

The following materials have been collected from the numerous sources including my own and my students over the years of teaching and experiences of programming. Please help me to keep this tutorial up-to-date by reporting any issues or questions. Please send any comments or criticisms to idebtor@gmail.com. Your assistances and comments will be appreciated.

Lab on BST

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Introduction

This problem set consists of three sets of problems but they are closely related each other. Your task is to complete functions to handle a binary tree(BT), the binary search tree(BST), and AVL tree in `tree.cpp`, which allow the user test the binary search tree interactively. The following files are provided.

- **treeDriver.cpp** : tests BT/BST/AVL tree implementation interactively. don't change this file.
- **tree.cpp** : provided it as a skeleton code for your BST/AVL tree implementations.
- `treenode.h` : defines the basic tree structure, and the key data type
- `tree.h` : defines ADTs for BT, BST and AVL tree. don't change this file
- `treeprint.cpp` : draws the tree on console
- `treex.exe` : provided it as a sample solution for your reference.

Your program is supposed to work like `treex.exe` provided. I expect that your `tree.cpp` must be compatible with `tree.h` and `treeDriver.cpp`. Therefore, you don't change signatures and return types of the functions in `tree.h` and `tree.cpp` files.

The function **build_tree_by_args()** in `treeDriver.cpp` gets the command arguments and builds a **BT, BST or AVL** tree as shown above. If no argument for tree is provided, it begins with BT by default.

```

Windows PowerShell
PS C:\GitHub\nowicx\psets\pset09-10tree> ./treex -b 1 2 3 4

  1
 / \
2   3
/
4

Menu [BT] size:4 height:2 min:1 max:4
g - grow          a - grow a leaf [BT]
t - trim*         d - trim a leaf [BT]
G - grow N        A - grow by Level [BT]
T - trim N        f - find node [BT]
o - BST or AVL?   p - find path&back [BT]
r - rebalance tree** l - traverse [BT]
L - LCA*          B - LCA* [BT]
m - menu [BST]/[AVL]** C - convert BT to BST*
c - clear         s - show mode:[tree]
Command(q to quit):

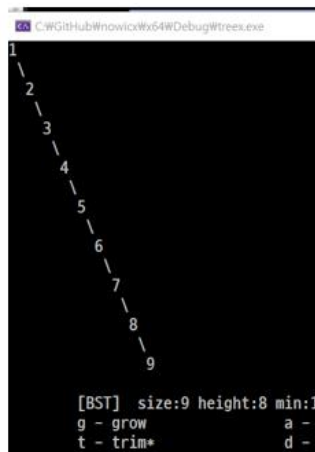
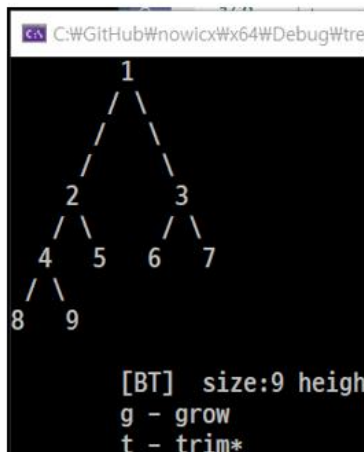
```

With the following three different options you can get three different trees created automatically at the beginning of the tree program execution.

./treex -b 1 2 3 4 5 6 7 8 9

./treex -s 1 2 3 4 5 6 7 8 9

./treex -a 1 2 3 4 5 6 7 8 9

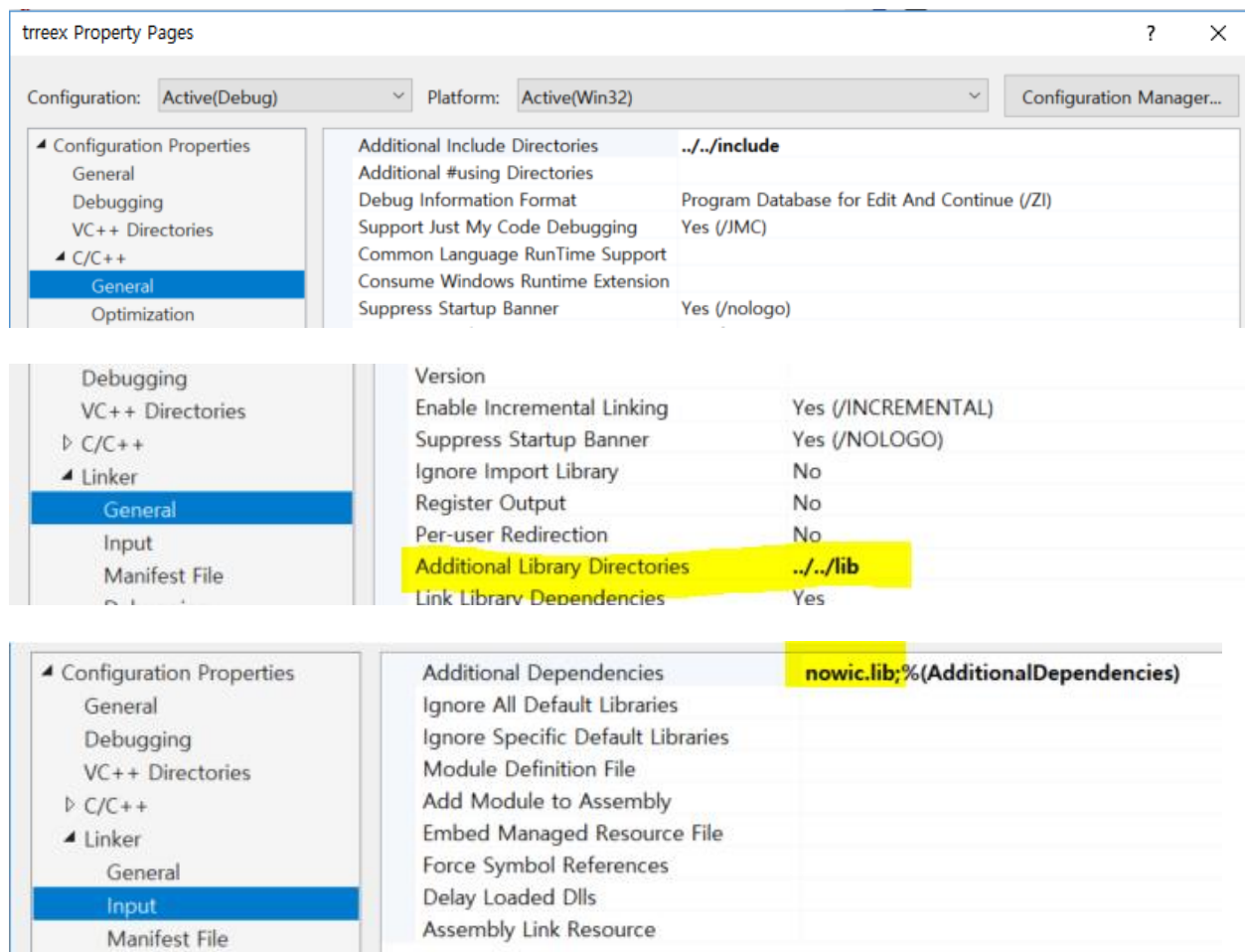


JumpStart

For a jump-start, create a project called tree first. As usual, do the following:

- Add ~/include at
 - Project Property → C/C++ → General → Additional Include Directories
- Add ~/lib at
 - Project Property → Linker → General → Additional Library Directories
- Add nowic.lib at
 - Project Property → Linker → Input → Additional Dependencies
- Add /D "DEBUG" at
 - Project Property → C/C++ → Command Line

In my case for example:

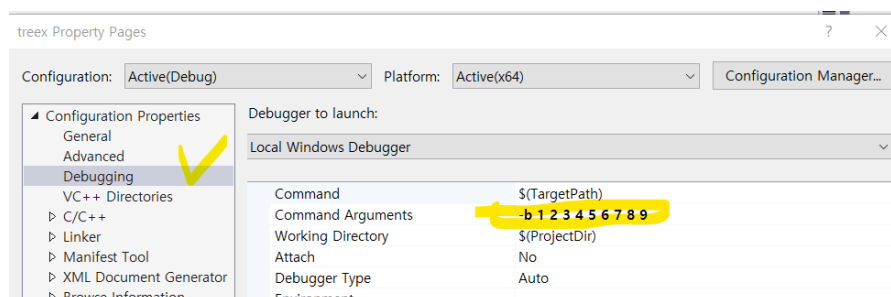


Add `~.h` files under Project 'Header Files' and `~.cpp` files under project 'Source Files'. Then you may be able to build the project.

Step 0: An easy way to create a tree for debugging

Quite often we want to create a same tree every time for debugging purpose initially. To have a tree to begin with, you may specify the initial keys for the tree in

Project Properties → Debugging → Command Argument



Step 2.1: Binary search tree operations:

There are a few additional functions for BST. You check and code them if not working

- `pred()`, `succ()` – returns predecessor node and successor node of a tree.
- `isBST()` – returns true if the tree is a binary search tree, otherwise false.
- `minimum()`, `maximum()`
- `contains()`
- `find()`

Step 2.2: `grow()` & `trim()`

In this step, implement the basic functions `grow()` and `trim()`. Since we covered `grow()` during class, let us go the `trim()` function once more. The trim (or delete) operation on binary search tree is more complicated than insertion (or grow) and search. Basically, it can be divided into two stages:

- Search for a node to remove **recursively**; for example:

```
if (key < node->key)
    node->left = trim(node->left, key);
```
- Eventually, this **`node->left`** will be set by the return value when **`trim(node->left, key)`** is done.
- If the node is found, run trim algorithm **recursively**.

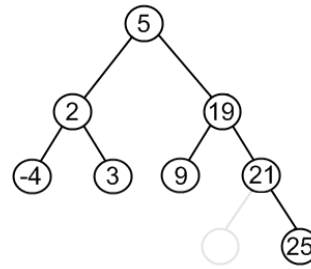
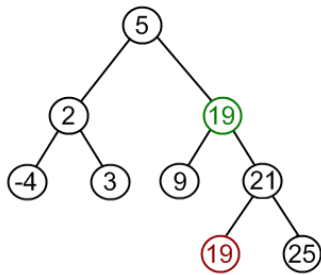
When we trim a node, three possible cases arise. Once it trims the node, it must return `nullptr` (if it is a leaf) or the node that is replaced by. This returned pointer is eventually set to either **`key->left`** or **`key->right`** of the parent node, as in **`node->left = trim(node->left, key);`**

- Node to trim is leaf (or has no children):
 - Simply remove from the tree. Algorithm sets corresponding link of the parent to **`nullptr`** and disposes the node. **Therefore, it returns `nullptr`.**
- Node to trim has only one child:
 - Copy the node to a temp node.
 - Set the node to the child.
 - Free the temp node (or the original node to be trimmed).
 - Recursive `trim()` links this child (with it's subtree) directly to the parent of the removed node. **This is done by returning this child (node).**
- Node to trim has two children:
 - Get heights of two subtrees to determine which one use, either predecessor or successor, (Read "Note" at the end of this section for detail.)
 - Copy the key value of the **successor or predecessor** to the node.
 - Call **`trim("Node to trim"s right child, succ()'s key)`** if the successor was chosen.
 - Call **`trim("Node to trim"s left child, pred()'s key)`** if the predecessor was chosen.

Example: Remove 12 from a BST.



1. Find successor (since the right subtree is higher than that of the left subtree) of the node to be trimmed. In current example it is 19.
2. Replace 12 with 19. Notice, that only values are replaced, not nodes.
Now we have two nodes with the same value.



3. Remove the original node 19 from the left subtree by calling **trim()** recursively. What will be input parameters to delete the node 19? Of course, the key should be 19 which is successor.
How about the node to pass? It should be **node→right**.
 This step may be done simply calling another trim(): node→right = trim(node→right, 19);

Note: Which one to use, Successor or Predecessor?

Once you make the trim option successfully using the successor of the node, now you are ready to improve it. When you keep on deleting a node using the successor, the tree tends to be skewed since the node will be trimmed from the right subtree.

You must make your **trim()** function such that it checks the heights of the left subtree and right subtree and decide whether you use either the predecessor or the successor in your trim operation to balance the tree if possible.

Step 2.3: growN() & trimN()

It performs a user specified number of insertion(or grow) or deletion(or trim) of nodes in the tree. The growN() function which is provided for your reference inserts a user specified number N of nodes in the tree. If it is an empty tree, the value of keys to add ranges from 0 to N-1. If there are some existing nodes in the tree, the value of keys to add ranges from max + 1 to max + 1 + N, where max is the maximum value of keys in the tree.

Implement the trimN() function which deletes a user specified number N of nodes in the tree. The nodes to trim are randomly selected from the tree. Therefore, we need to get the keys from the tree since they are not necessarily consecutive. For example, key values in a tree can be 5, 6, 10, 20, 3, 30.

If **a user specified number N** of nodes to trim is less than the **tree size (which is not N)**, you just trim N nodes. If the N is larger than the tree size, set it to the tree size. At any case, you should trim all nodes one by one, but randomly. You may have your own implementation, but here is a suggestion:

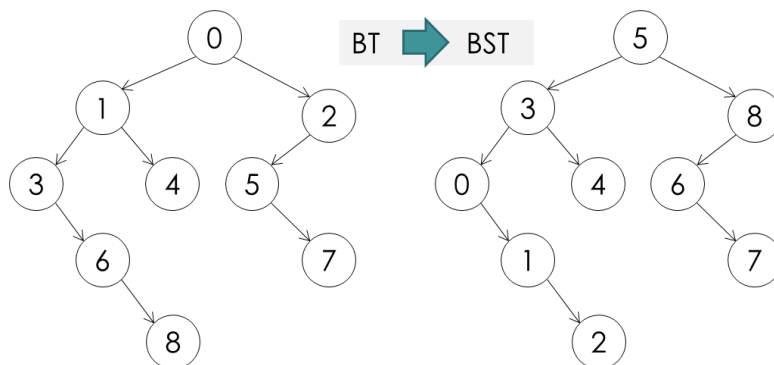
- Step 1:
 1. Get a list of **all keys** from the tree first.
 2. Invoke **inorder()** to fill a vector with keys in the tree.
(Use a vector object in C++ **to store all keys**. The vector size grows as needed.)
 3. Get **the size of the tree** using size()
 4. Compare the tree size and the vector size returned from inorder() for checking.
- Step 2:
 1. Shuffle the vector with keys. – shuffle()
 2. If you don't take this step, you end up deleting nodes sequentially from the root of the tree which is not our intention.
- Step 3:
 1. Invoke **trim()** **N times** with a key from the array in sequence. Recall that, Inside a for loop, **trim()** may return a new root of the tree.

Hint: How to get all the keys in a tree.

Use one of tree traversal functions that returns keys in a vector from the tree. You may take a look into a function called `inorder()` in `tree.cpp`.

Step 2.4: Convert BT to BST in place

In this step, we want to convert a binary tree to a binary search tree while keeping its tree structure as it is. An example is shown below:



Algorithm: Use either **vector** or **set** in **STL**, not an array, **because of a pedagogical purpose**.

- Step 1 – store keys of a binary tree into a container (vector or set in STL).
- Step 2 – sort the vector using any sorting technique. STL set is already sorted.
- Step 3 – Now, do the inorder traversal of the tree and copy the elements from the container to the nodes of the tree one by one.

Submitting your solution

- Include the following line at the top of your every source file with your name signed.
- On my honour, I pledge that I have neither received nor provided improper assistance in the completion of this assignment.
- Signed: _____ Student Number: _____
- Make sure your code **compiles** and **runs** right before you submit it.
- If you only manage to work out the problem partially before the deadline, you still need to turn it in. However, don't turn it in if it does not compile and run.
- Place your source files in the folder you and I are sharing.
- After submitting, if you realize one of your programs is flawed, you may fix it and submit again as long as it is **before the deadline**. You may submit as often as you like. **Only the last version** you submit before the deadline will be graded.

Files to submit

- Lab10 for BST - tree.cpp - 2.1 ~ 2.4

References

1. [Recursion](#) :
2. [Recursion](#):