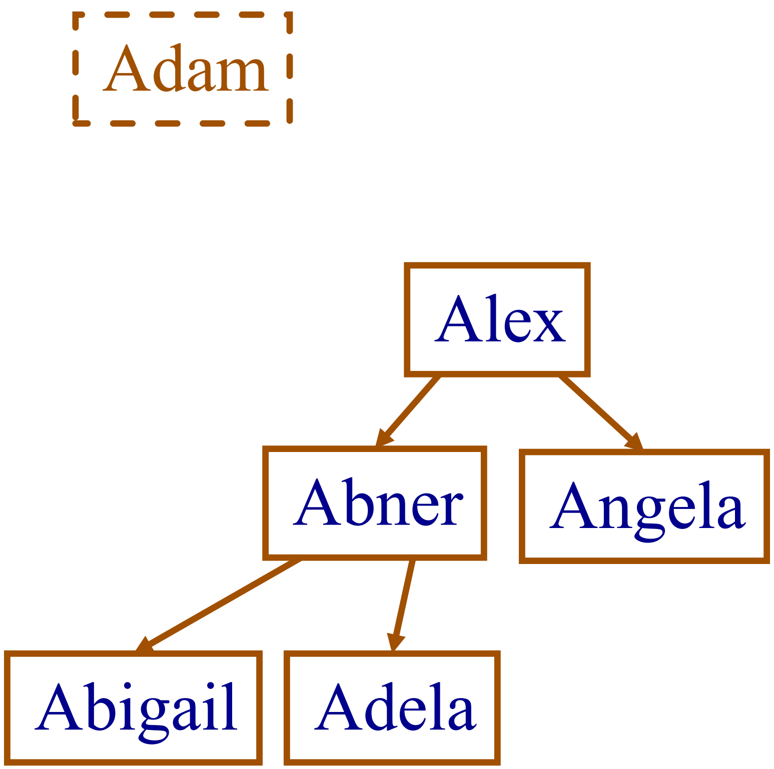
# Add

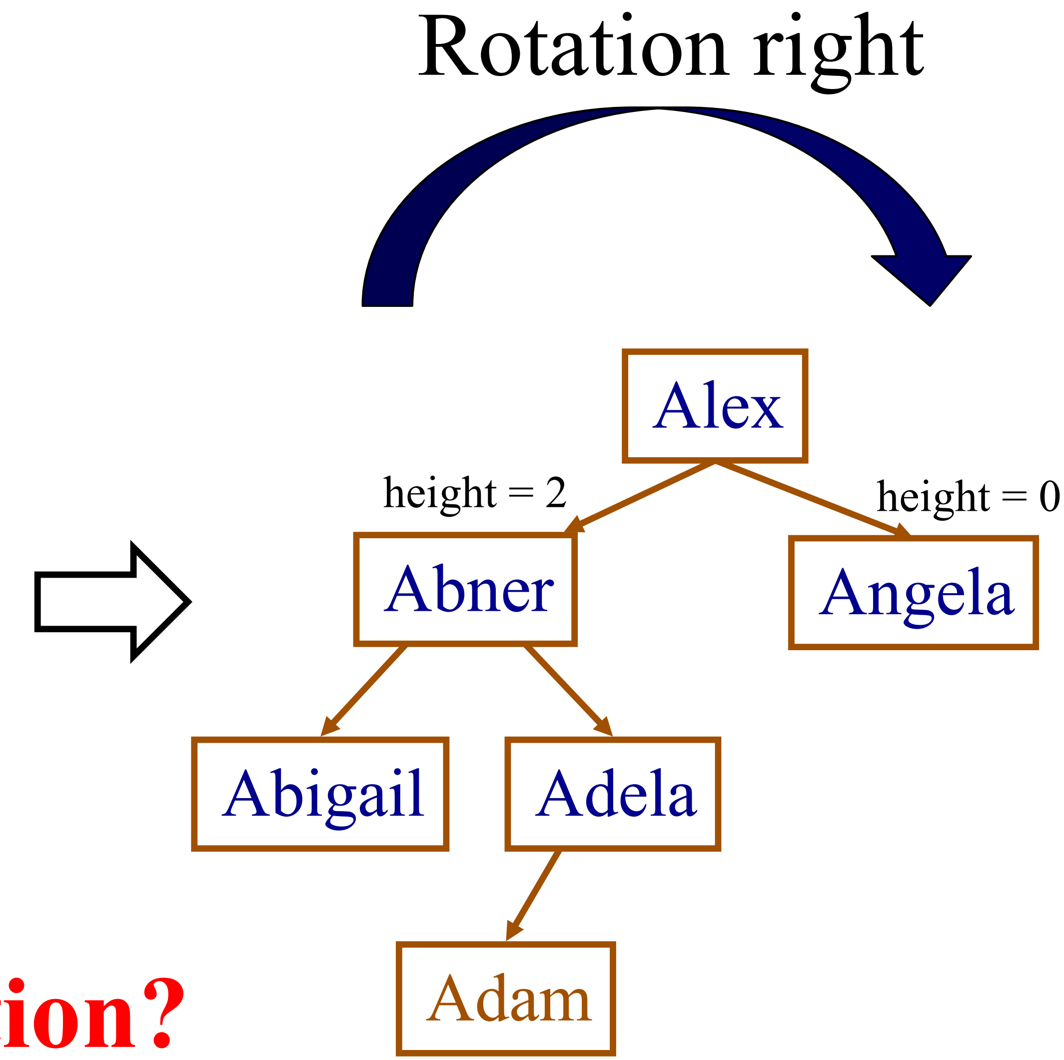


# Add – Insert at the Leaf Level



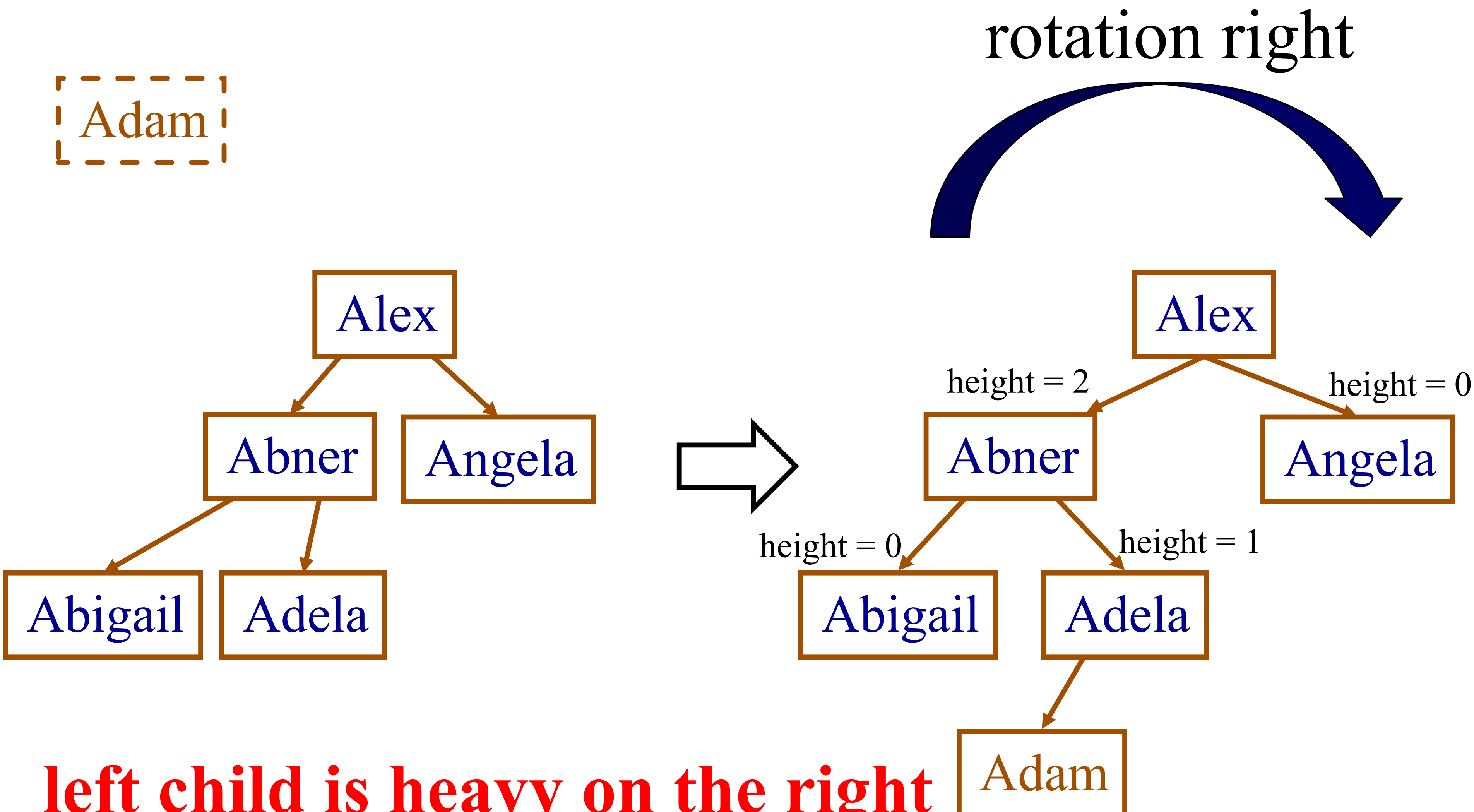
# Add – Insert at the Leaf Level



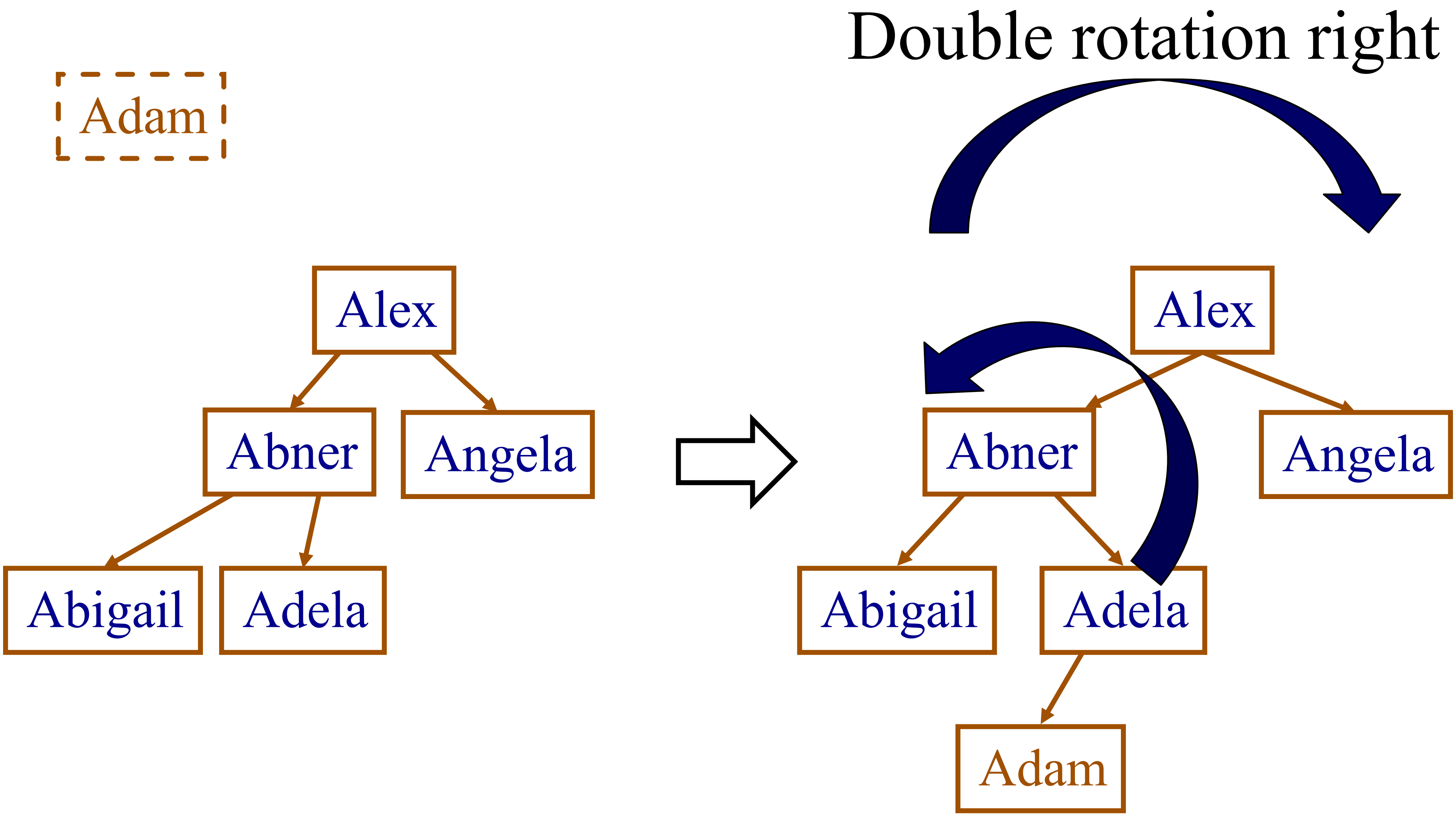

**Is it double rotation?**

# Add – Insert at the Leaf Level

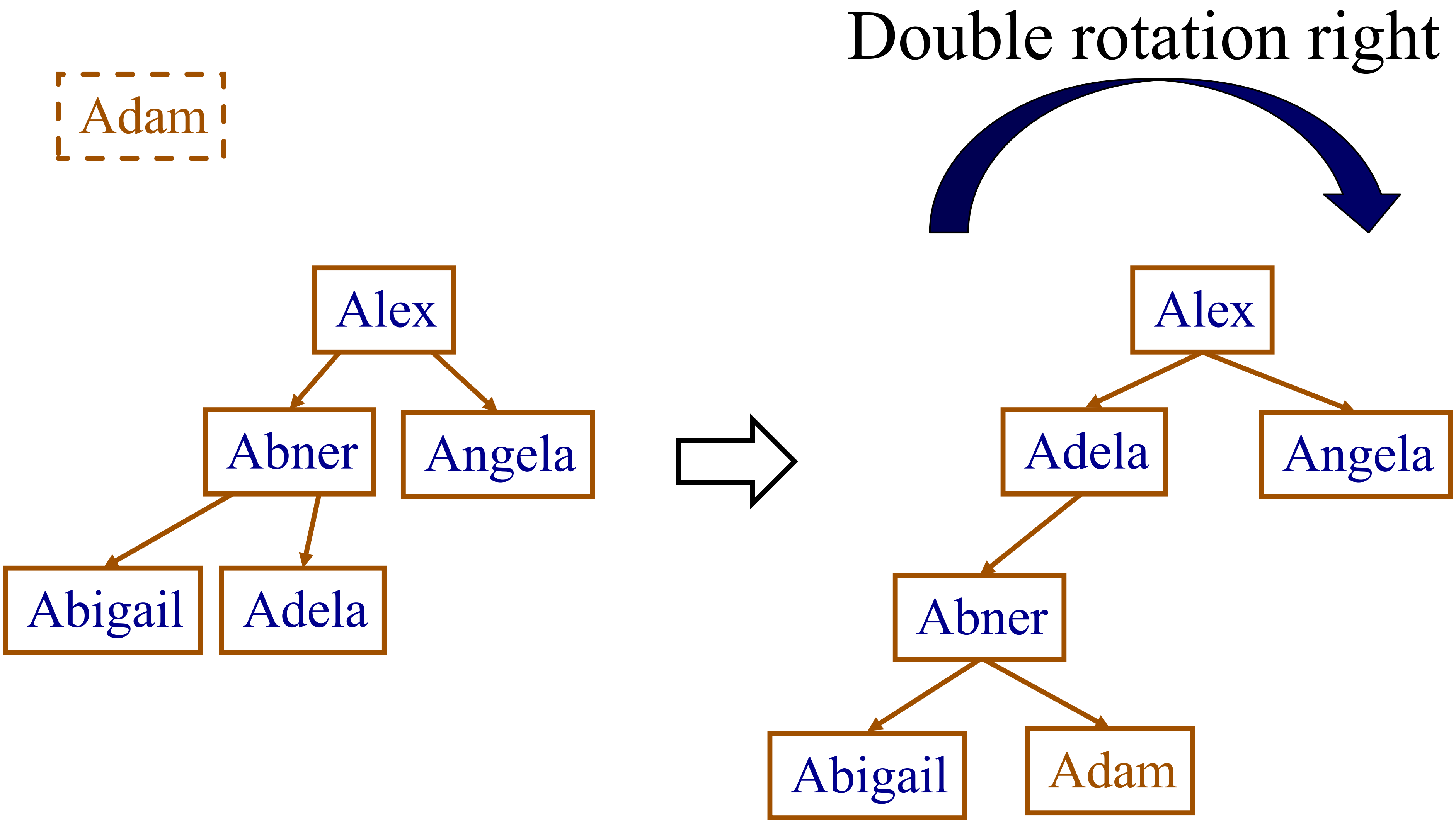



**left child is heavy on the right**

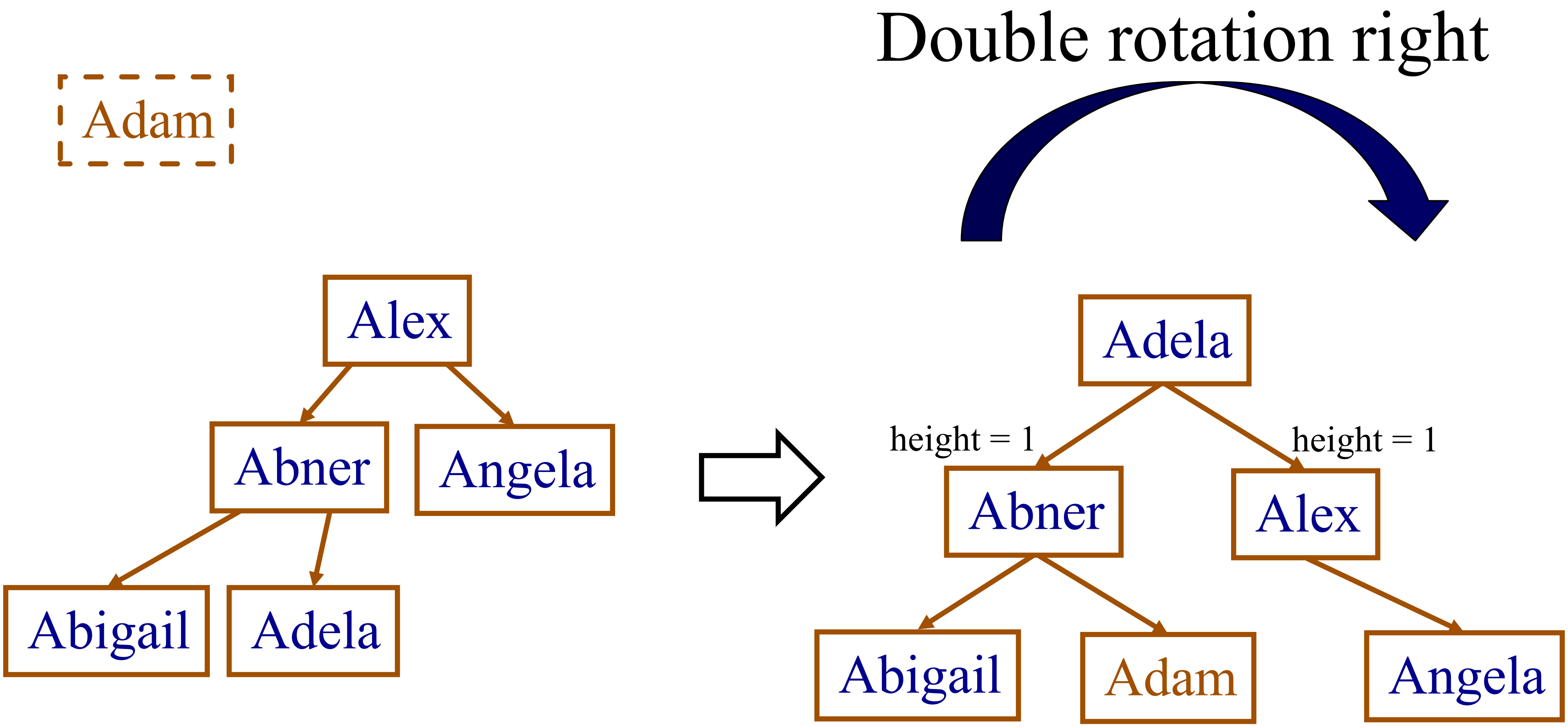
# Add – Insert at the Leaf Level



# Add – Insert at the Leaf Level



# Add – Insert at the Leaf Level



# Add – Recursive Function

```
struct AVLNode *_addAVLNode(struct AVLNode* current, TYPE e){
  ...
   if (current == 0) {/* stop recursion */
     ...
     /*allocate memory for newnode; add newnode to tree*/
     return newnode;
   }
   else {

     /* recursively move down the tree */

   }
   return     /* ???? */;
}
```

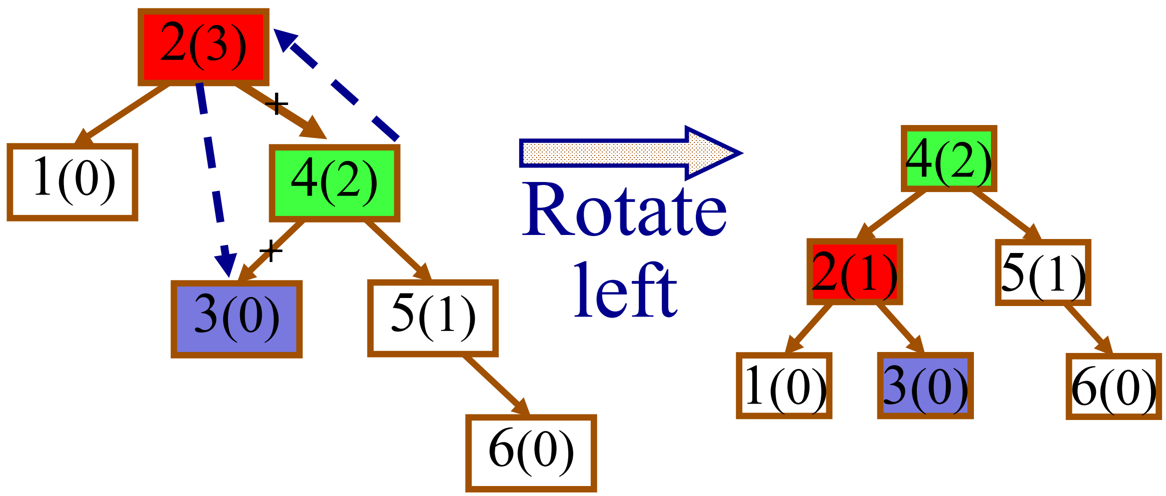
# Add – Recursive Function

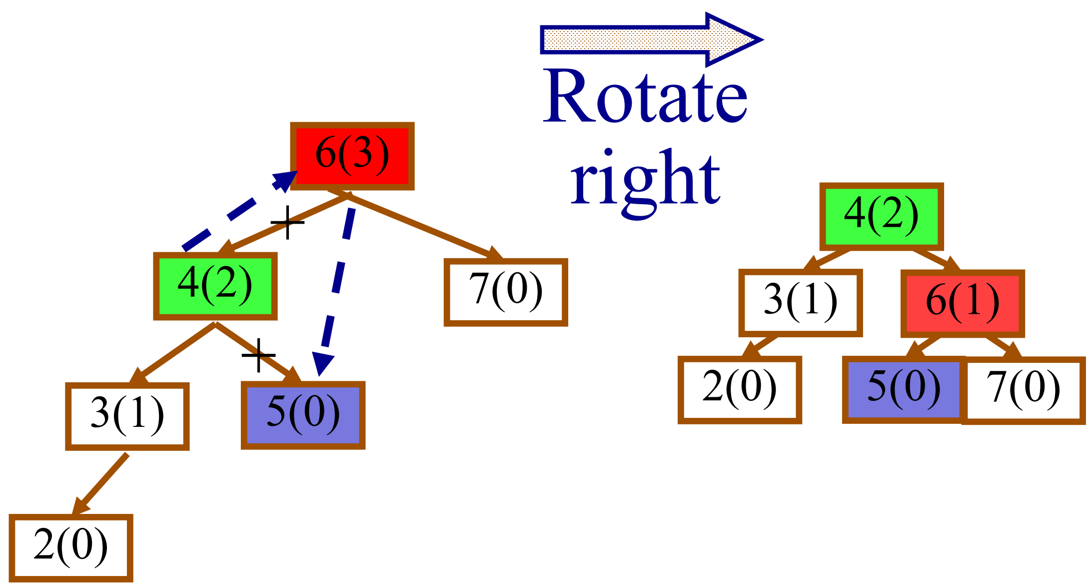
```
struct AVLNode *_addAVLNode(struct AVLNode* current, TYPE e){
  ...
   if (current == 0) {/* stop recursion */
     ...
     /*allocate memory for newnode; add newnode to tree*/
     return newnode; /* why not call balance() here? */
   }
   else {

     /* recursively move down the tree */

   }
   return balance(current);
}
```

# Add – Recursive Function

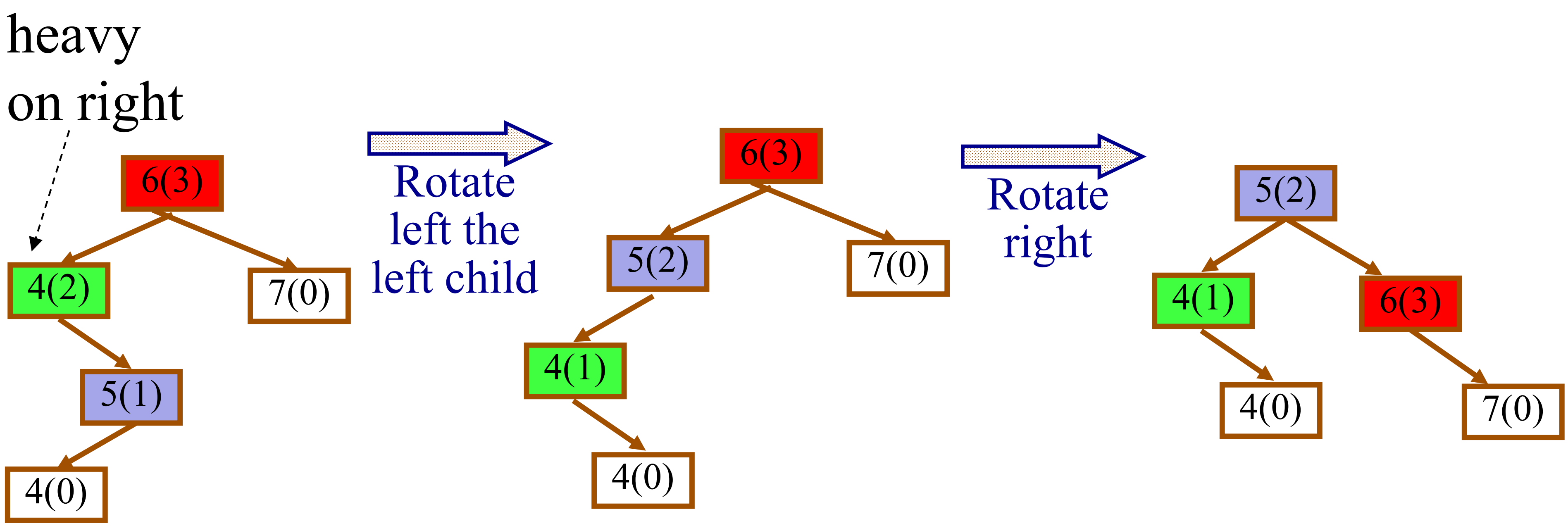
```
struct AVLNode *_addAVLNode(struct AVLNode* current, TYPE e){
  ...
   if (current == 0) {/* stop recursion */
     ... /*allocate memory for newnode; add newnode to tree*/
     return newnode;
   }
   else {/* recursively move down the tree */
      if( LT(e, current->value) )
        current->left = _addAVLNode(current->left, e);
      else
        current->right = _addAVLNode(current->right, e);
   }
   return balance(current);
}
```

# Rotation


2(3)
+
1(0)
4(2)
+
3(0)
5(1)
6(0)
Rotate left
4(2)
2(1)
5(1)
1(0)
3(0)
6(0)


Rotate right
6(3)
+
4(2)
7(0)
+
3(1)
5(0)
2(0)
4(2)
3(1)
6(1)
2(0)
5(0)
7(0)

# Double Rotation



# Balance

```
struct AVLNode * balance (struct AVLNode * current){
   int rotation = _height(current->right)
                        -  _height(current->left);

   if (rotation < -1) {
      /* (double) rotation right */
   } else if (rotation > 1) {
      /* (double) rotation left */
   }
   _setHeight(current);
   return current;
}
```

# Balance – (Double) Rotation Right

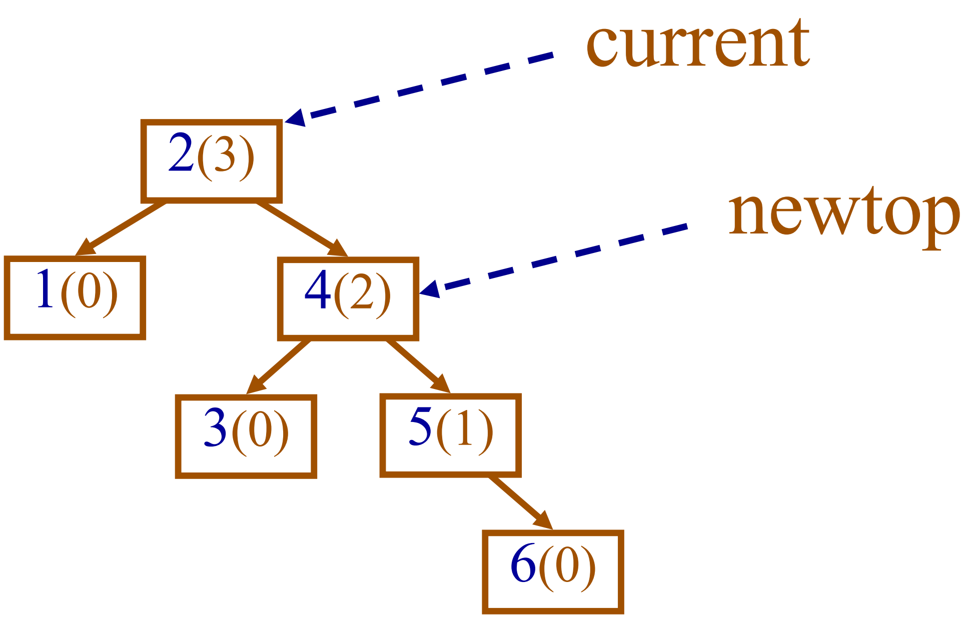
```
...

if (rotation < -1) { /* (double) rotation right */
  int drotation = _height(current->left->right)
                      -   _height(current->left->left);

  if (drotation > 0){ /* double rotation */

      /* left child is heavy on the right */

      current->left = _rotateLeft(current->left);

  }

  return _rotateRight(current);

}

else { ...
```

# Balance – (Double) Rotation Left

```
...
}else if (rotation > 1) { /* (double) rotation left */
   int drotation = _height(current->right->right)
                    -  _height(current->right->left);
   if (drotation < 0) {/* double rotation */
     /* right child is heavy on the left */
     current->right = _rotateRight(current->right);
   }
   return _rotateLeft(current);
} ...
```

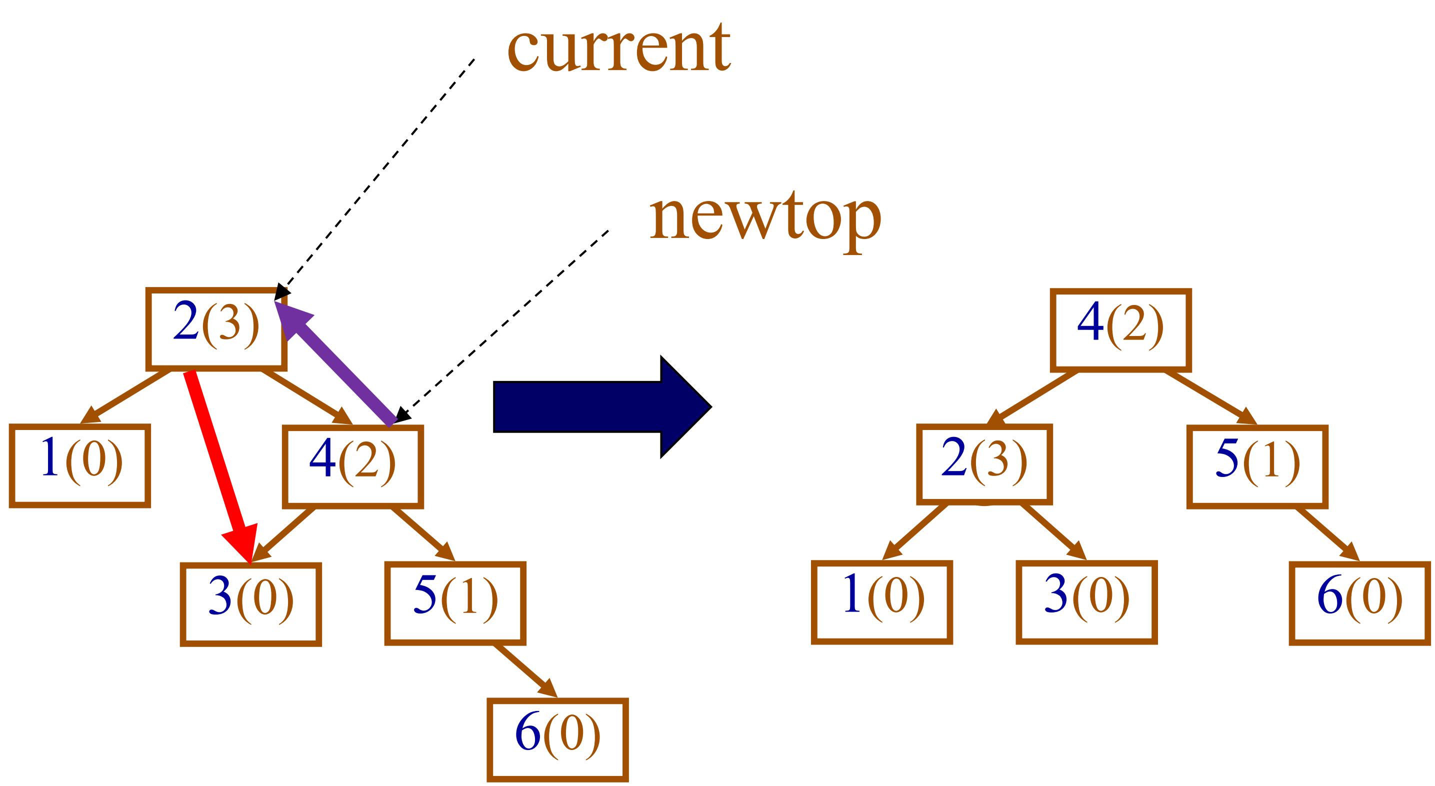
# Rotation Left

```
struct AVLNode * _rotateLeft (struct AVLNode * current){
   struct AVLNode * newtop = current->right;
   ...








}
```



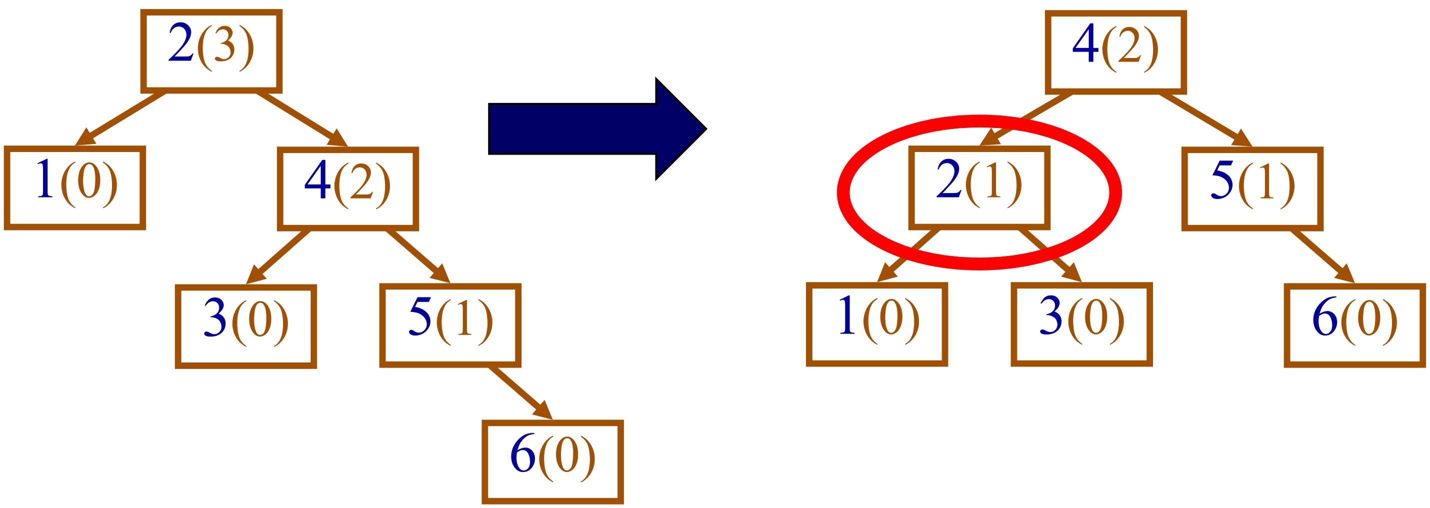
# Rotation Left

```
struct AVLNode * _rotateLeft (struct AVLNode * current){
    struct AVLNode * newtop = current->right;
    current->right = newtop->left;
    newtop->left = current;
    ...



}
```



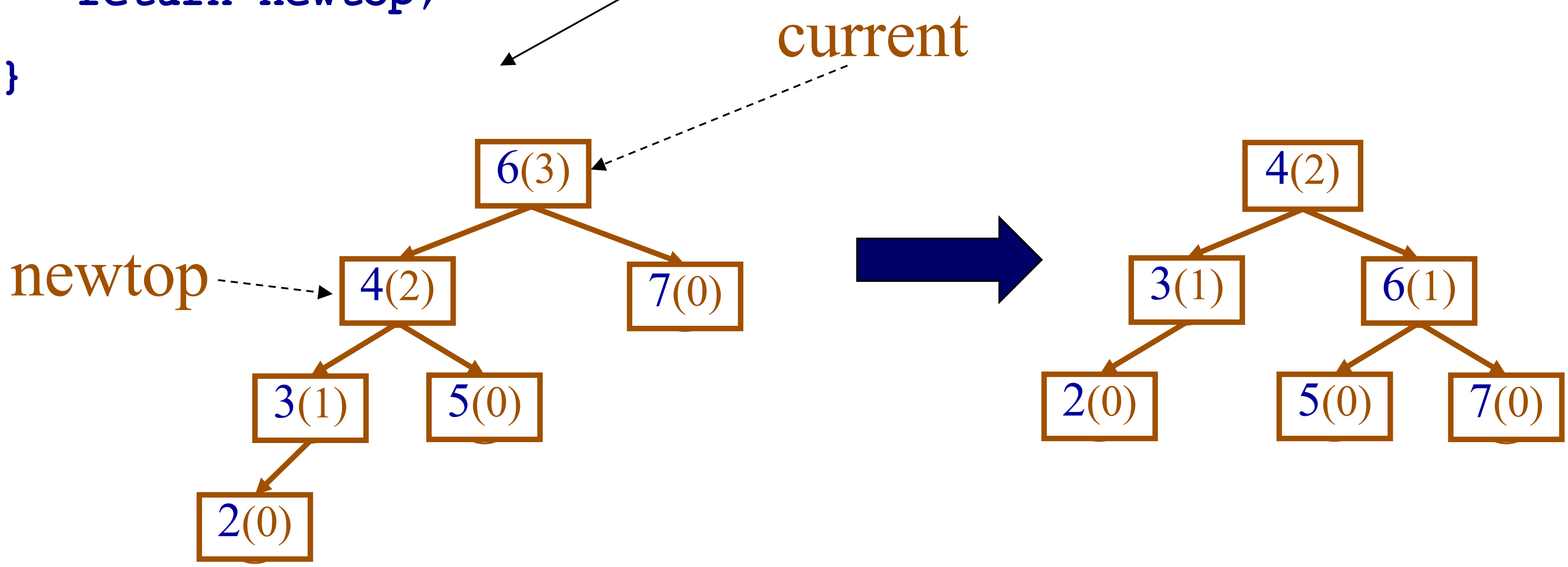
# Rotation Left

```
struct AVLNode * _rotateLeft (struct AVLNode * current){
    struct AVLNode * newtop = current->right;
    current->right = newtop->left;
    newtop->left = current;
    _setHeight(current);
    _setHeight(newtop);
    return newtop;
}
```



# Rotation Right

```
struct AVLNode * _rotateRight (struct AVLNode * current){
    struct AVLNode * newtop = current->left;
    current->left = newtop->right;
    newtop->right = current;
    _setHeight(current);
    _setHeight(newtop);
    return newtop;
}
```

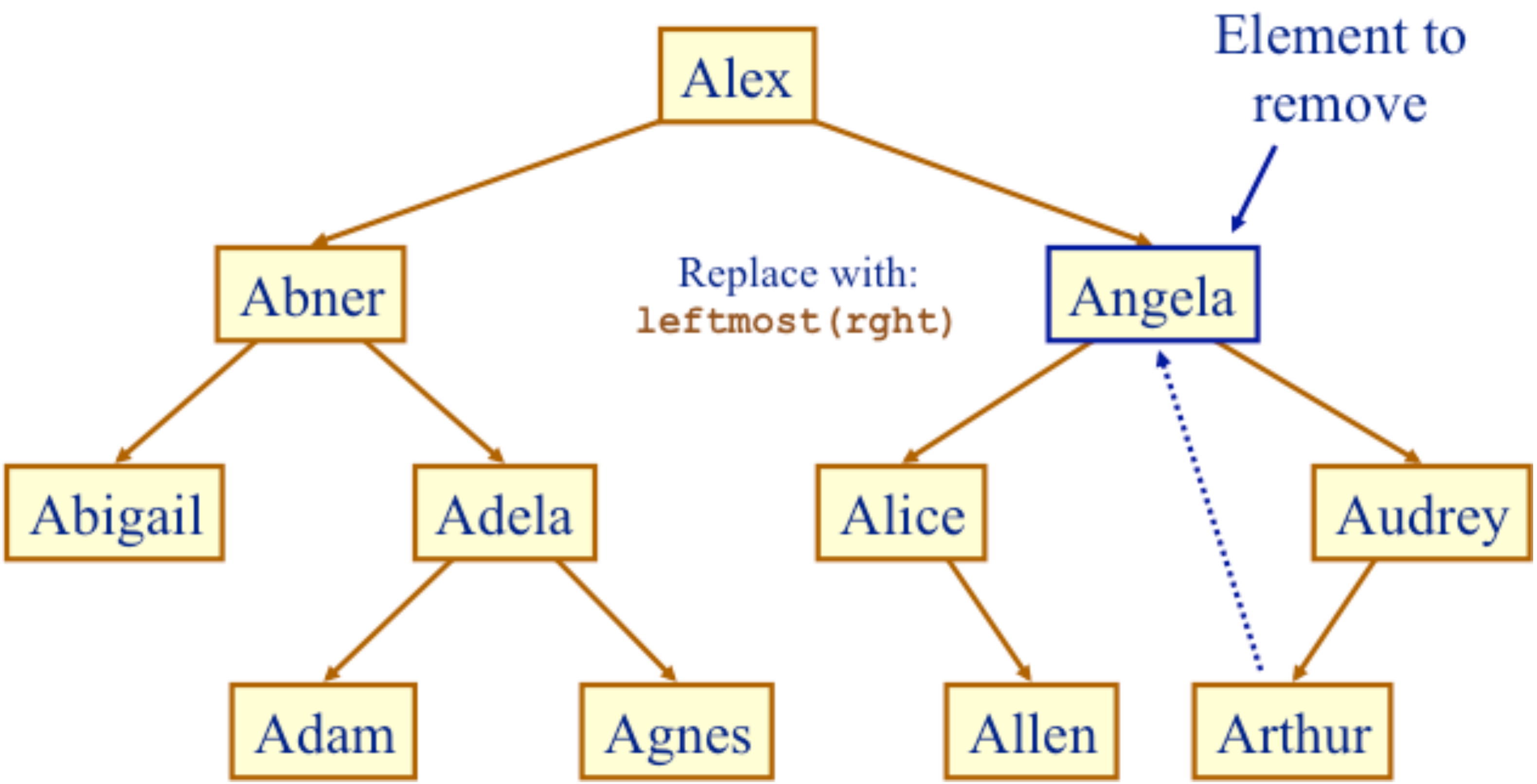


# Remove: Who fills the hole in the tree?

Answer:

**the leftmost child of the right child**

(smallest element in right subtree)



# Remove

```
void removeAVLTree(struct AVLTree *tree, TYPE val) {
   if (containsAVLTree(tree, val)) {
      tree->root = _removeNode(tree->root, val);
      tree->cnt--;
   }
}
```

# Remove

```
struct AVLNode *_removeNode(struct AVLNode *current, TYPE e)
{
   struct AVLNode *temp;
   assert(current);
   if(EQ(e, current->val)){
      /* replace current with the leftmost descendant
               of the right child */
   }
   else if(LT(e, current->val))
      current->left  = _removeNode(current->left, e);
   else
      current->rght = _removeNode(current->rght, e);

   return balance(current);
}
```

# AVL Trees: Sorting

- An AVL tree can sort a collection of values:

  1. Copy data into the AVL tree: O(*??*)

  2. Copy them out using the ?? traversal: O(*??*)

# AVL Trees: Sorting

- An AVL tree can sort a collection of values:

  Copy data into the AVL tree:

  $O(n \log_2 n)$

  Copy them out using the in-order traversal:

  $O(n)$

# AVL Trees: Sorting

- Execution time → O($n$ log $n$):
  - Matches that of quick sort in benchmarks
  - Unlike quick sort, AVL trees don't have problems if data is already sorted or almost sorted (which degrades quick sort to O($n^2$))

- However, requires extra storage to maintain both the original data buffer (e.g., a **`DynArr`**) and the tree structure