ECE368 Programming Assignment (PA) #1

First Deadline: Friday, June 26, 2020 at 11:59 PM

Important: By submitting your code, you certify that the work is your own and that you have not copied the code of any other student (past or current) while completing it. Code will be checked with a plagiarism checker and any failure to honor these requirements will be subject to disciplinary action as outlined in the course policy.

First submission: 5 points for your code → 5% of the final grade.
The next part of this assignment will include a peer review for the other 5 points of this programming assignment for a total of 10 points → 10% of the final grade.
The final (optional) deadline will be for resubmitting your code along with a Bug Report and Correction (BRAC) document for the possibility of earning back points for your code.

You are required to implement a program to construct a height-balanced binary search tree (BST), starting from an empty tree, based on a sequence of insertion and deletion operations. You may have to perform rotation(s) to maintain a height-balanced tree after each insertion or deletion. Note that a height-balanced tree is defined as we covered in the class. Given a node, its balance is the height of its left subtree minus the height of its right subtree. A tree is height-balanced when every node in the tree has a balance that is -1, 0, or 1. As in the class, we will define the height of a tree recursively. An empty tree has a height of -1. The height of a tree is 1 plus the maximum of the height of the left sub-tree and the height of the right sub-tree.

It is fine for you to use the code provided in the lecture notes for this assignment. However, you should re-organize the code. For example, you may want to write separate functions for clockwise rotation and counter-clockwise rotation, and the insertion function will call the appropriate rotation functions.

Insertion

In the lecture notes, we do not allow duplicate keys in a tree. In this assignment, **we allow the insertion of a duplicate key**. In other words, the resulting height-balanced may have multiple nodes storing the same key value. Recall that insertion of a key requires you to search for a suitable location to insert a leaf node. To handle nodes storing the same key value, when you search for a leaf node location to insert the key, you should **always go left when you encounter a node storing the same key**. This requirement is imposed for the grading purpose of this assignment.

Deletion

When you are asked to delete a key, the tree should stay intact if the key is currently not in the tree. There may be multiple nodes containing the key that you want to delete. You should delete the first such node that you encounter in the search process.

If the node you want to delete has two children, you should replace that node with its **immediate predecessor (in an in-order traversal of the tree)**. Again, this requirement is imposed for the grading purpose of this assignment.

Deliverables

In this assignment, you are required to develop your own include file(s) and source file(s), which can be compiled with the following command:

```
gcc -std=c99 -pedantic -Wvla -Wall -Wshadow -O3 *.c -o pa1
```

Your "main" should be in a file called pa1.c. It is recommended that while you are developing your program, you use the "`-g`" flag instead of the "`-O3`" flag for compilation so that you can use a debugger if necessary.

There are two options the executable pa1 can accept. The main function should simply return `EXIT_FAILURE` if the argument count is incorrect or the options are invalid (see further details below).

Option "`-b`": Building a height-balanced BST

```
./pa1 -b operations_input_file tree_output_file
```

The option "`-b`" means that you are building a height-balanced BST (starting from an empty tree) based on the operations specified in `operations_input_file`.

Input file format

The `operations_input_file` is an input file in binary format. Every operation is specified by `(sizeof(int) + sizeof(char))` bytes, with the first `sizeof(int)` bytes being an `int` and the next `sizeof(char)` byte being a `char`. The `int` is the key. The `char` is the operation. If it is an insertion of the specified key, the `char` is an ASCII character '`i`'. If it is a deletion of the specified key, the `char` is an ASCII character '`d`'.

If there are n keys to be inserted or deleted, the file size is `n`×`(sizeof(int)+sizeof(char))` bytes.

Output file format

The tree output file is an output file in binary format. This file stores the pre-order traversal of the constructed height-balanced BST. Each non-`NULL` node is represented by an `int` and a `char`. The `int` is of course the key stored in the node.

The `char` is a binary pattern, with the least significant two bits capturing the types of branches that node has. At bit position 0 (the least significant bit position), a 0-bit means that the right branch of the node is `NULL`. A 1-bit means that the right branch of the node is a non-`NULL` node. At bit position 1 (the second least significant bit position), a 0-bit means that the left branch of the node is `NULL`. A 1-bit means that the left branch of the node is a non-`NULL`.

Therefore, a binary value of 2 or 3 means there is a left child. A binary value of 1 or 3 means that there is a right child. A binary value of 3 means that there is both a left and a right child.

Output and return value of `main` function

If the given input file can be opened, your program should attempt to build a height-balanced BST. If the given input file cannot be opened, the program should print the value -1 (using the format `"%d\n"`) to the `stdout` and return `EXIT_FAILURE`.

Now, suppose the given input file can be opened. If in the process of building the BST, your program encounter a problem in the input file (wrong format, for example) or a failure in memory allocation, you should still write to the output file the tree that has been contructed so far. You should print the value 0 (using the format `"%d\n"`) to the `stdout` and return `EXIT_FAILURE`. We will test your program with valid input files of reasonable sizes. Therefore, it is unlikely that you will have to print the value 0 to the `stdout`.

If you can successfully read the entire input file to build a tree, you should print the value 1 (using the format `"%d\n"`) to the `stdout` and return `EXIT_SUCCESS`; your program should return `EXIT_FAILURE` otherwise. We are not asking you to check whether you can write to the output file. We will use the option `"-e"` to evaluate that.

Option `"-e"`: Evaluating a height-balanced BST

```
./pa1 -e tree_input_file
```

The option `"-e"` means that you are evaluating a tree specified in the `tree_input_file`. The `tree_input_file` is actually of the same format as the output produced using the `"-b"` option. For the given `tree_input_file`, your program should print three integers to `stdout` using the format `"%d,%d,%d\n"`, where the first integer indicates the validity of the input file, the second integer indicates whether the tree is a BST, and the third integer indicates whether the tree is a height-balanced tree.

If the input file cannot be opened, the first integer should be -1. If it can be opened, but of the wrong format, the first integer should be 0. If it can be opened and is of the correct format, the first integer should be 1.

If the input file is a valid tree, the second and third integers are meaningful (otherwise, their values are not important). If the tree is a BST, the second integer is 1; otherwise, it is 0. If the tree is height-balanced, the third integer is 1; otherwise, it is 0.

The `main` function should return `EXIT_SUCCESS` only if the input file is valid (i.e., the first integer of the terminal output is 1); your program should return `EXIT_FAILURE` otherwise.

Electronic Submission

The project requires the submission (electronically) of the C-code (source and include files) through Brightspace. You should create and submit a zip file called pa1.zip, which contains the .h and .c files. Your zip file should not contain a folder.

zip pa1.zip *.c *.h

You should submit pa1.zip to Brightspace.

Grading

The assignment will be graded based on the two tasks performed by your program. The first task of constructing a height-balanced BST accounts for 3.5 points and the second task of evaluating a height-balanced BST accounts for 1.5 points.

It is important all the files that have been opened are closed and all the memory that have been allocated are freed before the program exits. Memory errors or any errors reported by `valgrind` will result in a 2.0-point penalty.

Preparing for Peer Review

Clear instructions will be given about the peer review process when that part of the assignment begins. Those who are peer reviewing your code will *not* be responsible for writing code you have missing or fixing all your bugs.

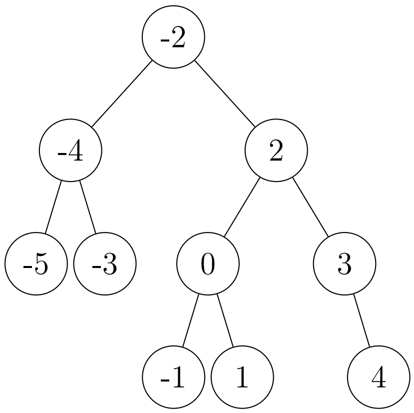
If you miss the first deadline, you automatically miss the peer review points, so turn in what you have even if it isn't working yet. **However, you should plan on having *all* the functions written by the first deadline even if not all your bugs are fixed yet.** During peer review, you will get to see some of your classmates' code. If it is apparent that you simply copied their way of completing the assignment to "fix" your own assignment, you will *not* be able to earn back your points with the BRAC and final submission.

In your first submission, use comments that being with `//PeerReview:...` to clearly mark and describe the areas you are having trouble with or the types of errors you are having. This will help the peer reviewer know where to start analyzing your code.

What you are given

You are given 4 sample input files (`ops0.b`, `ops1.b`, `ops2.b`, `ops3.b`) and the corresponding output files for the trees constructed (`tree0.b`, `tree1.b`, `tree2.b`, and `tree3.b`).

The `ops0.b` file inserts 10 ascending keys -5, -4, ..., 3, 4. The following figure shows the corresponding height-balanced BST in `tree0.b`.



The files `ops1.b` and `ops2.b` contain the same insertion operations and a deletion operation: delete 2. In `ops1.b`, the "delete 2" operation occurs after the insertion of 2. Therefore, the final tree contains only 9 keys. In `ops2.b`, the "delete 2" operation occurs before the insertion of 2. Therefore, the `tree2.b` and `tree0.b` are the same.

While `ops0.b`, `ops1.b`, and `ops2.b` involve the insertion of distinct keys, `ops3.b` file involves the insertion and deletion of duplicate keys.

Besides these height-balanced BSTs, we also provide you three invalid height-balanced BSTs (`invalidtree0.b`, `invalidtree1.b`, and `invalidtree2.b`). For `invalidtree0.b`, it is neither a BST nor a height-balanced tree (the corresponding print out to the screen should be 1,0,0 when evaluated with the `"-e"` option). For `invalidtree1.b`, it is not a BST, but it is a height-balanced tree (the corresponding screen dump is 1,0,1). For `invalidtree2.b`, it is a BST, but it is not a height-balanced tree (the corresponding screen dump is 1,1,0).

To help you interpret these binary files, we also provide you the "equivalent" text files (`ops0-3.txt`, `tree0-3.txt`, and `invalidtree0-2.txt`).

For an operations input file, each (`int`) key is printed with `"%d"` format. The key is followed by a space, and then the (`char`) operation ('`i`' for insertion and '`d`' for deletion).

For a tree file, each (`int`) key is again printed with `"%d"` format. The key is followed by a space, and then `char` '0' (the node has no children), '1' (the node has a right child and it has no left child), '2' (the node has no right child and it has a left child), or '3' (the node has a right child and a left child).

Additional information

You may want to write a program that allows you to convert from `tree0.b` to `tree0.txt` and a program that allows you to convert from `ops0.b` to `ops0.txt` (in fact, the two programs can be combined into one). Similarly, you may want to write a program that converts from `tree0.txt` (or `ops0.txt`) to `tree0.b` (or `ops0.b`). This way, you can easily create other examples (operations input files and tree files) to test your programs.

You should write the evaluation part first. This part allows you to test your construction part.(As a good practice, you think of how to evaluate/test your program before you write your program). There are two components of the evaluation (BST and height-balanceness), I recommend that you write the two components separately.

For the construction part, I suggest that you write the insertion routine (with rotations) first. However, try to write rotation operations as functions (that could be used by the deletion routine later on). Then, you write the deletion routine. It is easier to write the deletion as a recursive function because you may have to perform rotations all the way to the root node. A recursive routine makes it easier to keep track of all the nodes encountered in the process of searching for the deleted node. Otherwise, you should use a stack to keep track of the nodes encountered in the search process.

You should also write the deletion routine in such a way that the height-balancing part can be easily isolated such that if necessary, you could comment out the height-balancing part and the routine is simply doing a regular deletion of a key from a BST (without worrying about height-balancing). This could be helpful when it comes to debugging. Moreover, in the worst case scenario, you can also comment out this part and still have a somewhat functioning deletion routine in your final submission should you encounter problems in maintaining a height-balanced tree.

As you write the program, use the evaluation part to test your insertion and deletion routines.

Check out the Brightspace website and Piazza for any updates to these instructions.